Hydrologic Hazards in Brazil

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ABSTRACT

Major hydrological hazards in Brazil are: urban floods, droughts in the Northeast Region, floods in the valleys of large rivers (including the Pantanal), extreme floods that can affect safety of big dams and the so called "energetic droughts. Often technical soluctions to alleviate these hazards are not implemented, although Known due to lack of resources and/or lack of an efficient political organization.

INTRODUCTION

Brazil is a large country covering about 8.5 million square kilometers with a population of 136 million, growing at a yearly rate of 2.1%. Annual gross domestic product totals U$ 1672 per capita. Population is unevenly distributed: only 0.5% live in the North, a vast region of 3.8 million square kilometers (44% of the country) mostly composed by the Amazon Forest, while 43.0% live in the South and Southeast, a fertile and industrialized region of about 1.5 million square kilometers (17% of the country). Roughly two thirds of the population live in cities with more than 50,000 inhabitants. All data refers to 1985.

Annual mean precipitation is 1745 mm if we consider the country as a whole and 1370 mm if we discount the Brazilian part of the Amazon Basin, which accounts for 63% of the total area of the basin. Precipitation over the Amazon Basin, including the non-Brazilian part of it, is 2548 mm and the resulting streamflow at the mouth of the Amazon River has an estimated mean value of 202,000 cubic meters per second. Data on other major rivers basins of the country are given in Table 1 and their localization in Figure 1.

TABLE 1 - DATA ON THE MAIN BRAZILIAN RIVER BASINS

BASIN	DRAINAGE AREA (SQUARE KM)	PRECIPITATION (MM)	STREAMFLOW (CUBIC METER/SECOND)
Amazon	6112,000	2548	202,000
Tocantins	757,000	1767	11,300
Sao Francisco	634,000	987	3,040
Parana	877,000	1437	11,200
Paraguai	368,000	1400	1,340
Uruguai	178,000	1700	4,040

