Managing water resources along the Mexico-US border: Can we find workable market solutions?

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ABSTRACT

The Mexico-U.S. border has important clusters of population centers at various locations. The continued growth in these population centers has contributed to increasing the municipal demands for water resources along with the existing demands derived from current agricultural activities. In this paper we focus on two sets of Twin Cities along the U.S.-Mexico border, namely Calexico-Mexicali in California and Baja California respectively, and on Nogales, Arizona and Nogales, Sonora. These two case studies provide interesting insights due to their differences in size and development patterns. The purpose of this research is to develop a model structure of water for surface water use. The intended use of this model is to form the basis for designing a market structure and other policy instruments to more efficiently allocate scarce water resources along the border. Equity issues are also considered. The methodology developed in this paper is directly transferable to other water-stressed regions of this border and elsewhere.

KEY WORDS: *Transboundary water management, Mexico-U.S. border, water resources, economic incentives.*

INTRODUCTION

The U.S.-Mexico border faces significant challenges. Population increased from 6.9 million in 1980 to 13 million in 2005, and is expected to reach 19.4 million by 2020; the growth rate of the municipalities on both sides of the border is higher than the States they belong to and to their own national average (GNEB, 2010); and about 90% of the population that live in the border is clustered in 14 trans-boundary sister cities that share water resources, among other things (Frisvold & Caswell, 2000). Population growth, mostly in such sister cities, poses a great challenge in the region since a larger population tends to put more stress on water resources and infrastructure, water-related and otherwise.

Furthermore, the border region is mostly arid and frequently suffers from drought, and climate change is also expected to affect water quality (Zamudio, 2011). The U.S. Bureau of Reclamation and the U.S. Army Corps of Engineers have voiced the need for improving tools and information to attain a clearer understanding of how climate variability and change should be built into water management infrastructure and policies (USBR & USCE, 2011). Thus, there is a need of a better understanding of all these issues and how market incentives can help manage water resources in the region.

We analyze two sets of twin cities: Calexico-Mexicali in the California-Baja California region, and Nogales and Nogales in Arizona and Sonora respectively. These areas and their basins are shown in Figure 1. These two pairs of cities are different both in population size and dynamics and economic activities; however, they are facing the same type of issues related to climate variability and climate change. While Calexico-Mexicali represents high-quality urbanization and intensive agriculture, Nogales-Nogales has seen maquiladora-led growth. However, by developing a framework to address water management in these cities, and the effects of climate variability and change reflected basically through water scarcity, we can outline policies for other large and medium cities in the area that face the same fate. This is greatly needed by U.S. and Mexican authorities and this paper addresses this concern. The tools developed under this study provide a better understanding of interactions between water and sustainability under drought conditions and develop frameworks to assess water-related risk of climate variability and change in other cities and methodologies to identify sound strategies. This knowledge may be readily transferred to other cities and municipalities.

The purpose of this research is therefore to develop a model structure of water use where the sources are mainly surface water. The intended use of this model structure is to form the basis for designing a market structure that could be used to more efficiently allocate scarce water resources along the border. The paper begins with a background section on the twin cities and differences in regulation across countries. The second part presents the model

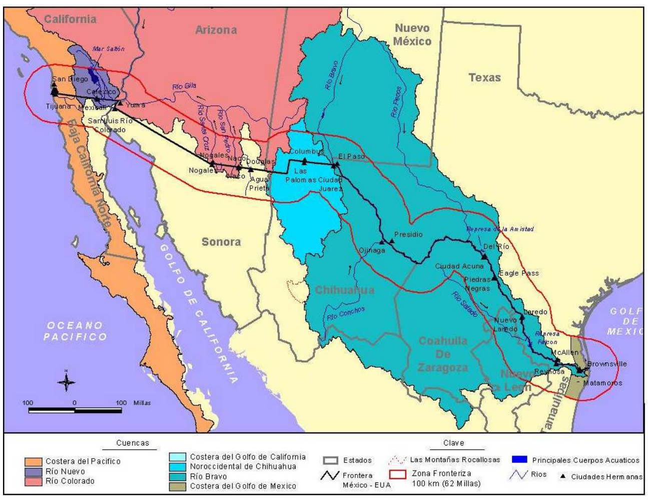

Figure 1. Location of area under study

structure and a brief description of how smart markets work. The last section addresses some issues on policy implementation.

