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Chapter 8

WATER SUPPLY FOR AGRICULTURAL, ENVIRONMENTAL AND URBAN USES IN CALIFORNIA'S BORDERLANDS

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ABSTRACT

This chapter explores optimal water supply portfolios for agricultural, environmental, and urban uses in Southern California, US and in Baja California, Mexico using a hydro-economic modeling approach. Hydro-economic models provide useful insights into water related problems in the borderland of both Californias. Fast growing cities, prominent agriculture and growing concerns for maintaining ecosystem functions characterize competing water uses in these arid regions. In California, water transfers from agricultural uses west of the south coast are limited by current conveyance capacity. Continuing current water imports from up north basins may become more challenging in the future as mandated flows for protecting fish in the Sacramento-San Joaquin Delta will likely limit the aforesaid water imports. Water conservation and augmenting water supply via wastewater reuse or desalination may alleviate possible shortages for cities in California's south coast. In the northern Baja California, Mexico surface water from the Colorado River supplies agricultural water in Mexicali along with most urban water uses in the northern border cities. Water supply for maintaining ecosystems in the Colorado River Delta can be found among existing uses and sources in the region. Increased conveyance capacity from east to west of northern Baja California and augmenting water supply via wastewater reuse are among the most promising alternatives to cope with

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population growth without compromising recommended environmental water uses for the Colorado River Delta. Enhancements in water conveyance capacity along with conjunctive use in Southern California and northern Baja California appear to be among the promising water management alternatives.

INTRODUCTION

Some regions of the American southwest and the Mexican northwest have semi-arid conditions. This is the case of the border between Baja California in Mexico and California in the United States, where precipitation is low, evaporation is high, and groundwater use is limited or unimpaired. In these regions, water resources needed are often located in other basins and demands for water are the highest during the dry season. Therefore, there is an inherent asynchrony in space and time.

Under these circumstances, water resources management in these areas calls for employing a portfolio approach to identify and evaluate economically worthwhile water supply strategies for all uses. Regions on both sides of the border are characterized by fast growing cities and relatively close large agricultural areas. While cities demand more water, agriculture forfeits some land and water to support urban growth in the southwestern U.S and in Baja California, Mexico. Environmental water uses, either mandated or identified, exacerbate scarcity.

Storing water either on surface or in underground basins provides flexibility in water operations. Among the many benefits of surface storage are the potential of hydropower generation, flood control, and the ability to capture water in the wet season to be used later in the dry irrigation season. This is the case of the southwestern United States where most of the rainfall occurs during the winter and the early spring in the north of state; but the highest demands occur during the summer when water is needed for hydropower generation and irrigation, among others, with peak seasonal demands. Conjunctive use of water resources provides additional flexibility in water operations without the need of additional surface storage capacity. With conjunctive use it is possible to store water via aquifer recharge during the wet years and recover it later during the dry years. Under this water management scheme, evaporative losses are reduced. However, the associated recharge and pumping costs have to be considered. Trading of water among regions and/or users is another method used for supplying water when local demand exceeds local supply. Water transfers among uses and regions involve only the consumptive portion of the original use. Thus, local recharge and runoff patterns are minimally affected by water transfers. Additionally, institutional constraints of water transfers across counties or basins may be in place.

In this chapter we discuss the insights provided by a hydro-economic modeling approach to manage water resources in the US-Mexico Border in California and Baja California. The areas in both countries share similar hydrological and socioeconomic characteristics. Water resources availability is the lowest in the areas where demand for the resource is the highest. Portfolios of water management alternatives include use of existing or worthwhile future conveyance and storage infrastructure, wastewater reuse, seawater desalination, water conservation and conjunctive use. Institutional constraints for water allocation as well as the binational US-Mexico Water Treaty are taken into account in our modeling work. In the next section, we introduce the concept of hydro economic modeling and the methods used in the study. Case studies are then presented and contrasted. Results from modeling are presented in the third section. Discussion and policy insights from our results close this chapter.

METHOD

Physically-based engineering models have traditionally neglected the economic aspects of water resources modeling. However, there is a growing need for considering appropriate economic factors in water resources models to enhance model robustness and ensure economic justification of proposed water resources development and/or management plans. Often, hydro-economic models use optimization methods to facilitate economic studies by maximizing or minimizing an economic objective function subject to a number of constraints such as natural, socioeconomic, environmental, and political (Harou *et al.*, 2009; Mirchi *et al.*, 2010).

