# Hydrological Transformations in Jaguaribe River Basin during 20th Century

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**Abstract.** This article evaluates hydrological transformations in Jaguaribe River Basin over this century after the construction of its twelve largest reservoirs. The results showed that, even with large reservoirs, the degree of control of Jaguaribe Basin is relatively low, and around 35% of the natural discharges keeps on flowing to the ocean. The main reason for that low efficiency of reservoirs comes from the high variability of rivers inflows. In order to analyze the behavior of this same system for a different scenario, Jaguaribe River and its tributaries were simulated as they were less variable on their annual discharges. The results obtained were completely different, with the reservoir system regulating up to 85% of the mean natural discharges and less than 1% flowing to the ocean.

## 1. Statement of the Problem

As water resources management occurs in a context of human values, each society develops its own management systems and goals. As a result, the management techniques reflects the environment realities as well as cultural values, historical experience and political realities (Peery and Vanderklein, 1996). In fact, there are an interactive process: the environment molds the human behavior, the man acts in the environment to accommodate his needs.

That statement has a particular fashion in the Semi-Arid of Northeast Brazil. As recurrent droughts have been plaguing the Society, it was created a culture of storing water in reservoirs as much as possible. It is common one read in drought's history that for solving the drought problem it would be necessary keeping in reservoirs up to the last drop of water from the intermittent rivers of the Region.

As a result, the action of governments has been built more and more surface reservoirs. The purpose of this article is to analyze the impact of this policy of storing water in the reservoir on the liquid discharge flowing to the ocean. In addition, it is analyzed using Monte Carlo Method the influence of variability of inflows in the amount of water controlled. The Jaguaribe River Basin in Northeast Brazil was selected as a case study (Figure 1).

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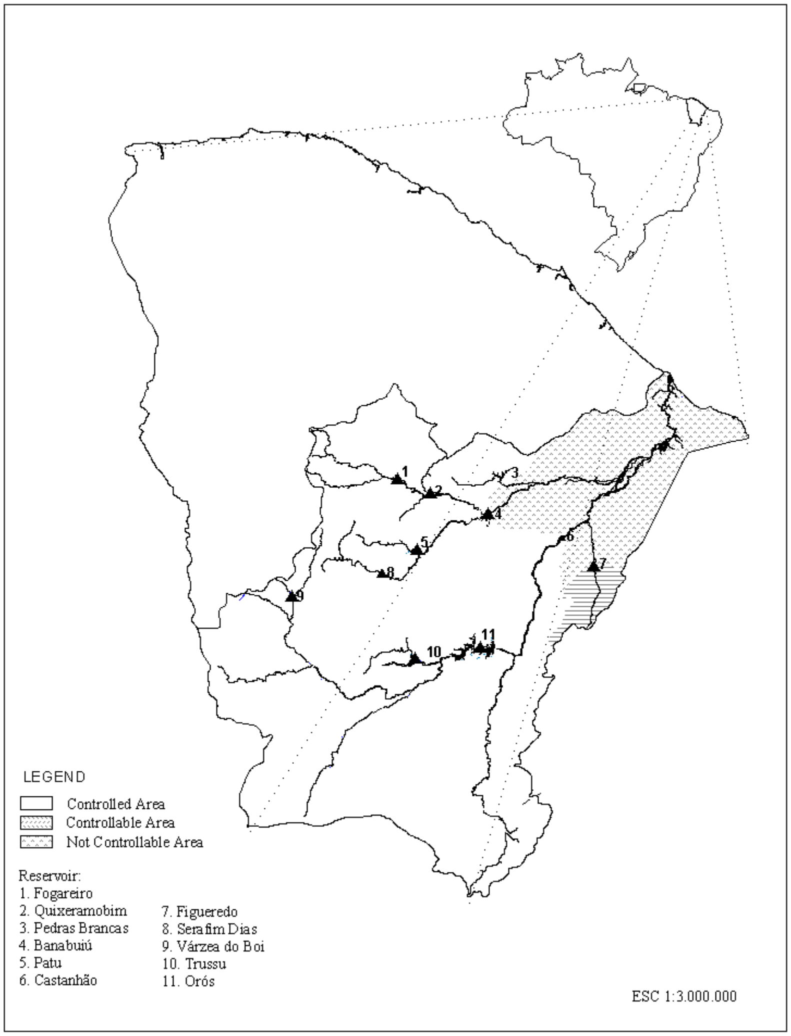


**Figure 1**. Jaguaribe River Basin and its Reservoirs

## 2. The Hydrological Context

Jaguaribe River extends for about 610 km and its drainage basin covers an area of 75,961.07 $km^2$, representing almost half of Ceará State's territory. One of the most significant characteristics of Jaguaribe River is the variability of its discharges, which is very accentuated within-the-year as well as overyear.