BACKGROUND

Twin cities, twin problems

Economic activity gives rise to cities on both sides of international borders. This is the case along the U.S.-Mexico border, where there are currently 14 twin cities. We analyze two sets of smaller twin cities: Calexico-Mexicali in the California-Baja California region, and Nogales-Nogales in Arizona and Sonora. These pairs of cities are different both in their population size and dynamics, and in their economic activities. While the Calexico-Mexicali metropolitan area has a population of almost 1 million as reported in 2010, Nogales-Nogales only reach approximately 235 thousand. Mexicali has a soaring urban growth with high-tech industry developing in the region as well as a buoyant agricultural sector that produces 72% of the state's agricultural production; its population increased 25% in the last decade. Calexico also has intense agricultural activity in the surrounding Imperial Valley, and its population increased 66% during the 2000-2010 period. Runoff from agriculture in both Baja California and California has been one of the main causes of pollution of the New River that crosses the border, one of the most polluted water bodies in the area. Thus, population growth, urban water use and intense economic activity impose high stress on the scarce water resources. These twin cities are located in the New River basin.

On the other hand, Nogales-Nogales, in the Colorado River basin, is a much smaller community but with growing populations and increasing pressure on water; additionally they do not have a significant water storage capacity. Sonora's Nogales population increased 50% during the 1990s and is now over 212 thousand people; between 2000 and 2020 its population is expected to increase by 86%. Nogales, Arizona, has a population of less than 20 thousand but during the 2000-2020 period it is expected to grow 67%. Water in that region comes mainly from the Santa Cruz and San Pedro Rivers that flow between Mexico and the U.S., and from the Colorado River that flows from the U.S. to Mexico. All three rivers have treatment plants, some only partially operational, and they are highly polluted, threatening groundwater in the region. This may be due to the maquiladoras, services, and agribusinesses that are the main sources of economic activity, and they help build pressure across the border for scarce water. Water tables for aquifers in the area are mostly falling, leaving residents, particularly in the Sonoran (Mexican) side, vulnerable to water shortages, especially during drought years (Ingram & White, 1993; Frisvold & Caswell, 2000).

Institutional complexities of border water management

The International Boundary and Water Commission was established as a result of the 1944 U.S.-Mexico Water Treaty on Utilization of Waters of the Colorado and Tijuana and of the Rio Grande to manage surface water. This treaty established water rights on these main rivers; however, water from other smaller rivers is unilaterally taken by each country. The treaty addresses water quantity issues from the main rivers only. Initially it did not discuss water quality. Due to this matter, controversies keep surfacing. For example, the recent conflict over the All-America Canal is due to diversion of surface water from the Colorado River to farmers in Imperial Valley and from the reduction in groundwater recharge due to the lining of canals in the U.S. This reduces aquifer recharge and increases salinity in the Mesa San Luis aquifer that supplies water to Mexican farmers in Mexicali (Frisvold & Caswell, 2000). Even though water allocations are mentioned in the 1944 treaty, water quality is not addressed, and water with higher content of dissolved solids and higher salinity is being delivered to Mexico. This in turn lead to the 1973 amendment that limits total dissolved solids (TDS) in the water flowing towards Mexico, and stated that they have to be within 115 ppm of TDS in the Imperial Dam in the U.S.. This addresses relative salinity, but not absolute salinity issues that will, in the end, affect both countries.

Water pollution is another pressing problem in the area with significant effects on human health. This is mostly due to raw sewage from Mexico crossing the border and polluting drinking water. As a result of this trans-boundary pollution problem, in 1983 Mexico and the U.S. signed the La Paz Agreement to formalize cooperation on solving environmental problems in an area 100 km north and south of the border. In 1994 the North American Free Trade Agreement (NAFTA) came into play and with it the Border Environmental Cooperation Commission (BECC) and the North American Development Bank (NADBank). Together they plan, overlook and finance water, wastewater and municipal solid waste projects. However, none of these new institutional changes addresses any treaties regarding surface or groundwater use in the border.

One issue that complicates things further when developing schemes for better water management is the level of government at which water use is regulated. While Mexico does so through the National Commission of Water (CNA) at the federal level, the U.S. handles it at the state level. Additionally each state in the U.S. has different rules regarding water ownership, exploitation and use.

MODEL STRUCTURE

Background

A range of studies can be found in the literature that attempt to identify the key contributors to the water resource problems along the border and also propose model structures that can be used to develop policy solutions. The common model strategy is a game-theoretic structure as reported by Fernandez (2006), Frisvold & Caswell (2000), and Nakao et al. (2002). Chermak et al. (2005) develop a continuous time dynamic joint maximization model that features an aquifer as a transboundary resource. However, most of this research gives little consideration to identifying workable market solutions to the transboundary water resource management problem.

