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Table of Contents

Editor's Foreword:
I am pleased to offer five articles in this ***Special Issue*** of the ***Western Economics Forum*** covering topics pertaining to Western Water. The initial article addresses institutional concerns as per the Colorado River. It is followed by an articulation of water supply risk and uncertainty. The third and fourth pieces provide some water allocation and mitigation perspectives. The final piece provides insights into the contribution of irrigation water to land values.

Donald M. McLeod

The Western Economics Forum

A peer-reviewed publication from the Western Agricultural Economics Association

Purpose

One of the consequences of regional associations nationalizing their journals is that professional agricultural economists in each region have lost one of their best forums for exchanging ideas unique to their area of the country. The purpose of this publication is to provide a forum for western issues.

Audience

The target audience is professional agricultural economists with a Masters degree, Ph.D. or equivalent understanding of the field that are working on agricultural and resource economic, business or policy issues in the West.

Subject

This publication is specifically targeted at informing professionals in the West about issues, methods, data, or other content addressing the following objectives:

- Summarize knowledge about issues of interest to western professionals
- To convey ideas and analysis techniques to non-academic, professional economists working on agricultural or resource issues
- To demonstrate methods and applications that can be adapted across fields in economics
- To facilitate open debate on western issues

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The *Western Economics Forum* is a peer reviewed publication. It usually contains three to five articles per issue, with approximately 2,500 words each (maximum 3,000), and as much diversity as possible across the following areas:

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The Disappearing Colorado River

Lawrence J. MacDonnell[1]

Introduction

On October 17, 2010 storage in Lake Mead dropped to its lowest level since the Bureau of Reclamation (Reclamation) began filling the reservoir behind Hoover Dam in the 1930s. Further declines may trigger the first ever declaration of a "shortage" condition in the Lower Basin of the Colorado River, under which deliveries to Arizona and Nevada water users will be reduced.[2] Increased amounts of water will be released from Lake Powell to help maintain storage levels in Lake Mead, reducing the buffer protecting uses in the Upper Basin from being curtailed to meet delivery obligations to the Lower Basin established in the 1922 Colorado River Compact.[3] Earlier in 2010, Reclamation acknowledged for the first time that uses of basin water now exceed supply.[4] Lurking behind these rather dramatic events is growing scientific evidence that the physical supply of water annually available in the Colorado River basin is declining as a consequence of global warming.[5]

These events bring to the fore long-standing legal issues concerning rights and obligations of the states under the Law of the River.[6] Disputes about one or more of these issues could take the states into court. Alternatively, the states could decide to address the problems presented by these issues through negotiation. This article provides a brief summary of the major legal issues, followed by preliminary discussion of some possible ways negotiated resolution might be accomplished. By bringing these consideration together in a summary fashion, the article hopes to stimulate discussion of the difficult choices ahead in the Colorado River basin.

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[2] A shortage means there is insufficient water available in the Lower Basin to make possible the delivery to Arizona, California, and Nevada of sufficient water to enable consumptive use of 7.5 million acre-feet in a year. In 2007, the Secretary of the Interior issued interim guidelines governing the circumstances under which a shortage condition would be declared (tied to the elevation of water stored in Lake Mead). Secretary of the Interior, Record of Decision, Colorado River Interim Guidelines for Lower Basin Shortages and the Coordinated Operations for Lake Powell and Lake Mead, December 2007, available online at http://www.usbr.gov/lc/region/programs/strategies/RecordofDecision.pdf. In an accompanying environmental impact statement, the Bureau of Reclamation provided an analysis of how these guidelines would be implemented. Final Environmental Impact Statement, Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead, Bureau of Reclamation, October 2007.

[3] The 1922 Colorado River Compact apportioned the beneficial consumptive use of 7.5 million acre-feet of water to an Upper Basin and a Lower Basin, divided at Lee Ferry in northern Arizona. Article III (a). It also placed a limit on uses in the Upper Basin that would reduce flows passing Lee Ferry during consecutive 10-year periods below 75 million acre-feet. Article III (d).

[4] *See* Bruce Finley, "Development in Colorado Going with the Flow of Water Deficit," Denver Post, June 20, 2010: "Federal data show that the average annual use of Colorado River water (15.4 million acre-feet) has surpassed the average annual supply (14.5 million acre-feet) in the river."

