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ARTICLE

Appropriation of Río San Juan water by Monterrey City, Mexico: implications for agriculture and basin water sharing

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Abstract Monterrey metropolitan area's growth has resulted in water transfers from the Río San Juan basin with significant impacts for downstream water users, especially farmers in the Bajo Río San Juan (BRSJ) irrigation district. El Cuchillo dam is the centerpiece of the basin's water management infrastructure and has become the flashpoint of a multi-faceted water dispute between the states of Nuevo León and Tamaulipas as well as between urban and agricultural water interests in the basin. Subsequent to El Cuchillo's implementation in 1994, the BRSJ irrigation district has been modifying its irrigation operations to adjust to the new water availability scenario. Compensation arrangements for farmers have been established, including crop loss payments on the order of US$ 100 per hectare unirrigable due to the diversion of water to Monterrey plus 60% of the water diverted to be returned to farmers as treated effluent via the Ayancual Creek and Pesquería River, a process with its own water competition and environmental implications. The Mexican irrigation sector will continue to face intense competition for water given: (a) low water productivity in agriculture leading decision-makers to allocate water to higher productivity uses particularly in cities, (b) priority accorded to the domestic use component of municipal water supply, and in the BRSJ case, (c) Mexico's national interests in meeting its water sharing obligations with the United States.

Keywords Water transfer · Water productivity · Water compensation · El Cuchillo · Rio Grande watershed · Effluent

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Introduction

Mexico's Northeast demonstrates an economic dynamism that outpaces the rest of the country. The region has historically taken advantage of linkages with the United States since 1848 when the Río Bravo (Rio Grande in English) was fixed as the border. Agricultural development was spurred by investments in irrigation infrastructure in the first half of the 1900s when urban growth also gained momentum, particularly in the City of Monterrey (Mexico's second largest city). The Mexican side of the border has experienced rapid urbanization, driven in part by the development of assembly plants ("maquiladoras") that expanded significantly with the 1994 signing of the North American Free Trade Agreement. The maquiladora sector competes with agriculture for labor and, to a lesser extent, land and water; it also generates significant pollution that is an issue of binational negotiation over environmental quality. The Río San Juan sub-basin (see Fig. 1), which is the focus of this study, is the final Mexican tributary to the Río Bravo before it empties into the Gulf of Mexico.

This paper assesses the transfer of Río San Juan water to Monterrey in the context of a multi-state, international basin. A brief overview of water, agriculture and urban growth in

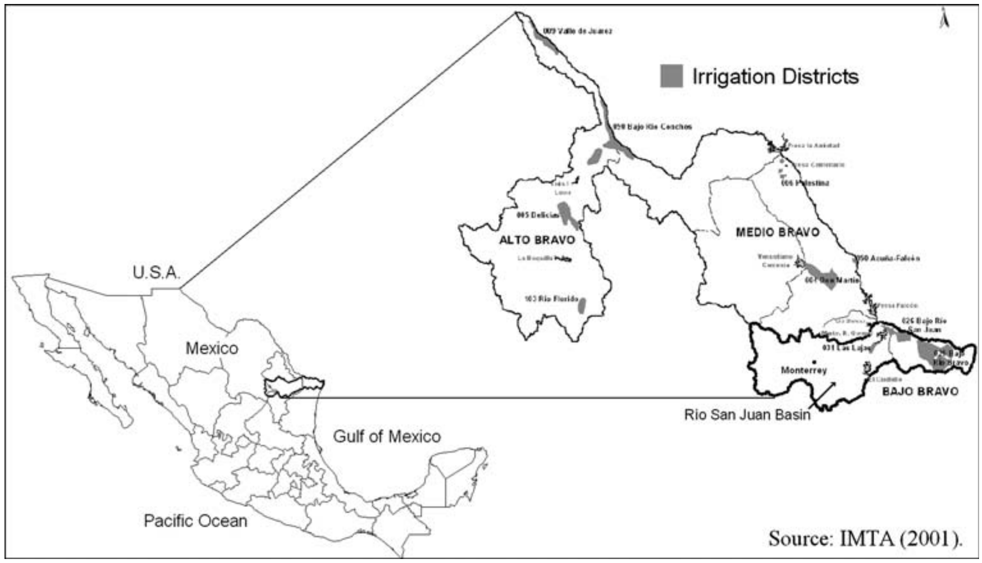


Fig. 1 Mexican Río Bravo (Rio Grande) basin including the Río San Juan sub-basin, Monterrey City, and irrigation districts

Mexico and the basin sets the context for an assessment of San Juan sub-basin water resources and their allocation among competing water uses. We follow this with data on Monterrey's water demand, the transfer process of San Juan water from El Cuchillo reservoir, impacts and adaptation on the part of downstream irrigation districts, implications of wastewater discharge for the environment, and summary comments on trends in the San Juan sub-basin for Mexico's basin water sharing with the United States.