In this paper, we design a market process for allocating permits to achieve the same type of behavior we observe for each decision maker in the overall cost minimization model. We use a method known as a computer assisted "smart market" which has been used in a number of electricity pricing situations. This approach has also been proposed and applied to some types of environmental and resource management problems. We provide the theoretical structure of the "smart market" model with a safety margin to allow for water quantity and quality. Then a set of pricing rules for the permits that reflect a margin of safety are discussed and the issues related to their implementation are explored.

Transboundary Water Management Model

The previous discussions illustrate that it is possible to find a vast array of literature on the general problem of transboundary water resource management problems, especially those dealing with areas along the U.S.—Mexico border. Most of these studies use a joint maximization approach in their problem formulation. This may also be thought to be a cooperative game theory formulation. There are other arrays of game theory formulations that have been the basis of this research. A number of studies pose the transboundary water resource management problem as a form of bilateral negotiation (many of these are represented as bilateral monopoly models). We can conclude that these studies tell us what types of outcomes should be considered, but they have little to say about the concrete institutional design and computational system for actually approaching a workable solution for policy purposes. This becomes increasingly important as we see more serious climate change outcomes in a region that is characterized as arid.

The focus of our research is to formulate a general structure of a river that flows across a border between two countries. We propose a computer-assisted smart market modeling framework for a transboundary water resources management problem. This framework will have the following features. First, the model is primarily concerned with surface water (could be extended to include surface lakes as well) from a river that goes between two countries. Primary water users are agriculture and municipalities. We will specify climate change variables, but these will be treated as exogenous factors and generally discussed. Very simple formulations are proposed. This raises issues for completeness, but there are also serious problems with detailed data availability. As a general rule, many of our formulations are influenced by the Ricardian models developed by Mendelsohn and colleagues. These models have mostly been used to look at the impact of climate change on land values. We have an alternative use in mind—we intend to look at what happens in a market—based setting for managing water resources with climate change taking place. The focus is on a property right for water defined as consumptive use. (The literature on this includes work by Johnson et al. (1981); Anderson & Johnson (1986); and Weber (2001)). We will need to make a distinction between water diversions, consumptive use, and return flows. We will include water quality and in-stream flows in our model. These formulations will follow to some extent the ones found in Weber (2001).

The modeling exercise begins with the individual decision making units, showing how they make decisions for water use. This exercise then leads to a set of bid schedules which form the basis for overall smart market model. The smart market model includes a constraint set that reflects the spatial nature of a particular river.

The irrigation water demand function and water rights bid function for a typical farmer is now developed. As previously noted, the property right being traded is defined as consumptive use. It is assumed that each farmer receives an initial allocation of water rights for surface water and can buy additional rights or sell surplus rights at a "market-determined" price. Climate change parameters are treated as exogenous and appear in the production function as shifters. The basic farm model formulation is based on the specifications found in Archibald & Renwick (1998); Dinar et al. (1992); and Weinberg et al. (1993).

Define the following for the i^{th} water diversion point (where *i = 1, ..., I*) in country n (*n = U for United States, n = M for Mexico*) which is a farm with a demand for irrigation water:

$P_c^n =$ Crop price for i^{th} farm in country *n*;

$x_i^n =$ Consumptive use of irrigation water by farm *i* in country *n*;

$m_i^n =$ Water rights bought or sold by farm *i* in country *n*;

$w =$ Market price paid or received for water right bought or sold by farm *i* in country *n*;

$A_i^n =$ Initial allocation of consumptive water rights for farm *i* in country *n*;

$z_i^n =$ Weather climate change variable measured as degree days or pan evaporation levels for farm *i* in country *n*;

$e_i^n =$ Effluent level generated by farm *i* in country *n*.

The production function relationship for farm *i* is represented as $f^{in}(x_i^n, z_i^n)$ with $f^{in}_{x_i^n}(x_i^n, z_i^n) > 0$ and $f^{in}_{x_i^n x_i^n}(x_i^n, z_i^n) < 0$. The pollution generation function is $e_i^n = g_i^n(x_i^n, z_i^n)$. More discussion on these functions will be developed in the formal draft of the paper. In the meantime, we assume that the individual farmer is myopic and does not consider its pollution generating function in its decisions concerning the demand for irrigation water.

The decision problem for a typical farmer is

$$Max\ \Pi_i = P_c^n f^{in}(x_i^n, z_i^n) - c_n^i(x_i^n) - w m_i^n \quad (1)$$

Subject to

$$x_i^n \leq A_i^n + m_i^n \quad (\lambda_i^n) \quad (2)$$

$$e_i^n = g_i^n(x_n^i, z_i^n) \quad (3)$$

Eq. 1 is the farm's profit function while constraint (2) represents the individual farm's irrigation water constraint. The variable in parentheses for constraint (2) is a Lagrangean multiplier. Eq. 3 is the farm's effluent generation function. As noted above, we assume here that the individual farmer is myopic and does not factor any of the effluent generated into its decisions. We can justify this by the fact that the farmer is assumed not to face any sort of regulations or financial penalties on the effluents generated. The farmer's decision variables are the level of irrigation water, x_i^n and the quantity of water rights bought or sold, m_i^n.