It is peculiar the fact that the river discharge can range from 7.000 $m^3/s$ up to zero in a time interval of few months. It also interesting to observe that Jaguaribe River, that is longer than Tamisa River, can stay more than 18 months completely dry during intense droughts**.**

When measured by the coefficient of variation of annual inflows (CV), the rivers of Northeast Brazil are among the most variables in the world. As a consequence of this degree of variability Campos et. all. (1997) showed that if 30 years of discharge data could be considered long enough for hydrological studies in northeast areas of United States, which present coefficient of variation around 0.25, to have this same discharge estimations error in Northeast Brazil it would be necessary up to 690 years.

## 3. Evaluating Hydrologic Transformations

Monte Carlo Method was used to evaluate the hydrological transformations in Jaguaribe River Basin due to the Reservoir Building Policy. The computation process consisted in: a) generating 5,000 synthetic traces of annual inflows from a Gamma population - it was assumed a coefficient of correlation equal to one in the whole space of the basin; b) desegregation annual inflows in monthly inflows using the Method of Fragments (Svanidze, 1980); c) simulating the reservoir system in the steady state, to wash out the influence of reservoir initial conditions as described by Studart and Campos (1999), with 90% reliability and solving the reservoir budget equation using SIMRES (Campos et. all. 1999).

The mean annual discharges of each river was calculated using the "Homogeneous Hydrologic Zones" established by SUDENE (1966). It was assumed for all rivers two different values of coefficient of variation of annual inflows: CV=1.3 – which represents the value of Jaguaribe River just upstream of Orós Reservoir (very close to the real situation), and CV=0.2 – which represents the average values for the rivers' discharges in the northeast of United States (a hypothetical situation).

In simulation, the budget equation of reservoirs was solved using the procedure showed by Campos (1997). The reservoir, as a system acting over the natural inflows, makes the transformation of inflows in: spill; regulation and evaporation losses.

## 4. Application of Monte Carlo Simulation

The simulation was performed using only the 12 largest reservoirs of the basin, whose main characteristics are given in Table 1. It is known that in Jaguaribe River Basin there are hundreds, or even thousands, of small dams. The effect of these small reservoirs on the liquid discharges to the ocean is only partially included here and will be estimated in further studies.

**Table 1.** Main Characteristics of Jaguaribe River

| Basin Area ($km^2$) | River Length (km) | Mean Annual Inflow ($hm^3$) | Coefficient of Variation of Mean Annual Inflow |
|---|---|---|---|
| 75,961.07 | 610.0 | 4,264.3 | 1.3 |

The simulation of whole Jaguaribe River System was made chronologically. The liquid discharge to the ocean, reservoir yield and evaporation loss were calculated for the existent reservoir for a given year.

Some reservoirs were simulated in parallel (denoted here by "+"); others were simulated in series (denoted here by "/"), which means that a spill from one reservoir is transformed in inflow for the next one. The scheme of simulation is shown as follows (the reservoir subscripted means the new action for that year):

**Before 1906 –** natural discharges

**1906** = <u>Cedro</u>

**1918** = Cedro + <u>Riacho do Sangue</u>

**1954** = Cedro + Riacho do Sangue + <u>Várzea do Boi</u>

**1960** = Cedro + Riacho do Sangue + Várzea do Boi + <u>Quixeramobim</u>

**1962** = Cedro + Riacho do Sangue + Quixeramobim + (Várzea do Boi/<u>Orós)</u>

**1966**= Cedro + Riacho do Sangue + (Várzea do Boi/Orós) + (Quixeramobim/<u>Banabuiu</u>)

**1978** = (Cedro/<u>Pedras Brancas</u>) + Riacho do Sangue + (Várzea do Boi/Orós) + (Quixeramobim/Banabuiu)

**1987** = (Cedro/Pedras Brancas) + Riacho do Sangue + (Várzea do Boi/Orós) + [(Quixeramobim + <u>Patu</u>)/Banabuiu]

**1995** = (Cedro/Pedras Brancas) + Riacho do Sangue + (Várzea do Boi/Orós) + [(Quixeramobim + Patu + <u>Serafim Dias</u>)/Banabuiu]

**1996** = (Cedro/Pedras Brancas) + Riacho do Sangue + [(Várzea do Boi + <u>Trussu</u>)/Orós] +{[(Quixeramobim/<u>Fogareiro</u>)+ Patu + Serafim Dias]/Banabuiu}

**2002** = (Cedro/Pedras Brancas) +{[(Quixeramobim/Fogareiro)+ Patu + Serafim Dias]/ Banabuiu}+ {[(Várzea do Boi + Trussu)/Orós] + Riacho do Sangue}/<u>Castanhão</u>