The context

Mexico's irrigated area is 6.3 million hectares (ha), the largest in Latin America; 3.4 million ha are concentrated in 82 irrigation districts (primarily surface water) and 2.9 million ha are private or small-scale public irrigation units (primarily groundwater) (CNA 2005a). The irrigated area during 2001–2003 was 23.2% of Mexico's total cropland. Although the value of total agricultural sector output has increased marginally, as a percentage of Mexico's gross domestic product (GDP) it has decreased from 5.7% in 1995 to 3.8% in 2005 (World Bank Group 2006a, b), even with growth in horticultural crops for export.

Mexico's total population of 106 million was over 76% urban in 2005. The share of rural population dropped below 50% of the total as early as 1960. Domestic water supply has priority over other uses as per a 1992 water law discussed further below. Water for agriculture and livestock ostensibly has higher priority than industry. Water resources in Mexico's Río Bravo including the San Juan sub-basin are used as follows: 78% for agriculture, 12% for urban-public supply, 8% for industry, and 2% for livestock (CNA 2001). The Río Bravo basin has 71 aquifers for which total extraction remains below estimated annual recharge; however, 20 aquifers are over-exploited. In the lower San Juan sub-basin, groundwater is predominantly saline and is not used for irrigation. The principal irrigation districts (ID) in the sub-basin are ID026 Bajo Río San Juan (BRSJ) and ID025 Bajo Río Bravo (BRB). Statistical data for BRSJ and BRB irrigation districts were obtained from the Comisión Nacional del Agua (National Water Commission, hereafter referred to as CNA) irrigation districts division in Mexico City. Water transfer agreement information and hydrological data for the Río San Juan sub-basin involving the Monterrey Metropolitan Area (MMA) were obtained from published sources and the Internet.

Irrigation in the San Juan sub-basin

Conventional, large-scale irrigation has been practiced in the BRSJ area since at least 1906. The Marte R. Gómez (MRG) dam, constructed in 1936 just upstream of the San Juan's confluence with the Río Bravo, serves as the BRSJ irrigation district's principal reservoir with 829.9 million cubic meters (MCM) active storage capacity. Subsequently, El Cuchillo dam (1,123.0 MCM active capacity) was constructed ~75 km upstream and began operations in 1993 primarily to supply water to Monterrey (Flores-López and Scott 1999; see further details in the section on water transfer below). The BRB receives water from the Mexican share of Río Bravo water and, as a result, is not the primary focus of this study. Due to high salinity, groundwater in the lower San Juan and Bravo basins is not an important source of irrigation supply. Average annual rainfall in the San Juan sub-basin is 510.1 mm for the 1994–2003 post-Cuchillo period (CNA 2005a, b), with a longer-term average of 532.8 mm (IMTA 2001).

Table 1 Río San Juan sub-basin water balance at Marte R. Gómez Dam

	Average past 60 years (million cubic meters, MCM)	Average past 10 years after Monterrey water transfer (MCM)
Inflows (San Juan + Pesquería)	883.2	434.6
Withdrawals (for BRSJ, urban supply, and water sharing obligations)	428.6	259.1
Evaporation	150.0	
Flood releases	302.9	
Deficit	2.5	
Transfer from Las Blancas		60.8
Sustainable volume		428.6

Source: CNA (2005a)

The CNA has calculated the basin water balance at MRG dam shown in Table 1. Figure 2 demonstrates that since El Cuchillo's construction, MRG's average annual storage has been approximately half of El Cuchillo's, although with significant variation about the mean.

San Juan surface water from MRG dam is the source of water for irrigation units (sections) I, II, and III of the BRSJ district, which has a total irrigation service area of 75,049 ha. Units IV and V (totaling 10,852 ha) irrigate with water pumped directly from the Río Bravo when there are spills from the Amistad and Falcon binational reservoirs and the International Boundary and Water Commission (see brief description below) gives its approval. The BRB irrigation district with a service area of 269,000 ha receives its water supply from the Amistad and Falcon binational reservoirs.

Water rights and allocation

The Ley de Aguas Nacionales (1992) (Mexican Law of the Nation's Waters) stipulates that water is property of the nation, with the CNA administering a system of titles for water use. These are typically granted as 25-year concessions; for surface irrigation water, the title is held by the water user association (WUA). For groundwater, water is titled at the level of the well (individual farmer or small group).

Water resource allocation decision-making in Mexico is the purview of the CNA. Beginning in 1992, public irrigation districts including the BRSJ were transferred to water users associations called "módulos" (Johnson 1997). Currently, operations and maintenance plans proposed by the WUAs are approved or modified by the irrigation district "hydraulic committee" headed by the CNA district chief with WUA representation. Field-level decisions remain with farmers, constrained by irrigation supply and scheduling (Rymshaw 1998). WUAs are taking a more active role in supporting farmers' input procurement and marketing.

