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Review Article

The Brazilian San Francisco River Basin Narrative

Jerson Kelman*

COPPE, Rio de Janeiro Federal University, Cidade Universitária, Brazil

***Corresponding author:** Jerson Kelman, COPPE, Rio de Janeiro Federal University, Cidade Universitária, CEP 21941-594, Rio de Janeiro, Brazil. Tel: + 55 21 995108232; Email: jerson@kelman.com.br

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Abstract

Although Brazil is a country with mighty rivers, like the Amazon, the Northeast part of the country is semiarid. The San Francisco River that runs across this dry region resembles the Colorado and the Nile rivers, as most of the water discharge results from the precipitation falling over the upstream part of the basin. What really differentiates this area from the rest of the country is the hydrological variability, rather than the mean annual precipitation, which is not particularly low. In the San Francisco River Basin, most of the effort has been historically concentrated on the creation of irrigation districts and on building and operating nine large hydropower plants (installed capacity of 10.3 GW) connected to the high voltage grid.

Despite the problems that historically affected the public irrigation districts, private irrigation in the valley is a success because one can control the water supply - not too much, not too little-almost to the level of an industrial process. Presently, private entrepreneurs operate most of the agricultural production. There is an ambitious US\$ 3 billion engineering project recently completed to divert water from the San Francisco River to the other river basins located in the Semiarid. The idea is to use the infrastructure in its full capacity only in wet years, when the excess of water would flow to the reservoirs of the recipient area, rather than to the Atlantic Ocean.

Keywords: Hydropower; Inter Basin Water Transfer; Irrigation; San Francisco River Basin, Water Dispute

Introduction

The Semiarid region in the hinterland of the Brazilian Northeast (Figure 1) an area of almost one million square kilometers - is a good example of the relationship between poverty and lack of water security. Roughly, 20 million people - 10% of the Brazilian population - live there. They share the same language, culture, institutions, education and political system of the other 90%. Yet, they have by far the lowest per capita income.



Figure 1: Brazilian Northeast.

What really differentiates this area from the rest of the country is the hydrological variability, rather than the mean annual precipitation, which is not particularly low, ranging from 500 to 800 mm¹. The problem lies on an ensemble of several adverse factors: it only rains three or four months each year, the variance of annual precipitation is high, the soil is shallow and the potential evapotranspiration is extraordinarily high. Because of the accumulated effect of these factors, most of the rivers are intermittent and people can only settle along the banks of the perennial San Francisco River or close to artificial reservoirs created by dams built in more than a century. Nevertheless, there are historical registers of several migration waves caused by long lasting droughts that forced millions of people to swallow the population of big cities.

These waves became rare in the last decades. Not because of climate change but because the investment on water infrastructure along more than a century is finally paying dividends. As stated by [1], “it is necessary an initial stock of investments on water infrastructure before reaching the ‘inflexion point’ when water security is reached, despite the hydrological natural conditions, and then real progress starts”. Developed countries and regions blessed with a temperate climate and deep soils don’t need the initial investment, or have already had significant capital expenditure in order to reach the inflexion point, as occurred in the American West.

Although there has been substantial improvement in the Semiarid, it is necessary to do much in order to reach the inflexion point. In properties that cannot use directly the water from the San Francisco River or from some large reservoir, farmers tend only to grow low value seasonal crops because they are afraid of losing several years of hard work due to the occurrence of a dry year. Analogously, industries fear to build new factories that could take advantage of lower wages, because water availability is uncertain. (Figure 2) shows that the San Francisco river basin is partially contained in the semiarid region (delimited by the red line) and entirely contained in Brazil, covering 5 of the 27 states. It has an impressive drainage area (640 thousand square kilometers), larger than, for example, France. The total river length is almost 3 thousand kilometers.



Figure 2: The San Francisco River Basin (white).