The farmer's decisions can be represented by a set of marginal conditions. Assume the farm manager's demand for water is based on the first order conditions which are:

$$P_c^n f^{in}_{x_i^n}(x_i^n, z_i^n) - c_{in}'^n(x_i^n) - \lambda_i^n \leq 0 \quad (4)$$

$$\left(P_i^n f^{in}_{x_i^n}(x_i^n, z_i^n) - c_i'^n(x_i^n) - \lambda_i^n\right) x_i^n = 0 \quad (5)$$

$$-w + \lambda_i^n \leq 0 \quad (6)$$

$$(-w + \lambda_i^n) m_i^n = 0 \quad (7)$$

$$x_i^n - m_i^n - A_i^n \leq 0 \quad (8)$$
$$(x_i^n - m_i^n - A_i^n)\lambda_i^n = 0 \quad (9)$$

Assume that $x_i^n > 0, m_i^n > 0, and\ \lambda_i^n > 0$. The demand for irrigation is non-zero, the ith farmer will buy or sell water rights and the farmer's water constraint is binding. Combining these conditions yields the following outcome:

$$P_C^n f_{x_i^n}^{in}(x_i^n, z_i^n) - c_i'^n(x_i^n) = w \quad (10)$$

Eq. 10 is the equilibrium condition for the optimal use of irrigation as well as the decision to buy or sell water rights. The left side of the above equation represents the marginal product of irrigation water used by a farmer while the right side is the price of a water right. If we see that $P_C^n f_{x_i^n}^{in}(x_i^n, z_i^n) - c_i'^n(x_i^n) > w,$ there is an economic incentive for a farmer to purchase additional water rights until the condition above is reached. If on the other, hand we see that $P_i^n f_{x_i^n}^{in}\left(x_i^n, z_n^i\right) - c_i'^n(x_i^n) < w$, farmer *i* has an incentive to sell water rights until the condition above is reached. Of course the value for x_i^n is adjusted accordingly.

In summary, the above condition represents the *i*^th farmer's decision rule for buying and selling water rights. This then becomes the basis for each farmer's bid schedule which is placed in the smart market model.

The water demand function and water right bid function for a municipality are next developed. The following notation is defined for a municipality:

$Z_i^n =$ Initial allocation of water rights for a municipality at point *i* in country *n*;

$u_i^n =$ Quantity of water demanded by a municipality at point *i* in country *n*;

$v_i^n =$ Number of water rights bought or sold by a municipality at point *i* in country *n*;

$r_i^n =$ Effluent generated by a municipality at point *i* in country *n*;

$y_i^n =$ Climate change variable for a municipality at point *i* in country *n*.

Define a municipality's demand function for water as $D_i^n(u_i^n, y_i^n)$ and the corresponding cost of drawing water from the river as $d_i^n(u_i^n)$. Effluent generating function is $r_i^n = h_i^n(u_i^n, y_i^n)$. The municipality's decision problem is

$$Max \int_0^{u_i^n} D_i^n(\theta_i^n, y_i^n)d\theta_i^n - d_i^n(u_i^n) - wv_i^n \quad (11)$$

Subject to

$$u_i^n \leq Z_i^n + v_i^n \quad (\pi_i^n)(12)$$

$$r_i^n = h_i^n(u_i^n, y_i^n) \quad (13)$$

The municipality's objective function Eq. 11 is defined as consumer surplus while constraint (12) represents the municipality's water use constraint. The variable in parentheses for constraint (12) is a Lagrangean multiplier. Eq. 13 is the municipality's effluent generation function. We assume that the individual municipality is myopic and does not factor any of the effluent it generates into its decisions. We assume the municipality does not face any sort of regulations or financial penalties on the effluents it generates. The municipality's decision variables are the amount of water withdrawn from the river, u_i^n and the number of water rights bought or sold, v_i^n. Decisions made for this problem can be represented by a set of marginal conditions. Assume the municipality's demand for water is based on the first order conditions which are as follows:

$$D_k^n(u_k^n, y_k^n) - d_u'^n(u_k^n) - \pi_k^n \leq 0 \quad (14)$$
$$(D_k^n(u_k^n, y_k^n) - d_k'^n(u_k^n) - \pi_k^n)u_k^n = 0 \quad (15)$$
$$-w + \pi_k^n \leq 0 \quad (16)$$
$$(-w + \pi_k^n)v_k^n = 0 \quad (17)$$