Mexico signed a treaty in 1944 with the United States that covers all shared water resources, principally the Río Bravo/Grande and the Colorado in the West. Water sharing is overseen by the binational International Boundary and Water Commission (IBWC)—Comisión Internacional de Límites y Agua (CILA). IBWC and CILA are headed by commissioners who report to their respective federal authorities (State Department in the case of the US, and Secretario de Relaciones Exteriores in Mexico), but operationally work with state and local agencies on water management and allocation.

City of Monterrey urban water supply

Water is supplied in the MMA by Servicios de Agua y Drenaje de Monterrey (SADM) (water and sewer services of Monterrey), an autonomous public utility under the government of the state of Nuevo León. Withdrawals from El Cuchillo reservoir (1,123 MCM active capacity) are augmented by surface supplies from Cerro Prieto (393

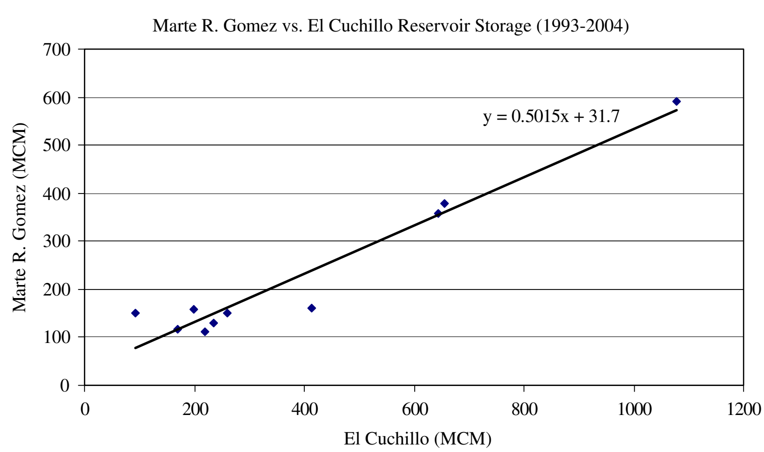


Fig. 2 Marte R. Gómez versus El Cuchillo reservoir storage (1993–2004). Source: CNA (2005a)

MCM), La Boca (45 MCM), San José Vaquerías (30 MCM), and four smaller reservoirs (combined 30 MCM), in addition to groundwater from a battery of 100 wells distributed in a 200 km perimeter surrounding Monterrey City. SADM estimated 2002 per capita domestic water consumption to be 130 l per capita per day, down 18% from 1997 (due to constant supply of 335 MCM/year with increased customer base).

Nature and characteristics of water transfer to Monterrey

Prior to assessing the water transfer process, it is important to note that San Juan irrigation is predominantly supply-driven and appears to be evolving toward a de facto rainfed-supplemental irrigation system. The hydraulic committee headed by the CNA district chief with WUA representation determines the volume of water to be delivered to the irrigation district; the módulos in turn define their irrigation plans based on crop water demand and conveyance and distribution efficiencies. So, the irrigation plan must be based on a total water requirement less than or equal to the volume allocated by the hydraulic committee. There is some scope for altering irrigation plans in response to rainfall. Reservoir releases on the main canal that are not diverted to secondary canals, e.g., if rain falls during transit time, are captured in the drainage system given that any water returning to the Río Bravo main stem becomes binational water. Additionally, percolation resulting from excess in-field irrigation is lost to the (saline) aquifer. As a result, the emphasis on efficiency is warranted. BRSJ tracks the “supply index” at each of its units’ control points on water delivered as a ratio of water scheduled (based on availability); over the 1996–2003 period, the head-end módulo fared relatively well with 0.87–1.10 while the tail-end modulo had 0.24–1.38. The 2003–2004 season was poor with values of 0.45 at the head and 0.01 at the tail. Overall, the lowest point of water measurement is the control point for each water users association (13 in total for BRSJ plus one for the headworks). This points to marked head–tail distribution problems and the need for improved management of irrigation, which suggests that infrastructure improvements as part of the transfer agreement have potential to partially offset declines in water supply.

