INNOVATIVE WATER SUPPLY RELIABILITY ARRANGEMENTS

by

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DEDICATION

To Lexi

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ABSTRACT

This thesis presents a historical approach to water law and economics in the western US and then provides a framework for conducting innovative water transfers for the purpose of augmenting traditional water sales and leases. Innovative transfers considered include: dry-year water supply reliability contracts, water auctions and water banking. Determinants of price in typical water leases at a statewide spatial scale for California, Colorado and New Mexico, using econometric analysis, as well as the minimum price required for growers to forego irrigation in Yuma County in Arizona are discussed. Several case studies are compared, including pilot fallowing programs conducted by the US Bureau of Reclamation.

1. INTRODUCTION and BACKGROUND

Water supply availability is highly variable across seasons and years in many regions and may become even more difficult to predict as climate change progresses (Garrick and Jacobs 2006; Williams 2007). There are many approaches to address the challenges posed by supply variability. One method of mitigating the impacts of water supply variability is to limit water users' reliance on water in the first place. Put differently, a state could mandate restrictions on volumes of water used by municipalities, industries, agriculture and individuals. While these rules and restrictions may be a necessary component of an overall strategy to improve supply reliability, this thesis focuses primarily on another issue: utilizing voluntary transfers of water to improve water supply reliability. The emphasis here is placed on innovative transfers; that is, transfers other than typical water sales and leases. In this thesis, the term "innovative transfers" refers to dry-year water supply reliability contracts, water auctions and water banking. Before innovative methods and means of transfer are considered, however, it is necessary to outline the basic aspects of water transfers in general.

The underlying economic rationale for transferring water is simple: individuals who value the water most highly are motivated to acquire it from those who receive lower value from its use. This eventuality can only occur if water transfers are permitted. This rationale assumes that decisions are made in a vacuum and that the transfer of water from one individual to another does not create ancillary impacts to individuals not directly involved in the transaction. That is, it assumes a transaction with no externalities. It is clear, however, that several types of externalities often occur when water is transferred and if these externalities are considered in the transfer, then they necessarily modify the net benefits of transferring the water. For example, if water is transferred from an agricultural use to an urban use, an increase in dust or pests may occur, which may create higher operational costs to surrounding growers.

Outright sales[1] and leases[2] have historically been the primary method of moving water from one entity to another. While sales and leases are an important tool for enhancing water supply reliability, their value is enhanced in instances when information is close to perfect and diminished when information becomes relatively more imperfect. For example, if it is known with perfect certainty that an urban area can never meet the future water demand of its populace, it may be appropriate for it to purchase a water entitlement. While an outright purchase may be costly, it may be more cost effective than leasing a volume of water in perpetuity while minimizing the risks associated with supply shortage and price volatility.

Leases, on the other hand, may be an appropriate vehicle to transfer water when an additional volume of water is only periodically necessary. The value of leases is enhanced particularly when it is known with perfect certainty when additional water is needed and when current supplies are sufficient. If information is imperfect, the value of the tool can be diminished in two ways. First, if water is leased and then is subsequently not needed, the price paid to obtain the lease represents a waste of financial resources. Furthermore, if storage of excess water is impractical, the excess may have to be disposed

[1] A sale refers to a permanent legal transfer of title from the selling party to the purchasing party.
[2] A lease refers to a temporary transfer of a use right in the water. The lessor retains title to the water while the lessee obtains a proscribed use right.

of, representing a waste of the actual resource. Even if the lessee decides to sell the excess, the terms of negotiation will likely be unfavorable. Second, if water is not leased, but is subsequently needed, it may become more costly to obtain the water. For instance, if a municipality is in need of water and may obtain the water from growers, the price tends to be lower if the water is obtained before the planting cycle begins. However, if the lessee waits until after the costs of planting and irrigation occur, the lessee will have to subsidize the growers' investment costs *as well as* income foregone.

Innovative water transfers, the primary focus of this thesis, may be used as a method to improve flexibility and achieve efficient outcomes. Specifically, this thesis focuses on two different transfer types and one transfer mechanism. The two transfer types include dry-year supply reliability contracts (reliability contracts) and water auctions, and the mechanism contemplated is water banking. Reliability contracts imply an arrangement that is made in advance of need that is triggered by low supply conditions. With this transfer type, consideration is provided in advance for the option to lease water at a later date. Because water shortage conditions are probabilistic in nature and not perfectly understood, reliability contracts provide insurance against the risk of shortage because water may be obtained if actually needed. Additionally, insurance is provided against the risk of obtaining more water than is necessary because water will not be leased unless needed. The main drawback is that payment is made upfront regardless of whether water is actually leased. Nevertheless, reliability contracts may provide a more efficient means of water procurement and risk distribution over time.

The value of water auctions tends to be enhanced when water supply conditions are low and entities are facing high costs of shortage. A water auction takes the place of regular individualized face-to-face negotiations and helps to create a visible market where prices and quantities can be easily an accurately compared. Auction theory suggests that individuals in an auction are more likely to reveal their true value of the resource and less likely to be able to collect rents as a result of an asymmetry of information between buyer and seller (or lessor and lessee). As a result, an entity interested in leasing water entitlements may be able to obtain the resource at a lower cost than would have occurred otherwise. Despite these benefits, conducting an auction can entail relatively high costs associated with information dissemination as well as actually conducting the auction; however, some of these costs replace the transaction costs from individual negotiations. Ultimately, in order to be a viable method, the net benefits of the auction must exceed the net benefits of obtaining the water via another means.

Water banking includes, but is not limited to: the storage of water (in a reservoir or underground) to be used at a later date, an entity that facilitates water transfers (whether or not the bank is a market participant), or the management of water entitlements such that the water may only be utilized for a particular prescribed purpose (i.e. administration of a trust developed to ensure minimum stream flows). While the term "water bank" is generic and may be applied to a variety of different activities, water banks all share the goal of ensuring water supply reliability through voluntary trading. In order to achieve its goal, a water bank may engage in sale and leasing transactions, as well as more innovative transaction methods like reliability contracts and water auctions.

1.1 Economics of Drought

The effects of drought may reach farther than the direct location experiencing supply shortage. The U.S. incurs an estimated \$6 to \$8 billion in drought-related costs and losses annually from economic sectors such as agriculture, energy, recreation, municipal and industrial, governmental, and the environment (National Oceanic and Atmospheric Administration 2002).

The western US, for instance, may experience severe drought related costs in agriculture, as that industry is the principal water demander for the region (Colby 2007). Costs of drought in this region may include crop failure, reduced crop productivity and increased susceptibility to disease and insects, wind erosion, and federal spending on drought support for farmers. The agricultural impacts may also have a negative trickle down effect to other related industries such as agricultural input providers that supply fertilizers, seeds, pesticides and machinery; processing and packing industries; and also financial industries supporting agricultural production.

Municipal and industrial water users, who are often junior appropriators, vis-à-vis agricultural appropriators, may also experience high costs during times of water shortage. In the case of industrial users, water shortage can mean an inadequate volume of water to continue operations, or the inability to operate at full capacity. For the municipal users, water shortage can mean an inadequate volume of water available for normal day-to-day uses by the municipality and for the citizens serviced by the municipality. This may require the municipality to utilize demand reduction programs like requiring businesses to utilize low- flow water fixtures or limiting the days of the week for which individuals are able to water their lawns.

Drought may also have a negative impact on energy production. Hydropower production, for instance, is directly tied to reservoir levels. During drought conditions, a reservoir may fall to a level whereby hydropower production must be limited or stopped entirely. Nuclear energy production also requires water, which is used for the purposes of cooling, and during times of shortage an insufficient volume may be available for energy production.

Finally, shortage may have a negative impact on both tourism and recreation. Opportunities to directly benefit from the water through activities such as boating, rafting, fishing, bird watching, etc. will be diminished. Additionally, negative indirect impacts to local communities that rely on tourism as a source of income may occur because they may not receive a necessary financial infusion. In times of low supply, it may be important to have tools available to mitigate those conditions. This thesis is devoted to exploring some of the costs and benefits of those tools and providing a framework for their institution.

1.2 Description of Chapters

Chapter 2 begins with a brief literature review of water markets generally and then moves into review of econometric methods and net returns to water (NRTW). Chapter 3 discusses the history of the legal and institutional regimes of water law and provides a basic analytical framework for analyzing the differences in water law throughout the United States. Chapter 4 introduces water supply reliability contracts Chapter 5 introduces water auctions and Chapter 6 introduces water banking. The benefits and drawbacks of each are considered and relevant case studies are included. Chapter 7 begins the data analysis component by introducing the states included in this study of water transactions, as well as the data and econometric methods used. Chapter 8 provides the raw results from the econometric modeling as well as in depth analysis of the results.

Chapter 9 provides net returns to water (NRTW) data from Yuma County in Arizona, and information on pilot fallowing programs that the US Bureau of Reclamation has entered into, and analysis. Chapter 10 wraps up the major content by providing final conclusions and suggestions for future work. Appendix A provides a dry-year water supply reliability timeline as well as checklists for things to consider when conducting supply reliability contracts, water auctions and water banking. Appendix B provides some raw data used in this study. Appendix C provides calculation of net returns to water. Finally, a glossary of terminology used in this thesis is provided.

Figure 1.1, below, illustrates the relationship between each chapter. Chapters 2 and 3 provide general background on water transfers and quantitative methods used. Chapters 4, 5 and 6 discuss innovative water supply reliability tools and may be compared against real world data in Chapters 7, 8 and 9. Finally, Chapter 10 synthesizes the material from the prior chapters.

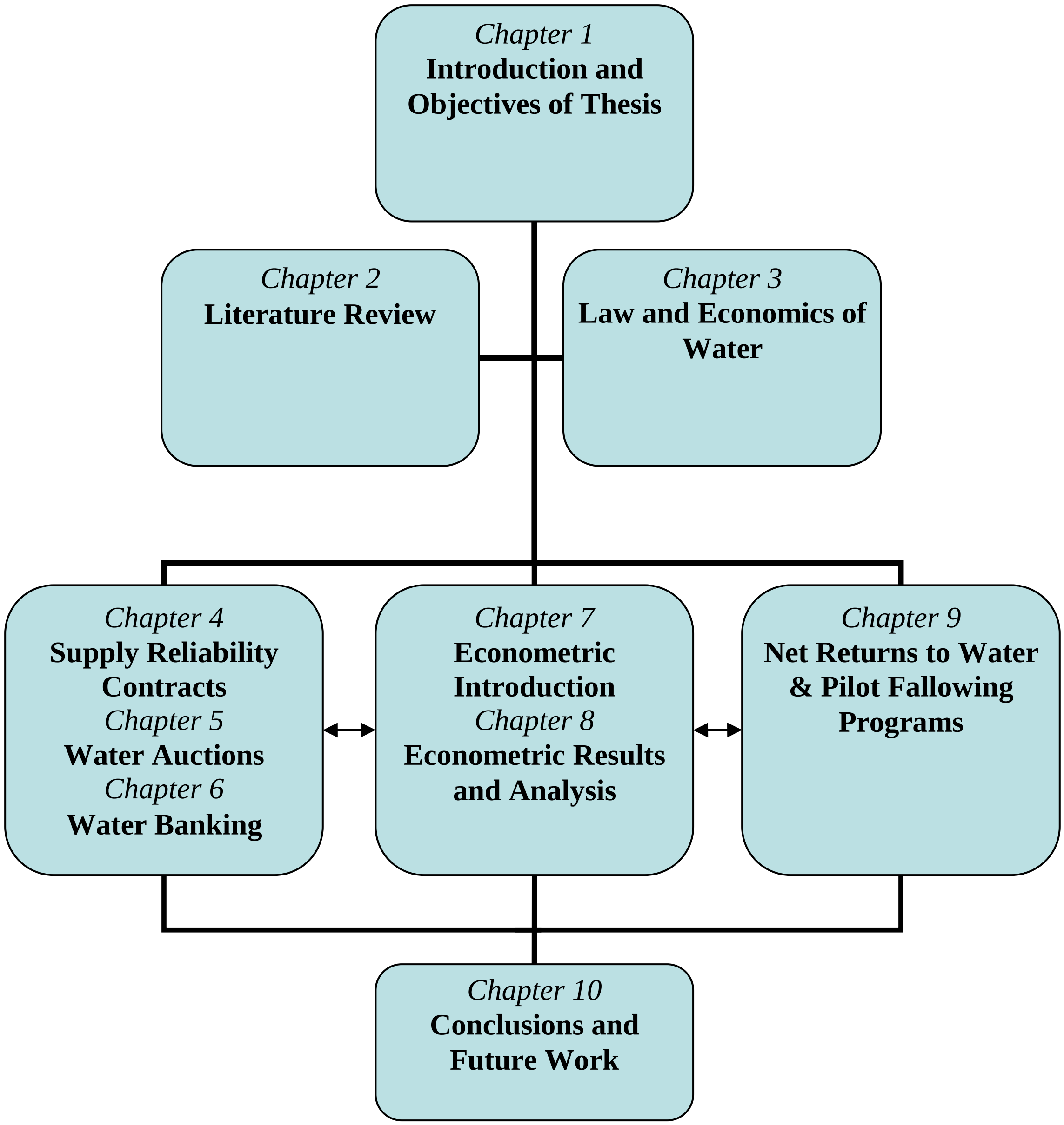

Figure 1.1: Thesis Organizational Structure

2. LITERATURE REVIEW

This chapter provides a brief background and literature review of water markets in general. A literature review of econometric quantitative techniques as well as net returns to water is also included. The chapter concludes with a discussion of the contributions that this thesis provides.

2.1 Water Markets

Today, supply-side responses to improving water supply reliability, such as reservoir building or large infrastructure projects, are becoming less economically, environmentally and politically viable. Rapid growth and the desire to move water from the source, particularly in the western US, have placed increased demands on the resource and have prompted efforts to improve water supply reliability through a demand-side response. Market mechanisms through voluntary trading present a viable method for improving reliability.

Water markets have a long and distinguished history dating back to at least the 15^{th} century in Spain (Maas and Anderson 1978). In terms of landscape and climate, Spain shares characteristics with the western US. Specifically, Spain is relatively arid, experiences low levels of precipitation and the watercourses tend to not be adjacent to the most productive agricultural lands (Jordana 1927). In general, water rights were historically bundled with irrigated lands and its use vested in the irrigator; however, there is one major exception: at Elche and Lorca, the ownership of the irrigation waters from certain reservoirs was separated from the irrigated lands and the waters were sold at public auction (Jordana 1927). As a result, the movement of price was consistent with normal supply and demand conditions; when supply was relatively low in times of drought, price increased, while when surplus conditions were present, price fell. Water markets have been used, or are currently used, in one form or another in various countries throughout the world.[3] What follows is a basic summary of the important aspects of modern water transfers.

A transfer of water from one party to another can occur through a permanent sale or a temporary lease transaction. Because the majority of transfers occur via lease, as opposed to sale, the focus here will be on lease transactions, and specifically leases in the western US (Jones 2008). Leases tend to be the preferred method of transfer for several reasons. Leases by their very nature lack the permanency of a sale. As a result, many of the negative externalities associated with permanent water transfer, such as altered streamflow, aquifer drawdown, and in the case of agricultural water sales, dust, weed and insect outbreaks. Also third party economic impacts to local communities may occur. These include direct economic impacts to communities that require the water for production processes, such as agricultural communities as well as indirect impacts to both suppliers of inputs as well as demanders of final goods.

Leases also generally enjoy the benefit of having relatively fewer legal impediments and are therefore also easier to obtain than sales (Howitt and Hansen 2005). Buyers often only need to obtain water when it is relatively scarce and their entitlement does not satisfy their demand, so (relatively) short-term leases provide the security that the buyer seeks. Additionally, sellers may not wish to not relinquish legal entitlement to the water and instead choose lease it, but only in times when the consideration obtained

[3] Notable countries include: Australia, Chile and the United States.

from a lease is greater than the value likely to be received if the water was put to beneficial use. Along similar lines, contractual terms may be examined and renegotiated prior to entering into subsequent agreements, providing greater flexibility and the ability to respond to changed conditions.

In the western US, these lease transactions have been historically undertaken through spot market transactions. In general, the spot market refers to lease transfers of one year or less and often require negotiation for each transaction. As a result, the transaction costs may be high and, in certain circumstances, may overwhelm the benefit of the water entirely (Howitt 1998). There is an additional risk that the water will not be available when it is needed. The price and supply uncertainty attributable to the spot market may lead to inefficiencies thereby making market participation unattractive (Howitt 1998). Because of these potential inefficiencies, innovative methods of transfer designed to augment the current water market are contemplated in this thesis.

2.2 Econometric Analysis of Water Transfers

When considering the alteration of a policy regime, it is important to consider whether the new regime is superior to the status quo. A necessary component of this particular analysis is to determine what factors have an influence over price and quantity determinations in current water markets. This provides a baseline for which to consider alternatives. Therefore, what follows is a review of selected literature that has been used to formulate the econometric analysis of lease price data in this thesis.

Loomis et al. (2003) examines water transactions for instream flows and how price is influenced by environmental transfer. This study uses a non-linear logarithmic equation to estimate market prices. The years analyzed are 1995-1999 and the data used are mainly from the *Water Strategist*. From this study, several results are notable. First, the predictive power of the model, and its ability to explain the variation in the data, was relatively good as the R^2 was .61. Second, the model indicated that the price was lower when the purchaser or seller was a government entity. Therefore, the government tends to engage in transactions where it provides or receives discounts, so that below market prices are observed. Third, precipitation was found to have a significant negative relationship with price. This provides evidence of the negative relationship between precipitation and water supply, and the consequent reduction in price when a larger supply is available. Fourth, the model found that prices in sales transactions are significantly higher than prices in lease transactions. This result provides empirical support for separating sales and leases into different modeling processes, or at least accounting for their differences. Fifth, no significant relationship was found between price and quantity. This result rebutted the general hypothesis of economies of scale; that is, price did not decrease when quantity increased.

Brown (2006) analyzed western water markets for 1990-2003 from water sale and lease data published by Stratecon, Inc. Throughout that period, median lease prices stayed relatively constant. Brown used ordinary least squares regression and seven explanatory variables to explain changes in price. The variables used were: transaction year, the Palmer Drought Severity Index, ML transferred, the buyer's county population in 2000, a groundwater dummy variable (with surface as the alternative) and dummy variables for municipal or environmental use (with irrigation as the alternative). The results were significant but had relatively low R^2 values. Higher prices were linked to drier climates, larger populations, and municipal and environmental uses. The study also concluded that prices were not affected by transaction size, suggesting that transaction costs may not significantly influence price. One concern is that Brown does not address the possibility of endogeneity between price and quantity.

Brookshire et al. (2004) examines water market prices in three major markets in Arizona, Colorado and New Mexico. The three markets include the Central Arizona Project in Arizona (CAP), the Colorado Big Thompson market in Colorado and the Middle Rio Grande Conservancy District in New Mexico. The markets were chosen for study because they emerged from US Bureau of Reclamation projects, which ensure the existence of physical infrastructure necessary for water marketing to occur. Data was collected from the *Water Strategist* from 1990-2001 as well as yearly population and income data from the US Bureau of Economic Analysis and mean temperature and Palmer Drought Severity Index values from the National Oceanic and Atmospheric Administration. Observations were pooled and dummies were created for each of the three distinct markets. A two-stage least squares model was used to estimate the quantity demand equation while instrumenting for endogenous price.

Several results from this study are noteworthy. First, the prices in Colorado and New Mexico were higher than those in Arizona’s CAP market. The authors hypothesized that this is the case because the former markets are more developed than Arizona’s market. Second, government buyers tend to pay a lower price versus agricultural and municipal buyers. This provides additional support for the notion that the government provides or receives discounts in lease transactions. Third, the Palmer Index variable was inversely related to price, indicating that the price tends to be lower in wetter periods. With respect to demographic variables, population growth did not have a significant impact on demand, whereas income had a positive and significant coefficient, suggesting that wealthier populations have a higher level of demand. Finally, the study found a significant negative relationship between price and quantity, indicating that as quantity increases, price decreases.

Previous University of Arizona Agricultural and Resource Economics master's students and affiliates have also conducted quantitative and/or econometric analysis of water prices and quantities utilizing data provided by the *Water Strategist*. Pullen (2006) and Pittenger (2006) used sale and lease data, respectively, to look at determinants of price with a focus on the effects of climate change. Both used ordinary least squares and two-stage least squares. Colby et al. (2006) synthesized these results to explain the effect of climate on prices. Results from this analysis suggest that price generally increases with drier conditions and decreases as quantity transferred increases, supporting the notion that water markets tend to exhibit the expected negative slope of a demand curve.

Emerick (2007) estimated water transfer characteristics using a game theoretic approach arguing that strategic behavior is important as a result of the nature of thin water markets. Analysis is conducted to examine the decision to buy or lease water, price and quantity. Estimation takes place in two stages: The first stage estimates a bargaining model between buyer and seller using two-stage least squares, ordinary least squares and probit estimation. The second stage estimates the three equations simultaneously. His results provide two interesting insights: first, that drought does not affect the amount of water transferred but does lead to higher prices. Second, market power in regions with a limited number of sellers may make transfers prohibitively expensive.

Jones (2008) extended the methodology used in Loomis (2003), Pullen (2006), Pittenger (2006) and Colby et al. (2006) to estimate water sale and lease prices for environmental and non-environmental purposes. Jones hypothesizes that water demand price can be influenced by per capita income, population, development pressure, climate conditions, the new use of water and the state in which the transaction occurred. Her analysis was conducted utilizing ordinary least squares for the sales transactions and two-stage least squares for the lease transactions. Her spatial scale was at the climate division level of several states including: Arizona, Utah, New Mexico, Nevada, Utah and California.

Two-stage least squares was used for the lease transactions because she found endogeneity between price and the quantity term in the non-environmental lease model. Although not initially detected, two-stage least squares was also used in environmental lease model so that the results would be comparable. After conducting her econometric analysis, she found that the predicted quantity used in the non-environmental lease model was significant and the sign was positive, but had an extremely small marginal effect. The positive result was surprising, indicating that price and quantity may not have the normal negative relationship in a typical demand function. It was surmised that the larger the quantity transferred, the more impediments to transfer, thus increasing the cost of transfer. The predicted quantity was insignificant, however, in the environmental model.

Demographic variables, such as income and population, were found to be significant in some models and not others. Certain climate variables, such as the standard precipitation index (SPI), were found to be significant, while others such as temperature was deemed insignificant. The new use variables were generally found to be significant while the dummy variables for the states were largely insignificant in the non-environmental lease model and largely significant in the environmental lease model.

The present thesis builds upon and extends the previous work conducted by Jones (2008), Pullen (2006), Pittenger (2006), Colby et al. (2006) and others with a specific focus on lease prices in the states of California, Colorado and New Mexico. Because of the relative costliness of analyzing at the climate division level, this thesis utilizes a statewide spatial scale. Efficiencies may be gained if the results at the statewide spatial scale are comparable to the climate division spatial scale. Also, additional climate variables are tested in order to assess whether they provide better indicators of lease prices than the climate variables typically used. Indices tested are Pacific Decadal Oscillation (PDO) and Atlantic Multidecadal Oscillation (AMO). Finally, Lake Mead reservoir level measured in feet is included in this study to determine whether its relationship to lease price. It is hypothesized that including reservoir levels of key reservoirs can provide a valuable tool for assessing the value of water generally and lease prices specifically.

2.3 Net Returns to Water (NRTW)

Like the econometric analysis, NRTW provides a mechanism for assessing whether an alternative regime is superior to the current. This is done by estimating the on-farm economic value of water in crop production, and is calculated by subtracting variable production costs (exclusive of water costs) from gross returns per acre (Gibbons 1986).[4] In other words, the residual from the difference between the gross value of crop production and non-water input is attributed to be the return to irrigation water in crop production (Naeser and Bennett, 1998). What follows is a description of NRTW and how it may be calculated in practice.

NRTW represents the theoretical minimum payment that a grower would accept for refraining irrigation of a particular crop. The calculation is relatively formulaic and may be used as a benchmark for water entitlement transfer negotiation. Gibbons (1986) and Colby, Pittenger and Jones (2007) provide a useful framework for calculating NRTW by following a series of steps: First generalize to one or more representative farm models the approximate soil type, climate, labor supply and other crop production inputs, and crop patterns for farmers in a specific area. Construct a table detailing operations and inputs for each crop based on the representative farm. Include data on the steps in the production process, timing, required production resources, and resulting outputs are generally obtained from farmer and extension agent interviews to produce a crop and location specific budget. Use this data to calculate and display net returns to water per acre for each crop. The value obtained is the on-farm value of water in crop production and is calculated by subtracting variable production costs (exclusive of water costs) from gross returns per acre.

[4] Another approach is to consider both variable and fixed costs of production in the NRTW assessment (Young 2005). However, only variable costs are utilized in this analysis because the short-run value of water is of interest.

Although straightforward, the farm budget analyses are sensitive to the assumptions made about the nature of the production function, as well as input and output prices and quantities (Young 2005). One criticism is that it treats each farm in a given area as homogenous (Young 2005). For example, the analysis undertaken in this thesis is on the spatial scale of Yuma County in Arizona. The approach requires the assumption that each farm is equally productive and that each has identical cost structure. Neither of these assumptions may be realistic nor reflect actual conditions.

Another criticism is the manner in which the costs are calculated (Young 2005). For instance, one way to estimate input costs is to list all of the required activities to be completed during the preparation, planting and harvesting cycle and attribute appropriate costs for those activities. Costs of agricultural inputs such as seeds, fertilizers, pesticides, herbicides, etc. should also be included. The activity costs are generally estimated by obtaining information from growers and the input costs are often estimated by communicating with agricultural and chemical suppliers. However, the input cost information may be overstated for two main reasons. First, growers have an interest in inflating the costs of production. This is because NRTW is partially calculated as a function of variable input costs; as input costs increase, the apparent value of the water also increases. Second, the prices quoted by agricultural and chemical suppliers may not represent the prices actually paid by growers because growers may bargain with suppliers to obtain reduced prices.

Of additional interest is that NRTW may not represent the minimum payment that a grower will accept; rather, a grower may accept *less than* that amount. The reason is that NRTW does not explicitly take into account the inherent risk in the agricultural market. A risk-averse grower may be willing to forego planting, irrigating and harvesting activities for a guaranteed payment.

Nevertheless, NRTW can be used as a baseline to enhance the understanding of the true economic value of water; particularly when the water is obtained from the transfer of agricultural entitlements. As a basis of comparison with econometric results, and to illustrate how prices may diverge based upon location of water used as well as crop type grown, NRTW for four crops (alfalfa, wheat, cotton and lettuce) in Yuma County, Arizona is examined. The NRTW assessment contained here updates previous work by Colby, Pittenger and Jones (2007).

2.4 Contribution

This research provides several contributions with respect to the potential use of innovative water transfers for the purpose of enhancing water supply reliability in the face of climate variability. The first is that this thesis provides a thorough history and analysis of water law regimes in the United States. An important hypothesis is that prior appropriation regimes tend to develop in relatively arid regions and when the water is not spatially located where its value is maximized. The development of prior appropriation, and the ability to legally move water from one location to another, leads to the development of water markets. These water markets lay the foundation for water transfers.

This thesis asserts that water sales and leases may lead to suboptimal results. Therefore, a comprehensive framework for assessing whether innovative techniques ought to be considered is provided. Once it has been determined that an alternative should be employed, this thesis provides important background and step-by-step instructions for conducting dry-year water supply reliability contracts, water auctions and water banking activities. The strengths and weaknesses of each are examined and pitfalls are illuminated from various case studies. Practitioners may use this portion of the thesis as a primer and guide for conducting innovative water transfers.

Additionally, insight into the current market value of water and what causes lease prices to change is provided. This is done by conducting an econometric analysis of water lease prices, examining net returns to water of water and by considering select fallowing programs. Armed with a better idea of the market value of water and the causes of price change, a practitioner can more effectively make policy-related decisions.

3. LAW AND ECONOMICS REVIEW of US WATER LAW

This chapter provides a law and economics and historical analysis of water law regimes in the US. With that background, the chapter concludes with a brief discussion of the more modern development of the US Bureau of Reclamation and current complications inherent in water transfers.

3.1 US History of Legal Regimes

3.1.1 Early British Riparian Water Law[5] and Economics

Like many natural resources, surface water has inherent public goods characteristics, as it is relatively difficult to exclude rival users; that is, absent laws or customs prohibiting wholesale exploitation of the resource, upstream users are not constrained by downstream users' desire to exploit the resource. Furthermore, the act of consumption by an upstream user can impart negative externalities on potential downstream users (Kanazwa 2003). To combat the potential negative consequences of open access, English law developed the Riparian doctrine, which restricted upstream users' exploitation of the resource.

With this early law, landowners adjacent to a stream were entitled to have the stream flow as it "was accustomed to flow and ought to flow" (Anon. Case, 1031; Rose 1998b). Under the British riparian doctrine, the notion that the water should flow in this manner indicated that the historical flow, or 'ancient flow,' of the water should remain unchanged. Individuals that modified the water course or water flow to the detriment of downstream riparians could be challenged in court and be forced to cease. The

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[5] Because the US developed largely under British rule, the appropriate place to start a legal analysis is with British law and custom.

underlying theory of this regime appears to be that the benefits of the resource are maximized when the resource is held in common and the flow is undisrupted. When considering a legal regime that contemplates whether to consume or not consume water, a simple maximization exercise becomes apparent:

$$\max NB(q) = \max(B(q) - C(q)),$$

where NB= net benefits of consuming water, B = benefits associated with consuming water, C = cost associated with consuming water, q = quantity of surface water and NB, B and C are all functions of q. However, it is important to recognize that while there are benefits to consuming water, there are also benefits to not consuming water. Likewise, while there are costs associated with consuming water, there are also (opportunity) costs associated with not consuming water. Hence:

$$B(q)=\Sigma B(q)_c - \Sigma B(q)_n$$

$$C(q)= \Sigma C(q)_c - \Sigma C(q)_n$$

where ΣB_c and ΣB_n is the sum of the benefits associated with currently consuming the water and not consuming water, respectively. Generally, these consumption benefits amount to *de minimis* domestic consumption. The total benefits of not consuming water include all of the benefits that may be obtained from leaving it in the stream. These may include aesthetic, fishing or any other potential riparian benefits. And ΣC_c and ΣC_n is the sum of the costs associated with consuming and not consuming water, respectively. The total costs associated with consuming water include all of the explicit costs of consuming the water such as capital investment and the costs imposed on downstream users for consuming the water upstream.[6] The cost of not consuming water includes the opportunity costs associated with leaving the water in the stream; that is, the benefits are foregone by leaving water in the stream. Substituting into the original equation:

$$max\ NB(q) = max\ (\Sigma B(q)_c - \Sigma B(q)_n - \Sigma C(q)_c + \Sigma C(q)_n).$$

Rearranging,

$$max\ NB(q) = max\ [(\Sigma B(q)_c + \Sigma C(q)_n) - (\Sigma B(q)_n + \Sigma C(q)_c)].$$

The above equation ("Equation 5") implies that depending on particular idiosyncratic circumstance, given a specific moment of time, a quantity q can be chosen such that the net benefits are maximized.[7] The equation will be considered with respect to the water law regimes in an effort attempt to decompose the underlying purposes of their different treatments.

Under the most restrictive reading of the British riparian regime where consumption of water (beyond a *de minimis* level) is not permitted, it was assumed by the courts and law makers that the net benefits of consuming water is very low. Put another way, the sum of the benefits associated with not consuming water and the costs of consuming water nearly outweigh the benefits of consuming water and the opportunity costs of water under the British riparian model. Although it is impossible to know exactly why this regime developed in Britain during this time period, a likely hypothesis is that because there is a relatively high volume of precipitation, consuming stream water

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[6] It is true that the cost of using the water is not solely a function of quantity of water consumed; rather, the cost of consuming the water may also be a function of capital and labor costs. For the purpose of simplicity, those costs are not contemplated here.

[7] I assume a single solution and $\delta^2 NB(q)/ \delta q^2 < 0$.

or altering the watercourse may not have been necessary to achieve the (agricultural) goals of the local people.

Figure 3.1, below, is a map of the British Isles that shows annual precipitation averages from the years 1971-2000. The rainfall values are quoted in *mm*, and for the purposes of conversion: 1 *mm* = 0.0393700787 inches. The average rainfall for this time period ranges between approximately 18 inches in the drier south east regions and 180 inches in the wetter western regions. Although this time period is much later than the historical British time period discussed above, it is reasonable to assume that historical precipitation patterns are roughly similar to current patterns.

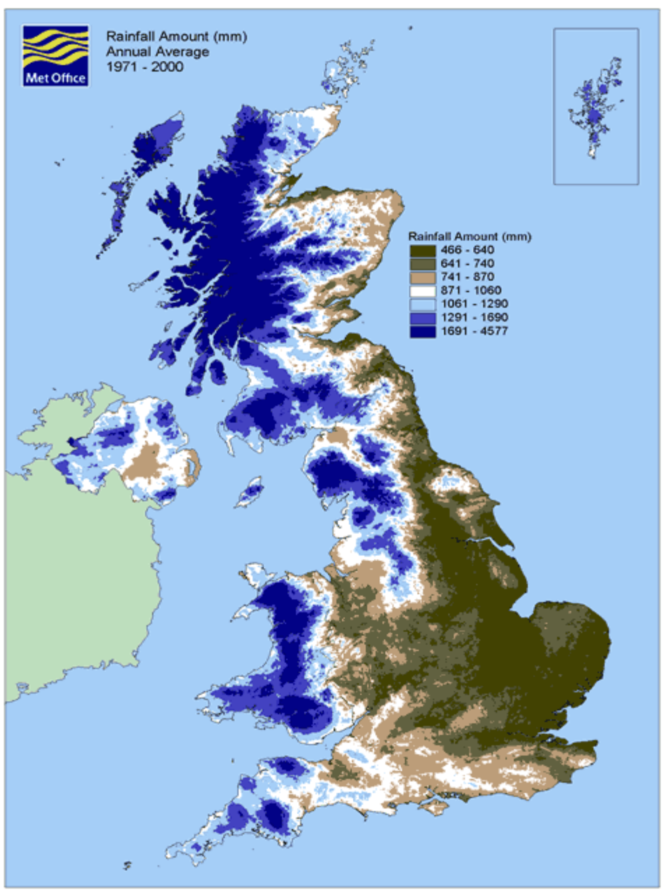

Figure 3.1: Precipitation Map of England

However, one caveat must be included: if an individual managed to modify the flow for a sufficient period of time, and that modification remained unchallenged, then the new flow would be treated as historical or ancient (Rose 1998b).[8] Despite the fact that downstream riparians could essentially control the behavior of their upstream counterparts, it is curious that there was relatively little conflict during the period of industrialization when water use patterns changed to accommodate industrial purposes (Rose 1998b). Rose suggests that little resistance may have been met because either new water users bought out existing users or because existing users did not know the law. In either event, something occurred during this time period that caused the value of q that maximizes Equation 5 to change. In order for this to happen, one (or more) of the following things had to occur: (a) the benefits associated with consuming the water increased; (b) the opportunity cost of leaving the water in the stream increased; (c) the cost of consuming the water fell; and/or (d) the benefits of not consuming the water (i.e. leaving the water in the stream) fell.

It is difficult to envision how (a) or (d) changed as (a) represents current consumption, and with respect to (d) it does not appear as the benefits of leaving water in the stream would have fallen. Additionally, it is difficult to assess whether (c) occurred. However, it does appear that (b) occurred; that is, it may have been the case that an event occurred that caused the opportunity cost of the water to increase. The most likely candidate for change in water use is industrialization – where some water use changes

[8] Professor Rose suggests that 20 years is the requisite number of years to convert a modification into an ancient flow.

would likely produce correspondingly larger benefits or where the opportunity cost of not fully utilizing the resource would increase.[9]

3.1.2 Early Colonial Riparianism and Reasonable Use

Because the eastern United States was colonized by the British, it is certain that the original colonists would initially conform to the laws of England. Therefore, with respect to water law, it is no surprise that they would initially adopt riparian law to manage the resource. Further, as table 3.1 and figure 3.2 (below) show, precipitation levels in the eastern states are generally high – with rainfall levels generally averaging between 40 and 60 inches per year. Table 3.1 shows annual average precipitation in the United States between the years of 1961-1990.

State	***Order Admitted to Union***	***Census Bureau Region***	***Prior Territory-holder***	***Rainfall (in./yr.)***	***"Use Rights"***	***"Rule"***
Delaware	1	South	Britain	41.38	Reasonable Use	Common Property
Pennsylvania	2	Northeast	Britain	40.26	Reasonable Use	Common Property
New Jersey	3	Northeast	Britain	41.93	Reasonable Use	Common Property
Georgia	4	South	Britain	48.61	Reasonable Use	Common Property
Connecticut	5	Northeast	Britain	44.39	Reasonable Use	Common Property
Massachusetts	6	Northeast	Britain	43.84	Reasonable Use	Common Property
Maryland	7	South	Britain	41.84	Reasonable Use	Common Property
South Carolina	8	South	Britain	51.59	Reasonable Use	Common Property
N. Hampshire	9	Northeast	Britain	36.53	Reasonable Use	Common Property
Virginia	10	South	Britain	45.22	Reasonable Use	Common Property
New York	11	Northeast	Britain	39.28	Reasonable Use	Common Property
North Carolina	12	South	Britain	42.46	Reasonable Use	Common Property
Rhode Island	13	Northeast	Britain	41.91	Reasonable Use	Common Property
Vermont	14	Northeast	Britain	33.69	Reasonable Use	Common Property
Kentucky	15	South	Britain	43.56	Reasonable Use	Common Property
Tennessee	16	South	Britain	48.49	Reasonable Use	Common Property
Ohio	17	Midwest	Britain	37.77	Reasonable Use	Common Property

[9] Perhaps this is the reason that Blackstone ignored the doctrine of ancient use in favor of a scheme of first possession (Rose 1998b; Blackstone 1765-9).

