A Market for Water Transfers in the Upper Colorado River Basin and the Role of Transaction Costs

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A Market for Water Transfers in the Upper Colorado River Basin and the Role of Transaction Costs

Genevieve Meller

Honors Thesis in Economics
Abstract

Allocation of water in the Upper Colorado River Basin is currently determined by the system of prior appropriation; a legal structure that has led to an inefficient allocation of water in the basin. A market for tradable water rights is proposed that would allow for a more optimal allocation to be achieved. An analytical framework for the analysis of water allocation systems is presented and its application to a hypothetical Upper Basin market is discussed. A quantitative model is designed that simulates a market for tradable water rights permits in the Upper Basin, with an emphasis on transaction costs. The simulated market is found to provide a more socially and economically efficient allocation of water for the Upper Basin than currently exists.
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1. Introduction

1.1 The Legal Context: History of Water Allocation in the West

Allocation of water is an issue of paramount importance in the American southwest, where water is in persistently short supply. The Colorado River is one of the primary sources of freshwater for the entire region. The river supports cities, small towns, recreational industries, hydropower generation, diverse ecosystems, and vast agricultural operations. The river is currently governed by the 1922 Colorado River Compact and subsequent laws, collectively referred to as the Law of the River. Water rights under the current system are allocated based on the principle of prior appropriation; whoever first diverted water for beneficial use maintains a superior right to continue diverting that volume of water. This right is constrained by the requirement that the allocation be put to continuous beneficial use. Colloquially referred to as “use it or lose it,” per this clause any allocations not consumed may be re-appropriated, thus providing a strong incentive to consume one’s full allocation on an annual basis, regardless of need, to prevent future losses. In effect, there are no incentives to conserve and no mechanisms in place to ensure that water is being put towards its most beneficial uses.

Such water allocation mechanisms in the West are not adapting to fit the growing population. Prior appropriation doctrine means that the majority of senior water rights are held by mining and agricultural operations, whose only current incentive is to consume as much water as is allowable. Municipal and other modern industrial users have much more vulnerable junior rights. This vulnerability has led cities to focus almost entirely on supply side availability of water, primarily in terms of efforts to augment local supplies via pipelines and reservoirs, which divert or hold water to be consumed by humans when
deemed optimal. This supply-side approach has developed as a response to the legal structure and is economically inefficient and often environmentally destructive (Carey 2001). Several types of solutions exist that may be employed in order to improve the current situation, including but not limited to; renegotiated agreements (van den Brink 2012), water banking (Colby 2010), and water markets (Howe 1986). Water markets have consistently been indicated as the lowest-cost method of remediating instances of poorly managed water supplies (Rosegrant 1994). There is currently no comprehensive market system for reallocating water rights between users so that water may be consumed by the user who values it the most. This study will explore the potential for development of such a market in the Upper Colorado River Basin (henceforth referred to as Upper Basin).

1.2 Economic Context: Why Water Markets Don’t Already Exist in the West

The barriers to market establishment for water are far higher than for normal goods and services. In addition to typical transaction costs arising from information, negotiation, and enforcement issues, water markets are also subject to policy induced transaction costs (Colby 1990). Rosegrant et al. (1994) studied transaction costs under riparian rights, public allocation, and prior appropriation and then evaluated the burden-sharing of those costs depending on whether water is allocated by public administration, opportunity cost pricing, or tradable rights. These alternate structures may be worth studying and pursuing; however, this paper focuses exclusively on the potential establishment and functioning of a tradable permits market. Regardless of prior existing institutional structures, the most efficient method of allocation is via water rights trading
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(Rosegrant 1994). This is contingent, however, on the possibility of establishing a market of any kind for water rights. Broadly, failures arise primarily from qualities inherent to water and thus are difficult and costly to remediate. The high transaction costs of legal restrictions and market establishment have therefore precluded creation of a market up to this point in time.

1.3 Research Questions and Contributions

This paper proposes the creation of a water transfer market in the Upper Basin utilizing a costs minimizing approach, by minimizing costs of water saving and water trading including transaction costs. A market approach would allow water allocation to be based not only on appropriation laws and supply conditions, but also on demand, defined as willingness to pay by various users. It has been found that markets for transfers are the best available option for managing water allocation. Current legal structures impose transaction costs well above optimal levels and the externalities generated by pure public ownership are prohibitive.

This paper creates several new contributions to the natural resource and water economics literature. Firstly, it provides a comprehensive and synthesized framework for evaluating the success of water markets, which may serve also as a framework to evaluate the aspects necessary to establish a water market in the Upper Basin in the future. Second, it provides a thorough discussion of the role of transaction costs as they uniquely impact establishment of a water market in the Upper Basin. Finally, it examines the impact of those transaction costs on trading outcomes and prices.
The structure of the paper follows directly the sequence of the research questions listed above. Section 2 discusses the reasons why water is not a normal market good and the economics of water allocation. Section 3 details the structure of water markets, discusses the framework for assessing successful water markets, and uses this structure to evaluate the proposed market for the Upper Basin. Section 4 examines the role of transaction costs in establishing water markets and discusses the impact of transactions costs on trading in the Upper Basin. Section 5 explains how transaction costs will affect the outcome of a market for tradable permits using a numerical simulation of a water rights market for the Upper Basin. Section 6 will conclude the paper and discuss overall findings.

2. The Economics of Water Allocation

2.1 Water as a Non-Standard Commodity

The physical characteristics of water, described in this section, make it a nonstandard commodity, giving rise to the public good problem and externality problem, which will be discussed next. The supply of water is determined by the hydrologic cycle and is therefore ultimately not controllable via human systems. Human processes can impact the short-term availability and deliverance of water, but not the overall supply. This is much different than most market goods, whose production may be increased or decreased in response to changes in demand.

Therefore, the risk of non-deliverance in dry years is one of the many risks of water markets arising from the inherent physical properties of water. While extensive
channelization and built infrastructure exists to control the flow of water, it is not ultimately controllable.

For many users of water, the benefit received is dependent on the quality of the water, which may be altered by natural and anthropogenic processes. While water rights attempt to describe the quality of water an individual or firm may be promised in a given year, there is no guarantee on that quality. In markets for private goods, consumers have unique ownership of the good they purchase and thus degradation of others’ goods has no impact on the quality of the good held by anyone else. This is not true of water, where changes upstream may degrade the quality, and thus value, of water downstream.

Finally, not all uses of water are consumptive. Markets for private goods function on the premise that the market price equals the marginal benefit accrued to a purchaser of a good. This does not always hold for water as, for example, in-stream uses have recreational value and industrial processes may use non-consumptive once-through methods (Chong and Sunding 2006).

In order for a water market to exist, therefore, modifications to the standard market assumptions must be made. The high-risk, high-externality nature of water trades generates significant transaction costs, which must be mitigated through unique institutional and legal structures.

2.2 Using Economic Theory to Explain the Non-Optimal Allocation of Water

2.2.1 Public Goods
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Economic theory delineates primary categories of goods based on their properties of rivalry and excludability. Private goods (those which are excludable and rival) can be efficiently allocated through markets while pure public goods (those which are non-excludable and non-rival) are efficiently allocated by public agencies such as governmental offices. Water has both public good and private good features.

A good that is rivalrous in nature cannot be simultaneously consumed by two parties, while a unit of a non-rival good can be distributed to two or more parties without incurring additional per-unit costs of production and without violating the integrity of the good. When an agricultural operation irrigates land, the water taken up by crops on that land is no longer available for any other use, designating that use as rival. On the other hand, if a tourist pays to be taken on a white-water raft excursion, they do not preclude any other visitors from enjoying the water on the same stretch of river, as they are making use of water in a non-rival manner.

