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Towards a Water Leasing/Banking System on the Middle Rio Grande: Progress to Date

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Towards a Water Leasing/Banking System on the Middle Rio Grande: Progress to Date[1]

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I. Introduction

Since 1950, the demand for water has more than doubled in the United States. Historically, growing demands have been met by increasing reservoir capacity and groundwater mining, often at the expense of environmental and cultural concerns. The future is expected to hold much of the same. Demand for water will continue to increase, particularly in response to the expanding urban sector, while growing concerns about the environment are prompting interest in allocating more water for in-stream uses, and cultural issues will remain at the fore. So, where will this water come from? Virtually all water supplies are allocated. Providing for new users requires a reduction in the amount of water dedicated to existing users and a mechanism for transferring water between users.

Markets typically are formed to facilitate the efficient allocation of goods and services. Under simple conditions buyers and sellers pursuing their own self-interest willingly agree upon a single price that fully compensates sellers and provides the commodity to those who value it highest[6]. The general concept of water marketing (here taken to mean a permanent transfer of a water right) and water leasing/banking (a temporary transfer) has gained considerable attention as a volunteer, market-mediated system for transferring water between competing uses.

A sampling of investigations into water marketing where the focus in upon the formal trading of rights (as against leasing) can be found in Howe et al (1986), Burness and Quirk (1980), Simpson (1994), Saliba (1987), Easter (1999), Easter et al (1999), Colby (1993), Colby (2000), Howe and Goemans (2003) and Brookshire et al (2005). Often water marketing is viewed as movement from agricultural use to urban uses, which are typically viewed as permanent.

Formal market transfers are also often slow, and do not necessarily increase the flexibility of water users to trade quickly in response to near terms shortages and thus they do not directly address the need for a trading mechanism that can rapidly respond to climatic induced needs.

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[6] It cannot be emphasized enough that any transfer of water within a market-based system is a voluntary transfer.

Water Banking/leasing approaches have been set forth as one possibility for addressing the increasing needs and the possibility of reallocation within and across current uses, in a timely fashion. The Water 2025: *Preventing Crises and Conflict in the West (2005)* calls for consideration of market-based principles in the context of existing institutional structures[7]. The New Mexico State Water plan also calls for an efficient water transfer plan (Office of the State Engineer (2003)). The New Mexico plan specifically supports water transfers as a strategic management tool for efficient water transfers inclusive of water banks[8]. Specifically, the State Engineer is responsible for implementation and encourages the creations of water banks in areas that are experiencing shortages.

A recent report details the limited nature of water leasing/banking in the Western U.S. (West Water Research (2004)). The report provides an analysis of water banking legislation policies and programs in 12 Western states. There are 23 active water banks of which seven are market based pricing, meaning that the price is negotiated between the buyer and the seller with one bank having online negotiations. The other 16 banks are fixed pricing or administrative pricing schemes that are set annually. Length of transaction varies and the number of transactions is limited annually.

Here we explore the role of water leasing/banking in allocating resources among competing demands. In particular, we develop a stylized template for temporary voluntary transfers amongst competing uses (agriculture, Native American farming, environmental interests, urban interests) on the Middle Rio Grande. There are many issues (engineering, physical, legal, and institutional) to be addressed in allowing for water transfers within a basin. Central to our effort is linking of a hydrological/engineering/institutional model that allows for water transfers to be evaluated within the various frameworks.

II. Objectives

In our initial framework, we represent one physical component by tracking evaporation associated with trades up and down the river. Our stylized template allows for future exploration of different physical, hydrological, engineering, spatial resolutions, market systems, legal institutions and priority frameworks, option trading through time, various representations of uncertainty, and different frameworks for third-party effects. The model design allows behavioral experiments to be conducted with subjects from key water use sectors to test how a voluntary water banking/leasing exchange process might operate.

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[7] The 2025 report sets forth some guiding principles for water transfers. These include in part, that recognition and respect must be made for state, tribal, and federal water rights, contracts, and interstate compacts or decrees of the United States Supreme Court that allocate the right to use water, that methods should include efforts to enhance water conservation, use efficiency and resource monitoring to allow existing water supplies to be used more effectively and that collaborative approaches go hand in hand with market based transfers in order to minimize conflicts.