Louisiana	18	South	Britain	59.74	Reasonable Use	Common Property
Indiana	19	Midwest	Britain	39.12	Reasonable Use	Common Property
Illinois	21	Midwest	Britain	33.34	Reasonable Use	Common Property
Alabama	22	South	Britain	56.90	Reasonable Use	Common Property
Maine	23	Northeast	Britain	43.84	Reasonable Use	Common Property
Missouri	24	Midwest	France	33.91	Reasonable Use	Common Property
Arkansas	25	South	France	49.20	Reasonable Use	Common Property
Michigan	26	Midwest	Britain	32.23	Reasonable Use	Common Property
Florida	27	South	Spain	49.91	Reasonable Use	Common Property
Iowa	29	Midwest	France	34.71	Reasonable Use	Common Property
Wisconsin	30	Midwest	Britain	30.89	Reasonable Use	Common Property
Minnesota	32	Midwest	Britain	26.36	Reasonable Use	Common Property
West Virginia	35	South	Britain	40.74	Reasonable Use	Common Property
Hawaii	50	West	Hawaii	23.47	Reasonable Use	Common Property

Table 3.1: Riparian Doctrine States

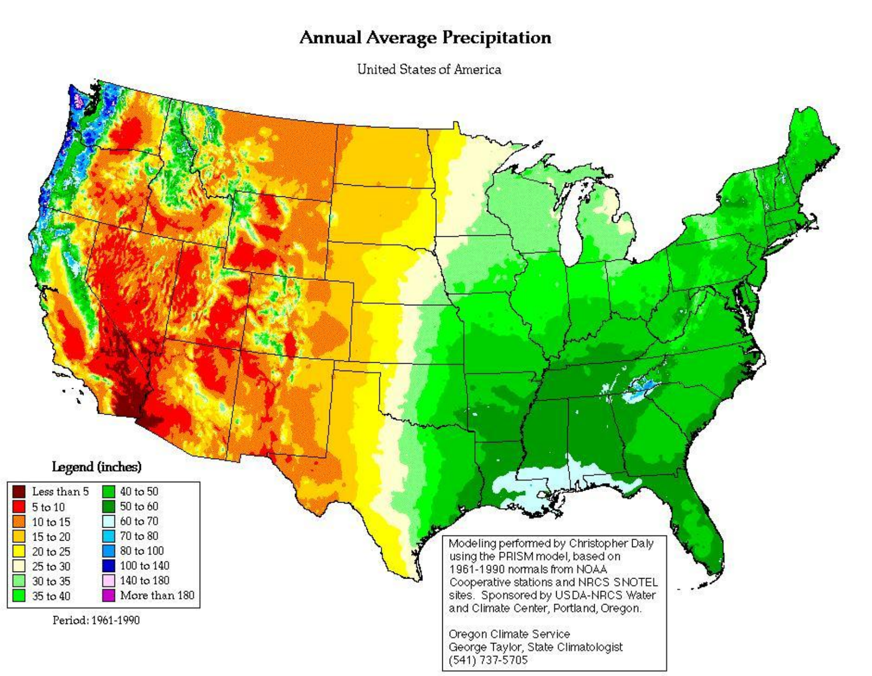

Figure 3.2: Precipitation Map of the United States

However, because the English riparian system did not allow for consumption beyond a *de minimis* level, a constraint was placed on industrial growth. As a result of technological innovation, the law was forced to confront the fact that riparian landowners could now more efficiently convert the power of the river into mechanical power, which could be utilized in milling processes. When maximizing Equation 5, the law was now required to explicitly include the opportunity cost of foregoing the utilization of the water course for power creation. This likely caused a situation where in order to maximize net benefits, it was necessary to consume a larger volume of water.

As a result, the English Riparian regime was in need of modification, and that modification came by way of the doctrine of "reasonable use." The theory underlying reasonable use first came to the forefront in New York in the case of *Palmer v. Mulligan*, 3 NY 307 (1805). In *Palmer* the court held that an upstream riparian landowner could obstruct the flow of the water for milling purposes, despite the fact that downstream riparians may be harmed. The judge, recognizing the value of water power, indicated that unless the courts were willing to ignore "little inconveniences" to downstream riparians, they ran the risk of losing the positive benefits associated with development along the stream.

The holding in *Palmer* was expanded in the subsequent U.S. Supreme Court case *Tyler v. Wilkinson*, 24 F. Cases 427 (1827). In that case, a lower mill owner brought suit against an upper mill owner for diminishing the flow of the water. The court held that under the current riparian regime, all riparians held equal rights to the water, but upper riparians could not diminish the flow to the lower riparians. However, under the current conditions, the constraint imposed by this rule renders it impractical. Therefore, the court held that an upper riparian could make use of the stream and its flow, including the reasonable consumption of the water or alteration to the stream flow.[10] As a result of this shift, riparians were now legally permitted to exploit and modify the resource under the condition that their exploitation proved reasonable. However, riparians were generally not allowed to move the water to a location off of riparian land and the bulk of the stream flow was generally kept intact.

Whereas under the English riparian system, the resource was held jointly by all riparians but could not be modified or reduced by any of them, the American riparian system essentially provided the riparians with a right to exploit and modify that resource, even if there were negative consequences to a downstream riparian. The right that this jurisprudence provided, however, did not rise to the level of a personal property right; rather, it was a use right to a reasonable volume.[11] Nevertheless, the resource continued to have a uniquely common property character, where a significant portion of the benefits are derived from keeping the water in the stream. As a result, the U.S. riparian system could be viewed as regulated common property system whereby manner of use restrictions are placed on the resource (Rose 1998a).

3.1.3 Western Expansion and Prior Appropriation

Although the riparian regime worked relatively well in the wetter eastern U.S. regions, it was not an attractive option as settlements began to develop in the western U.S. The relatively drier region, and the fact that the water was not necessarily located where the

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[10] Rose indicates that shortly after this case, the reasonable use doctrine was included in treatises of American law and many U.S. jurisdictions adopted versions of reasonable use riparianism. Additionally, English courts, citing to the U.S. decisions, adopted a similar framework (Rose 1998b).

[11] Nevertheless, it is almost certain that the expansion of the riparian's right to utilize the stream flow had the side impact of increasing the value of property adjacent to the stream.

benefits from consuming the resource were maximized, required that the riparian regime be replaced with another. The replacing regime became known as the doctrine of prior appropriation. Table 3.2 (below) lists all of the states that currently utilize a strict prior appropriation regime. The census bureau designates all of the states in the table as within the western region.

State	***Order Admitted to Union***	***Prior Territory -holder***	***Rainfall (in./yr.)***	***Current Surface***	***"Use Rights"***	***"Rule"***
Nevada	36	Mexico	7.84	Prior Appropriation	Beneficial Use	First Possession
Colorado	38	France	15.31	Prior Appropriation	Beneficial Use	First Possession
Montana	41	France	11.37	Prior Appropriation	Beneficial Use	First Possession
Idaho	43	Britain	11.71	Prior Appropriation	Beneficial Use	First Possession
Wyoming	44	France	13.31	Prior Appropriation	Beneficial Use	First Possession
Utah	45	Mexico	15.31	Prior Appropriation	Beneficial Use	First Possession
N. Mexico	47	Mexico	8.91	Prior Appropriation	Beneficial Use	First Possession
Arizona	48	Mexico	7.11	Prior Appropriation	Beneficial Use	First Possession
Alaska	49	Russia	53.15	Prior Appropriation	Beneficial Use	First Possession

Table 3.2: Prior Appropriation States

With the exception of Alaska[12], all of the states listed in table 1 have relatively low precipitation levels. An examination of figure 2 reinforces the fact that the western states that utilize prior appropriation are dry except for small pockets of relatively wet areas within particular states.[13] As a result, in order to conduct agriculture, water generally had

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[12] The value of Alaskan rainfall is artificially high as that value is not an aggregate value for the entire state; rather it was a value for only one location. In reality the volume of precipitation varies dramatically. Perhaps that is why a riparian regime was used until 1966 and then replaced with prior appropriation via the Alaska Water Use Act.

[13] Northern Idaho, western Montana, small portions of Wyoming and small portions of Colorado are relatively wetter than the surrounding west.

to be obtained from sources other than rainwater; water had to be diverted from streams to locations where the water could be used productively – and the most productive lands were not necessarily appurtenant to the stream.[14]

However, the possibility of conducting agriculture almost certainly did not bring the settlers out west; more likely, the western expansion was facilitated by the discovery of valuable minerals in those states (Brackman 1982).[15] In order to conduct mining operations, relatively large volumes of water had to be diverted from the water source to the mining claim. The claims, like the viable agricultural land, were not necessarily appurtenant to the stream. Again, a water diversion was required in order to move the resource to the location where it could be most productively used.

Because the settlers that moved west realized that water must be diverted from the source in order to conduct agriculture and mining operations, a shift away from riparianism and toward an appropriative regime was taken. The legal validity of the shift from riparianism in the west was solidified, however, by the Colorado case of *Coffin et al. v. The Left Hand Ditch Company* (1882). In *Coffin*, the defendant destroyed the ditch that the plaintiff used to divert stream water to non-riparian land. The defendant, using an argument based on riparianism, asserted that because the plaintiff had altered the flow of

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[14] With the exception of Alaska, the prior appropriation states are often characterized as the Mountain States because in many locations within those states it is mountainous and rocky (Mountain States). Streams that originate in and flow through a states particular mountain range(s) may need to be diverted in order to take advantage of the benefits of the water.

[15] Colorado Supreme Court Justice Greg Hobbs would take exception to this theory. He believes that agriculture, not mining, was the driving force behind the prior appropriation doctrine (Woodka 2009). Regardless of which story the reader believes, however, the fact remains that the water was not necessarily near to the most productive land; hence, in order to maximize the value of the resource, a diversion was necessary.

the river by diverting onto non-riparian land, they had a right to destroy the canal that provided that diversion.

The court, however, held for the plaintiff indicating that in the arid west, water has a "value unknown to the moist climates" and as a result rises to a level of a "distinct right to property." The court then held that "…in the absence of express statutes to the contrary, the first appropriator of water from a natural stream for a beneficial purpose has, with the qualification contained in our constitution, prior right thereto, to the extent of such appropriation."

The court in *Coffin* clearly stated that the water in the western US was more valuable that in the eastern U.S. Put differently, the net benefits associated with diverting water from the stream and consuming it on non-riparian land was higher than the net benefits associated with leaving water in the stream. The court, by creating the doctrine of prior appropriation, determined that the opportunity cost of leaving the water in the stream was high – higher, in fact, than the opportunity cost of water in the eastern US. Furthermore, the court seemed to indicate that the benefits of leaving water in the stream were relatively low and/or the costs to the downstream users, if water was consumed upstream, were relatively low.

Additionally, the court enumerated the "first in time, first in right" rule that characterizes a priority system under this regime.[16] This gives the relatively earlier appropriators (senior appropriators) a more secure right to divert and consume the

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[16] Many prior appropriation states continue to utilize the phrase "first in time, first in right," or something similar, in their respective state water codes.

resource against later appropriators (junior appropriators). Inherent in this is that the most senior rights of appropriation are the most valuable rights because the possibility of water supply interruption is minimized.

The court also indicated that rights to water in the west rise to a level of property right and not simply a use right.[17] This was a significant shift in the way that people viewed water; although there were benefits to keeping water as a common property resource, the benefits associated with consuming the resource could be increased by assigning actual, legally recognized, property rights. Because the value of the resource was higher in the west than in the east, some commentators would predict the movement away from the ambiguous system of common property to the defined system of personal property rights (Demsetz 1967).

In this case, in order for a system of personal property rights to develop, it was likely that the opportunity cost of leaving the resource in the stream was extremely high (i.e. that if the water was consumed, it could be put to extremely valuable uses). This is because the costs associated with enforcing and monitoring the system were also high.[18] For instance, under most current systems of prior appropriations, an appropriator must submit a permit application in order to appropriate a volume of water. These permits are either granted or denied and are catalogued by the permit granting entity. Then the actual

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[17] Although it is interesting to note that many states still consider the appropriative right a "use right" of either the State's or the Peoples' water. Nevertheless, it is clear that an appropriator holds something that is identifiable, may be quantified and has value.
[18] Not to mention the fact that the cost to divert the water was also likely high.

appropriation may need to be monitored to ensure that the proper volume is appropriated and that the water is being put to beneficial use and not wasted.

3.1.4 "Mixed" Water Systems

Below is a table listing the states that employ a "mixed" system of water rights. The ten states employ a mix of riparianism and prior appropriation, with prior appropriation being generally dominant (Backman 1982). The relative proportion of riparian to prior appropriation differs between states.

State	***Order Admitted to Union***	***Census Bureau Region***	***Prior Territory-holder***	***Rainfall (in./yr.)***	***"Use Rights"***	***"Rule"***
Mississippi	20	South	Britain/France	52.82	Varies	Common Property+
Texas	28	South	Mexico	34.70	Beneficial Use	First Possession
California	31	West	Mexico	17.28	Beneficial Use+	Varies
Oregon	33	West	Britain	37.39	Beneficial Use+	First Possession
Kansas	34	Midwest	France	28.61	Beneficial Use	First Possession
Nebraska	37	Midwest	France	30.34	Beneficial Use	First Possession
N. Dakota	39	Midwest	France	15.36	Beneficial Use	First Possession
S. Dakota	40	Midwest	France	17.47	Beneficial Use	First Possession
Washington	42	West	Britain	27.66	Beneficial Use	First Possession
Oklahoma	46	South	France	30.89	\Beneficial Use	First Possession

Table 3.3: Mixed States

With the exception of Mississippi, the states listed generally tend to have lower annual rainfall than the riparian states, but a higher annual rainfall than the prior appropriation states. On examination of the precipitation map in figure 3.2, it is clear that another interesting characteristic of "mixed" regimes is that they tend to have a relatively large degree of variation in rainfall across their respective states. For instance, the states of Washington, Oregon and California contain areas of the highest precipitation in the country; however, they also contain areas of some of the lowest precipitation in the country.

Additionally, all of the states directly north of Texas have a wide variation in rainfall. Most of those states tend to have a relatively high volume of rainfall on their eastern border but also tend to have relatively dry conditions on the western border. In order to accommodate these relatively wide variations in precipitation intrastate, a "mixed system" of water rights developed.[19] Using Equation 5 as a frame of reference, it appears as the mixed states realize that while there are benefits to consuming the water, and those benefits are often obtained off of the watercourse, there are also strong benefits to keeping the water in the stream.[20]

Nevertheless, in most of these states the law generally favors prior appropriation to riparianism. In many instances, although some riparian rights are recognized, those riparian rights became subsumed by the doctrine of prior appropriation. In those cases, historical riparian use of the watercourse is treated as an appropriation, and that appropriation priority date relates back to when the riparian use began. In other cases, the two doctrines are kept distinct and insulated from each other; a riparian landowner has a particular right and the water that is remaining after the riparian use is available to be appropriated.

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[19] Mississippi is the only state that does not seem to be consistent with this story. The entire state of Mississippi receives a relatively high volume of rainfall, so it is puzzling that it retains a mixed system.

[20] An alternative theory is that in many of the states the riparian law is an artifact of older law, and rather than a wholesale acceptance of prior appropriation political pressure dictated that certain aspects of riparianism be retained.

It is unclear whether the shift to these hybrid systems could have been predicted. On the one hand, mixed states tended to move toward a system whereby property rights were more completely defined. On the other hand, states that retained riparian components essentially constrained those rights. It is difficult to ascertain whether the underlying purpose of retaining the two regimes was to maximize the benefits obtained from the resource, or if political pressure was sufficient to cause its retention.

Compiling the information of the three types of water regimes into a map elicits figure 3.3, below. In figure 3.3, the blue states represent strict riparian regimes, the burnt orange states represent prior appropriation and the tan states represent mixed regimes.

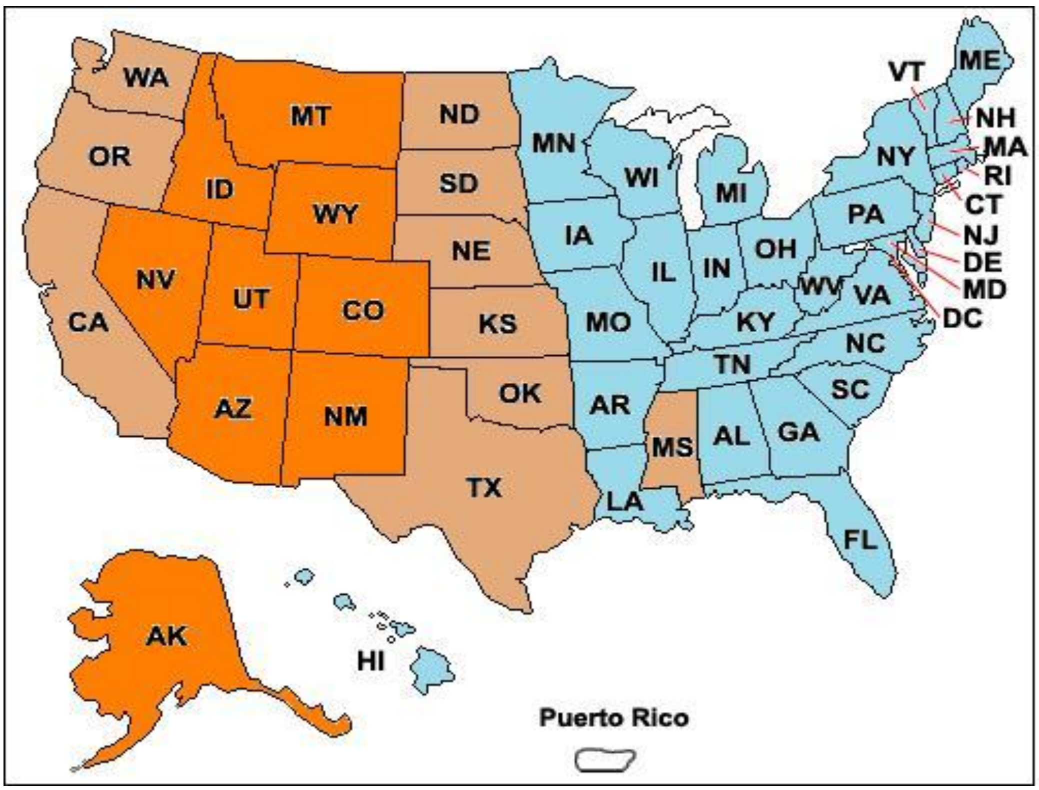

Figure 3.3: Map of Water Law Regimes, by State

In order to obtain an understanding of how a mixed regime state differs from a riparian or a prior appropriation state, and how the mixed regimes states differ from each other, a description of five of the ten states is provided. The five states chosen include Mississippi, Texas, California, South Dakota and Washington. These states were chosen because they either have unique characteristics or because they seem to be relatively representative of some of the other mixed regime states.

Mississippi[21]

Mississippi, a state with a relatively large volume of rainfall and sharing a border with five riparian states,[22] appears to be a perfect candidate for a riparian regime; however, the Mississippi Water Code contains language that explicitly incorporates prior appropriation. Sec. 51-3-1 states: "It is hereby declared that the general welfare of the people of the State of Mississippi requires that the water resources of the state be put to beneficial use to the fullest extent of which they are capable, that the waste or unreasonable use, or unreasonable method of use, of water be prevented, that the conservation of such water be exercised with the view to the reasonable and beneficial use thereof in the interest of the people…" Sec. 51-3-3(e) then defines beneficial use as "the application of water to a useful purpose as determined by the commission, but excluding waste of water." Reasonable use, however, is not defined.

In general, a permit is required to appropriate water in Mississippi; however, "a person using water for only domestic purposes shall not be required to obtain a permit to use water for domestic purposes, and no permit shall be required for the use of surface

[21] Without a true understanding of the legal conditions in Mississippi, it is difficult to gauge exactly how it is riparian law is used. More study is needed to ascertain how Mississippi incorporates prior appropriation with riparian law.

[22] Mississippi shares a border with Louisiana, Arkansas, Tennessee, Alabama and Florida; which are all riparian states.

water in impoundments that are not located on continuous, free-flowing watercourses." (Sec. 51-3-7(1)).

Texas

Texas, in general, applies the doctrine of prior appropriation to surface water. The Texas Water Code defines the terms "beneficial use" and "appropriator" and outlines the bounds of the two terms.[23] Interestingly, Sec. 11.021(a) and (b) of the Texas Water Code specify that any water within the state of Texas belongs to the state; however, Sec. 11.022 indicate that the "right to the use of state water may be acquired by appropriation in the manner and for the purposes provided in this chapter. When the right to use state water is lawfully acquired, it may be taken or diverted from its natural channel."[24] Sec. 11.141 then indicates how the date of priority is determined.

As a result, Texas appears to be a prior appropriation state; nevertheless, it is considered a "mixed" state for two main reasons: first, much of the state was historically riparian and only became prior appropriation after a series of adjudications (Sansom 2008). Second, Sec. 11.142 provides a riparian permit exemption in one specific case. That section reads in part: "Without obtaining a permit, a person may construct on the

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[23] Sec. 11.002(4) "Beneficial use" means use of the amount of water which is economically necessary for a purpose authorized by this chapter, when reasonable intelligence and reasonable diligence are used in applying the water to that purpose and shall include conserved water.
Sec. 11.002(6) "Appropriator" means a person who has made beneficial use of any water in a lawful manner under the provisions of any act of the legislature before the enactment of Chapter 171, General Laws, Acts of the 33rd Legislature, 1913, as amended, and who has filed with the State Board of Water Engineers a record of his appropriation as required by the 1913 Act, as amended, or a person who makes or has made beneficial use of any water within the limitations of a permit lawfully issued by the commission or one of its predecessors.

[24] Sec. 11.023-11.024 indicates what uses are to be considered beneficial and ranks those uses based upon what the State considers preferable.

person's own property a dam or reservoir with normal storage of not more than 200 acre-feet of water for domestic and livestock purposes."

California

Of all of the "mixed" states, California is probably the best representation of a mixed regime as the California Water Code specifically recognizes both riparian and prior appropriation regimes. Sec. 100 and 1240 of the code indicate that the water within the state should be beneficially used and Sec. 1450 indicates that an individual applying for a permit to appropriate obtains a priority date as to the date of the permit application.[25]

Nevertheless, Sec. 101 and 1201 recognize riparian rights. Sec. 101 indicates that "Riparian rights in a stream or watercourse attach to, but to no more than so much of the flow thereof as may be required or used consistently with this and the next preceding section, for the purposes for which such lands are, or may be made adaptable, in view of such reasonable and beneficial uses; provided, however, that nothing in this or the next preceding section shall be construed as depriving any riparian owner of the reasonable use of water of the stream to which his land is riparian under reasonable methods of diversion and use, or of depriving any appropriator of water to which he is lawfully entitled." While Sec. 1201 impliedly recognizes riparian rights: "All water flowing in any natural channel, excepting so far as it has been or is being applied to useful and beneficial

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[25] Interestingly, in contrast to Texas, Section 102 indicates that "[a]ll water within the State is the property of the people of the State…"

purposes upon, or in so far as it is or may be reasonably needed for useful and beneficial purposes upon lands riparian thereto…"[26]

South Dakota

Like the other "mixed" states, South Dakota recognizes the doctrine of beneficial use. Sec. 46-1-4 of the South Dakota Water Code reads in part that "[i]t is hereby declared that because of conditions prevailing in this state the general welfare requires that the water resources of the state be put to beneficial use to the fullest extent of which they are capable…" Sec. 46-1-6(3) and Section 46-1-8 explain the bounds of beneficial use and Sec. 46-1-15 indicates that in general a permit is required to appropriate the waters of the State. Additionally Sec. 46-5-4 and 46-5-7 indicates that a priority system is utilized.

The reliance on beneficial use indicates that a prior appropriation regime exists; however, the prior appropriation regime is tempered by Sec. 46-1-5(1) which states in part that "the use of water for domestic purposes is the highest use of water and takes precedence over all appropriative rights." Additionally, Sec. 46-1-9 allows for an exemption from the permit requirement for certain vested rights. Sec. 46-1-9(1) and (3) provides that appropriation is subject to the constraint of historical (vested) riparian rights. However, Sec. 46-5-1 indicates that no "landowner may prevent the natural flow of a stream, or of a natural spring from where it starts its definite course, or of a natural

[26] California is also interesting because Sec. 1725 of the code specifically allows for a change of diversion point and/or a change of place of use of the water but only in the volume that would have been consumptively used.

spring arising on his land which flows into and constitutes a part of the water supply of a natural stream…"

Washington

Although Washington water law employs a system of prior appropriation for its recent appropriations, it still recognizes historical riparian rights. Sec. 90.03.010 of the Washington Water Code provides up front that "[s]ubject to existing rights all waters within the state belong to the public, and any right thereto, or to the use thereof, shall be hereafter acquired only by appropriation for a beneficial use and in the manner provided and not otherwise; and, as between appropriations, the first in time shall be the first in right. Nothing contained in this chapter shall be construed to lessen, enlarge, or modify the existing rights of any riparian owner, or any existing right acquired by appropriation, or otherwise."

3.1.5 Summary

Table 3.4 presents a brief summary of the four components of Equation 5 in tabular form. Included are brief descriptions of the English riparian, U.S. riparian and prior appropriation regimes. The mixed regimes are not included because in those states, the benefits and costs are essentially the same as those in the U.S. riparian and prior appropriation regimes – the only analytical difference is that a different (smaller) quantity of water consumed will maximize the net benefits of the resource. Interestingly, the main sources of variability across regimes are the opportunity costs of not consuming the water and the actual costs of using the water (to the downstream riparians, and as a result of investment of infrastructure).

While it is difficult to predict with certainty exactly how property rights will develop *a priori*, or what exactly caused a particular set of rights to develop *ex post*, it seems likely that as the potential benefits associated with consuming water increased, a set of property rights developed. In particular, it is interesting that a different set of rights and expectations developed in the western U.S. and in the eastern U.S. A reasonable explanation of this is that a large portion of the value of water in the east was associated with keeping the water in the stream, while water could be more beneficially used out of the stream in the west. As a result, many of the water transactions that are currently occurring, or have historically occurred, are in the arid west. Nevertheless, as water supply for consumptive and environmental uses has become a more pressing issue, and the accompanying expected cost of drought in other parts of the US has increased, water valuation and trading is expected to gain in prominence.

Regime	***Benefits of Currently Using***	***Costs of Not Using or Opportunity Cost***	***Benefits of Not Using***	***Costs of Using***
English Riparian	Mainly de minimis domestic use	Does not appear to be high; although some entrepreneurs modified the stream for their benefit. The law was not quick to respond to this; however, if the modification was for a sufficient period of time, the modification became "ancient."	Enhanced stream flows for fishing, aesthetic purposes, etc.	Any costs associated with modification and the costs imposed on downstream riparians.
American Riparian	Mainly de minimis domestic use	The benefits lost by not using the water for industrial purposes; mainly as a power source.	Enhanced stream flows for fishing, aesthetic purposes, etc.	Capital investment in industrial operations; modifying the flow, constructing mills, etc. Costs are imposed on downstream riparians because of the modification to

				the flow.
Prior Appropriation	Mainly de minimis domestic use	The benefits lost by not taking the water out of the riparian area and using it; mainly for agricultural purposes or for mining purposes.	Enhanced stream flows for fishing, aesthetic purposes, etc.	Capital investment associated with water diversions. Costs are potentially imposed on downstream landowners due to dewatering or manipulation of the habitat.

Table 3.4: Summary of Water Law Regimes

3.2 Modern Developments

Not surprisingly, water law is not solely the province of state law and regulation; rather, the federal government is an important player in many aspects of the process – particularly in the western US. For instance, the federal government may be called upon to adjudicate disagreements between states, ensure that states follow through with the terms of interstate agreements, and must ensure that international treaties are validated. Beginning in 1902, much of this authority was given to the newly established United States Reclamation Service (USRS), which was within the Division of Hydrography in the US Geologic Survey (USGS) (Bureau of Reclamation 2000, Reclamation).[27] In 1907, the USRS separated from the USGS and became an independent branch of the Department of the Interior. In 1923, it was renamed the Bureau of Reclamation (Bureau of Reclamation 2000). The Reclamation Act required that:

[27] In 1907, the USRS separated from the USGS and became an independent branch of the Department of the Interior. In 1923, it was renamed the Bureau of Reclamation (Bureau of Reclamation 2000).

"Nothing in this act shall be construed as affecting or intended to affect or in any way interfere with the laws of any State or Territory relating to the control, appropriation, use, or distribution of water…"

This meant that Reclamation was bound to operate in conformity with applicable state laws. The prior appropriation doctrine, already in force in the western states, however, provided a framework for which Reclamation was able to operate. It offered credence to the idea that large federal investment could be used for the construction and operation of dam and canal projects, and would not be contrary to state laws. By erecting physical infrastructure, Reclamation provided a means to move large quantities of water long distances, thus facilitating and bringing to the forefront water marketing and transfers.

3.3 Economics and Complications of Water Transfers

Before individual methods of transfer are examined, it is important to briefly enumerate the potential complications inherent in any transaction that moves water from one user and/or location to another. The financial costs of moving water from one location to another may exceed the benefits of the water (Hartwell and Aylward 2007). If the costs associated with moving water exceed the benefits, then there will be no incentive to enter into the market. These costs may include anything from the cost of the water itself to transaction costs to energy costs associated with conveyance. In addition to the financial costs of moving water from one location to another, there may be associated environmental and third party costs (Colby 2000; Hartwell and Aylward 2007). When added to the direct financial costs, the overall costs may also outweigh the benefits of water trading and may make entering into the market less attractive. Water entitlements are heterogeneous. They may represent different volumes or priority dates and there may be positive costs associated with examining particular entitlements.

Water rights can be difficult to measure or vague. For instance, although an irrigator often has the right to divert a particular volume of water, she may not have the legal right to sell the entire divertible volume; rather, a state may only allow the irrigator to transfer the volume that is consumptively used. Calculating the consumptive use volume may be costly and difficult to do with accuracy. Additionally, the seller may have an incentive to overstate the consumptive volume, while other interested parties may have an incentive to understate the consumptive volume.

There may be legal limitations that circumscribe the location of transfer. For instance, state law may not permit interbasin transfers or interstate transfers (Hartwell and Aylward 2007; Garrick, et al. 2008). These rules are often designed to keep water within a particular basin, watershed or state; however, they can create an impediment to transfer even when the benefits to transfer strongly outweigh the costs.

Finally, there may be conveyance loss associated with transferring water from one location to another due to evaporation or seepage. Therefore, if an individual purchases an irrigator's consumptive volume, the volume obtained by the purchaser is invariably smaller than that amount. As a result, the price paid to obtain water should reflect not only the volume of water transferred, the transaction costs associated with consummating an agreement, third party and environmental costs, but also the expected losses in the system.

4. DRY-YEAR WATER SUPPLY RELIABILITY CONTRACTS

This chapter provides a background for understanding the basic aspects of dry-year water supply reliability contracts for the purpose of enhancing water supply reliability. Included is a review of economic theory supporting its use as well as a guide for its use.

4.1 Reliability Contract Background[28]

The term reliability contract[29] is used to refer to contractual arrangements made in advance of need under which a change in water use is triggered by low supply conditions. Like all contracting devices, a reliability contract specifies payment and risk sharing between the contractor and contractee.[30] The contract generally specifies up-front payment and then exercise payments if the trigger event occurs, and may extend for one year or any number of predetermined years. Under this scenario, the contractor guards against at least five risks while the contractee receives consideration.[31]

First, the contractor guards against the threat of drought as the option may be exercised if the trigger event occurs (Williams 2007). Second, by not purchasing or leasing the water outright, the contractor guards against the threat of having too much water in relatively wet years; consequently, the contractor minimizes the likelihood of

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[28] This thesis is not intended to be used in lieu of legal advice. If the user intends to enter into a contract it is advisable to retain an attorney.

[29] A water supply reliability contract may take the form of an option contract or other similar contract. Because there is a large degree of overlap between the two arrangements, an option contract framework is generally used and distinguished where appropriate.

[30] The contractor is the party seeking to procure water. The water-selling parties, or contractees, are generally irrigators. This is because irrigator water withdrawals account for approximately 40% of the freshwater withdrawals in the United States and 80% in the western United States (USGS 2009).

[31] Consideration may take a variety of forms: a monetary payment, debt forgiveness, favorable pricing for services, livestock feed to substitute for crops not grown, water management benefits or other services. If the contractee is a grower, then consideration received can be treated as analogous to producing another "crop" (forbearance) in the farm's financial risk management portfolio.

purchasing excess water and associated costs of storing permanent water acquisitions and of storing the excess (Williams 2007).[32] Third, the contractor guards against the risks associated with political resistance to permanent water transfers, which may limit the quantity and duration of a transfer agreement (Howe 1996). Fourth, the contractor guards against the risk of price volatility over time (Woo et al. 2001). The contractor locks in a contractual rate for the life of the contract and is insulated from market rate variation.[33,34] Finally, a reliability contract may mitigate the likelihood or impact of urban demand hardening because water is transferred only if the trigger event occurs.[35] Therefore, urban users may be more willing to participate in conservation measures due to the extra protection provided against drought or shortage.

If an option contract framework is used, the party selling the option receives a negotiated payment per volume of water and refrains from using that volume for the contractually specified period.[36] The reliability of this arrangement rests on the probability that water is available in the system for the entitlement holder. Under severe dry conditions, even very senior entitlements may not yield water. When the option is

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[32] Storing the excess water underground may be an added mitigation measure if the contractor has access to a recharge facility. (Guenther 2008).

[33] As water price and scarcity increases, contractors face associated increased levels of uncertainty. As a result, contractors may seek multiple arrangements so that they have some choice regarding where to get water and how much to pay. This process of seeking multiple deals, however, may ultimately increase the procurement costs of water because searching and negotiation across multiple potential agreements is costly.

[34] Likewise, this can be attractive to the contractee because she is also insulated from the variation in market rate.

[35] Demand hardening is the concept that as a water service area becomes more efficient, it becomes more difficult to save increased volumes of water during a shortage or drought (Maddaus 2008).

[36] In an option contract framework, the up-front payment is generally called an option premium. In other reliability contracts, however, the up-front payment is not considered a premium; rather, it is exactly what the name suggests: an up-front payment.

exercised, the contractor pays the contractee a specified additional amount of consideration (exercise payment) per volume of water obtained; the irrigator then fallows a portion of her land in order to transfer water that would have been used for irrigation to the contractor in accordance with the terms of the contract (Hass 2006). The upfront consideration (option premiums) and exercise payments can help to smooth out the typical variability in agricultural revenues by diversifying a growers agricultural portfolio to include water leasing revenues (Mays, et al. 2002).[37]

If a different type of reliability contract is used (instead of an option contract framework), many of the important components of the process remain the same. In each case there is a negotiated upfront payment and a trigger event is identified. If the trigger occurs, then the contractor is entitled to use the volume of water specified in the contract. A key distinction between the typical option contract framework and other reliability contracts is the payment structure and/or the type of consideration exchanged. For instance, instead of paying an option premium, a contractor may elect to purchase a grower's land and then lease that land back to the grower and allow the grower to continue irrigation. If an agreed upon trigger occurs, the grower relinquishes the right to irrigate.[38] In this case, neither an option premium nor an exercise payment is paid to the

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[37] Hansen, et al. (2007) calculated that gains of trade could be had by parties and that prices converge to a relatively competitive level even in thin markets.

[38] This type of arrangement is often referred to as a "contingent lease-back."

grower; however, this arrangement is still considered a reliability contract because it is an arrangement made in advance of need that is triggered by a specific event.[39]

A dry-year supply reliability contract can extend for a single year or for any number of contracted years (Mays, et al. 2002).[40] The time horizon of the contract will depend in part on the type of water supply variability that the contractor would like to mitigate (Mays, et al. 2002).[41] As with any contract, details should be developed and finalized before water shortage conditions occur, or at least with adequate time for all parties to agree to review and agree on its terms.[42]

The procured water may move to a different type of user or be temporarily used out of its original geographic area. Therefore, it is important to consider the potential impacts on parties affected by, but not engaging in, the transactions. For instance, a result of not using the water in a particular area (or on a particular farm) may be that return flows that downstream users expect are no longer available.[43,44] Additionally, if growers

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[39] This is not the only type of non-option contract supply reliability contract. A contractor may creatively tailor a contract to suit her needs. Several other examples of these types of arrangements are explained in the section below.

[40] Some participants may be wary of participating in multiple year contracts or even participating in too many consecutive years (SacBee 2004). Irrigator caution in water transactions has also been documented in the Yakima River basin (Rux 2008). To this end, it is important to build trust with the contractees/irrigators so that they feel involved and a part of the process.

[41] Mays, et al. (2002) provide an example where the time horizon for the length of the option contract may be different if the purpose of the contract is to potentially acquire a volume of water during an earthquake versus periodic drought.

[42] The volume of water to be obtained if options are called must not exceed the volume of water that is legally allowable. For instance, while an irrigator may enter into a reliability contract, the maximum volume that may be called and transferred is typically that irrigator's consumptive amount. Relevant laws should be consulted. It is important to note that although the consumptive volume may be transferrable, the contractor may receive less than the consumptive volume because of conveyance losses.

[43] If an irrigator diverts a volume of water but not all of it is consumed, then the non-consumed portion (seepage and runoff) may return to the original watercourse. When, however, the water is conveyed sufficiently far away from the original water source, return flows patterns will be altered.

are paid to fallow their fields there may be lost income to agricultural laborers due to reduced demand for labor services (Sunding, Mitchell and Kubota 2004). To offset such third party economic impacts, payments to affected third parties might be included in the contractual arrangements (Sunding, Mitchell and Kubota 2004).

It may also become necessary to consider the potential environmental impacts of fallowing, although the impacts may be considered positive or negative. For instance, fallowing may lead to the potentially negative impacts of erosion or excessive weeds and dust. This may become particularly acute in situations where the reliability contract is several years in length. One potential solution to this problem is to rotate land fallowed (MacArthur 2004). Fallowing, however, may lead to positive benefits in some situations. Assuming that larger volumes of water are kept in the watercourse, riparian habitat and fish populations may benefit (Israel and Lund 1995).

The types of environmental impacts (positive and negative) that ought to be considered are case specific and in some cases, a mitigation strategy may be integrated into the supply reliability contract.

4.2 Dry-Year Reliability Contract Examples

Option Contracts

Dry-year option contracts have been used intermittently in California beginning in the early 1990s (Jercich 1997). In 1995, the state of California's Water Bank negotiated contracts with local irrigation districts for the option to purchase 29,000 acre-feet of

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[44] Generally, the procured water must be upstream from the diversion point. If it not upstream, then groundwater/surface water and storage exchanges may be available in some instances.

water (Jercich 1997).[45] The Bank was permitted to call the option by May 1995 and if the option was not called, the growers kept their option premiums (Jercich 1997).[46] In this instance, the options were not called because the winter months were wetter than anticipated, so additional water was unnecessary (Jercich 1997).

In the winter of 2002, the Metropolitan Water District of Southern California (MWD) negotiated with the Sacramento Valley irrigation districts for one-year option contracts for 146,000 acre-feet of water (CDWR 2002; Jenkins 2008). Under the contract terms, MWD had until March 2003 to call the option and if the option was not called, the growers kept their option premium (CDWR 2002; Jenkins 2008).[47] Because the end of 2002 and beginning of 2003 was dry, MWD called all of the options (MWD 2003a; Jenkins 2008). In April, after the options were called, it began to rain – making the called water unnecessary (MWD 2003b; Jenkins 2008). As a result, MWD had more water than could be stored and much of the option water flowed out to the ocean (Jenkins 2008).

In an effort to minimize the likelihood of repeating the 2003 experience, MWD negotiated with the irrigation districts for an additional year of option contracts. However, it negotiated with the irrigators to extend the deadline to call the optioned water from March to April in exchange for a higher option premium (MWD 2004;

[45] The price paid for the option premium was $3.50 per acre-foot (Jercich 1995).
[46] If the options were called, the price paid to the irrigators would have been a pre-negotiated price of $35.50 – $41.50 per acre-foot, in 1995 dollars (Jercich 1995).
[47] The option premium was $10 an acre-foot. If the option was called, MWD was obligated to pay an additional $90 per acre-foot for the option water (Jenkins 2008).

Jenkins 2008).[48] In 2005, this contract modification was validated as a relatively heavy rain hit in April, making calling the optioned water unnecessary (Jenkins 2008).[49]

In addition to relatively short-term option contracts, MWD has also entered into a long-term (35-year) fallowing contract with the Palo Verde Irrigation District (PVID) beginning in 2005. Under the terms of the agreement, a base load area of approximately 6,000 acres will be fallowed for each of 35 years up to a maximum of 24,000 acres in any 25 years and a maximum of 26,500 in any 10 years (PVID 2004a).[50,51] MWD determines the acreage for fallowing and that is based upon forecast demand, supply and storage conditions. Regardless of the volume of water called in any particular year, MWD must call at least 12,000 acres on average over the 35 years of the program to fulfill contractual requirements (PVID 2004a). In return, MWD agreed to pay $3,170 per water toll acre times the landowner's maximum fallowing commitment, where a maximum of 35% of a particular landowner's land is eligible for the sign up payment (Trends 2004). If an option is called, MWD will pay an additional $602 per acre fallowed that year (PVID 2004a).[52]

Other Supply Reliability Contracts

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[48] MWD agreed to pay the irrigators an option premium of $20 per acre-foot for the ability to call the water in April instead of March (Jenkins 2008).
[49] Although MWD paid a total of $1.25 million in option premiums in 2005, it would have had to pay $16 million if it had purchased the water outright.
[50] The years do not need to be consecutive.
[51] Participants are not allowed to switch to groundwater if options are called. Additionally, the agreement requires participating irrigators to participate in land management measures including weed control and erosion control (PVID 2004b).
[52] Annual payments will be adjusted by 2.5% per year for the first ten years and then between 2.5% and 5% in all subsequent years based on the Southern California Consumer Price Index (PVID 2004a).