A party that owns a good that is excludable in nature can prevent others who have not paid for the good from benefiting from its use. Managed water is excludable; existing laws protect water users by delineating who may and may not consume certain quantities of water. A ditch company is prohibited from drawing excess water into their managed waterway, as this would constitute theft from other users (Colo. Rev. Stat. § 37-84-108). However, non-consumptive use of free-flowing water is non-excludable; for example, homeowners benefiting from the increased property values attributed to proximity to water cannot prevent any other individual from accruing similar benefits (Freeman 1979). As a consumable commodity, water may be wholly owned by an entity that obtains water for private or commercial use. As a public and environmental good, water is a shared
resource. Water therefore does not fit neatly within the standard matrix that defines economic goods. The markets that distribute water are obliged to be similarly unique.

In order to increase the efficiency of the allocation, an emphasis must be placed on the non-consumptive and social benefits of water that tend to be ignored in market transactions. Even where limited transfers do take place, in-stream and public flow values tend to be undervalued, creating inefficiencies which may be remedied by substituting economics for politics (Howe 1986). A typical market transaction is carried out at the price where a private buyer’s willingness to pay equals a private seller’s willingness to accept; this price is not an adequate reflection of the value of water when social non-consumptive values are ignored.

A unique and significant feature of water as a resource is therefore that its markets may not be driven by scarcity as per the neo-classical supply and demand model, but are rather strictly controlled by the institutional structures present before the evolution of the water market (Carey 2001). Markets thus should be established with the aim of optimizing long-term functionality, rather than short-term allocation.

2.2.2 Externalities

Externalities, perhaps the most common type of market failure in environmental economics, are impacts generated by a market activity that affect third parties who were neither a buyer nor seller in the transaction. An externality is any impact created by a market transaction that benefits or harms an individual or firm not party to the transaction. Externalities therefore are not represented in market prices. In a market where externalities exist, the market allocation will be inefficient. While externalities can
be internalized through government regulation of markets, over-regulation can generate market failures.

In the market for a good with externalities, marginal social benefit (MSB) does not equal marginal private benefit (MPB). MSB is the total benefit accrued to society through the use of a good or service, while MPB is the benefit accrued only to the individual or party purchasing that good or service. Market prices are determined by the intersection of MPB and marginal private cost (MPC); that is, the willingness to pay of one party is equal to the willingness to accept of the party offering the sale. In a market with positive externalities, the MSB is higher than the MPB. For example, in-stream flow of water allows for ecosystems to flourish, property values to rise, and benefits recreational users. None of these aforementioned parties typically enter into market transactions when they use water. Their benefit is reflected in the MSB and not MPB of any transaction. For the market as a whole, willingness to pay of all individual users that typically participate in the market are summed up to MPB. MSB includes MPB plus the values accrued to all other users of water.
Figure 1: Graphical representation of the difference in market price and value of good or service in the case of a positive externality.

Figure 1 shows the case of a positive externality with water supply in the market fixed in the short run. The intersection of the supply (marginal private cost) and demand (marginal private benefit) curve determines $P_p$, the market price. The market price is the only price observed and is common to all users. Because water generates benefits beyond those that are captured in market transactions, $MPB$ is less than $MSB$. This means that, at a given quantity of water, the price of sales will be too low because the market price will not reflect the external, non-market benefits associated with water. The difference between the private market price and the socially efficient price ($Ps$) is the marginal external benefit (MEB). The MEB equals the value of those benefits, such as recreational and habitat benefits, that are not included in market transactions. If the market price charged is $P_p$, total demand ($MSB$) exceeds supply, indicating inefficiency.

In addition to the economic issues of public goods and externalities that arise from the unique characteristics of water, the existing legal structure further exacerbates the non-
optimality of current water use in the Upper Basin. This is discussed in detail in the following section.

2.2.3 Legal Structures as a Barrier to Efficient Allocation

Perhaps the most obstructive of the numerous transaction costs to water market establishment stems from the legal framework currently in place in the American southwest. Historical provision of water was carried out by legal rather than economic mechanisms and the structures currently in place reflect outdated and inefficient systems of allocation. Establishment of a water market in the Upper Basin requires understanding and negotiating the heterogeneous water laws of the five Upper Basin states. Throughout the Upper Basin, the primary legal framework determining current allocation is prior appropriation (USBR 2012). This system allows the initial diverter of a quantity of water to maintain a senior right to that annual volume in perpetuity. Prior appropriation requires that the quantity appropriated be withdrawn annually and put to beneficial use; any unconsumed quantity can be reclaimed by the state as a public resource to be reallocated (Chong 2006). Many of the first users of water in the developing West were mining and agricultural operations. These entities retain a majority of the senior water diversion rights throughout the region. Municipalities tend to hold junior water rights; their dates of initial allocation are more recent than those for senior rights. Allocation of water from the Upper Basin to municipalities is often uncertain because prior appropriation dictates that in years of reduced river flow, junior rights holders must forgo their allocation if it would hinder senior rights holders from obtaining their full volume of water. As the West develops, population centers are growing and the region's primary economic interests are
shifting. The historically driven prior appropriation system is inefficient in the modern era (Chong 2006). Status quo entrenchment and the political clout of the mining and agricultural industries in the West render market establishment exceptionally difficult, however; the alternative is a decrease in the environmental health and habitability of the West.

Figure 2: Hypothetical demand curves and allocations under legal versus trading scenarios. Adapted from Chong 2006. The unit MAF indicates million acre-feet of water.

Because of the history of development in the American southwest, the majority of senior rights holders are agriculture and mining operations (left hand panel of Figure 2), while municipalities hold the majority of junior rights (right hand panel of Figure 2). Under the scenarios presented in Figure 2, without trading, the total sum of consumption by senior rights and junior rights holders will equal the total supply available, equal (in this example) to 7.5 MAF, composed of 4 MAF of consumption by senior rights holders and 3.5 MAF of consumption by junior rights holders. Senior rights holders may consume up to point A, where water is valued at price PA, while junior rights holders consume at point B, where water is valued at price PB. Under this scenario, the last unit of water consumed by junior rights holders is of higher marginal value than the final unit
of water consumed by senior rights holders: PB > PA. When water is not traded, these prices are not observed on any market, as they are not prices paid but represent instead two different values of water. This is the current situation given the legal framework and is an inefficient allocation.

3. Solving Misallocation with a Market for Water

3.1 General Market Structure

Water markets may exist as either spot or forward markets and may lease or sell short-term, long-term, and permanent water rights (Carey 2001). Spot markets allow water to be purchased at a current market rate for immediate transfer while forward markets use contracts to organize transfers of water to occur in the future at an agreed upon rate. In addition to the timing of the transfers, buyers and sellers may choose the duration of the transfer (Howe 1986). Short-term leases may last for only a season, while long-term leases may last for several years. A sale of a water right is a permanent transfer from one water user to another (Rosegrant 1994).

Current owners of water rights are included in the market as both sellers of those rights and potential buyers of additional allocations. Parties who are not currently consuming water may also enter the market as buyers of water rights. Water rights exist as a permit to withdraw and utilize a specific volume of water. Water rights also are delineated by seniority based on the year of their issuance (Colby 1988). In years of reduced flow volume, senior rights holders have a priority on their allocations. Junior rights holders may only withdraw a portion of their water or may not withdraw any at all,
depending on their standing and the withdrawal volumes of the more senior rights holders.

Existing economic structures are designed to accommodate the distribution of either public or private goods. Private goods (those which are excludable and rival) can be efficiently allocated through markets while pure public goods (those which are non-excludable and non-rival) are efficiently allocated by public agencies such as governmental offices. The market for water must combine aspects of both of these distribution mechanisms by creating “a governance structure capable of administering the rules while not determining outcomes.” (Slaughter 2009) This means that all interested parties must be free to trade water on an open market but a public agency must set legally binding guidelines regarding limits to trade in order to protect collective social and environmental interests. Policies must be flexible enough to accommodate evolving social and environmental conditions but must be stable enough to not create uncertainty in present transactions. The need to adapt current knowledge of market structures to the physical limits of water generates exceptional transaction costs.

