

Interbasin Water Transfers: The Brazilian Experience and International Case Comparisons

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Received: 20 October 2009 / Accepted: 27 January 2011 /

Published online: 17 February 2011

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Abstract This paper critically examines Brazil's transbasin diversion experiences and two select, large-scale transbasin projects outside of Brazil. Rather than simply compare Brazil's experiences with international cases, the authors explore the historical context of the projects, focusing on the water resources and environmental regulatory and institutional frameworks in place during the initial proposals and how they influenced the projects' development and completion rates. Huge investments, the lengthy time span between the date of the initial project proposals and the start of construction, the need to garner public and political support, and more recently, the need to fulfill national and regional environmental laws are major factors underlying heated public debates about the proposed projects. After a broad discussion about the subject, the authors examine a recently approved large-scale Brazilian project, the São Francisco river transbasin diversion. This river diversion project is considered crucial to the economic development of Brazil's semi-arid northeastern region. Despite the fact that this government-funded project was debated for several decades among the various stakeholders, it was approved under Brazil's newly formed water resources regulatory and environmental framework, which enabled improvements in various key technical aspects of the project, and greater involvement of various key social players.

Keywords Water transbasin diversion · Water supply · Water resources management · Interbasin transfers

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1 Introduction

This paper examines three select Brazilian experiences of transbasin water diversion between river basins, with a comparative review of other similar projects around the world.

Despite Brazil's overall high water availability, the major geographic and economic differences between regions in Brazil, including aspects related both to water supply sources and demand distribution, have strengthened interest in solutions based on large transfers of water between river basins. In fact, this interest has grown globally as nations aim to achieve a greater level of water security. The literature presents the experiences of large-scale water diversion implementation in several countries. These experiences have resulted in many successes, some failures, and many lessons learned, and have helped governments and the private water infrastructure sector to establish technical standards, and environmental, engineering, and social best practices.

From this perspective, this paper reviews a few major projects of transbasin diversion across the world, including two Brazilian projects completed since the turn of the twentieth century. In addition, the authors discuss a Brazilian case in progress, the Rio São Francisco water transfer project in the northeast region. From previous experiences as reported in the literature, a number of factors have been identified that influence the success or failure of a project's implementation. Among these, according to Simpson (1995), are the following key factors: basic legal and institutional (laws, regulations, and approval processes), managerial, user participation, economic sustainability, financial and administrative, environmental impacts in the basins (source and recipient), compensatory measures and project costs. These aspects will be discussed in the analysis of the three selected cases in Brazil and two cases in other countries, in this paper.

2 Main Issues Facing Transbasin Water-Diversion Projects

Transbasin diversion projects have some remarkable features common across most countries and regions, despite cultural, legal and socio-economic differences. Regardless of the unique local aspects of each project, international experiences have provided learning opportunities and best practices that can benefit future projects. The first commonality is that such projects usually require enormous amounts of public funding and long-term construction that span many years, sometimes decades. These two aspects alone provide fodder for extended, frenzied public debates, since other social needs and infrastructure projects are competing for limited public funding. Furthermore, the benefits of these long-term projects are reaped years from the allocation and disbursement period, so immediate benefits are elusive. In addition, considering the lengthy duration and monitory magnitude of investments, such public projects often face short-term economic, political and administrative contingencies that can imperil project completion and cause significant delays.

The contentious debates over whether the government should fund such massive infrastructure projects involve many players, from end users, often commercial entities, who may benefit, including businesses, entrepreneurs, financial institutions,

government entities, politicians and representatives of the riparian basin and other social actors vying for a piece of the public pie. Also involved in public debates are the residents of the areas to be affected, including farmers, small businesses and others whose lives and livelihoods may be permanently affected by such large-scale projects. Addressing these diverse interests creates enormous difficulties for decision makers of various governmental entities. This difficulty is often exacerbated when regulations, laws and jurisdictions are ambiguous, incongruous or altogether absent (Klein 2007).

Given the complexity in managing the approval process of transbasin river projects and other large-scale infrastructure endeavors across the world, Yevjevich (2001) considers that interbasin water diversion projects generate some of the greatest controversies and deepest conflicts in water resources development, and notes that the technical aspects are often dwarfed by conflicting social, political, economic and administrative concerns. The assessment of who or which interests will benefit or suffer as a result of project implementation is another source of administrative difficulties for several reasons. If entrepreneurs or those involved in funding or building such projects make such estimates, they will likely overestimate the benefits to all the players, and underestimate the potential damages, which undermine fair compensation measures aimed at reducing opposition to the project. On the other hand, the opponents of the project usually exaggerate the damages and minimize their potential benefits. Thus, it is easy to understand the resulting complexity for decision-makers, which can be enlarged by the media, which often highlights the antagonistic views, which in turn, can further polarize opposing sides, making it more difficult to achieve a final consensus (Braga et al. 2008).

Based on empirical studies on several transbasin diversion projects (as shown in the worldwide water transfer database at www.transboundarywaters.orst.edu/database), any diversion project has a fundamental rationale based on an estimate of water needs in a targeted river basin, which, in the present or future, needs additional water resources. The comparison between the water balances of this river basin with that one of the source river basin is the main rationale for the decision making on transbasin projects. However, several issues arise at that time when estimates are made of the future water needs. First, we must recognize that most fundamental hypotheses cannot confirm what will happen in the future, either because the donor basin can grow at rates much greater in the future thereby affecting the need for water to be exported. Also, deviations or errors can occur in estimating demands in the receiving basin. Furthermore, conflicts do not derive solely from project opponents in the source basin; other interests, which emerge during the approval process, include those of politicians, and environmental and preservation groups that may represent the source or recipient basins. Also, increased competition for available water resources and inadequate management in the basin often result in water deficits which can hamper development in the downstream catchment, as occurred in the Upper Ewaso Ng'iro North Basin in Kenya (Mutiga et al. 2010).