[5] *See, e.g.,* Climate Change in Colorado A Synthesis to Support Water Resources Management and Adaptation, Colorado Water Conservation Board, 2009, available online at http://cwcb.state.co.us/Home/ClimateChange/ClimateChangeInColoradoReport/

[6] The Law of the River refers to a number of legal documents that, collectively, establish rights to use the water of the Colorado River and its tributaries. Many of these documents are available online at http://www.usbr.gov/lc/region/pao/lawofrvr.html.

Legal Issues

Over the years, the basin states have debated the meaning of aspects of the laws governing uses of basin water as they perceived their interests were at risk. Presented here are three issues that have received the most attention.

1. Is the Lower Basin Using More Water than Authorized under the 1922 Colorado River Compact?

The 1922 Compact apportioned 7.5 million acre-feet of beneficial consumptive use to the Lower Basin (the states of Arizona, California, and Nevada, plus small parts of New Mexico and Utah) in perpetuity, together with the right to increase those uses another one million acre-feet until such time as another commission should meet to allocate remaining unallocated basin water.[7] The U.S. Supreme Court in *Arizona v. California*[8] determined Congress had allocated 7.5 million acre-feet of consumptive use from the main Colorado River among Arizona, California, and Nevada, raising questions about the status of tributary water that had been included in the Compact apportionment. Counting uses in the tributaries, consumption in the Lower Basin presently exceeds 10.5 million acre-feet.[9] This amount does not account for reservoir evaporation of approximately 1.5 million acre-feet and other losses of water that support consumptive uses in the Lower Basin.[10] The Upper Basin might decide to challenge the amount of consumption occurring in the Lower Basin on the basis it exceeds the amount authorized under the 1922 Colorado River Compact.

2. Must the Upper Basin provide at least 750,000 acre-feet annually towards meeting the Mexican Treaty obligation?

The 1922 Compact anticipated an agreement with Mexico that would ensure use of some amount of water from the Colorado River in that nation annually.[11] The 1944 Treaty committed the U.S. to an annual delivery of 1.5 million acre-feet. Under the Compact, this water was to come out of the "surplus" the commissioners believed existed beyond the 16 million acre-feet of consumptive use they allocated. Any insufficiency is to be equally borne by the two basins, with the Upper Basin to supply half of the deficiency at Lee Ferry.

Since there is not enough water to enable consumptive use of 16 million acre-feet annually in the U.S., Reclamation requires the Upper Basin to provide half of the 1.5 million acre-foot

[7] Colorado River Compact, Articles III (a), (b), & (f).
[8] 373 U.S. 546 (1963).
[9] Bureau of Reclamation, Consumptive Uses and Losses Report, 1996-2000. This is the most recent five-year report of Upper and Lower Basin uses and losses available. Arizona alone consumes about 2.6 million acre-feet from its tributaries, while Nevada, New Mexico, and Utah consume approximately 0.568 million acre-feet. Personal Communication, Jim Prairie, Bureau of Reclamation, Consumptive Uses and Losses Report, 2001-2005, Lower Basin Tributaries (preliminary).
[10] Such losses substantially increase the amount of water that must be available in the Lower Basin to support the 7.5 million acre-feet of consumption in the Lower Basin states and the delivery of 1.5 million acre-feet to Mexico.
[11] Colorado River Compact, Article III (c): "If, as a matter of international comity, the United States of America shall hereafter recognize in the United States of Mexico any right to the use of any waters of the Colorado River System, such waters shall be supplied first from the waters which are surplus over and above the aggregate of the quantities specified in paragraphs (a) and (b); and if such surplus shall prove insufficient for this purpose, then, the burden of such deficiency shall be equally borne by the Upper Basin and the Lower Basin, and whenever necessary the States of the Upper Division shall deliver at Lee Ferry water to supply one-half of the deficiency so recognized in addition to that provided in paragraph (d)."