In addition to the typical option contract framework, there are other interesting examples of agreements that may be made in advance of need and are triggered by a particular event. The first is the Bonneville Power Administration's (BPA) load reduction program. BPA is a federal agency headquartered in Portland, Oregon which markets hydro-generated power to the Pacific Northwest (BPA 2008). Because electricity generation is tied to water availability, a reduction in water volume can limit generation capacity. In dry years, BPA uses a load reductions and load buy-backs in an effort to limit their own water demand (BPA 2002). This ensures that minimum stream flows for fish passage are observed (BPA 2001). Years are considered 'dry' when winter runoff is below a predetermined volume (BPA 2006).

An important component to this arrangement is that BPA's dry-year buy-backs may only be used during specified times during the calendar year for some purposes. For example, a buy-down is available whenever the direct service industries (DSI) are operating at high capacity and are willing to participate whereas an irrigation buy-down is available only between April and September and must be implemented prior to planting (BPA/KC 2001).

Another example of an innovative supply reliability agreement occurred in Utah when a city paid a farmer $25,000 for a 25-year dry year option and agreed to provide $1,000 and 300 tons of hay in any year that the option was exercised (Clyde 1986). Because of this agreement, the city was able to acquire the volume of water that it desired and the farmer was able to continue farming operations. A similar model was used by the Oregon Water Trust when it paid a farmer $6,600 to compensate him for not growing hay to feed his livestock (Anderson 1998).

A similar supply reliability contract is a conditional lease-back. A conditional lease-back is an agreement in which land and water are purchased by the entity desiring long-term control of the water and are leased back to the irrigator so that irrigation can continue except when water is needed to replace drought shortfalls (Colby 2003). This is similar to an option contract in the sense that the water may be called periodically and irrigation suspended. In order for this arrangement to be attractive to farmers, the up-front payment by the water seeking entity to purchase the farm and water rights must be attractive, along with the timing of notice to cease irrigation and other terms of the lease.

4.3 Structuring the Reliability Contract[53]

A preliminary consideration when engaging in a dry-year reliability contract is to determine what volume of water is needed to achieve the desired levels of supply reliability.[54] Because it costs the contractor more money to keep a larger volume of water in option, the goal is to keep the minimum volume of water in option to achieve adequate insurance against supply shortfall. This balancing should incorporate available climate and hydrological models used for predicting supply variability, where practical (Hartmann 2005; Troch et al. 2008; Lyon, et al. 2008; Teuling et al. 2007; Hirsch et al. 1993; Salas 1993; Stedinger et al. 1993). The models can assist in the determination of

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[53] It cannot be overemphasized that it is necessary to consult local and federal laws to determine what volumes are legally available to be transferred, if any. For instance, a state may only allow an irrigator's consumptive volume to be traded (as opposed to the diversion or beneficial use volume). *See*, Section 1725 of the California Water Code. And this transfer is likely to be subject to transportation losses due to seepage and/or evaporation. Additionally, to ensure the legal validity of the contract, the buyer and seller must be aware of the volume that is legally available to be transferred, if any.

[54] It is also important to decide whether to utilize an option contract or other form of reliability contract.

whether a year is expected to be relatively wetter or dryer, and in dryer years, or in those years when reservoir storage is low, it may be appropriate to place more water in option.

It is also necessary to determine with whom to contract. Generally it is expedient to contract with parties that own relatively senior water rights, as they are less likely to have supply interruptions (Mayes, et al. 2002). The contractor may purchase the option to more junior rights, but because such rights are not as secure as more senior rights the water may not be available during drought.[55] Also, it may be necessary to either rotate eligible participants or eligible tracts of land from one contract period to the next to minimize some of the negative impacts associated with fallowing (IID 2007).[56]

When utilizing an option contract, an important issue is the determination of how much money to spend per volume of water for the option premium, and how much to spend per volume of water if the options are exercised (the exercise payment). With respect to the option premium, from the perspective of the contractor, the minimum amount of money that is necessary to keep the option open is desirable. However, the contractee likely wants to receive a large premium for enrolling a portion of their acreage. Negotiations must be successfully concluded between the contractor and the contractee to determine a mutually acceptable trade. Likewise, if the option is called, the contractor would like to spend the minimum amount of money where the contractee would like to receive the maximum payment. Again, the contractor and contractee must

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[55] Purchasing senior rights helps ensure that wet water rights are likely to be transferred rather than paper rights. If water is needed by the contractor, it is important that wet water rights are transferred (Yardas 1989).

[56] Rotating the eligible participants can provide an additional side benefit of making the non-selected participants feel involved in the process.

negotiate to determine an acceptable amount of money per volume of water on the called water.

Determining how much to pay for the option premium and exercise payment can be a difficult task, and in regions with relatively rare transactions, it may be difficult to find a basis for comparison. Nevertheless, the prices paid should reflect current market conditions (as nearly as possible) for water rights and the level of risk associated with supply shortfalls.[57] Put differently, the offer amount should be gauged against the benefits foregone by using the water in the manner proposed by the contract and foregoing the usual use of the water (Jaeger and Mikesell 2002). While many potential methods of establishing a value for water exist, three methods are commonly used. First is the sales comparison method, which uses direct observation of transactions prices in voluntary water transfers (Colby, Pittenger and Jones 2007; Young 2005). This method may be appropriate where sales information of voluntary water transaction exist and is available in a particular area or basin. However, because water transactions are relatively uncommon, this approach may not be appropriate in all instances.

Second is the water-crop production function method, which measures the relationship between water application and crop output and is useful for locations and crop mixes where "accurate up-to-date water crop functions are available" (Colby, Pittenger and Jones 2007). The models can be used to show how crop yields, farm

[57] This may be difficult to accomplish, particularly when the contract extends for multiple years. Additionally, "the value of water varies enormously, depending on the supply source's reliability, quantity of water, access and cost of conveyance, duration and firmness of contractual commitments, and the buyer's type of use and alternative sources of comparable water supplies" (Water Strategist 1997). Additionally, economic conditions, federal farm programs, political climate and many other variables may impact the prices paid.

operations and net income will respond when water supplies are constrained, and can therefore provide insight into the values that irrigators may place on their water entitlements (Jaeger and Mikesell 2002). However, this approach is limited to regions for which the necessary data and production functions are available. The third approach is the residual (or farm budget) method, which estimates net returns to water per acre for regional crop mixes. (Colby, Pittenger and Jones 2007; Young 2005). This method provides insight into the role of crop input and output prices and quantities in determining on-farm water values (Young 2005; Colby, Pittenger, and Jones 2007).[58]

In years of relative water scarcity or high demand (or the expectation of scarcity or high demand) prices would be relatively higher. Nevertheless, in order for a deal between the two parties to be realized, the sum of money paid to the irrigator must equal or exceed the net income she would have received had her land not been fallowed (Haas 2006). Also, if the contractor is assigning a greater level of risk to the irrigator by extending the date at which the option can be called, as was the case with MWD in 2003, the option premium would be expected to be higher (Jenkins 2008). As with any negotiation strategy, the contractor should have a predetermined budget for the amount of money it is willing to spend if the optioned water is called and a predetermined budget for the option payments.

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[58] The Water Strategist suggests using an Equivalent Single Price (ESP) technique for calculating the value of a water contract when the expected volume of deliveries is different from year to year. Under this method, ESP = present value payments/present value deliveries; the payments then have financial integrity (Water Strategist 1997). This method could be considered when the option recurs annually.

It may also be necessary to determine when the contractees will be compensated for participating in the contract.[59] At a minimum, the contractees must be paid by a particular date for engaging in the option contract and a date (or date range) must be specified for which the contractee must be paid if the option is called. If the option is called the contractee may be paid in installments over the time period the water is being used for other purposes (IID 2004b).

An important related concern when structuring the option contract is to determine the date range within which the option may be called. In this determination, two main issues are important: first the window to call the option must be timed such that the contractor is able to take delivery of the water when it is most likely to be needed. For instance, if the optioned water is needed in summer the contractor will want the call window to be in spring not in fall. If the options are called too early, the contractor faces the risk that the optioned water will no longer be needed if late spring rains ease the drought.

Second, the contractor's optimal timing windows must be counterbalanced against financial considerations for irrigators in their seasonal farm planning and operations cycle.[60] If the call window is negotiated near to or after the planting cycle, then irrigators will demand a higher option premium in consideration of crop production costs already incurred. The closer to the planting cycle that the option window is open, the more costly it is for the irrigator to cease irrigation on short notice. MWD encountered this timing

[59] This is true for both the option payment and the exercise payment.
[60] For an example of the potential differences in crop planting cycle, see Sample Dry-Year Supply reliability Contract section.

issue in 2003 and increased the premium that it paid irrigators for keeping the option window open an additional month (Jenkins 2008).

4.4 Trigger Mechanisms

A practical consideration is determining what events will cause the option to be called. There is no clear cut method for determining when to call an option; however, the trigger should be pre-specified, objective, not influenced by actions of parties to the agreement and observable to the participants so that they have a reasonable expectation of the outcome and the trigger should be related to the ultimate purpose of the optioned water (Mayes, et al. 2002). For instance, calling the optioned water may be based upon stream flow levels (Willis, et al. 1998; CDWR 2000). That is, the option would be called if stream flow fell below a predetermined critical level. Stream flow was proposed as a trigger for calling an option in the Snake River Basin to ensure adequate water levels for the salmon population (Willis et al. 1998). In areas where winter runoff provides an important water supply, winter runoff volume may be used as a trigger mechanism (BPA 2002). BPA has used runoff volume as an indicator of when to employ dry-year techniques to ensure water availability.

Another potential trigger for calling optioned water is reservoir elevation. Because a particular reservoir may be used to determine whether drought conditions exist, a contract may be structured such that if a chosen reservoir falls below a predetermined target elevation (or volume) some of the optioned water may be called (CDWR 2000). In areas where groundwater is used to supplement surface water, marked increases in groundwater pumping may be used as a trigger to call optioned water (CDWR 2000). A dramatic increase in groundwater pumping may indicate drought conditions because it may imply that surface water resources are limited. In order for this trigger to be effective groundwater pumping must be measured and a threshold for calling the optioned water must be developed. If groundwater is used to supplement surface water supplies, then it may be valuable to create a trigger index based on some combination of reservoir levels and groundwater conditions.

There is potential to use climate forecast information for several purposes related to dry year water use arrangements (Hartmann 2005). Climate forecasts potentially can be used to assess how frequently an option is likely to be exercised over a specific period of years. This may affect the terms of the contract and the payments parties require to participate. In addition, climate forecasts may also be useful to determine when to call optioned water within a specific year. Climate change is projected to alter the probability, magnitude and duration of water shortages in the Southwest (Hartmann 2005). Climate and water supply forecasts may be useful in predicting how often a trigger condition would occur in a decade. This information can be valuable in structuring the contract as the contractor likely will want more frequent opportunities to exercise options and irrigators may wish to have higher option premiums to compensate them for more frequent disruption of farm operations. More general climate information, such as whether a particular year is strong El Niño with snowpack likely to be above average, can be valuable to both contractor and irrigators in their planning.

In some years it may be the case that not all of the options need to be exercised, and so it is necessary to develop a decision rule for selecting which options to exercise.[61] Any method that is logical and clearly enumerated to program participants may be employed for this purpose. For instance, one method that may be utilized is to exercise the options starting from the most senior (i.e. most secure) water right to the most junior until the desired water supply is acquired.[62] However, senior water rights may command a premium and cost more per unit of water transferred. An alternate selection rule would be to exercise options moving from lowest cost per unit to higher costs until water reliability needs are satisfied. Another possible method is to employ a random selection scheme among water entitlements of similar cost and reliability characteristics.[63]

4.5 Monitoring and Evaluation

After a volume of water is called in a reliability contract, it is necessary to implement a monitoring and enforcement scheme to ensure that program participants comply with contract terms. Typically this involves ensuring that participants cease irrigation on the lands the contract obligates them to refrain from irrigating for the time period agreed upon. Because monitoring and enforcement of irrigation for specific land parcels can be costly, it is important to utilize tools appropriate for the given situation. Regardless of

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[61] An additional caveat may be included that those that are not selected this year have priority in the subsequent years.

[62] It may be desirable to only contract with irrigators that have a desired priority date; i.e. with irrigators with the most secure entitlements.

[63] In some circumstances it may be appropriate to design a system where those individuals (or acreage) not selected this year have priority the following year. This can help in minimizing the negative environmental impacts associated with continuously fallowing the same land.

what tools are utilized, it is important to clearly specify what agency is responsible for monitoring compliance and how that compliance will be determined.

Several tools to enforce the terms of the contract may be available. For instance, in some situations locking irrigation gates may be appropriate (IID 2004a). Another manner of ensuring compliance is to utilize remote sensing imagery to ensure that water is not being used on specific tracts of land. Remote sensing imagery can distinguish whether land is being actively irrigated in many arid areas. A common manner of enforcement, however, may be to have enforcement staff drive through and inspect parcels that are no longer supposed to be irrigated.

As with any implemented program, conducting an evaluation is necessary to determine success or failure. The goal of a water supply reliability contract is to manage the risk associated with water supply variability while minimizing the cost to do so. In a given year, therefore, it is appropriate to first consider whether the proper volume of water is optioned or exercised. A contractor is interested in exercising a sufficient number of options to minimize the risks associated with water variability while avoiding exercising too many options such that the program becomes unduly expensive.

By the very nature of this type of contract, however, options would only be called when they are necessary. That is, on average the option contract scheme should bring about the desired result by properly insulating the contractor from risk. Thus, to judge a program's efficacy, it may be helpful to study a series of years to determine whether the underlying hydrologic model is effective at determining probabilities of shortage. This type of long term analysis can assist in determining whether too many, or not enough, options are being exercised from year to year and whether modifications to the contract should be made.

It may also minimize the likelihood of false positive and false negative results. A false positive occurs when the trigger indicates an upcoming shortage and water options are exercised but not actually needed. A false negative occurs when an insufficient volume of water is optioned and a genuine shortage materializes. If the volume of water called when the trigger occurs consistently overshoots or undershoots the volume actually needed, then it may be necessary to alter the trigger indicator and the underlying hydrologic model that indicates probabilities of shortage, and to update the volume of water optioned.

Another important measure of success is the amount of money paid to: (1) create the options (or the upfront payment amount); and (2) pay for the called options (or the consideration paid if the trigger occurs).[64] If a volume of water was called in option, then one measure for assessing the success of the program is whether the cost of obtaining the optioned water is less than the cost of an alternative supply method. Alternative methods may include storing water in a reservoir or underground (i.e. banking the water for a later date) or obtaining water after it is needed through auctions, leases, purchases or any combination of the three.

If it is less costly, or more secure, to engage in an alternative supply reliability strategy, then it may be more effective to utilize that alternative. In order to compare across alternatives, it is important to consider the whole range of costs incurred for the

[64] This must include all of the costs associated with contracting and contract administration.

reliability contract[65] and compare that against the total costs of implementing an alternative program.[66]

This discussion assumes a series of single year contracts; however, a long-term contract may be analyzed in a similar manner. The long-term contract can be examined on a year-to-year basis or over the life of the contract. A contractor must be aware, however, that because she receives a higher level of security for a longer-term contract (because of the guarantee of water availability by the contractee for a longer period of time), the up front and exercise payments may be higher on average.[67] However, a relatively shorter-term contract, because the terms can be renegotiated on a more frequent basis, may exhibit a higher degree of variability from contract to contract. Therefore, it may be necessary to determine whether it is more cost effective to enter into a series of short-term contracts or a long-term contract. But this must be counterbalanced by the fact that the contractor receives a higher degree of security in a relatively longer-term contract.[68]

In order to fully assess the effectiveness of the program, it is also necessary to consider the contract administration and monitoring costs. Because of their relative complexity, negotiating and drafting reliability contracts are time and labor intensive;

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[65] This includes the cost of all of the option premiums plus the payments paid for the options that were exercised plus any contract administration costs.

[66] Another strategy that may be employed by the contractor is to do nothing at all. The costs associated with that strategy include costs of a potentially having an insufficient water supply.

[67] However, this is not necessarily the case because the irrigators are also provided with security due to obtaining the up-front option premiums.

[68] It may be that an optimal contract length can be determined. This contract length will minimize both risk associated with water supply variability and cost while also providing the contractor the opportunity to be responsive to changing conditions.

legal counsel will likely be necessary to negotiate and draft a contract and the cost(s) may be high. Assuming that a contract is consummated, there may be additional contract monitoring costs to consider. It is necessary to monitor growers' water consumption to ensure that they are following the terms of the agreement.[69] If they are not following its terms, it may be necessary to spend additional resources to enjoin their use.[70]

4.6 Summary

Reliability contracts provide a method to reallocate risk between water supplier and water demander whereby water is only transferred when a predetermined and verifiable trigger condition occurs. Although an initial investment by the demander is required for the opportunity to obtain the water at a later date, the costs and risks associated with not having access to enough water during times of shortage and with having too much water in times of surplus is minimized. Additionally, even if options are not called by the demander, the water supplier essentially has another item in its crop portfolio, which helps to diversify her agricultural risk. Reliability contracts are one potentially valuable tool for acquiring water supplies as part of an overall strategy to address supply uncertainty and longer, more severe droughts that are expected to accompany to climate change.

[69] Even if the State is ultimately responsible for calls and monitoring, the State may require funding for providing the service.

[70] This may be done by way of a simple cease and desist letter from counsel or it may be necessary to litigate the issue in a court of law.

5. Water Auction Design for Supply Reliability[71]

This chapter provides a background for understanding the basic aspects of water auctions for the purpose of enhancing water supply reliability. Included is a review of economic theory supporting the use of water auctions as well as a guide for its use. Also included is a table that provides metrics that may be used to determine whether an auction is successful as well as detailed instructions for conducting each calculation.

5.1 Water Auction Background

Water auctions can generally be described as a special type of auction called a procurement auction. In a conventional auction, several bidders attempt to purchase a particular item from a singular seller of the item (the auctioneer). In a procurement auction, however, several bidders compete to sell a particular item to one purchaser (the auctioneer).[72] Conventional auction principles can be applied to procurement auctions which fit a typical water acquisition scenario: one purchaser and many sellers (Hartwell and Aylward 2007). It is also generally assumed that revenue equivalence exists amongst auction designs (Vickrey 1967; Milgrom 1989).[73] The building blocks of water auctions are described below.

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[71] In any arrangement transferring water, the buyer and seller should proceed with caution. State and federal laws may limit either the volume of a proposed transfer or the location of transfer. Local laws should be consulted. For a state statutory example, *see* footnote 9, below.

[72] In a procurement auction, the auctioneer's objective is to obtain the resource at the lowest possible cost. Additionally, in a procurement auction, bidders are attempting to sell an item (or service) at the highest possible price. This is contrasted with a conventional (non-procurement) auction where the auctioneer's objective is to sell the item at the highest possible price and the bidder is attempting to buy the item (or service) at the lowest possible cost.

[73] Revenue equivalence implies that regardless of the specific auction design chosen, the dollar value of the winning bid is expected to be the same. To sustain this result, however, several assumptions are required. They are: independence of bidders' values, bidder risk neutrality, lack of bidder budget constraints and that

First, it is important to determine who is eligible to participate in the auction. The auctioneer must determine whether geographical restrictions are necessary (Garrick, et al. 2008; Hartwell and Aylward 2007). For instance, it may not be appropriate to allow out-of-state water entitlements[74] to be included in an auction. Further, it may also be advantageous to refine the geographic restrictions to those entitlements that can serve the goals of the particular auction, for example, if the entitlements are from within particular river basin(s) or regions.

Second, it is necessary to determine which entitlements, or what type of entitlements, will be included in the auction. For example, it may be advisable to only allow entitlement holders that actively use their water allotment and have a minimum entitlement amount to participate in an auction (Hartwell and Aylward 2007). This requirement serves at least two purposes. First, if the entitlement holder is not actively utilizing her entitlement but the water is still auctioned, and potentially transferred out of the area, return flow patterns will be disrupted which may impact other downstream water entitlements and downstream ecosystems.[75] Second, by only allowing volumes of

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all bidder values are drawn from the same distribution (Krishna 2002). These assumptions often are not satisfied in practice.

[74] For the purposes of this guidebook, the term "water entitlement" is a generic term referring to any type of transferrable water entitlement; including water rights defined by state law, contractual rights to water from a federal project, etc.

[75] If the purpose of the auction is to acquire wet water, it may be necessary to ensure that the auction is restricted to the most senior or "drought proof" types of entitlements in a region and to entitlements which have been regularly exercised.

water that are above a minimum threshold level, costs of administering the auction are contained.[76]

After a threshold level is set, it is necessary to determine how much of their entitlement the bidders can offer for auction. In some auctions, participants were required to place their entire entitlement amount (or consumptive use volume) in auction (Cummings 2003), while in other auctions participants were able to auction a portion of their entitlement amount (Hartwell and Aylward 2007). An advantage of the full entitlement requirement is that it simplifies post-auction monitoring (Cummings 2003). Counterbalancing this, however, was that most of the participants owned more than one entitlement, so auctioning one (or more) entitlement would not severely handicap their agricultural activities. If post-auction monitoring is not problematic then allowing participants to auction portions of their entitlement may lead to preferable results.[77]

A related legal consideration is whether individuals may auction a volume based upon a permitted (or diversion) volume, or whether the auction should be designed to consider consumptive use amounts (Garrick, et al. 2008). In order to determine the volume that an entitlement-holder may transfer, it may be necessary to consider the type of right being transferred. For instance, if a water right is arising from an imported water supply, the State may not require return flows to be left in the river because absent the

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[76] If the auction is designed to occur in several subsequent years, it may be necessary to require rotation of eligible participants to broaden overall participation. In addition, it may be useful to rotate the specific tracts of land on which irrigation is being foregone in order to minimize possible environmental impacts from continuously fallowing the same fields (IID 2007).
[77] This is based mainly on the assumption that individuals will be more likely to participate in an auction if they can determine what portion of their entitlement (or consumptive volume) they are willing to auction, rather than being required to auction an entire entitlement amount. As a result, a larger volume of water at a lower price per unit may be obtained.

import of the water, the return flows would have not been available in the first place. Similar idiosyncratic issues may need to be considered on a case-by-case basis. This is particularly important in states that practice the doctrine of beneficial use because while the entitlement holder has ownership over the volume that she beneficially uses, in many cases she may only transfer a volume of water that she consumptively uses (*see*, Arizona Revised Statutes (A.R.S. 45-141(b)).[78,79] This is because downstream users benefit from the runoff, or unused portions by upstream users, and can claim legal injury if the return flow volumes that they have come to expect and beneficially use are not available (A.R.S 45-141). Because it is difficult to determine the exact volume that is consumptively used, it may be necessary to instead use a proxy in order to estimate the volume.[80] Regardless of the method chosen, it must be clear to all participants exactly how the calculation is made.

In the case of a water auction, an additional consideration is what units of volume to use in conducting the auction. Both Hartwell and Aylward (2007) and Cummings (2003) provide examples of actual auctions conducted on a basis of price per acre of land

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[78] Although the doctrine of beneficial use is a well know water law concept and codified in statute, it can become complex as implemented across various jurisdictions. For an interesting discussion, see Neuman 1998.

[79] For instance, Section 1725 of the California Water Code reads in part: "A permittee or licensee may temporarily change the point of diversion, place of use, or purpose of use due to a transfer or exchange of water or water rights if the transfer would only involve the amount of water that would have been consumptively used or stored by the permittee…"

[80] It may be necessary to consult local laws and consider precedent in other water transfers to determine how the consumptive volume is determined. This is for two main reasons. First, in order for a valid transfer to occur, both parties must agree, and be clear, on the volume to be transferred. Second, there are often state and federal laws that restrict the volume that may be transferred. If these laws are violated, the agreement may be invalidated.

removed from production.[81] However, auctions could be conducted on a basis of acre-foot[82] or any other standard volumetric unit. What is critical, is selecting a quantity that is relatively easy to calculate and is well understood by the participants.

Another important consideration is whether to incorporate information technology into the auction design. Information technology can aid in streamlining many facets of the auction process including bid submission and data collection, and it facilitates communications between the bidders and auctioneers. Cummings (2003) provides an example of how bids can be submitted in several different locations but can be quickly compared as a result of using the internet. Hartwell and Aylward (2007) explains how the Deschutes River Conservancy used a combination of fax machines and telephone calls to collect bids in an ascending bid groundwater auction and immediately posted those bids online. This method provided the bidders with instantaneous and up to date information so that they could revise and resubmit bids.[83] Bjornlund (2003) discusses how the internet is used in South Australian spot water market in an interactive manner for the same purpose. Rather than occurring once a year, however, the South Australian internet auctions are conducted weekly.

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[81] Conducting auctions in terms of acres of land removed from production may only be practicably employed when the duty of all of the participants' water rights are nearly the same per acre of irrigated land. For instance, in the Deschutes River auction, the duty of all of the participants' water rights was 4 acre feet of water per acre of land. This allowed the participants to submit a bid based upon the amount of acreage they wished to take out of production rather than being required to submit a bid based upon acre-feet. *See*, Hartwell 2007.

[82] An acre-foot of water is defined as a volume of water that would cover one acre to a depth of one foot. http://www.merriam-webster.com/dictionary/acre-foot.

[83] Because bidders may attempt to game the auction between rounds, care must be taken when using this type of iterated approach. Nevertheless, despite the risks, this type of auction design can bring about desired results (Cummings 2003; Bjornlund 2003).

Despite these successful uses of information technology in facilitating the auction process, it is not used in every instance. Potential participants may not all have access and experience with using the technology (Hartwell and Aylward 2007). If the auction is conducted entirely over the internet, but some participants do not have access to the internet or have misgivings with the technology, then there will be reduced participation. The level of information technology used must be considered and perhaps training administered for likely participants.

With water auctions, timing is important because the individuals most likely to participate in the transaction are farmers that need to plan participation based upon crop planting cycles (Jenkins 2008; Cummings 2003; Hartwell and Aylward 2007). Because an important intermediate goal of any auction is robust participation, it is important to conduct the auction at a particular time that minimizes uncertainties created by the auction. The auction should be held early enough in the annual crop planting cycle so that the participants can plan their farming operations and leasing portfolio simultaneously.

At the conclusion of the auction, it is necessary to determine how and when winning bidders will be compensated. A simple method of compensation is to pay a lump sum amount to the winning bidders by a specified date. Another, more complex, method is to pay the winning bidders in installments. For instance, in one water transaction, participants were paid in three installments: the first installment was paid within sixty days of entering into the agreement, the second installment was paid within six months of entering into the agreement but only after bidder compliance had been verified, and the third installment was paid once it had been determined that all of the provisions of the agreement had been met, and no later than sixty days from the contract termination date (IID 2004b). Various payment schedules and methods may be devised. These should be explicitly described in auction program information for potential participants.

5.2 Overview of Water Auction Design

Procurement auctions can be broken into three different types: ascending auctions, descending bid auctions, and sealed bid auctions (Hartwell and Aylward 2007). In an ascending auction, the price starts at a relatively low level and begins to rise. The winner is the participant that is the first to stop the rising price of the item. This ensures that the bidder who wishes to sell the item at the lowest possible price is victorious.[84] In contrast, in a descending bid auction, the bid price starts at a relatively high level and begins to fall. In this scheme, bidders compete to bid the price downwards until no participant wishes to challenge the preceding bid. The bidder with the lowest bid is the winner. In a sealed bid auction, the participants submit confidential bids, the bids are collected and the auctioneer chooses the lowest bid.

Sealed bid auctions offer a further complication because the winner of the auction may receive one of two prices (Hartwell and Aylward 2007). The first, and most obvious, price that the winner may receive is the amount that they submitted in their winning bid. The second is the winner receives the Vickrey price (Vickrey, 1961); that is, the price that was submitted by the second place bidder. The purpose of using the Vickrey price is that it is said to induce truthful bids on the part of the bidders by reducing the bidders'

[84] Using the language of economics, this ensures that the participant that places the lowest value on the resource is selected and is able to sell the item at the lowest possible price.

incentive to misstate their value for the resource; a Vickrey auction is used to minimize the possibility of bid shading by the participants.[85] Despite this expected advantage, Vickrey auctions are rare in practice (Rothkopf 1990).

5.3 Sealed Bid Multiple-Unit Procurement Water Auctions

The auction types above may be applied to a wide variety of auction designs. Modifications can be made to the generic types depending on what is being auctioned and the goal of the auction. In the case of a water auction, the overarching goal is often to acquire the maximum volume of water at the minimum price. Although there is generally only one purchaser of water, the purchaser may accept bids from more than one participant. Accordingly, water auctions generally take the form of a sealed-bid multiple-unit procurement auction (Hartwell and Aylward 2007).

In a multi-unit auction, more than one unit of a resource is auctioned (Hartwell and Aylward 2007; Rux 2008; Cummings 2003). In the case of a water auction, participants submit bids that contain different volumes of water and corresponding different prices per unit of water. The process is further complicated because water is not necessarily homogeneous. As a result, the auctioneer is required to compare disparate bids of a heterogeneous resource.[86] This difficulty may be alleviated through two main practices: a) requiring that the water entitlements offered for auction be as nearly

[85] In a procurement auction, bid shading occurs when bidders submit bids that are higher than they privately value the resource.
[86] Variability may exist due to different priority dates, location in a particular basin affecting conveyance costs, water quality, etc.

homogenous as possible[87] and b) by using a sealed bid technique to conduct the auction.[88] Any other method/practice becomes unwieldy because of difficulties in comparing bids on a per unit basis.

Sealed bid multi-unit procurement auctions, like any other auction type, have their own unique complications. The first consideration is whether to create an auction that has a discriminatory price structure or a uniform price structure. A discriminatory price structure is one in which each winner receives the respective amount of the submitted/accepted bid. Whereas, a uniform price structure is one in which each winner receives the same price, regardless of the submitted bid: the auctioneer sets a maximum threshold for bid acceptability and each participant whose bid is less than this threshold is paid the maximum threshold price (Hartwell and Aylward 2007).

While economic theory indicates revenue equivalence among auction designs (Vickrey 1961; Milgrom 1989), when economists have tested these theoretical results experimentally in the context of a hypothetical water auction, revenue equivalence has not been achieved (Tisdell, et al. 2004). In particular, uniform price auctions tend to outperform discriminatory price auctions because bidders tend not to overstate their value

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[87] For instance, in the Deschutes River Auction, the participants all had the same duty of water per acre and a relatively non-variable supply. Nevertheless, the auctioneer assumed the risk that water allotment may diverge from expectations (Hartwell 2007). Another practice that may be utilized is to only allow right-holders that own rights that were granted prior to a particular priority date to participate. Other methods for ensuring water homogeneity may be utilized.

[88] This facilitates a multi-unit auction because the auctioneer can more easily compare disparate bids by calculating a price per unit of resource acquired. Due to time constraints and impracticability, other auction methods are not amenable to this type of calculation.

for the resource as dramatically (Hailu and Thoyer, 2007).[89] Despite these experimental findings, both the Deschutes River Conservancy in Oregon and the Environmental Protection Division in Georgia utilized a sealed bid multi-unit procurement discriminatory auction to acquire water from appropriators. In both instances, the discriminatory method was chosen out of political concern; the water agencies believed that appropriators would be less likely to participate in an auction where every bid that was accepted was paid the same per unit amount rather than each bidder's true marginal value for water (Hartwell and Aylward 2007; Cummings 2003).

Another important consideration is whether to conduct a single round auction or a multiple round (iterative) auction. In the case of a single round auction, each bidder submits a single bid and bids are either accepted or rejected at the conclusion of that one round. In an iterative auction, bids are collected and provisionally accepted or rejected. The bidders, even the bidders whose bids were provisionally accepted in the previous round, are then allowed to submit another round of bids and those new bids are again either provisionally accepted or rejected. This process continues for either a predetermined number of rounds, or until bidders are satisfied with the results and no longer wish to submit new bids (Cummings 2003).[90]

In general, the benefit to conducting a single round auction is that it is simpler both to administer and for the participants (Hartwell and Aylward 2007). However, the

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[89] In computer simulations of markets with little participation, discriminatory auctions lead to extreme overbidding, whereas uniform pricing produces relatively more consistent and predictable results (Hailu and Thoyer 2007).

[90] If an iterative approach is used, an important consideration is how much and what type of information to provide to the participants between rounds. This consideration is discussed *infra*.

advantage of conducting an iterative auction is that in theory it will maximize participation and minimize procurement costs.

Regardless of whether discriminatory or uniform auctions are chosen and whether a single round or iterative rounds are used, it is also necessary to develop a decision rule that separates winners from losers. In a procurement auction, there are several ways to accomplish this. The first way is to set a cap on the price per unit that will be accepted by the auctioneer (Hartwell and Aylward 2007). This cap is generally referred to as the reserve price. Under this scheme any bid that is below the reserve price is accepted and any bid above the reserve price is rejected. A potential problem is that the auctioneer is required to accept all bids regardless of the volume of water required or the budget for the program. This happened in the 1991 California Drought Bank (Howitt 1994; Israel and Lund 1995).

Another way to determine winners is based on a fixed maximum budget (Hartwell and Aylward 2007). In a procurement auction, bids are ranked from lowest to highest and the auctioneer accepts the bids from lowest to highest until the budget cap is reached. Alternatively, a quota, or a maximum unit amount of water, may be fixed for the auctioneer to acquire. In practice, both a reserve price and a budget cap can be used to minimize the per-unit cost paid for water (Hartwell and Aylward 2007; Cummings 2003). Using both a reserve price and a budget cap is generally preferable to using either method alone because it simultaneously minimizes the likelihood of overpayment per unit and it also ensures that the overall budget is not exceeded.

In a similar vein, it is important to consider the possibility of ties (Cummings 2003). To motivate this concern, consider a situation in which reserve price is set and a budget cap is set. Suppose that there are two equal bids which are below the reserve price, but the acceptance of both bids would place the auctioneer above the budget cap. The auctioneer needs some type of rule that governs such a situation. In the Georgia water auctions, the auctioneer set a rule that in the event of a tie, the winners would be randomly selected up until the point at which the budget cap is exceeded. Although it is not absolutely necessary for the winner to be chosen randomly it is likely the preferable method because it will reduce the likelihood that the participants will view the auction as unfair.

Tie breaking rules are important not only because of the pragmatic concern of choosing the winners, they also reduce the likelihood that the participants collude in an effort to subvert the auction. That is, if the participants know that the tied winners will be chosen at random when the budget cap is exceeded the incentive to collude will be minimized and competitive bidding is more likely to occur (Cummings 2003).

Another important consideration is the determination as to how much information to provide to the participants and what kind of information to provide to them (Hailu and Thoyer 2007). Information disclosure should be designed to build participant confidence in the process to maximize participation and simultaneously minimize the likelihood that participants overstate their bids (Hartwell and Aylward 2007; Cummings 2003; Garrick et al. 2008). In any sealed-bid auction, the type of information that may be provided to the participants includes: whether a reserve price exists and, if so, the level of the reserve price, and whether a budget cap (or procurement quota) exists and the level of the cap or quota. If an iterative approach is utilized, the participants may be notified between rounds which bids are provisionally accepted or the price for which bids are provisionally accepted (Cummings, 2003). So that the participants perceive the auction to be fair, the participants should be informed in advance of how a tie breaking operates.

Determining the optimal amount of information to provide the participants is a delicate balancing act. On the one hand, by providing more information the auctioneer is creating an environment where the participants are more likely to feel comfortable with the auction process and thus more likely to participate. On the other hand, the more information that is provided to the participants, the greater their ability to submit collusive bids (such as all submitting the same price). In the case of the Deschutes River auctions, the auctioneer instructed the participants that a reserve price existed but they were not provided the amount of the reserve price (Hartwell and Aylward 2007). In the subsequent year's auction, the participants were told that a new reserve price existed and they were informed as to the level of the prior year's reserve price. Hartwell and Aylward (2007) concluded that the participants acted strategically based upon this disclosure of information in the second year because many of the submitted bids in the second year were near to the disclosed first year's reserve. The presence of a budget cap was also disclosed to the participants; however it is unclear whether the amount of the cap was disclosed (Hartwell and Aylward 2007).

Participant trust is an important aspect of a successful water auction, and providing information to the participants may be a means of acquiring that trust, as is concluded in the Yakima River water auction (Rux 2008). In that instance, there was virtually no participation (only one bid received) and no water obtained by the auctioneer. A focus group was conducted to determine why the auction failed. The most common response was that eligible participants did not bid because they did not trust the auction process nor did they trust the auctioneer. Despite these findings, it is unclear exactly what information could have been provided to the potential bidders to remedy the lack of trust in this instance.

5.4 Possible Modifications to the Typical Water Auction Design

Although most water auctions have historically taken the form of a typical sealed bid procurement auction, the auctioneer may elect to utilize a more sophisticated method. A more complex process may be used in an effort to minimize some of the potentially negative consequences, or complications, associated with using the typical auction design. Below is an explanation of benefits and costs of two such methods: the submission of complete supply schedules and an indexing scheme.

One possible variation to the standard procurement auction design is to allow the bidders to provide a bid schedule rather than one bid. (Hartwell and Aylward 2007; Hailu and Thoyer 2007). In this method, bidders do not submit one bid with one price; rather, each bidder submits a bid that contains the different acceptable prices for various quantities of water. At low prices the volume of water offered is expected to be low, but as prices increase the volume of water offered by farmers is also expected to increase – much like a standard supply curve. This takes into consideration participants' different marginal values for water and allows for the proper alignment of incentives. In theory, this method would provide optimal results; however, as a practical matter it is a relatively difficult process to undertake. First of all, it is necessary to explain to each of the participants how the auction operates and to ensure the participants are comfortable with the auction design. Because this is a radically different from a typical auction it may be difficult to obtain the requisite trust.

Second, logistical considerations make this method relatively complicated. As a practical consideration, it is necessary to compare complete supply curves to determine the winners rather than simply comparing single bids. In doing so, the auctioneer will be able to accept portions of bids rather than having to accept or reject entire bids. Further, the auctioneer may be required to determine which final portions of bids to accept so that the budget cap is not exceeded but a maximum amount of the resource is acquired.[91] While economic theory indicates that results from this type of auction lead to cost effective water acquisition results, it is likely that difficulties would overwhelm the theoretical appeal.

Another possibility is to rank bids based upon a predetermined indexing scheme. Bryan, et al. (2005) explains that the index may take one of several forms including: the Environmental Benefits Index (EBI), Habitat Hectares Approach (HHA), a risk analysis method, or some other variation. The United States Department of Agriculture (USDA) sanctions the use of the EBI and enumerates criteria for ranking bids (Bryan, et al. 2005; Tisdell, et al. 2004). Under the EBI approach, an indexed value is calculated based upon six environmental factors and one cost factor.[92] Bids are then ranked and compared.

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[91] There are four potential methods to cope with this scenario. However, the analysis is further refined to a double-sided auction, meaning that the bidders submit supply schedules while the auctioneer has a predetermined demand schedule. The analysis is only slightly more complicated under the scenario of a strict budget cap; nevertheless, the four methods are still the same: single increment spread, market-maker liquidity, large spread, and iterative bidding (Hartwell 2007, 39-44).