When a large-scale project includes sensitive areas of environmental or archaeological value, the debate takes on a larger scope, sometimes reaching the national and international scale. Best practices of international experience offer lessons learned in terms of public education and public relations that highlight the relevance, needs and scope of the project, and are aimed at driving the best process for approval, construction and subsequent operation of the project as highlighted by Priscoli

and Wolf (2009) and Pereira et al. (2002). In other words, efforts are necessary to avoid the dissemination of misinformation can be an ally of opponents. Instead, the required public participation in such projects will be better swayed to accept such projects the more the population and potential users are educated about the project, as noted by Wolf (2001), Lebel et al. (2005), and Hespanhol (2008) among others authors.

It is worth remembering that the long execution period of the construction is also a risk factor, because it becomes a period of exposure to controversy without any concrete benefits, which can strengthen the perception of losses among the opponents. The CB-T water transfer project (Big Thompson), in the western United States, is an example of long execution period (1938 to 1957). This allowed exposure to diverse problems and risk factors, like the following ones: (a) a strike was called by the American Federation of Labor (AFL), causing delay for the construction; (b) momentum for and against to the proposed Grand Lake project occurred many occasions during the construction time period as a result of natural resources activism initiatives; (c) events related to the Second World War that also intervened in the completion of the CB-T, because of shortage of construction materials and manpower; (d) years with heavy snows also caused delays. Considering this source of risk, it is imperative that the project proponents find a good fit between the financial planning and administration, so the work can be completed within the deadline.

We must recognize that even with the work in progress or even close to completion, the conflicts do not necessarily stop. Opponent initiatives can cause project interruptions or alterations in the plan. Such initiatives, discussed in the literature, arise due to strengthening of social groups that assume that political and judicial entities will favor them if the case comes to litigation, in a perspective very different from that on the occasion of the approval of the project. This type of opposition after the construction stage occurred often in the Cantareira transbasin project in the Southeast region of Brazil, which began operating in 1973 primarily because the cities of the riparian basin (of the Piracicaba River) received no compensation (Barbosa et al. 1996). In fact, as Wolf (2001) notes in a review of several water transfer cases, the intensity of conflicts is more severe within the country than at international transboundary basins. Wolf (2001) noted many examples of internal water conflicts, ranging from interstate violence and deaths along the Cauvery River in India, to California farmers blowing up a water pipeline leading to Los Angeles. Also, in 1934 the U.S. desert state of Arizona even commissioned a Navy ferryboat and sent its state militia to stop a dam and diversion project on the Colorado River. These examples underscore the importance of an attitude of ongoing attention for project leaders' in terms of communicating to the public the project benefits, to help guarantee its approval and completion.

Government and stakeholder efforts towards obtaining approval for a project should not inhibit the need for a clear, long-term vision. The economic and financial planning should include both the constructive phase and the stage of operation, ensuring completion within the time frame, and also the financing commitments to maintain and operate the project throughout its lifetime. In regions where the beneficiaries cannot bear the costs of the project and its maintenance, planners should ensure, at the minimum, the recovery of operational and maintenance costs. However, initiatives to obtain fast, total recovery of investments

can result in high tariffs for the end users, which can prompt them to find other options for water supply if the project is still under consideration, or if it is completed, this can reduce consumption, and the use of the project's full capacity.

It is interesting to note over time the development of the legal and institutional framework of such water diversion projects in various countries, which might be prone or contrary towards more agility between the initial proposal and the construction of the diversion project. Case studies of projects across the globe that involve high levels of public participation, decentralized approval processes, and numerous legal and environmental law considerations, inevitably require more time to approve and implement than less complex projects. However, there are cases in which clear legislation has helped to minimize conflicts and get better definition of the form of participation of the social actors, based on fully institutionalized procedures and practices. Case studies reveal that projects are most successful in receiving approval when the laws, development and land use regulations, the administrative approval process, and oversight procedures result from a gradual, thoughtful evolutionary process, and reflect the view that some degree of loss is acceptable before potential gains that can be achieved, and if compensatory measures are properly considered and implemented (Deason et al. 2001).

Another interesting issue is related to the recent trends on using system analysis and decision making methodologies to provide support on water transfer projects. As previously discussed, inter-basin water transfer projects require careful evaluation with many indicators based on society, economy, technology and environmental values. Therefore, Multicriterion Decision Making (MCDM) has emerged as an effective methodology to be applied due to its ability to combine quantitative and qualitative criteria for selection of the best alternative. The Xi-River-to-Tanghe Reservoir Water Transfer Project System is a very interesting case study using MCDM, as described by Xuesen et al. (2009). Also, Mojtaba Sadegh et al. (2009) have developed a new methodology based on crisp and fuzzy Shapley games for optimal allocation of inter-basin water resources. The effectiveness of this method was examined by applying it to a large scale case study of water transfer from the Karoon river basin in southern Iran to the Rafsanjan plain in central Iran. In this same country, a transbasin water diversion in the Zayandeh-Rud river basin was studied using a System Dynamics formulation (Madani and Mariño 2009). System dynamics provided a unique framework for integrating the disparate physical, socio-economic and political systems important to watershed management. A simulation model, built based on causal loop diagrams of the problem, showed that transbasin diversion was not the best and only solution to the problem. A similar system dynamics (SD) model was designed to serve as a decision-support system (DSS) for water managers while operating the water transfers in the Mexican Conchos basin, which meets the water demand to the agricultural sector in the Mexican side of the Rio Grande basin and also for meeting Mexico's obligation to deliver water to the United States. As described by Gastélum et al. (2009), this DSS can simulate different short and long term scenarios combining temporary water right transfers inside and outside irrigation districts. Also, different short scenarios were implemented to investigate the benefits of water transfer from México to the United States.