The San Francisco resembles the Colorado and the Nile rivers, as most of the water discharge results from the precipitation falling over the upstream part of the basin. Not surprisingly, the specific discharge decreases from 15 to 5 liters per second per square kilometer, from upstream to downstream. In the medium or lower San Francisco, if one walks in a dry year a short distance away from the mighty river, the landscape changes entirely (Figure 3).



Figure 3: Landscape of Brazilian Semiarid Region.

Hydropower

Challenges facing the Brazilian states in the São Francisco Basin itself are distinct from the challenges faced by the neighboring states, which lack direct access to the São Francisco’s water. In the San Francisco River Basin, most of the effort has been historically concentrated on the creation of irrigation districts and on the building and operating of nine large hydropower plants (Figure 4).

1. For the sake of comparison, mean annual precipitation in Paris and Berlin are around 600 mm.

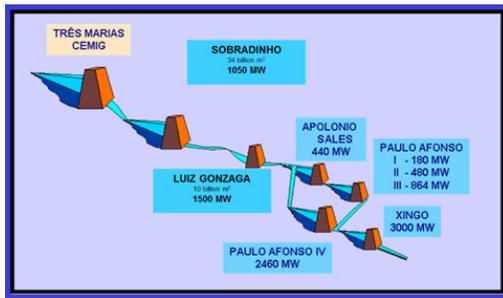


Figure 4: Schematic representation of cascade of power plants in the San Francisco River Basin.

As the plants connect to a large high voltage grid, the generated electricity benefits not only those that live in the basin, but practically all the Brazilian population². It was conceived to take advantage of the hydrological diversity among river basins within the large Brazilian territory (8.5 million square kilometers), allowing the energy produced in rivers under normal hydrological condition to flow to consumption centers located in basins under hydrological stress. With this arrangement, it is possible to attend more than 60% of the electricity demand relying only on renewable hydropower. The total installed capacity of the 9 large hydropower plants built in the San Francisco river basin is 10,3 GW. The firm energy—that is, the production under adverse hydrological conditions - is of the order of 49 million MWh per year. The accumulated useful water storage capacity of the reservoirs is 45 billion m³, which matches half of the mean annual flow at the river mouth.

Most of the plants built decades ago are still in excellent operating conditions. Since then, Brazil went through several changes of currency due to bursts of high inflation rates. It is therefore cumbersome to calculate the historical and ex-post cost of this infrastructure expressed in terms of current currency. However, as the unit cost for new firm energy in Brazil is around US\$ 52/MWh³, the cost of a new system that could replace these 9 plants would be approximately $52 \times 10^6 \times 49 = \text{US\$ } 2.5 \text{ billion}$ per year.

Irrigation

In addition to power production, irrigated agriculture has been historically a relevant objective of the Federal Government in the Semiarid. Between the 1950s and 1990s, more than 28 irrigation projects were built in the San Francisco River Basin alone⁴, with 50 percent of the irrigated land typically reserved

2. If drawn over a map of Europe the high voltage grid would link Lisbon to Moscow.
3. Marginal expansion cost of R210/MWh and exchange rate of 4 R\$/US\$
4. According to the [3], the average cost was US\$ 10,000 / hectare.

specifically for local small-scale farmers. Most of the land for such public irrigation projects was purchased inexpensively from private owners, with Government assuming responsibility for the construction of irrigation and transport and energy infrastructure. Smallholder farmers received 5-hectare lots through land-reform schemes, while the remaining plots were sold in 5- to 200-hectare lots in public auctions. It was expected that once the basic conditions for agricultural production were in place (i.e. construction had been completed and the lots occupied), Government would surrender operation and maintenance responsibilities to another association, the Irrigation District, which would charge all producers the requisite fees for water, fixed costs, agricultural services, and operation and maintenance [2].

Unfortunately, it did not work that way in the majority of the cases. True, there are notable very successful cases, like some public irrigation districts in the region of Petrolina-Juazeiro, where the actual production of fruits, particularly grapes and mangos, is close to one million tons per year. However, the reality is that, contrariwise to the success of the power infrastructure built by the Federal Government in the San Francisco River, most of the public investments in irrigated agriculture resulted on failures that wasted the taxpayer money.