Hydro-economic optimization is a framework for utilizing economic concepts along with various sub-models of a water resources system (e.g., hydrologic, environmental, social) to provide answers to "what is best" type of questions. In hydro-economic modeling, once the decision about a set of viable development and/or management plans has been made, the economic values produced by alternative plans are compared and fed back into the decision making process helping the decision makers reach their best choice given the predefined constraints. Thus, hydro-economic models help promote the efficiency of water resources management plans (Harou *et al.*, 2009).

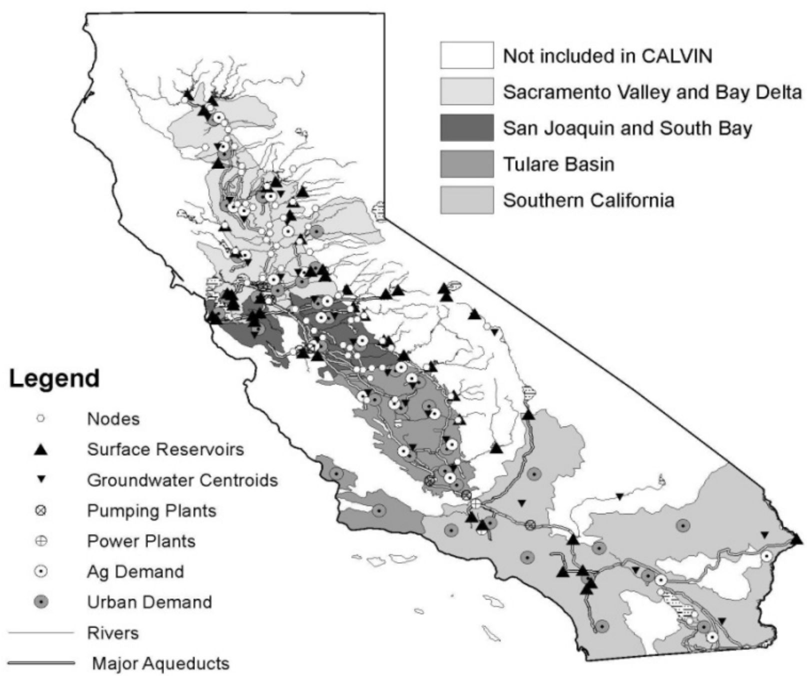

Figure 1. CALVIN hydro-economic model for California (adapted from Draper *et al.*, 2003).

Typically, hydro-economic models comprise basic components such as hydrologic and hydrogeologic conditions, water resources infrastructure, sectoral water demands, operating costs, and operating rules (Harou *et al.*, 2009).

