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The integration of water quality into transboundary allocation agreements Lessons from the southwestern United States

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Abstract

There is now a fairly substantial literature that addresses transboundary water allocation both at the international and interstate level. However, most of this literature deals almost exclusively with the question of allocation and ignores quality considerations. At the same time, there is a growing literature on transboundary pollution control and upstream/downstream externalities. What is missing is an attempt to integrate quality consideration into allocation agreements. This paper examines several allocation agreements and disputes in the southwestern United States and Mexico and looks at the ramifications of omitting pollution control and quality considerations in these negotiations. © 2000 Elsevier Science B.V. All rights reserved.

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1. Introduction

In the western United States there are currently 21 interstate rivers governed by interstate river compacts.[1] The United States is also party to an international treaty with Mexico on the Colorado River and another treaty on the Rio Grande River. These agreements have, for the most part, either resolved allocation disputes or provided a mechanism through which states may claim damages. This paper examines several of these agreements and provides an evaluation of the potential costs of ignoring quality considerations in allocation rules.

There is now a fairly substantial literature that addresses transboundary water allocation both at the international and interstate level. However, most of this literature deals exclusively with the question of allocation and ignores quality consideration. At the same time, there is a growing literature on transboundary pollution control and upstream/downstream externalities. Attempts to integrate quality consideration into allocation agreements are largely absent. This paper examines several allocation agreements in the western United States and Mexico and looks at the ramifications of ignoring pollution control and water quality. It examines several multi-jurisdictional rivers including the Colorado River, the Rio Grande River, the Arkansas River, the Pecos River, the Republican River and the Big Blue River. Given the growing pressure on water scarce regions to negotiate agreements and to reallocate water typically used in agriculture, an examination of existing agreements and their success or failure can provide valuable lessons. Ongoing negotiations the southeastern United States, the Middle East and elsewhere could benefit from such hindsight.

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[1] For a summary of these agreements and an overview of the interstate river compact, see Bennett and Howe (1998) or Bennett et al. (2000).

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This paper begins with an historical examination of the interstate river compact. The potential effects of the lack of water quality considerations are addressed. International rivers are then addressed using the case of US and Mexico. Finally, allocation rules inclusive of water quality are reconsidered.

2. The interstate river compact: allocation disputes and water quality

An interstate river compact is a negotiated agreement, which once ratified by Congress becomes a federal law. As such, disputes must be heard by the Supreme Court. Disagreements over interstate river compact allocations, resulting from underdelivery of water by upper basin states, have been the focus of several lawsuits between upper and lower basin states.

2.1. Pecos River

An example of a case in which damages were assessed is the *Texas v. New Mexico*[2] suit over Pecos River Compact violations. New Mexico was found to be in violation of the compact as a result of underdeliveries of water to Texas. Analysis of direct and indirect economic impacts were critical in the resolution of the damage phase of this case. While Texas claimed some $ 50 million in damages, analysis of regional spillover benefits showed greater economic benefits to Texas if the water continued to be used in New Mexico (Hamilton et al., 1994). Irrigators in New Mexico, being closer to Texas suppliers, purchased most of their inputs in Texas. New Mexico's use of the disputed water created multiplier effects that benefited the Texas economy (Frederick, 1993). Furthermore, the water reaching Texas is of poor quality. After flowing through salt beds in New Mexico, leaching water must be applied by the Red Bluff Irrigation District (Bennett and Howe, 1998). Thus, while all parties were in agreement that the marginal value of water to New Mexico was greater and providing additional water to Texas would reduce allocation efficiency, the compact allocation rule specified otherwise. The outcome of this case provided Texas additional water and some $ 16 million in damages.[3] In hindsight, failure to incorporate economic considerations into compact negotiations may have predestined the compact to failure. In particular, had the marginal value of salinity damages been incorporated into the allocation rule, a lawsuit may have been prevented.

2.2. Arkansas River[4]

Another recent case concerning underdeliveries of water by an upper basin state to a lower basin state is Kansas v. Colorado.[5] Apportionment of Arkansas River flows has been the focus of conflict between the states of Kansas and Colorado four times this century: Kansas v. Colorado (1902);[6] Kansas v. Colorado (1907);[7] Colorado v. Kansas (1943);[8] and Kansas v. Colorado (1995). In each of the four suits Kansas claimed that Colorado irrigators were using more than their fair share Arkansas River flows.

In the earlier cases Kansas failed to prove that Colorado had materially decreased Arkansas River flows and any alleged decreases had caused damages to the state.[9] However, given the history of disputes, following the 1943 case, the Supreme Court recommended that the two states enter into compact negotiation — the intent being to avoid further conflict.[10] The Arkansas River Compact was ratified by the legislatures of Kansas and Colorado and the US Congress in 1949.[11] The Compact has two main purposes: (1) to settle existing disputes and prevent future controversies over Arkansas River water; and (2) to equitably apportion Arkansas River water as well as the benefits from John Martin Reservoir (see Footnote 11). Article IV of the Compact contains a material depletion clause which prohibits future developments which would materially deplete the usable flow of the river (see Footnote 11). Article V apportions the water in

[2] 482 US 124 (1987).

[3] 482 US 124.

[4] This case draws from Naeser and Bennett (1998).

[5] 475 US 1079 (1995).

[6] 185 US 125 (1902).