[92] To calculate the EBI, the following formula is used: EBI=N1+N2+N3+N4+N5+N6-N7 where the N's are equal to (with the following maximum number of points available): N1 is the wildlife factor (100 points), N2 is the water quality factor (100 points), N3 is the erosion factor (100 points), N4 is the enduring benefits factor (50 points), N5 is air quality benefits from reduced erosion (50 points), N6 is state or national conservation areas (25 points), N7 is cost factor. For a complete breakdown of how the points are awarded within each sub-category, see USDA (1999).

In a HHA, characteristics of existing vegetation are compared against benchmark communities of mature stands in their natural undisturbed state (Bryan, et al. 2005; Tisdell, et al. 2004). In particular, aspects of vegetation in an area are scored and summed and are multiplied by the area of the site in order to calculate a magnitude of actions (Bryan, et al. 2005; Oliver and Parkes 2003).[93] An index then may be created, as was the case of the Victorian Bush Tender trials, by multiplying the previously obtained score by a Biodiversity Significance Score. The Biodiversity Significance Score is a measure of the rarity of the ecological vegetation class. The result is then divided by the bid price to create a Biodiversity Benefits Index (Bryan, et al. 2005; Tisdell, et al. 2004)

Under a risk analysis framework, as was used in the Catchment Care Auction, a numeric value is obtained by calculating the environmental value of an area and determining the potential threat to that area (Bryan, et al. 2005). The risk of each site is calculated as the threat score multiplied by the respective environmental value score and summed over all threats (Bryan, et al. 2005).[94] Sites with the greatest environmental value and subject to the most serious threats are at highest risk. Participants then submit bids that outline a proposed method for reducing their respective environmental threat scores as well as a price for undertaking the action (Bryan, et al. 2005). Bids can then be indexed by using the following formula: benefit to be obtained multiplied by

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[93] "…[v]egetation assessed include physiognomy (e.g. presence of large trees, understorey), viability (i.e. presence of weeds, regeneration, litter, logs), and landscape context (e.g. area, shape, connectivity)." (Bryan, et al. 2005).

[94] "[The] environmental value of a site is derived from the site's Geomorphology, Hydrology and Remnant Vegetation characteristics. Sites may also be subject to specific threats. Threats are processes that degrade the biophysical environment including Bed Instability, Bank Instability, Dams and Offtakes, Patch Size, Invasive Weed Presence, Weed % Cover, and Grazing Pressure." (Bryan, et al. 2005).

environmental value divided by the cost of the bid (Bryan, et al. 2005). This allows for a direct comparison of the bids in terms of an environmental benefit/cost ratio and allows the auctioneer to choose the bids that maximize this ratio.

A simplified comparison approach was utilized in the Edwards Aquifer region of Texas. In that example, irrigators were asked to submit bids based upon acres of land they were willing to fallow (Colby and Pittenger 2006). Bids were evaluated based upon several criteria, including: crop types, irrigation system, commitment to dry land farming[95], and the bid price per acre. The Edwards Aquifer Authority favored fallowing lower valued crops to minimize local impacts and revenue losses to irrigators. In this example, bids were compared but no strict method of indexing was developed.

Although the above indexing methods apply mainly to auctions designed to improve environmental characteristics, they could be modified and used for other water auction purposes, such as supply reliability or reduced economic impacts. In the case of supply reliability, bids could be indexed by reliability characteristics of water sources. In the case of concern over local economic impacts, bids could be indexed based on crops grown or projected job and revenue losses.

Nevertheless, the cost and potential difficulty of undertaking a precise indexing approach, however, may be high. Specific criteria for the auction must be carefully designed in advance. This includes creating a set of goals to be achieved through the use of such an auction as well as creating a scoring algorithm. Also, the implementing organization must have staff competent to review water entitlements and to conduct a

[95] Clearly, this component of the index is only applicable to locations where non-irrigated farming is viable.

quantitative assessment. It is then necessary to conduct an analysis of the cost effectiveness of an individual bid and then rank all of the bids in order from most cost-effective to least cost-effective.

The most obvious potential benefit to this type of arrangement is that there is a simultaneous maximization of the auction purposes and a minimization of the cost. As a result, there is a common ground between those two interests and bids are accepted based upon what appears to be objectively reasonable. The drawback to this type of arrangement is that it is relatively difficult and expensive to administer. Land and water characteristics must be properly surveyed by an expert, risks must be calculated, and an analysis of those results must be undertaken. Nevertheless, on a situational basis, the benefits may outweigh the costs.

The second potential drawback is that the indexing process may not be viewed as fair and impartial. Despite the fact that algorithms may be used to calculate particular scores, staff or consultants will collect the original data, determine risk and potential benefits and input it into the algorithm. Landowners may not feel comfortable with participating in this type of arrangement and may object to intrusion on their land for surveying purposes as well as the indexing process.

5.5 Post Auction Compliance and Evaluation

After a water auction is conducted, it is necessary to implement a monitoring and enforcement scheme to ensure that winning bidders comply with the terms of the auction. Typically this involves ensuring that participants cease irrigation on the lands their winning bid obligates them to refrain from irrigating for the time period agreed upon in the auction program. Because monitoring and enforcement of irrigation for specific land parcels can be costly, it is important to utilize tools appropriate for the given situation. Regardless of what tools are utilized, it is important to clearly specify what agency is responsible for monitoring compliance and how that compliance will be determined.

Several tools to enforce the terms of the auction may be available. For instance, in some situations locking irrigation gates may be appropriate (IID 2004a). Another manner of ensuring compliance is to utilize remote sensing imagery to ensure that water is not being used on specific tracts of land. Remote sensing imagery can distinguish whether land is being actively irrigated in many arid areas. A common manner of enforcement, however, may be to have enforcement staff drive through and inspect parcels that are no longer supposed to be irrigated.

Although water auctions are being used more frequently they are not commonplace. Consequently, it is important to evaluate auction performance so that design and implementation can be improved (*see,* Hartwell and Aylward 2007; Cummings 2003; Garrick, et al. 2008; Bryan, et al. 2005; Rux 2008). To facilitate the evaluation, it is important to have specific goals beforehand against which the success of the auction can be assessed. Success can be determined in a variety of ways.

For instance, in the Georgia auctions, because the desired volume of water was acquired, the auction was declared successful. Nevertheless, when the results of the auction were analyzed, Cummings (2003) determined that the same volume of water could have been acquired in a more cost-effective manner. Another criterion could be used for evaluation; such as minimizing the total amount of money spent to acquire the resource (Hailu and Thoyer 2007). This criterion, however, seems to suffer from the same shortcoming as above in the sense that it does not appear to capture the true goal of a typical water auction – maximization of resource obtained while minimizing procurement cost (Garrick, et al. 2008; Bryan, et al. 2005).

An auction may seek to maximize benefit per dollar spent, with success based upon maximizing the benefit-cost ratio (Hailu and Thoyer 2007; Bryan, et al. 2005).[96] In practice, however, it is difficult to design and implement a simultaneous maximization and minimization auction. Therefore, it is advisable to create several criteria that operate as a proxy for evaluating success. Table 1, below, provides a nonexclusive list of criteria that may be used individually or simultaneously to evaluate auction success, along with an explanation of the appropriate metric and how the metric may be calculated.

5.6 Summary

Auction theory suggests that water can be obtained at a lower price than through individual negotiations and that transaction costs can be minimized. The auction design should be tailored to reflect the particular situation and the sophistication of the participants. Assessment should be conducted to ensure that goals and objectives of the auction are being achieved, that improvements to design are implemented and that other methods of water procurement are not more effective. Table 4.1 presents metrics to consider when conducting an assessment of a water auction. Auctions are one potentially valuable tool for acquiring water supplies as part of an overall strategy to cope with drought and adapt to climate change.

[96] In an auction that does not utilize an indexing method, this assumes that the volume of water obtained by the auctioneer is directly proportional to the environmental benefit.

Type of Criteria	Explanation of the Metric
Total volume of water obtained	A goal in a water auction may be to maximize the volume of water obtained within a budget constraint. To calculate the total volume obtained, sum the volume of each accepted bid and compare against a predetermined target volume of water. Success may be judged by how close the acquired volume is to the target volume.
Total amount of money spent to procure water (inclusive of auction administration costs)	Generally a goal in any procurement auction is to minimize the money outlay to acquire the resource; or alternatively, to stay within a specified budget. The total amount of money spent may be determined by summing the money spent on each accepted bid. Success may be determined by not exceeding a predetermined budget. However, in order to achieve other auction goals, it is necessary to spend at least a minimum amount of money; therefore, it may be appropriate to set a budget range to judge success.
Average price paid per unit of water, to sellers and/or lessees	This metric focuses on the price paid per unit of water to sellers and/or lessees. To calculate, sum the payments for water to sellers and lessees, and divide by the volume of water obtained. The average price paid per unit of water can be compared against a predetermined target or against indicators of water's value. It is often compared with measures of water's economic value in regional agriculture. Success may be determined by whether the price paid is "high" compared with other measures of value, or high compared to a target.
Cost of administering the auction	The goal of a procurement auction is to acquire a resource at the lowest possible cost; however, this does not necessarily consider the cost to design, implement, monitor and evaluate the auction. Therefore, in order to determine auction success the cost element could include auction administration costs. In order to determine whether the auction itself was conducted in a successful manner, with respect to auction administration costs, sum the administration costs and compare the actual costs against a predetermined target.
Participation	In order for any auction to be successful, participation is crucial. The total number of participants may be compared against a target level of participation, or as a proportion of those eligible to participate. Success may be determined by how closely the actual participation compares to the target.
Absence of participant collusion	To achieve optimal results in an auction, collusion must be minimized. Although there is no direct method for calculating collusion a direct analysis of the bids may be used to determine whether it is likely that collusion has occurred.
Participant trust	In order to achieve other auction goals, participants must trust the auction process. Although the number of participants serves as a proxy for this, trust can be more directly assessed through the use of survey techniques. Participants may be asked, post-auction, whether they believed that the auction process was fair and whether they trusted the auction process. Non-participants may be asked what factors prevented their participation.

Table 5.1: Auction Evaluation Metrics

6. Water Banking

This chapter provides a background for understanding the basic aspects for conducting water banking operations. Included is a thorough review of water banks that have been developed and used in practice as well as a guide for developing and conducting water banking.

6.1 Water Banking Background

A water bank is one approach for smoothing out the effects of variability in water supplies. A water bank is an institutional mechanism designed to facilitate transfers of water on a temporary, intermittent or permanent basis through voluntary exchange.[97] Specifically, water banks are generally established to accomplish one (or more) of the following: a) create a more reliable water supply during dry years through voluntary trading; b) ensure a future water supply for various water needs; c) promote water conservation by encouraging water users to conserve and deposit conserved water into the bank; d) facilitate more active water market activity; e) resolve issues between groundwater and surface-water users; and f) ensure compliance with intrastate agreements regarding instream flows and with interstate compacts (Clifford, et al. 2004). Water banks range in geographic scale from involving local water users in a specific urban area or a county to offering services across broad regions, sometimes including several states (the Arizona Water Bank, for instance, also serves Nevada and California).

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[97] In any arrangement transferring water, the buyer and seller should proceed with caution. State and federal laws may limit whether a transfer may occur, the volume of a proposed transfer, or the location of transfer. Local laws should also be consulted. Further, if water is transferred interstate, a state or federal agency may be required to administer the bank.

Several types of arrangements can be used to bank water. Here we discuss four key ways water banks operate to make water available for future use: surface storage in a reservoir, underground storage in an aquifer, facilitating transactions among entitlement holders, and institutional banking (i.e. water trusts).

Surface storage banking includes the storage of physical water to be used later in the year if the need arises (Clifford, et al. 2004). Because the water is physically stored, and can be accounted for, a great level of security is obtained. This may be accomplished through actual entitlement diversions to a reservoir or through "top water banking," where an annual allocation of surface water is not diverted but left in a reservoir storage for future use. However, because the water must be moved to the storage location and stored there, a fair amount of capital investment may be required in conveyance and storage infrastructure or in paying for access to existing infrastructure. Additionally, there will be transmission losses of the banked water due to percolation into the groundwater basin or evaporation into the atmosphere.

Groundwater banking and/or aquifer storage and recovery is a process of using available aquifer space to store surface water in years of surplus water availability which can then be pumped in years where water is in shortage (Semitropic 2004). Groundwater banking generally occurs in one of two ways: in-lieu (or indirect) recharge and direct recharge. With in-lieu recharge, groundwater is allowed to remain in the aquifer by substituting surface water for groundwater that would normally have been pumped. With direct recharge, water is stored in a defined recharge basin and allowed to percolate directly into the groundwater basin (Semitropic 2004). Rather than allowing excess water to passively percolate into an underlying aquifer, it is also possible to directly inject water into the aquifer, as is often done in an aquifer storage recovery program (Washington Department of Water Resources 2009).[98] An advantage to groundwater banking is that the water is physically stored with relatively low capital investment, as the aquifer is naturally occurring.[99] Additionally, by allowing the water to percolate (or be injected) into the groundwater basin, the likelihood of land subsidence is reduced.

The main limitation of groundwater banking is that groundwater rights are often poorly defined and absent legislative or judicial intervention, the "rule of capture" is often used as the means and measure of groundwater ownership (Lueck 1998). That is, because it is difficult to assign property rights in groundwater and because it is often difficult to exclude potential pumpers or limit pumping, groundwater is often managed as an open access resource. Under this arrangement, individual groundwater pumpers tend to pump "too much and too soon" (i.e. use groundwater sub-optimally). As a result, the resource tends to become depleted in a manner consistent with the so called "tragedy of the commons" (Hardin 1968).[100] In order to combat this tendency, states and water districts have adopted groundwater use regulations of various types with varying degrees of success in maintaining groundwater levels and minimizing drawdown. The security of

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[98] Rather than storing water in a cavernous aquifer, it may be possible to store water into locally occurring sands during times of surplus and extract that water in times of shortage (Eckhardt 2009).
[99] However, sometimes the capital investment may be large. For example, the Central Arizona Water Conservation District (CAWCD) recently spent $19 million to construct its Tonopah Desert Recharge Project.
[100] As groundwater pumpers draw down the water table, the cost of pumping tends to increase with higher energy demands and in some cases wells have to be deepened or new ones drilled. Therefore, it becomes more likely that pumpers will race to capture the resource in an effort to minimize the costs associated with pumping from greater depths.

water banked in an aquifer depends on the regulatory framework in place to protect banked water so that it will be available for recovery, and to prevent water contamination and excessive drawdown.[101] One practical example of such a regulatory framework is the Arizona long-term storage credit system. Depending on a particular set of criteria, underground storers of water have a right to pump the water back out of the ground (Arizona Revised Statutes 45-852.01).

A water bank may also be involved in facilitating arrangements that secure water for future use, such as water transaction or brokerage activities. A bank may operate primarily to bring together buyers and sellers, lessors and lessees, and to facilitate trades. This may be achieved by either providing a venue for buyers and sellers to exchange information such as an electronic forum where water quantities and prices may be placed for sale (or lease) and where buyers may purchase (or lease) entitlements.[102] The immediate purpose of this framework is to reduce the costs associated with water transactions (Howe and Weiner 2002). In order for this to occur, the process must be

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[101] Several solutions have been proposed to combat excessive drawdown: yield stock rights, unitization, proportional rights. With yield-stock rights, individual water users in the aquifer are given property rights for a share of the groundwater. Each right has two components: 1) claim to a percentage of the annual recharge into the aquifer, and 2) claim to a percentage of the aquifer's storage or stock. The initial allocation of the water right is based on an individual's historic water use during a specific time period (Clifford, et al. 2004). Unitization, which was originally developed as a tool for managing oil reservoirs but may be extended to groundwater management, means an aquifer is operated or managed by a single firm or entity. Individual landowners within the aquifer elect a manager and the manager’s objective is to ensure efficient yield production from the aquifer by regulating the spacing of wells and applying an extraction rate that maximizes long term benefits (Wiggins and Libecap 1985).[101] The proportional rights approach develops a market for groundwater rights that is based on a proportion of the aquifer's annual safe yield. The principal objective of this proposal is to ensure that the aquifer maintains a minimum level (Clifford et al. 2004).

[102] Another way to describe this scenario is a bulletin board system where sellers supply information to the bulletin board and purchasers may read the board and make purchase offers to sellers.

streamlined; that is, trades must be relatively easy to consummate and the process should be open to a variety of participants (irrigation districts, cities, individual irrigators, etc.).

Another water banking format is “institutional banking.” Institutional banking refers to the transfer of legal documents that represent access to a specific water quantity during a specific time period (Clifford, et al. 2004). In general, institutional banking refers to holding and management of water entitlements in trust for either a predetermined amount of time or indefinitely, usually for the purposes of augmenting instream flow. Because the water is not required to be physically stored at a particular location, the large capital investment requirement characteristic of the surface storage banking format is unnecessary; however, because the water is not physically stored, the water availability is not as secure. Nevertheless, institutional banking may be attractive when the cost of capital investment is extremely high or when the main purpose is stream flow augmentation (Burke et al. 2004).

6.2 Water Banking Creation and Operation

Management and Operation

An important aspect of the water bank is the determination of who should run and operate the water bank. Generally, ownership and administration of a water bank may take one of four forms: public organization, private-nonprofit organization, private-for-profit corporation, or public-private partnership (Clifford, et al. 2004). The type of organization chosen can have a direct impact on the level of acceptance and trust that water users have. For instance, in a location where the potential water bank participants have had negative experiences with a specific federal or state agency, it would be imprudent to organize a water bank managed by that agency.[103] In some regions, there may be a widespread resistance to for-profit enterprises overseeing water matters and so a private enterprise water bank may not gain acceptance and participation. In the western United States, there exist water banks managed by federal agencies, by state agencies, by water districts, by non-profit organizations and by private firms. Examples are provided in a subsequent section of this paper. As a component of encouraging participant trust, it is important for the water bank to encourage general community acceptance. To encourage acceptance, a water bank may provide community outreach and education opportunities. Additionally the water bank should attempt to be as transparent as possible and attempt to explain the economic, environmental, and legal costs and benefits of water banking to the community. This process may be achieved through a variety of means including literature distribution, community meetings, open houses, telephone hotlines, internet websites, or any viable mechanism of information dissemination. Included in this discussion should be an explanation of whether participants risk losing their water rights by participating in the water bank under a state "use-it-or-lose-it" provision.[104] If the particular state does have a use-it-or-lose-it provision, it may be appropriate for the water bank to encourage legislation that allows participation in the water bank without the fear of forfeiting entitlements.[105]

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[103] An example of this is the Yakima Basin in Washington. In that basin, water appropriators reportedly distrust government, particularly when it is engaging in water transactions (Rux 2008).
[104] A use-it-or-lose-it provision refers to the notion that it is possible for an individual to forfeit a water entitlement simply by not using the entitlement for a period of time.
[105] It is important point is that if the participant's water entitlement is a federal contract, the state law might not determine whether a use-it-or-lose-it provision applies; rather federal law is likely to control.

To encourage political consistency, local and state agencies may choose to promote the water bank and the benefits that are to be realized by its operation. Finally, key community members and representatives of stakeholders should be included on the board or advisory committee (Clifford, et al. 2004). This serves at least three purposes. First, by including key community members and representatives of stakeholders, the water bank appears more transparent, and thus more likely to be perceived as fair by the community. Second, the water bank will appear to the community as more legitimate, as the individuals within the community will be aware that some of the decision makers will also be impacted by the creation of the water bank. Third, information dissemination to community members is more likely to occur, trickling down from the key community members to the rest of the community.

Encourage Irrigator Participation

Because much of the banked water is likely to be supplied by the agricultural community, it is important to encourage the agriculture community to participate.[106] One way to encourage agricultural participation is for irrigation districts to promote water banking activities to their members or for the district itself to become involved by becoming buyers or sellers within the water bank (Clifford, et al. 2004). By involving entire irrigation districts, the supply (or demand) of water may become consolidated such that larger volumes of water are available (or purchased). If the bank provides temporary transfers, and assuming that a use-it-or-lose-it provision does not apply, then a

[106] In the western United Stated, irrigators account for approximately 80% of freshwater withdrawals (USGS 2009).

mechanism for meeting new water demands without water permanently leaving the agricultural sector will become available. This alternative may be more favorably perceived than agricultural water being permanently purchased away from agricultural use because water entitlements are retained by the agricultural landowner. However, if the bank provides for permanent transfers, then market trades can be used to gauge the value of the water. Finally, it may be true that the agricultural community may benefit as a demander, because the bank may be used to provide a source of water for growers seeking water to expand operations (Clifford, et al. 2004; Howe and Weiner 2002), or provide an alternative water source during supply shortfalls. This intra-farm component is pivotal to improving relationships and encouraging trust with the agricultural community because it indicates a willingness of the water bank to sell water to the highest value use, whether that use is agricultural or dry-year municipal supply.

Strategic Policy

A water bank needs a long-term strategic policy and established policies and standards for daily operations (Håkansson and Snehota 2006). The strategic policy should reflect the underlying goals and vision of the water bank. As a practical consideration, the bank must determine whether it will buy, sell and hold water itself, whether it will operate as more of a brokering service or whether it will operate in a more institutional manner (i.e. more like a water trust). This focus assists in setting the bounds of what the bank is capable of doing and may have an impact on the manner in which the bank's internal funds are distributed. To minimize the potential costs associated with potential disputes, a mechanism of dispute resolution should be created and clearly defined so that disputes can be quickly, equitably, and efficiently resolved.

Unless taxes or state appropriations support operations, as may be the case for a state funded water bank, a fee-for-service structure needs to be developed and implemented. Depending on the services that the water bank is providing, the types of transactions that are likely to take place and the particular market structure utilized, the fee structure may vary. For instance, the type of fee structure utilized by a bank engaged in physical storage may be different than the fee structure that is appropriate for a water bank engaged in brokering transactions.

Geographic Area and Eligibility

The bank ought to consider the geographic area(s) for which participants are eligible to participate in the bank. The bank should include an area large enough such that participation, and the consequent procurement of enough water to rationalize the creation of the bank, is likely. But the area should not be so large that water bank administration and resource transportation costs are overly burdensome. Additionally, it may become necessary to determine which (types) of water entitlements are eligible for participation.[107] For instance, it may be important to determine whether a particular seniority date is required in order to participate. This particular decision may turn on the type of water bank used. If the water is physically transferred and stored, the seniority

[107] For the purposes of this guidebook, the term “water entitlement” is a generic term referring to any type of transferrable water entitlement; including water rights defined by state law, contractual rights to water from a federal project, etc.

date of the water entitlement may not be important so long as the storage arrangements are secure, i.e. not susceptible to being lost in flood releases. However, some water banks will want to specify an acceptable range of seniority dates given that junior entitlements may not have a reliable yield for the bank during drought.

Operational Policy and Market Creation

In order to ensure that administrative red tape is kept to a minimum, the bank should strive to provide a relatively simple method for market-based transfers, particularly for relatively short-term transfers. This is for two main reasons: first, in a relatively short-term transfer situation, the water demanded is often needed nearly immediately. Red tape and the prospect of complex transfer processes make engaging in a short-term transfer less attractive because there is a possibility that the demander will not obtain the desired water when the demander requires the water (Howe and Weiner 2002). Second, because complex transfer processes generally take longer than relatively less complex processes, the price agreed upon upfront may not accurately reflect the current market price and therefore may provide the market with skewed information. Longer transfers, of course, may require more extensive approval but may be streamlined to encourage the transfer of resources from lower- to higher-valued uses. In order to facilitate transfers, it may be prudent to establish a method of verifying bankable quantity, type of entitlement, and transfer capability of water entitlements which includes requiring evidence that shows the water right ownership is valid and in good-standing (Clifford, et al. 2004). A system of pre-approved enrollment may be developed for those who have previously participated, so long as the water entitlements are the same. Pre-approval of water rights is also essential before listing permanent transactions.

A water bank must also determine what type of market (or pricing) structure to use in order to transfer the water from willing seller to willing buyer. In order to ensure that the water market pricing mechanism is structured correctly, a set of principles should be developed that reflect the goals of the water bank (Clifford, et al. 2004). First, the market pricing structure should be developed such that the net benefits are maximized and equity among affected parties is considered. The pricing structure should encourage competitive bidding and discourage misrepresentation of values (O'Donnell and Colby 2009a). The market risks to all of the parties should be considered and the costs and risk should be spread among the bank, buyer, and seller to encourage participation (O'Donnell and Colby 2009b).

Several market structures exist that may be utilized to assist in market price determination. One market structure that a water bank may utilize is a clearing house structure (Clifford, et al 2004). Under this framework, the water bank operates as a bulletin board service that lists individually submitted water supplies available for transfer. Water demanders access the bulletin board and attempt to find a water volume (and potentially priority date and location) that they deem satisfactory. The buyer and the seller communicate via the water bank, and a transaction may or may not occur. With this method, the overall cost to run the water bank is relatively low; however, its applicability is limited by at least two factors. First, for this approach to be effective the volume of water supplied by a particular water supplier must be equal to the volume of water demanded by a particular water demander. The supplier and demander will have very little latitude to negotiate because the water bank will be reluctant to release personal supplier information to the demander (or vice versa). This leads to the second limitation: if the water bank provides enough information to the parties such that they are able to communicate with one another, then they may attempt to transact outside of the water bank. Thus, depending on how the water bank is organized, it may not receive a payment for pairing the supplier and demander.

Another structure that a water bank may use is a fixed price structure (Clifford, et al. 2004). Under this structure, the water bank sets the price of the water at the maximum price it believes it can set and still clear the market. This structure is limited in practice because the price that is set is not the market price; rather, it is merely conjecture. Additionally, because not all water entitlements carry the same value (because of seniority date) it may be necessary to have a tier of prices that reflect the relative value of rights. Therefore, the bank will be required to guess the market prices of several heterogeneous entitlements. Additionally, the price setting function of the bank may actually influence, and consequently bias, the market by establishing a price for transfers.

The water bank may use an auction market structure (O'Donnell and Colby 2009a). This can take two forms: a procurement auction form and a conventional auction form. A procurement auction, in this case, refers to the water bank obtaining volumes of water from willing sellers (bidders). The water bank's goal is to obtain a target volume of water at the lowest possible price. The information that the bidders submit includes two key pieces of information: the volume of water being offered and the price per volume of water. The auctioneer water bank either accepts or rejects bids based upon a series of predetermined criteria. The process is complicated because water and water rights are heterogeneous. For instance, there may be water quality or seniority differences that may make comparing various bids difficult.

To mitigate this heterogeneity problem, it may be appropriate to have minimum standards of water quality and have a priority cut-off date.[108] Under this structure, water is supplied to the water bank, and when needed, the bank/auctioneer, commences an auction. Under a conventional auction format, the water bank is already in possession of the water (or the entitlement to the water) and auctions the water off to willing purchasers. This ensures that the highest and best economic use is achieved and it also ensures that there is a continual updating of market values (O'Donnell and Colby 2009a).[109]

Finally, the water bank may use a contingent contract structure, also known as a dry-year water supply reliability contract ("reliability contract"). A reliability contract is an arrangement to transfer water that is made in advance between parties (usually an irrigation district and a large municipal water supplier), that is triggered by pre-specified low supply conditions (O'Donnell and Colby 2009b). This structure requires that individual contracts be consummated on either the irrigator or irrigation district level and

[108] For a full discussion of creating a water procurement auction, *see* O'Donnell and Colby 2009a.
[109] It may be possible to combine both the procurement and conventional auction into what is called a double-sided auction (Hartwell and Aylward 2007).

as such may be prone to high transaction costs. However, because water is only transferred when it is needed, the probability of unnecessary transfers is minimized.[110]

Environmental and Third Party Impacts

Because environmental objectives are likely to be important, water banks may be required to ensure that bank exchanges do not inadvertently impact existing stream flow levels – particularly when there are federally or state set minimum stream flow levels (Burke et al. 2004). In order to facilitate this, it is important that instream flows be legally classified by applicable state or federal law as a beneficial use so that the water will not be subject to forfeiture. Additionally, the water bank should allow open participation in the bank by third parties that would like to acquire water for instream use. Also, it may be necessary to consider not only stream-flow levels, but also other potential environmental impacts of transferring water to the bank. For instance, there may be negative environmental impacts resulting from agricultural fallowing where the runoff from irrigation supported riparian habitat. In order to combat this potential issue, a mitigation fund may be developed to compensate for negative impacts from water transfers. Information should be made available to individuals that may be impacted by the water bank concerning the presence and operation of this mitigation fund.

Water bank operations may not only have environmental impacts but also third party impacts. For instance, if water is banked in lieu of agricultural production, there may be localized economic consequences. These may include a reduction of the number

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[110] For a full discussion of dry-year water supply reliability contracts, *see* O'Donnell and Colby 2009b.

of individuals in the workforce in a particular community[111] which, in turn, may have a negative impact on the local economy. It is important to consider whether these impacts are likely to occur and whether it is appropriate to implement a mitigation fund to alleviate these impacts.

Costs of Administration and Monitoring

It is important to consider what administrative costs will be incurred by the bank and determine whether the benefits attributable to the water bank exceed the operational and administrative costs. In each case, there will be costs associated with developing the appropriate structure and operating framework (Clifford, et al. 2004). There will be costs associated with the process of implementation and analysis. Because education and outreach is an important component to the creation of a successful water bank, it may be necessary to fund a public awareness campaign. This may be as relatively costless as recruiting and training volunteers to go door-to-door or as costly as creating a workable webpage; regardless of the methods chosen, there are likely costs associated with the campaign. Additionally, there will be costs associated with record keeping and reporting. This will include costs associated with record keeping of deposits, updating databases of potential buyers and completed transactions and also reporting to stakeholders.

6.3 Examples of Water Banks

The following section provides brief descriptions of a variety of water banks that have been implemented, are currently operating, or have been proposed. This section

[111] For example, it has been reported that 450 jobs were lost in Yolo County, California as a result of California's 1991 Drought Water Bank (McClurg 1992).

highlights key aspects of water bank design and implementation and illustrates an array of types of banks.

Arizona Water Bank

The state of Arizona conducts water banking operations through the Arizona Water Banking Authority (AWBA) in order to store water (underground) and utilize the state's entire 2.8 million acre-foot entitlement of Colorado River water (Guenther 2008). Created in 1996, the AWBA stores Arizona's unused Colorado River water entitlement to meet future needs for: 1) Firming (to secure) adequate water supply for municipal and industrial users in the Central Arizona Project (CAP) service area and along the Colorado River in times of shortages; 2) Meeting the management plan objectives of the Arizona Groundwater Code; 3) Meeting the State's obligation pursuant to Indian water rights settlements; 4) Assisting the Colorado River fourth priority municipal and industrial users in developing credits that could be used to increase their future supplies for firming; and 5) Assisting Nevada and California through interstate water banking (Guenther 2008).

The Arizona Water Banking Authority (AWBA) operates not as a market mechanism or a facilitator of transfers between buyers and sellers; rather, it operates as a system of storage facilities. The AWBA purchases excess CAP water or effluent and the price that AWBA pays is set annually by the Central Arizona Water Conservation District (CAWCD) (Clifford et al. 2004).[112] AWBA can not own, develop, operate or

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[112] Three primary sources of funding are utilized: 1) the state general fund; 2) groundwater withdrawal fees collected within the Phoenix, Pinal and Tucson Active Management Areas (AMA); 3) 4 cent ad valorem property tax charged in the CAWCD three county service area (Clifford et al. 2004).

construct storage facilities but has obtained permits to reserve storage capacity in all state facilities (Clifford et al. 2004). Stored water refers to the amount of accrued long-term storage credits. These credits will equal the purchased quantity minus delivery conveyance losses and the statutory five percent contribution to the aquifer for maintaining the long-term health of the ground water system (Clifford et al. 2004). AWBA cannot be the entity which recovers the water. Instead, the storage credits are transferred to either the Arizona Department of Water Resources or the Central Arizona Groundwater Replenishment District CAGRD. The Arizona Department of Water Resources could acquire these storage rights and extinguish them whereby leaving the water permanently in the aquifer as a water management tool. CAGRD would acquire the storage credits during dry years and recover the water to meet the water demands of the CAP subcontractors (Clifford et al. 2004).

AWBA also participates in an interstate water management function for the benefit of the state of Nevada. In this arrangement, Arizona stores available Colorado River water (up to 1.25 million acre feet) apportioned to Nevada in an underground aquifer. Nevada then receives credits for the water stored underground. When Nevada needs to recover some of this banked water, it uses its storage credits and withdraws a portion of Arizona's Colorado River water directly from Lake Mead. Arizona then withdraws the same amount of water from its groundwater aquifer (Southern Nevada 2009). Per the terms of the agreement, Nevada paid Arizona $100 million in 2005, and will make 10 annual installments of $23 million beginning in 2009 until the entire 1.25 million acre-feet is exhausted (Southern Nevada 2009).[113]

The Arizona definition of beneficial use facilitates transfers to the AWBA because forfeiture of rights does not result if the water rights are stored in a groundwater bank for future beneficial use or if surface and groundwater are exchanged.[114] Additionally, subject to approval by the Arizona Department of Water Resources, a water right may be severed from the appurtenant place of use and transferred to another place without loss of priority of right.[115]

California's Drought Water Bank

California's Drought Water Bank, operational in the years 1991, 1992, and 1994, was a clearinghouse that pooled water and allocated supplies to critical demands in the state (Clifford et al. 2004; Howitt and Lund 1999). The purpose of the drought bank was to move drought water supplies from the northern part of the state to the southern part of the state through a market-based approach. The California Department of Water Resources (DWR) negotiated water supply contracts with individual suppliers at varying prices (Clifford et al. 2004). The seller could be an owner of appropriative water rights or an individual who held entitlements to delivery for irrigation (Clifford et al. 2004). In 1991, three main methods were utilized: 1) fallowing contracts, whereby the surface irrigation

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[113] In 2007 and 2008 the Southern Nevada Water Authority (SNWA) could withdraw 20,000 acre-feet of water, in 2009 and 2010, 30,000 acre-feet. Beginning in 2011, the SNWA has a maximum recovery rate of 40,000 acre-feet per year until the bank reserves are fully exhausted (Southern Nevada 2009).

[114] Under nearly any other circumstances, the water entitlement may be forfeited if not beneficially used for five years. Arizona Revised Statutes §45-141.

[115] The type of use may also be changed. Arizona Revised Statutes §45-172.

water was sold in lieu of irrigating; 2) groundwater contracts, where groundwater would be used instead of surface water and the surface water would be sold; 3) stored water contracts for releasing water from reservoirs. The bank also obtained special riparian rights. All potential buyers were required to quantify their "critical needs" for the current year remaining after maximum utilization of normal sources including surface water allocations, groundwater, reclaimed water, and other water transfers (Clifford et al. 2004). Extreme critical needs were given priority and included water for drinking, health, sanitation, fire protection, and agricultural critical needs (Clifford et al. 2004).[116]

The 1992 bank was similar to the 1991 bank with some modifications. First, a water seller was found only after a buyer had been identified and a purchase contract signed. This was done to limit the cost carry-over associated with storage of excess water (Clifford et al 2004). Second, the water supplies were divided into six separate pools of water which could have different pricing mechanisms. However, all six pools established the same purchase price and selling price (Clifford et al. 2004). Third, fallowing contracts were eliminated resulting in less concentrated impacts (Clifford et al. 2004). Finally, buyers could store purchased water as long as its use occurred prior to December 1995 (Clifford et al. 2004). The 1994 bank operated under similar rules as the 1992 bank. A

[116] "A seller had representation on the "Water Purchase Committee" which set the purchase price. Water was sold at $175 [per acre foot] reflecting all the acquiring costs including the purchase contracts, transport through the Delta, and administration of the bank. The water was delivered at the Harvey O. Banks Delta Pumping Plant, and a buyer was responsible for transportation costs beyond the pumping station. The DWR sold 396,000 acre-feet to 12 purchasers. The remaining 264,000 acre-feet was purchased by the state at $45 million to increase carryover storage which was delivered to [The State Water Project] SWP contractors in 1992" (Clifford et al. 2004; Water Education Foundation 1996).

precautionary bank was developed in 1995, but the bank design switched to the use of option contracts.[117] Due to a relatively wet year, the 1995 bank was never operational.

The data from the 1991, 1992 and 1994 banks indicates significant price responsiveness (or, to use the economist's term, price elasticity) (Howitt and Lund 1999). That is, when price changes, water suppliers (primarily agricultural water users foregoing use of their water) were willing and able to provide more water to the bank at relatively higher prices, while water demanders were more willing to demand significantly more water at relatively lower prices. This natural adjustment of supply and demand in response to price signals is one advantage of allowing a market pricing mechanism to reallocate water resources rather than an administratively fixed price (Howitt and Lund 1999).[118] In the 1991 water bank, it was identified that 499,000 acre-feet was the minimum volume of water that would be required to meet critical needs. However, after the price was set at $175/acre-foot, only 389,000 acre-feet were actually purchased (Howitt and Lund 1999). "Critical needs" was calculated partially as a function of the volume that cities and agricultural districts indicated they critically needed. However, when the price was set, the volume of water purchased was 22% lower than what the demanders indicated was critically needed. A market pricing mechanism that adjusts in response to changing demand and supply conditions can avoid the problems with setting a fixed price and then encountering excess demand or supply of water offered by a bank.

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[117] For a full explain of option contracts, *see* O'Donnell and Colby 2009b.

[118] Howitt enumerates, however, that in some public water projects it may be appropriate for the water bank to engage in price setting because private valuation of water entitlements may undervalue the resource vis-à-vis public valuation.

A thorough analysis of the third party impacts of the 1991 Bank found that net jobs were created and that it had a net positive impact on the state economy because low-value water uses were exchanged for relatively higher-value uses. However, water exporting regions suffered an income loss while importing agricultural regions experienced an income gain (Howitt 1994).[119]

California's Dry-Year Purchasing Program

California's Dry-Year purchasing Program, established in 2001, features a one-year leasing program intended to create a more reliable water supply through voluntary trading. Water is supplied to the bank by irrigation districts in the northern part of the state and demanded by irrigation districts in the southern part of the state (Clifford 2004). The dry-year purchasing program operates in a similar manner to the prior drought water banks and features two different contract structures: 1) dry-year option contracts[120] and 2) direct purchase contracts.[121] After contract terms were arranged, potential sellers were then contacted to supply the buyers. Buyers with similar terms were incorporated into a

[119] Howitt also indicates that short-run and long-run effects of a water bank ought to be considered. For instance, with periodic reductions in economic activity, capital and labor remain in a particular district but are at times under-employed. Under permanent shifts, however, capital and labor must make other arrangements for the future (Howitt 1994).

[120] "Under the dry-year option contract, the buyer submitted an option request to DWR by November 30 of previous year. This request specified the quantity, maximum price, and delivery terms. At the time of the option request submittal, the buyer paid a non-refundable agreement preparation payment of $2,500 in 2002 to offset the cost incurred by DWR in preparing the Memo of Understanding (MOU) for the current year. In addition, the buyer paid an option deposit fee of $10 per acre-foot requested. The DWR charged $5 for an administrative fee, and the remaining $5 was applied to the option exercise payment" (Clifford et al. 2004).

[121] "A buyer submitted a purchase water request specifying the quantity, maximum price and delivery terms. All requests were submitted by March 31st. At the time of request, the potential buyer submitted the agreement preparation payment and a purchase deposit of $25 per acre-foot requested. This fee consisted of a $5 administrative fee retained by the DWR and a $20 fee applied to the purchase component" (Clifford et al. 2004).

purchase pool (Clifford et al. 2004). Under both contract types, the buyer was responsible for conveyance costs beyond the point of delivery.