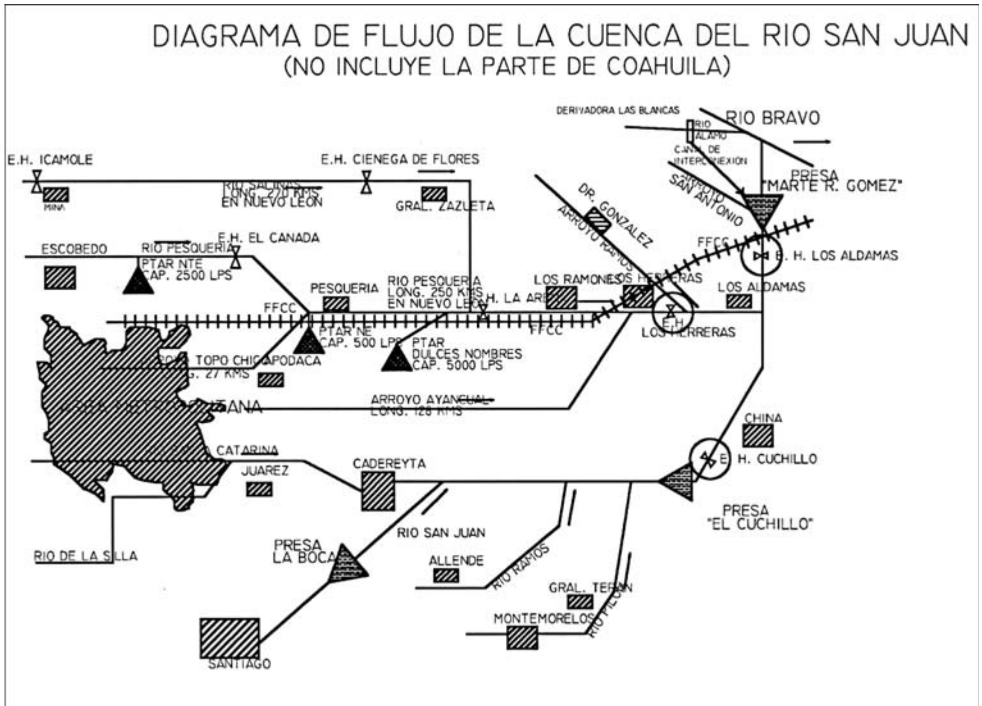
On 9 October 1989, SADM signed a special coordination agreement with the federal and Nuevo León state governments for the Monterrey IV Program that set forth the planning, financing, and construction of El Cuchillo dam; operation began in 1993. Downstream Tamaulipas state brought pressure to bear and on 6 September 1990, signed its own coordination agreement with the federal and Nuevo León governments with the objective of “rational” water use to satisfy MMA’s urban and industrial water demands while preserving the multiple uses of water of the BRSJ irrigation district. By CNA’s account (CNA 2005a), this was supported by the district’s hydraulic committee that set forth the following action plan: (1) rehabilitation of the Anzaldúas-Rhode pumping station on the Río Bravo; (2) relocation of domestic and industrial water supply sources of the Tamaulipas populations of Camargo, Díaz Ordaz, Reynosa, Río Bravo, and rural communities (population approximately one million by the authors’ estimates) from their existing sources on the Rhode canal; and (3) allocation by the CNA of 189 MCM of treated effluent from Monterrey, with Nuevo León assuming the responsibility and cost of treatment in compliance with federal water quality standards.

In parallel developments, the 1992 water law created the institutional model for river basin councils in Mexico and the Río Bravo was one of the first basin councils created. Water user participation in decision-making, subject to official approval, is one of the aims of the basin councils. However, allocation policies and water sharing remain the purview of the CNA. Wilder and Lankao (2006) review the slow progress of user participation in water management following the 1992 law. River basin councils have been established in a limited number of basins; however, their influence on water management in practice remains limited (Wester et al. 2004).

In the ensuing mid 1990s drought that gripped much of North America, Río Bravo and Río San Juan flows declined dramatically. Río Pesquería (effluent) return flows were increasingly intercepted by water-short irrigators immediately downstream of Monterrey and reportedly did not reach the MRG dam. Inadequate attention has been paid to the environmental implications of effluent flows in the Pesquería, although there are reported impacts on water quality (Flores-Laureano and Návar 2002) and public health (Rodríguez Castro et al. 2004).

In response to declining irrigation supply, the Tamaulipas irrigators filed suit against the federal and two state governments; however, the court ruled that in signing the 1989 and 1990 coordination agreements, irrigators had forfeited claims to Río San Juan water above MRG, originally granted through Presidential decree in 1952 (although they still claimed return flows). Additionally, the intervening 1972 and 1992 national water laws were ruled to have annulled the 1952 decree.

For its part, the BRSJ hydraulic committee met on 19 January 1996 with the two state governments and the CNA to draft minutes (CNA 2005a) conferring to the irrigation district access to Monterrey’s effluent as long as existing (third-party) rights were observed. Monterrey would extract 5 m^3/s from El Cuchillo, and subsequently increase extraction to 10 m^3/s. BRSJ’s first three irrigation units



Source: CNA (2005a).

Fig. 3 Río San Juan sub-basin flow diagram, Source: CNA (2005a)

would be entitled to a maximum of 553.8 MCM, including effluent, to irrigate 69,099 ha registered in the users list for the district. SADM, the Monterrey water utility, would return annually a minimum of 189 MCM of effluent (meeting Mexican official quality guidelines), equivalent to 6 m^3/s, to be released through the Río Pesquería to the MRG dam as shown in Fig. 3 (CNA 2005a). In compliance with this agreement, three wastewater treatment plants (Norte, Noreste, and Dulces Nombres) located just outside Monterrey release effluent to the Ayancual Creek and Río Pesquería, along with runoff from the urban areas and industries along Ayancual. However, in practice, over the past ten years the average annual flow from the Pesquería to MRG has been 4.2 m^3/s, with dry season low flow (as a proxy for effluent contribution only) of 2.4 m^3/s. There was consideration of an 8 m^3/s capacity pipeline to convey effluent all the way to MRG. In the event that the 189 MCM were not received by BRSJ, farmers would be compensated for the deficit. We will return to the compensation issue later. SADM was only entitled to use effluent in excess of the 8 m^3/s pipeline capacity.