[7] 206 US 46 (1907).

[8] 320 US 383 (1943).

[9] For a more detailed discussion of these early cases, see Naeser (1997) and Wagner (1984).

[10] 320 US 383 (1943).

[11] Arkansas River Compact, Public Law 82, 81st Congress, 1st Session (1949).

John Martin Reservoir and specifies operating standards for the reservoir (see Footnote 11).

Although the Compact was meant to prevent further disputes, rapid growth in agriculture in the lower Arkansas River Basin led to many new wells in Colorado. At the time the Compact was ratified, 121 alluvial wells were in operation in Colorado. By 1985, the number of wells had increased to almost 2000 (Naeser and Smith, 2000). In 1983, the Kansas State legislature authorized a preliminary study to determine whether adequate evidence existed to demonstrate material depletions in Arkansas River flow caused by post-Compact well pumping in Colorado and the operation of two of the federal reservoirs in Colorado (see Footnote 11). After attempts at negotiation failed, Kansas filed suit against Colorado in 1985 claiming material depletion of usable stateline flows.[12] Kansas claimed that increases in post-Compact alluvial groundwater pumping by southeastern Colorado irrigators caused a significant decline in usable stateline flows.

At the conclusion of the liability phase, Colorado was found to be in violation of the Arkansas River Compact.[13] Kansas and Colorado now agree that Colorado underdelivered 328,000 acre-feet (af) of Arkansas River water to Kansas between 1950 and 1985,[14] and an additional 100,000 af between 1986 and 1996.[15] As a result, southeastern Colorado irrigators have been told to cease pumping from, or find augmentation water for approximately 2000 alluvial wells and Colorado will likely be assessed financial damages arising from 45 years of underdelivery of water to Kansas (see footnote 14). Naeser and Bennett (1998) discuss damage estimation for this case. In addition, economists for the State of Kansas have estimated damages at $ 78 million. The case is still in the damage phase. Negotiations include whether or not the damages will be paid in dollars or in water. Currently, Colorado is measuring depletions by collecting monthly pumping data from all wells affected by the ruling (Naeser and Smith, 2000).

According to David Robbins, the Colorado Attorney for the case, and as of the date of this writing, no wells have been shut down as a result of the ruling. A complex hydrologic model which integrates surface water and groundwater was developed by the state of Kansas to support their case and is now being used to ensure continued compliance with the Compact.[16] Colorado also monitors power usage on a monthly basis to ascertain pumping levels and then replenishes the river for water owed to Kansas. Depletions are measured, and well associations are credited or debited monthly. Well associations must procure water to replace any measured depletions. This seems to suggest that impacts to Colorado farmers are zero as the state is responsible for replacement water which may be purchased from a variety of sources. The annual depletion averaged approximately 9200 af, and annual impacts to Kansas farmers are minimal. Kansas is still claiming total damages of around $ 70 million, inclusive of 50 plus years of direct and indirect economic impacts plus interest (personal communication with Robert Naeser).

As in the Pecos River case, the 1986 case may be the last lawsuit between Kansas and Colorado over the quantity of Arkansas River flows delivered to Kansas. The agreement between the two states seems to imply that both sides have settled on a quantity to which Kansas is entitled. Improved monitoring technology and better understanding of hydrologic connections enabled Kansas to finally prove underdeliveries of Arkansas River water by Colorado (Naeser and Bennett, 1998).

While the water quantity dispute seems to be resolved, at least for the time being, water quality issues could be problematic in the future. As a result of dependence on flood irrigation by Colorado irrigators, the middle Arkansas River is the most saline stream of its size in the United States. Within the middle Arkansas River Valley average salinity levels increase from 300 ppm total dissolved solids (TDSs) east of Pueblo to 4000 ppm TDS near the Kansas stateline (Naeser and Bennett, 1998).[17] Kansas irrigators

[12] 475 US 1079.

[13] Kansas v. Colorado, _ US _ (1995).

[14] Address by David Robbins, Arkansas River Basin Forum Annual Meeting (1996) (hereinafter, Robbins).

[15] Naeser and Smith (2000).

[16] For a detailed description of this model, see Naeser and Smith (2000).

[17] TDS concentrations greater than 2000 ppm are considered unsuitable for agriculture.

may sustain economic damages from applying highly saline water to their crops.

Upstream Colorado irrigators in Pueblo and Otero counties divert high quality water and are able to grow salt sensitive, specialty crops. Water entering canals in these upstream counties has TDS concentrations averaging 500 ppm. In the counties just 25 miles downstream, however, concentrations increase to 2500 ppm forcing irrigators to plant less salt sensitive crops — alfalfa, sorghum and wheat.[18] Salinity also poses a problem for municipal and industrial users, recreators and fish and wildlife. If such factors are considered, then actual damages to Kansas are much higher than suggested by the 1986 ruling. However, this externality is not an issue addressed by the Compact.