3 An Analysis of Selected International and National Transbasin Diversion Cases

The enactment of environmental laws around the world are a recent, yet significant development for large-scale infrastructure projects and have been enacted to avoid damages that can occur when environmental concerns are ignored or overlooked in engineering projects. Approval of new water transfer projects is clearly influenced today by an environmental awareness and laws absent decades ago. Recent examples are in the western United States, as described by Woodhouse (2008) who examines the impact of the federal application of the Endangered Species Act (ESA). Its requirements forced major changes to the design and construction of the yet-to-be-completed Animas–La Plata project, in the upper Colorado region. The project was significantly scaled down, and all non-Indian irrigation uses were eliminated; in addition, allowable depletions were reduced. In another case the groundwater transfer proposed by the Southern Nevada Water Authority is currently undergoing scrutiny by state and federal agencies to determine how much water can be removed from basins without causing environmental damage; the amounts eventually approved will be subject to future reduction if environmental impacts surface during construction phases.

Clearly, many large-scale projects constructed in the past would not have received the required environmental permits today. We will cite selected cases of transbasin diversions to highlight issues of key interest. These examples represent the “evolutionary timeline” of humans’ relationship with the natural environment, particularly humans’ awareness of the need for a sustainable approach to altering the environment. In this context we will examine some national and international experiences of water basin diversion projects. The main details of the selected water transfer cases discussed in the paper are shown in Table 1.

3.1 Two Brazilian Cases

The Canadian Light Company instituted the first transbasin river diversion project in Brazil in 1913 aimed to generate hydroelectric power for the growing city of Rio de Janeiro. It involved building a series of hydroelectric plants with a total head of 300 m on the Atlantic side of the Sierra Mar, with a capacity of 1,407 MW. This project transferred 180 m³/s of the Paraíba do Sul River watershed (about 2/3 of the river’s average flow) to the Guandu River. The Paraíba do Sul basin

Table 1 Selected water transfer projects and their main characteristics

Country	Paraíba do Sul Brazil	Cantareira Brazil	Colorado B. T. USA	Snowy H. S. Australia	São Francisco Brazil
Water transfer flow capacity (m ³ /s)	160	33	15.6	322.8 (297.3 + 25.5)	127 m ³ /s (99 + 28)
Hydropower generation (MW)	1,407	None	192.7	3,756	None
No. of inhabitants served (millions)	12	8.8	3	–	12
Initial year of operation	1952	1973	1947	1949	Under construction

covers approximately 57,000 km² and crosses three states, Rio de Janeiro, Minas Gerais, and São Paulo. The river basin is home to 4.0 million people and, in addition, supplies water—via a complex diversion and water transfer system—for nearly 8 million residents of the metropolitan region of Rio de Janeiro, located outside (downstream) of the basin. A total of 180 municipalities in the basin depend on the Paraíba do Sul River for water (Campos 2001), and the basin produces approximately 13% of Brazil's gross domestic product (Braga et al. 2005). It should be noted that the project, initially designed for power generation, diverted enough water to enable the development of a large portion of the metropolitan region of Rio de Janeiro. Today, the Guandu River supplies water to about 12 million people, 7,000 industries and 6,000 rural properties. However, this project resulted in adverse environmental impacts including degradation of water quality; the river is estimated to receive about 1 million cubic meters per day of sewage without any treatment. At the start of the twentieth century when this diversion project was built, there were no environmental discussions about such large-scale projects of this nature and thus, the environmental impacts were not assessed in the source basin (Paraíba do Sul) or in the recipient (Guandu) basin, nor were they assessed for the population (including future generations) to be affected. Furthermore, the difficulties of maintaining adequate water flows during periods of drought were not considered in the plans, and have caused conflicts between the populations of the two basins. As a result, the Committee for Integration of the Rio Paraíba do Sul River Basin (CEIVAP) was formed in 1978 and has worked to mediate these conflicts. More recently, in 2005, CEIVAP pioneered the development of a new institutional framework to collect tariffs from water resource end users. These tariffs are aimed to support water quality maintenance programs. Currently the transbasin must be maintained even if power generation is stopped (Azevedo et al. 2005) since the urban water supply is the top priority under the requirements of Law 9.333/97 on water policies.

The challenging period of drought between 1998–2004 was a significant test to CEIVAP. In responding to the prolonged drought, committee members showed a high degree of cooperation, integration and flexibility. First, when the drought hit hard, the committee was recognized as too large to make efficient and fast decisions necessary to avoid collapse. Consequently, to address competing needs, CEIVAP formed a working group of professionals both from the private and public sector that met weekly to examine and address system needs and limitations. Whereas in the past, decisions about river flow were controlled primarily by the power sector, after the creation of CEIVAP, pressure mounted to include broader representation of stakeholders. The small working group made decisions regarding reservoir and transfer release levels during the six-year drought. As the situation improved, the group met with less frequency and continued to monitor the situation.

Another major transbasin project in Brazil, called the Sistema Cantareira project, was completed in 1973, located in the southeast region. It started pumping 33 m³/s of water from the Piracicaba River basin (source) to the Alto Tietê River basin; today it provides 60% of the water supply to the metropolitan region of São Paulo and neighboring cities, totaling approximately 8.8 million people (Barbosa et al. 1996). This project encompasses four reservoirs (total of 979 hm³ of available storage), 27 km of water tunnels, 120 m of head elevation and a pump station with four units of 20,000 HP. It cost approximately US \$1 billion for the water transfer capacity

of 33 m³/s, a demonstrated competitive advantage to the alternative option (water transfer from the Ribeira River basin) with estimated cost of US \$7 billion for a water transfer capacity of 70 m³/s. During the 1960s and 70s, public participation in Brazil diversion projects was not commonly practiced, thus, no compensatory measures were established for riparian users when construction on the Sistema Cantareira project began in 1966. Project planners conducted a water demand assessment of the source basin during project planning. However, the cities of the riparian basin of the Piracicaba River have since undergone enormous industrial and urban development over the following two decades, generating fierce debate and conflicts related to water use, particularly from the users of Alto Tietê River. In this context, the first river basin management committee in Brazil, called Committee of the Capivari, Piracicaba and Jundiaí rivers (CPJ), was established in 1991 and included representatives of the three river basins involved (Azevedo et al. 2005). This committee also played an active role in 2004 to better define the goals of the Piracicaba River basin during the State licensing renewal process needed to continue water transfers (the original water transfer allowance expired in 2004). After many meetings and intense negotiations with the regional water supply company (SABESP,) which runs the water transfer, a renewal rate of 31 m³/s was defined, along with several operational rules to be applied during drought conditions. Counting on the support and supervision of National Water Agency-ANA, this negotiation process and its results were considered a successful experience for both river basin users.