[8] The New Mexico plan state: “Consider water rights transfer policies that balance the need to protect the customs, culture, environment and economics health and stability of the states diverse communities while providing for timely and efficient transfers of water between uses to meet both short-term shortages and long-term economic development needs.”

III. Approach

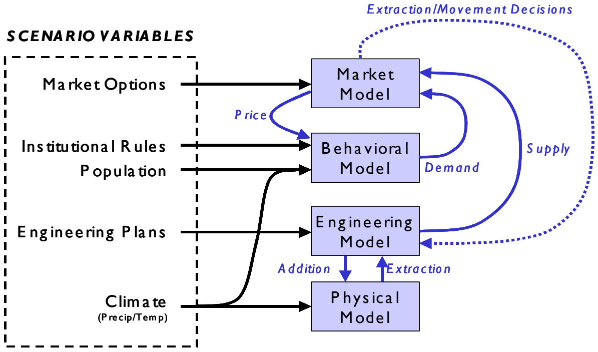

Figure 1. Schematic of integrated model architecture and feedback structure.

The model addresses the Middle Rio Grande basin in New Mexico, which is bounded by Cochiti Reservoir to the north and Elephant Butte Reservoir to the south. The model (Figure 1) integrates a physical/engineering model (e.g., climate, surface water, groundwater and riparian habitat) with a behavioral/economic model (e.g., lease trading system, water demand). The model allows a series of players representing Agricultural/Native American farming, municipalities and environmental interests to trade water under high, average, and low water supply years. The model yields price paths for the exchanges and tracks water movements by users and by reach.

IV. Physical Setting

The Middle Rio Grande of central New Mexico (Figure 2) is characterized by basin and range topography with mountains along the east, and arid valleys and mesas to the central and west. The principle drainage for the basin is the Rio Grande, which is the primary source of irrigation water for the region's farmers. Municipal demands are met though pumping of deep alluvial aquifers that are directly connected with the Rio Grande River. Vegetation classes found within the region range from riparian along the Rio Grande to desert grassland, pinyon-juniper woodlands and mixed coniferous forest at higher mountain elevations. The planning region includes Albuquerque, the principal urban center of New Mexico, and several smaller communities including Rio Rancho, Belen, Los Lunas, Socorro and Bernalillo. These communities are located along the Rio Grande, while sparse rural populations characterizing the outlying areas. From 1900 to 2000 the population of this region grew from about 51,000 to about 713,000 (a 1298% increase), according to the U.S. Census Bureau. The most recent doubling of population occurred from about 1970 to 2000.

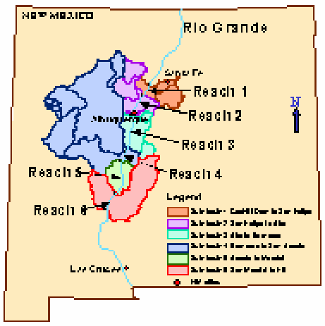

Figure 2. Map of the Middle Rio Grande basin along with the 6 primary river reaches/watersheds.

V. System Dynamics

The water leasing/banking model is formulated within a system dynamics context. System dynamics provides a unique mathematical framework for integrating the natural and social processes important to managing natural resources, while providing an interactive interface for engaging the public in the decision process. System dynamics is formulated on a spatially aggregated, temporally dynamic basis (i.e., lumped parameter model). Simply put, these models track the temporal trends in key system commodities (e.g., surface/groundwater) resulting from variable inflows and outflows (see Figure 3). These "flows" are modeled by way of historic data, empirical relations, analytical models, or from the output of spatially disaggregated models. Stocks and flows rarely operate independently but rather in a system of feedback and time delays.