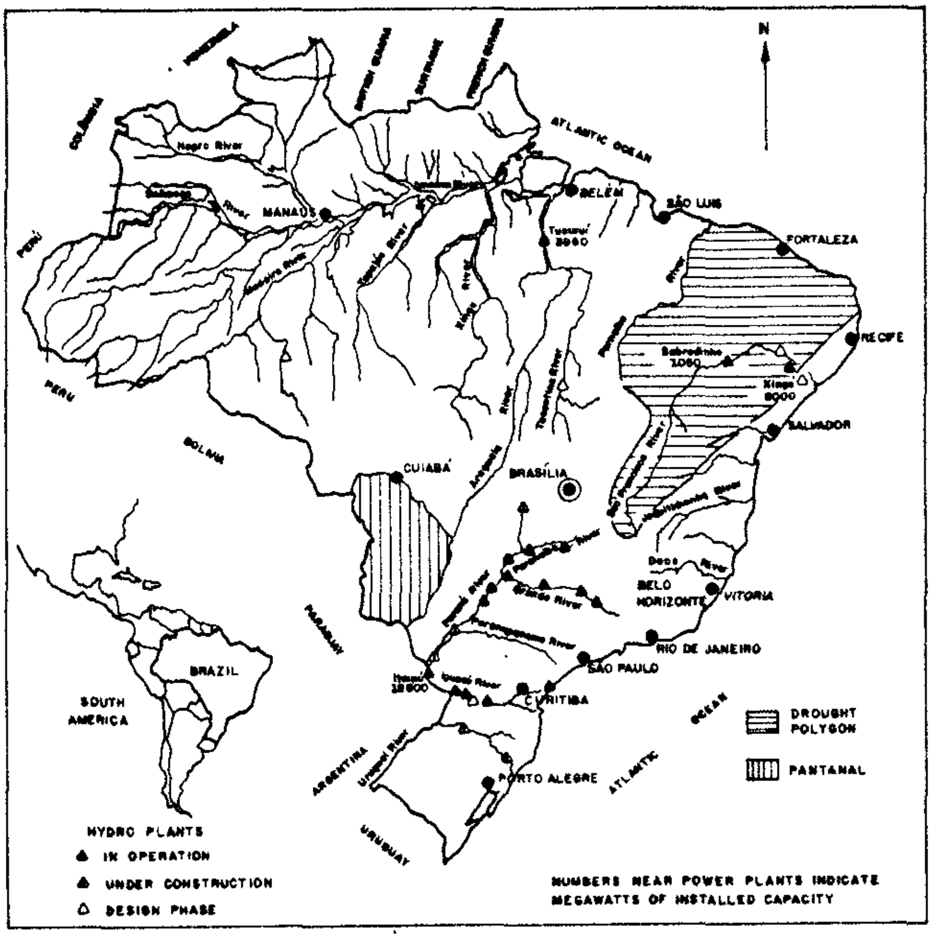

FIG. 1 - MAIN BRAZILIAN RIVERS

There are several hydrological hazards in Brazil, in the sense that the population is often affected by too much or too little water. Sometimes the technical solutions are not implemented, although known, due to lack of resources and/or lack of an efficient political organization. This is the case, for example, of heavy rainfall in the large cities. The resulting floods are usually associated with losses for the poor people because they build their houses in improper places, such as in flood plains or on unprotected steep slopes. Obviously the poor would build their homes in safer places, if they had the economical alternative.

There are hydrological hazards for which technical solutions are not so simple. For example, calculating hypothetical extreme floods in a tropical environment. These floods are important for defining the spillway capacity. For large dams, the flood recurrence interval should be of many thousand years or else be calculated by an approach like the PMP. Underestimation of this flood may result on dam break, due to overtopping. On the other hand, overestimation will mean a non efficient use of scarce resources. The engineers that are designing the dams to be built in the tributaries of the Amazon River, for power production, are presently facing this problem. They have to make decisions with scarce hydrological data and with a limited knowledge about physics of extreme rainfall, for a duration of many days, in a tropical region. They know that it is not advisable to plainly use methods developed for temperate climates because, among other reasons, the moisture content in a column of air in a rain forest has a smaller coefficient of variation.

Beyond urban flooding and dam overtopping, the following hydrological hazards will be discussed in the ensuing text: crop failing droughts in the Northeast, power supply shortage due to lack of water in reservoirs and floods in the large rivers.

URBAN FLOODS

Since the late forties, there is an industrialization process going on, which has resulted on a steady migration of millions of poor people, seeking for a better life, from the countryside to the large cities. Sao Paulo and Rio de Janeiro have now more than 10 million inhabitants each, if we include the population of the satellite cities. These migrants seldom actually improve their standard of living. Most commonly they end up building their homes in the shantytowns known as "favelas", which are located in the outskirts of the cities, *usually in the flood plains, or on* unstable hills.

Building codes are not enforced in these neighborhoods due to a number of reasons:

a) They are usually overcrowded because transportation system is deficient and everybudy prefers to live close to the working place;

b) People usually don't own the piece of land where they have built their "unauthorized" houses. This means that they don't have the incentive to invest their savings on house improvements, as they can be dislodged at any moment;

c) Most people simply don't have enough money to follow the codes and enforcement would drive them to live in the streets, as some actually do.

Favelas are usually defenseless against heavy rainfalls. Let's take the city of Rio de Janeiro as an example. Mountains occupy about 1/3 of its area and more than one million people live in the favelas located on the colluvial deposits at the hillslopes. It has been observed that the silty-clayey-sand colluvial soil presents a transition layer to the underlying residual soil, consisting of a gravelly-sand of high permeability. This layer receives appreciable contribution of water from upper regions of the slope, which can lead to the failure of the colluvium during exceptional rainy seasons (Pedrosa et al, 1987). This happened in 1976, in 1977 and very recently in February of 1988. During this last event, it has been measured in a gauge located uphill (Capela Mayrink) a rainfall depth of 450 mm during four days, while the mean annual precipitation is 1600 mm (Araujo, 1988). Landslides resulted from this persistent and large precipitation. Mud flow and all sorts of debris went down the hills, destroying the fragile houses that were in their way and adding more debris to the flow. It is estimated that more than 100,000 tons of solid material, mud, trash and debris, were left over in the plain part of the city when the flood was over (Magalhaes, 1988). All this material clogged the drainage system as well as the river channels. Consequently the water level of the streets rose in some parts more than 2 m and all activities were disturbed by streets transformed into "rivers".