A comparison between water transfer flows and water availability in the source basin (at the diversion point) is shown in Table 2 for the three Brazilian water transfer projects discussed in this paper. The Paraíba do Sul River is the oldest water transfer project in Brazil, built in 1913. Furthermore, based on data shown in Table 2, this was the greatest water transfer project in terms of the amount of water transfer capacity as a fraction (66.7%) of the water availability of the source basin, which could be acceptable only considering the lack of environmental awareness in the 1950s. In fact, in this case, the large water transfer initiated primarily for hydropower purposes turned out to be beneficial for greater Rio de Janeiro's water supply needs and its many industrial users. The Cantareira water transfer also represents a large fraction (69.2%) of water availability in the source basin. Despite the more recent completion of this project (1973) compared to Paraíba do Sul (1913), project's opponents had to recognize that the water transfer was designed to supply the water needs of the greater metropolitan region of São Paulo, which was large at the time of construction and has since become a booming, international city since then. The most favorable outcome situation of São Francisco River project is due to the

Table 2 Water availability of the source basin compared to the water transfer flows

Water transfer project	Long term average river flow at the diversion point (m ³ /s)	Water transfer flow to the recipient basin (m ³ /s)	Remaining flow (m ³ /s) downstream the diversion point
Paraíba do Sul	240.0	160 (maximum) 119 (minimum)	Minimum requirements: 90.0 (normal conditions) 71.0 (critical drought conditions)
Cantareira	44.8	31 (maximum) 25 (minimum)	Minimum requirements: 5.0
São Francisco	1850.0	63.2 (average)	Minimum requirements: 1300.0

small amount of water transfer flow as a fraction (3.4%) of water availability in the source basin. Public discussion about this project along 8 years after 2000 occurred under stricter environmental laws and involved a more socially and environmentally conscious and participative society than those of Cantareira and Paraiba do Sul projects. Despite the distinct date in which the projects were implemented, a common issue facing the three Brazilian projects discussed before is a strong need driving the water transfer, aimed at providing an adequate water supply for the most populated areas in the country for the first two projects (Rio de Janeiro and São Paulo), and to supply water needs of the most severe regional drought area of the country for the last project (São Francisco).

Indeed, the great and ever-increasing need for water and sewer management in the São Paulo and Rio de Janeiro metropolitan areas illustrate a typical problem facing Brazil's large cities, the resolution of which requires the integration of the two main dimensions of water management: water resource and environmental sanitation management (Barraqué et al. 2007). This is what the new state policies initiated in the early 1990s aims to develop: the environmental engineering paradigm such as demand-side management, water conservation, water allocation flexibility, and an integration of water services, water resources management, and land use policies. Greater São Paulo's water resources policy has been strengthened to protect headwaters (water sources) from urban sprawl, one of the most serious water-related problems of the basin (and the most difficult to resolve). Initiated under in the mid-1970s and revised in 1997 under the State Headwaters Law (9.866/97), this new approach also represents a remarkable departure from São Paulo's traditional segmented approach, which separates water management from environmental concerns, especially water pollution and land use. However, the full implementation of such policies will likely face significant barriers, since reaching the proposed goals depends on the capacity and will of municipal authorities (*vis a vis* political forces and pressure from the general public) to strengthen urban regulations so as to guarantee the control and monitoring of land use in the sub-basins.

3.2 A U.S. Case: The Colorado–Big Thompson Project

The Colorado–Big Thompson Project (C-BT; Grigg 1996) is considered a prime example of successful transmountain water diversion project because it mitigated a water scarcity problem in Colorado, a semi-arid interior state in the western United States. Colorado is divided by the Rocky Mountains running north–south in the west, and vast dry plains in the east. The C-BT project was designed to collect Rocky Mountain West Slope water from the headwaters of the Colorado River and divert it to Colorado's Front Range, at the eastern base of the Rocky Mountains, and the state's plains for agricultural purposes. Built between 1938 and 1957, the C-BT provides supplemental water to 30 cities and towns. The entire project contains more than 100 major features, 125 water user organizations, 60 reservoirs and many distribution canals. While the project was built for agricultural purposes, it now serves multiple purposes including municipal and industrial water supplies, hydroelectric power generation, and recreation, including fish and wildlife activities. In recent years, however, water demands shifted and municipal dwellers and industrial users are now the main beneficiaries, rather than agricultural interests. Today, approximately 80% of Colorado's precipitation falls on the West Slope of

the Rocky Mountains, yet approximately 80% of the state's growing population lives along the East Slope, between the cities of Fort Collins and Pueblo, including Denver.