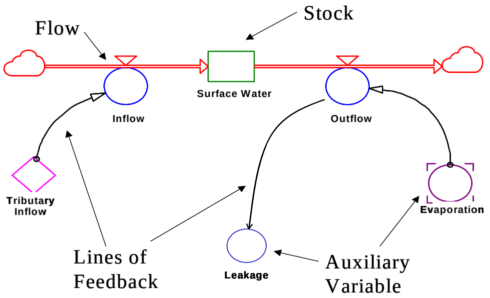

Figure 3. Schematic of simple system dynamics stock and flow diagram.

VI. Physical Model Structure

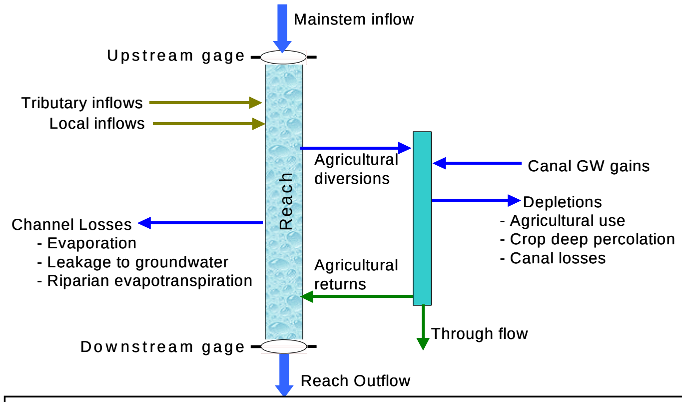

Figure 4. Schematic of generic reach showing the key water budget terms calculated by the hydrologic/engineering model.

The physical/engineering model is developed within the commercial system dynamics software package, Powersim Studio 2003. The model is designed to operate on a yearly time step. The model is structured according to 6 interacting reaches, as delineated by the major gages on the Rio Grande. Rio Grande inflows, tributary inflows and climatic conditions taken from historical records define the external forcing applied to the model. In this way, simulations can be run for dry, average, or wet years with either high or low reservoir storage. The model then calculates the basic water balance components for each reach of the model. The basic water balance terms are given in Figure 4. These terms are calculated by way of empirical models, analytical models, or through mass balance calculations. For each time step, two model runs are performed. During the first run the model calculates river flows, conveyance losses, and available irrigation water. This information is supplied to the leasing/behavioral model. When a trading period ends, the water balance is re-calculated with the physical/engineering model. The second run of the model then calculates impacts of the trades on the hydraulic system.

VII. Market/Behavioral Model: Water Leasing/Banking Exchange Design

We utilize an open market trading system similar to the system used to trade other commodities such as wheat, corn, pork bellies and metals. Specifically, we employ a system known as a double oral auction. Buyers and sellers declare their bids and offers to the market. Contracts are established when a buyer and a seller agree on a standing price. The market is open for a fixed amount of time. Time in the experiment consists of a series of years, during which the market for water occurs during the six months of the growing season. There are four classes of participants in a leasing experiment. The participants (subjects in the experiments) represent the interests of specific users, including agricultural, Native Americans, urban interests, and environmental interests. Each agent represents the interests of one of these four user groups in a single reach of the model. Trades are allowed between reaches and within reaches. Subjects are motivated by monetary reward in the experiments and are paid based on profits earned through the leasing of water or by obtaining their yearly payoff based on their water use. We are not conducting simulations rather we are assuming the participants in the experiments maximize profits based on their underlying payoff functions. The experiment is based on the engineering model with a stylized river. The river flows from reach 1 to reach 6 (Figure 5). Using Powersim Studio 2003 water reduction factors are calculated for the four different classes of experiments.