The non-standard commodity nature of water, the physical infrastructure required to convey water, and the legal structure of water law create barriers to market establishment above and beyond the typical transaction costs of information and negotiation, which are also present. While the costs associated with these barriers are high, they are not insurmountable. If the root causes of the costs are understood they may be appropriately addressed in order for the costs to be minimized. Minimizing transaction costs is a prerequisite to market establishment.
Once trading begins total supply is still fixed but now each user is not facing a fixed individual allocation but instead has the option to either buy or sell water. The following assumptions are held: there is currently a shortage of water in the municipal markets and a surplus of water in agricultural markets. Water follows the law of diminishing marginal returns; therefore for agricultural operations that consume very large quantities of water, each additional unit is less valuable to them than it is to a household who is consuming relatively few units of water. Individual consumption comprises a larger portion of total urban consumption in comparison to agricultural consumption; therefore supply is more elastic for agricultural operations than it is for municipalities.

By allowing trades to occur, a common market price is reached which allows the surplus in one area to be sold to cover the shortage in the other and for the market to reach equilibrium through the common trading price. In Figure 2, the horizontal distance A-A’ represents the volume of water sales by agricultural and mining users, while the horizontal distance B-B’ represents the volume of water purchases by municipal users. The two distances must be equal to each other to maintain the same fixed supply of 7.5 MAF. Junior rights holders are willing to pay for water up to a price PA and senior rights holders would be willing to sell water for any price above the minimum of PB. This difference in marginal value allows for the possibility of mutually beneficial trade. With trading, the market converges to a single price P*, where willingness to pay and willingness to accept are equal. After trading, senior rights holders consume at point A’ while junior rights holders consume at point B’. The total volume of water consumed has not changed, however its distribution amongst users has changed. Because the marginal
benefit of the final unit of water consumed is the same value across users, this is an efficient allocation. The current legal systems in place hinder the ability of water users to reach this system of allocation.

3.2 Framework for Evaluating a Water Market in the Upper Basin

The Bureau of Reclamation recently completed the most comprehensive analysis undertaken to date of the supply/demand disparities in the Colorado River Basin. The resulting paper, the Colorado River Basin Study, identified the immense potential benefit that may result from the creation of a successful market in the Upper Colorado River Basin (USBR 2012). This study discussed some of the barriers to development of a market and acknowledged that these barriers must be overcome for the future health of farms, cities, and ecosystems in the Basin. The study did not identify how such a market should be created, but rather simply stated that it must be done.

In order to assess the success of the market structure in its ability to minimize transaction costs and allow trading to proceed, a structure for the evaluation of market success must be determined. Because water markets are unlike traditional private goods markets, their success must be measured on different and more numerous variables. A water market is designed to simultaneously maximize the welfare of all market participants while also accounting for third party and non-human impacts. Three general frameworks for water market evaluation are used and integrated in this section to assess the proposed market for the Basin.

The first structure comes from Grafton 2010, and offers perhaps the most thorough structure for the evaluation of water. This study developed a 26-point framework for the
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assessment of water markets. This framework allows for the comparison of markets on the merits of their institutional underpinnings, economic efficiency, equity, and environmental sustainability. Classifying markets in this way allows specific characteristics of water markets to be identified that lead to success or failure of management. A sustainably effective water market should meet most, if not all, of these standards. This structure for the evaluation of successful water markets is presented in detail in Appendix A.

Second, integral to the success of the water market is the clear, actionable definition of water rights. If the rights themselves do not exist in clear, full, functional manner, there can be no basis for trades. An additional structure for evaluation, following Le Quesne et al. 2007, focuses on the parameters that must be included in descriptions of well-defined tradable water rights. Well-defined and legally defensible rights are a prerequisite to market establishment and therefore are an important subset of the overall framework of market evaluation. These parameters are listed in full in Appendix B.

Third, the Helsinki Rules, non-binding guidelines regarding the use of international waters adopted by the International Law Association in 1966, provide a framework for evaluating the equity of allocation. Per Article V of the Rules, entities are entitled to “a reasonable and equitable” share of water which passes through their territories (Rules 1966). While the Helsinki Rules focus on the equity concerns of cross-basin water transfers, many of the elements enumerated are relevant to ensuring the equity of any water transfer. Many of the same issues may arise whether a transfer is inter-basin or intra-basin and thus equity must be included in the evaluation of any market, regardless of its boundaries. The criteria to consider when determining such a share include, but are
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not limited to, the list presented in Appendix C.

Finally, an additional consideration comes from the work of Carey 2001. While this study did not produce an evaluative framework, the comparative analysis of the Colorado-Big Thompson and California Central Valley Project found that “the institutions that exist today, and thus the differences in water market development, are a legacy of the initial institutional structures established during the formative stages of each project” (Carey 2001). Moving forward, it is therefore critical that market structures be assessed before implementation so that potential failings can be addressed, restructured and avoided. A key point of market assessment is whether or not the market structure seems suitable to the long-term successful and efficient allocation of water rights. Markets that are designed to target a single short-term goal are not sustainable in the long run. Water markets must therefore be structures in which the system, rather than a particular outcome, is paramount and the structure is adaptable to changing boundary conditions. This aspect of market design must also be considered in evaluating the proposed market.

In order to evaluate the proposed Upper Basin market, a synthesis of the above theories is necessary. A unified framework for the evaluations of water markets is created and is presented in full in Table 1.
Table 1: Framework for the evaluation of a water market to be used to evaluate the simulated water market for the Upper Basin.

**Market Structure: Legal, Economic, and Institutional Reform**

1. Well defined and legally enforceable water rights which delineate
   a. Quantity available for use and quantity required as return flow, if applicable;
   b. Duration of use permitted;
   c. Quality of water, particularly as return flow;
   d. Sources from which the water is drawn;
   e. Timing of permitted withdrawals, including any seasonal restrictions for environmental purposes;
   f. Price of the water right itself and transaction costs;
   g. Limits to use, if applicable;
   h. Ownership extent and transfer capabilities.

2. Accessibility, reliability, and stability of market price information

3. Legal and administrative clarity

4. Conflict resolution mechanisms

**Efficiency of the Market and Allocation**

1. Allocation of water to highest benefit users

2. The avoidance of unnecessary waste in the extraction and use of water

3. Market thickness

**Social Equity and Environmental Concerns**

1. The degree to which the needs of a user may be satisfied, without causing substantial injury to another user

2. Provision of basic human needs

3. Recognition and minimization of third-party impacts

4. Water quality considerations regarding ecological needs and downstream user needs

The criteria presented here will be used to evaluate the simulated market to the fullest extent possible, given that some uncertainty in impacts will remain as long as there is no functioning market in existence in the Upper Basin.
3.3 Analysis of the Proposed Upper Basin Market

The design of the market is such that it meets the criteria for optimal market design and allocation of water as enumerated by the evaluative framework. Of the eleven points of the framework, this market design explicitly addresses each. This is of critical importance, as the implementation of a market might only occur if stakeholders can be assured that the impact of the market would be a more efficient allocation of water in the Upper Basin.

First, a prerequisite for market success is the reformation and improvement of understanding regarding water rights. All water rights must be defined by the eight criteria listed here before they can be posted for sale. More explicit definitions of existing water rights would aid in the process of transferring those rights. This will require work on the part of the administrative agency in charge of the market. Most likely, this agency would be the Bureau of Reclamation as it currently manages a majority of water in the west. While their work thus far has focused primarily on built infrastructure, their institutional knowledge of water allocation operations is suitable to redirection towards water marketing.