Similar to many large water transfer projects, the road to authorization for Colorado–Big Thompson was often regionalized and raucous, but unlike other projects, this battle was pitched, public, and an item of national debate. One important feature of the C-BT Project was the creation in 1937, the year before C-BT construction began, of the Northern Colorado Water Conservancy District (NCWCD), to assume the construction and operations tasks based on sustainable environmental basis. The NCWCD had a wide authority to contract with construction firms to expand the system, to set taxes for water users, and to outline and oversee agreements with federal institutions, among others tasks. The particular time period of the C-BT implementation can help us understand the role of public community participation. This project was one of several federal initiatives to help the U.S. economy recover after the Great Depression of the 1930s. Therefore, the time was favorable to involve regional community members and political representatives to discuss the goals and possible benefits of the C-BT project. Although not required by U.S. environmental laws at 1930, the C-BT had to collect compensatory fees from the project users for the construction of the Green Mountain reservoir, required to regularize flows of the Blue River, a tributary of the Colorado River. Also, the NCWCD set a minimum river flow standard for the Blue River to assure ecological and water use requirements along the river.

Despite the fact that the C-BT resulted in a great regional resource that aided in Colorado's economic development, some Colorado residents, agricultural producers, and other businesses in the western part of the state continue to voice their displeasure with the project because they have faced water shortages from the diversion. This demonstrates that most water diversion/transfer projects result in some degree of ongoing conflicts between source basin and recipient basin users, thus strengthening the need for meticulous planning, along with thorough public discussions, and open negotiation and agreements.

3.3 The Necessity of Public Involvement

Learning from this and other large-scale transbasin water diversion projects, it is clear that public involvement in the planning of such projects requires much thought and foresight on the part of developers and planners, along with time, sometimes years, to gather input from the communities to be affected, and to assess environmental considerations. After regional development, which usually takes place in the diverted river basins, the resulting multiple water uses strengthens the need for transbasin projects. The following section provides another example of this.

3.4 The Australian Case

As described by Ghassemi and White (2007), in Australia, the proposals for utilising the waters of the Snowy River to supplement the summer flows of the inland rivers, the Murray and the Murrumbidgee, date back to the 1880s. These proposals were in the context of additional water supplies to relieve the occurrence of often inland drought conditions. However, more than 60 years later, in 1944, a committee of state

and local community representatives was created to assess the project feasibility, that was examined also from a different aspect, the harnessing of the Snowy's waters for hydro-electric power production. In 1949 the Snowy Mountains Authority was created by the local government to supervise the planning, construction and financial support of the project to the dual-purpose Snowy Mountains Scheme. The final project, called the Snowy Mountains Hydroelectric Scheme (SMHS) was developed for hydropower generation, farmland irrigation, and to supplement Southeast Australia's water supply. Completed in 1974, SMHS includes 16 reservoirs, seven hydroelectric power plants, a pump station, 145 km of tunnels and 80 km of pipes. Today, it provides electricity to Australia's eastern region, and also water for irrigating the areas of the Murray and Murrumbidgee river basins.

Despite its benefits, the planners' failure to thoroughly assess environmental issues and potential negative results has led to adverse impacts, including reduction of water flow and natural irrigation of the riparian basin and erosion downstream in the receiving basin. As a result of the growing environmental problems in the two river basins, the Murray–Darling Initiative was created in 1992, with an agreement between the government and the local community aimed at providing a regulatory framework to plan, coordinate and manage efficient, equitable and sustainable water resources for the river basins. It is evident from this initiative's work that the lack of an environmental regulatory framework at the time of construction caused many problems that had to be mitigated at high costs (Azevedo et al. 2005).

4 Analysis of the São Francisco Transbasin Project Based on Brazilian and International Experiences

4.1 Project Overview

Brazil has approximately 12% of the world's freshwater, and adequate annual rainfall in more than 90% of the country. Geological conditions and its climate support a large and dense network of rivers. However, this water resource is distributed irregularly throughout Brazil. The Amazon River region encompasses 70% of Brazil's water resources, but is home to only 7% of its population. In contrast, the southeast region contains only 6% of Brazil's water resources but 43% of its population. A more critical situation exists in the northeastern region with only 3.3% of the country's water resources and 29% of the Brazilian population. Adding to these unique features, is Brazil's weather patterns, including high temperatures, and rainy, wet seasons that alternate every six months of the year with a dry season. Yet another unique feature is the conditions of Brazil's soil and geology, which are inhospitable to underground water storage (e.g., underground reservoirs and wells). This has given rise to the moniker for Brazil's northeast region, "Drought Polygon" (Fig. 1), as it has critical water deficits and consequently is the least developed region of Brazil, with development rates comparable to the least developed countries in the world (MIN 2004a, b).

From the perspective of Brazil's federal and state governments, the São Francisco River transbasin diversion project is considered instrumental for the economic development of the semi-arid areas of northeastern Brazil. Since as far back as 1847, numerous proposals for major transbasin water transfers to the north and east of the