For example, Government built in the 70's a huge system of channels and pumping stations (peak flow equal 75 m³/s) designed to irrigate 100 thousand hectares in a place called Jaiba, using the water of the São Francisco River. Half a century later, less than 1/3 of the project had been implemented. This waste of taxpayer money resulted from an ill-conceived development plan, which main objective was to settle humble families, often unskilled. The farmers were selected disregarding their knowledge and motivation to produce crops valued by the market. Furthermore, there were no anchor companies in the region with resources to buy the local production and sell in the national and international markets, taking advantage of the scale factor. Without a feasible production chain, the farmers stayed isolated and dependent of Government aid. In few years a paternalistic relationship developed between the government and the settlers, who remained for a long time (many still are!) dependent on protection and assistance.

Despite the problems that historically affected the public irrigation districts, private irrigation in the San Francisco valley is a success because it makes sense to grow crops in a region where the supply of water to the crops - not too much, not too little-can be controlled almost to the level of an industrial process. Private entrepreneurs have been attracted to the region and currently there are some 500 thousand hectares of irrigated land in the Semiarid (140 thousand and 360 thousand respectively in public and private properties). Most of the hydraulic infrastructure is privately owned [3] and there is a strong agro research activity going on, conducted by Embrapa (a Government agency specialized in

tropical agriculture), that has helped to boost productivity of the agribusiness.

Hydropower X Irrigation

One could expect that the progress of agribusiness in the San Francisco Basin would trigger an open dispute for water between the agriculture and the power sectors. This has not happened yet due to a peculiarity of the Brazilian power system: the revenue of a hydro plant is proportional to the joint production of all hydro plants scattered all over Brazil, rather than to its own production. Under this arrangement, the power companies are more interested in keeping their share of the joint production, which depends on an intricate regulatory calculation, than on keeping their power production stable vis-à-vis advancement of agribusiness. In other words, the power companies operating in the San Francisco basin have no incentive to enter in the dispute for water because they still can get a free ride from the production of hydro plants located in other river basins. Consequently, reservoir storages of the San Francisco’s reservoirs have decreased much faster in recent years than in the past. This in turn is affecting the reliability of power supply in Brazil as a whole.

Despite the lack of interest from the power companies on competing for water with the agribusiness, the economic feasibility of a new irrigation plot should take into account the externality caused to the downstream power plants. For example, each m³/s continuously withdrawn from the river through an intake located between the Sobradinho and Itaparica power plants (Figure 5), and actually consumed in the irrigation fields, decreases 2.54 MWmed (continuously) from the firm energy of the cascade of power plants. Therefore, the opportunity cost for the water allocated to a new irrigation plot in this river reach is at least 4 cents of dollar per cubic meter⁵.

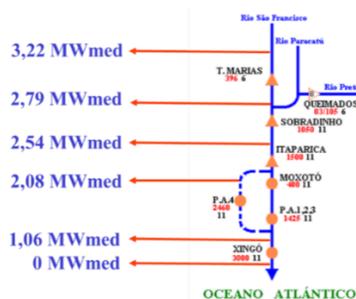


Figure 5: Effect of the location of water withdrawn for irrigation on the firm energy of the river basin.

As the farmer don’t actually pay the opportunity cost, he has little concern for it. However, the public authority has to take

5 During one hour, 3600 m³ would produce 2.54 MWh, which values R\$210/MWh. Assuming 4 R\$/US\$ as the exchange rate, $(2.54 \times 210) / (3600 \times 4) = US\$0.04 / m^3$

it into consideration before granting a water right to a newcomer. Naturally, there are many other dimensions to the water right request, including the effect of the use of water on the reduction of social inequalities. [4] have estimated the total cost of the San Francisco’s water, including the externalities, for use in irrigation. Their study considered irrigated fields located not only within the basin, but also in other lands of the Semiarid outside the basin that would benefit from an ambitious inter basin water transfer, described below. They showed that the unit cost of water outside the basin would be three times the cost within the basin⁶.