Second, the collection and centralization of price data will improve accessibility of information for all market users, thus facilitating ease of future trades. Australia’s Murray-Darling Basin has one of the world’s foremost functioning water markets. The Basin Authority employs an independent consulting firm to collect data on prices quarterly and make this information available to the public online (Carr et al. 2016). A similar approach would be feasible and beneficial in the Upper Basin. Ambiguity in existing use leads to uncertainty regarding the potential impacts of trading a water right.
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This may require more precise data collection on the part of mutual ditch companies, municipalities, and private users in order to understand the precise quantities and timings of water consumption.

Third, market establishment will necessarily entail moving away from the provisions of prior appropriation, which have created legal and administrative murkiness and economic inefficiency. While the legal proceedings necessary to permit such a change are beyond the scope of this paper, such a change is no doubt possible, given that individual one-off trades have occurred throughout the west already (Water Transfer Data Base 2008).

Fourth, conflict is reduced when water is allocated by economic rather than legal mechanisms, as trades are pre-negotiated and mutually beneficial, resulting in a decreased incidence of disagreement requiring litigation. However, a system for conflict mediation should be established through the governing agency, USBR, to accommodate any disputes that may arise.

Fifth, the principle that water should be allocated to the user who will benefit the greatest from its use will be achieved through the process of sales, which inherently ensure that water users who value water most highly receive it. There may be issues that arise regarding the high marginal benefit associated with in-stream recreational activities. These users do not purchase water but would rely upon municipalities and environmental groups purchasing water for instream flow. Municipalities are likely to carry out such activities as recreation is an important driver of economic activity in many Upper Basin communities, thus purchases of water that preserve or enhance opportunities for recreation will be beneficial to those communities.
Sixth, the avoidance of unnecessary waste in the extraction and use of water will be accomplished by necessitating water saving in order to realize water trading means that water use efficiency will be improved. Users with high rates of consumption will have a newfound incentive to use water more conservatively. High market prices will also encourage efficiency amongst purchasers of water who will be less likely to waste water when they are paying more highly for it. This reduction in waste through reallocation can be seen in the rates of savings occurring in agriculture in the simulation presented in Section 5.

Seventh, market thickness will be achieved by the collection and centralization of information regarding market trades will improve availability of information for all, thereby facilitating market entrance for an increased number of users. This may be done by the independent consultant who is also entrusted with the task of collecting and publishing water price data.

Eighth, avoiding harm to other users through area of origin impacts and other similar harm may be avoided by capping total permissible transfer volume at 15% of initial use (Chong and Sunding 2006).

Ninth, by allowing municipalities to purchase Upper Basin water, they may be able to provide water to their citizens at a cost lower than that which would be demanded by high cost inter-basin transfers, thus meeting basic human needs at a lower cost.

Tenth, in the case of a good that generates externalities, the creation of a market allows the social value of the water, including recreational, ecological, and cultural values, to become endogenous to the price, thereby reducing externalities. Recognizing these third party impacts and ensuring adequate flows for recreation and habitat concerns
will be within the purview of the managing agency. Preemptive recognition of the implications of environmental law would also prevent suits under the Endangered Species or Clean Water Acts. These laws are some of the foundational guides to the methods by which we as a nation respect non-human biota and the abiotic environment, both for our own benefit and their intrinsic values. Water transfer contracts should delineate how the proposed sale would impact the natural world and how the buyer and seller propose to address any potential impacts. If this work is done thoroughly enough, parties to the contract should have no fear of later suit on the grounds of violating these laws.

Eleventh, a planned market with adequate information regarding all aspects of trade will allow users to be better informed on their impacts and obligations regarding down stream and Lower Basin users. This will allow water quality considerations regarding ecological needs and downstream user needs to be negotiated prior to trade. More explicit understanding of current consumption would allow third parties to better understand if their allocation would be harmed by a transfer, without adjudication.

Overall, the resulting impacts on the economy and ecology of the Upper Basin will be determined by the heterogeneous responses to water reduction chosen by water users (Sunding et al 2002). Some farmers may choose to reallocate lands amongst crops of various water needs while others may rotationally fallow lands, both methods allowing for reduced consumption overall. Others may choose to maintain current crop distributions and aim to achieve the same yields with less water by improving irrigation technology. Efficient irrigation technology has long been in existence, but the costs of installation and maintenance have been prohibitive while low costs of water have
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provided a disincentive to invest in improved technology (Chong and Suding 2006). Farmers who choose to sell water will find themselves with an unprecedented incentive to conserve as well as a source of revenue to fund the purchase of technology that makes conservation possible. While not widely available in the Upper Basin, groundwater is a resource to which some water users may turn. Increased pumping of groundwater combined with sales of surface water permits may increase total water consumption and thus have a counterproductive, negative environmental impact. It is not the place of market managers to dictate how water should be made available for sale. While there are clearly preferable methods for environmental and social reasons, farms should be free to pursue the lowest-cost method available to them. While that decision in some cases may generate less external benefit than another option, the total social and environmental benefit derived from water market transfers will still be positive. Efficient allocation would allow municipalities in the Upper Basin to obtain their water from the Colorado River, preempting the need to create more costly, environmentally destructive cross-basin conveyance systems.

4. The Role of Transaction Costs in Establishing Water Markets

This section has two primary objectives. First, to describe the literature on transaction costs as they pertain to water markets. Specifically, the aspects of water markets discussed in the framework presented in Table 1 (Section 3.2) that generate transaction costs will be highlighted. Second, to show which transaction costs may occur in the Upper Basin market. Relevant transaction costs from the literature will be discussed as they pertain to the Upper Basin. This will give rise to the inclusion of
transaction costs in the quantitative simulation of the market for water transfers in Section 5.

### 4.1 Economic Theory of Transaction Costs

The combination of the legal, institutional, and economic barriers to market establishment have led to a historical difficulty in effective creation of functional water markets. The rarity of existing water markets can be attributed in large part to the high transaction costs of market establishment. This is why the framework generated is of such high utility. Minimizing transactions costs prior to market establishment may facilitate later success. When transaction costs are high, fewer parties are likely to enter the market. Without a large number of willing buyers and sellers, too few parties will be able to find a counterpart with whom to carry out a mutually beneficial transaction. In water markets in particular, a lack of market thickness has led to market failure (Simpson 2005). The full compendium of transaction costs that would impact a market for water transfers is itemized in Appendix E; this condensed framework presents four categories of costs and nineteen distinct transaction costs that will be faced by market participants.

Firstly, the delivery of water requires a complex system of conveyances to ensure that the water promised by a right can actually be obtained. Before a transfer can take place, “the physical infrastructure needed to convey or exchange the water from the existing user to the new user must be in place, and all infrastructure owners must be included in transfer negotiations” (Reclamation 2012). It is not enough to transfer a water right on paper. Because of the natural variations in water availability, a transfer of water is not as simple as for most market goods. The negotiation that must occur in order to
understand the impacts of a trade on both trade participants and third parties thus poses high transaction costs. A water right refers to a specific volume of water but could not realistically refer to certain molecules of water. This therefore necessitates the development of reliable conveyance systems so that market participants are able to trust that the agreed-upon quantity will actually be delivered, to the extent humanly possible.

Secondly, in the creation of many new markets, lack of information poses substantial transaction costs. A market without informed participants will quickly fail. Buyers and sellers must be equipped with complete, symmetric information. If one party to a transaction has superior information in comparison to the other, a potential for manipulation results. Information regarding market regulations, previous transactions, and hydrologic conditions (historical, present, and projected future) must all be readily accessible. By removing the difficulty of accessing such information, a substantial transaction cost of market development would be reduced. Before market establishment however, systems of data collection should be put in place so that sufficient data are available once transactions begin to prevent disputes (Wolf 1999).