## 5. Results

It was observed that these 12 reservoirs control around 81% of the Jaguaribe Basin area, and only 2% more is controllable (Table 2). For the real situation of CV being equal to 1.3, the annual liquid discharge to Atlantic Ocean was 1,881.6 $hm^3$ (1,318.8 $hm^3$ from the reservoirs system's spill added to 562.8 $hm^3$ from not yet controlled and not controllable areas), the reservoir system's annual yield was 1,653.8 $hm^3$ and the annual evaporation losses from all lake surfaces were 536.7 hm$^3$, which correspond to 44%, 39% and 13%, respectively, of the mean natural discharge over whole basin ($\mu$ ). If only the controlled area was taken in account, the percentages of spill, regulation and evaporation losses would be, respectively, 35.6%, 44.7% and 14.5% of the mean annual discharges over this area.

**Table 2.** Characteristics of the Large Reservoirs in Jaguaribe River Basin.

| Year* | Reservoir | Total Storage Capacity (K) (hm3) | Mean Annual Inflow ($\mu$) (hm$^3$) | Catchment Area (km$^2$) | $f_K = K/\mu$ |
|---|---|---|---|---|---|
| | | Controlled Area | | | |
| 1906 | Cedro | 126.0 | 14.91 | 213.0 | 8.45 |
| 1918 | Riacho do Sangue | 61.4 | 81.9 | 1,346.3 | 0.75 |
| 1954 | Várzea do Boi | 51.8 | 81.5 | 1,486.8 | 0.64 |
| 1960 | Quixeramobim | 54.0 | 489.1 | 2,022.4 | 0.11 |
| 1962 | Orós | 1,956.3 | 1,280.0 | 22,624.1 | 1.53 |
| 1966 | Banabuiu | 1,800.0 | 929.0 | 4,467.8 | 1.94 |
| 1978 | Pedras Bran-cas | 434.0 | 149.11 | 1,990.9 | 2.91 |
| 1987 | Patu | 71.8 | 70.3 | 1,122.5 | 1.02 |
| 1995 | Serafim Dias | 43.0 | 95.4 | 1,571.2 | 0.45 |
| 1996 | Fogareiro | 118.8 | 347.5 | 4,963.7 | 0.34 |
| 1996 | Trussu | 263.0 | 92.6 | 1,542.6 | 2.84 |
| 2002** | Castanhão | 4,451.0 | 2,623.7 | 18,370.5 | 1.70 |
| Sub Total 1 | | 9,431,1 | 3,701.5 | 61,739.9 | 2.55 |
| | | Controllable Area | | | |
| *** | Figueiredo | 502.0 | 117..8 | 1,458.6 | 4.26 |
| Sub Total 2 | | 9,933.1 | 3,818.7 | 63,198.5 | 2.60 |
| | | Not Controllable Area | | | |
| | | | 445.6 | 12,762.6 | |
| Total = Sub Total 1 +Sub Total 2 | | | 4,264.3 | 75,961.1 | |

(*) end of construction (**) in construction (***) planned

For the hypothetical situation of CV = 0.2, the results obtained were completely different from the real situation, with the reservoirs being much more efficient than they really are. The annual liquid discharge to Atlantic Ocean was 565.5 hm$^3$ (only 2.7 hm$^3$ from the reservoirs system's spill added to 562.8 hm$^3$ from not yet controlled and not controllable areas), the annual regulation was 3,163.6 hm$^3$ and the annual evaporation losses were 411.5 hm$^3$, corresponding to 13.3%, 74% and 9.7% of $\mu$.. The numbers are even better if only the controlled area is considered: 0.07%, 85.5% and 11.12% of the mean annual discharges over this area, for spill, regulation and evaporation losses, respectively. The performance of the system for both CVs, considering only the controlled area, is shown in figures 2 and 3.