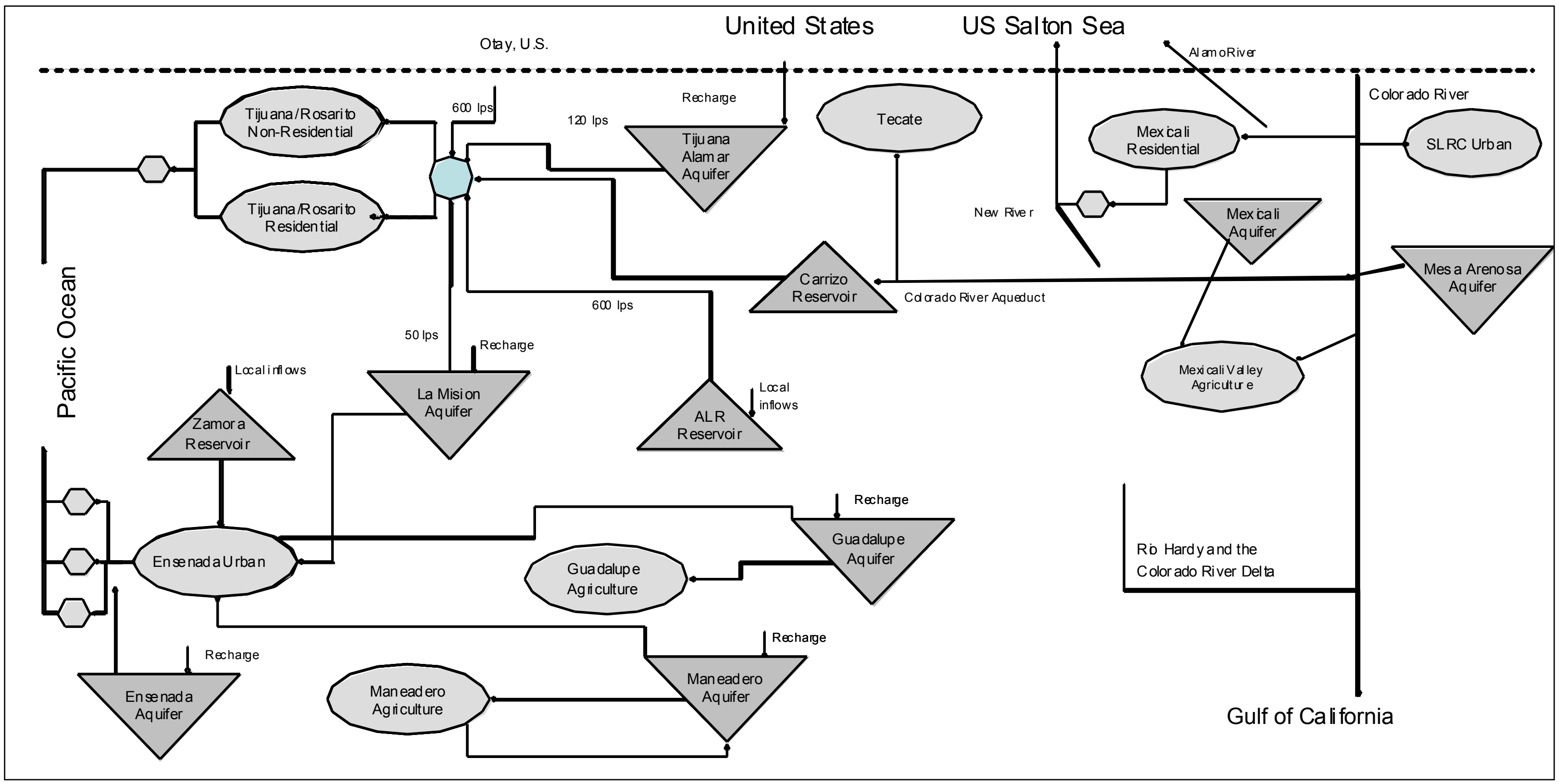

Figure 2. A simplified hydro-economic network for Baja California Mexico (adapted from Medellin-Azuara *et al.*, 2009).

Hydro-economic models have been developed and applied to address a wide variety of water resources problems including potential economic and environmental impacts of management practices, trade-off analysis for multi-sectoral water resources allocation, drought management and flood mitigation, policy selection and evaluation, climate-adaptive management strategies, and feasibility analysis for environmental conservation and/or restoration, to name a few (Harou *et al.*, 2009; Mirchi *et al.*, 2010).

Hydro-economic modeling is employed to present promising water management portfolios for California and Baja California, using CALVIN shown in Figure 1 (http://cee.engr.ucdavis.edu/CALVIN) and Baja-CALVIN in Figure 2 (http://cee.engr.ucdavis.edu/BajaCALVIN) as the main quantitative tools used in this study. These hydro-economic models, which are explained briefly later on, layout water allocation and scarcity overtime considering the least-cost water management portfolio strategy.

CASE STUDIES

Southern California US

California, one of the largest economies in the world is characterized by non-overlapping water demand and supply both in space and in time. The highest water availability is located in the northern hydrological regions of the California with less population and less irrigated agriculture. On the other hand, water demands are the highest during the summer in the drier Central Valley and Southern California which encompass most of the state's irrigated agriculture and population. The top portion of Figure 3 shows the Southern California border region, which contrasts to water uses. The south coast (west side of southern California) is characterized by high value agriculture, mostly in the counties of Ventura, Los Angeles, and San Diego. Most of California's population is also concentrated in this area. The southeastern corner of the state, in contrast, hosts agriculture in Coachella, Palo Verde and Imperial. These irrigation districts altogether have water rights on the Colorado River totaling 3.85 MAF/yr, more than 85% of California's portion of the Colorado River (4.4 MAF/yr). The Metropolitan Water District of Southern California, the main urban water wholesaler in the state constructed Colorado River aqueduct with a capacity of 1.3 MAF/yr to supply water to Los Angeles and San Diego. Currently, the Imperial Irrigation District and the MWD have a long term agreement to market water through the CR aqueduct.