Assume that $u_i^n > 0, v_i^n > 0$ and $\pi_i^n > 0$. The municipality's demands for water withdrawals are nonzero and water rights will be bought or sold if the water constraint is binding. Combining these conditions yields the following outcome:

$$D_k^n(u_k^n, y_k^n) - d_u'^n(u_k^n) = w \quad (18)$$

Eq. 18 is the equilibrium condition for municipal water withdrawals as well as the decision to buy or sell water rights. The left side of the above equation shows the net marginal benefit for municipal water withdrawals while the right side is the price of water. If we find that $D_k^n(u_k^n, y_k^n) - d_u'^n(u_k^n) > w$, there is an economic incentive for the municipality to purchase additional water rights until equation is reached. If, on the other hand, we see that $D_k^n(u_k^n, y_k^n) - d_u'^n(u_k^n) < w$, the municipality manager has an incentive to sell water rights until equation is reached. In the meantime, the value of u_i^n is adjusted accordingly.

In summary, Eq. 18 represents the *i*^th municipality's decision rule for buying and selling water rights. This becomes the basis for each municipality's bid schedule which is placed in the smart market model.

Smart Market Model

Assume economic agents with a demand for water rights permits can provide a central market coordinator with the information on quantities of permits to be traded at each possible price. It is then possible to determine the optimal prices and allocation of water permits using a computer-assisted smart market model. This type of market allows for the pricing and allocation of resources in technologically interdependent environments. The basic idea is to combine the information and the advantages of economic incentives derived from a decentralized property rights system with the coordinating advantages of central processing based on an optimization process. The optimization data requirements include the demand based on the willingness-to-pay, the supply based on the willingness-to-accept, budget, capacity and other problem-specific constraints. The data are provided by decentralized decision makers whenever price and allocation decisions are needed.

The central processing in such a market is based on the application of optimization algorithms to the submitted bid-offer messages to determine the prices and allocations that maximize net gains from exchange. In general, the market is a periodic auction that is cleared using mathematical programming techniques such as linear programming. Pricing information for permits is based on a range of shadow prices generated from the mathematical programming model. The smart market is operated by a market manager, and the trades are to or from a pool rather than bilateral trades.

These markets are particularly useful in situations where trades are likely to incur significant transaction costs. Also, several different types of auctions can be used as well. For example, the smart market can be a one-sided auction, where the market participants buy from a market manager, one-sided procurement (reverse) auction, where the market participants sell to the market manager. A two-sided auction can also be used in which the market manager can be a net seller, a net buyer, or a revenue-neutral broker.

RESULTS

Market-based instruments such as transferable water permits may help manage water in the U.S.-Mexico border. A well-established system may take care of efficiency issues, but at least two sets of constraints should be put in place to address equity across-countries: first, there must be a maximum amount of water traded to assure a given flow of water into Mexico; second, water quality delivered across the border to Mexico must be clearly stated to ensure health to both humans and ecosystems. These two conditions may help build equity constraints into efficient market solutions for water allocation and use.

IMPLEMENTATION ISSUES AND CONCLUSIONS

The institutional structure of the smart market we propose is based on an online trading system similar to that described in Prabodanie et al. (2010). A central market manager is assigned to coordinate the online trading system and facilitates multilateral trades which take place through a web interface. Trades are based on buying and selling on the centrally controlled market. Each firm determines its demand or supply of permits for each possible permit price by solving its version of the decision problem given by the above Eqs 1 and 2 for a wide range of permit prices. Users are assumed to submit their bids and offers to the online trading system as a series of price and quantity (buy or sell) pairs.

A number of complicating factors must be addressed for the market-clearing process to be completed. First, the property right traded is constrained by ambient standards at various receptor points. Thus emitters will be bidding for water use rights that have direct impacts on water quality constraints at different receptor locations, making the bids non-comparable between the traders. The market manager is faced with the task of finding a different price for each source such that the demand for water use rights meets the market supply, water quality standards are met at all receptor points and the net social benefits from trading are maximized.

The nature of the information made available to traders is also important to consider in the institutional design. First, everyone should have access to information such as trading history and prices. However, information such as each trader's pending bids is not released. Important information such as bids and offers, details on the initial EDP allocations for each emitter together with other important information can be stored in a database. It is also important that the market manager was provided with the administrative rights and was capable to execute the linear program and also determine optimal feasible trades.

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