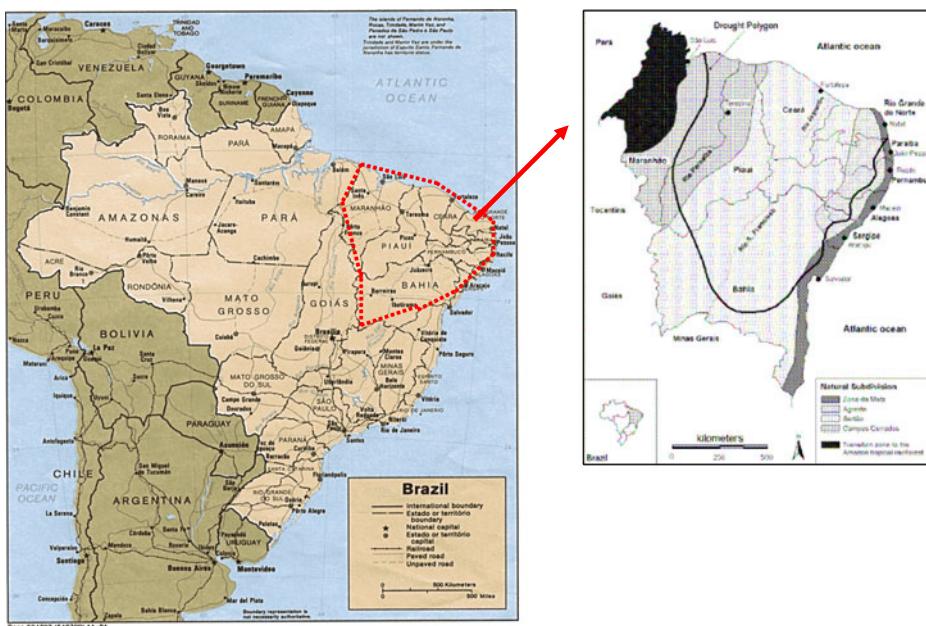


Fig. 1 Brazilian northeast and the drought polygon

river basin have been proposed. When complete the project will benefit 12 million people, irrigate 300 000 ha, create an estimated one million jobs and remedy, for residents, and agri-businesses the region's frequent droughts. The São Francisco River Basin Committee, with representatives from eight states, agrees that having an adequate water supply is imperative (National Water Agency-ANA et al. 2004), but publicly expressed concern about the approach proposed. Recommendations and strategic actions were strongly proposed in the Strategic Action Program (National Water Agency-ANA et al. 2004) for the source basin that would prioritize measures for revitalizing the river so that future population growth and socio-economic development demands will not ultimately jeopardize the environmental sustainability of the basin and its coastal zone. Despite government planning initiatives in 1980, 1990 and 2000, the Rio São Francisco transbasin diversion project was not approved due to a lack of solid technical plans, financial resources and public consensus about its potential benefits. However, this situation has changed since the Brazilian Ministry of National Integration developed the most recent northeast region water diversion proposal in 2007, called the Project Integration of the São Francisco River (PISF; Machado 2008; in some circles, the river is called "The river of national integration," as it unites the central and northeastern regions of Brazil). This plan seems to have found political footing with the national government, yet it has also garnered significant resistance from the five states that the river flows through. The project has been under construction since 2008. The PISF aims to:

1. Augment the water supply to meet the needs of the four semi-arid states in the region (Ceará, Paraíba, Pernambuco and Rio Grande do Norte), mainly for irrigation and urban residential and industry needs;

2. Provide additional water to supplement the existing reservoirs in the region, enabling better water management;
3. Reduce regional water supply differences caused by the uneven supply of water among the river basins and people.

The PISF's goal is to transfer water from the São Francisco River basin, the main water source in the northeast region, to small basins in the arid regions. The São Francisco River begins in the Canastra Mountains in the state of Minas Gerais and flows across the states of Sergipe and Alagoas into the Atlantic Ocean. It runs for 2,700 km through a rich fauna and forests, and feeds hundreds of lakes and reservoirs home to numerous species of fish. Its basin extends 641,000 km², and covers about 7.5 percent of the total area of Brazil, where 15.5 million inhabitants live, 70% of which reside in urban areas (465 municipalities). The long-term, average river flow is 2,980 m³/s and the minimum historical flow is 644 m³/s. The region's mean annual rainfall varies from 1,900 mm in the northern regions of the basin to 350 mm in the lower basin. The mean annual evaporation rate ranges from 500 mm in the upper basin to 2,200 mm in the lower basin.

The PISF aims to supplement water supplies for urban and agricultural irrigation uses in the semi-arid area of northeast region, inhabited by 12 million people. It will transfer water from the São Francisco River downstream from the Sobradinho reservoir, which currently has a flow of 1,850 m³/s, and minimum environmental required 1,300 m³/s plus downstream uses at downstream. To minimize the proposed project's negative impacts on both the environmental area and hydropower production the water transfer will be limited to 24.3 m³/s and intermittently it will increase to 114.3 m³/s only when the Sobradinho reservoir is at or above 94% of its storage capacity or at the storage limit for flood control. This highly and limited variable transfer flow of 24.3 m³/s or 114.3 m³/s must be distributed and stored to regularize use in the reservoirs in the attended area. The average water transfer planned for 2025 is 63.20 m³/s, derived from the intermittent use of 114.3 m³/s. An additional 24.02 m³/s will come from regulating reservoirs along the São Francisco River basin. In addition to the source basin supply of 87.22 m³/s (63.20 plus 24.02) is 77.22 m³/s from regulating the reservoir capacity of the regional recipient river basin, resulting in 164.22 m³/s of water. This amount will meet the total water demand of 164 m³/s forecast for 2025.

The planned water diversion will be carried out through two main routes (Fig. 2). The north route will provide water to the Jaguaribe, Apodi, Piranhas and Brigida rivers. The east route will deliver water to the Paraíba and Moxotó rivers and the Agreste Pernambucano region. The maximum water volume to be transferred through the north canal is 99 m³/s, and 28 m³/s through the east route. Water transfer flows and other relevant data for each route are shown in the Table 3. In total the project includes nine pumping stations, 27 aqueducts, eight tunnels, 35 water reservoirs and two hydroelectric plants.

4.2 Contentious Issues

The proposed water transfer of the São Francisco River is the first mega-project under Brazil's new water policy law (9.333/97), which established Brazil's national water resources policy and the National Water Resources Management System (Braga et al. 2009). Most of the basic principles of this law affect transbasin water



Fig. 2 North and east routes of the São Francisco water transfer system (WTS)

diversion projects: (a) water is a public good; (b) water is a limited natural resource with economic value; (c) priority in the use of water resources is given to human consumption and the watering of animals; (d) the river basin is the territorial unit for the implementation of National Water Resources Management System; (e) water resources management should always allow for multiple uses of water; (f) water resources management shall be decentralized and shall involve participation of the government, water users, local communities and the organized civil society (Zambon et al. 2008).

The São Francisco River is under federal jurisdiction, thus requiring the authorization from the National Water Agency (ANA) to abstract the water needed for the project. Abstraction rights for the water transfer were approved by the São Francisco River Basin Committee, with a certificate issued by the ANA in September 2005.