Additional areas of concern include sulfate levels and groundwater contamination. Sulfate levels on the Kansas side of the border can be as high as 2400 ppm during low flow periods (Kansas Geological Survey, 1996).[19] While surface water quality is of concern, the effects of salinity and pollutants on groundwater are also becoming issues. Much of the Arkansas River's flow soaks into the alluvial aquifer and subsequently seeps into the underlying Ogalalla aquifer. The High Plains Aquifer in southwestern Kansas includes both the Ogalalla and alluvial aquifers. Based on current conditions, the Kansas Geological Survey estimates that within 40 years polluted Arkansas River water will contaminate 500 square miles of the High Plains Aquifer (Kansas Geological Survey, 1996). In addition, one of the sources of replacement water used to satisfy the Compact dispute is Colorado Springs effluent water. Colorado Springs exchanges transmountain return flows for native diversions.

Colorado's failure to abide by the allocation rules of the Arkansas River Compact has led to a lawsuit that has been in the courts for over a decade. The case and its outcome emphasize the need for allocation rules to incorporate flexibility, as well as the need for strong enforcement and monitoring. Technology has played a role in solving a quantity dispute, but the current condition of the river also highlights the need for future negotiations over water allocation to integrate water quality concerns into the discussion.

2.3. Republican River

Most recently, in May 1998, Kansas filed suit in the US Supreme Court against Nebraska alleging violations of the 1943 Republican River Compact. The Republican River Compact allocates flows of the Republican River between Colorado, Kansas and Nebraska using a percentage allocation rule. The proportions are calculated from an estimate of the annual virgin water supply which includes both ground and surface waters. The suit alleges that Nebraska has been overusing its share of the Republican River in violation of the 1943 Compact. Kansas is claiming an annual shortfall of approximately 10 billion gallons.[20] This is a *much* larger claim than that of Kansas v. Colorado. Kansas is arguing that Nebraska allowed more than 10,000 wells to be drilled in the region which have depleted river flows.

According to the 1989 *Proposal for the Republican River Compact Administration*,[21] submitted by the State of Kansas, concern over water shortages has existed in the Compact Administration since at least 1974. According to the Kansas Compact Commissioner, much of the problem arises from inconsistencies among state laws regarding groundwater withdrawal. The Kansas commissioner explained that Nebraska is consistently in violation of the compact, but since Nebraska's state laws differed from Colorado's and Kansas' in terms of groundwater allocation, not much could be done (without a Supreme Court decision). Both Colorado and Kansas have laws limiting groundwater withdrawal. Nebraska had no such state laws during much of the period of dispute.[22] Kansas has been threatening a lawsuit for years. Although a lawsuit is likely to last years and costs millions of dollars in legal fees, Kansas may be encouraged by the Special Master's finding in Kansas v. Colorado on the Arkansas.

Interestingly, Nebraska filed a counter suit against Kansas in April 1999. The counter suit denies Kansas'

[18] Naeser and Bennett (1998).

[19] US Environmental Protection Agency (EPA) has proposed a maximum contaminant level (MCL) for sulfate of 400 ppm in drinking water.

[20] The Topeka Capital-Journal, 26/5/1998 and US Water News, July 1998.

[21] Proposal has not been accepted by all states to date.

[22] David Pope, personal communication.

claims and alleges that Kansas has used more than its share of the Republican River. In the counter suit, Nebraska also claims that the issues of drilling alluvial wells along the river and groundwater are not covered by the Compact. The counter suit requests damages from Kansas. Most recently the Nebraska Attorney General has asked the Supreme Court to dismiss the Kansas lawsuit claiming that in a 1982 Supreme Court case, states, including Kansaas told the court that the Ogallala Aquifer is not apportioned by agreement between the states.[23] This case, in content, appears remarkably similar to Kansas v. Colorado. The counter suit is an added twist.

The examples discussed above — the Pecos River dispute and the Arkansas River dispute — illustrate that while there is a mechanism for resolving allocation disputes on interstate rivers governed by a compact, the fact that water quality has been ignored is beginning to cause additional problems. This lack of coordination between quantity and quality management early on can lead to larger and costly problems at later dates. It remains to be seen whether a recent suit on the Republican River (Kansas v. Nebraska) will also lead to discussions of water quality.

2.4. *Quality problems without quantity disputes: South Platte and Big Blue Rivers*

Even on rivers where there are no compliance disputes, the downstream state may not be receiving quality water. For example, the South Platte River Compact allocates flows of the South Platte River between the states of Colorado and Nebraska on a fixed basis (Bennett and Howe, 1998). While there have been no lawsuits related to the Compact, the extensive irrigated acreage in northeastern Colorado has led to salinity problems in the section of the river governed by compact. Repeated reuse of both surface and ground waters for irrigation has increased salinity both in the lower South Platte River and the surrounding aquifer (NAWQA Program, USGS).

Interestingly, the Colorado–Big Thompson project is a west slope diversion that takes water from the Colorado River and pumps it through a tunnel under the Continental Divide where it eventually reaches the South Platte River. The water is primarily used for agriculture and municipalities. It is not clear whether the Colorado–Big Thompson project alleviates or exacerbates salinity in the river. While the project does add more water with low TDSs to the system, the increased flows also allow for increased agricultural diversions which negatively impact water quality. The project does negatively affect water quality in the Colorado River as water is being taken out of the system. Booker and Young (1991) suggest that the marginal value of salinity control in the Colorado River basin could be as high as $ 60 per af.

In addition to increased salinity, nitrate concentrations and agricultural chemicals negatively affect water quality in the lower South Platte River, as well as in other river basins. An interesting case of a river basin for which the Compact addresses water quality, yet for which the presence of agricultural chemicals has become a concern, is the Big Blue River basin.