El Cuchillo operating rules reflect a combination of its own storage and that of MRG. Releases from El Cuchillo would only be made when MRG storage was less than 700 MCM (to prevent losses resulting from oversupply). Additionally, in the first phase of Monterrey's extraction of 5 m^3/s, El Cuchillo would only release if its storage exceeded 315 MCM (to preserve a buffer for supply to Monterrey), and in the second phase of 10 m^3/s for Monterrey, El Cuchillo would only release if its storage exceeded 516 MCM.

The CNA and the Tamaulipas government defined an investment schedule for improvements in irrigation efficiency in BRSJ to be carried out during 1997–1998. Stated to take account of the feasibility of proposals made by water users associations, the investments involved primarily rehabilitation, infrastructure improvement, and the adoption of "modern technology."

The Monterrey IV Program second phase aqueduct bringing the total extraction from El Cuchillo to 10 m^3/s would only be started (using Nuevo León's own funds) after completion of the improvements to safeguard BRSJ's multiple uses of water as detailed in the 13 November 1996 agreement signed by the CNA, the Nuevo León and Tamaulipas state governments, and SADM. These improvements included: (1) the effluent pipeline from the treatment plants to MRG to be initiated in 1997 and completed in 1998; (2) rehabilitation, infrastructure improvement, and modern technology investments of Mex$ 200 million (approximately US$ 20 million) to be expended in 1997–1999 in order to improve BRSJ irrigation efficiency; and (3) completion of the feasibility study by the CNA for the construction of Las Blancas dam (84.5 MCM total storage with 60.8 MCM live storage) in Tamaulipas to capture Río Alamo runoff for use by the BRSJ irrigation district. This feasibility study was completed by 1 August 2000.

Additionally, the CNA was charged with conducting annual analyses every November after the completion of the rainy season with semi-annual updates every May to determine the El Cuchillo operating plan to ensure water supply to the MMA, the BRSJ in Tamaulipas, and a smaller irrigation district (031 Las Lajas) in Nuevo León.

The 1996 agreement described above was put to the test in 1997, when Nuevo León failed to return 189 MCM of treated effluent to BRSJ, and in February 1998 the federal government paid 15 million pesos (US$ 1.4 million at current exchange rates, equivalent to US$ 20 per ha) in compensation to the farmers (from an original figure of US$ 0.375 million). This payment was not regarded as a debt for Nuevo León as a result of drought conditions. Barajas Aguilar (2000) confirms that almost every major issue in the dispute resolution process has required a great deal of commitment and federal financial resources, in addition to political willingness.

As a result of acrimonious legal wrangling and opaque decision-making, irrigation interests that might otherwise have played a constructive role—had the participation of a broad base of irrigators been facilitated in the basin councils—found themselves in an adversarial position and took increasingly strident postures (Barajas Aguilar 2000; press reports). The federal government sought to promote further water transfers to meet increasing urban demand and forged a new agreement in November 1998, which five of the 11 irrigation districts in the larger Río Bravo basin refused to sign. This agreement included the creation of a Río San Juan basin council; however, the membership and influence of water users on the council were perceived to be low in comparison with officials (federal and state), and as a result, the irrigation districts boycotted the council and took recourse to social and political mobilization to demand compensation for unmet commitments. Press reports cited in CEFPRODHAC (2001) indicate that farmers' initial claims for Mex$ 2,154 per ha were reduced to Mex$ 1,025 per ha (approximately US$ 100 per ha). Farm economic viability remains a major concern. Programs for crop support (PROCAMPO) in 2004–2005 was Mex$ 935 per ha with additional marketing support of up to Mex$ 500 per ha for maize (leading some farmers to switch to maize from more traditional sorghum or cotton, with lower support prices).

On 12 March 2002, Tamaulipas Governor Tomás Yarrington Ruvalcaba addressed BRSJ and BRB farmers in Reynosa in response to the claim that federal authorities (the CNA) had released 114 MCM of San Juan water to fulfill treaty obligations with the United States. The governor, of the Partido de la Revolución Institucional (PRI) party in opposition to the Partido de Acción Nacional (PAN) party in power at the federal level, pledged Tamaulipas state economic support of "more than Mex$ 62 million for farmers in districts 025 and 026" (an amount translating to US$ 18 per ha). He demanded the release of 44 MCM from El Cuchillo that never reached MRG. Finally, and perhaps most importantly from an institutional perspective, he pledged to create a water legal counsel to defend the state's interests. This positivist discourse built on the accusations he leveled at the federal government (PAN party) for colluding with Nuevo León.