Colorado's Arkansas River Basin Bank

The Arkansas River Basin Bank was established in 2001 as a pilot program to study the viability of water banking in the Arkansas River Basin.[122] The bank was designed to provide a clearinghouse to facilitate short-term (one year) bilateral trades between willing buyers (urban users) and willing sellers (agricultural users) through an online bulletin board listing service and was administered by the Southeastern Colorado Water Conservancy District (SCWCD) (Howe and Weiner 2002). The water bank was contentious primarily because it allowed some out-of-basin permits but also because irrigators may have been averse to some of the potential effects of transferring water out of a particular area, including local economic impacts and environmental impacts (Howe and Weiner 2002).

The bank functioned primarily through the online registry and webpage. Depositors and bidders are required to register through the website and the web page provides detailed information on depositors and bidders (Clifford et al 2004). The deposit information lists the name of the depositor, the quantity of water approved by the Division Engineer, the minimum asking price, the source of the water, as well as other location information (Clifford et al. 2004). The website also provides a listing of

[122] The bank became active in 2003 with a sunset provision of five years so that the bank's viability could be examined.

individuals seeking water, including contact name, requested quantity, and phone number (Clifford et al. 2004).

The prices set were based upon market-based negotiations between buyer and seller; however, no transactions were completed through the water bank. At least four reasons for the lack of transactions have been advanced. First, the price-per-acre-foot required by the seller was higher than the going market price of short-term leases (Clifford et al. 2004).[123] As a result, buyers were able to acquire the desired water in the lease market at a lower price. Second, although the process was designed to be streamlined, the administrative process and associated waiting periods were prohibitive.[124] The approval process was lengthy; the process was expected to require a

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[123] The range that the sellers requested was between $500 and $1000 per acre-foot per year.
[124] The Arkansas River Bank lists the steps required to consummate a transaction (Arkansas Basin River Bank):
Water owners wishing to temporarily lease their water shall fill out an application, gather all pertinent information and submit the documents to the Southeastern Water Activity Enterprise office along with an application fee of $15.00.

- The completed application will be reviewed by the Division 2 Engineer's office to assure that the water is available to be leased.
- The staff will then post the offering on the water bank website.
- Qualified bidders may then post their bids on the water.
- Bids are a binding offer to pay such amount.
- On the 11th business day after posting the offering, staff will review the in-basin bids. The highest bid(s) meeting the minimum acceptable bid required by the lessor will then be submitted to the lessor for acceptance.
- The lessor may then accept any out-of-basin bid as they are posted. Upon acceptance, a lease is prepared and posted as under contract for the thirty-day public review. The proposed lease will also be mailed to those on the notification list. After the thirty-day review, the Division Engineer has 5 days to consider comments and will provide the terms and conditions for the transaction.
- Quantification of the available water is based on historical consumptive use.
- Once all parties involved in the transaction accept the Terms & Conditions, then an agreement is signed and a transaction fee is paid to the bank.
- The water bank will notify the Division Engineer's office, the reservoir operator where the water is stored, and those on the notification list.
- The lessee must notify the Division Engineer 24 hours in advance of when they need the water released.

minimum of two months and average three months[125] (Clifford et al. 2004). This was deemed to be unwieldy for a single-year lease. Third, the bank provided seller names and contact information on its website. As a result, buyers could circumvent the water bank by perusing the website, finding names and contact information of potential sellers and contacting them directly.[126] Fourth, irrigators are sometimes cautious when agreeing to sell or lease their water entitlements. This is particularly true when leasing their entitlement requires them to fallow their land, as was the case in this instance, because the local community internalizes many of the costs associated with fallowing (Simpson 2005).

Colorado West Slope Bank

A bank that is under consideration by the Colorado River Water Conservation District is the proposed Colorado West Slope Bank. This bank is designed to manage the threat of a potential interstate compact call on the Colorado River. Because the West Slope's water consumption is mostly agricultural and because its priority is generally senior to the 1922 Colorado Compact, it is feared that junior municipalities and users with critical needs (i.e. fire districts) will either condemn or purchase the water rights and move them out of the West Slope should a curtailment occur (Water Information Program 2009). Therefore, the purpose of the program is to ensure a future water supply for various water needs.

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[125] This is the case even though the bank provided simple pre-written contacts on its website in an effort to expedite the process.
[126] In at least one case, a seller withdrew a volume of water from the bank and sold the water privately (Clifford et al. 2004).

In this bank, water users with pre-1922 rights would be compensated for entering into an agreement to offer their senior water rights that are exempt from compact administration[127] to junior users who would otherwise be called out by compact delivery requirements; temporary use of senior rights would only be permitted if a compact call was imminent or in effect (Water Information Program 2009). Junior entitlement holders would be permitted to subscribe to the bank as a sort of insurance policy (Water Information Program 2009). The bank would serve as the administrator and clearing house for those with senior, pre-1992 water rights and those with junior rights needing an alternative source of water (Water Information Program 2009). A potential hurdle of this program is that it is unclear which junior users would be allowed to participate if a compact call was eminent or whether priority would be given to particular users. It is also unclear which needs are truly critical and should therefore be validated.

Truckee Meadows Groundwater Bank

The Truckee Meadows Groundwater Bank operates as a recharge program through aquifer storage and recovery for the purposes of ensuring future water supply and to resolve potential surface and groundwater tensions. Surface water is recharged using wells to enhance the water resource, improve the water quality at well sites, and may be drawn upon in times of drought (Truckee 2009). During this recharge season, more than four million gallons per day are injected into different well sites across the Truckee Meadows and 19,000 acre-feet of water has been banked since 1993 (Truckee 2009).

[127] Article VIII of the Colorado Compact states that "[p]resent perfect rights to the beneficial use of waters of the Colorado River System are unimpaired by this [1922] compact."

The Truckee Meadows Groundwater Bank does not facilitate the sale of water; it is accounts for the groundwater credits and withdrawals in the Truckee Meadows basin. The administrative process is as follows: the total long-term average that can be withdrawn from the basin is 15,950 acre-feet per year. This baseline determines the credits and debits of the water accounting system. Credits are realized during years when withdrawals are less than 15,950 acre-feet, and debits are created during years when withdrawals exceed 15,950 acre-feet (Clifford et al. 2004).

New Mexico's Pecos River Basin Water Bank

Water banking in New Mexico has been limited, as the state does not have a comprehensive water banking program. However, as a result of state legislation in 2002, the water banks in the lower Pecos River Basin were permitted to develop. All transfers must be consistent with the Pecos River Compact and the water must remain within the basin. Specifically, all transfers must be used as "temporary replacement water" to augment flow in the lower Pecos River. The replacement water will augment stream depletions caused by continued (but temporary) use of water rights junior to the Compact Administration Date, primarily for the purpose of augmenting flows for a federally protected species, the bluntnose shiner (Clifford et al. 2004).

Any bank instituted is to be designed to act as a broker between the depositor of rights and the buyer. As of 2004, no applications for bank charters had been submitted. Hence, there has been no trading activity and a market price could not be determined. It is unclear why no water banks have been developed to specifically market water in the

Pecos River Basin; however, it may be because of the development of the website "www.waterbank.com/."

Waterbank.com and other private sector banks

Waterbank.com operates as a privately owned water bank and utilizes a bulletin board service for the purchase and sale of water resources in New Mexico (including the Pecos River Basin), other locations within the United States, and internationally. The site also offers to provide other services such as ranch sales and water valuation. Other privately held water banks can be found on the internet, typically specializing in a particular region.

Waterbank.com is not a unique instance of for-profit water banks; rather, they are becoming more commonplace. For example, watercolorado.com is a private broker of regional water rights in Colorado. Additionally, watercolorado.com engages in leasing operations of water entitlements. Additionally, private for-profit water banks (or entities engaging in water trading) are beginning to develop internationally.[128]

Pecos River Acquisition Program

The Pecos River Acquisition, beginning in 1992 and administered by the Interstate Stream Commission (ISC), operates on the lower Pecos River as a clearinghouse to facilitate bilateral trades of permanent purchases and temporary leases (Clifford et al.

[128] For instance, Archards Irrigation (http://www.archards.com.au/?watertrade) is a for-profit company based in Australia that, among other things, engages in water trading. Another example is Percat Water (http://www.percatwater.com.au/frameset.html).

2004). The ISC negotiates with the Carlsbad Irrigation District to purchase water in order to meet a flow compact with Texas.

Oregon-California Klamath River Basin Pilot Water Bank

In 2001, the US Bureau of Reclamation instituted the Klamath River Basin Pilot Water Bank (KWB) for the purpose of augmenting federally mandated minimum stream flow levels in the Klamath Basin for a threatened salmon population (GAO 2005). The KWB manages stream flow levels by utilizing at least two water supply reliability tools. The first tool is a groundwater substitution program where irrigators receive consideration for switching from surface-water to groundwater at the request of KWB. Second, KWB may ask irrigators to store a minimum volume of water in exchange for consideration. The stored water may then be called by KWB by a particular date, and released into the river (BOR 2009b).

Oregon's Deschutes River Conservancy

The Deschutes River Conservancy[129] operates mainly in the capacity of a brokerage or exchange between willing sellers and buyers[130] and primarily for the purpose of groundwater mitigation activities. Because surface water is generally oversubscribed, and groundwater is the only source of new water entitlements, Oregon often requires mitigation credits to drill and extract groundwater. The Deschutes Groundwater

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[129] The Deschutes River Conservancy is a non-profit corporation founded by the Environmental Defense Fund, the Confederated Tribes of the Warm Springs Reservation, and local irrigation districts (Deschutes 2009).

[130] The buyers must be "qualified" according to predetermined standards set by the Deschutes River Conservancy. This reflects the Conservancy's desire to minimize speculation in the market and allows it to have a greater degree of control over the market activities.

Mitigation Bank offers mitigation credits for this purpose. The credits mitigate for the effects of new water use on streamflow in the lower Deschutes River (Deschutes 2009). Credits can be leased on a yearly basis or permanently.[131]

Additionally, The Conservancy also operates The Deschutes Water Alliance Bank, which is explicitly designed to "improve streamflows and water quality in the Deschutes Basin, secure and maintain a reliable and affordable supply of water to sustain agriculture, and secure a safe, affordable and high quality water supply for urban communities" (Deschutes 2009).[132] Under the auspices of this bank, the Conservancy manages an in-stream leasing program which may be utilized until the more costly permanent groundwater mitigation credits are available. It also participates in the market by purchasing water entitlements for the purposes of stramflow restoration.

Idaho Rental Pools Water Bank(s)[133]

The state of Idaho has been engaging in water banking from as early as the 1930s and continues its water banking operations to this day (Idaho 2009). The main purpose of the rental pools water banks is to physically store water for the purposes of creating greater supply reliability within the state of Idaho; however, in recent years, water has also been leased by the U.S. Bureau of Reclamation for the purpose of streamflow augmentation for salmon recovery operations.

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[131] Mitigation credits may be purchased from private brokers, in addition to the Deschutes River Conservancy.

[132] In addition to the activities that the Deschutes River Conservancy characterizes as water banking, it is also engaged in other streamflow augmentation activities such as leasing programs, conserved water programs (i.e. ditch lining and the like), and transfer programs.

[133] There are several rental pool water banks within Idaho; here I discuss the banks in general. For a complete description of each of the banks please *see,* Idaho 2009 and Clifford 2004.

Texas Water Bank

The Texas Water Bank, established in 1993, is managed by the Texas Water Development board, which facilitates marketing and transfer of water rights in the state of Texas (Texas Water Bank 2009). The Bank acts as a clearinghouse of water marketing information and maintains registries of water bank deposits, sellers, and buyers, and negotiates acceptable sale price and terms (Clifford 2004). A fee system is utilized to offset the cost of operating the bank; however, the bank must be subsidized by state tax dollars as the fees collected are not sufficient to cover the operational costs (Clifford 2004).

The Bank may participate in the market by purchasing and transferring water rights in its own name (Texas Water Bank 2009). Additionally, under state law, transfers are reportedly allowed outside of the state (Clifford 2004). Therefore the Bank is capable of assisting in the development of regional water banks. The regional water banks would follow the same procedures as the statewide bank (Clifford 2004).

Australian Water Banks

Water banking has been used rather extensively in Australia mainly in the Murray Darling Basin through an online bulletin board approach (Water Find 2009; Murray 2009), but the Northern Victorian Water Exchange has also utilized auction methods to reallocate water resources (Bjornlund 2003). A main purpose of this water banking design is to provide an opportunity for buyers and sellers to be responsive to changing conditions. Price evidence suggests water traders are indeed responsive to changing conditions while participating in these water banks (Bjornlund 2003). That is, price does react to changing market conditions. Additionally, the banks are designed to make water resources available to those individuals that are in immediate need (Bjournlund 2003). As a result, the process is generally streamlined to facilitate a relatively quick turnaround.

6.4 Summary

Water banks can provide an institutional mechanism to conduct nearly any type of water supply reliability arrangement. Water banks may operate simply as a broker, facilitating transactions by aligning wiling buyers and sellers. They may also engage the banking of physical water either underground or in an above-ground reservoir. A water bank may also enter into the water market by buying and selling water in its own name. Finally, a water bank may operate as an administrator of water trusts for environmental purposes. Water banks can be a valuable tool to enhance water supply reliability, where legal frameworks and institutions governing water rights and water use allow for water banking activities. As the examples provided demonstrate, existing water banks display great variety in their geographic coverage, their objectives, the services they provide and the legal authorizations under which they operate.

7. DATA DESCRIPTION and ECONOMETRIC MODEL

This chapter contains background on the data used in this analysis as well as basic information about the econometric model. Econometric estimation of lease prices is conducted because it may provide a means of assessing the sign, magnitude and significance of certain variables on lease prices. Additionally, significant independent variables are discovered, and lease prices may then be predicted. The predicted values are then compared to actual prices in the lease market. In this study, predicted values may be compared against net returns to water (NRTW) prices or prices paid by the Bureau of Reclamation in its pilot fallowing programs (Chapter 9). Additionally, marginal effects may be assessed to determine which variables have strong impacts on lease prices.

The chapter also includes a discussion of the data cleaning methods as well as descriptive statistics of select variables. A quantity variable as well as demographic variables and climate variables are used to predict lease prices. A notable variable is Pacific Decadal Oscillation (PDO), which is a climate index that measures sea surface temperatures in the Pacific Ocean and may be related to climate patterns in the western US. Another notable variable is Lake Mead elevation level, which is measured in feet on a monthly basis. These variables are included because they have rarely, if ever, been used in an analysis of water lease prices and may contribute to the price determination.

Three models are estimated based upon lease data from California, New Mexico and Colorado. A fourth model is estimated by aggregating the lease data from each state. The analysis is conducted at a statewide spatial scale rather than by climate division or metro area. The spatial scale was chosen for two main reasons. First, analysis at a statewide spatial scale has hardly, if ever, been attempted. Second, if the results obtained by using a statewide spatial scale are comparable to prior analyses, efficiencies in data collection and analysis may be obtained by switching to that scale.

7.1 Data Description and Background

Much of the data used for this study was obtained from a monthly publication called the *Water Strategist* (preceded by the *Water Market Update*) for the years 1987-2009. The *Water Strategist* details sales and leases of water in the western US, as well as various trends related to water law, policy and administration. Transaction data, such as buyer and seller information, transaction date, length of lease and price and quantity is listed in varying degrees of detail and accuracy. The convention used for reporting transactions is by month and year; however, the date reported does not represent the time period in which price was negotiated because price negotiations occur over varying time periods depending on the complexity of the transaction and number of parties involved. This uncertainty about time period in which price was negotiated tends to have a larger impact on sales transactions than lease transactions because they often have more obstacles to complete (Jones 2008). This complication should not negatively affect the results from this study because only leases are contemplated.

All prices were adjusted to January 2010 values using a CPI calculator. **APPENDIX B** provides a table containing values used for discounting lease prices. The reader should be cautioned that the transactions are not necessarily representative of the water market as a whole. The *Water Strategist* does not report all types of water transactions, and therefore there is selection bias in the data; however, any selection bias is expected to be consistent across states (Howitt and Hansen 2005).

Data was also obtained on median home prices in the states of California, Colorado and New Mexico for the years 1987-2009. This data was provided by a variety of sources including the National Association of Realtors, the California Association of Realtors and the Office of Management and Budget.

Monthly precipitation and temperature data for the years 1986-2009 were used in this analysis. Monthly precipitation is given in inches and is represented by the accumulation of rain by month. The temperature variable was given by monthly mean temperature. Precipitation and temperature values were obtained from NOAA's National Climatic Data Center website: http://www.ncdc.noaa.gov/oa/climate/research/cag3/cag3.html. Monthly precipitation was lagged by three months as it was expected that price would be responsive to precipitation levels in the time period the transaction was being negotiated. Monthly mean temperature was lagged by 3 months. Temperature was lagged because it was suspected that non-trivial length of time is likely to pass from when the initial negotiation between supplier and demander occurs and the date for which the water transfer occurs and is reported.

Two climate variables are utilized in this analysis. The first is Pacific Decadal Oscillation (PDO), which is an oscillation above and below normal northern Pacific sea surface temperatures, where positive deviations correlate to enhanced El Niño and weakened La Niña conditions, and therefore more precipitation (NOAA2 2010). Negative deviations correlate to weakened El Niño and enhanced La Niña conditions in the western United States, and therefore less precipitation (NOAA2 2010). The second is Atlantic Multidecadal Oscillation (AMO) which is a series of long-duration changes in the sea surface temperatures in the North Atlantic Ocean (NOAA3 2010). Research suggests that AMO may be related to drought in the southwest United States; when AMO is in its warm (positive) phase, drought tends to relatively more severe (NOAA3 2010). The PDO and AMO were lagged because it was believed that some time would pass between the respective readings and the water supply availability. Additionally, a non-trivial amount of time is likely to pass from when the initial negotiation between supplier and demander occurs and the date for which the water transfer occurs and is reported. A 6-month lag was ultimately chosen for both variables because it was expected that a longer time lag would be required than the other lagged precipitation variables.

Demographic variables, population and income, were included in this analysis. Annual income data was collected for each of the three states in this study and was obtained from the Bureau of Labor Statistics website: http://www.bls.gov/data/. Several lags were considered; however, no lag represented a significant improvement. Therefore, the income variable was left un-lagged. Annual population data was obtained from the US Census Bureau at http://www.census.gov/popest/states/. Both variables were converted from annual to monthly timescales utilizing the PROC EXPAND function in SAS. This procedure fits cubic spline curves to non-missing values of variables to form continuous-time approximations of the input series (SAS 2010).

Monthly Lake Mead elevation levels were used in this study to determine whether the elevation level of a major reservoir has an impact on water lease prices. Data was obtained from the Bureau of Reclamation website http://www.usbr.gov/lc/region/g4000/hourly/mead-elv.html. The data on this website provides elevation in feet at Hoover Dam on a monthly timescale. This variable was lagged by 3 months because it was believed that a relatively short lag exists between the change in elevation level and the receptiveness of the market.

Several other variables were considered, but were not used in the final analysis because preliminary results were either strongly insignificant or volatile. An additional climate variable was considered, Multivariate Enso Index (MEI), but not used because it was insignificant in every preliminary model and was slightly correlated with the lagged versions of AMO and PDO used in this study. Demographic variables, such as monthly farm income and farm property values, by state, were not included because the preliminary results were insignificant and often inconsistent. Other variable combinations and variable lags were also considered and tested. Variables representing the month and year the transaction were considered but not used because they were generally insignificant. Additionally, the month variable was correlated with the temperature variable used in the analysis. What remained in the study where the variables that showed the greatest ability to impact the price determination. Finally, an omitted variable bias may exist because the underlying water itself is treated as homogenous and no adjustment is made for varying water quality or priority date.

7.2 Data Cleaning

Because the *Water Strategist* presents information in narrative form, the relevant quantitative information must be entered into a spreadsheet. The information entered into the spreadsheet includes: transaction number, month of transaction, year of transaction, the state where the transaction occurred, the group acquiring the water, the group supplying the water, the old use of the water, the new use of the water, the quantity transferred and the dollars per acre-foot for obtaining the water. When a particular quarter of the year was used to represent date, the date was changed to the first month in that particular quarter.[134] Note that the variables representing state, group acquiring the water, group supplying the water, old use of the water and new use of the water are categorical in nature and codes are used to represent each. The coded data was then converted into dummy variables under the assumption that each variable represents different behavior in the model.

Some observations were deleted from the dataset. Observations were deleted when a price or quantity figure was not provided by the *Water Strategist*. Because both price and quantity are necessary variables in this econometric analysis, it is inappropriate to include an observation missing that information. Some observations were deleted because the price of the transaction was so low per acre-foot that it would be difficult to characterize them as true transactions based upon bargained-for-exchange. A simple cut-off of $5 per acre-foot was arbitrarily used for this purpose. Likewise, observations were

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[134] For instance, if 1st quarter was listed, then January (month 1) was used. Or, if 2nd quarter was listed, then April (month 4) was used.

deleted because the transaction price was so high that it was difficult to characterize the transaction as a true market transaction. An arbitrary cut-off of $2,500 per acre-foot was used for this purpose. Some observations were deleted because a large price range was reported, rather than a single price for the transaction, and no additional detail was provided that reduced the ambiguity. A simple rule was used to delete these observations: If the mean of the highest and lowest reported prices was more than two times the lowest reported price (i.e. more than 100% larger than), then the observation was deleted. If, however, a range of prices was present and the mean price was less than twice as large as the lower limit, then the mean price was used to approximate the transaction price. Although this is certainly a crude approximation, it provided a standardized mechanism for comparing the data. In total, approximately 13% of the observations were ultimately deleted.

In some instances, single observations were split into multiple observations. In these cases, a single line in the spreadsheet, and therefore a single *Water Strategist* entry, contained information about a multifaceted transaction. The different components of the transaction were clearly listed with appropriate price and related quantity and were split into multiple entries. These new entries were then treated like separate transactions. A dummy variable was included to indicate which observations were split into multiple observations. This was done to more easily track the split observations.

Data cleaning, for the rest of the variables in this study, was minimal-to-nonexistent. In general, the data obtained from the original sources was unfettered except for the already described variable lags.

7.3 Econometric Model

In this study, I estimate demand models for lease prices in the states of California, Colorado and New Mexico. A demand model is used because similarly conducted prior studies have successfully utilized a demand model as a basis of analysis (Jones 2008; Pullen 2006; Pittenger 2006; Colby et al. 2006). Four models are considered: the Three State model, which is a model containing all of the data with state dummy variables; the California model, a model only containing data from the state of California; the Colorado model, a model only containing data from the state of Colorado; and the New Mexico model, which only contains data from the state of New Mexico. Price is used as the dependent variable for several reasons. First, because the volume of water in a system in a particular region is essentially fixed when the transaction occurs, and is unlikely to significantly change in the near future, price is relatively more responsive to changing conditions and is more likely to be the mechanism to align supply and demand. Second, determinants of price may be more relevant than determinants of quantity for policymaking purposes. In order to analyze the opportunity cost of water, it is helpful to utilize a tool that predicts price and adjust those determinants, such that private water values, which more closely coincide with social values.

Because price and quantity are presumed to be simultaneously determined in a demand function, it is necessary to consider whether price and quantity are endogenous. To conduct this analysis, it is important to utilize variables for which strong instruments exist and instruments for quantity tend to be stronger than for price (Wooldridge 2002; Jones 2008). Weak instruments may lead to biased results and incorrect asymptotic properties, even in large samples (Staiger and Stock 1997). For these reasons, an instrumented quantity is determined thereby leaving price as the choice dependent variable. The instruments include all the demand equation variables (excluding quantity) plus additional exogenous variables. The exogenous variables are included to ensure the instruments chosen are at least partially correlated with quantity after controlling for the effect of the other variables (Wooldridge 2002). Finally, as previously mentioned, the logarithm of price is used (LNDOLPERAFADJ) because it returns errors that are more normally distributed than an untransformed price is used.

Endogeneity between price and quantity was then tested using the regression form of the Hausman test (Wooldridge 2002). The regression endogeneity test consists of an initial regression using ordinary least squares. The proposed instruments are regressed on quantity and the residuals are saved. Quantity, the exogenous variables, and the residuals are then regressed on price also using ordinary least squares. A significant parameter for the predicted errors suggests the errors from quantity are related to the errors of the price equation and are therefore endogenous (Jones 2008). The output below shows parameter estimates and significance of the key variable QUANTRESIDUAL, which is the parameter associated with the predicted errors. The table includes the entire sample and output for each state.

	Three State	**California**	**Colorado**	**New Mexico**
quantresidual	-0.023	-0.04	-0.002	0.015
p-value	0.1866	0.0428	0.9779	0.3689

Table 7.1: Test of Endogeneity, Results

For the Three State model, Colorado model, and New Mexico model, endogeneity was not detected. Endogeneity was detected in the California model; however the instruments were determined to be weak because they were insignificant in the first stage of the two-stage procedure (P-value> 0.10), Therefore, to keep the interpretation of results consistent among models and to ensure that the same variables were used for each regression, I utilize a semi-log ordinary least squares model. This is done for the entire dataset, then individually for each state using the same explanatory variables where appropriate.[135]

Additionally, heteroskedasticity was detected using the Breusch-Pagan test in the Three States data, California data and Colorado data (Johnston and DiNardo 1996). White's Robust Standard Errors was used to adjust the standard errors. This was done by inserting /ACOV after the model statement in SAS. Heteroskedasticity was not detected in the New Mexico data and was therefore unadjusted.

7.4 Summary of Variables

The variables used for the ordinary least squares regression, testing for endogeneity between price and quantity, two-stage least squares along with brief description and expected sign are provided in table 7.2 below. Each variable is described in more detail afterwards.

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[135] Because ordinary least squares may lead to inconsistent results in the presence of endogeneity, two-stage least squares may be used (Greene 2003). The procedure for two-stage least squares is conducted as follows: The endogenous variable is regressed on all exogenous variables as well as proposed instrumental variables. From this regression, a new vector that includes the predicted values from the first stage estimation is created. In the second stage, the dependent variable is regressed on the exogenous variables in addition to the predicted values from the first stage estimation. See Stock and Watson (2002) and Wooldridge (2002) for more information on instrumental variables in two-stage ordinary least squares regression.

Variable	Description	Expected Sign
Lndolperafadj	The natural logarithm of price per acre-foot	N/A
Quant	Quantity in acre-feet of transaction	-
Quantpredict	Predicted quantity in acre-feet	-
Length	Length of lease in years	-
Inc2	Monthly mean income by state	+
POP2	Monthly population by state	+
Mead3lag	Lake Mead Elevation, lagged 3 months	-
Temp3lag	State mean temperature, lagged 3 months	+
PDO6lag	PDO, lagged 6 months	-
Precip3lag	Monthly precipitation, lagged 3 months	-
	Dummy Variables (=1 for:)	
CA	Dummy for state of California	+
NM	Dummy for State of New Mexico	-
Statesup	Dummy for "State" water supplier	-
Storagesold	Dummy for storage old use	+
Muninew	Dummy for municipal new use	+
Environnew	Dummy for environmental new use	-
Interstatecompnew	Dummy for interstate compact new use	+
	Proposed Instrumental Variables	
AMO6lag	AMO, lagged 6 months	+/-
Hompriceadj	Median monthly home price by state	+
Quantresidual	Residuals when quantity regressed on Instruments	+/-

Table 7.2: Variables, Descriptions and Expected Signs

Description of Variables and Expected Signs:

LNDOLPERAFADJ: is the natural logarithm of price per acre-foot for each lease transactions. Price was adjusted to January 2010 prices, see Appendix B. Price is the dependent variable.

QUANT: is the actual quantity associated with each lease transaction. The quantity parameter is expected to be negative as the functional form of a demand equation is assumed.

QUANTPREDICT: is the predicted quantity obtained from the first stage of the two-stage least squares estimation. Like actual quantity, this parameter is expected to be negative.

QUANTRESIDUAL: is a vector of residuals obtained from regressing quantity on the proposed instruments and exogenous variables. This variable is obtained for the purpose of testing for endogeneity between price and quantity.

LENGTH: is the length of the lease in years. This parameter is expected to be negative as transaction costs are expected to be lower when negotiating lease terms upfront for multiple years rather than renegotiating lease terms annually.

INC2: Mean monthly income by state in January 2010 prices. This parameter is expected to be positive. As income increases, the price that individuals are willing to pay should also increase.

POP2: is the monthly population for each state. This parameter is expected to be positive because as population grows, we expect higher level of demand for the resource and consequently for prices to be bid upwards.

MEAD3LAG: is the monthly change in Lake Mead elevation in percentage terms, lagged three months. This parameter is expected to be negative because as elevation level increases, we expect the supply of available water to also increase, leading to a decrease in price. This variable is lagged because there is often a time lag between when lease negotiations occur and the water delivery and reporting date.

TEMP#LAG: is the mean monthly temperature by state lagged 3 months. This parameter is expected to be positive because as temperature increases, demand is expected to simultaneously increase. Temperature is lagged because there is often a time lag between when lease negotiations occur and the water delivery and reporting date.

PDO#LAG: represents the value of the Pacific Decadal Oscillation index, lagged # months. This parameter is expected to be negative. As PDO increases, winter La Niña conditions are expected to be muted, thereby making it more likely that precipitation will occur in those months and increasing water availability. PDO is lagged because there is often a time lag between when lease negotiations occur and the water delivery and reporting date. A six month lag was used because it was believed that a longer lag should be used than the lag used for temperature and precipitation.

AMO#LAG: represents the Atlantic Multidecadal Oscillation index lagged # months. It is unknown whether this parameter is positive or negative.

PRECIP#LAG: is the monthly precipitation by state lagged # months. This parameter is expected to be negative. As rainfall increases we expect that price will decrease. Precipitation is lagged because there is often a time lag between when lease negotiations occur and the water delivery and reporting date.

HOMPRICEADJ: is the monthly median home sales price by state adjusted to January 2010 prices. It is unclear whether this parameter will be positive or negative.

CA: is the dummy variable representing the state of California. This parameter is expected be positive as the highest demand pressures for water appear to currently be in California.

NM: is the dummy variable representing New Mexico. This parameter is expected to be negative because the demand pressures for water appear to be relatively lower in New Mexico.

STATESUP: is the dummy variable representing the state as a supplier of water to the market. Here, state represents federal, state and city suppliers. This parameter is expected to be negative as the state is more likely to subsidize water transactions thereby artificially reducing the price.

STORAGESOLD: is the dummy variable representing storage being the old use of the water. This parameter is expected to be positive because we expect relatively high costs of recovering the water from storage facilities.

MUNINEW: is the dummy variable representing the new use of the water being municipal. This parameter is expected to be positive as a municipality is likely to acquire water in the event of an emergency or when available supplies are low.

ENVIRONNEW: is the dummy variable representing environmental use being the new use of the water. Consistent with Jones (2008), this parameter is expected to be negative. Environmental use is expected to be subsidized, leading to a lower price.

INTERSTATECOMPNEW: is the dummy variable representing the satisfaction of an interstate compact being the new use of the water. This parameter is expected to be positive as states will be willing to spend a relatively high amount to ensure that interstate compacts are not violated.

7.5 Summary Statistics

7.5.1 Price Data

The cleaned dataset consists of 793 observations; 503 from California, 73 from New Mexico and 217 from Colorado. All prices are adjusted to January 2010 prices using the Bureau of Labor Statistics' CPI calculator (CPI 2010). The mean lease price per acre-foot of water for the entire data set is $184.67 with a standard deviation of $316.24. An examination of the distribution of prices suggests that they are not normally distributed; rather, the distribution appears to be lognormal. Figure 7.1, below, displays a histogram of price data along with normal curve, lognormal curve and kernel estimate.

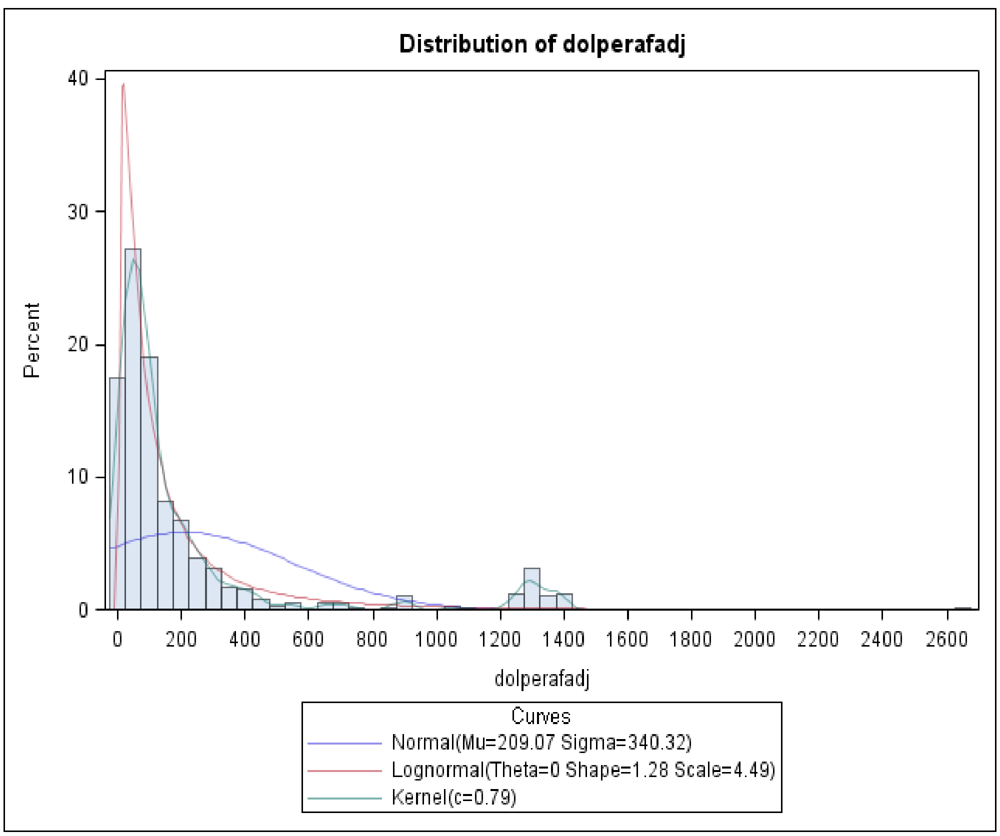

Figure 7.1: Dependent Variable Distribution

In an effort to normalize the dependent variable, the natural logarithm of the lease prices was taken. Figure 7.2 shows the distribution of lease prices after the data was transformed. The graph includes a histogram of lease prices as well as a normal curve and a kernel estimate.

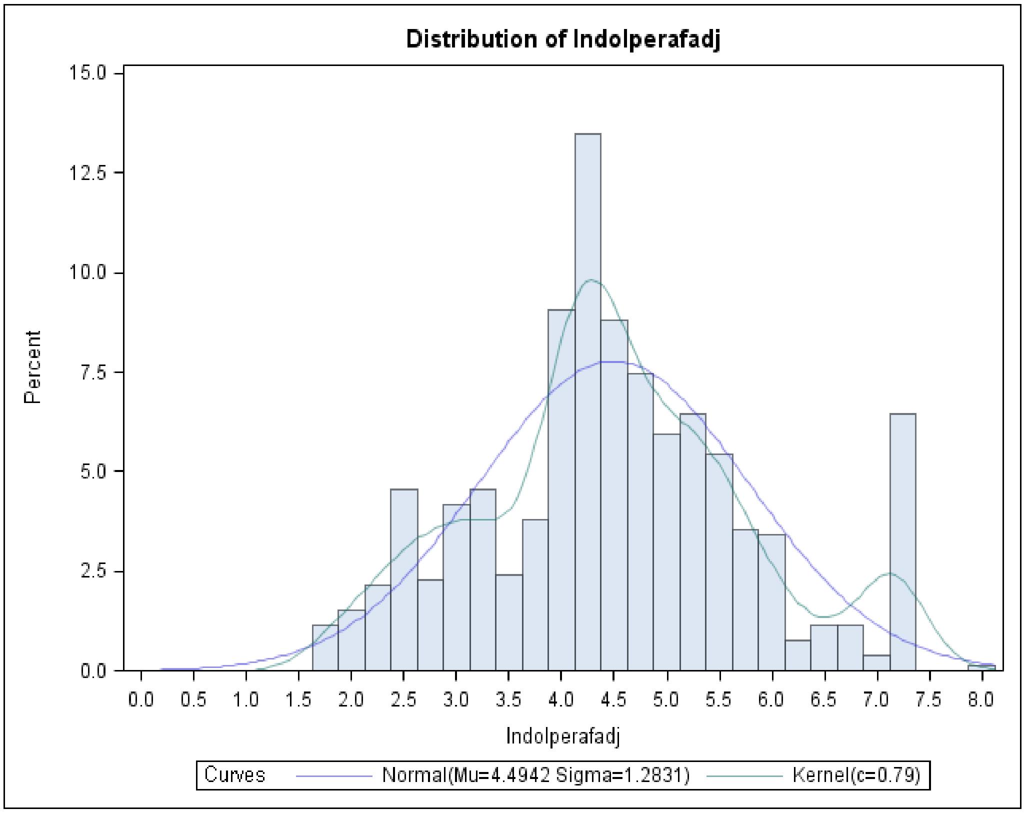

Figure 7.2: Natural Logarithm of Dependent Variable

Because the transformed data conforms relatively well to the normal curve, and because the normal distribution generally has desirable statistical properties, the natural logarithm of lease price (LNDOLPERAFADJ) is used throughout. Table 7.3 presents the natural logarithm of mean lease price per acre-foot and standard deviation of each lease transaction broken down by state.

Price by State			
	Obs	**Lndolperaf**	**Stan. Dev**
CA	503	4.544	1.244
NM	73	4.069	1.211
CO	217	4.523	1.374

Table 7.3: Dependent Variable Means Analysis, by State

7.5.2 Transaction Data

Data on the transactions used in this analysis is presented below. In figure 7.3, it is clear that the months in which transactions occur is roughly bi-modal; nearly 30% of the transactions accounted for in the data occurred in the two months of May and October. It is unclear exactly why this phenomenon occurs. However, one explanation may be that by the month of May, water demanders have a better idea of water availability for the coming summer months and thus procure water if shortage exists. Another possible explanation is that the high number of transactions in October are related to agricultural planting cycles; demanders can acquire the water at the lowest cost before growers sink resources into agricultural production.