Mexico obligation at Lee Ferry, releasing this 750,000 acre-foot amount from Lake Powell annually. The Upper Basin has objected to this interpretation of the Compact, arguing water for Mexico should come first from the consumption in the Lower Basin exceeding its 8.5 million acre-foot apportionment.[12]

In addition, the Upper Basin may argue the consumption occurring in the Lower Basin in excess of 8.5 million acre-feet comes from surplus water that was supposed to be used to meet the Mexican Treaty obligation. Before uses in the Upper Basin are limited to provide half of the Mexico water, uses above 8.5 million acre-feet should be restricted.

Finally, the Upper Basin has consistently objected to bearing any responsibility for transit losses between Lee Ferry and the Mexican border. In its view, its obligation to provide half of the water if surplus is not available is satisfied at Lee Ferry.

3. Must the Upper Basin ensure flows of 75 million acre-feet at Lee Ferry every consecutive 10-year period if it means being unable to consumptively use 7.5 million acre-feet allocated under the 1922 Compact?

Since more than 80% of the basin's water originates in the upper region, Lower Basin commissioners insisted on insurance that sufficient water would pass the dividing point at Lee Ferry so that Lower Basin uses would be protected. Agreement on 75 million acre-feet over consecutive 10-year periods was a compromise, splitting the difference between the positions of the two sub-basins.[13] Information available to the commissioners in 1922 indicated annual average flows at Lee Ferry during the previous 20 years of 16.4 million acre-feet, suggesting there would be enough water to support annual consumption of 7.5 million acre-feet in the Upper Basin with plenty of water left over for the Lower Basin and Mexico.[14] Now it is apparent that, even with Lake Powell, the Upper Basin will never be able to consume 7.5 million acre-feet of system water and still meet the Lee Ferry flow obligation.[15] A recent study for the State of Colorado, incorporating hydrological assumptions of lower runoff indicated using tree-ring analysis and potential further reductions associated with anthropogenic climate change, concluded the State likely has little, if any, reliably developable apportionment.[16]

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[12]As storage in Lake Powell dropped sharply between 2000 and 2004, Upper Basin representatives once again raised their objection to the "deficiency" release from Lake Powell. Letter from Scott Balcomb et al., Governors' Representatives on Colorado River Operations of the States of Colorado, Wyoming, New Mexico & Utah to Herb Guenther et al., Governors' Representatives of the States of Arizona, California, and Nevada (October 7, 2004). The Lower Basin, led by Arizona, responded that the existence of a surplus or deficiency must be determined annually, based on the volume of water available in the Colorado River. If that volume exceeds 16 million acre-feet, there is surplus. W. Patrick Schiffer , et al., " From a Colorado River Compact Challenge to the Next Era of Cooperation Among the Seven Basin States," 49 ARIZ. L. REV. 217, 222 (2007).

[13] The 10-year period reflected the fears of Upper Basin commissioners that prolonged periods of drought could otherwise prevent achievement of this commitment.

[14] Norris Hundley, Jr., WATER AND THE WEST: THE COLORADO RIVER COMPACT AND THE POLITICS OF WATER IN THE WEST, 2d ed. (1975, 2009) at 192.

[15] Estimates of just how much consumptive use the Upper Basin may be able to make have gradually decreased over the years. Reclamation's most recent "hydrologic determination," published in 2007, concluded the Upper Basin can expect to consumptively use 5.76 million acre-feet, not including the evaporation losses associated with the large federal reservoirs in the Upper Basin. Bureau of Reclamation, Hydrologic Determination 2007, Water Availability from Navajo Reservoir and the Upper Colorado River Basin for Use in New Mexico (April 2007). Present consumptive uses are estimated to be about 4.0 million acre-feet.

[16] AECOM, Colorado River Water Availability Study, Phase I Report, Draft, Colorado Water Conservation Board, March 22, 2010.

The Upper Basin states might choose to litigate the 10-year, 75 million acre-foot flow obligation. Two arguments have been suggested. One is based on mutual mistake—that this provision resulted from flawed information about basin water supply and should be reformed (as a matter of contract law) to reflect more accurate information.[17] Another argument is this provision must be read in combination with the provision apportioning beneficial consumptive use of 7.5 million acre-feet to each sub-basin. The argument is the flow obligation cannot override the specific apportionment to the Upper Basin, especially so long as the Lower Basin has sufficient water to consume 7.5 million acre-feet. Another version of this argument would reduce the flow obligation according to the reduction in water availability attributable to climate change.