These transaction costs impact the price of water rights. The presence of high transaction costs in a market will increase the total cost associated with water rights trading (buying or selling) beyond the technological costs of water saving, and therefore would increase the price of water rights and thereby reduce the volume of trades that will occur. Therefore, in order to improve the efficiency of allocation by increasing the volume of water traded, transaction costs must be minimized.

The issues highlighted above are the primary transaction costs of water market establishment. Minimization of transaction costs is a necessary precursor to market
establishment. The failure of other water markets to come to fruition may be attributed, at least in part, to an inability to properly minimize the magnitude of these barriers to market establishment.

Because market participants are geographically dispersed throughout the Upper Basin, it would be inefficient for the market to require parties to find one another in person. An online clearinghouse would allow market thickness to develop. An online format would also allow for the information regarding the market and market transactions to be widely and freely available.

In the allocation of water, transaction costs should be reduced but not eliminated. The presence of some transaction costs would serve as a Pigouvian tax to aid in internalizing the social costs of private water use (Colby 1990). The market administrators, by allowing some transaction costs to persist in the market, would be able to effectively impose this tax. The benefit derived from some limitations to total trade volume should be built into the market design. The numerous non-consumptive social and environmental benefits of water are not adequately represented in market transactions. Potential externalities of trading may negatively impact these valuable services.

The speed with which a transaction occurs is a potential source of high costs as well as a clear example of the benefit of maintaining some transaction costs. Transactions which occur over an exorbitantly long timeframe may, in the case of a lease contract, effectively render no benefit to the buyer who may have needed water at the time negotiations began but would, by the time negotiations concluded, no longer willingly enter the market. Clearly, transactions must run more smoothly than this. Preexisting
administrative guidelines for the approval of leases and sales would allow for a more efficient process. Due care must be given to each transaction to ensure that the proposal would not harm other users. There must remain, therefore, a slight transaction cost in the form of time devoted to approval of sale. This cost would allow the market to promote social equity and environmental concern.

Water resource management requires balancing “economic efficiency, social equity, and the environment.” (Chong 2006) Market structures that impose some well-designed transaction costs therefore may serve to protect the social and ecological quality of the Basin.

4.2 Transaction Costs in the Upper Basin

The types of transaction costs that would be faced in the Upper Basin fall into the categories of: legislative environment including defining policy goals, authorizing, and enabling legislation; administrative overheads including public consultation and education; defining the commodity and exchange rules; and implementation and program operation. These categories contain numerous specific transaction costs that will increase the market price of water and render market establishment more difficult.

Redefining the legislative environment in the Upper Basin poses substantial transaction costs to market establishment. Agricultural, municipal, and industrial users, as well as environmental and recreational advocacy groups, will be interested in understanding how revised legislation authorizing and expanding trading procedures would impact their own water use. The uncertainty that will arise until the implications of
the legislative environment are well understood will hinder progress towards market establishment in the Upper Basin.

Similarly, agricultural, municipal, and industrial users will seek to understand and influence the administration of the market as it pertains to their own use. Programs to inform users of expected changes and implications will be necessary. Depending on their perceptions of changes, users may seek to shape the administrative process to their own favor.

Users will further need to have a comprehensive understanding of the trading system and exchange rules. This will pose transaction costs to both market establishment and trading allocations. Clarity of market understanding overall must precede market establishment, while clarity of understanding individual trades will be necessary on each transaction. The education and negotiation necessary to achieve those goals will pose transaction costs.

Finally, implementation of trades will pose transaction costs on trading in the Upper Basin. Agricultural, municipal, and industrial users will first need to evaluate their own market position given the opportunity to buy or sell. Participants must decide if they would like to save and sell or buy water rights. Participants must then be able to find suitable exchange partners who have complementary wants. Finding partners for trade and implementing trades may require USBR coordination.

Many of these transaction costs must be minimized before the market can be established. One of the most common and pernicious transaction costs comes from a lack of information or asymmetric information between buyers and sellers, which can be seen as an aspect of many of transaction costs enumerated in Appendix D. There is currently
no centralized database providing all market users with the information they may need to carry out an informed trade. Such a system must be put in place before trade begins in order to assure that all users are adequately and equally informed.

The legal system further requires that in order for water sales contracts to be effective and legally binding, clear and enforceable property rights regarding water must be antecedent. Existing and now-defunct water markets have been significantly hindered by legal battles (Colby 1988). Third parties, including environmental and recreational advocacy groups, hold an important right to bring potential water transactions to court if they feel that the sale would cause them direct harm. This is a valuable resource for many water rights holders who could potentially be negatively impacted by a reduction in quantity or quality of their water if a sale improperly alters a flow of water. This right, however, also imposes extremely high transaction costs on market allocation of water as any transaction could be brought to suit (Colby 1990).

In order to prevent future market failure in the form of lawsuits on each transaction, comprehensive general property rights of water must be clarified. As discussed in the above section regarding allocative structures, water is neither a purely public nor purely private good and thus defining its ownership wholly under either of those structures would be inefficient. A clear system of water rights must be outlined which addresses the unique characteristics of water. Systems of understanding and managing anticipated third-party impacts must be built into the market in order to avoid substantial legal problems during transactions. Water quality and quantity requirements set in place by the Endangered Species Act and Clean Water Act should be accounted for within the structure of the market. Formulating a generalized system by which to preemptively deal
with third-party impacts would prevent the market stagnation that may occur through exorbitant legal proceedings.


This model simulates a potential market for water transfer in the Upper Basin and shows the potential impact of transaction costs on market prices and trading outcomes. This model seeks to minimize transaction costs arising during trade. This includes institutional and administrative transaction costs of trade execution. This simulation model is adapted from Wang (2012), which created a simulation of market trading with transaction costs for the Yellow River Basin. The Wang model has two users, an agricultural sector and an industrial sector, in eight provinces, for a total of 16 unique water users. Users are able to save or consume water based on their unique technological cost of saving water, exogenously set transaction costs and any trade of excess savings with any other user. Province-specific and user-specific quotas and water saving costs determine the highest potential consumption for each user in this model. No such quotas exist in the Upper Basin; therefore that aspect of the Wang model is not reflected in this study’s model.

5.1 Structure of the Model

This section adapts the model of Wang (2011) for water users in the Upper Basin by simulating the prices and water saving volumes occurring with varying transactions costs. For each of the 47 counties of the Upper Basin, three users types exist: agriculture, municipal, and industrial. The model therefore represents the actions of 141 unique users.
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Each user independently faces the choice to consume their full allocation of water, reduce consumption and sell the excess, or consume beyond their allocation by purchasing another user’s surplus. Water savings (r) may be positive or zero, if \( u_0 - r < u_1 \); the user must buy water in order to consume at the volume \( u_1 \). The decision to buy or sell rests on the user’s cost of saving water (c), the price of water on the market (p), and the transaction costs faced by the user (t). Both buyers and sellers of water will face transaction costs.

The model is a multi-user cost-minimization problem, essentially a social planner’s problem. The social planner seeks to minimize all the costs associated with water savings and trade for all users \( y \) in all counties \( j \).

\[
\min K = \min_{p, c} \sum [(C_{yj}(ryj) + P(uyj - ryj) + T(uyj - ryj))] \quad (1)
\]

The first term, \( C_{yj} \), represents the cost of saving water through improvements in water use technology. It is directly proportional to \( ryj \), the volume of water saved. The second term, \( P(uyj - ryj) \), is the price of a market transaction. The price is positive for a buyer of water, representing the price paid for the water right, while the second term is negative for a seller, indicating the income received by selling a water right. The third term, \( T(uyj - ryj) \), represents the transaction costs incurred. Transaction costs of trade are proportional to the quantity traded and therefore \( T \) is proportional to the absolute value of \( (uyj - ryj) \), as both buyers and sellers incur transaction costs. In order to find the cost-effective level of savings, each user must choose the level of savings that minimizes total cost, which involves taking the derivative of (1) with respect to with respect to \( ryj \), yielding:

\[
\frac{dk}{dr_{yj}} = \frac{\partial c}{\partial r_{yj}} - p + \left| \frac{\partial T}{\partial r_{yj}} \right| \geq 0 \quad (2)
\]
Further, for each user in each county:

\[ r_{yj} \left( \frac{\partial c}{\partial r_{yj}} - p + \left| \frac{\partial T}{\partial r_{yj}} \right| \right) = 0 \]  (3)

Users may choose to not save water, making \( r_{yj} = 0 \) if \( \frac{\partial c}{\partial r_{yj}} - p + \left| \frac{\partial T}{\partial r_{yj}} \right| > 0 \) or they may choose to save some positive volume of water (\( r_{yj} > 0 \)), in which case the MC of saving (\( \frac{\partial c}{\partial r_{yj}} \)) would equal the net MC of trading (\( p + \left| \frac{\partial T}{\partial r_{yj}} \right| \)).