Pulido-Velazquez et al. (2004) used CALVIN (California Value Integrated Network Model) to perform a scenario-based analysis of the potential for and limitations of conjunctive use of surface water and ground water, and water banking in the southern California which is shown in Figure 3. CALVIN is a hydro-economic optimization model representing California's major water supply system. It is a network-flow based model accounting for operation of water resources facilities, available resources, and California's sectoral demands (Draper *et al.*, 2003).

CALVIN requires several physical and economic input parameters such as infrastructure facilities, hydrologic conditions, allowable minimum flow, penalty-demand functions, and variable operating costs. The model was satisfactorily calibrated using 1922–1993 monthly historic time series of inflows to capture hydrologic conditions. Additionally, appropriate economic value demand functions were used to represent the demand of various stakeholder groups such as agricultural and urban demands (Pulido-Velazquez *et al.*, 2004).

Figure 3. Map of Southern California, US, and Baja California border regions.

CALVIN has also been applied to provide precious insights for adaptive water management policies to boost California's preparedness against changing climatic conditions from a hydro-economic perspective (Medellin-Azuara *et al.*, 2008). Using the projected 2050 water demand and land use change, Medellin-Azuara et al. (2008) analyzed a dry climate warming scenario to address imminent challenges due to climate change and associated implications for various stakeholder groups. This study illustrates that, while California's urban economy would demonstrate more relative resilience, economic water scarcity costs are expected to increase by $118 million/year from 2020 to 2050 and the urban areas in the Southern California would struggle with exacerbated water scarcity. Additionally, California's reduced water availability would translate into a considerable (as much as 24%) agricultural water shortage.

Baja California

The northern border of Baja California, Mexico is characterized by a semi-arid environment, fast growing cities and prominent agriculture. Precipitation can be as low as 100 mm per year in the most arid areas of the Mexicali Valley, in the northeast of the state, where more than 200,000 thousand hectares are cultivated every year. Despite its low precipitation rate the region is unique in the sense that it has water guaranteed through the 1944 Mexico-

U.S. Water Treaty, which provides 1,850 million cubic meters per year (MCM/yr) of water to Mexico from all U.S. sources. The Treaty, did not account for water quality; therefore the early 1970's agricultural return flows from the Central Arizona Project were put into the Colorado River deliveries to Mexico. This was the source of an international conflict which ended up in a Treaty Minute 242 according to which salinity limits as TDS in the deliveries to Mexico should be observed by the U.S. government.

Once water crosses the border to Mexico, most of it is allocated to agricultural and urban uses. Surface water supply in the region averages 1,850 MCM/yr from the treaty, and the Mexicali and the San Luis Rio Colorado aquifers provide an additional 700 MCM/yr. As a result, roughly 180 MCM/yr are used by the five northern cities: Ensenada, Tijuana-Rosarito, Tecate, Mexicali and San Luis Rio Colorado, this last in the neighbor state of Sonora. Irrigated agriculture uses more than 2,000 MCM of water per year. The east side of the region, where the Colorado River's water is received and the largest aquifer resides does not provide an appropriate geomorphology for surface storage. Therefore, deliveries from the U.S. are used as they reach the region or in some occasions, the exceeding water is fed into the Mexicali aquifer through old canals in the north of the Mexicali valley. Water is pumped to the coastal cities through the Colorado River-Tijuana aqueduct with current capacity of 126 MCM/yr. Tijuana-Rosarito, Ensenada, and Tecate have an allocation of 198 MCM/yr from the Colorado River. The city of Ensenada has not reclaimed its full allocation from the River (9,000/yr). Like Tecate and Tijuana-Rosarito, the city supplements its supply from local sources, mostly groundwater.

With a pressing and growing population, environmental water uses in the Colorado River Delta have lessened in importance. Water flow reductions in the CRD have been correlated to reductions in habitat of native species of flora and fauna in the Delta such as the cottonwood willow, the Yuma Clapper Rail and the Desert pup fish. The CRD is part of the Pacific Flyway hosting more than 200 thousand birds per year.