Experience with state versus state litigation in the U.S. Supreme Court suggests resolution will require many years. For example, Arizona filed suit against California in 1952 to get resolution of its share of the Lower Basin's Compact apportionment; the U.S. Supreme Court issued its decision in 1963 followed by its decree in 1964 and now supplemented by four additional opinions.[18] Moreover, it is difficult to assess how the Court might rule. The issues are complex, and there are good arguments on both sides. Still, the states might choose litigation as the only possible way to achieve resolution. Alternatively, the states could choose to focus on searching for negotiated solutions that might provide the basis for legal accommodation. That is the subject of the following section.

The Search for Solutions

Human-caused depletions to the water of the basin now exceed the recorded average supply of water. Yet there are legally-based expectations in most basin states to further increase consumptive uses of basin water. Negotiations need to focus on ways to reduce depletions while meeting essential basin water needs. Outlined here are possible elements of a basin negotiation.

First, there should be no new net depletions of water in the Colorado River basin.

The basin states should not approve any new water uses or allow the exercise of any already-established water rights that would increase the depletion of basin water. Additional consumptive uses (or evaporative losses associated with new water storage) should only be allowed if at least the equivalent amount of existing consumptive uses (or evaporative loss) is retired. Thus, for example, water consumptively used for new energy development or urban growth would have to be fully offset by the retirement of an equivalent amount of existing consumptive uses so there would be no net increase in the depletion of basin water. Presumably, such transactions would be managed by the party wanting to make a new consumptive use, although states might instead choose to acquire the water and make it available to new uses.

Such a proposal imposes heavily on continued expectations in the Upper Basin to develop more of the 7.5 million acre-foot consumptive use apportionment under the 1922 Compact. While most water leaders in the Upper Basin accept the fact that the 7.5 million acre-foot allotment will

[17] John U. Carlson & Alan E. Boles, Jr., "Contrary Views of the Law of the Colorado River: An Examination of Rivalries between the Upper and Lower Basins," 32 ROCKY MT. MIN. L. INST. 21-1 (1986).
[18] *Arizona v. California,* 373 U.S. 546 (1963); 376 U.S. 340 (1964); 439 U.S. 419; 460 U.S. 605 (1983); 530 U.S. 392 (2000); 531 U.S. 1 (2000).

never be fully used, they have fiercely guarded their expectations to consumptively use more basin water. They are unlikely to accept such a cap on new depletions without other changes that would justify loss of what Upper Basin water leaders believe was the essential bargain achieved by the 1922 Compact—that the slower growing economy in this region would still have water to develop when eventually needed.

Second, the Lee Ferry flow obligation (including releases for Mexico) should be relaxed so long as there is sufficient water available to supply Lower Basin (including Mexico) consumptive uses.

The purpose of the Lee Ferry flow obligation was to ensure sufficient water reached the Lower Basin to help supply apportioned uses. The 10-year, 75 million acre-foot requirement was a compromise agreement. There should be nothing talismanic about the number so long as its purpose is achieved. Agreement on this principle would likely make the Upper Basin more willing to consider accepting a no-new-net-depletion requirement. When Congress funded construction of Glen Canyon Dam and the other Colorado River Project Storage reservoirs in 1956, it was believed that storage in these reservoirs would enable the Upper Basin to increase its consumptive uses to 7.5 million acre-feet/year while delivering enough water to the Lower Basin to ensure consumptive use of 8.5 million acre-feet of from the main stream and tributaries in the Lower Basin, as well as delivery of another 1.5 million acre-feet to Mexico. It is now clear there is simply not enough water in the system to make this possible.

We should reconsider the bifurcation of the basin at Lee Ferry and focus instead on stabilizing and securing some sustainable level of consumptive uses and depletions in the basin, considering a basin-wide water budget. With a reduced water supply there may be different and better ways to utilize the basin's extensive system of water storage facilities. The possibilities are enormous, and it is impossible to say which particular approaches would work best and also be acceptable to the complex mix of stakeholders in the basin.