The total sum of water saved by all users in all counties must be greater than or equal to a policy determined target level of savings for the entire basin (\( X \)). This can be expressed as:

\[ \Sigma r_{yj} \rightarrow r_n \geq X \]  (4)

Further, transaction costs must be restricted to within reasonable bounds, derived from empirical data, expressed as a fraction of price. The treatment of transaction costs in this study differs from Wang (2011) who sets exogenous values of transaction costs.

The upper bound, \( K \), must exceed the lower bound, \( k \).

\[ Kp \geq t \geq kp \]  (5)

Finally, each user in each county then has unique bounds on their water saving target (\( r \)):

Lower bound \( i_j \leq r_{ij} < \) Upper bound \( i_j \)

Lower bound \( a_j \leq r_{aj} < \) Upper bound \( a_j \)

Lower bound \( m_j \leq r_{mj} < \) Upper bound \( m_j \)  (6)

Given the model above and the first order conditions, the solution will involve a user and county specific savings level, \( r_{yj} \), provided that water savings costs are unique
for each user in each county (as in Wang 2012), and provided that there are county-specific savings target for each user as in Wang (2011). If so, there will be a single price that would apply to all users, regardless of whether they are buyers or sellers of water rights. The section below adapts the model using data specific to the Basin.

5.2 Applying the Model to the Upper Basin

For each county, there are three users of water such that the index y will refer to either an industrial (i), agricultural (a), or municipal (m) user. Agriculturak current use is a sum of all withdrawals for aquaculture, livestock, and irrigation (minus irrigation for golf courses). Municipal current use is a sum of all withdrawals for public supply and domestic self-supplied use. Industrial current use is a sum of all withdrawals for mining, thermoelectric (once-through and recirculation), irrigation for golf courses, and industrial self-supplied use. The user equations are therefore now individualized as follows:

The user-specific cost-minimization problems are as follows:

\[
\min_p, r_i \sum [(C_{ij}(r_{ij}) + P (u_{ij} - r_{ij}) + T (u_{ij} - r_{ij})] \\
\min_p, r_a \sum [(C_{aj}(r_{aj}) + P (u_{aj} - r_{aj}) + T (u_{aj} - r_{aj})] \\
\min_p, r_m \sum [(C_{mj}(r_{mj}) + P (u_{mj} - r_{mj}) + T (u_{mj} - r_{mj})]
\]

(1')

where \(r_{aj}\) is the amount of water saved in that county’s agricultural sector, \(r_{mj}\) is the amount of water saved in that county’s municipal sector, and \(r_{ij}\) is the amount of water saved in that county’s industrial sector. The rest of the terms with "yj" subscripts represent user-county specific versions of the same variables already defined above.

The costs of technology for water saving for each user type are taken from the lowest cost technology types provided in the USBR Basin Study. For municipalities, this
ranges from $1,500 per acre-foot annually for non-potable reuse to $1,800 per acre-foot annually for potable reuse. For agriculture, this ranges from $100 per acre-foot annually for improved irrigation scheduling to $800 for conveyance systems improvements. For industrial users, this is $2,000 per acre-foot annually for wastewater reuse. Therefore, using the low-end cost estimates for agriculture and municipalities, the first-order conditions for cost minimization yields:

\[
\begin{align*}
\text{(a)} & \quad 2000 - p + t_{ij} \geq 0 \\
\text{(b)} & \quad 100 - p + t_{aj} \geq 0 \\
\text{(c)} & \quad 1500 - p + t_{mj} \geq 0 \\
\end{align*}
\]

(2′)

Note that in this formulation, each user faces unique transaction costs, reflected by \(t_a, t_m, \text{ and } t_i\) respectively, where \(t_{ij}\) is the derivative of \(T\) with respect to \(r_{ij}\).

Following equation (2′), the following condition must be true for each county:

\[
\begin{align*}
\text{(a)} & \quad r_{ij} (2000 - p + t_{ij}) = 0 \\
\text{(b)} & \quad r_{aj} (100 - p + t_{aj}) = 0 \\
\text{(c)} & \quad r_{mj} (1500 - p + t_{mj}) = 0 \\
\end{align*}
\]

(3′)

If the cost of savings exceeds the income obtained from trade the parenthetical term is positive for a user and hence the user will not save \((r_{ij} = 0)\). The user will save some volume of water \((r_{ij} > 0)\) if the parenthetical term equals zero, as their cost of saving will be equal to the revenue obtained from trade.

Consistent with estimates of water availability in the Upper Basin, the total sum of water saved by all users in all counties must be greater than or equal to 6% of the total 2010 surface water withdrawals by all users in all counties of the Upper Basin. The water withdrawal or usage data for 2010, \(u_0\), represents the baseline use conditions prior to
any potential trade in the future, and is taken from the USGS Water Use in the United States 2010 study. USBR estimates that only 94% of baseline flow will be available by 2025, following the Downscaled GCM Projected Streamflow Scenario presented in the USBR Basin Study. This model also projects a -7.5% change from the long-term mean (1906-2007) will be experienced in 2025 and a -10.9% change from the long-term mean will be experienced in 2055. A 6% reduction therefore represents an interim adjustment to the surface water availability conditions. It does not reflect additional savings for ecological or recreational uses, which would be socially beneficial, but simply compliance with availability of water given projected climate change. Six percent of the total baseline withdrawal is 0.4946 millions of acre-feet per year (MAFY), which is the lower limit of equation (4’)

\[ r_{11} \ldots r_{m47} \geq 0.4946 \]  

\[ (4’) \]

Transaction costs for industrial users must be between 6% and 12% of the trade price. Per Colby 1990, average observed transaction costs in the southwest are equal to 6% of the price of the trade. The highest percentage observed is in Colorado and is 12% of the price of the trade. These therefore create the reasonable bounds for transaction costs. Because there is no available information about how transaction costs may vary across users, this study assumes uniform transaction costs for all users, i.e., \( t_{ij} = t_{ij} = t_{mj} \). which is one of the reasons user-county specific savings rates cannot be solved.

\[ 0.12 p \geq t_{ij} \geq 0.06 p \text{ for all } y = a, i \text{ and } m \]  

\[ (5’) \]

The relationship between price and transaction cost under various scenarios is always positive. This relationship is logical in the case of a water market because each trade may
require unique infrastructure or individual litigation including and beyond the transaction costs of information and negotiation that are expected with all transfers.

Unlike the general formulation however, there is no equivalent to equation (6) that define user-country specific bounds for water savings levels. There are currently no targets for water saving in the Upper Basin.