The Big Blue River Compact is a rare example of a compact that addresses water quality, yet still falls short of providing guidelines for water quality. The Big Blue River Compact of 1972 apportions the waters of the Big Blue River, a tributary of the Kansas River, between Nebraska and Kansas. About 75% of the Big Blue River is in Nebraska, and the remainder is in Kansas. The Big Blue River and its principal tributary, the Little Blue River, join near Blue Rapids, Kansas. Water is apportioned by mean daily flow and Nebraska has 72 h to make up any deficiencies in meeting Compact requirements. While there have been no disagreements on the quantity of water deliveries, there are currently discussions on water quality in the basin. According to Ann Bleed of the Department of Water Resources, State of Nebraska, "If flows are below the Compact requirements then we regulate diversions and/or turn off the junior users in Nebraska." This seems to be the case as Nebraska has usually met the Compact requirements. Deliveries, however, have been of low quality. While salinity is not an issue for Kansas, flows of the Big Blue and Little Blue Rivers have measured high levels of atrozene, a herbicide. As water is used for drinking in Kansas, this issue has raised concerns.[24]

Article VI of the Big Blue River Compact addresses water quality. However, unlike the flow requirements,

[23] US Water News, June and October, 1999.

[24] Keith Paulson (Department of Water Resources, State of Nebraska), personal communication, May 1999.

water quality is discussed generally. No limits are set for quality. A water quality initiative was started in 1995 and is ongoing. A network of 250 water quality monitoring stations have been established and the State Conservation Commission is in the second year of a pesticide incentive program for farmers. Survey data is also being collected on cropping patterns. [25]

The compact negotiators were obviously foresighted enough to recognize potential water quality impacts and to incorporate the issue into the compact. This can most likely be attributed to the more recent date of ratification — during a time when quality issues were beginning to draw attention. However, without set limits on water quality, there is no recourse for the downstream state.

The examples presented above illustrate the need for coordination among quality and quantity objectives during the negotiation stage, and for flexibility embedded in rules. Incorporation of water quality consideration could help avoid damaging downstream externalities, or at the very least, reduce some of the impacts.

Expanding the scale of analysis, the next section presents an example of the resolution of allocation disputes on two international rivers — the Colorado River and the Rio Grande River. We again suggest that while allocation issues were resolved, quality issues were ignored. This lack of foresight has led to expensive mitigation projects and decreased economic efficiency in water use. While damages have not been measured for the interstate river examples presented above, the costly projects pursued on the Colorado River provide insight into mitigation expenses.

2.5. The Colorado River and Rio Grande River: international rivers and water allocation and water quality

The Colorado River and the Rio Grande River both make excellent case studies, because they are interstate and international rivers. The Colorado River, with its headwaters in Colorado, lies primarily in the United States, flowing through Mexico for only the final 100 miles of its journey. It is an extremely complicated, heavily regulated and extensively managed system. There are numerous agreements governing flows, dams and water quality including two interstate compacts and an international treaty. This group of agreements is referred to as the *Law of the River* (see Table 1). In addition to the Colorado River being *over appropriated*, there are also downstream concerns about water quality; and as such, it presents a perfect example of a classic downstream externality.

The Rio Grande River also begins in Colorado, and flows south through New Mexico and into Texas where it forms a 1200 mile-long international border between the United States and Mexico. It flows through five states in Mexico. While all of the flow of the Colorado originates in the United States, much of the flow in the lower Rio Grande River comes from tributaries in Mexico. The Rio Grande River is also governed by an interstate compact and an international treaty both dealing with streamflow allocation.

The earliest treaties dealing with the Colorado and Rio Grande Rivers established international boundaries and dealt with navigational use only. These treaties included no provisions on the regulation of water usage. [26] As early as the 1880s conflicts over usage on both sides of the international border arose as US and Mexican agriculture developed in both the Colorado River and lower Rio Grande River basins. At this time there were no existing international rules for deciding water allocation issues. In the Rio Grande River basin, extensive irrigation development in Colorado caused water shortages near El Paso. The Mexican government filed a claim for damages with the US government. The US–Mexican Water Treaty was signed in 1906 and guarantees Mexico 60,000 af of water annually at the International Dam at Ciudad Juarez (Niemi and McGuckin, 1997). This Treaty, however, only guaranteed water to Mexico and did not cover the large amount of flow from the Mexican side of the border.

Conflicts over usage continued in both the Colorado and lower Rio Grande River basins. In the absence of other international laws, countries relied on various arguments to support their claims to water, including riparian rights, prior appropriation rights, national sovereignty over natural resources, and violation of navigational provisions (even for river stretches that were not originally navigable). Conflicting demands

[25] Kansas–Nebraska Big Blue River Compact, 25th Annual Report, Fiscal (1998).

[26] For a complete history of early agreements, see Hundley (1966).