At the time this paper is being written, there is a hope that the urban flooding will start to receive an institutional solution: Congress is writing a new Constitution and it is possible that this unique opportunity will be used to impose progressive taxation upon urban real state located in the "safe" part of the city, that is speculatively kept vacant. In this way, it will be easier for someone who is presently living in a dangerous favela to move to some urban plot of the regular city. Besides, local governments are improving safety conditions of the favelas that can be transformed into regular urban neighborhoods.

These improvements consist mainly in enlargements of the drainage system, regular collection of trash and/or debris and reforestation of the hills.

AGRICULTURAL DROUGHTS IN THE NORTHEAST

Most of the migrants that come to live in the favelas of the big cities are rural workers of the Northeast, escaping from droughts. Droughts in the Northeast Region may be singled out as the most important hydrological hazard in Brazil because they can be catastrophic for millions of individuals. Although the mean annual precipitation is roughly 950 mm, crop failures occur very often in the region, due to the uneven distribution of the precipitation, in time and in space. The most affected sub-region is the so called "drought polygon", which covers roughly 1 million square kilometers, with 22 millions inhabitants (Figure 1). In the drought polygon, the mean annual precipitation ranges from 400 to 800 mm, with a mean value of 650 mm. Potential evapotranspiration is 2000 mm per year. Rivers are intermittent.

The latest large drought in the region occurred from 1979 to 1983. In the worst period of this event, practically all the Northeast (1.5 millions of square kilometers) suffered from lack of water. About 30 million people were directly affected by the drought. A large contingent was reduced to absolute poverty. Federal Government had to create emergency jobs to mitigate starvation. More than 3 million people were enrolled in this program, receiving each less than US$ 30 per month. This large "army" was kept busy by doing thousands of small construction works, aimed to improve the water resources of the region. It is estimated that 7,000 wells were drilled and countless micro reservoirs have increased the total storage capacity from 12,000 to 20,000 billions of cubic meters (SUDENE, 1987). Unfortunately, however, many of these constructions were done without minimal technical guidance and vanished after the first flood.

Several initiatives have been proposed to alleviate the consequences of droughts in the Northeast. A big failure was the attempted colonization of a strip of the Amazon basin, by the landless of arid Northeast, through the opening of a new road. Another proposal was to divert part of the flow of the Sao Francisco River, at Sobradinho Reservoir (Figure 1). The water would be used to feed a large irrigation project. This proposal has not been implemented due to the high cost of the hydraulic conveyance structures and also to the cost of the substitute sources of energy that would have to be built, in order to compensate the decrease of energy production by the hydro plants located downstream of Sobradinho Reservoir.

Presently an irrigation program is beginning to be implemented in the region, based on the availability of local water resources.

FLOODS IN LARGE RIVERS

Rivers with Flood Control Storage

Most of the large dams and reservoirs built in Brazil are owned by the Hydroelectric System. They have been traditionally operated aiming to maximize the energy production. However the resulting river flow regulation has made the downstream population overconfident in the capability of the reservoirs to mitigate floods with moderate recurrence intervals, say 10 years. Furthermore, lack of proper surveillance resulted in several places on a dangerous occupation of the flood plain, which has created, or has reinforced, a political problem. It has become necessary to reevaluate the operating rules in order to take flood control constraints into account.

Flood control restrictions are represented by the maximum normal outflow, which is the upper bound on the release of each reservoir to avoid downstream flooding. An emergency occurs whenever the level of the reservoir reaches a critical limit and dam safety procedures impose releases bigger than the maximum normal outflow. Since 1979, ELETROBRAS, the federal holding company controlling all Brazil's power utilities, has created a task force to coordinate an effort to leave flood control storage in the reservoirs, during the flood season. In the beginning, flood control storage was sized by simulating the river system with the worst historical flood. Soon it was noticed a *nuisance in the method: it tends to allocate larger flood* control storages to reservoirs with longer streamflow records, everything else being the same.