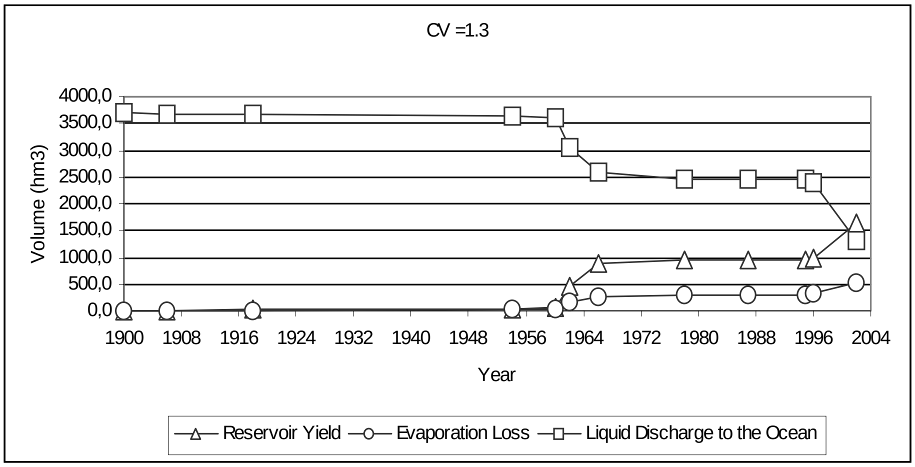


**Figure 2.** Temporal Variation of Liquid Discharges to the Ocean, Reservoir System's Yield and Evaporation Losses for CV = 1.3 over the controlled area of Jaguaribe River Basin.

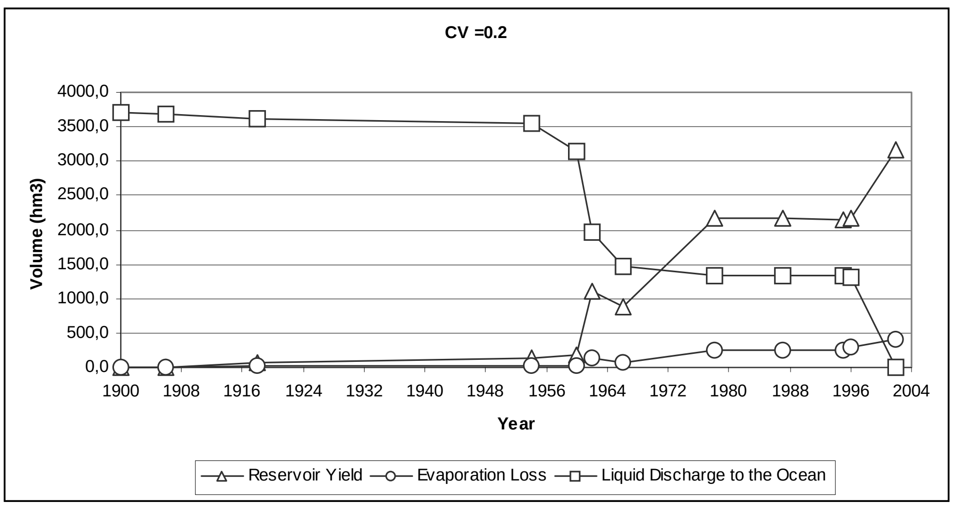


**Figure 3.** Temporal Variation of Liquid Discharges to the Ocean, Reservoir System's Yield and Evaporation Losses for CV = 0.2 over the controlled area of Jaguaribe River Basin.

## 6. Conclusions

The results showed that, for the real situation, even with a high degree of surface control of hydrographic basin by reservoirs – 2.5 times the mean natural discharge – more than 1/3 of the inflows over the controlled area keep on going to the sea. This paradox, high control of surface with relatively low control of mean discharges, comes from the high overyear variability (CV = 1.3) of the annual discharge of the river. A simulation using Monte Carlo Method showed that if the coefficient of variation of discharges were 0.2 (as in the rivers of Northeast of USA) the regulation would be near 85%.

These numbers make understandable the policy of building reservoirs as large as possible, practiced in Northeast Brazil. Even with low efficiency, a large surface reservoir can make the difference, keeping life conditions in *Sertão* of Northeast.

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## References

Campos, J.N.B.; Souza F°, F.A.; Araújo,J.C.,1997: Errors and Variability of Reservoir Yield Estimation as a Function of the Coefficient of Variation of Annual Inflows. In: 27th IARH Congress, San Francisco, USA.

Campos, J.N.B.,1997: Dimensionamento de Reservatórios: O Método do Diagrama Triangular de Regularização. Edições UFC. Fortaleza, Ceará, Brazil.

Campos, J.N.B., Martinz, D., Studart, T.M.C. and Coêlho, L.,1999: SIMRES: Um Laboratório Computacional de Teoria da Estocagem de Águas. INTERNET : Home Page: www.deha.ufc.br/nilson.

Perry, J. and Vanderklein, E.,1996:Water Quality: Managemente of a Natural Resource. Blackwell Science. Massachucsetts, USA.

Studart, T.M.C. and Campos, J.N.B.,1999: Reservoir Storage Problem: The Faster Convergence Rate from Transient to Steady State Conditions". In: Nineteenth Annual Hydrology Days, Colorado State University, Fort Collins,. Colorado, USA.

SUDENE, ,1967: Monografia Hidrológica. In: Estudos de Base do Vale do Jaguaribe". Recife, Brazil.

Svanidze, G.G., 1980: Mathematical Modeling of Hydrologic Series. Water Resources Publications, Fort Collins, Colorado, USA.