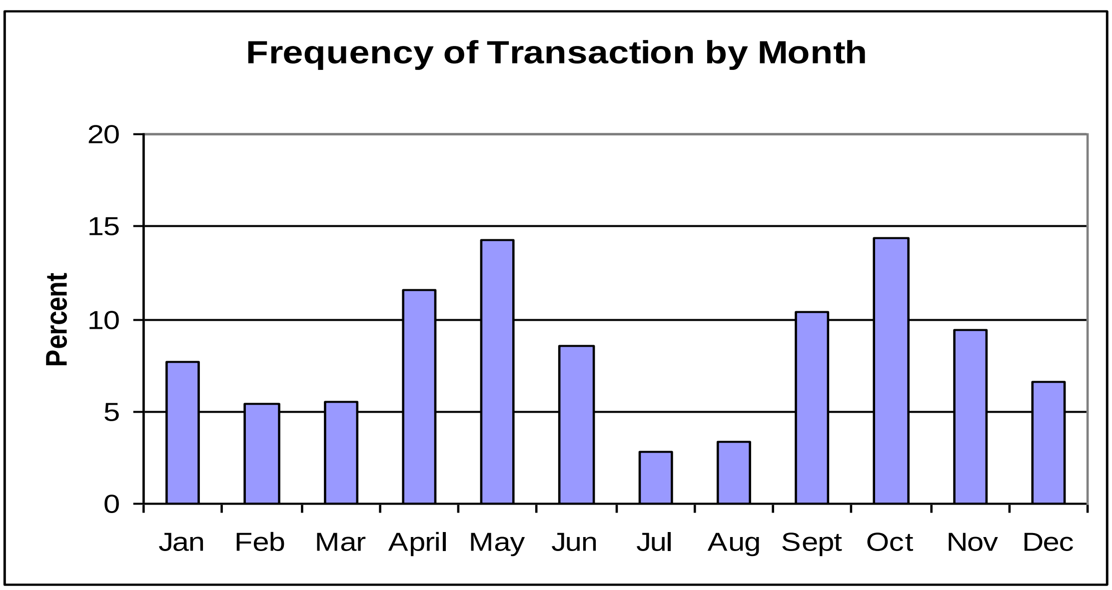

Figure 7.3: Frequency of Lease Transactions, by Month

Figure 7.4 presents the frequency of transactions in the data by percent by year. The graph shows that the frequency of transactions stayed roughly the same between the years of 1987 and 2004, more than doubled in 2005 and has continued to stay relatively higher than the 1987-2004 period. This phenomenon may have occurred as a result of increased drought conditions, an increased number of demanders (presumably willing to pay for the resource), or a loosening of regulations circumscribing water leasing. Another possibility is that sales transactions may have become more costly to consummate, making leases appear relatively more attractive. Most likely, however, is that the sharp increase is related to the drought water banks administered by the state of California.

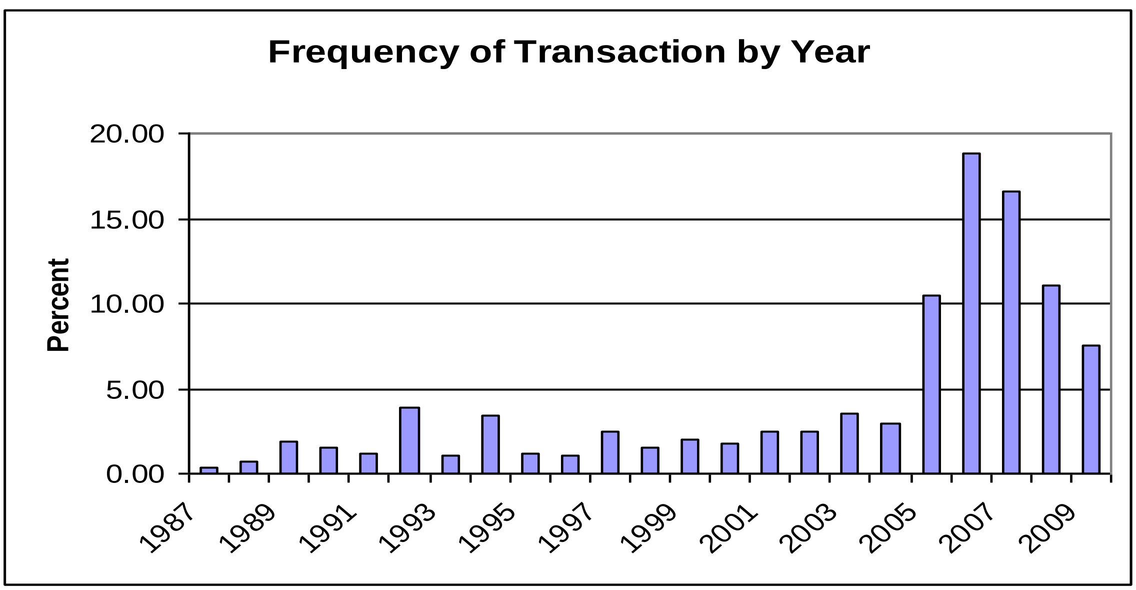

Figure 7.4: Frequency of Lease Transactions, by Year

Additionally, the typical lease length varies by state. For the entire dataset, the average number of years for a lease is 3.2. The average lease length in California and New Mexico is 2.2 and 2.1 years, respectively. Colorado lease lengths are longer on average at 5.9 years.

Figure 7.5 shows which entities have been involved in either acquiring or supplying water through leasing transactions. In this data, State refers any state or federal government agency or entity and represents a large player in both aspects of the market. Private Group, generally representing private interests (business, etc.) accounted for roughly 25% of the transactions from1987-2009, while only accounting for roughly 11% of the supply transactions. Water districts engaged in approximately 20% of both the supply transactions as well as the demand transactions. Every other group participated in less than 15% of both the supply and demand side of the market in terms of number of transactions from 1987-2009.

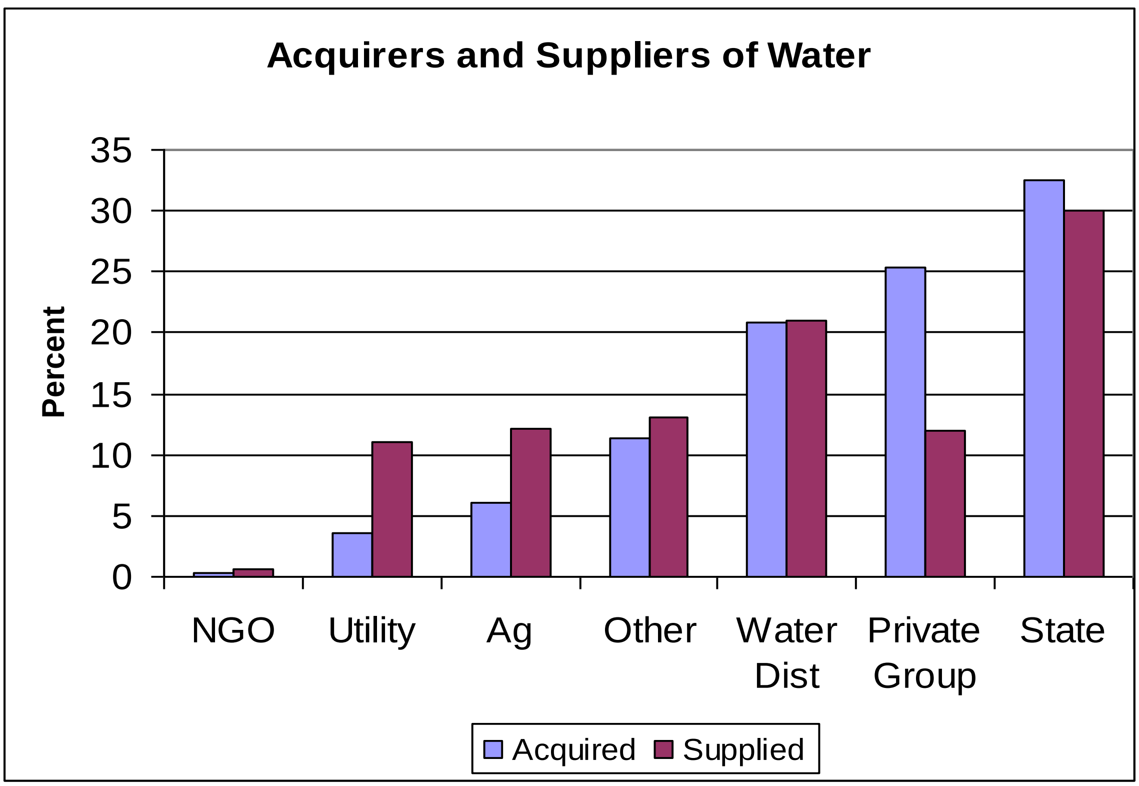

Figure 7.5: Entities Supplying and Acquiring Water, by Percent

Figures 7.6 and 7.7 present the relative proportion of the old use for each entitlement and the new use for each lease, respectively. In both cases, the category “Other” represents at least 33% of the total number of transactions. Other is comprised of the sum of transactions that comprise less than 5% of the total market and transactions where the old use (or new use) is unknown. The ambiguity is interesting because it may mean that there are many old and new uses and thus are difficult to categorize and/or the documentation of old and new uses is not particularly good so it is difficult to obtain a clear understanding of what exactly is occurring.

In figure 7.6, storage is a noteworthy old use because it is used as a regressor in the econometric analysis while the other variables are not. Therefore, the hypothesis that storage as the old use of the water is significantly different from other old uses. Additional old uses are included in the chart to provide a visual assessment of the relative proportion of alternatives.

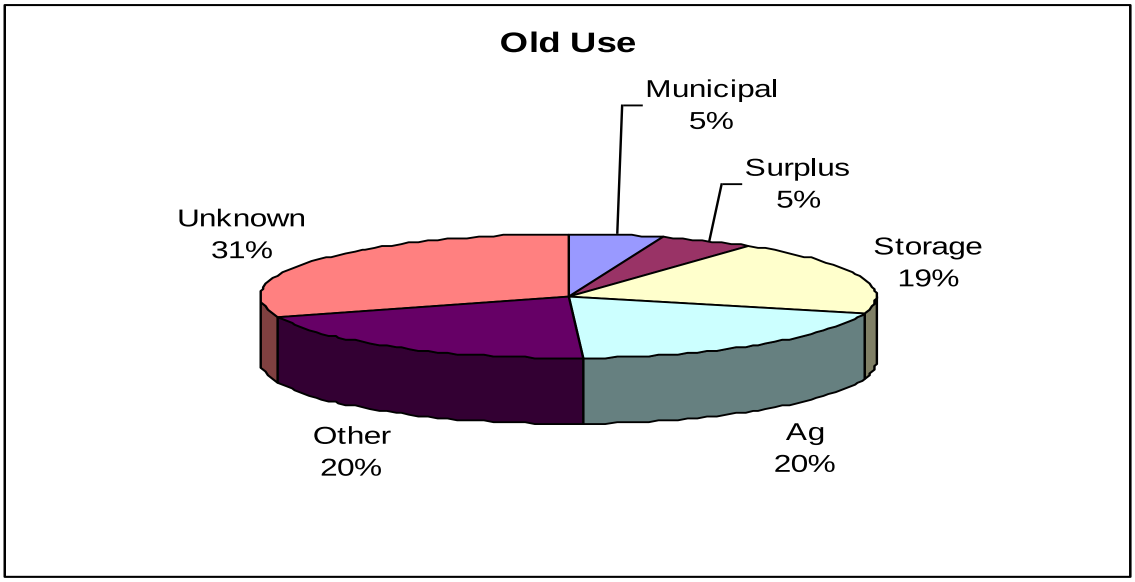

Figure 7.6: Proportion of Old Use

Three variables are noteworthy for the new uses in figure 7.9: municipal, which represents new municipal use; environment, which represents new environmental use;

and interstate compact, which represents satisfaction of an interstate compact being the new use. All three variables are used as regressors in the econometric analysis. Agricultural new use and other new uses are included in the chart to provide perspective as to the relative proportions in the data.

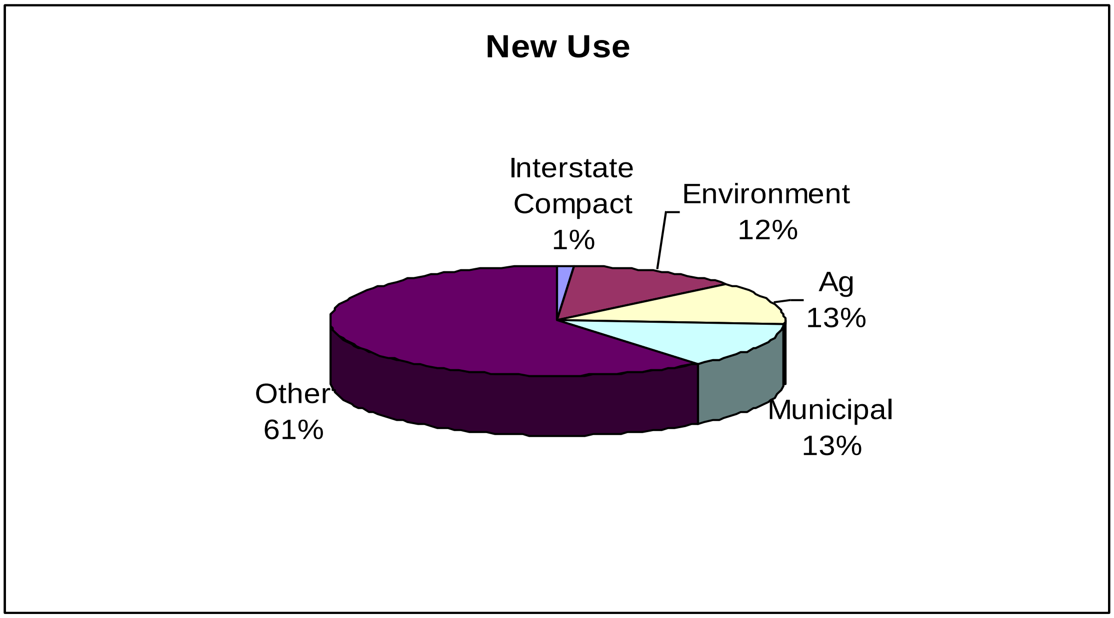

Figure 7.7: Proportion of New Use

7.5.2 Median Home Price Data

Figures 7.8, 7.9 and 7.10 present yearly median statewide home prices in both nominal dollars and also adjusted for inflation to 2010 dollars for California, Colorado and New Mexico, respectively. California values were provided by the California Association of Realtors. Colorado values were provided by the National Association of Realtors and represent a weighted average of Denver (80%) and Colorado Springs (20%) values, based roughly on population. New Mexico values, also reported by the National Association of Realtors, use Albuquerque values. In all cases, the year 2007 represents the beginning of a drop in home prices, which coincides with start of the financial crisis. The starkest drop in price occurred in California and has continued to fall in both California and Colorado. New Mexico prices, on the other hand, have apparently begun to move upwards. It is unclear, however, whether the New Mexico 2009 prices merely represent a data anomaly, a significant trend upwards or a measurement error. Note that the scale on the vertical axis is different for each figure.

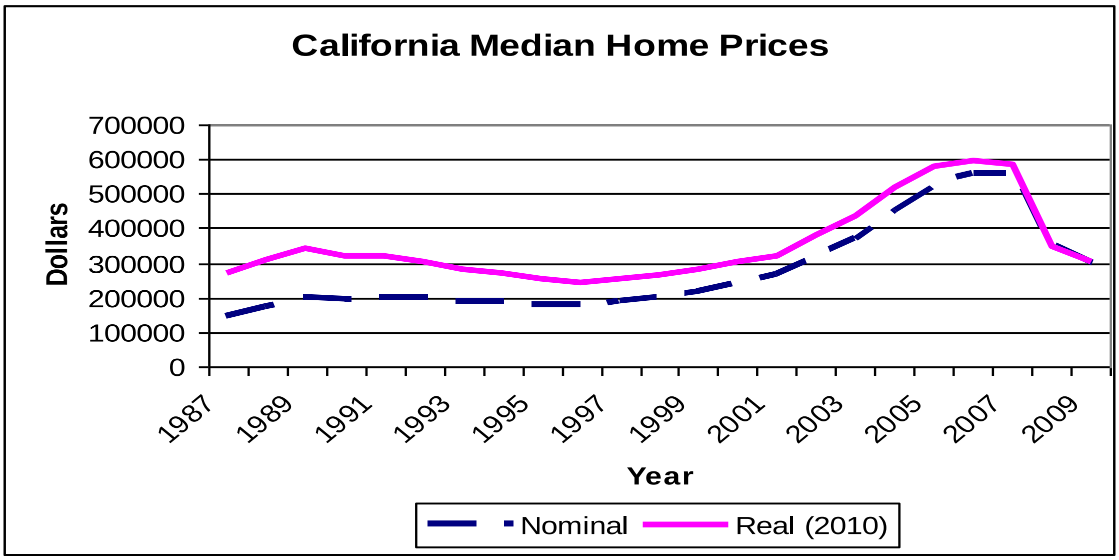

Figure 7.8: Median Home Price, California

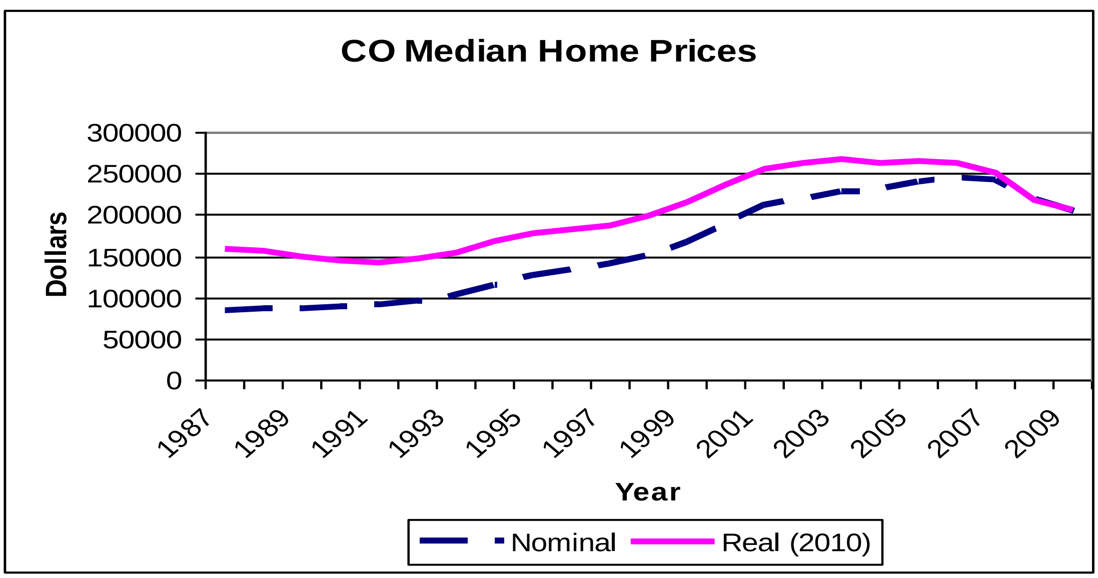

Figure 7.9: Median Home Prices, Colorado

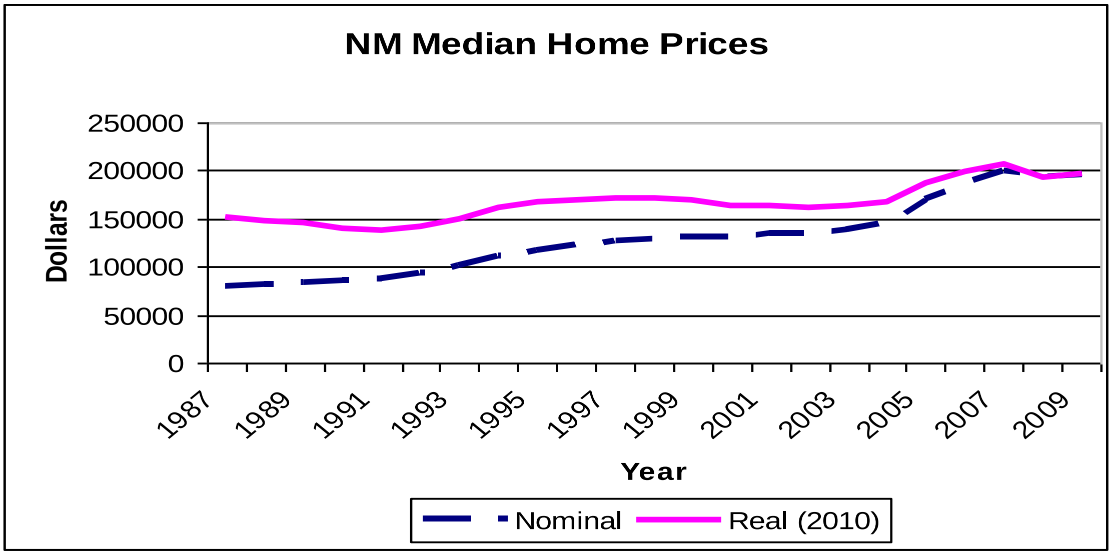

Figure 7.10: Median Home Prices, New Mexico

7.5.3 Precipitation Data

Figure 7.11 shows monthly precipitation in inches by state beginning January 1986. The sharp spikes indicate that California exhibits a high degree of volatility. Colorado and New Mexico exhibit relatively less volatility. This measure is used as a proxy to represent relatively short-term shortage or surplus.

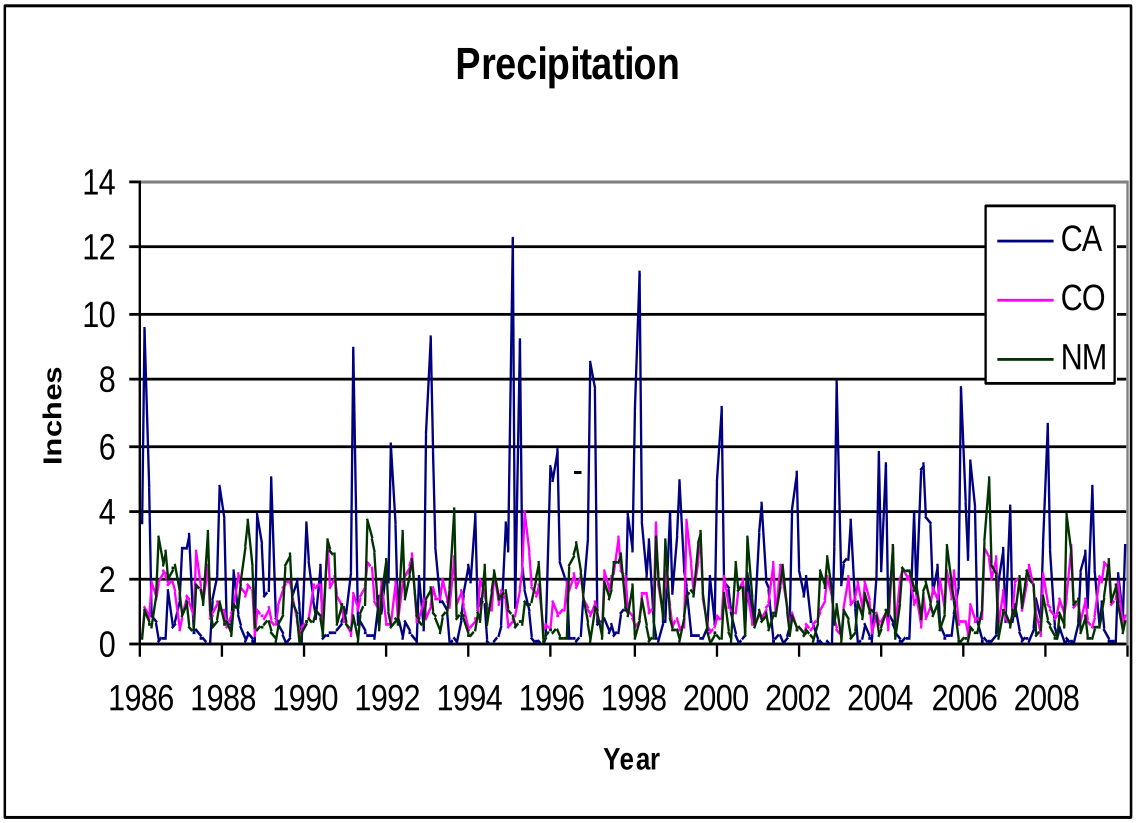

Figure 7.11: Monthly Precipitation, by State

Because the monthly precipitation graph contains a large degree of variation, Figure 7.12 is included to show the variation on an annual basis. This figure is included even though annual precipitation is not an explanatory variable in this analysis. On average, precipitation levels tend to be higher in California; however, they appear more volatile.

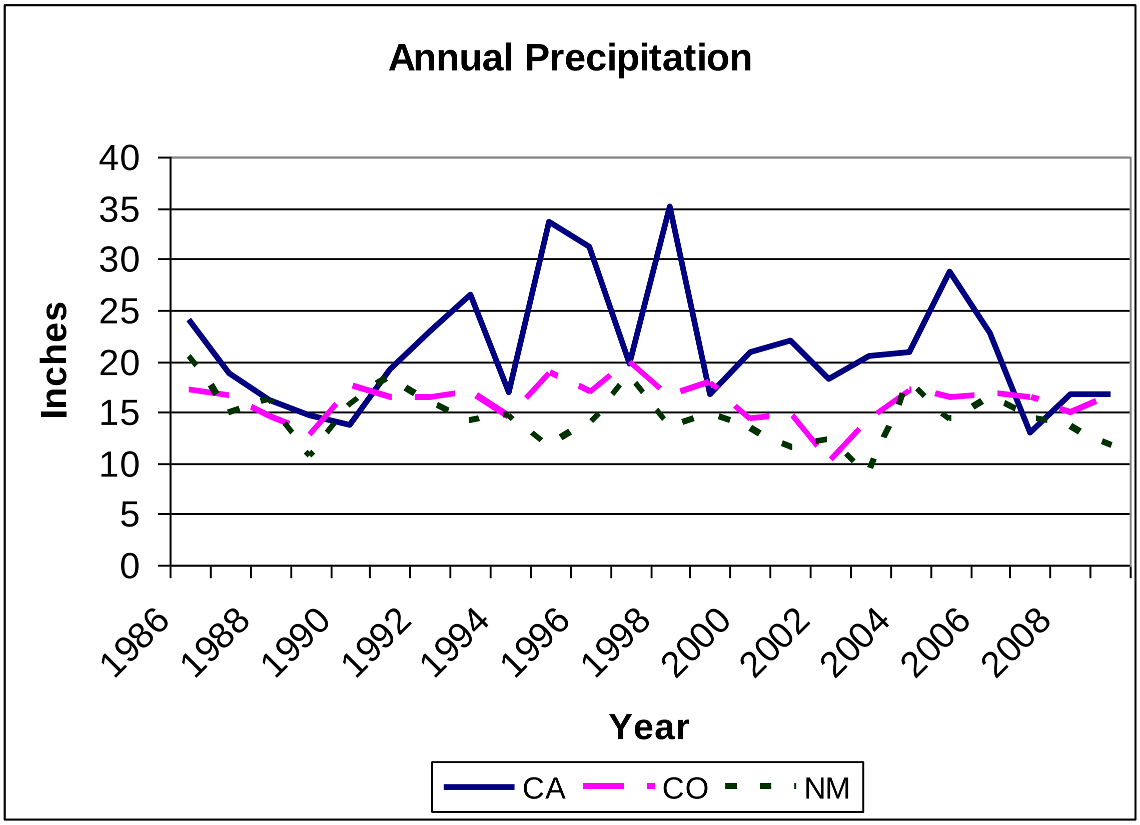

Figure 7.12: Annual Precipitation

7.5.4 Temperature Data

Figure 7.13 shows monthly mean temperature by state. The figure shows the cyclical pattern of increasing mid-year temperatures followed by falling end-of-year temperatures. Colorado temperatures show significant inter-annual temperature variation, with relatively less variability for New Mexico and even less for California.

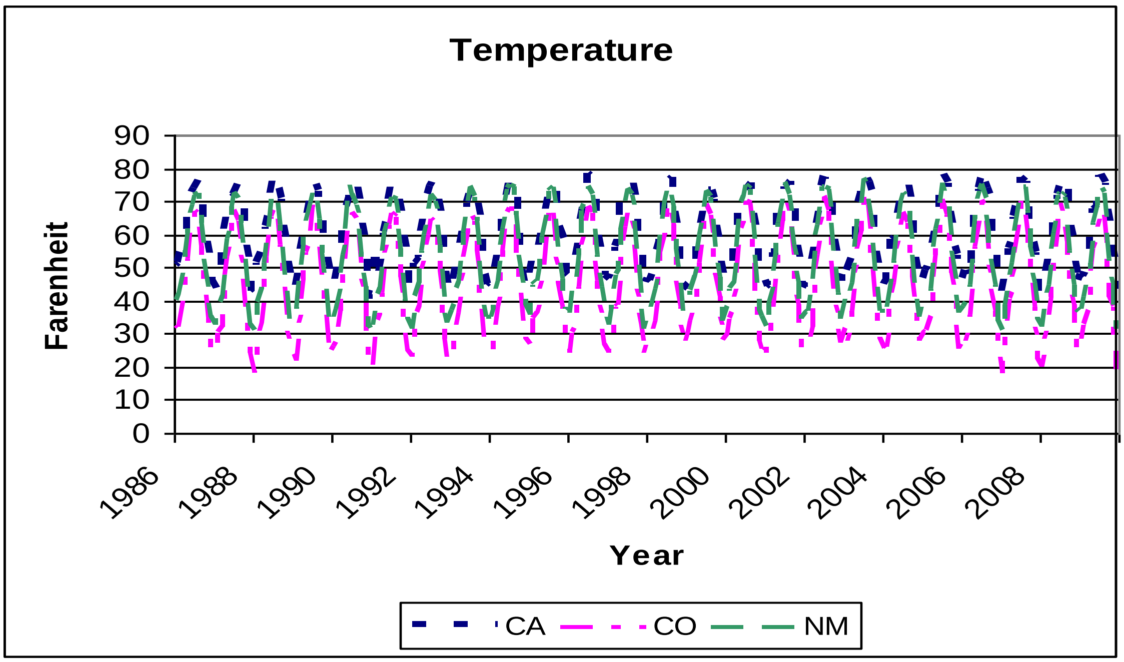

Figure 7.13: Monthly Mean Temperature, by State

7.5.5 Climate Variables

Figure 7.14 shows data from three major climate indices, Multivariate ENSO Index (MEI), Pacific Decadal Oscillation (PDO) and Atlantic Multidecadal Oscillation (AMO). Because MEI, PDO and AMO are all climate variables, and should thus be measuring similar phenomena, it is important to consider wither the indices are correlated. Tables 7.4 and 7.5 show the Pearson and Spearman correlation coefficients, respectively. In those tables, * represents significance at a 10% level. The tables show that PDO and MEI are slightly correlated as well as AMO and MEI; however, all variables were initially retained because the correlation coefficient is not unacceptably large. PDO and AMO, however, show no significant correlation. Because the econometric models used in this study utilized a lagged version of PDO, the table below reports the correlation of the lagged variables. MEI was ultimately dropped from the analysis because its use proved insignificant in preliminary modeling.

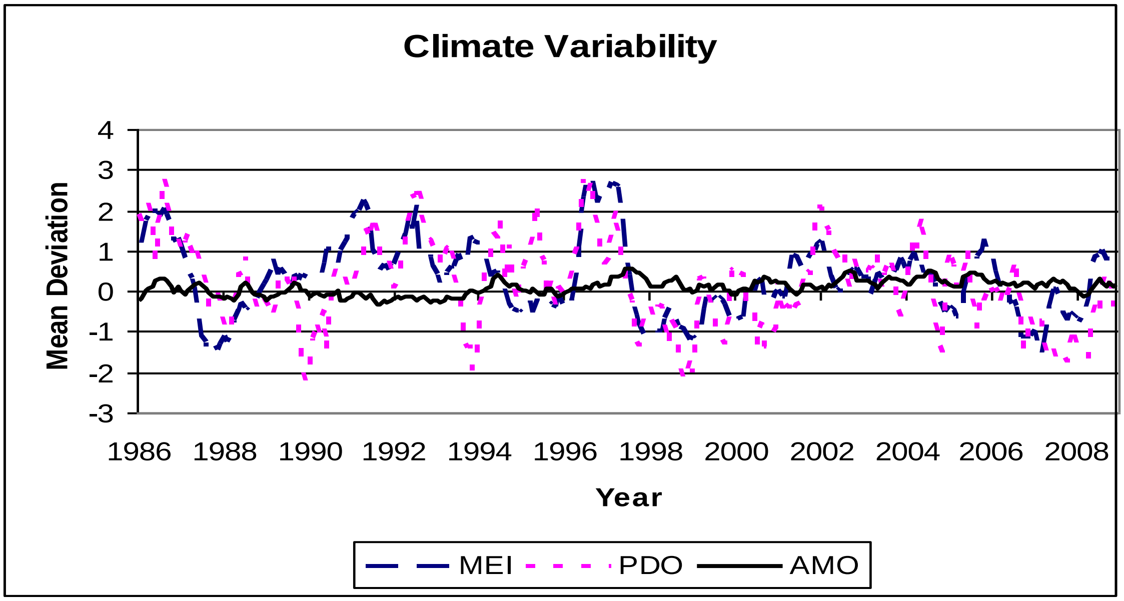

Figure 7.14: Climate Variable Indicators

Pearson Correlation Coefficients, N = 793 Prob > |r| under H0: Rho=0			
	PDO6 lag	**MEI**	**AMO 6lag**
PDO6lag	1.00		
MEI	0.23*	1.00	
AMO6lag	-0.03	-0.37*	1.00

Table 7.4: Pearson Correlation Coefficients

Spearman Correlation Coefficients, N = 793 Prob > |r| under H0: Rho=0			
	PDO6 lag	**MEI**	**AM O6l ag**
PDO6lag	1.00		
MEI	0.23*		
AMO6lag	0.06*	-0.31*	1.00

Table 7.5: Spearman Correlation Coefficients

7.5.6 Population and Income

Figures 7.15 and 7.16 show monthly population by state and mean annual income by state adjusted to January 2010 prices. The data begins in January 1987 and runs through December 2009. Total population increases in every year with the exception of in Colorado in 2008, where it decreased. The general trend is for income to increase throughout each series; however, income declines sharply in California in the early 1990s and plateaus near 2006.

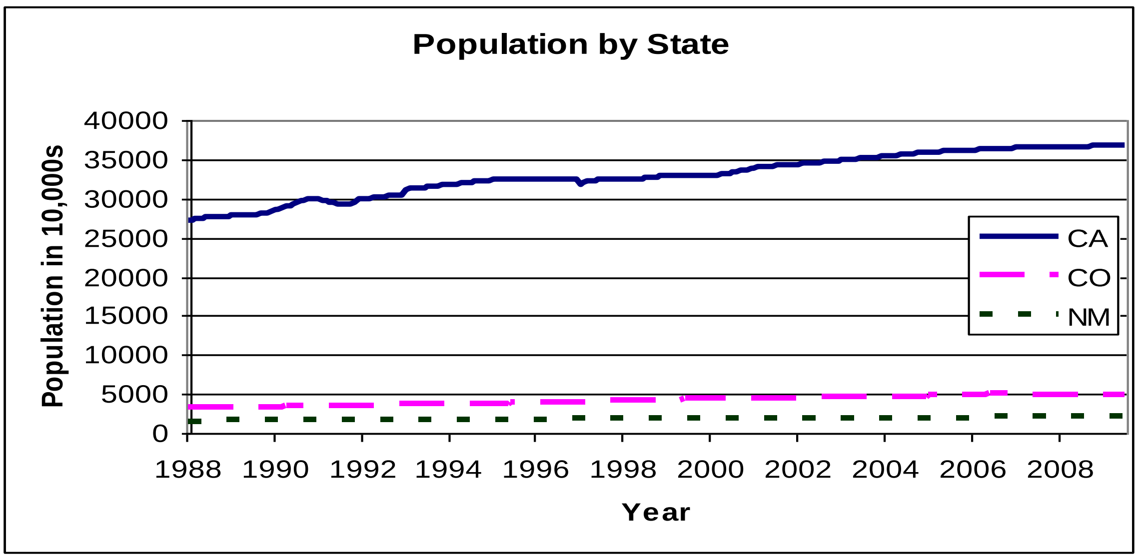

Figure 7.15: Annual Population, by State

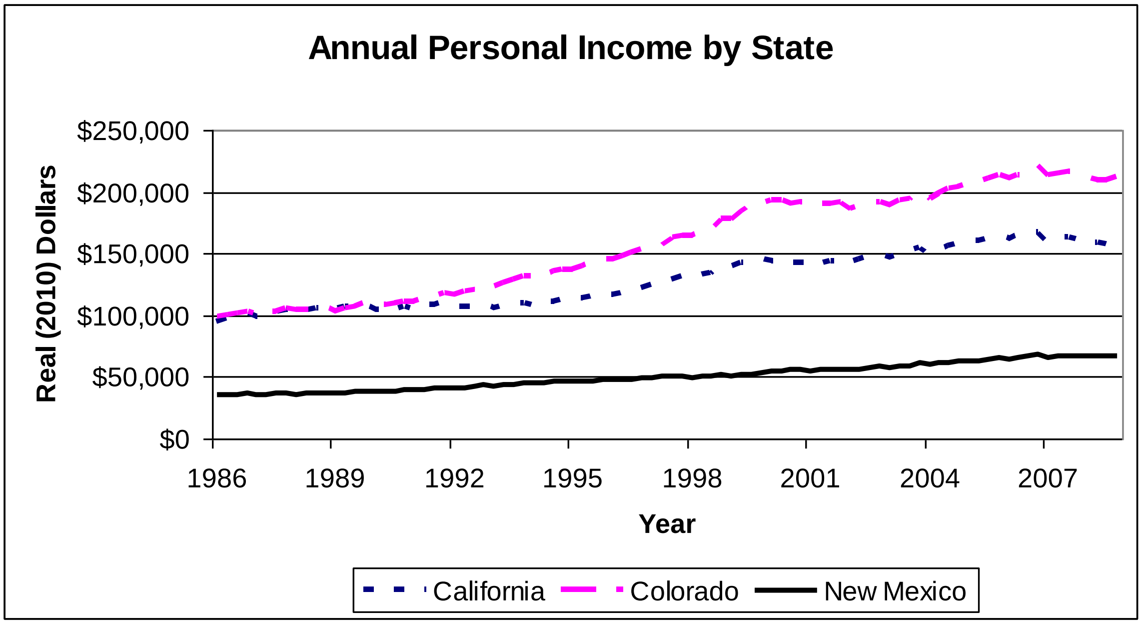

Figure 7.16: Annual Personal Income, by State

7.5.7 Lake Mead Elevation

Figure 7.19 below shows Lake Mead elevation levels, beginning in January 1987. The graph shows a relatively large degree of monthly variability and is generally decreasing.

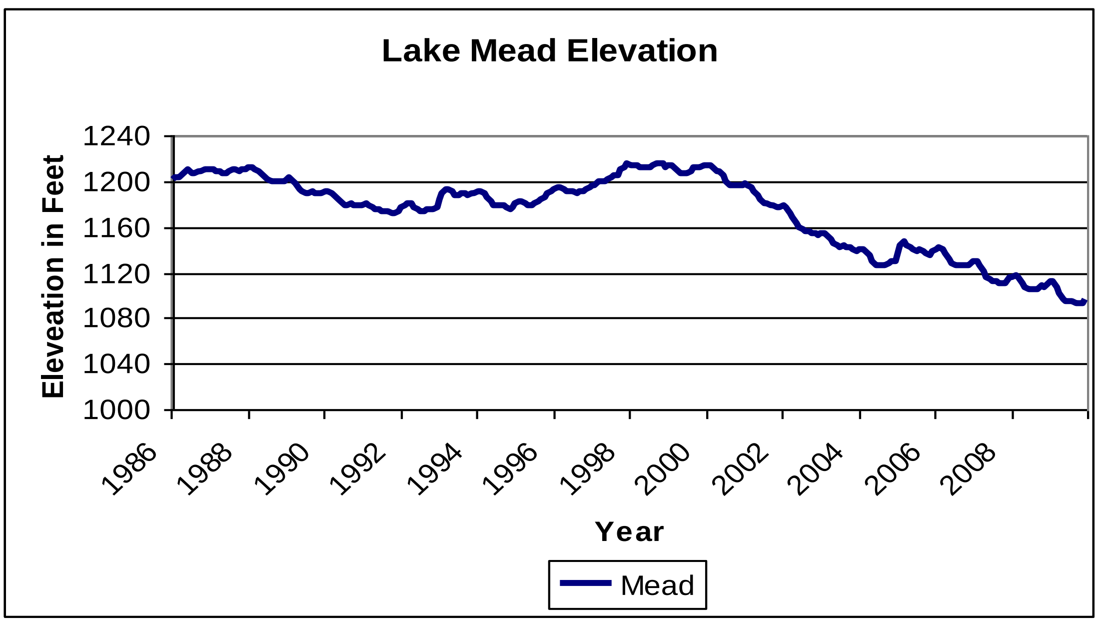

Figure 7.17: Lake Mead Elevation

8. RESULTS and ANALYSIS

Four models are used in this study: Three State model, California model, Colorado model and New Mexico model. The Three State model is a compilation of data from the California, Colorado and New Mexico models where Colorado is the excluded dummy variable. After a methodological introduction, raw results from SAS are provided. Following the raw results is a discussion of the marginal effects of each model as well as an interpretation of results.