More recently, several new methods have been developed which define the flood control storage for a given recurrence interval, typically 30 years (Kelman 1988, Tavares and Kelman 1985, Damazio et al 1987). These methods use synthetic daily streamflow sequences, produced by a stochastic model (Kelman et al 1985). The flood control storage volumes can be allocated *in many different* ways, so that each reservoir shares the responsibility for valley protection, provided the controllability conditions are satisfied (Marien 1984, Damazio and Marien 1988). Little has been done in Brazil to compare economically and socially the flood-control-storage solution to non-structural alternatives, like for example the flood plain zoning. There are some hints that the cost associated to the decrease of the firm (or reliable), energy may exceed a lot the cost of a proper flood zoning (Dias et al 1985).

The Pantanal

Most of the Paragual River Basin in Brazilian territory is a marshy region of about 140,000 square kilometers largely swamped during floods and characterized by stagnant water long after the rains. It is called the "Pantanal" (Bonneto et al 1988). The most important economical activity in the Pantanal is cattle raising on natural vegetation. The Brazilian Government operates a large network of stream gauges in order to support a flood warning system. The main purpose of this system is to advise farmers about the flood, long ahead of its arrival. This task is made relatively easy by the large "inertia" of the basin: there is a 4 months lag, on the average, between the peak of the rainy season and the ocurrence of the maximum anual discharge (Pereira, 1988). In this way, most of the cattle can be rescued, moving them to higher lands. However, because cattle lives almost freely in the fields, many can't resist long periods with their feet under water, get sick and ultimately die. From the 3 million cattle of the Pantanal, it is estimated that more than 200,000 died during the 1988 flood, which was the largest of the century.

When water covers the farms, the workers loose their jobs. Because they can't count with a reliable social security system, many survive by fishing, hunting and smuggling alligator leather (Costa, 1988).

In recent years, mechanized soya cultivation is developing rather quickly in the upstream tributaries of the Paragual River. Soil erosion has grown steadily. Consequently there has been a decrease of water depth in several river channels, which has crated some navigation difficulties. Navigation is also disturbed during major floods because big chunks of vegetation get loose from the sandy soil of the flood zone and slowly drift towards the main channel, clogging it completely. Being aboard in such conditions, one has the impression to be navigating across a grass field (S.R.V. Laan, 1988, personal communication).

DAM SAFETY

Most of the large dams built in Brazil are earth filled. Overtopping for such dams leads in general to dam failure and to a destructive flood wave. This happened with two dams located in the Pardo River, Sao Paulo State, in January of 1977. A major storm, which resulted on a rainfall depth of 230 mm in 24 hours, was centered on the small drainage area (about 4000 square kilometers) of the upstream reservoir (Euclides da Cunha). The dam personnel didn't open the spillway gates during the first hours of the flood due to a failure of the communication system between the dam and the headquarters of the power company. Water level rose quickly and soon the gates couldn't be operated anymore, due to mechanical failure. Water level reached the dam crest and during seven hours it kept overflowing, before rupturing. The reservoir volume of 13 million cubic meters was suddenly released and the resulting flood wave went down the river at a speed of 20 km/h. It took only half an hour for this wave to reach the downstream dam, and another half an hour for the second dam to collapse. This event, which is comprehensively described by Siqueira (1978), triggered a deep concern about dam safety in Brazil.

One of the consequences of this concern is a technical report, called "Guidelines for Flood Evaluation in the Design of Spillways", which was issued by ELETROBRAS in 1987. The report suggests that the design flood of a large dam should be calculated using either the Probable Maximum Flood criteria or the 10,000-year flood. This suggestion corroborates the recent trend of the Brazilian Electric Industry. Nevertheless, the report admits that under special conditions, economical studies may indicate other safety levels.