Demographic and economic growth coupled with increasing environmental amenity values drive increases in MMA's water demand. It is likely that limited existing and future water sources will entail that MMA further increases its dependency on Río San Juan water from El Cuchillo dam. In the context of recurring, persistent drought coupled with national imperatives to meet Mexico's obligations to the water sharing treaty with the United States, the sub-basin's limited water resources will be subject to very significant, sustained competition that will test Mexico's system of water rights, institutional arrangements for water transfers, and establishment of a river basin council for the Rio Bravo that has jurisdiction only for the Mexican tributaries.

Water transfer outcomes

The BRSJ has witnessed continued decline in water supplies and cropped areas as shown in Fig. 4a, the combined result of intersectoral competition and drought. For comparison purposes and plotted on similar relative scales, Fig. 4b shows these data for BRB through 2000. During the critical 1994–2002 period, both districts appear to have similar responses of irrigated area per unit of water supply; however, these are not a marked departure from values before El Cuchillo came on line.

Land and water productivity at the BRSJ irrigation district scale after El Cuchillo are shown in Table 2. In the following analysis we must clarify the terminology used in Mexico: "bruto" ("gross") refers to reservoir-level water volumes, while "neto" ("net") refers to módulo-level volumes delivered to farmers, i.e., after main canal losses measured at the módulo's control points as well as estimated losses in the "minor" distribution system to farmers' offtake points. The significant productivity declines in 1997–1998 and 2000–2001 were caused by limited water supply of 1.3 and 1.0 irrigations per year, respectively (CNA 2005a), with high total planted areas that farmers based on their expectations of both adequate reservoir storage and rainfall. In 2003–2004 there was an apparent improvement in both land and water productivity attributed to an increase in the area under maize (46.5% of the total cultivated area in 2003–2004, up from an average of 5.7% over the 1995–1996 to 2002–2003 period, due in large part to subsidy support for marketing maize that is nearly twice as high as for sorghum, and good rainfall leading to high irrigation water productivity in 2003–2004) and a decrease

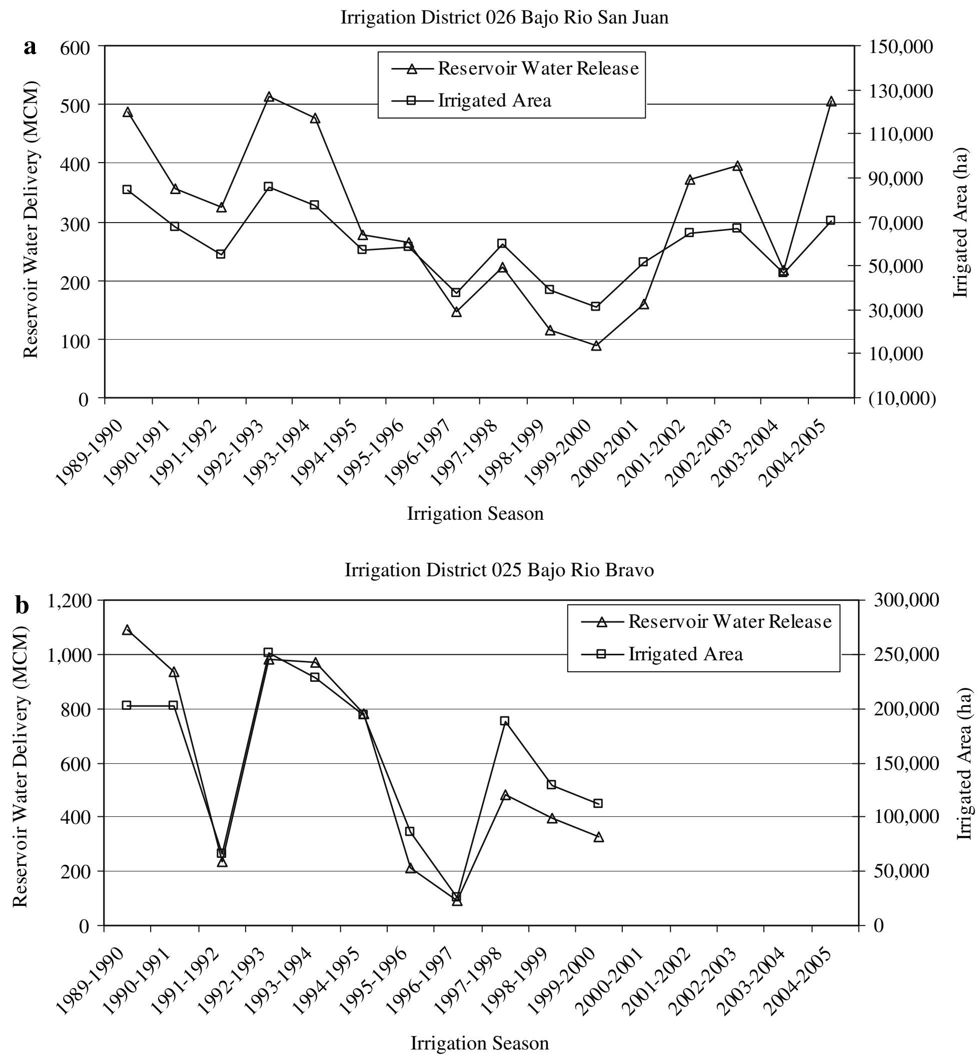


Fig. 4 **a** Bajo Río San Juan irrigation supply and irrigated area, 1989–2005, **b** Bajo Río Bravo irrigation supply and irrigated area, 1989–2000