In the 1980s El Niño Southern Oscillation flood events brought back some water flows and habitat to the Colorado River Delta in Mexico. It was concluded that flood events helped the reestablishment of native riparian vegetation and consequently habitat for native fauna, deterring invasive species. Thus, groups of scientists and NGOs devoted substantial research efforts and advocacy in the 1990's to restore the CRD and its companion wetland, the Cienega de Santa Clara.

With high economic value in other water uses in the region, devoting water for environmental uses becomes a big challenge. Base flows of 37-61 MCM/yr with pulse flows of 320 MCM/yr every four years have been prescribed by the scientific community working in the CRD. This roughly represents 1% of the mean annual flow in the Colorado River. Finding ways to provide these flow at the minimum operating and other uses' scarcity cost is a challenging policy and water management endeavor.

Modeling Approach for Water Portfolios

Conjunctive use of surface water and groundwater can enhance operational flexibility of water resources management plans. Appropriate mechanisms for flexible water allocation such as economically driven water markets can add to the flexibility of the management plans ensuring that economic benefits are not compromised. To provide insights into conjunctive water resources management in Southern California CALVIN was run by Pulido-Velazquez et al. (2004) under a "base case" scenario followed by "unconstrained case" and "unconstrained case with new conjunctive use facilities" scenarios.

The "base case" run considered available facilities and operations and was constrained to the existing allocation policies projected for year 2020 levels of demand. The "unconstrained case" illustrates the current resources and facilities assuming that a more flexible water management system is in place where current water rights and operating rules are replaced with a water market in which water rights can be freely transferred to other parties and transactions are driven only by economic objective functions. The "unconstrained case with new conjunctive use facilities" reveals the benefits of building additional conjunctive use facilities by examining the changes of water management, system operation, and use efficiency. Model results facilitate an improved understanding of how flexible water allocation along with conjunctive use can be used as a means of adapting to water scarcity and reducing the reliance on imported water in Southern California (Pulido-Velazquez *et al.*, 2004).

Currently, the Colorado River Tijuana Aqueduct can deliver 126 MCM/yr to all cities in the northwest Baja California. An ongoing expansion of this main artery will increment its capacity to 164 MCM/yr. However, if cities grow at the current pace, by year 2025 Tijuana-Rosarito may double its water use from 104 MCM/yr in 2005 to 216.3. Ensenada might claim its Colorado River allocation as well as Tecate. Under these circumstances and without new sources of water, the coastal cities might face water scarcity unless local water supply alternatives such as seawater desalination and wastewater reuse come into play. Water purchased by the cities from agricultural uses is also a candidate if the transaction costs are low enough and the institutional constraints allow it. In the modeling portfolios agriculture was assumed to keep the current water uses and urban population was fixed at the projected 2025 levels. The following water management portfolios were explored in Medellin-Azuara et al. (2009) using Baja-CALVIN:

1) Base case with an expanded Colorado River-Tijuana aqueduct (164 MCM/yr);
2) Available seawater desalination, but no other expansions or sources;
3) Wastewater reuse availability and an expanded Colorado River-Tijuana aqueduct; and
4) A larger expansion of the Colorado River-Tijuana aqueduct

The following section summarizes and discusses the hydro-economic modeling results generated for the case studies.

RESULTS AND POLICY INSIGHTS

Water allocation, water scarcity and scarcity costs were explored for each of the water management portfolios analyzed. Overall, opportunities to transfer water from agriculture to other uses exist both in California and Baja California. However, existing conveyance infrastructure prevents this from happening to a level that will result in no economically optimal water scarcity for urban users.

SOUTHERN CALIFORNIA WATER SCARCITY AND OPERATING COSTS

Assuming a constant total surface water and groundwater available to conjunctive use (constrained base case), Pulido-Velazquez et al. (2004) simulated an economically driven water market allowing for flexible water allocation (unconstrained base case). Their results illustrate that adoption of a flexible water allocation mechanism would serve as a more reliable conjunctive use approach with increased economic benefits. Furthermore, the "unconstrained case with new conjunctive use facilities" reveals potential benefits of introducing additional conjunctive use facilities taking into account the possibilities for new operation plans and economic value of the new infrastructure. The study demonstrates potential reduction of water scarcity cost by implementing flexible conjunctive use programs (Table 1). For instance, under the "unconstrained case with new conjunctive use facilities" water scarcity costs can be reduced by up to 92% in lieu of 17% increase of the system operation cost.