Table 1
List of documents known collectively as "The Law of the River"[34]

The River and Harbor Act, 3 March 1899	Gila Project Act of 30 July 1947
The Reclamation Act of 17 June 1902	The Upper Colorado River basin Compact of 11 October 1948
Reclamation of Indian Lands in Yuma, Colorado River, and Pyramid Lake Indian Reservations Act of 21 April 1904	Consolidate Parker Dam Power Project and Davis Dam Project Act of 28 May 1954
Yuma Project authorized by the Secretary of the Interior on 10 May 1904, pursuant to Section 4 of the Reclamation Act of 17 June 1902	Palo Verde Diversion Dam Act of 31 August 1954
Protection of Property Along the Colorado River Act of 25 June 1910	Change Boundaries, Yuma Auxiliary Project Act of 15 February 1956
Warren Act of 21 February 1910	The Colorado River Storage Project Act of 11 April 1956
Patents and Water-Right Certificates Acts of 9 and 26 August 1912	Water Supply Act of 3 July 1958
Yuma Auxiliary Project Act of 25 January 1917	Boulder City Act of 2 September 1958
Availability of Money for Yuma Auxiliary Project Act of 11 February 1918	Report of the Special Master, Simon H. Rifkind, *Arizona* v. *California*, et al., 5 December 1960
Sale of Water for Miscellaneous Purposes Act of 25 February 1920	US Supreme Court Decree, *Arizona* v. *California*, 9 March 1964
Federal Power Act of 10 June 1920	International Flood Control Measures, Lower Colorado River Act of 10 August 1964
The Colorado River Compact, 1922	Southern Nevada (Robert B. Griffith) Water Project Act of 22 October 1965
The Colorado River Front Work and Levee System Acts of 3 March 1925, 21 June 1927, ..., 28 June 1946	The Colorado River basin Project Act of 30 September 1968
The Boulder Canyon Project Act of 21 December 1928	Criteria for the Coordinated Long Range Operation of Colorado River Reservoirs, 8 June 1970
The California Limitation Act of 4 March 1929	Supplemental Irrigation Facilities, Yuma Division Act of 25 September 1970
The California Seven Party Agreement of 18 August 1931	Minutes 218, 22 March 1965; 241, 14 July 1972, (replaced 218); and 242, 30 August 1973, (replaced 241) of the International Boundary and Water Commission, pursuant to the Mexican Water Treaty
The Rivers and Harbors Act of 30 August 1935	The Colorado River basin Salinity Control Act of 24 June 1974
The Parker Dam Power Project Appropriation Act of 2 May 1939	US Supreme Court Supplemental Decrees, Arizona v. California, 9 January 1979, and 16 April 1984
The Reclamation Project Act of 4 August 1939	Hoover Power Plant Act of 17 August 1984 (98 Stat. 1333)
The Boulder Canyon Project Adjustment Act of 19 July 1940	The Numerous Colorado River Water Delivery and Project Repayment Contracts with the States of Arizona and Nevada, cities, water districts, and individuals
The Flood Control Act of 22 December 1944	Hoover and Parker-Davis Power Marketing Contracts
Mexican Water Treaty, 3 February 1944	

and claims in both basins would need to be resolved by international allocation treaties that formally assigned rights on the two rivers.

The difficulty of the negotiations would be exacerbated by other events occurring in the two basins. In the Colorado River basin, plans to build Hoover dam and the All-American Canal, and the subsequent negotiation of a compact to allocate the water between the upper and lower US basin states caused worry in Mexico about its future access to water. The Colorado River Compact, signed in November 1922, allocates flows of the Colorado River between the upper basin states of Colorado, Utah, New Mexico and Wyoming, and the lower basin states of Arizona, California and Nevada. The Compact allocates flows on a fixed basis, giving the lower basin an average of 7.5 million acre-feet (maf) per year. The Colorado River Compact also states that "any water given to Mexico by future treaty should be supplied from surplus, and if that was insufficient, then each basin would contribute equally to the burden" (Hundley, 1966, p. 51). At that time, the surplus was estimated to be about 2 maf, which was substantially less than Mexico believed it was entitled to receive (Ragland, 1995).

Simultaneously, Mexico was expanding its irrigated acreage on the Colorado River delta and in the Mexicali Valley. Agricultural acreage in production rose from about 7000 acres in 1908 to about 217,000 acres in 1925. US farmers, aware of these activities, were concerned that the longer they waited for a treaty, the higher Mexico's claim (based on prior rights) to water would be (Ragland, 1995). Indeed, Mexico continued to expand acreage through the 1930s.

In the lower Rio Grande River basin, Mexico was planning to build water projects that would impound water from the tributaries that had been flowing to Texas farmers. Mexico was planning to divert the water through canals to its own farmers and was increasing irrigation activities at this time. Farmers in Texas were expanding acreage in an attempt to establish prior rights to the water to improve their negotiating status. [27]

In 1924, the US Congress authorized negotiations with Mexico over the Rio Grande below Fort Quitman, Texas. Roughly 70% of the river's flow in this stretch came from tributaries in Mexico, and farmers in Texas were using a large portion of that flow. Mexico refused to discuss the Rio Grande River without simultaneously negotiating the share of water that it would receive from the Colorado River, which had been placed at risk by recent events in the United States (Morgan, 1990; Hundley, 1966). In 1927, the US Congress authorized the joint negotiations because it wanted to guarantee water for Texan farmers. The US Congress did this over the strenuous objections of the Colorado River basin states (Meyers and Noble, 1966). [28]

After a lengthy period of negotiations and threats and pressures from both sides, an agreement was reached. The International Boundary Waters Treaty, signed in February 1944, embodied a trade of Colorado water for Rio Grande water, bringing several decades of negotiations over water appropriations to a close. It granted Mexico water rights on the Colorado of 1.5 maf per year, and the United States received rights to approximately half of the flow on the lower Rio Grande River, which included rights to water from Mexico's Rio Grande tributaries. Shortly thereafter, the upper basin states of Colorado, Wyoming, Utah and New Mexico negotiated the Upper Basin River Compact which allocates the upper basin share of the Colorado River on a proportional basis.