in the sorghum area (to 46.1% of the total area in 2003–2004, down from an average of 83.7% over the 1995–1996 to 2002–2003 period). The profit shifted from US$ 57.10 per hectare of sorghum to US$ 468.20 per hectare of maize representing a significant increment in the total production value.

In Table 3 the mean módulo-level water productivity values are shown for the period after El Cuchillo dam. The

Table 2 Water and land productivity at BRSJ irrigation district scale

Year	Total production value (1,000 US$)	Total cultivated area (ha)	Total gross volume used (1,000 m^3)	Mean gross land productivity (1,000 US$ per ha)	Mean gross water productivity (US$ per m^3)
1995–1996	25,075.23	56,863	263,331.00	0.441	0.095
1996–1997	8,898.65	32,141	146,811.00	0.277	0.061
1997–1998	182.34	53,751	222,875.00	0.003	0.001
1998–1999	7,623.18	32,453	114,272.00	0.235	0.067
1999–2000	8,896.94	31,221	110,100.00	0.285	0.081
2000–2001	602.22	52,559	160,499.00	0.011	0.004
2001–2002	25,882.31	62,104	383,171.00	0.417	0.068
2002–2003	34,677.88	72,370	395,429.90	0.479	0.088
2003–2004	56,521.11	72,923	217,267.50	0.775	0.260

Source: CNA (2005a)

Table 3 Water productivity at Módulo scale

Year	Total production (ton)	Total gross volume used (1,000 m^3)	Total net volume used (1,000 m^3)	Gross water productivity (ton/ 1,000 m^3)	Net water productivity (ton/ 1,000 m^3)
1995–1996	202,131.86	263,331.00	146,743.00	0.77	1.38
1996–1997	101,029.00	146,811.00	78,927.00	0.69	1.28
1997–1998	175,891.00	222,875.00	128,059.00	0.79	1.37
1998–1999	84,614.00	114,272.00	64,089.00	0.74	1.32
1999–2000	90,555.00	110,100.00	64,201.00	0.82	1.41
2000–2001	6,609.00	160,499.00	83,283.00	0.04	0.08
2001–2002	250,578.00	383,171.00	219,372.00	0.65	1.14
2002–2003	281,786.20	395,429.90	213,457.40	0.71	1.32
2003–2004	394,543.58	217,267.50	110,089.20	1.82	3.58

Source: CNA (2005a)

effects of an exceptionally good rainy season in 2003–2004 years are apparent with higher water productivity. The opposite scenario occurs during 2000–2001, which was a dry year. The same trend is shown for 2003–2004 in which an apparent increase in water productivity is presented over the previous years.

Water releases from MRG to BRSJ irrigation district have witnessed continued declines since El Cuchillo began to operate as shown in Fig. 5. The implementation of El Cuchillo compounded the impacts of a severe drought in the northeast region of Mexico and this effect is seen in the MRG releases until 2001. The delivered volumes at the offtakes from the minor distribution system are shown as well. All these volumes only correspond to módulos (in units I, II, and III) irrigated from MRG releases; Tables 2 and 3 correspond to these irrigation módulos plus the módulos in units IV and V, for which the water source is the Río Bravo.

The crisis over El Cuchillo dam has brought about some positive changes in the way water has been considered in the BRSJ irrigation district. From being regarded almost as a free good, now some measures are being taken to increase water productivity. For instance, farmers are adapting by shifting crops, especially from sorghum to maize. Farmers and irrigation district managers are cognizant of the increased profitability of maize; however, the increased water demand would have to be met by increasing irrigation efficiency with fixed area planted. In general, conveyance efficiency is low (see Fig. 5) and represents one means to improve water productivity. Other means include marketing and reducing the costs of inputs other than irrigation. Additionally, loss reduction must be applied in the MMA as well. The CNA (2005a, b) reports that 1,659 ha of pressurized irrigation have been introduced in BRSJ, of which 70% is slotted pipe distribution in the tail-end módulo IV-1. This represents just 2.4% of the area of BRSJ. The need for more comprehensive long-term planning is certainly a necessity, including a more appropriate valuation of water. Regarding plans for rehabilitation in BRSJ, the challenge is not only of primary conveyance and distribution infrastructure, but also of operational plans and water management policies.