While this major project will likely bring extensive benefits to the region in terms of regional development, it is also expected to cause adverse impacts, including environmental issues as described by Pittock et al. (2009a, b). Specific environmental

Table 3 Main characteristics of the North and East routes

	North route	East route
Channel capacity in m^3/s	99	28
Average flow transfer in m^3/s	48	16
Minimum flow transfer in m^3/s	16.4	10.0
Channel length in km	400	300
Total pumping elevation in meters	165	304

issues will derive from biodiversity loss, destruction of native vegetation, risk of introducing non-native species potentially harmful to people and the environment, disrupted fishing due to added dams, siltation, and water loss from evaporation as the water cycle is altered. The East Route canal has been constructed on either side of the Serra Negra Biological Reserve, Brazil's first nature reserve. Further construction would bisect and damage this critical remnant of the Atlantic Forest, which belongs to the Pipipa and Kambiowa indigenous peoples. The uncertainties produced by these potential adverse impacts have generated concern and opposition from residents and business leaders in the riparian basin, primarily in the state of Bahia. The main concern is that after diversion, the river will not have enough water to meet the social and economic activities of the basin's residents, which will affect adversely their welfare and well-being. The Brazilian government has assured the users that developments in the donor basin will not be restricted because of the transfer (Magalhães and Oliveira 2001).

The energy sector is currently the main user of São Francisco water. A federal state owned company, CHESF, currently has 9,973 MW of installed capacity. A basic concern of the project planners was whether they could offer firm assurance to CHESF that the operation of its hydropower plants will not be significantly affected by the water transfer. In fact, the project has very carefully calculated the volume of water needed to cover the present energy demands, and to satisfy the future hydropower generation needs from 2010 to 2015. Based on simulation studies that considered historical river flows, the project is not expected to adversely impact electricity generation even during what is considered the critical hydrological period between 2010 and 2025.

Another important consideration is the project's impacts on the riverside population. The hydropower plants have regulated the river's flow for more than 30 years, with no adverse results. The water transfer is expected, however, to affect the hydropower plant operations to a relatively small degree, 3.4% (obtained by dividing the average water transfer, of $63.2 \text{ m}^3/\text{s}$, by $1850 \text{ m}^3/\text{s}$ of mean term flow). The population living along the river and the estuary are not expected to face serious adverse impacts from progressive river flow reductions. One of the claims from the donor states and NGOs opposing the project is that the water transfer project will deliver water and benefits only to the powerful landowners and agribusinesses and not to the general population, as claimed by its proponents, which, they assert, could result in increasing the socioeconomic inequality in the northeast region. In spite of the opposition to the water transfer project, the government and the population of the riparian basin agree that a permanent solution is necessary to remedy the problem of water scarcity in Brazil's semi-arid and underdeveloped northeast (National Water Agency-ANA et al. 2004). The difference of opinion, however, is how to achieve this. States that share the São Francisco River basin (the source) prefer a solution that will not affect them as much as they think the proposed project will.

The farmers from Minas Gerais and Bahia states (upstream from the Sobradinho Dam), whose livelihood is agricultural-related activities, have been assured that their existing water allocation will not be reduced by the diversion. In fact, currently, the large Sobradinho reservoir ($34,000 \text{ hm}^3$ of active capacity) situated upstream from the planned diversion point, significantly regulates the river flow in the source basin. The only limitations for the use of water are, and will continue to be, the restrictions

imposed by the navigation sector and the volumes of water needed to maintain the river's fluvial ecosystem. The users downstream from the Sobradinho Dam are not expected to face any detrimental impacts. It has been estimated that the amount of water that is to be transferred, along with whatever water would be required for irrigation; even if the entire basin needs to irrigated, not more than 3% (annually) of the water stored in the Sobradinho Reservoir will be needed. Since the volume of water stored in this reservoir is expected to fluctuate minimally, no variations should occur downstream. Thus, the farmers should receive their needed share of water for agricultural uses.

Critics of the project point out that the problem of the semi-arid region is not the lack of availability of water but rather the unfair distribution of existing water resources, such as the 37 million m³ of water retained in the more than 70,000 small, medium and large reservoirs and dams in the region. Opponents claim that the drought problem in the northeastern semi-arid region requires effective management of available water, and should not be solved by building an expensive mega project as proposed.

4.3 Similarities and Differences between the São Francisco Transbasin Project and Other Transbasin Projects

The São Francisco Transbasin Project has one feature that sets it apart from all other projects constructed and analyzed previously, whether in Brazil or compared with many ones abroad, since its approval had followed rigorous existing environmental laws.

In the two Brazilian cases presented, the Cantareira System and Paraíba do Sul, discussions for the approval of the projects did not consider the environmental impacts that the implementation would cause due to river loan and its disposal. The projects were also developed for specific purposes with no discussion and planning for multiple water uses that had been transposed. The Cantareira System project's basic goal was to increase the water supply to the city of São Paulo. The Paraíba do Sul project's aim was to generate power mainly for the Rio de Janeiro region. However, conflicting objectives related to the use of water have appeared over time following its completion, thus requiring the creation of legal instruments to manage these issues. Currently, Brazil has a CPJ Committee that manages the diversion of water to São Paulo and has also explored alternative water supply sources in order to alleviate water needs from the transbasin project. In addition, compensatory measures in the PCJ basin had to be instituted using financial resources from fees collected from water users. The tariffs for water users in the source basin (PCJ basin) were defined in 2005, assuming unit values (currency \$ R: Brazilian reais; average exchange rate 1 U.S. dollar = 1.85 reais) as follows: R\$ 0.01/m³ for wholesale users; R\$ 0.02/m³ for end users; R\$ 0.10/kg BOD for sewage dilution into the rivers and R\$ 0.015/m³ for water transfers. These tariffs have been continually applied since 2006. Based on the annual report of the National Water Agency described by ANA (2009), the total economic amounts collected in 2008 were around R\$ 14.5 million from wholesale users (water supply services for 29 cities and towns), R\$ 2.1 million from end users (74 industrial users) and R\$ 1.3 million from sewage dilution users, and R\$ 10.0 million from water transfer user (recipient basin of the Cantareira transbasin

project). Most part (59%) of the collected tariffs has been allocated to construction of sewage treatment stations and waste disposal in the recipient basin.