While the Colorado River Compact, the Rio Grande River Compact and the International Boundary Waters Treaty have resolved previous allocation disputes, these agreements provide no guidance on water quality maintenance. The lack of integration of quality and quantity considerations has proven to be extremely costly. Improved water quality could lead to substantial benefits in both countries, however, continued discussions over interstate water allocation within the United States have pre-empted any serious discussion of quality rules.

2.6. Salinity and the Colorado River

As is typical for a river system, salinity damages occur primarily in the lower basin, while the majority of the salts come from the upper basin. This is a classic pollution externality. Since the Colorado River Compact and the International Boundary Waters Treaty do not specifically address water quality, the lower basin states and/or country have no recourse. Without recourse, "victim pays" outcomes are likely.

The Bureau of Reclamation recently estimated that annual economic losses from Colorado River water salinity are approximately $ 1 billion. This estimate is just for the United States (Smith and Vaughan, 1996). While natural sources account for approximately half of the salt load in the Colorado system, human contributions add almost 5 million tons and as a result of salt loadings, over half of the irrigated acres are classified as saline (TDS > 1300 mg/l) (Lee and Howitt, 1996). The largest contributor of salts is runoff from irrigated acreage adding approximately 3 t of salt or

[27] It is interesting to note that on both sides of the border, the lack of an agreement acted as an incentive for overuse of water resources.

[28] It should be noted that at the same time Colorado, Texas and New Mexico were involved in disagreements over flows and water shortages in the upper Rio Grande River basin. The Rio Grande River basin Compact was signed in 1938 and allocated (by proportion) flows of the average annual flow of the river to Colorado, New Mexico and Texas. The Compact's intent was to preserve the existing allocation of the Rio Grande's surface water among the three states as it existed in 1929 (Niemi and McGuckin, 1997).

37% of salt concentrations. Lee and Howitt (1996) report that for the Colorado River basin, salinity damages 63% of the irrigated acreage in the lower basin, while 72% of the salts originate in the upper basin. The Bureau of Reclamation estimates that 400,000 acres currently experience severe salt accumulation while 1,000,000 acres have potential for as serious damage. Annual damages to farmers are projected to rise to $ 300 million by the year 2000. To put this number in some perspective, annual losses from salinity were approximately $ 31 million in 1979 (Stewart, 1998).

Lower basin irrigators are not the only parties damaged by increased salt concentrations. Municipal and industrial users also experience losses as equipment and household appliances have short life spans and there are higher water treatment costs. A good example is the delivery of Central Arizona project water (CAP) to residential users Tucson, Arizona, who had previously received very high quality groundwater.[29] Complaints from residential users led to the passage of Proposition 200 which temporarily halted deliveries of CAP water and restricted CAP use to recharge only. The resulting controversies have not been resolved, but options including treatment and mixing with groundwater are being explored. Finally, the ecosystem experiences losses from increased salts as well as from agricultural chemical runoff.

Mexico also has experienced diminished water quality and damages to a once productive agricultural region. In the most famous incident, a series of events in 1961 lead to discussions on Colorado River water quality. The combination of a low flow year, the recent completion of Glen Canyon Dam and agricultural waste being pumped by Arizona's Wellton-Mohawk Valley into the Gila River all resulted in water reaching Mexico's Mexicali Valley that measured salt loads of 2500 ppm. Damages to Mexican agriculture at the time were estimated to be $ 3.7 million.[30] In November 1961, Mexico formally protested to the United States that the "delivery of water that was harmful to the purposes stated in the treaty constituted a violation of the treaty."[31] In 1965, a temporary (5 year) agreement was signed by the two governments.

In 1972, a permanent agreement (Minute No. 242) was signed by Presidents Nixon and Echverria on Colorado River water quality that requires the US to maintain salinity at the Mexican border at just over the level at the Imperial Dam (Howe, 1994). Specifically, the United States guarantees an annual delivery of 1.36 maf with salt concentrations of not more than 115(+30) ppm above the concentrations measured at Imperial Dam. The US Congress set water quality standards at Hoover Dam (723 mg/l), Parker Dam (747 mg/l) and Imperial Dam (879 mg/l). In June 1974, The Colorado River basin Salinity Control Act (43 USC 1571–1599, PL 93-32) was ratified. This Act authorized the construction of facilities necessary to meet the terms of the Salinity Agreement with Mexico. In particular, it imposed the water quality standards listed above, and authorized the construction of the Yuma Desalting Plant and the Wellton-Mohawk and Yuma bypass drains. It also provides for 140,000 af of water to be delivered annually at San Luis (Bureau of Reclamation). It further provides financing for additional projects such as the lining of irrigation canals in the Coachella Valley. Federal funds have been allocated to salinity control through 2015. To date annual salt loads have been reduced by approximately 270,000 t and proposals exist to remove an additional 1.26 million tons at a cost of $ 700 million (Stewart, 1998).