8.1 Econometric Results

Where practicable, all four models utilize the same variables. In the individual state models, some variables were deleted to ensure that the models were not over-specified and full rank. For instance, the state dummy variables were deleted in all of the individual state models. Additionally, INTERSTATCOMPNEW was deleted from the California model and MUNINEW was deleted from the New Mexico model as the *Water Strategist* did not report that that either state had engaged in those respective types of leasing transactions over the time period studied.

All models are in a semi-log form. Non-dummy variable parameters represent the percent change in price for a one-unit increase of that particular variable. The marginal effect of dummy variables, on the other hand, are calculated by raising the exponential function to the value of the reported parameter and subtracting by one (Kennedy 2003).

8.1.1 Three State Model Results

Below are regression results from the ordinary least squares regression of the entire sample, adjusted for heteroskedasticity.

ANOVA

Source	DF	SS	MS	F-Value	Pr>F
Model	15	206.60	13.77	9.75	<.0001
Error	777	1097.38			
Corrected	792	1303.98			

N=713
R-Square = 0.158
Adj-R = 0.1422

Parameter Estimates

Variable	Parameter Estimate	P-value
Intercept	7.63	0.007
CA	-0.43	0.04
NM	-0.91	0.03
Length	-0.016	0.003
Inc2	-0.041	0.15
Mead3lag	-0.001	0.51
Pop2	0.06	0.21
Temp3lag	-.004	0.26
PDO6lag	0.17	0.0001
Precip3lag	-0.13	<.0001
Statesup	-0.51	<.0001
Storagesold	0.30	0.02
Muninew	-0.29	0.01
Environnew	-0.89	<.0001
Interstatecompnew	-1.75	<.0001
Quant	0.001	0.34

Table 8.1: Regression Results, Entire Sample

8.1.2 California Model Results

Below are regression results from the ordinary least squares regression of the California sample, adjusted for heteroskedasticity.

ANOVA

Source	DF	SS	MS	F-Value	Pr>F
Model	12	125.14	10.43	7.89	<.0001
Error	490	651.11	1.33		
Corrected	502	776.25			

N= 503
R-Square= 0.16
Adj-R= 0.14

Parameter Estimates

Variable	**Parameter Estimate**	**P-value**
Intercept	-1.62	0.72
Length	-0.04	<.0001
Inc2	0.001	0.99
Mead3lag	0.005	0.09
Pop2	0.49	0.45
Temp3lag	-0.01	0.21
PDO6lag	0.19	.0003
Precip3lag	-0.16	<.0001
Statesup	-0.18	0.23
Storagesold	0.01	0.96
Muninew	-0.17	0.27
Environnew	-0.91	<.0001
Quant	-0.001	0.48

Table 8.2: Regression Results, California Model

8.1.3 Colorado Model Results

Below are regression results from the ordinary least squares regression of the Colorado sample, adjusted for heteroskedasticity.

ANOVA

Source	DF	SS	MS	F-Value	Pr>F
Model	13	130.21	10.02	7.33	<.0001
Error	203	277.27	1.37		
Corrected	216	407.48			

N= 217
R-Square= 0.32
Adj-R= 0.28

Parameter Estimates

Variable	**Parameter Estimate**	**P-value**
Intercept	12.62	0.04
Length	-0.05	0.48
Inc2	-0.10	0.01
Mead3lag	-0.004	0.37
Pop2	-0.12	0.02
Temp3lag	-0.009	0.15
PDO6lag	0.13	0.14
Precip3lag	-0.18	0.29
Statesup	-1.18	<.0001
Storagesold	0.79	0.0006
Muninew	-0.31	0.17
Environnew	-0.69	0.06
Interstatecompnew	-1.40	0.06
Quant	0.01	<.0001

Table 8.3: Regression Results, Colorado Model

8.1.4 New Mexico Model Results

Below are regression results from the ordinary least squares regression of the New Mexico sample.

ANOVA

Source	DF	SS	MS	F-Value	Pr>F
Model	12	33.26	2.78	2.3	0.02
Error	60	72.30	1.21		
Corrected	72	105.62			

N= 73
R-Square = 0.32
Adj-R = 0.18

Parameter Estimates

Variable	**Parameter Estimate**	**P-values**
Intercept	2.60	0.87
Length	0.06	0.12
Inc2	-0.16	0.91
Mead3lag	0.0005	0.96
Pop2	7.64	0.92
Temp3lag	0.01	0.27
PDO6lag	-0.13	0.37
Precip3lag	-0.17	0.51
Statesup	0.25	0.47
Storagesold	-0.04	0.94
Environnew	-1.14	0.01
Interstatecompnew	-1.30	0.04
Quant	0.002	0.63

Table 8.4: Regression Results, New Mexico Model

8.2 Analysis

The marginal effects in percentage terms, significance levels and adjusted R^2 values for each model are summarized below.

Variable	Three State Model	CA Model	CO Model	NM Model
CA	-0.35**	*N/A*	*N/A*	*N/A*
NM	-0.60**	*N/A*	*N/A*	*N/A*
Length	-0.016***	-0.04***	-0.05	0.06
Inc2	-0.041	0.001	-0.10***	-0.16
Pop2	0.06	0.49	-0.12**	7.64
Mead3lag	-0.001	-0.005*	-0.004	0.0005
Temp3lag	-0.004	-0.01	-0.009	0.01
PDO6lag	0.17***	0.19***	0.13	-0.13
Precip3lag	-0.13***	-0.16***	-0.18	-0.17
Statesup	-0.40***	-0.16	-0.69***	0.28
Storagesold	0.35***	0.01	1.20***	-0.04
Muninew	-0.25***	-0.16	-0.27	N/A
Environnew	-0.60***	-0.60***	-0.50*	-0.68***
Interstatecompnew	-0.83***	*N/A*	-0.75*	-0.73**
Quant	0.0001	-0.001	0.01***	0.002
	n=793 Adj R^2=.14	n=503 Adj R^2=.14	n=217 Adj R^2=.28	n=73 Adj R^2=.18

* Significant at 10% level, ** Significant at 5% level, *** Significant at 1% level

Table 8.5: Marginal Effects, by Model

The adjusted R^2 values for all of the models are relatively low, indicating that they do not explain the variability in the data particularly well. The Three State Model and California model are particularly poor with an adjusted R^2 of only .14. The Colorado and New Mexico models provide relatively better results with an adjusted R^2 of .28 and .18, respectively.

For the purpose of comparison, the adjusted R^2 in Jones (2008) ranged from .32 to .45 when lease prices were modeled, depending on the model. In that study, Arizona, New Mexico, Utah and California were modeled together in a two-stage least squares procedure. Also modeling lease prices, Pittenger (2006) found an adjusted R^2 ranging from .30 to .74, depending on which model was used. In that study, Arizona, California, Colorado, Idaho, New Mexico, Oregon and Texas were modeled separately. Additional models combining states by region were also tested with similar results. Two-stage least squares was used for models where endogeneity was present, while ordinary least squares was used when it was not. In both previous studies, the results show an improved adjusted R^2 when compared to the adjusted R^2 in the present study. A likely culprit for the relatively lower values is the statewide spatial scale used; both Jones (2008) and Pittenger (2006) use a smaller spatial scale of climate division. As a result, the models are more likely to pick up the intrastate climate and demographic variation, whereas an analysis based upon a statewide spatial scale is blind to that variation.

The variable, QUANT, which is the quantity figure measured in acre-feet for each transaction, is insignificant in every model except for the Colorado model. The models in which quantity is insignificant likely indicate that quantity does not have a significant impact on price. In the Colorado model, the quantity is positive and indicates that a 1000 acre-foot increase in quantity leads to a price increase of 0.1%. The increasing relationship counters the assumption that the phenomenon being modeled is a downward sloping demand curve (downward sloping in quantity). This may be explained by the possibility that transactions with higher quantities tend to have more impediments to transfer, and thus have higher transactions costs. Nevertheless, the overall results suggest that quantity and price are only tenuously related in water lease transactions. And if they are related at all, a positive relationship seems to exist. Jones (2008) found a similar result; in her non-environmental lease estimation, the quantity parameter was positive and barely significant, in her environmental lease estimation, it was insignificant. Pittenger (2006) also showed mixed results. In the California model, the quantity parameter was insignificant while the quantity parameter in the New Mexico model was positive and significant. It is important to note, however, that the Jones (2008) and Pittenger (2006) results are not strictly comparable to the results in this thesis because both utilized two-stage least squares estimation rather than ordinary least squares.

The dummy variables for the states of California and New Mexico are only present in the Three State model. Both the New Mexico and California dummies are negative and significant, which indicates that both states have lower lease prices than Colorado, the base state. The marginal effect of the New Mexico dummy is -0.91 indicating a -91% discount compared to Colorado prices. The marginal effect of the California dummy is -0.43 indicating a 43% discount in California when compared to Colorado prices.

LENGTH, the variable representing the length of the lease is significant and negative only in the Three State model and the California model. The leases spanned from 1 year to 40 years and the average lease length for the Three State model was 3.2 years while the average lease length for the California model was 2.2 years. In the Three State model, a marginal effect of -0.016 indicates that for each additional year in lease length, the price is reduced by 1.6%. In the California model, the marginal effect -0.04 indicates that for each additional year in lease length, the price is reduced by 4%. A possible explanation for this decreasing relationship is that transaction and negotiation costs are reduced by entering into a longer length lease. This is because the parties are required to negotiate and agree only once upfront, rather than negotiating and entering into leases on an annual basis.

INC2, the variable for annual personal income by state, is only significant in the Colorado model. The income variable for that state is negative and marginal effect indicates that a ten thousand dollar increase in annual income leads to a 10% decrease in price. The negative nature of this variable was unexpected; as income increases, price is expected to increase. The insignificance of income in the Three State Model, the California model and the New Mexico model indicates that annual personal income does not have a significant impact on price in those models. Jones (2008) found income to be significant in both her environmental lease model as well as her non-environmental lease model. However, her results were mixed. In her environmental lease model, the parameter was positive and small (.0001%) while in her non-environmental lease model, the marginal effect was negative and small (-.0001%).

POP2, the variable indicating monthly state population, is only significant in the Colorado model. The Colorado marginal effect is negative and indicates that a 10,000 population increase causes price to decrease by 12% percent. This results is inconsistent with the assumption that price would increase with increasing population. Nevertheless, the marginal effect is relatively small in absolute terms. For instance, if the variable is rescaled, a 1,000 increase in population only causes price to decrease by 1.2%. This indicates that population does not have a large impact on price in absolute terms.

MEAD3LAG, the variable representing monthly Lake Mead elevation in feet, lagged 3 months, is significant at a 10% level only in the California model. The marginal effect -0.005 indicates that for a 1-foot increase in elevation, lease price declines by 0.5%. This result is consistent with the expected negative sign; I expected that as Lake Mead elevation increased, price would decline because it would indicate a larger supply of available water. However, the marginal effect is extremely small indicating that the variable's impact on lease prices is also small.

TEMP3LAG, the variable representing state mean temperature lagged 3 months is insignificant in all models. This indicates that temperature does not play a role in lease price determinations. In general, Jones (2008) found temperature to be insignificant or only slightly significant, which is consistent with the results in this study.

PDO6LAG, the variable representing the Pacific Decadal Oscillation index, lagged 6 months, is significant in the Three State model and the California model at a 1% level. It is insignificant in the Colorado and New Mexico models. The marginal effect of the Three State model indicates that a one unit change in PDO, 6 months in advance, leads to a 17% increase in price. The marginal effect for the California model indicates that price increases by 19% when PDO increases by one unit, 6 months in advance. The expected parameter for this variable was negative, so the result is counter to the expectation. It is unclear why the actual parameter is positive; however, there are two likely explanations for this. First, the impact of PDO on water supply availability may be poorly understood and therefore the expectation of lower prices when PDO increases may not be correct. Second, because this variable was lagged 6 months, the lag has not been properly accounted for. The insignificance of PDO in the Colorado and New Mexico models suggests that it does not play a significant role in the prices in those states.

Nevertheless, prior studies on climate in the southwestern US suggest that PDO plays a role in New Mexico and Colorado precipitation patterns. Brown and Comrie (2002) found that PDO exhibits a strong relationship with winter and spring precipitation in New Mexico, while Schoennagel et al (2005) found that PDO variability impacts precipitation in Colorado. As such, more research is required to untangle the relationship between PDO, precipitation and lease prices in Colorado and New Mexico.

The variable for precipitation, PRECIP3LAG, which is the monthly precipitation by state, lagged 3 months, is negative and significant at 1% level only in the Three State model and the California model. In the Three State model, the marginal effect indicates that one inch of precipitation leads to a 13% reduction in price. In the California model, the marginal effect indicates that one inch of precipitation leads to a decrease in price of 16%. Although a slightly different variable was used in Jones (2008) and Pittenger (2005), both found precipitation to be significant with a negative marginal effect. This result provides important evidence of an inverse relationship between precipitation and lease price in the market.

STATESUP, the dummy variable for state supplier is negative and significant at a 1% level only in the Three State model and the Colorado model. Recall that state suppliers refers to any water lease transaction where the supplier is a city, the respective state or a federal supplier. For the Three State model, the marginal effect indicates a 40% price reduction compared to other forms of supply. Likewise, the marginal effect for the Colorado model indicates a -69% price reduction compared to other forms of supply. The negative marginal effect was expected, as I assumed that when the state supplies water it would provide a discount. The fact that the parameter is insignificant in the California and New Mexico models indicates that the price of leases by state suppliers is not significantly different from other suppliers.

STORAGESOLD, the dummy variable representing the old use of the water being in storage is positive and significant only in the Three State model and the Colorado model. The marginal effect of the Three State model indicates a 35% increase in price compared to old uses excluded from the model. The Colorado marginal effect is also positive and rather large; the marginal effect indicates that water coming out of storage is 120% more expensive than other old uses. This result coincides with the expected positive sign. It was expected that water obtained from storage would have costly administrative impediments to transfer; thus the marginal effect should be positive. The insignificant parameters for the California and New Mexico models indicate that water obtained from storage is not statistically different in price from water obtained from other old uses.

MUNINEW, the dummy variable representing new municipal use, is negative and significant at a 1% level only in the Three State model. It was not a regressor in the New Mexico model. The marginal effect for the Three State model indicates that when the new use of the water is municipal in nature, a price discount of 25% results. The negative parameter was unexpected but may simply be explained by municipal new users receiving a price discount compared to the new uses excluded from the model.

ENVIRONNEW, the dummy variable representing new environmental use, is negative and significant at a 1% significance level in the Three States model, the

California model and the New Mexico model. The Colorado model is negative and significant at a 10% level. In the Three State model, the marginal effect indicates a 60% price reduction for new environmental uses. The California model also indicates a 60% price reduction. The Colorado model indicates 50% price reduction. The New Mexico model indicates a 68% price reduction. The marginal effects of each model suggest that discounts are provided when environmental purposes are the new use of the water when compared against the new uses excluded in the model. The result that environmental new uses receive a discount was expected as Jones (2008) found a similar result.

INTERSTATECOMPNEW, the dummy variable representing an interstate compact being the new use of the water, is negative and significant at a 1% level in the Three State model, a 5% level in the New Mexico model and at a 10% level in the Colorado model. This variable was not a regressor in the California model. The marginal effect for the Three State model indicates an 83% price reduction when the new use of the lease is to satisfy an interstate compact, compared to new uses excluded from the model. The marginal effect for the Colorado model indicates a 73% price discount is given when the new use is to satisfy an interstate compact. The marginal effect for the New Mexico model suggests a 75% price reduction when the new use is to satisfy an interstate compact. This result was unexpected as I had assumed that the satisfaction of an interstate compact would require the party seeking to satisfy the compact to transfer water on short notice, thereby having to pay a premium. Nevertheless, the negative result indicates that the party receives a discount.

8.3 Interpretation of Results

The four models suggest that despite the fact that the same variables were used, each state is idiosyncratic and different factors affect transaction prices in each state. It is clear that lease prices are higher in Colorado than in California and New Mexico, *ceteris paribus,* and that lease prices in California are higher than in New Mexico.

Demographic variables, such as income and population, generally do not appear to have much impact on price. These variables may be largely insignificant because the data tends to have relatively little variation and therefore lends little explanation to dependent variable variation. The exception is Colorado, which is impacted by both income and population; however, the impact of these two variables on lease prices is relatively small, and in the case of population, the actual sign is inconsistent with the expected sign.

The climate variable, PDO6LAG, and temperature and precipitation variables are interesting because they are significant in some models and insignificant in others. Another interesting factor is that while these variables may help to explain water lease prices, they cannot be used in any way as policy tools to increase or decrease demand, as we do not have the technological capability to alter those variables. Nevertheless, an understanding of the manner in which these variables operate may yield insight into price change as well as provide a useful tool to assist in price forecasting and planning for future supplies. The PDO variable is only significant in the California model and the Three State model and insignificant in the others. This is somewhat surprising as PDO is believed to strongly impact climate in both Colorado and New Mexico (Brown and

Comrie 2002; Schoennagel et al 2005). More study is necessary to assess the manner in which PDO impacts lease prices in those states. The temperature variable is insignificant in all four models. The precipitation variable, on the other hand, is generally significant with the expected sign. It appears that price properly declines concurrently with higher levels of precipitation.

The variable for Lake Mead elevation is interesting because it may provide insight into how price changes when water volume storage changes in a major reservoir. As expected, the sign was negative, providing a signal that increased storage likely indicates greater water availability, and consequently, lower lease prices. While it is interesting that only California lease prices are impacted by Lake Mead elevation, the result is not unexpected. California is downstream from Lake Mead and receives 4.4 million acre-feet per year (maf) of the Lower Colorado Basin's 7.5 maf (BOR 2010). New Mexico and Colorado, on the other hand, are in the Upper Colorado Basin and receive 0.84 maf and 3.84 maf, respectively (BOR 2010). While non-trivial volumes, the water apportioned to those states is diverted upstream of Lake Mead and so Lake Mead elevation should have no direct impact on lease prices in these upstream states.

The dummy variable for state supplier is negative and significant only in the Three State model and the Colorado model. The dummy variable for storage as the old use is positive and is also only significant in these two models. Both results can provide important political and policy implications. First, because the state provides a price discount when supplying water in Colorado, care must be used when it engages in a particular transaction as prices do not coincide with market values. Second, because water obtained from storage tends to be priced higher, a strong disincentive to withdraw water is provided. If the goal of a particular program is to bank water for a later date, then the higher price of stored water can ultimately assist in that effort.

The new use variable, municipal new use, is only significant in the Three State model.[136] Environmental new use and interstate compact new use are negative and significant in all of the models where the variables were present. The models suggest that price discounts are generally occur with these types of new uses compared to excluded new uses. By implication, other new users are required to pay a higher price. Nevertheless, this result should be used with caution because it is unclear what the other new uses are. By construction, the base new use in these models is not clearly defined and the new uses in these models only account for a small percentage of transactions. As a result, more information can be gleaned about the particular new uses in the models than the alternatives not included.

Finally, the quantity variable is interesting because, with the exception of the Colorado model, it is insignificant. In the Colorado model, the variable is significant and positive, but extremely small. Although the positive result in the Colorado model was not expected, it may be explained by the possibility that larger quantity transactions have face more objections and regulatory scrutiny and need to involve more high value water to be worthwhile to undertake. Thus transactions costs provide a framework for explaining systematically higher prices in larger transactions. Nevertheless, the relationship between

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[136] Recall that INTERSTATECOMPNEW was not a regressor in the California model and that MUNINEW was not a regressor in the New Mexico model.

price and quantity in water lease transactions is variable across states in both sign and magnitude, and price is likely driven by factors other than quantity.

9. NET RETURNS TO WATER and PILOT IRRIGATION FORBEARANCE PROGRAMS

This chapter provides data and analysis for net returns to water (NRTW) for Durum wheat, alfalfa, Upland cotton and head lettuce produced in Yuma County, Arizona. These crops were chosen for study because they are common crops planted in the region and represent significant acreage.[137] Also provided is analysis of four pilot irrigation suspension programs that the US Bureau of Reclamation has recently entered into. This analysis is complementary to the econometric analysis conducted in Chapter 8. While the econometric analysis seeks to discover trends in market prices, NRTW is used to assess the net value of water to agricultural producers and give an indication of the range of payments that may be required to lease or purchase water from growers. Under this framework, it is hypothesized that agricultural water users seek to exploit informational advantages when negotiating over price in water transactions in order to receive a greater share of the economic surplus generated by a transaction that moves water from a lower value to a higher value use. An analysis of NRTW can assist a water purchaser when conducting price negotiations. Analysis of the four Bureau of Reclamation pilot irrigation forbearance programs is included in this chapter to provide actual examples of recent agreement and negotiated prices that may be compared against both market prices and NRTW.

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[137] For instance, 54,300 acres of Durum wheat, 10,000 acres of Upland cotton and 31,500 acres of alfalfa were planted in Yuma County in 2008. Also, 50,101 acres of head lettuce was planted in 2002 (USDA 2010).

9.1 Yuma County NRTW

NRTW provides a benchmark that may be used to represent the minimum payment required for a grower to cease irrigation. To compute NRTW, the variable costs of production (excluding the cost of water) are subtracted from the revenues obtained, on a per-acre basis. Because all of the variable costs other than the cost of water are accounted for, the difference may be considered as one measure of water value. The per-unit value of water is of interest in this study, so the difference is divided by the consumptive volume of water per-acre necessary for production of the particular crop. The consumptive volume estimates used in this study were obtained from the Bureau of Reclamation's Final Environmental Impact Statement (BOR 2007). Crop prices and input costs were updated to their current levels. Fertilizer, insecticide and herbicide prices were collected through personal interviews with input suppliers. For a detailed summary of input costs and the NRTW calculation, see Appendix C.

Tables 9.1, 9.2, 9.3 and 9.4 present data on NRTW per acre-foot of water for Durum Wheat, Alfalfa, Upland Cotton and Head Lettuce, respectively, in Yuma County, Arizona. With the exception of the Upland Cotton table, each contains a column representing average values for the years 2002-2006, a column representing average values for the years 2005-2009, and a column representing the change of those two averaged series in percentage terms. The Upland Cotton table contains the average values for the years 2006-2008 instead of 2005-2009 because a full set of data was not available for the relevant 5 year-long comparison. In order to assess trends in the two time-periods, yields, prices, gross revenues per acre, total variable costs per acre and net returns to water per acre are included in each table. In the case of cotton, loan deficiency payments (LDP) are listed. A LDP is a governmental payment to growers when the market price falls below a certain threshold. Figures in parentheses represent negative values.

NRTW calculations below are based on costs from University of Arizona crop budgets (Teegerstrom and Knowles 1999; Teegerstrom and Tickes 1999; Teegerstrom, Palumbo, and Zerkoune 2001) updated using USDA producer cost indices (USDA 2010). All chemical input prices were updated through personal communication with chemical input suppliers. Yields and commodity prices come from Arizona Agricultural Statistics Bulletins (USDA 2005; 2006; 2007; 2008; 2009). Crop consumptive water use was derived using Lower Colorado River Accounting System annual water use (Reclamation 2007a). 2002-2006 data was updated from Jones (2008). All prices are adjusted to January 2010 values using a CPI inflation calculator (CPI Inflation Calculator 2010).

Yuma Durum Wheat 5yr Avg			
Year Range	**2002-2006**	**2005-2009**	**% Change**
Revenue per Acre			
Yield/acre	102	106.1	4
Price($)/bushel	4.80	6.93	44
Gross Revenue ($/Acre)	490.06	737.36	50
Total Variable Costs per Acre	406.06	582.02	43
Net Returns to Water per Acre	83.97	155.34	85
A/F water consumptively used per acre			
Net Returns to Water Per Acre-foot of Water Consumed	**44.20**	**81.76**	**85**

Table 9.1: NRTW, Durum Wheat

Yuma Alfalfa 5yr Avg

Year Range	2002-2006	2005-2009	% Change
<u>Revenue per Acre</u>			
Yield/acre	9.3	9.3	0
Price($)/bushel	116.30	148.91	28
Gross Revenue ($/Acre)	1081.56	1388.83	28
Total Variable Costs per Acre	430.78	624.79	22
Net Returns to Water per Acre	650.78	764.04	17
A/F water consumptively used per acre			
Net Returns to Water Per Acre-foot of Water Consumed	**114.17**	**134.04**	**17**

Table 9.2: NRTW, Alfalfa

Yuma Upland Cotton 5yr and 3yr Avg			
Year	**2002-2006**	**2006-2008**	**% Change**
<u>Revenue per Acre</u>			
Yield/Acre (lint)	1323	1397	6
Price($)/Pound (lint)	0.56	0.59	5
LDP/Pound	0.097	0.03	(70)
Yield/Acre (seed)	1.05	1.05	0
Price/ton	161.22	223.03	40
Gross Revenue ($/Acre)	1038.49	1103.32	6
Total Variable Costs per Acre	1236.42	1318.20	7
Net Returns to Water per Acre	(197.93)	(217.88)	(10)
A/F water consumptively used per acre	3.6	3.6	
Net Returns to Water Per Acre-foot of Water Consumed	**(54.98)**	**(60.52)**	**(10)**

Table 9.3: NRTW, Upland Cotton

Yuma Head Lettuce 5yr Avg			
Year	**2002-2006**	**2005-2009**	**% Change**

<u>**Revenue per Acre**</u>			
Yield/Acre	345	342	(1)
Price($)/cwt	21.48	18.47	(14)
Gross Revenue ($/Acre)	7408.95	6348.88	(14)
Total Variable Costs per Acre	5463.25	3522.70	(36)
Net Returns to Water per Acre	1946.39	2826.18	45
A/F water consumptively used per acre			
Net Returns to Water Per Acre-foot of Water Consumed	**1389.79**	**2018.70**	**45**

Table 9.4: NRTW, Head Lettuce

In all cases, except for Upland cotton, a positive value for net return over variable costs per acre is shown in both the 2002-2006 and 2005-2009 time-periods, indicating that revenues exceed variable costs of production. Upland cotton shows a negative value for net returns to water per acre for both time periods, indicating that variable costs exceeded gross revenues.

In every case, except for head lettuce, both the gross revenues and total variable costs increased from the 2002-2006 average to the 2005-2009 average. Specifically, gross revenues for Durum wheat, Upland cotton, and alfalfa increased because market price increased in every instance while yields also increased in the case of Durum wheat and Upland cotton and alfalfa yield remained unchanged. Lettuce yield and market price both declined.

Gross revenues for Durum wheat and alfalfa grew at a faster rate than the total variable costs per acre, while variable costs for head lettuce decreased faster than gross revenue, leading to positive increases in net returns to water per acre for those crops. Variable costs for Upland cotton, on the other hand, grew faster than gross revenue, leading to a negative change in net returns to water per acre.

For the purposes of this thesis, the most important value, however, is the net returns to water *per acre-foot of water consumed* because that figure represents a benchmark of the net value per unit of water to a grower. It also provides insight into which crops ought to be targeted in a water acquisition program because purchasers seek to pay a lower price per volume of water, *ceteris paribus.* All crops except for Upland cotton show an increase in net returns to water per acre-foot of water consumed from the 2002-2006 average to the 2005-2009 average. Durum wheat shows approximately an 85% increase, alfalfa a 17% increase and head lettuce a 45% increase. Upland cotton, however, shows an approximate 10% decrease in price.

Likewise, all crops except Upland cotton show positive values for net returns to water per acre-foot of water consumed for both the 2002-2006 average and the 2005-2009 average. Focus is placed on the averages from 2005-2009 because they represent the most recent prices. The price required to pay a grower to forego watering of Durum wheat, alfalfa, Upland cotton and head lettuce over that period is $81.76, $134.04, -$60.52 and $2018.70, respectively. Interesting to note are the extreme values; the data suggests that Upland cotton growers do not recoup their investment. If this is the case, it is unclear why they continue to produce because the analysis indicates that they would be better off ceasing cotton production. One possible explanation is that the official variable costs listed in the University of Arizona Cooperative Extension Field Crop Budgets are higher than growers actually pay[138]; that is, it costs less for the grower to produce than the reported variable cost figure used in the NRTW calculation. Another possibility is that cotton growers receive other benefits from growing cotton, in terms of crop rotation and participation in government payment programs. The NRTW calculations provided here only include a federal program payment if that payment is tied to actual farm production levels. Cotton program payments are decoupled, that is not tied to specific cotton harvest levels from the farm receiving the payments.

In contrast to cotton, head lettuce exhibits a large positive value is calculated. This suggests high rents in the head lettuce market, for which it would require large payments to growers to convince them to cease irrigating. The lettuce market and high NRTW, however, must be considered in the context of its volatile nature and narrow market windows for the various lettuce growing areas (Teegerstrom 2010). Because the input costs are high, if a grower misses a key market window for harvesting and delivering their lettuce the grower may suffer a significant loss.

Durum wheat and alfalfa show more moderate NRTW with approximate prices of $82 and $134, respectively. These relatively low prices make the selection of Durum wheat and alfalfa ideal for irrigation suspension programs because the price required to pay growers to cease irrigating is low. It also provides an order of preference whereby an entity interested in obtaining water would target Durum wheat first and then target alfalfa, but only if additional supplies were necessary.

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[138] The University of Arizona Cooperative Extension Field Crop Budgets may be accessed at: http://ag.arizona.edu/arec/ext/budgets/counties.html.

It is important to reiterate that timing of payment to growers is important. Seasonality and crop rotation cycles may have an impact on the crop mix. For instance, if growers are rotating through head lettuce, the cost of water procurement may be higher. Or if it is a particular season when other high-value crops are typically grown, the cost to obtain water may also be higher. Additionally, the NRTW calculation assumes a payment over and beyond the variable costs of production, so it is important to consider crop cycle timing. If a grower has already devoted resources to production activities, however, it may be necessary to pay an amount corresponding to the net returns to water per acre-foot of water consumed *plus* any costs already sunk in the operation. The chart below illustrates the timing of planting, growing, and harvesting cycle for major crops in Yuma based on University of Arizona crop budgets (Teegerstrom and Knowles 1999; Teegerstrom and Tickes 1999; Teegerstrom, Palumbo, and Zerkoune 2001; Jones 2008).

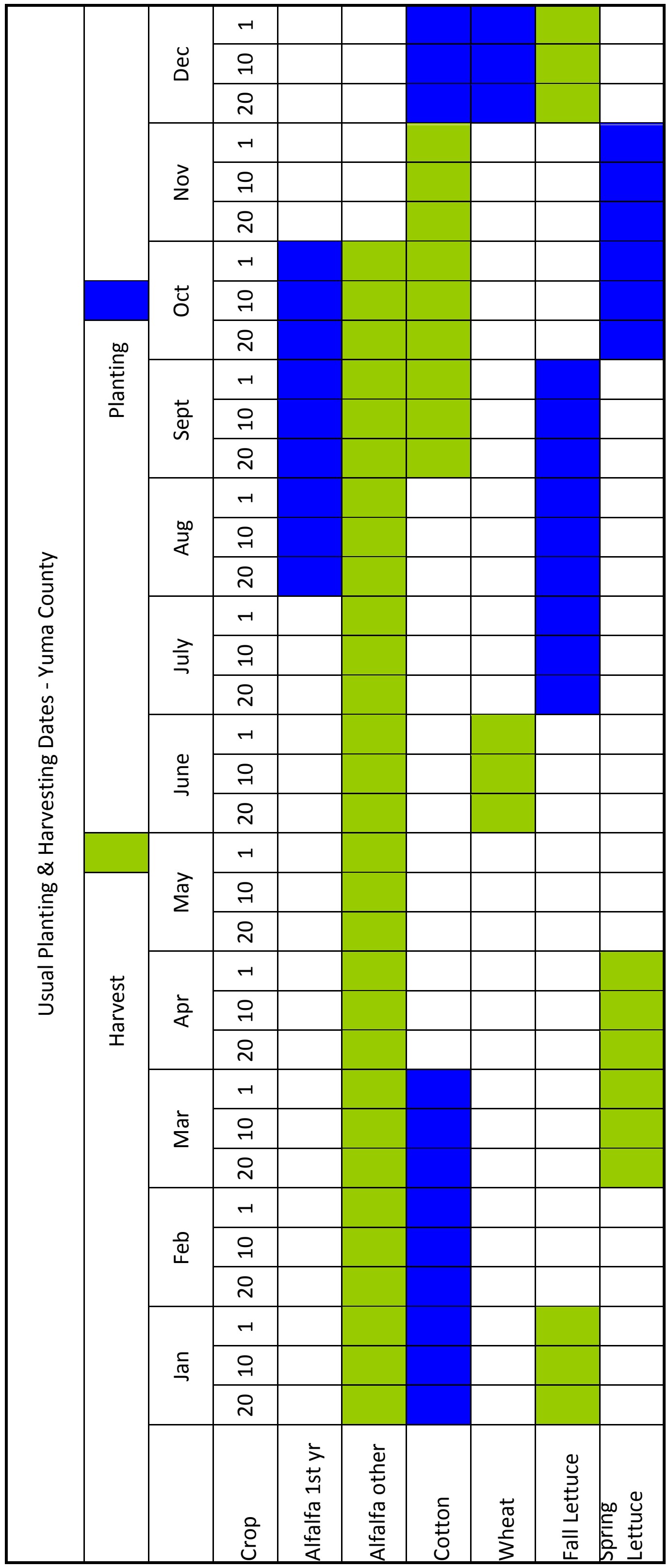

Figure 9.1: Usual Planting and Harvesting Dates in Yuma County, Arizona

9.2 Demonstration Programs for Colorado River Water Conservation

Metropolitan Water District (MWD) and Yuma Mesa Irrigation and Drainage District (YMIDD) have each entered into voluntary forbearance agreements with the US Bureau of Reclamation (Reclamation) to conserve a portion of growers' Colorado River use (BOR 2008a; BOR 2008b; BOR 2009a). The agreements were designed to provide a supplemental source of water to replace the drainage water from the Wellton-Mohawk Irrigation and Drainage District that is bypassed to the Cienega de Santa Clara and the reject stream from operation of the Yuma Desalting Plant.[139]

A water demander would like to obtain the water at a price near the NRTW price. However, because of issues such as disparate bargaining power and asymmetric information between demander and grower, the grower may be able to conceal the true value of water, obtain a higher price and receive a large portion of the trade surplus. As a result, a bargaining window whereby a demander would be willing to pay a relatively high price, but would prefer to pay a lower price and a supplier would accept a lower price, but would prefer a higher price becomes apparent. Because these agreements have been successfully negotiated with growers and implemented, they are interesting to compare and measure against the NRTW estimates. A review of the agreements suggests that as the water acquirers become more knowledgeable, the price paid gets closer to the NRTW for major crops. Each agreement is discussed in detail; differences between the agreements are then discussed.

9.2.1 MWD/PVID and Reclamation's System Conservation Program

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[139] The authority for the agreement is based upon the Boulder Canyon Act of 1928 and the Colorado River Salinity Control Act of 1974.

On May 26, 2006, Reclamation entered into a pilot irrigation suspension program with MWD to conserve 10,000 acre-feet of Colorado River water (BOR 2006).[140] In an earlier agreement, MWD, who generally supplies water to urban users, had entered into a multi-year forbearance agreement with the Palo Verde Irrigation District (PVID). Therefore, water supplied to Reclamation for the purpose of conservation came directly from PVID entitlements for which MWD had contracted for. Despite this logistical complication, the essence and purpose of this agreement is similar to the YMIDD agreements.

The 10,000 acre-feet was to be conserved from August 1st 2006 to July 31st 2007, where 3,000 acre-feet was conserved in 2006 and the remaining 7,000 acre-feet conserved in 2007 (BOR 2006). In return, Reclamation agreed to pay $1,700,000 ($170 per acre-foot). The agreement states that the "amount is based on reimbursing Metropolitan for the proportionate share of the annual payment made to the participating landowners for fallowing…a share of the initial payment made to the participating in the Program [between MWD and PVID] and a proportionate share of the annual costs reimbursed to PVID for assisting in implementation and management…" Provisions in the agreement are made for situations where either Reclamation or MWD does not perform. For instance, if MWD only delivers a portion of the agreed-upon volume, the Bureau will only be required to pay for the portion that it receives.

The payment structure is as follows: on or before August 15, 2006, MWD will send Reclamation an invoice indicating that it has satisfied the terms of the agreement (BOR 2006). In return, Reclamation will pay ½ of the total amount by September 30,

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[140] The authority for the agreement is based upon the Boulder Canyon Act of 1928 and the Colorado River Salinity Control Act of 1974.

2006. The second ½ of the total amount will be paid within 60 days of a field inspection by Reclamation conducted no later than March 1st 2007. Finally, the conserved volume is not charged against MWD or PVID's use of Colorado River water or charged against the apportionment to the state of California.

9.2.2 YMIDD - Agreement I

On February 4th 2008, Reclamation entered into its first agreement with YMIDD (BOR 2008a). Under the terms of that agreement, Reclamation agreed to pay $120 per acre-foot of Colorado River water conserved (on a consumptive basis) where 7.0 acre-foot of water is presumed to be saved per acre fallowed. In return, YMIDD agreed to fallow 500 acres of irrigated farmland from January 1st – December 31st 2008 (retroactive). The maximum amount to be paid to YMIDD was $420,000. The actual volume of water conserved is determined by Reclamation through an examination of water delivery records, field inspections and satellite imagery. For this purpose, YMIDD agreed to allow Reclamation two field inspections per year.

Payment to YMIDD was staged as follows: ½ of the total amount by March 1, 2008 and the remaining balance to be paid within 30 days of the second field inspection (BOR 2008a). The agreement outlines other rights, responsibilities and regulations. For instance, the land has to have been used recently in irrigation; the rule used is: it must have been irrigated 3 out of the 5 last years preceding the year 2008. The rationale for this is that unless the land is actively irrigated, Reclamation would not be achieving any water savings because water would not have been applied anyway. Also, the environmental cost of fallowing including weed, dust and pest control are to be born by YMIDD. Finally, YMIDD is responsible for ensuring that water is not delivered to lands subject to the fallowing agreement. The agreement also contains a clause whereby in the event of emergency, YMIDD may submit a petition for an increase in the water diversion estimate.

9.2.3 YMIDD - Agreement II

The second agreement was operational from October 1, 2008 to December 31, 2009 and retains much of the same terms as the original agreement (BOR 2008b). The cost per acre-foot as well as the consumptive use volume and total acreage to be fallowed remained the same. The main difference between this and the original is the timing and structure of field inspections and payment. Instead of two field inspections, Reclamation requested at least three field inspections. The payment structure is as follows: ½ the total amount by March 1st, 2009. ¼ the total amount paid upon receipt of an invoice sent from YMIDD, which is based upon a field inspection conducted by Reclamation the prior month, on or around August 1st 2009. And ¼ the total amount paid upon receipt of an invoice sent from YMIDD, which is based upon a field inspection conducted by Reclamation the prior month, on or around December 1st 2009.