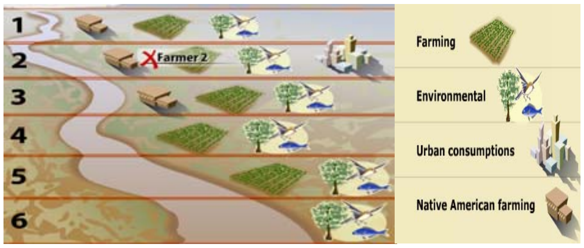

Figure 5. Depiction of stylized river

VIII. Utility Functions

Each water user group is motivated by a utility function unique to their needs. Agricultural/Native American users require three acre-feet of water during the growing season for their crops. Failure to obtain this minimum amount of water results in complete failure of their crop for the season. Excess amounts do not increase the crop payoffs but can be leased out for monetary gain. Players have the option of leasing their water instead of growing a crop, or if they are unable to obtain sufficient quantities of water for a crop. The urban region within the model represents Albuquerque. For this user, it is assumed that water produces value in ever increasing amounts but is subject to the law of diminishing marginal utility. For this reason, we model the urban payoff to water using a quadratic specification. Environmental uses of water are assumed to be for minnow protection and riparian restoration. These demands are modeled by a set of preferences that depend upon maintaining a minimum of two acre-feet of water in the river. Below this minimum, environmental losses occur. Above the minimum, positive Environmental outcomes are forthcoming.

Figure 6 shows the demand functions for the three user groups. The demand functions for agricultural/Native American farming and environmental interests are a step demand function while the urban user has a downward sloping demand curve. Agricultural/Native American users seeking to maximize monetary payout will be willing to pay up to (b/a) to obtain (a) units of water. The Environmental user's demand function is also a step function. The environmental user is willing to pay up to (c/b) to obtain (b) units of water. However, the environmental user receives a negative payoff if they allow water in the river to drop below a threshold of (b) units. This effectively models environmental concerns such as silvery minnow protection in the Middle Rio Grande. The urban user faces a downward sloping demand curve to model the idea of diminishing marginal returns.

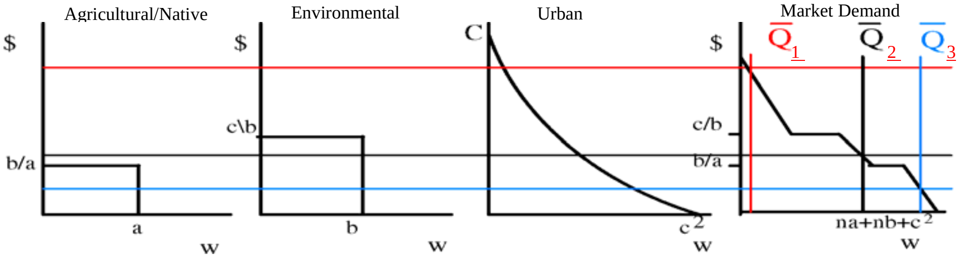

Figure 6. The three different water user groups are summed to create a market demand in order to develop the efficiency price. Q_1 represents a dry water scenario, Q_2 a normal water scenario and Q_3 a wet water scenario.

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Multiplying the agricultural/Native American demand function by the number of players (n), environmental by the number of players (n) and the Urban by the number of players (n), then summing creates a market demand curve, the diagram on the far right of Figure 6. Using the experimentally set market supply and the market demand that comes from the aggregation of the three demand functions, an equilibrium or efficiency price can be calculated as the intersection of the market supply and the market demand. This allows the observed experimental prices to be compared to the efficiency price in order to determine if the market is efficient.

Three different climatic scenarios are also represented in Figure 6 with red (Q_1) representing a dry climatic scenario, black (Q_2) representing a normal climatic scenario and blue (Q_3) representing a wet climatic scenario. The different climatic scenarios are the market supply of water, with the intersection of the aggregate demand curve being the efficiency price for the market.

IX. Experiments

The market experiments are conducted through a series of bidding sessions. In these sessions information from the physical/engineering model is passed to participants via a web interface. Water users may enter bid quantities and prices to sell or buy a unit of water, or they may accept specific offers at one-unit increments. The web interface checks to make sure both the buyer and seller each have sufficient amounts of money and water, and then determines if the transfer is possible using loss estimates from the physical/engineering model. Other potential constraints on a trade include water availability, Rio Grande Compact compliance, and/or Minimum River flow requirements. When a trade is made, the accepted bid or offer disappears from the bid/offer sheet. Buyers and sellers are free to update their bids and offers throughout the duration of the trading year. At the end of the year, the compact balance is checked and the hydrological model is recalibrated based upon the contracts impact on water flows. Bidding is concluded when all bidders have bought or sold as needed, some set number of transfers have been refused, or a fixed time limit is exceeded. All trades are voluntary.