While construction of the desalting plant was underway, an interim measure of diverting all Wellton-Mohawk drainage into the Colorado River immediately below Morelos Dam until June 1977, was adopted by the United States. The bypass drain was placed into operation in June 1977.

Booker and Young (1991) estimate the marginal value of salinity damages in the Colorado River basin to be $ 50–60 per af. Howe (1994) finds substantial damages from increasing levels of TDSs in the river basin due to increased upper basin agricultural use. He finds an average damage estimate of $ 1.5 million per parts per million of change in TDS, implying a benefit per ton of reduced salt input of approximately $ 150 t^{-1} ($ 1988). In the Grand Valley of Colorado alone, salinity damages averted per acre-foot of

[29] CAP water carries total dissolved solids of 700 ppm. Tucson groundwater carries approximately 210 ppm.

[30] Stewart (1998) excerpted from *Western Water Made Simple*, 1987.

[31] Bureau of Reclamation.

reduced consumptive use have been estimated at \$ 280 (Howe and Ahrens, 1988). Howe and Young (1978) estimated that 635,000 t of TDS per year could be saved through various changes in cropping patterns and acreage reductions at an estimated cost of \$ 4–29 t^{-1}. They suggested that some simple, relatively inexpensive changes could have been made that would provide substantial downstream benefits. Howe and Young (1978) detail some options for salinity control that might have been more cost effective than those that were pursued. Instead of pursuing some of the options outlined in Howe and Young (1978), the Bureau of Reclamation built a reverse-osmosis plant at Yuma, Arizona at an estimated (at the time) annual cost of \$ 50 million or at least \$ 50 t^{-1} of TDS (Howe, 1994).

The Yuma Desalting Plant was finally completed in 1992 at a capital cost of \$ 258 million and annual operating costs are approximately \$ 32 million or a cost of \$ 407 per af of water delivered to Mexico (Stewart, 1998). The irony comes from the fact that upper basin agricultural users (the largest contributors of salt) pay only \$ 8 per af for water deliveries. Perhaps even more ironic is that the plant is no longer operating and accrues \$ 6 million in annual maintenance costs. Had water quantity planning been coordinated with water quality planning, Howe suggests that the Wellton-Mohawk project might not have been built and Mexico would not have had to press for a water quality agreement. The Bureau of Reclamation has estimated annual economic losses to the United States from Colorado River salinity to be approximately \$ 1 billion (Smith and Vaughan, 1996).

Smith and Vaughan (1996) argue that better management of flows by reservoir operations could substantially reduce economic damages from salinity. However, reservoir operations are frequently used to meet compact delivery obligations. This obvious conflict of interest remains unresolved.

Interestingly, the Clean Water Act does not specifically address return flows from agriculture as they are not point sources and rules governing non-point source pollution from agriculture are limited. The Colorado River basin Salinity Control Act of 1974 addresses this key quality issue in the lower Colorado River basin. However, from an economics perspective, it does nothing to ensure that salinity costs are internalized by upstream users (Stewart, 1998). Instead, the federal government is the responsible party — at taxpayer expense. The Yuma desalinization plant is but one example The Act also does not limit upper basin development. Since the upper basin has yet to utilize its full share of Colorado River water the salinity ramifications could be large. The State of Colorado (the largest upper basin user), has in place an extensive water supply management system for the Colorado River. Water allocation is the primary goal.

Colorado River basin management is a complex and politically charged topic. Water allocation continues to be a divisive subject and states continue to haggle for more water. California has been using more than its allocated share of 4.4 maf for decades. Nevada has occasionally called for renegotiation of the Compact. The State of Colorado has developed a complex management system called the Colorado River Decision Support System as an attempt to manage compact obligations, water rights administration and water resources planning. [32] These are just a few of many examples of ongoing discussions, research and negotiations over water use in the Basin. For the time being, integrated management may continue to take a back seat.

2.7. *Rio Grande River basin management*

The Rio Grande River has not escaped quality disputes largely because of heavy degradation in the both the upper and lower basins. Heavy agricultural use in both the upper and lower Rio Grande has increased salinity and concentrations of agricultural chemicals and nutrients. Municipal effluent frequently fails to meet water quality standards and groundwater from under Albuquerque and El Paso–Ciudad Juarez of measures elevated levels of dissolved solids including arsenic (Niemi and McGuckin, 1997). Salinity has become a large concern. In addition, the US International Boundary and Water Commission has identified the area in the lower Rio Grande River basin as having substantial water quality problems with potential for toxic chemical impacts on aquatic health.

As in the Colorado River basin, population growth continues to put intense pressure on water supply. In addition to the interstate compact and international treaty, other agencies are involved including the New Mexico/Texas Water Commission whose main

[32] http://crdss.state.co.us.

responsibility is to facilitate dispute resolution and prevent future disputes over the water supplies below Elephant Butte Dam. The State of Colorado has put together the Rio Grande River Decision Support System, which similar to the Colorado River Decision Support System, serves to manage water supplies. Thus, while there are mechanisms in place to allocate water supplies, there are limited means to address water quality concerns. Damages specific to this basin have not been estimated, but are likely to be high. As for the Colorado River, salinity control costs are also high.

The examples presented above highlight the difficulties associated with transboundary water supply management and illustrate some of the successes and failures in the southwestern United States and Mexico. The resolution of quantity disputes is a complex, time intensive and political process. The question becomes whether or not it is possible to have an integrated allocation system.