9.2.4 YMIDD - Agreement III

This contract is operational from October 1, 2009 to December 31, 2010 (BOR 2009a). Under the contract's terms, Reclamation agreed to pay $90 per acre-foot of Colorado River water conserved, as opposed to $120 per acre-foot, and 7.0 acre-foot of water is still presumed to be saved per acre fallowed. In return, YMIDD agreed to fallow a maximum of 529.24 acres of land over the life of the contract. This is an expansion of the original 500 acres that were to be fallowed in the previous two agreements. Additionally, minimum participation acreage was set; each fallowed parcel is required to be at least 3 acres. This is important because it is costly to monitor acreage enrolled, and parcels smaller than 3 acres are particularly problematic. The minimum number of field inspections by Reclamation is reduced from three to two. Also, the payment timing and structure, again, changed. Reclamation will pay ½ of the total payment by March 1^{st} after receiving an invoice from YMIDD of a field inspection conducted the previous month. The other ½ is to be paid by October 2010 after receiving an invoice from YMIDD of a field inspection conducted the previous month.

9.3 Summary and Evaluation

The NRTW prices are interesting to compare against the prices paid by the Bureau in its demonstration irrigation suspension. The relatively high price ($170/acre-foot) in the MWD/PVID pilot program suggests that the Bureau paid far more than NRTW. However, the price paid was based on a pre-existing arrangement between MWD and PVID. The high price that the Bureau was willing to pay may have been induced by the novelty in the region of this type of arrangement and the high upfront negotiating and implementation costs involved in such a complicated transaction. Not only was the Bureau cooperating and negotiating with MWD, PVID was also an interested stakeholder; therefore, the Bureau had to engage in discussion with more than one large stakeholder. Additionally, there may have been high political costs to MWD and PVID from engaging in the transaction. The high prices may represent the Bureau's willingness to pay a premium to ensure that political support for MWD and PVID is not eroded, as well as reflecting the value of water in urban and environmental uses during dry periods.

The three YMIDD demonstration programs are interesting because they show that contracts evolve to a changing understanding of each party's water values. One interesting feature is that the Bureau determined that the cost of evaluating small parcels of land (< 3 acres) was too high. There is certainly a positive cost to monitoring lands; by setting the minimum land acreage, the costs are reduced while simultaneously reducing the ability to covertly violate the agreement. Another interesting feature is that it determined that the price decreased over time from the early contracts to the most recent agreement. The movement from $125/acre-foot to $90/acre-foot illustrates a phenomenon found in developing water markets - prices paid in consecutive arrangements in a region tend to move towards the NRTW for major regional crops.

10. CONCLUSIONS AND IMPLICATIONS

Water law in the US initially followed the riparian regime and was informed by English law. As settlers moved westward, however, the riparian regime became obsolete as rainfall was relatively low and water was not adjacent to where it was most needed. To remedy this problem, the prior appropriation regime developed which allowed movement of water. This process laid the framework for water marketing as economic conditions, water use patterns and social values changed, and water scarcity prompted an interest in utilizing water in ways which stimulate regional economies. Water sales and leases began to occur in the western US, but those sale and leasing tools need to be refined to improve the efficiency of the water transfer process.

Reliability contracts and water auctions may provide viable mechanisms to augment current water markets, while water banking may provide an infrastructure for conducting water supply reliability operations. Although an initial investment of consideration is necessary for reliability contracts, a reliability contract may minimize the risk of not having access to water during times of shortage as well as the risk of having too much water in time of surplus. The reliability contract is a forward-looking mechanism which serves to reallocate risk between water users and water suppliers in an environment of high variability. This tool is comparable to insurance: The water demander assumes that additional water will not be required every period; however, the demander is cognizant that there is a positive probability that an additional supply may be necessary.

Auction theory suggests that water may be acquired at a lower price in a water auction than through negotiations because individuals will be more likely to disclose their true value of the water. Additionally, transaction costs may be lower through an auction because individual negotiations are not necessary. Despite these advantages, the determination of whether to conduct a water auction should be carefully considered. Conducting a water auction may be costly; costs may include advertising expenses, distribution of auction information, administrative expenses, general overhead expenses, monitoring and enforcement expenses, among others. All of these costs need to be tallied and compared against the expected benefits to be obtained from the auction. In order to rationalize using an auction, the net benefits of the water auction must be greater than the expected benefits of using an alternative method of water procurement.

Water banking may provide an institutional framework to conduct nearly any type of water supply reliability arrangement. Water banks may operate simply as a broker, facilitating transactions by aligning willing buyers and sellers. They may also engage the banking of physical water either underground or in an above-ground reservoir. A water bank may also enter into the water market by buying and selling water in its own name. Finally, a water bank may operate as an administrator of water trusts for environmental purposes. A moderating factor of a water bank is that it may be costly to create and operate a water bank. In order to assess whether the use of a water bank is appropriate, it is important to compare the expected benefits to be obtained from the water bank with the costs of creating, administering and operating the water bank. Additionally, the net benefits of the water bank need to exceed the net benefits of any alternative to rationalize its existence.

In order to assess the effectiveness of innovative agreements, it is important to understand the determinants of price in typical water markets. If market price and determinants of price can be ascertained, they may provide benchmarks for which to compare innovative transfer agreements. As this thesis suggests, econometric analysis of past water leases can provide some information about both water lease prices and determinants of price. This thesis also suggests several variables to consider. These variables include: temperature and precipitation variables, climate variables, demographic variables, variables related to the old and new uses of the water and reservoir level variables. Additional study is necessary to further understand the impact of the variables on lease prices and to determine whether additional variables ought to be included in the calculus.

Because a large percentage of water in the western US is consumed through irrigation, net returns to water (NRTW) may be a means for determining the value of water. The figure from this calculation can be used to indicate a price range that a grower will accept to cease irrigating a specific crop. In practice, however, a water demander will likely pay more than NRTW because growers have some degree of market power due to an asymmetry of information and a thin market. Nevertheless, the NRTW determination and the econometric market price determination may serve as a range within which an innovative agreement can be expected to fall. If a water demander is able to better estimate the minimum that a grower will accept to forego irrigating, then the demander may be able to acquire a portion of the surplus that the grower would have otherwise obtained. Needless to say, price determination is not the only important cost metric; rather, it is important to consider any other relevant costs, including: transaction costs, cost associated with setting up various programs and potential costs associated with liability.

Finally, this thesis provides a description and comparison of several water transfer case studies. Notable is the analysis of the Bureau of Reclamation Pilot Fallowing Programs. Those case studies provide several important insights. One insight is that agreements tend to evolve over time to reflect changing conditions as well as reflecting a better understanding of the capabilities of the involved parties. Important factors such as price, monitoring and various responsibilities vary from contract to contract. Another insight is that a water supplier and a water demander are likely to agree upon a price that is greater than the NRTW determined price. In every contract, the price paid by the Bureau of Reclamation is greater than the average value of water used in Durum wheat and Upland cotton production from 2005-2009. In all but the most recent Bureau of Reclamation contract, the price paid was greater than the average value of water used in alfalfa production from 2005-2009. Finally, the contracts can provide an invaluable source of information to potential suppliers and demander who are interested in considering whether to enter into a water transfer because they enumerate the rights and responsibilities of each party in a clear and concise fashion.

10.1 Future Work

Several areas of this thesis may be expanded in future work. An area that may be considered is why the California econometric model does not explain the pattern of market prices particularly well. One thought is that because the spatial scale is so large, and because climate is vastly different in various parts of the state, treating the entire state as one entity is inappropriate. Perhaps it would be appropriate to break the state into two halves or into quadrants. At the extreme, the state could also be broken down into climate divisions or micro-climate divisions. If this is done, then the results from the analysis could potentially be compared to the results from this study to determine whether there is a significant difference.

Endogeneity between price and quantity was only discovered in the California model in this study. It has been discovered in some previous studies and not others, and so it may be valuable to determine whether a systematic explanation for endogeneity or its absence exists. A demand equation is utilized in this type of study, and so it is presumed that quantity and price are negatively related. It is therefore curious that quantity has been found to be insignificant in some studies, while others have shown quantity to have a positive relationship with price. Again, systematically investigating the relationship between price and quantity in lease transactions may be non-trivial.

Another interesting variable to consider is reservoir elevation level. Only Lake Mead's elevation was considered in this study. Although Lake Mead provides water regionally, results may be improved if other more localized reservoirs are included. The difficulty of this approach is choosing which reservoirs to include and how exactly to include them. Although reservoirs likely would need to be selected based on their importance to regional water supply and availability of reliable data over the time period, there are several ways to include the reservoirs selected. One way is to include each reservoir individually as a regressor in an econometric analysis. The variable may be in absolute elevation level (in feet or another unit) or it may be in percentage change terms, as done in the present study. Another interesting approach may be to create an index that combines several reservoir elevation levels or quantities of water in storage at the desired spatial scale. Whatever approach is taken, the impact of reservoir levels on transactions and market prices has not been fully studied and may prove to be a powerful analytical tool.

APPENDIX A

A.1 Sample Dry-Year Supply Reliability Contract Timeline

Assuming that there is a probability that water will be needed in the following period, it may be necessary to utilize a dry-year supply reliability contract. What follows is timeline that would be typical of a contract lasting one year. This sample timeline will need to be modified based on the particular area, months in which drought is likely to limit water supplies, type of crops grown, and length of contract.

I. Summer:

Conduct preliminary assessments. Determine the likelihood additional water will be necessary and the volume of water that is desired. Set acquisition budgets. Begin forming program goals and expectations. Begin publicity and outreach.

II. Fall

Begin preliminary negotiations with growers. Determine whether to utilize an option contract framework or another similar arrangement. If an option contract framework is chosen, this includes negotiating option premiums and exercise payments amounts. If a different type of agreement is used, determine how to implement that agreement. This includes determining the payment structure. In either case, it is necessary to determine how and when growers will be paid. Set the trigger mechanism that will cause the water to be called.

III. Winter

Conclude negotiations with growers, draw up agreement and obtain necessary signatures and other authorizations to formalize contract If modifications are necessary to existing infrastructure (i.e. remote sensing technology, locks on head gates, etc.) it may be necessary to conduct installation. If specified in the contract, begin paying the option premiums (if option contracts are used).

IV. Spring

Continue paying option premiums (if specified in the contract). If the predetermined trigger event occurs, determine what volume of water to call (if any). If a volume of water is called, begin monitoring operations (including locking head gates and monitoring changes in lands irrigated) to ensure that participating growers are complying with the agreement. If specified in the contract, begin payment (begin paying up-front payments or option premiums).

V. Summer

Continue paying up-front payments/option premiums (if specified in the contract). Continue monitoring operations. Conduct final assessment of the effectiveness of the program. Begin paying exercise payments (if a volume of water was called in the Spring). Begin preliminary assessment for the next year of contracts.

As indicated, the timeline may have to be adjusted based upon the type of crops grown by participating growers. In order to ensure program cost effectiveness, it is important to select relatively low value crops for fallowing and provide growers with sufficient notice such that they do not invest resources in preparation and planting activities, if water is called by the contractor. For example, the table below lists the months that planting typically begins in Yuma County, Arizona and illustrates the importance of adjusting the timeline based upon the crops grown (Colby, Pittenger and Jones 2007; Teegerstrom and Knowles 1999; Teegerstrom and Tickes 1999; Teegerstrom, Palumbo, and Zerkoune 2001).

Months Planting Begins For Various Crops – Yuma County, Arizona	
Crop	***Month***
Alfalfa 1st year	August – October
Alfalfa other years	N/A
Cotton	December – March
Wheat	December
Fall Lettuce	July – September
Spring Lettuce	October – November

A.2 Checklist for Dry-year Supply Reliability Contracts

This checklist has been developed to highlight reminders intended to assist with the dry-year option contract implementation process.

Preliminaries

☐ **Determine volume of water desired.**

☐ **Determine whether a reliability contract is the most cost effective type of water supply acquisition method. Compare against:**

- Doing nothing.
- Leases.
- Spot market.
- Outright purchases.
- Other possible water acquisition methods.

☐ **Set planning and implementation timeline.**

- Are there seasonality or planting cycles to consider?
- Start of publicity, outreach and informational meetings.

☐ **Determine eligibility to participate.**

- Should there be constraints on the type or location of eligible water entitlements?
- Are there supply stability issues?

☐ **Determine the volume that each person may offer.**

- May individuals offer their entire permit amount? Their historical diversion amount? Their consumptive use amount?

☐ **Develop a public information and participant engagement plan and timetable.**

☐ **Develop a method for determining which options to exercise if some, but not all, of the options are exercised (i.e. set a priority system).**

☐ **Determine whether side payments may be necessary as a result of fallowing activities (due to lack of return flow or environmental consequences).**

☐ **Determine how and when contractees will be compensated.**

Contract Design

☐ **Determine an overall option contract budget.**

- Determine prices for the option and for calling the option.

☐ **Determine the number of years that the contract will remain valid**.

☐ **Determine whether to employ an option contract framework or another framework.**

- If an option contract framework is chosen:
  - Determine starting and ending dates for the window to call the options.
- If a different supply reliability contract design is chosen:
  - Determine the bounds of that agreement: what may be traded and how consideration may be made.

☐ **Determine the trigger mechanism.**

- Surface stream flow levels.
- Snowpack levels.
- Reservoir levels.
- Increased groundwater pumping.

- Climate.

Post Supply Reliability Contract Evaluation

☐ **Determine the evaluation methods to be used for auction success.**
  - What type of metrics will be used to assess option contract success? Should success be based upon obtaining a desired volume of water? Upon minimizing procurement costs? Upon minimizing auction costs? Based upon a calculation of benefit per dollar spent? Through the use of focus groups or surveys? Or some other method?
  - Develop a plan to collect data needed for evaluation.

☐ **Monitor actual change in water use to assure compliance.**

☐ **Determine whether improvements can be made to the option contract process for the future.**
  - Were the goals achieved? If not, what can be done to improve the outcome?

A.3 Sealed-bid Procurement Water Auction Checklist

This checklist is provided as a set of reminders intended to assist with the water auction design and implementation process.

Preliminaries

- ☐ **Determine volume of water desired.**
- ☐ **Set the auction date and implementation timeline.**
  - o Are there seasonality or planting cycles to consider?
  - o Start of publicity, outreach and informational meetings.
- ☐ **Determine eligibility to participate.**
  - o Should there be constraints on the type or location of eligible water entitlements?
- ☐ **Determine the volume that each person may offer.**
  - o May individuals auction their entire entitlement amount? Their historical diversion amount? Their consumptive use amount?
- ☐ **Determine the units of volume to conduct the auction in.**
  - o Should the auction be conducted in terms of acre-feet, standardized water per acre amount or a different metric?
- ☐ **Determine the type of information technology to use.**
  - o Can any part of the auction be conducted over the telephone, fax, or internet? Is any other information technology consideration important?
- ☐ **Develop a public information and participant engagement plan and timetable.**
- ☐ **Determine how and when winning bidders will be compensated.**

Auction Design

- ☐ **Determine an auction budget.**
  - o Should a budget cap or a quantity quota be set? If so, should any or all of this information be divulged to the bidders?
- ☐ **Establish a tie-breaking rule.**
  - o Should the existence, or the operation, of the tie breaking rule be divulged?
- ☐ **Set a reserve price.**
  - o Should the existence, or the level, of the reserve price be divulged?
- ☐ **Set the number of rounds of bidding.**
  - o Should only one round be used? Should multiple rounds be used, but the number be predetermined? Should there be multiple rounds but the number not be predetermined?
    - ▪ Should the number or rounds be divulged? Should information be divulged between rounds? If so, how much and what type of information should be disclosed?
- ☐ **Determine what price the winning bidders will be paid.**
  - o Should a uniform price bid selection be used or a discriminatory price bid selection?
    - ▪ Should the existence of the uniform or discriminatory auction be divulged?

Post Auction Evaluation

- ☐ **Determine the evaluation methods to be used for auction success.**

  - What type of metrics will be used to assess auction success? Should success be based upon obtaining a desired volume of water? Upon minimizing procurement costs? Upon minimizing auction costs? Based upon a calculation of benefit per dollar spent? Through the use of focus groups or surveys? Or some other method?
  - Develop a plan to collect data needed for evaluation.

☐ **Monitor actual change in water use to assure compliance.**

☐ **Determine whether improvements can be made to the auction process for the future.**

☐ **Were the goals achieved? If not, what can be done to improve the outcome?**

A.4 Water Banking Creation and Operation Checklist

Below is a checklist of major issues to consider when creating a water bank.

Management and Operation

- ☐ Determine appropriate entity to manage/operate the bank:
  - o Public organization
  - o Private non-profit organization
  - o Private for-profit organization
  - o Public-private partnership
- ☐ Create a system of education and outreach.
  - o Public awareness campaign created?
  - o Is there a manner in which individuals may conduct water bank inquiries?
- ☐ Include key community members in the decision-making and/or management processes.

Strategic Policy

- ☐ Develop long term strategic policy.
- ☐ Should the bank be designed to store water in a physical location?
  - o If yes, should the bank utilize reservoir storage or underground storage?
  - o If no, should the bank be designed to accommodate brokerage services or institutional (trust) services?
- ☐ Should the bank have the ability to purchase water entitlements on its own, or should the bank operate in a more administrative capacity?
- ☐ Set a fee for service structure.
  - o Set flat participation fee?
  - o Charge a fee per transaction?
  - o Set different fees depending on the types of transactions or transaction volumes?
- ☐ Set an equitable and efficient dispute resolution mechanism.

Geographic Area and Participant Eligibility

- ☐ From what area should participation be allowed?
  - o Large enough are to encourage robust participation, but not so large make administration and transportation costs overly burdensome.
- ☐ Which entitlements should be allowed to participate?

Operational Policy and Market Creation

- ☐ Establish a method of verifying bankable quantity, type of entitlement, and transfer capability of water entitlements.
- ☐ Determine what type of market (or pricing) structure to utilize:
  - o Unilaterally set prices per volume of water?
  - o Utilize a bulletin board method for pricing?
  - o Utilize an auction method?
    - ▪ Single sided or double sided?
  - o Allow a contingent contract (option contract) structure?

Encourage Irrigator Participation

- ☐ Utilize outreach activities to target irrigators and irrigation districts.
- ☐ Explain that irrigators may directly benefit from both the purchase and sale of entitlements.

Environmental and Third Party Impacts

- ☐ Has instream flows been legally classified as a beneficial use?
- ☐ Will water banking create negative environmental or third party impacts?
  - Should a mitigation fund be developed to compensate for negative environmental or third party impacts?

Cost of Administration and Monitoring

- ☐ Design a system of record-keeping and reporting.
- ☐ Implement a system of monitoring and enforcing fallowing agreements

APPENDIX B

B.1 Consumer Price Index Data

Data obtained using a CPI calculator provided by the bureau of labor statistics (CPI Index 2010)

Year	*CPI*	*2010 CPI*	*Inflated Multiplier*
1986	109.6	216.687	1.977071168
1987	113.6	216.687	1.907455986
1988	118.3	216.687	1.831673711
1989	124	216.687	1.747475806
1990	130.7	216.687	1.657895945
1991	136.2	216.687	1.590947137
1992	140.3	216.687	1.54445474
1993	144.5	216.687	1.499564014
1994	148.2	216.687	1.462125506
1995	152.4	216.687	1.421830709
1996	156.9	216.687	1.381051625
1997	160.5	216.687	1.350074766
1998	163	216.687	1.329368098
1999	166.6	216.687	1.300642257
2000	172.2	216.687	1.258344948
2001	177.1	216.687	1.22352908
2002	179.9	216.687	1.204485825
2003	184	216.687	1.177646739
2004	188.9	216.687	1.147098994
2005	195.3	216.687	1.109508449
2006	201.6	216.687	1.07483631
2007	207.3	216.687	1.0452822
2008	215.303	216.687	1.00642815
2009	214.537	216.687	1.010021581
2010	216.687	216.687	1

B.2 Median House Price Data

Data obtained from the California Association of Realtors and the National Association of Realtors (California Association of Realtors 2009; National Association of Realtors 2009).

State	Year	Median	Adjusted (2010)	CA % Change
CA	1987	142060	270973	
	1988	168200	308088	0.14
	1989	196120	342715	0.11
	1990	193770	321251	-0.06
	1991	200660	319239	-0.01
	1992	197030	304304	-0.05
	1993	188240	282278	-0.07
	1994	185010	270508	-0.04
	1995	178160	253313	-0.06
	1996	177270	244819	-0.03
	1997	186490	251775	0.03
	1998	200100	266007	0.06
	1999	217510	282903	0.06
	2000	241350	303702	0.07
	2001	262350	320993	0.06
	2002	316130	380774	0.19
	2003	371520	437519	0.15
	2004	450990	517330	0.18
	2005	524020	581405	0.12
	2006	556240	597867	0.03
	2007	558100	583254	-0.02
	2008	346750	348979	-0.40
	2009	300000	303006	-0.13

CO	Year	Median	Adjusted (2010)	CO % change
	1987	75500	144013	
	1988	80000	146534	0.02
	1989	85500	149409	0.02
	1990	86400	143242	-0.04
	1991	89100	141753	-0.01
	1992	93100	143789	0.01
	1993	101033	151505	0.05
	1994	112600	164635	0.09
	1995	123100	175027	0.06
	1996	131133	181101	0.03
	1997	137233	185275	0.02
	1998	147633	196259	0.06
	1999	162500	211354	0.08
	2000	182567	229732	0.09
	2001	224200	274315	0.19
	2002	234483	282431	0.03
	2003	241717	284657	0.01

	2004	244883	280905	-0.01
	2005	257117	285273	0.02
	2006	263767	283506	-0.01
	2007	262550	274383	-0.03
	2008	240383	241928	-0.12
	2009	238000	240385	-0.01

NM	Year	Median	Adjusted (2010)	NM % change
	1987	75000	143059	
	1988	80000	146534	0.02
	1989	83000	145040	-0.01
	1990	84500	140092	-0.03
	1991	86800	138094	-0.01
	1992	92000	142090	0.03
	1993	100400	150556	0.06
	1994	110000	160834	0.07
	1995	117000	166354	0.03
	1996	122300	168903	0.02
	1997	126700	171054	0.01
	1998	128200	170425	0.00
	1999	130300	169474	-0.01
	2000	130400	164088	-0.03
	2001	133300	163096	-0.01
	2002	133800	161160	-0.01
	2003	138400	162986	0.01
	2004	145400	166788	0.02
	2005	169200	187729	0.13
	2006	184200	197985	0.05
	2007	198500	207446	0.05
	2008	192006	193240	-0.07
	2009	230000	232305	0.20

APPENDIX C

NRTW calculation below are based on costs from University of Arizona crop budgets (Teegerstrom and Knowles 1999; Teegerstrom and Tickes 1999; Teegerstrom, Palumbo, and Zerkoune 2001) updated using USDA producer cost indices (USDA 2010). All chemical input prices were updated through personal communication with chemical input suppliers. Yields and commodity prices come from Arizona Agricultural Statistics Bulletins (USDA 2005; 2006; 2007; 2008; 2009). Crop consumptive water use was derived using Lower Colorado River Accounting System annual water use (Reclamation 2007a). Numbers in parentheses represent negative values. All prices are adjusted to January 2010 values using a CPI inflation calculator (CPI Inflation Calculator 2010).

Yuma Alfalfa Production	**2009**	**5yr Avg**	**High**	**Low**
Revenue per Acre				
Yield/acre	9.05	9.29	9.8	9.05
Price/ton	$123.23	$148.91	$186.12	$123.23
Gross Revenue ($/Acre)	$1,115.16	$1,388.83	$1,824.65	$1115.16
Total Variable Costs per Acre	$624.79	$624.79	$624.79	$624.79
Net Returns to Water Per Acre	$490.37	$764.04	$1199.86	$490.37
A/F water consumptively used per acre	5.7	5.7	5.7	5.7
Net Returns to Water Per Acre-foot of water Consumed	$86.03	$134.04	$210.50	$86.03

Yuma Durum Wheat	2009	5yr Avg	High	Low
Revenue per Acre				
Yield/acre	107.5	106.1	107.5	103
Price/bushel	$8.94	$6.93	$8.94	$4.66
Gross Revenue ($/Acre)	$960.91	$737.36	$960.91	$479.97
Total Variable Costs per Acre	$582.02	$582.02	$582.02	$582.02
Net Returns to Water Per Acre	$378.89	$155.34	$378.89	($102.05)
A/F water consumptively used per acre	1.9	1.9	1.9	1.9
Net Returns to Water Per Acre-foot of water Consumed	$199.42	$81.76	$199.42	($53.71)

The most recent data for Yield/acre (lint) is from 2008 and the most recent data for Yield/acre (seed) is from 2006; thus, the table spans the years 2006-2008. LDP are not available unless county prices fall below the loan rate set by the Farm Service Agency (FSA 2010). LDP was only available in 2006.

Yuma Upland Cotton	2008	3yr Avg	High	Low
Revenue per Acre				
Yield/acre (lint)	1420	1397	1420	1315
Price/pound (lint)	$0.59	$0.59	$0.62	$0.57
LDP/pound	$0.00	$0.03	$0.00	$0.09
Yield/acre (seed)	1.05	1.05	1.05	1.05
Price/ton (seed)	$286.83	$223.03	$286.83	$179.50
Gross Revenue ($/Acre)	$1,137.21	$1063.87	$1,137.21	1059.13
Total Variable Costs per Acre	$1,318.20	$1,318.20	$1,318.20	$1,318.20
Net Returns to Water Per Acre	($180.99)	($217.88)	($180.99)	($259.07)
A/F water consumptively used per acre	3.6	3.6	3.6	3.6
Net Returns to Water Per Acre-foot of water Consumed	($50.27)	($60.52)	($50.27)	($71.96)

Yuma Head Lettuce	2009	5yr Avg	High	Low
Revenues per Acre				
Yield/acre	345	342	345	325
Price/cwt	$23.13	$18.47	$22.90	$15.16
Gross Revenue ($/Acre)	$7,979.67	$6,348.88	$7,979.67	$4,925.44
Total Variable Costs per Acre	$3,522.70	$3,522.70	$3,522.70	$3,522.70
Net Returns to Water Per Acre	$4,456.98	$2,826.18	$4,456.98	$1,402.74
A/F water consumptively used per acre	1.4	1.4	1.4	1.4
Net Returns to Water Per Acre-foot of Water Consumed	$3,183.55	$2,018.70	$3,183.55	$1001.96

The costs below are based upon University of Arizona crop budgets (Teegerstrom and Knowles, 1999; Teegerstrom and Tickes, 1999; Teegerstrom, Palumbo, and Zerkoune, 2001) updated using USDA producer cost indices (USDA, 2010). All chemical input prices were updated through personal communication with chemical input suppliers.

County:	**Yuma**					
Crop:	**Alfalfa**					
Tot. Variable Cost:	**$624.79**					
Month	**Operations**	**Class**	**Cost**	**Running Total ($)**	**% of Total Variable Cost**	**Running Total (%)**
Jan	Irrigate	Growing	58.98	58.98	9.4	9.4
Jan	Swathing	Harvest	82.70	141.68	13.2	22.7
Jan	Raking	Harvest	38.93	180.61	6.2	28.9
Jan	Bailing	Harvest	168.43	349.04	27.0	55.9
Jan	Roadsiding	Harvest	90.28	439.32	14.4	70.3
Feb	Rerun Borders	Growing	15.46	454.78	2.5	72.8
Feb	Apply Herbicide/Ground	Growing	34.91	489.69	5.6	78.4
Mar	Apply Insecticide/Air	Growing	32.26	521.95	5.2	83.5
Sep	Irrigate/Run Fertilizer	Growing	22.93	544.88	3.7	87.2
Oct	Renovate	Growing	2.43	547.31	0.4	87.6
Oct	Plant	Land Prep	18.97	566.28	3.0	90.6
Misc.	Pickup Use		31.13	597.41	5.0	95.6
	Operating Interest		27.38	624.79	4.4	100.0
TOTAL			**624.79**	**624.79**	**100.00**	**100.00**

County:	**Yuma**					
Crop:	**Upland Cotton**					
Tot. Variable Cost:	**$1,318.20**					
Month	**Operations**	**Class**	**Cost**	**Running Total ($)**	**% of Total Variable Cost**	**Running Total (%)**
Dec	Rip	Land Prep	15.39	15.39	1.2	1.2
Dec	Disk	Land Prep	18.45	33.84	1.4	2.6
Jan	Laser Level	Land Prep	52.46	86.3	4.0	6.5
Jan	Roll Beds	Growing	3.38	89.68	0.3	6.8
Jan	List	Land Prep	9.96	99.64	0.8	7.6
Feb	Preirrigate	Growing	6.39	106.03	0.5	8.0
Mar	Mulch	Land Prep	7.91	113.94	0.6	8.6
Mar	Plant	Land Prep	11.29	125.23	0.9	9.5
Mar	Remove Cap	Growing	6.45	131.68	0.5	10.0
Apr	Cultivate	Growing	29.66	161.34	2.3	12.2
Apr	Soil Fertility	Growing	3.00	164.34	0.2	12.5

May	Irrigate/Run Fertilizer	Growing	75.37	239.71	5.7	18.2
Jun	Irrigate	Growing	6.39	246.1	0.5	18.7
Jun	Hand Weeding	Growing	100.00	346.1	7.6	26.3
Jun	Apply Insecticide/ Ground	Growing	45.49	391.59	3.5	29.7
Jun	Apply Herbicide/Ground	Growing	12.21	403.8	0.9	30.6
Jul	Apply Insecticide/ Ground	Growing	200.13	603.93	15.2	45.8
Jul	Apply Insecticide/ Ground	Growing	14.89	618.82	1.1	46.9
Jul	Hand Weeding	Growing	100.00	718.82	7.6	54.5
Jul	Apply Insecticide/Air	Growing	14.89	733.71	1.1	55.7
Aug	Apply Insecticide/Air	Growing	12.66	746.37	1.0	56.6
Aug	Apply Insecticide/Air	Growing	16.17	762.54	1.2	57.8
Aug	Irrigate/Run Fertilizer	Growing	67.02	829.56	5.1	62.9
Sep	Apply Insecticide/Air	Growing	16.55	846.11	1.3	64.2
Sep	Apply Defoliant/Air	Harvest	44.44	890.55	3.4	67.6
Sep	Apply Defoliant/Air	Harvest	26.03	916.58	2.0	69.5
Sep	Dust Control	Growing	30.45	947.03	2.3	71.8
Sep	Prepare Ends	Harvest	1.71	948.74	0.1	72.0
Sep	Cotton, First Pick	Harvest	80.00	1028.74	6.1	78.0
Sep	Cotton, Make Mounds	Harvest	17.62	1046.36	1.3	79.4
Sep	Cotton, Rood	Harvest	43.33	1089.69	3.3	82.7
Sep	Haul	Harvest	6.80	1096.49	0.5	83.2
Sep	Cotton Ginning	Post Harvest	112.67	1209.16	8.5	91.7
Dec	Cotton Classing	Marketing	3.30	1212.46	0.3	92.0
Dec	Crop Assessment	Marketing	9.38	1221.84	0.7	92.7
Dec	Cut Stalks	Post Harvest	6.68	1228.52	0.5	93.2
Dec	Disk Residue	Land Prep	18.79	1247.31	1.4	94.6
Misc.	Pickup Use		37.35	1284.66	2.8	97.5
	Operating Interest 6%		33.54	1318.2	2.5	100.0
TOTAL			**1318.20**	**1318.20**	**100.00**	**100.00**

County:		Yuma				
Crop:		Durum Wheat				
Total Variable Cost:		$582.02				
Month	**Operations**	**Class**	**Cost**	**Running Total ($)**	**% of Total Variable Cost**	**Running Total (%)**
Dec	Disk	Land Prep.	63.16	63.16	10.9	10.9
Dec	Roll Beds	Land Prep.	3.38	66.54	0.6	11.4
Dec	Laser Level	Land Prep.	42.88	109.42	7.4	18.8
Dec	Apply Fert/Ground	Growing	105.30	214.72	18.1	36.9
Dec	Plant	Land Prep.	37.00	251.72	6.4	43.2
Jan	Make Borders	Growing	3.26	254.98	0.6	43.8
Jan	Irrigate	Growing	5.12	260.1	0.9	44.7
Feb	Apply Herb/Ground	Growing	29.57	289.67	5.1	49.8
Feb	Irrigate/Run Fert	Growing	117.96	407.63	20.3	70.0
Feb	Apply Herb/Ground	Growing	25.32	432.95	4.4	74.4
Mar	Apply Insect/Air	Growing	17.34	450.29	3.0	77.4
Mar	Irrigate	Growing	10.23	460.52	1.8	79.1
Jun	Combine Harvest	Harvest	57.68	518.2	9.9	89.0
Jun	Haul	Harvest	15.75	533.95	2.7	91.7
Jun	Disk Residue	Land Prep.	18.79	552.74	3.2	95.0
Misc.	Pickup Use		18.68	571.42	3.2	98.2
Misc.	Op. Interest 6%		10.60	582.02	1.8	100.0
TOTAL			**582.02**	**441.88**	**100.00**	**100.00**

County:		Yuma				
Crop:		Head Lettuce				
Tot. Variable Cost:		$3,522.7				
Month	**Operations**	**Class**	**Cost**	**Running Total ($)**	**% of Total Var. Cost**	**Running Total (%)**
July	Rip	Lnd Prep	28.10	28.1	0.8	0.8
July	Disk	Lnd Prep	19.11	47.21	0.5	1.3
July	Laser Level	Lnd Prep	27.43	74.64	0.8	2.1
July	Make Borders	Growing	0.64	75.28	0.0	2.1
July	Preirrigate	Growing	6.39	81.67	0.2	2.3
July	Soil Fertility	Growing	3.00	84.67	0.1	2.4
July	Dust Control	Growing	5.99	90.66	0.2	2.5
Aug	Apply Fert/Ground	Growing	115.42	206.08	3.2	5.8
Aug	Apply Herbicide/Ground	Growing	131.14	337.22	3.7	9.4
Sep	List	Lnd Prep	7.39	344.61	0.2	9.6
Aug	Pre-Shape	Lnd Prep	11.13	355.74	0.3	10.0
Aug	Shape Beds	Lnd Prep	24.12	379.86	0.7	10.6
Sep	Plant	Lnd Prep	135.25	515.11	3.8	14.4
Sep	Bird Control	Growing	6.10	521.21	0.2	14.6
Sep	Set Sprinklers	Growing	6.09	527.3	0.2	14.8
Sep	Irrigate/Sec Sys	Growing	6.97	534.27	0.2	15.0
Sep	Apply Insecticide/Air	Growing	32.51	566.78	0.9	15.9
Sep	Field Scouting	Growing	90.00	656.78	2.5	18.4
Oct	Apply Insecticide/Ground	Growing	33.82	690.6	0.9	19.3
Oct	Apply Insecticide/Ground	Growing	54.94	745.54	1.5	20.9
Sep	Irrigate/Run Fertilizer	Growing	23.57	769.11	0.7	21.5
Sep	Remove Sprinklers	Growing	6.09	775.2	0.2	21.7
Sep	Make Ditches	Growing	3.32	778.52	0.1	21.8
Oct	Irrigate/Run Fertilizer	Growing	150.29	928.81	4.2	26.0
Oct	Thinning	Growing	100.00	1028.81	2.8	28.8
Oct	Cultivate	Growing	44.02	1072.83	1.2	30.0
Oct	Apply Fungicide/Ground	Growing	52.38	1125.21	1.5	31.5
Oct	Apply Insect/Ground	Growing	11.21	1136.42	0.3	31.8
Oct	Apply Insect/Air	Growing	33.57	1169.99	0.9	32.7
Oct	Irrigate/Run Fertilizer	Growing	46.49	1216.48	1.3	34.0
Oct	Hand Weeding	Growing	100.00	1316.48	2.8	36.8
Oct	Apply Insect/Ground	Growing	26.60	1343.08	0.7	37.6
Nov	Knock Borders	Growing	0.64	1343.72	0.0	37.6
Nov	Knock Ditches	Growing	1.11	1344.83	0.0	37.6
Nov	Harvest, Load and Haul	Harvest	2167.20	3512.03	60.7	98.3
Dec	Disk Residue	Lnd Prep	9.55	3521.58	0.3	98.6
Misc.	Pickup Use		31.13	3552.71	0.9	99.4
	Operating Interest 6%		19.99	3572.7	0.6	100.0
	Fixed Water Assessment		(50.00)	(50.00)		

TOTAL			**3522.70**	**3522.70**	**100.00**	**100.00**

GLOSSARY

Ascending Bid Auction - In an ascending bid procurement auction, the price starts at a relatively low level and begins to rise temporally. The winner is the bidder that first stops the ascending price and accepts that price in payment for the resource. In this way, the bidder that is willing to accept the smallest price for the resource is chosen as the winner.

Bid Shading – A process by which bidders attempt to conceal their true value of the resource. In a procurement auction, bidders attempt to shade their bids in such a manner that the auctioneer believes that they value the resource more highly than they really do in an effort to obtain a premium for the resource.

Budget Cap – In a water auction, a budget cap is the maximum total amount of money that the auctioneer is willing to spend to acquire the entire volume of water.

Called option – Optioned water that is purchased, or called, by the contractor.

Conditional Lease-back – an agreement whereby land is purchased by the entity desiring long-terms control of water and where the land is leased back to the irrigator so that farming operations may continue except when the water is needed to replace drought shortfalls.

Contingent water contract – see, dry year water option contract.

Contractee – In a supply reliability contract, the contractee is the party selling the option. Generally the contractees in this scenario are irrigators.

Contractor – In a supply reliability contract, the contractor is the party purchasing the option to call the water in the future.

Descending Bid Auction - In a descending bid procurement auction, bidders bid down the price that they will accept sequentially until no bidder wishes to bid the price down any further. The bidder that will accept the lowest price is the winner.

Dry year option contract – A contract where a contractor pays the contractee a premium for the option to exercise the option at a later date.

Dry-year water supply reliability contract – A contract that is designed to shift the risk of water supply variability. Under this scheme, the contractor pays the contractee a sum of money (in advance of need) for the option to call on the option at a future date. Includes both dry-year option contracts and other similar reliability contracts.

Exercise payment – The payment that is made to a contractee when options are called (or exercised).

Index – A method of ranking bids based upon predetermined set of criteria.

Iterative Auction – An auction that consists of more than one round of bidding where bidders are allowed to revise bids between rounds.

Junior water rights – In a state recognizing the doctrine of prior appropriation, a junior water right holder is a person that may appropriate water but only after relatively senior right holders appropriate.

Multiple Unit Auction – An auction where more than one unit is placed for auction. In the case of a multiple unit water auction, participants submit bids consisting of various volumes of water.

Option premium – The amount of money paid by the contractor to the contractee to keep the option open.

Procurement Auction – An auction where the auctioneer's goal is to obtain, rather than sell, a particular item or resource.

Reserve Price – In a water auction the reserve price is the maximum amount of money that the auctioneer is willing to spend per given volume of water.

Revenue Equivalence – The theory that regardless of what auction design is used (ascending, descending or sealed bid), the chosen bid price is expected to be the same.

Sealed Bid Auction – An auction where bidders submit confidential bids. In a procurement auction, the auctioneer obtains the confidential bids and selects the lowest bidder as the winner.

Sealed Bid Multi-Unit Procurement Auction - An auction design particularly suited for water auctions because it permits the submission of bids that may vary in quantity.

Senior water rights – In a state recognizing the doctrine of prior appropriation, a senior water rights holder owns rights to a relatively more secure source of water. These rights are the most valuable.

Up-front payment – The payment paid to a contractee up-front in a dry year water supply reliability contract. May or may not be considered an option premium.

Vickery Auction – In a procurement Vickrey auction, the winning bidder is paid the amount that the second place bidder submits. Under economic theory, this method minimized the threat of bid shading.

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