Table 1. Total annual average scarcity cost and associated system operation cost (adapted from Pulido-Velazquez *et al.*, 2004)

	Scarcity cost, $ million/yr		Operating cost, $ million/yr	
Run	Average value	Change from current policy (%)	Average value	Change from current policy (%)
Constrained base case	1,541	0	22	0
Unconstrained base case	226	-85	25	16
Unconstrained base case with new conjunctive use facilities	127	-92	26	17

Baja California Water Scarcity and Operating Costs

Implementation of flexible water resources management plans inclusive of the possibility for adding new conjunctive use facilities and increasing the groundwater storage capacity can substantially increase the regional economic benefits. Hydro-economic optimization of conjunctive use programs along the Colorado River Aqueduct suggests that economic demand decreases in response to augmenting water transfer into Southern California. Thus, transferring the water from the agricultural regions on the Colorado River to urban demands in Southern California is found to be the most economically beneficial method for alleviating imminent water scarcity problems. The model also facilitates the identification of positive changes in the system operation and provides insights for boosting economic benefits by expanding conveyance capacity (e.g., Mojave Pipeline) and storage facilities (e.g., in the Kern groundwater basin) (Pulido-Velazquez et al., 2004).

Results in Medellin-Azuara et al. (2009) show that water shortages for agriculture in Baja California are the largest relative to urban uses. Region-wide shortages total 68 MCM/yr, of which 47 MCM/yr goes to agriculture. However, the scarcity cost share for agriculture is only \$1.2 million /yr (2008 US) out of the \$33.8 million/yr total costs. Operating costs are as high as 282.6 million under this portfolio.

When only seawater desalination is available as a new source of water, scarcity both for agriculture and urban uses is decreased slightly to 55 MCM/yr at \$24.2 million/yr, but operating costs go up slightly. Prevalence of scarcity in agriculture reveals that some level of shortage is economically optimal, given the high cost of seawater desalination (\$1.4 /m^3).

Wastewater reuse aids in reducing water scarcity costs to just \$30 million/yr, but water scarcity is reduced by more than half (to 30 MCM/yr). The reason is that reuse is mostly for agriculture which has the lowest scarcity costs. More important in magnitude is the reduction in operating costs from \$282 million/yr in the base case to \$262 million/yr with wastewater reuse.

A much larger aqueduct of 250 MCM/yr will bring total scarcity to 48 MCM/yr and the scarcity cost to the lowest level in all portfolios, \$10 million/yr. Operating cost of this portfolio is the lowest of all the presented portfolios making this alternative the most attractive cost-wise if capital costs are not considered. Uncertainty in this worthwhile expansion invites to explore a reasonable range of capacities for this artery connecting east and west of northern Baja California. Figure 4illustrates how scarcity and scarcity costs are decreased as the aqueduct is expanded.