The Inter Basin Water Transfer Project

The ambitious inter basin water transfer project (Project) has been the most relevant water right request submitted to the Brazilian Water Authority (ANA) to date. The plan is to divert water from the San Francisco River to the other river basins located in the Semiarid using two routes, North and East (Figure 6). After a fierce technical and political dispute between those in favor and those against the project, the water right was finally granted and the project is almost completed (2019), at an estimated cost of US\$ 3 billion.



Figure 6: The two routes to bring water from the San Francisco River to the other river basins in the Semiarid.

The idea is to use the infrastructure in its full capacity only in wet years, when the excesses of water would be diverted to the reservoirs of the recipient area, rather than flowing into the Atlantic Ocean. The project should work in a dual mode. The high mode is supposed to be active in wet years, when the Sobradinho reservoir is spilling or close to spill. In this case, the pumping will be at highest capacity (127 m³/s) and the opportunity cost of the electricity used in the pumps will be close to zero⁷. Otherwise, the low mode would be activated, which means a pumping of only

6 Considering the sum of capital and operation, as well as the opportunity cost of water for power.

7 When the reservoir is full and the power plant is not dispatched at full capacity (as it is usually the case), the marginal production cost of electricity is close to zero because a small fraction of the flow would be diverted from the spillway to the turbines.

26 m³/s. Simulation studies have shown that the probability of operating in low mode is close to 60%. Therefore, the expected discharge diverted to the recipient area is 66 m³/s or 2 billion cubic meters per year⁸.

The Project has caused heated discussions. On one side, those that view any water exportation as the bleeding of a dying river. They argued that diverting water is analogous to forcing an unhealthy person, under intensive care, to donate blood. On the other side, those that prefer the analogy of the Sao Francisco River being a healthy person donating blood in order to save the life of a moribund region located outside the river basin. These dramatic images obscured the concept of water security. However, before shedding light on the relevant topics of the discussion, it is necessary to give a brief description of the recipient region.

It has very limited groundwater resources and on non-perennial rivers. The obvious solution adopted along the XX century was to build reservoirs to store water of the intermittent rivers. Most of these reservoirs were small ponds built with public resources in private properties to meet exclusively the needs of the influential landlords. However, as small is not always beautiful, the scattering of thousands of small dams all over the territory has had the effect of decreasing water availability, due to the increase of evaporation.

Of course, good reservoirs—those with large storage capacity and small surface area—were also built. Nevertheless, their water managers have restrained from taking full advantage of the stored water, even in normal years, in order to be prepared to fulfill the population survival needs during the eventual occurrence of future droughts. Because of this operation rule, and due to the high temperature and low humidity, immense quantities of water were lost through evaporation, without use for economic production and job creation. To change this situation, it would be necessary to rely on some other source of water, capable of meeting the basic needs in times of drought. With this assurance, evaporative losses could be reduced and existing water resources used more productively. In other words, if one could trust that water from the Sao Francisco River would be available in case of a water shortage, this would bust the use of the local water reserves, maximizing social and economic benefits, this was the main motivation for launching of the Project.

Presently most of the irrigated land in the recipient region produces low market value crops, such as beans. If a mango plantation were much more profitable than a beans plantation, why someone would choose to produce beans rather than mangos? The main reason is the lack of water security. Applying the minimax

8 $0.6 \times 26 + 0.4 \times 127 = 66 \text{ m}^3/\text{s}$, which is equivalent to 2 billion cubic meters per year or to 100 cubic meters per capita per year in the recipient area.

criterion, it makes sense to decide in favor of the beans because, in case of a water failure, the damage would be limited to one year. On the other hand, lack of water for someone that has planted mango trees may imply a much greater loss because the tree may die and a new one would take several years to yield the first fruits. For the same reason, very few job intense industries have factories in the region, despite the low labor cost. The Brazilian Semiarid has been the set of this “vicious cycle” people are poor because there are few investments to grow high value crops; there are few investments because there is no firm water supply; there is no firm water supply because people are poor and cannot pay for the infrastructure that would provide firm water supply. The Project aimed the dismantlement of this vicious cycle. In a few years, it will be possible to evaluate the results.