X. Results

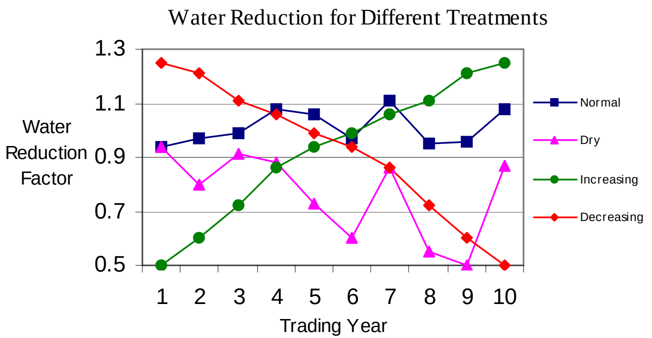

Figure 7. Four different climatic scenarios

Fourteen experiments were conducted over the summer of 2005; 3 decreasing scenarios, 3 increasing scenarios, 3 dry scenarios, 3 normal scenarios, 1 above normal scenario and 1 below normal scenario. Scenarios were developed by coupling the physical (hydrological) model with the engineering model. The water reduction factors for the experiments are shown in Figure 7. For example, in the decreasing water scenario the Agricultural/Native American user begins trading year 1 with 3.75 acre feet of water which is above the 3 acre feet required to grow a crop for the trading year. Over the course of the trading years, water becomes scarce. In year 10 the user begins the trading year with 1.45 acre-feet of water. The water reduction factor was used to calculate the allocation for each user. Results show that the weighted average price obtained in the experiment is above the efficiency price calculated from the demand functions (Figure 8). The model also proved to be robust as all users engaged in multiple trades during each trading year.

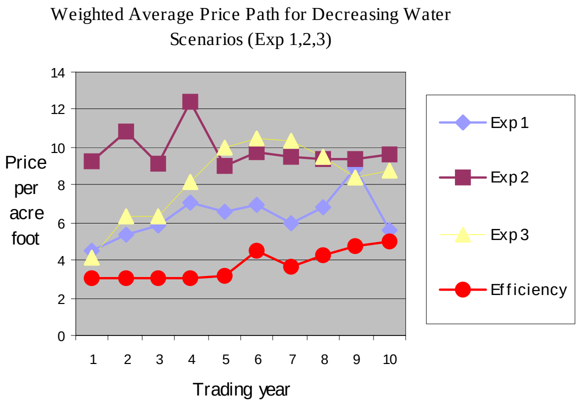

Figure 8. Weighted average price in relation to efficiency price

Trading of water was observed both between reaches and within reaches. The current model only has one representative per user type on a reach (i.e. only one environmental user per reach). Even with a single representative, the results have shown that trading occurs amongst the user groups and within the user groups. Figure 9 shows how water was traded for the Agricultural/Native American user during one decreasing water scenario (experiment 1). As can be seen, most of the trading occurs between the user group itself, with very few trades occurring with the urban user. As water became scarce, the number of trades engaged in by the Agricultural/Native American group declined. Figure 10 shows that although the number of trades declined for this user group the amount of water traded increased as water became scarce. Results show that Agricultural/Native American users leased water in dry years to obtain monetary benefits rather than grow a crop. The initial allocation of water for this user group is the point zero in Figure 10. The negative percentage means that farmers are net sellers of water.