2.8. Allocation rules

An allocation agreement that incorporates both flexibility (allows marketing and transfers) as well as quality targets would be economically efficient. While quantity concerns have historically been the focus of western United States water allocation, it can be shown that incorporation of externalities into allocation rules can increase economic efficiency.

Bennett et al. (2000) illustrate the efficiency differences for the two general types of allocation rules. In particular, they identify the main factors that determine the economic efficiency and risk-sharing characteristics of the types of compacts most frequently found in the western United States. While earlier work (e.g. Burness and Quirk, 1981) suggest that systems of equal sharing may be most efficient (when benefits functions are identical), most river systems do not develop uniformly. In addition, if upstream return flows are contaminated or if there are substantial instream benefits, then efficiency would dictate that these users divert less water than those downstream (Kanazawa, 1991). Kanazawa shows that the value of the marginal product of water should be larger for upstream users. Given declining marginal productivity, this implies lower water use. The effect becomes larger the further upstream, as a larger the number of downstream users are potentially affected (Kanazawa, 1991). Kanazawa also points out that upstream users should receive less water when diversions contain large amounts of dissolved salts, but also when diversions cause increased concentrations of salts simply because of reduced river volume.

Fig. 1 illustrates an alternative way to think about this. Consider the simplest case of two users (e.g. an upper basin and a lower basin) with identical benefits functions. Identical marginal benefits would suggest a system of equal sharing as a compact rule (represented by the point $Q_{UB} = Q_{LB}$). However, subtracting the

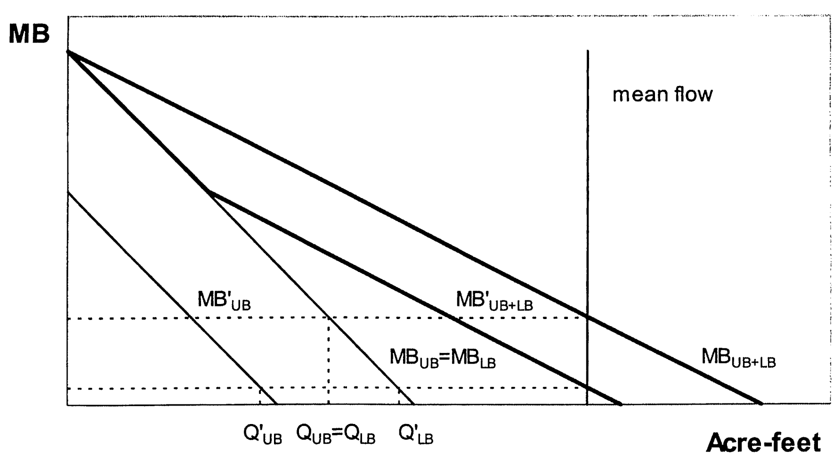

Fig. 1. Economic efficiency when return flows are contaminated.

effect of contaminated return flows would imply differing marginal benefit functions and unequal sharing — e.g. less water to the upper basin ($Q'_{\rm UB}$ and $Q'_{\rm LB}$).

This simple theoretical principle illustrates the concept of economic efficiency in the presence of degraded return flows.

Bennett et al. specifically address allocation issues with respect to interstate river compacts. Incorporation of a quality constraint would alter the allocation rules by changing the marginal benefit functions. However, incorporation of the new rule would be difficult in the absence of damage data. In addition, while accounting for downstream externalities would increase economic efficiency, doing so across state lines might prove difficult. Theory and practice frequently diverge in western water management. As illustrated in the examples above, these compacts do not usually address water quality and, as such, might not be perfect models for other areas currently negotiating compacts.[33] They do, however, provide valuable lessons.

3. Discussion and conclusions

In this paper we examine the linkages between water quality and quantity and suggest there are mechanisms for incorporation of quality into allocation agreements. The water management case studies from the southwestern United States presented in this paper provide valuable lessons for areas currently attempting to resolve allocation disputes. Integrated management in regions under intense water pressure can help to prevent damaging downstream externalities.

Currently, the states of Alabama, Florida and Georgia are negotiating an interstate compact for the Appalachicola–Chattahoochee–Flint River basin. Negotiations were to have been completed by December 1998. A 1-year extension was signed giving the states until December 1999. At the time of this writing, negotiations have stalled and it is not clear how the issue will be resolved. At the same time, at the international level, water issues have become important for the Israeli–Palestinian peace accord. Extreme drought conditions (one of the harshest in 60 years) has prompted Israel to announce 40% reductions in water allotments to Israeli farmers and may enforce the same reduction on Palestinian agriculture intensifying an already bitter dispute.

This paper has shown by example, that while resolution of allocation disputes is of crucial importance, lack of foresight into future quality concerns can sometimes lead to larger problems down the road. However, this paper has also illustrated the complications associated with negotiation of compacts and treaties as well as the lengthy and sometimes contentious dispute resolution process. Given the difficulties involved with negotiating allocation formulas in water stressed regions, it may be that quality considerations will continue to take a back seat. This paper suggests, however, that water quality should be an integral part of the negotiation process.

[33] Florida, Alabama and Georgia are currently negotiating an interstate river compact for the Appalachicola–Chattahooche–Flint River basin.

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