The Project didn't have a good start as the water users in the recipient region were not asked to pay for the use of diverted water before the beginning of construction. In this way, an opportunity was lost to increase the sense of ownership among beneficiaries. Even when Government pays for the entire construction cost, as it is the case of the Project, it is desirable that the beneficiaries pay for the “secure water”, at least to cover O&M. As there was not any firm commitment, very likely the water users will be allowed to get benefices from the Project without assuming any responsibility. In this unfortunate possibility, the maintenance cost of the Project would depend on the governmental budget, which would risk the US\$ 3 billion investments to become a white elephant.

The local water availability in the recipient region, considering the regulated outflow of the existing reservoirs, would be sufficient to meet, for several years, the basic needs of the population (roughly 40 cubic meters per year is all one person needs to drink, bathe, clean and cook). Those that have opposed the Project argue that all the Government should do is to help people have these basic needs attended. This could mean the construction of pipelines to connect remote villages to the local reservoirs or the building of individual tanks, one per household, capable of storing rain that falls on the roofs⁹. However, water use goes beyond the exclusive satisfaction of human consumption. It is also used as input for agricultural or industrial production. Taken all the water uses into account, it is necessary some 1,500 cubic meters per year and per capita for a technologically unsophisticated community to achieve a reasonable income level and, associated with it, a reasonable quality of life.

Because the water availability in the recipient states is around this threshold level, there are two possible policies for the region: export people or import water. The first alternative was implicitly applied for decades, as a significant portion of the population in the relatively wealthier Brazilian Southeast is composed of

9 Since 2003, half a million of water tanks of 16 cubic meters were built in individual households in the semiarid.

descendants of migrants from the dry Northeast. Those that propose public investments where water is easily available, like in the Sao Francisco River valley, defend this alternative. The idea is to create an immigration flux coming from the dry area. The second alternative is more political than economical. It tries to avoid the endurance of moving millions out of places inhabited for centuries by a people that built along the decades an infrastructure to survive in the Semiarid.

Conclusions

During the last decade of the XX century, it became obvious in Brazil that progress depended on water infrastructure and institutions. From the 1980s onwards, some states made substantial progress in developing modern water resource management agencies, often in cooperation with the World Bank. This was one strong motivation for the creation in 2001 of the Brazilian Water Agency (ANA). In her early years, ANA received help from the World Bank in the development of a program aimed to provide water security in the Brazilian Northeast, based on five concepts.

First, deep reservoirs are in general technically sound. However, shallow reservoirs, those with large surface area and small storage volume, in general are not. When the proposed reservoir has a small mean depth, often the best decision is not to build such a reservoir, thus avoiding the creation of a new evaporating water surface, without significant improvement to water reliability. In these cases, it is often preferable to build water conveyance structures for transporting water from the existing reservoirs to where is needed. Second, the balance between supply and demand depends not only on always increasing the supply through new constructions works. It also depends on the implementation of well-known integrated water resources management practices,

such as the issuing of water rights and the creation of river basin committees.

Third, new infrastructure should only be built when and where there is an institutional and commercial arrangement to take care of O&M. Otherwise the water infrastructure would have a short life span, due to lack of maintenance, as unfortunately it is the usual case in developing countries. Fourth, Government contracts should focus on the delivery of results, rather than on the construction of new infrastructure. For example, rather than giving a contract for the building of new water conduits, Government should sign concession contracts or public private partnerships for the public service of bulk water supply. The construction work would be, in this case, a responsibility of the concessionaire, rather than of Government. In the traditional way, when Government pays for the construction, the contractor has all the incentive to maximize the cost and does not care about the result.

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