The report has been supported by some research work, that has indicated:

a) Goodness-of-fit tests are not sufficient for choosing the probability distribution that will be used for estimating the 10,000-year peak flood. It is preferable to use a robustness criteria (see for example Wallis, 1988) to make the selection. In this context, the two-parameter exponential distribution resulted in an overall better behavior, for the typical range of peak flows observed in Brazil. The theory of extremes was not found as useful as often reported, due to several reasons, explained elsewhere (Kelman, 1987).

b) Stochastic modeling of the streamflow time series is a suitable approach for design, particularly when the flood attenuation storage of the reservoir is sized jointly with the maximum flow capacity of the spillway.

c) Extreme floods in large basins located in a tropical region are the result of temporal and space rainfall patterns which not necessarily induce extreme daily point rainfall. Some plausible events, meteorologically adverse, may be "synthetized" by rearranging the pattern of recorded storms.

ENERGETIC DROUGHTS

The industrialization process has been supported in Brazil by a steadily increasing supply of electric power. 95% of this production comes from hydro power plants. The oil production of the country (roughly 600,000 barrels/day) cannot be used to generate electricity because it is not enough to meet the consumption necessary for transportation and for industrial heating. Total installed capacity is 42,710 MW and annual production of electricity is close to 172 TWh (1987). This means a consumption of less then 1,300 KWh/year per inhabitant, as compared to the consumption, for example in the USA, of roughly 10,000 KWh/year per inhabitant.

Most of the Brazilian hydro plants are located in the Parana River Basin (Figure 1), including the 12,600 MW Itaipu

Binational, on the border of Brazil and Paraguay. The ninth turbine of Itaipu was commissioned recently, bringing the total installed capacity to half the total planned output. Tucurui is the first large hydroplant built in the Brazilian rain forest, on the Tocantins River. It will have an installed capacity of 3,969 MW and 8,000 Mw, respectively at the end of the first and second stages. From the hydrological point of view, Tucurui is an interesting dam because its spillway has the largest discharge capacity in the world to the knowledge of this writer (115,000 cubic meters per second).

Most of the hydro plants of the North-Northeast Interconnected system are located on the Sao Francisco River. Xingo, which will be the plant with the highest installed capacity in this river (5,000 MW), began to be constructed in August 1987 to start operating in the early 1990s. However, inauguration of Xingo, as well as of five other Brazilian hydro plants (total installed capacity of 2,500 MW) are likely to be postponed as a result of lack of funds. (Water Power & Dam Construction, page 7, February 1988).

In the last few years, utilities have not found the resources to support the generation expansion of the hydroelectric system because of the financial constraints presently imposed upon Brazil, associated with Brazil's debt of approximately US$ 115 billions. Investments have lagged behind the needs. Lack of investments means, in general, that new consumers and new industries have to wait for several years before being connected to the grid. Economical consequences are obviously devastating for countries which are still underdeveloped and that do not control the population growth. In a electric system based predominantly on hydro energy, like Brazil, there is one "optimistic alternative" as an attempt to avoid complete disaster: one may count with favorable hydrological conditions to refill the reservoirs, which are used intensively to meet the growing demand for energy. In other words, the optimistic alternative calls for a higher risk of energy curtailment due to lack of water in the reservoirs.

In predominantly thermal systems, the main role of hydro plants is to meet the peak load. For this reason, hydropower capacity is often expressed in terms of installed capacity. However, in predominantly hydro systems, the basic variable to be considered is the "reliable energy". This is defined as the maximum quantity of energy that can be delivered during each year, under adverse hydrological conditions.

Traditionally this adverse condition was the worst drought observed in the past and the reliable energy was called firm energy. Because of the lack of funds, utilities are accepting droughts with small recurrence interval, sometimes less than 10 years, as "the adverse condition". *Consequently, energy shortages have occurred* in the South Region (1986) and in the Northeast Region (1987). These events spread among the general population, and even among engineers, the misconception that electric energy based on hydropower production is quite unreliable, due to droughts. It is not generally perceived that in a large territory like Brazil, hydrologically heterogeneous, the risk of energy shortage can be indeed very low, *provided there are* sufficient reservoirs and power plants.

CONCLUSION

Alleviation of hydrological hazards in Brazil, as well as in many other parts of the world, will not result solely from technical progress. It is also necessary to achieve an integrated development of the human resources, institutional and political structures, and last but not least, economic prosperity.

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