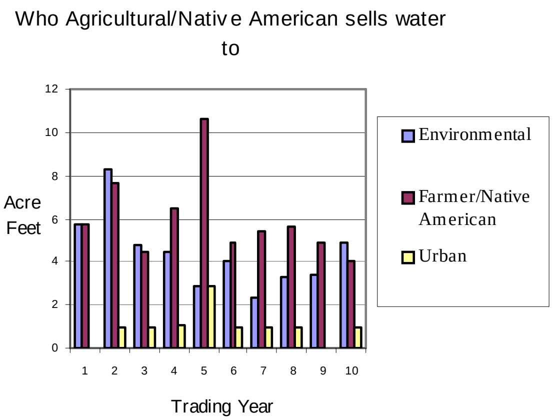

Figure 9. Agricultural/Native American trading of water

Environmental users benefited the most in a decreasing water scenario, as they became net purchasers of water. The market system is able to meet environmental concerns such as protecting the silvery minnow and farmers were able to make a positive monetary reward by selling water to these users. The model is also able to track water movement between reaches and user groups. A priori expectations are that water would be traded upstream due to the effect of evaporation. Thus, water that would have been lost to evaporation can be saved through the trading of water from the lower reaches to the upper reaches. Results from the experiments have shown this to be true.

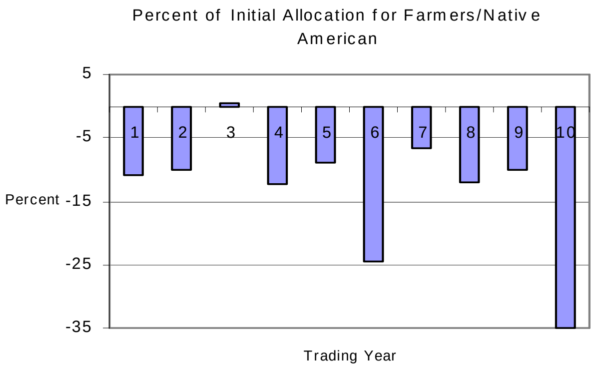

Figure 10. Agricultural/Native Americans percentage of initial allocation

Figure 11 is a representation of the stylized river before a trading year (left side) and after a trading year (right side). The result shows the 7th round of a decreasing water scenario. To determine water movement by reach it was necessary to aggregate total water in each reach. Summing each user's water allotment by each reach did this. Since the Environmental user's initial water allotment is below the minimum flow requirement needed to protect riparian interest and the silvery minnow, they purchase water since they are facing a monetary punishment if they allow the river to fall below this threshold. This explains why the results show a positive gain in the lower reaches of the river in figure 11, as there is only an Agricultural and Environmental user in reaches 4 and 5 with only an Environmental user in reach 6. The Environmental users in the lower reaches are purchasers of water because of the demand functions they face as shown in figure 6.

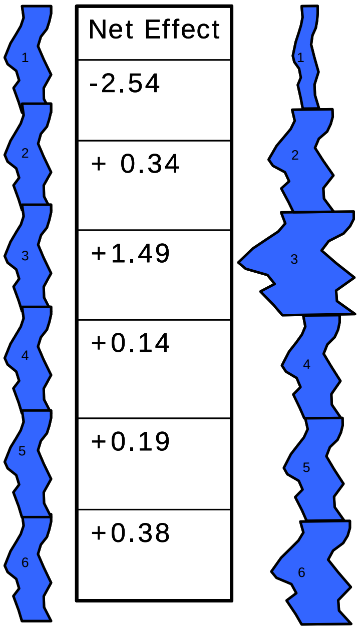

Figure 11. Representation of the stylized river before and after trading with the net effect for each reach.

Not only were these outcomes realized from the experiment, it was also observed that participants are able to handle the cognitive complexity of trading in a complex water market subject to exogenous hydrological forces. Multiple trading was observed in each experiment run showing that participants comprehend the cognitive complexity of the model and that the model is robust.

XI. Extensions

This model is merely a starting point, where any possibly climatic scenario and its affect upon behavior can be modeled. Further research to be conducted will have real farmers play the role of the agricultural agent, along with Native Americans, Environmentalists, and Urban consumers playing their respective role. This will allow for water and its role in the culture of acequias to be more accurately modeled and included in later experiments. Currently third party effects are not included in the model; including such effects will introduce solution concepts for these situations. The current economic model is a double oral auction; other models will be examined as a way of conducting trades. Examination of intertemporal trading-both within years and between years will be incorporated into the model. The inclusion of transaction costs, modeling laterals, and the use of a central planner in the model will also be explored as extensions or variations to the current economic model.

XII. Literature

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