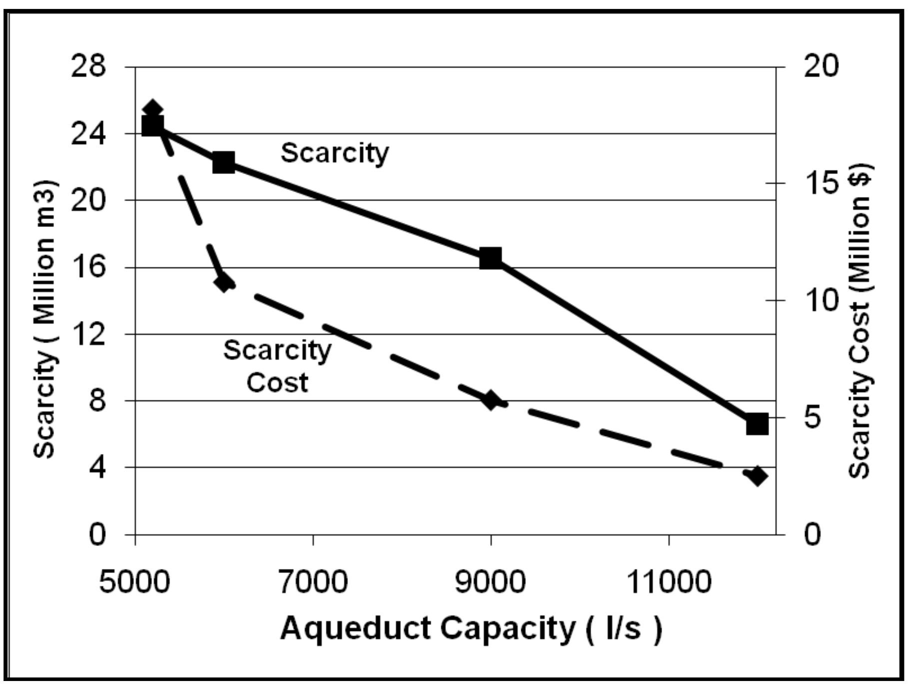

Figure 4. Water scarcity and Scarcity Cost in Baja California versus Colorado River-Tijuana aqueduct capacity (adapted from Medellin-Azuara et al., 2009).

Results for Baja CALVIN indicate that water reuse and expanded conveyance infrastructure offer the least cost water alternatives to supply water for all users in northwestern Baja California. Water market is an economically promising way of supplying water for urban uses in particular. However, limited conveyance capacity from east to west jeopardizes the efficiency of this option.

The high operating cost of seawater desalination makes portfolios including this water supply source less attractive. Sufficiently low treatment costs would make desalination competitive (Figure 4). However, recent reports (e.g., Fryer, 2010) suggest this will not be the case in the foreseeable future in California, considering energy and other operating costs all together. In the case of Baja California, desalination facilities are part of the hydrologic region water management plans, but economically viable operation of these facilities can only be justified through high government subsidies.

CONCLUSIONS

The results of the hydro-economic models applied to borderland Californias, characterized by limited water supplies and large urban water demands, highlight the potential of water markets between agriculture and urban water uses. For the most part, limitations on conveyance capacity prevent more economically efficient water allocation from happening. Institutional arrangements also pose additional challenges to overcome as water transfers between hydrological regions may have undesired distributional effects to some economic sectors relying on water as a production factor. Considering these system constraints and challenges in both Californias' borderland, some level of shortage is economically optimal. Water supply augmentation via wastewater reuse or even water conservation may decrease the dependence on imported marketed water in most cases. Seawater desalination remains an economically unsustainable solution for most water management portfolios for a wide range of treatment costs. Hydro-economic modeling provides useful water management insights for the case study regions presented in this chapter. Water conservation, water recycling and increase in conveyance capacity are among the most economically promising water management portfolios to fulfill future water demands in the Californias.

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REFERENCES

Draper, A.J., M.W. Jenkins, K.W. Kirby, J.R. Lund, and R.E. Howitt 2003. Economic-engineering optimization for California water management, *J. Water Resour. Plan.* Manage.-ASCE, 129(3), 155-164.

Fryer, J. 2010. An Investigation of the Marginal Cost of Seawater Desalination in California, 25 pp, Residents for Responsible Desalination. April 2010 last accessed, <http://r4rd.org/>.

Harou, J.J., M. Pulido-Velazquez, D.E. Rosenberg, J. Medellin-Azuara, J.R. Lund, and R.E. Howitt 2009. Hydro-economic models: Concepts, design, applications, and future prospects, *Journal of Hydrology*, 375(3-4), 627-643.

Medellin-Azuara, J., C.R. Connell, K. Madani, J.R. Lund, and R.E. Howitt 2008. Water Management Adaptation with Climate Change, 30 pp, California Energy Commission, Public Interest Energy Research (PIER), Sacramento, CA.

Medellin-Azuara, J., L.G. Mendoza-Espinosa, J.R. Lund, J.J. Harou, and R. Howitt 2009. Simple Virtues of hydro-economic Models: Baja California, Mexico, *Journal of Environmental Management*, 90, 3470-3478.

Mirchi, A., D. Watkins, and K. Madani 2010. Modeling for Watershed Planning, Management and Decision Making, in *Watersheds: Management, Restoration and Environmental*, edited by Vaughn, Nova Science Publishers, Inc.

Pulido-Velazquez, M., M.W. Jenkins, and J.R. Lund 2004. Economic values for conjunctive use and water banking in southern California, *Water Resources Research*, 40(3), 15.