Thus, there are differences between (5) and (5’) and (6) and the absence of targets in the Upper Basin. In the general model in Section 5.1, user- and county-specific savings rates (user-county observations) are obtained when savings costs and transaction costs are unique for each user-county observation. In that case, the user-county specific bounds, if they are defined would be taken into account when solving simultaneously for user-county savings level, prices and transaction costs (using (1’), to (5’)). However, the data for the Basin does not differentiate savings costs for each user in each county. Further, the savings targets are not specified as they were in Wang (2012), which examined provincial specific goals. There is currently no target for savings at any administrative level of the Upper Basin. Because the Upper Basin users are classified according to their county, which are data reporting units but not administrative units, a county-specific target for each user does not exist, nor would it make sense. Hence, the solution to the above problem would involve only determining prices and the corresponding transaction costs as percentage of the price according to the saving costs (using (1’)). The extent of water savings will be determined by the lowest cost user in the whole system.

The simulation will thus require examining the relationship between prices and transaction costs for varying costs of water savings technology. In addition to the baseline
simulation that is based from the model presented above, five additional scenarios were investigated. They are described below.

Table 2: Description of water market trading simulation scenarios for the Upper Basin.

<table>
<thead>
<tr>
<th>Simulation Scenario</th>
<th>Water Savings Costs</th>
<th>Transaction Costs</th>
<th>Aggregate and Individual Savings Targets</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Low cost of water savings with low savings target</td>
<td>$C_{ij} = 2000$</td>
<td>0.06 p</td>
<td>6% of $u_0$</td>
</tr>
<tr>
<td></td>
<td>$C_{aj} = 100$</td>
<td>0.095 p</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$C_{mj} = 1500$</td>
<td>0.12 p</td>
<td></td>
</tr>
<tr>
<td>2 Higher cost of water savings with low savings target</td>
<td>$C_{ij} = 2500$</td>
<td>0.06 p</td>
<td>6% of $u_0$</td>
</tr>
<tr>
<td></td>
<td>$C_{aj} = 800$</td>
<td>0.095 p</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$C_{mj} = 1500$</td>
<td>0.12 p</td>
<td></td>
</tr>
<tr>
<td>3 Low cost of water savings with mid-range savings target</td>
<td>$C_{ij} = 2000$</td>
<td>0.06 p</td>
<td>7.5% of $u_0$</td>
</tr>
<tr>
<td></td>
<td>$C_{aj} = 100$</td>
<td>0.095 p</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$C_{mj} = 1500$</td>
<td>0.12 p</td>
<td></td>
</tr>
<tr>
<td>4 Higher cost of water savings with mid-range savings target</td>
<td>$C_{ij} = 2500$</td>
<td>0.06 p</td>
<td>7.5% of $u_0$</td>
</tr>
<tr>
<td></td>
<td>$C_{aj} = 800$</td>
<td>0.095 p</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$C_{mj} = 1500$</td>
<td>0.12 p</td>
<td></td>
</tr>
<tr>
<td>5 Low cost of water savings with high savings target</td>
<td>$C_{ij} = 2000$</td>
<td>0.06 p</td>
<td>10% of $u_0$</td>
</tr>
<tr>
<td></td>
<td>$C_{aj} = 100$</td>
<td>0.095 p</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$C_{mj} = 1500$</td>
<td>0.12 p</td>
<td></td>
</tr>
<tr>
<td>6 Higher cost of water savings with high savings target</td>
<td>$C_{ij} = 2500$</td>
<td>0.06 p</td>
<td>10% of $u_0$</td>
</tr>
<tr>
<td></td>
<td>$C_{aj} = 800$</td>
<td>0.095 p</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$C_{mj} = 1500$</td>
<td>0.12 p</td>
<td></td>
</tr>
</tbody>
</table>

Each scenario explores a unique set of possibilities for the Upper Basin and as a whole they provide a more complete understanding of the potential for water trading. Scenario 2 maintains the target of a 6% reduction in water use with variable transaction costs, but in this case each user implements the high cost technology available to them. Agriculture is still the lowest cost saver and therefore still drives the resulting market price. Scenarios 3 and 4 increase the target for water saving to 7.5% in order to reach the supply level anticipated by 2025 per the Downscaled GCM Projected Streamflow Scenario presented in the USBR Basin Study. Scenario 3 reaches this target with low cost technology options while Scenario 4 reaches the same target with high cost technology.

Scenarios 5 and 6 increase the target water savings level to 10%, which represents the
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anticipated reduction in available water by 2055. Scenario 5 is the low cost technology version of this scenario and Scenario 6 is the high cost technology version.

Further, Carrey and Sunding (2001) found that only a 10% transfer of water from agriculture to municipalities would be sufficient to ameliorate the current situation. Additionally, if total transfers in a basin exceed 15% there is potential for negative area of origin impacts, such that reduced agricultural production may decrease the economic output of a county overall, potentially reducing livelihoods of others not directly involved in water trading (Chong and Sunding 2006). In the arid west, depriving a region of water may seem tantamount to depriving it of economic sustainability and thus no higher rate of savings was investigated.

5.3 Price and Transaction Cost Results of the Simulation

Simulations of the six trading scenarios results in finding market prices for water transfers varying with transaction costs and cost of savings technology. The values for price and transaction cost do not change with various levels of saving. Therefore, the figures presented below represent only Scenarios 1 and 2, as the price and transactions costs are identical to those generated for mid-range and high savings rates at low and high costs of technology respectively. The prices output by this model are reasonable and relatively low in comparison to observed prices for water transfers. Per the Bren Water Transfer data, the most complete relevant data set available, which includes records of individual water transactions throughout the southwest from 1987 to 2009, the minimum price paid for an annual acre-foot of water was $0.0012, the maximum price paid for an annual acre foot of water was $140,873.02, the mean price was $2,681.68, and the
median price was $918.62. A comparison of the prices resulting from this simulation to the empirical observations is shown below in Figure 3.

![Figure 3: Comparison of simulated and observed market prices for water transfers.](image)

Examining these various scenarios for the Upper Basin allows trends involving price and transaction costs to be elucidated. The relationship of price and transaction costs in regards to variable levels of water saving is static as saving more water does not change the per-unit cost. Higher levels of saving will, of course, result in higher aggregate levels of purchases and sales on the market, but the cost per unit of transfers does not change. Further, the increase in transaction costs occurs at a slightly decreasing rate. As transaction costs increase from 6% to 9.5% of p (3.5 percentage points), price increases by 4%. When transaction costs doubles from 6% to 12% (6 percentage point increase), price increases by 8%.
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Increased cost of technology increases the price paid for water transfers, as savers must be compensated for their higher expenditures. When technology costs are low, market price increases by a smaller amount with each increase in transaction costs, than when technology costs are high. It was expected that technology costs and price would have a positive relationship, but the increased steepness of this relationship at higher costs was not anticipated. This relationship has not been explicitly studied for water markets and may be an area for future research.

The prices simulated are also reasonable in comparison to the prices observed in the Murray-Darling Basin of southeast Australia, where a highly functional water market exists.

![Figure 4: Comparison of Upper Basin market simulated prices to Murray Darling basin observed prices](image)

Employing low cost technology for all users therefore results in prices well below the observed median, while employing high cost technology for all users results in prices
just below the observed median. Minimization of transaction costs is therefore integral to market success, as it allows prices to be low enough to expect a high volume of transactions to occur.

5.4 Water Savings in Agriculture

In order to comment on the variation in the impact of water savings among agricultural users, counties were grouped according to volume of initial agricultural use and agricultural contribution to county GDP. These groups were then used to examine how savings vary across counties with the savings rates set to 6, 7.5, and 10% of initial use.

![Average Projected Volumetric Water Savings in Agriculture Across Counties, Grouped by Pre-Market Agricultural Water Use](image)

**Figure 5: Water Savings in Agriculture, grouped by initial use**

Logically, counties in which agricultural withdrawals are initially high will do the majority of saving once trading begins. Operations with initial use greater than 200,001 acre-feet per year are likely large industrial agricultural operations, which will therefore
have greater ease in acquiring financial resources to invest in improvements in water use technology. Large agricultural operations also tend to generate more environmental degradation than smaller operations, allowing for greater potential improvement once water saving measures are employed.