On the other hand, the diversion of the Paraíba do Sul River, which was built mainly for power generation, has become an essential source of Rio de Janeiro's water supply. In this case the river basin committee (CEIVAP) has managed the use of water by charging users in order to develop programs designed to maintain water quality and sustainable use. These post-diversion initiatives of CEIVAP and PCJ committees were instituted to correct environmental problems caused by water transfer that were not addressed and worked out in the planning phase. In contrast, the diversion of the São Francisco River was extensively discussed by most stakeholders in Brazilian society—residents, businesses, environmental groups, and government bodies—and endorsed through the public hearings required by Brazilian law, thus allowing the planners to implement several measures to mitigate the possible adverse effects of the water diversion projects. It should be highlighted that civil works have been developed since 2008 and the revitalization of the São Francisco River has also started.

The Colorado Big Thompson Project (U.S.A.) was constructed primarily for power generation. Despite having been built in a time of few environmental laws and regulation, it involved strong participation of political leaders, Congress, consultants, and regional and local water users. Although environmentalist advocates were not part of the planning process, environmental issues and compensation were discussed at the beginning of the project. Therefore, in the following expansion stages, the planners had to adopt Environmental Impact Assessments-EIA and establish agreements for compensatory measures for those living in the basins of the loan. It should be noted that the project management model, which is concerned with sustainability, has predetermined rates that incorporate the costs of capital, operation and maintenance. Similarly, the water transfer of the São Francisco River has defined rates to support the overall costs of the project, including capital, operation and maintenance costs. Indeed, this project's unit costs were significantly higher than other projects in Brazil, with rates based only on the partial components of the cost.

The Australian Snowy Mountains Hydroelectric Scheme was designed with the main objectives of irrigation and power generation in southeast Australia. Similarly, it was built in a period with few environment regulations or concerns, without approval of the EIA and only partial involvement of community in the project approval. As a consequence it resulted in various negative environmental impacts and lacked proper water use oversight and management. Subsequently, by agreement of the Murray–Darling Basin, the government entities and the community came together to create a management structure for the basin. In the implementation of the São Francisco River transbasin project, Brazilian government with its numerous ministries, was ultimately responsible for the project's management. Although the recipient basin communities actively participated in project planning through public hearings and even influenced his amendment, it remains unclear how the water use will be managed after completion of the project. It is expected that a specific management agency will be created, one that will involve the government, representatives of the donor and receiving basins, financial supporters and entrepreneurs, and local residents; their focus will be the problems of equitable use, efficient and sustainable water use and maintaining water quality.

Table 4 Main factors in the five select water transfer projects discussed in this paper

	Paraíba do Sul	Cantareira Colorado B. T.	Snowy H. S.	São Francisco
A private company or administrative entity in charge of implementing and managing the project	None	None	Yes	Yes
Open public discussion with actors and regional and local communities directly impacted by the project	None	None	Yes	Yes
Compensation measures in place during the project formulation	None	None	Yes	None
Conflicts among water users during the project operation	Yes	Yes	None	Yes
Price or tariff set for water users	None	None	Yes	None
Main drivers of the water transfer project	Hydropower generation	Water supply	Regional development	Hydropower generation
Current uses of water	Water supply irrigation	Water supply hydropower	Water supply irrigation	Water supply irrigation

Table 4 summarizes the main factors considered in the five water transfer projects discussed in this paper.

5 Conclusions

From this examination, all transbasin diversion projects discussed required extensive planning and public discussions from the initial proposition through the final approval, and construction, which took up to several decades in many cases.

Today, with environmental laws and regulations, the approval of such projects is much more complicated than in past, mainly due to legal requirements to assess and mitigate all environmental impacts from such large-scale developments. From this perspective, the transbasin diversion of the São Francisco River in Brazil stands apart from the rest, since it passed strict environmental law scrutiny. One can say with conviction that all public discussions, technical or not, led to improvements in the project and to well defined compensatory measures for potential problems occurring in the source basin. Also, the maturation time of these projects, the long discussions and the overall approval process aimed to comply with environmental laws contributed decisively to minimize and mitigate future conflicts.

From examining all of the transbasin cases discussed in this paper we learn that having an effective management entity in place at the project's start is a key factor for success. Such management organizations should include representatives of all sectors

involved in the project, and mediators capable of addressing expected conflicts over water use and promoting solutions with the perspective of sustainable development.

In summary, this paper discusses the diverse environmental, political and economic complexities associated with massive water infrastructure projects, from the planning to the construction and operations phases, which can span decades. Even with the clear and undisputed need for water as was the case in the metropolitan regions of Rio de Janeiro and São Paulo, Brazil numerous factors create barriers. The huge investments, the lengthy time needed to complete construction, the need to garner public and political support, and more recently, the need to fulfill national and regional environmental laws, represent the major difficulties. Yet, as we have seen, these barriers can be mitigated. To do so, the planning process must consider the larger legal and political context, along with the institutional framework. Furthermore, planners must develop sound communication strategies, build new communication channels and clearly communicate the project's purposes and expected outcomes, along with the benefits. They must also plan to compensate those players who may experience hardships as a result of the project. These communication channels must include all societal players so that conflicts can be aired and resolved in a public, transparent forum; this is as important as securing funding or ensuring the project's technical feasibility.

Acknowledgements Funding of this research includes grant from State of São Paulo Research Foundation-FAPESP (#2008/58508-1). The authors are also grateful to reviewers for their persistent and deep analysis of the manuscript.

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