Conclusions

Water transfers from agriculture to cities must be viewed in a broader context of economic transformation, political negotiation, water law and policy, and for the Río San Juan and Monterrey, Mexico case described in this paper,

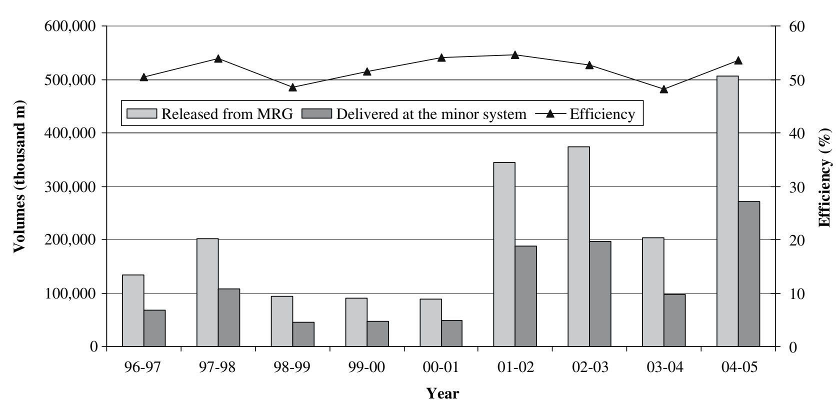


Fig. 5 Released water volumes from MRG dam and delivered water volumes at farmer offtake points for BRSJ. Source: data source for 1996–1997 to 2003–2004 was from CNA (2005a). For 2004–2005, data was obtained from the CNA irrigation districts division in Mexico City. Efficiency figures were derived from linear regression analysis of previous years

international affairs. MMA's continued growth has generated significant demand for urban water supply that it met through the appropriation and transfer of water that historically had been used for irrigation. Although Mexican water policy accords priority for domestic use, Monterrey's considerable industrial sector that benefited from the water transfer needs to be explicitly included in the dispute negotiations. The industrial sector's role in reaching a negotiated agreement is underscored by the fact that effluent (with water quality impacts from industry) is returned to downstream irrigators.

In the paper we describe the negotiations, institutional process, and political dimensions of the transfer and examine the irrigation sector's responses and adaptation. These may be characterized as follows: farmers in the BRSJ irrigation district whose water supply was directly affected after the construction of El Cuchillo dam for diversion of water to Monterrey were subject to official allocation decisions, although they were largely bypassed in the decision process and negotiations over water sharing in both federal—(inter) state—local coordination agreements, and in the basin councils created with an explicit objective of addressing disputes of this nature. Instead, the CNA acted to quell the dispute by attempting to represent all interests, including farmers. We conclude that public participation in water resource allocation decision-making and dispute resolution must go a step further than having farmers as observers to farmers being actively involved in setting priorities and determining outcomes. This is not only possible in Mexican water policy, it is written into the 1994 water law. The rationale and implications of diminished or ineffective public (farmers') participation in water allocation requires further research.

In the Río San Juan case, conditions for compensation to farmers were established, and although Monterrey and Nuevo León did invest in wastewater treatment, it is likely this would have taken place even without the condition of returning effluent to farmers to offset the water transfer. It was the federal government that stepped in to compensate farmers for water scarcity under the prevailing drought. While drought certainly contributed to farmers' economic losses, the more persistent reduction in water for agriculture has resulted from the transfer itself.

Farmers adapted to the transfer through efforts to improve water productivity and irrigation efficiency. In the BRSJ irrigation district, efficiency gains are an important strategy given that irrigation percolation is "lost" in the saline aquifer, and surface return flows may enter the Río Bravo, where they become binational water and are "lost" to Mexico. The shift to maize in 2003–2004 dramatically improved water productivity and although subsidy support for maize is better than for sorghum, maize requires additional water, which came in 2003–2004 through good rains. This fact, coupled with irrigation water scarcity resulting from the transfer, leads to the possibility that the irrigation district is evolving toward a rainfall-supplement system for maize. The production and economic risks of this approach, however, are significant.

Decision-making in the Río San Juan case is made exceedingly complex by USA–Mexico water sharing. Although the contribution of San Juan water to meet Mexico's treaty obligations is a topic beyond the scope of this paper, it is important to emphasize that in the binational context, the Mexican federal government takes a primary role in water management and allocation in the larger Río Bravo basin. This has tended to diminish the role farmers can play in decision-making, underscoring our conclusion above on farmer participation.

Finally, the case study presents some interesting long-term challenges. It is unclear what strategies are appropriate for farmers likely to face permanent transfer of increasing volumes of water, as Monterrey plans its second-stage diversion from El Cuchillo. Under these circumstances, the effluent exchange represents an innovation in water resources and institutional terms; however, management of the effluent flows to ensure they reach farmers whose water is transferred, in addition to mitigating the impacts of effluent on environmental quality and public health, need particular attention. Federal, state, and local government roles and responsibilities for the effluent exchange, as well as farmer participation, will need to be negotiated within Mexico's legal and institutional frameworks.

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