Figure 6: Water Savings in Agriculture, grouped by contribution of agriculture to county GDP (income approach)

Counties in which agriculture contributes more highly to county GDP tend to be counties in which agricultural production, and thus water use, is initially high. This leads to the largest reductions in agricultural water use occurring in counties where agricultural is most economically important. This data validates the idea that total transfers should be limited to 15% of initial use in order to prevent undue economic harm to those counties.
6. Discussion

The importance of water management reform in the American southwest cannot be understated. Water is the lifeblood of any community and any economy, and the persistent drought coupled with poor management history in the region has left the southwest, including the Upper Basin, in a dire situation. Establishment of markets for tradable water rights would be one step in the right direction.

Further research into the behavioral economics of water trading would be highly valuable. Particularly, analysis of the behavior of firms selling water would provide insights for future market designs that could properly incentivize sales. Firms tend to be myopic in their pursuit of profit and water may or may not be considered a profit-driving factor. Particularly in the southwest where water has been granted to firms, through prior appropriation, water may be viewed as something to which firms are entitled, rather than a cost of production. Further, if firms indeed feel as if water is something they have been granted, rather than a cost of production, firms currently holding water rights may suffer the endowment effect. The implication of this effect is that firms holding water rights may value those rights, by virtue of their being already held, more highly than firms seeking to purchase water rights, who view them as a good to be traded. This would cause a dramatic change in the assumptions regarding initial marginal benefits associated with water use and may cause a change in trading outcomes.

Continued research on the decision making processes involved with buying and selling water, particularly in the American southwest, will allow models to be improved and recommendations to be refined.
7. Conclusion

The creation of a market for tradable water rights would allow for sales of water across user types and location and would substantially reduce the inefficiency of the current allocative system in the Upper Basin. The importance of water to human life and prosperity and the impending persistent shortages in the Upper Basin demand that the current allocative structure be revised in order to generate the greatest total benefit at the lowest cost. Trading water rights via an established market is one way to achieve this important goal.

Making transaction costs endogenous to the market price for water transfers represents a significant increase in understanding regarding the barriers to and potential for a market for tradable water rights. The nature of water as a commodity and the administrative structures currently in place generate costs of trade beyond those expected for a normal market good. However, study of these costs allows their causes to be elucidated and therefore their impacts to be minimized. There are transaction costs both of market establishment and market operation that must be addressed. Transaction costs are one of many costs associated with water usage and allocation and their influence on price depends upon the cost of the price of the complementary activity to trade: water savings. It is the minimization of transactions costs and costs of water saving technologies that may ultimately allow a market for tradable water rights to flourish in the Upper Basin.

While the model presented in this study makes progress in comparison to the current allocative system, it does not represent an ultimate solution. The next necessary step for improvement of the model is the development of an ecological/in-stream flow user. In
order to allow for the ecological integrity of the Upper Basin, trade must proceed such that water remains in the river for the purpose of preserving the inherent value of nature. Recreational use also relies on in-stream flows and generates revenue for the states of the Upper Basin. The option must exist for non-profit or governmental agencies to purchase water rights to devote to instream uses, in a process similar to that of a permanent land conservation easement. A market emphasis on the value of free-flowing water would increase recreational, ecological, and quality of life benefits throughout the Upper Basin.
References


“Water Transfer Data Base” Data set published by the Bren School of Environmental Science & Management UCSB, 2008.

### Appendix A: Framework for the Evaluation of Water Markets (adapted from Grafton 2010)

<table>
<thead>
<tr>
<th>Institutional Underpinnings</th>
<th>Economic Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Recognition of public interests</td>
<td>1. Size of the market</td>
</tr>
<tr>
<td>2. Administrative capacity</td>
<td>2. Annual monetary gains from water trades</td>
</tr>
<tr>
<td>3. Well-developed horizontal linkages</td>
<td>3. Size of storage capacity</td>
</tr>
<tr>
<td>4. Well-developed vertical linkages</td>
<td>4. Nature or characterization of water rights</td>
</tr>
<tr>
<td>5. Legal and administrative clarity</td>
<td>5. Quality of title</td>
</tr>
<tr>
<td>7. Adaptive management mechanisms</td>
<td>7. Stability of price formation</td>
</tr>
<tr>
<td>8. Registration and titling</td>
<td>8. Accessibility and reliability of market price information</td>
</tr>
</tbody>
</table>

**Equity**

| 1. Beneficial use of water extractions       | 1. Adequate information regarding environmental needs |
| 2. Provision of basic human needs            | 2. Delivery of water to meet environmental needs    |
| 3. Limits of market power                    | 3. Adaptive management to suit environmental needs |
| 4. Recognition of third-party impacts        | 4. Water quality consideration in water planning and markets |
| 5. Considerations of equity in initial allocations | 5. Complementary catchments and basin wide planning and trading |
Appendix B: Necessary Components of Legally Defensible Water Rights (adapted from Le Quesne et al. 2007)

1) Quantity available for use and quantity required as return flow, if applicable
2) Duration of use permitted;
3) Quality of water, particularly as return flow;
4) Source from which the water is drawn;
5) Timing of permitted withdrawals, including any seasonal restrictions for environmental purposes;
6) Conditions regarding the state of the source of the water and assurance of supply to the environment, given low flow conditions;
7) Price of the water right itself, as well as any fees to water management authorities to cover data collection, compliance, or remediation;
8) Limits to use, if applicable;
9) Ownership extent and transfer capabilities.
Appendix C: Criteria to Evaluate the Equity of Cross-Border Water Allocations
(adapted from Helsinki Rules 1966)

1) The geography of the basin, including in particular the extent of the drainage area in the territory of each basin State;
2) The hydrology of the basin, including in particular the contribution of water by each basin State;
3) The climate affecting the basin;
4) The past utilization of the waters of the basin, including in particular existing utilization;
5) The economic and social needs of each basin State;
6) The population dependent on the waters of the basin in each basin State;
7) The comparative costs of alternative means of satisfying the economic and social needs of each basin State;
8) The availability of other resources;
9) The avoidance of unnecessary waste in the utilization of waters of the basin;
10) The practicability of compensation to one or more of the co-basin States as a means of adjusting conflicts among uses; and
11) The degree to which the needs of a basin State may be satisfied, without causing substantial injury to a co-basin State.
## Appendix D: Classifying Transaction Costs of a Water Trading Program (adapted from Rees and Stephenson 2014)

<table>
<thead>
<tr>
<th>Activity</th>
<th>Transaction Cost to Imposed</th>
</tr>
</thead>
</table>
| Legislative Environment: defining policy goals, authorizing and enabling legislation | 1. Participation in legislative process (including public consultation and lobbying)  
2. Investment in understanding the authorizing and enabling legislation  
3. Costs of participating in legal challenges to authorizing and enabling legislation  
4. Opportunity cost of waiting for clear legislative environment and the impact of uncertainty on trade decision making  
5. Design of enforcement policy |
| Administrative Overheads: public consultation and education | 1. Participation in consultation processes  
2. Participation in educational programs |
| Defining the Commodity and Exchange Rules | 1. Investment in understanding the system  
2. Opportunity cost of waiting for clear regulatory environment and clarity of decision-making space  
3. Trading eligibility rules  
4. Defining conditions/limits of exchange  
5. Defining transfer requirement and trade approval rules |
| Implementation and Program Operation | 1. Determine consequences of changes  
2. Adapt behavior in light of changes  
3. Search costs to identify possible market participants  
4. Assessing desirability of entering the market  
5. Hiring third parties for negotiations with trading partner, contract review, and legal challenges to trade  
6. Ensuring eligibility for trading  
7. Search for trading partner |