Third, consumptive uses in the Lower Basin states and Mexico of the water of the Colorado River must be managed so they are limited to no more than nine million acre-feet per year in normal years.

Water use practices in the Lower Basin and Mexico developed under conditions of surplus. When water was relatively abundant, careful management was less important. So, for example, between 1996 and 2000, an annual average of 1.1 million acre-feet passed to Mexico beyond the amount required by the Treaty.[19] With the disappearance of these surpluses, water management in the Lower Basin needs to change.

Steps already are being taken to improve the efficiency of Lower Basin water management, but with the intention of enabling increased consumption of basin water in some cases.[20] There are many opportunities for such efficiencies that should be pursued solely for the purpose of reducing the need for releases from Lake Mead. The goal should be to limit such releases to no more than the amount necessary to meet apportioned beneficial consumptive uses.

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[19] Bureau of Reclamation, Colorado River System Consumptive Uses and Losses Report, 1996-2000, Summary Table at iv, available online at http://www.usbr.gov/uc/library/envdocs/reports/crs/pdfs/crs962000.pdf.

[20] In return for helping to finance the Drop 2 structure, the Southern Nevada Water Authority is getting rights to increase its consumption of basin water.

Fourth, a federally-funded program to strategically reduce the annual level of consumptive uses in the basin should be established.

More fundamentally, it is time to put the question of the sustainable level of consumptive uses in the Lower Basin on the table. It has long been recognized the basin's water supply is overallocated. The full extent of this overallocation is now painfully evident. If the Upper Basin is to give up its expectations of increasing its consumptive uses of basin water, the Lower Basin must be willing to make some changes in the amount of consumptive uses it now enjoys. That such reductions can be managed is evidenced by California's cutback from 5.2 million acre-feet of consumptive use to 4.4 million acre-feet in 2004. Mexico needs to be part of this discussion as well. A reduced basin water supply means that all beneficiaries must be part of working out ways to live with that reality. It is never easy to reduce uses, but it is time to start doing so.

Fifth, all basin states must facilitate voluntary processes allowing reallocation of basin water to new uses within their states.

Despite the existence of shortages of water in relation to demand, there is in fact sufficient water to meet basin needs. Most of the basin's water is used for irrigation of crops. The allocation of this water occurred in an era in which irrigated agriculture represented an important economic engine for the basin states. Because most of this agriculture could not bear the full costs of developing and delivering this water, governments subsidized much of these costs. Today, however, the economic justification for these decisions no longer exists, yet the subsidized uses continue.[21]

The process of voluntary reallocation of a portion of the basin's water now dedicated to irrigation is well underway. Much, much more is needed, however, if the basin's reliable water supply is to meet emerging essential demands.

Conclusion

Basin leaders face a difficult challenge. Water supply issues now require responses that mean getting along with less water in some cases and paying more for the water that is used. The political culture of western water developed on the basis of governmentally-supported expansion of water supplies to promote economic development. Despite the broad recognition that this era has ended, the culture remains well entrenched. It will take real leadership to move the basin states beyond the still- powerful perception that economic growth requires ever increasing (low cost) supplies of water. Yet the realities in the Colorado River basin are forcing reconsideration of long-held assumptions about water availability and uses of basin water. The basin's water budget is untenable. Supplementation of water supplies from outside the basin remains the hope of many to bring this budget into balance, but options are few and enormously expensive. More feasible (and already underway) are approaches based on improved water management to reduce losses, reduced consumption in lower economically-valued uses, and voluntary reallocation to meet new demands. Real progress depends, however, on shared agreement or acceptance of a sustainable basin water budget, one that realistically balances consumption and unavoidable losses with reliable supplies. Reaching such agreement is the challenge ahead.

[21] As an example, users of water supplied from Reclamation dams such as Lake Mead pay little or nothing for the water.

Water Management, Risk, and Uncertainty: Things We Wish We Knew in the 21st Century

W. Douglass Shaw and Richard T. Woodward[1]

Introduction

A survey is offered of the most difficult and challenging issues to water managers in the 21st Century, focusing on the economics of risks and more so, uncertainty. Risk and uncertainty is addressed a great deal here because so many water management and policy issues involve them, as will be seen below. It is deemed unwise for the water community to model decisions as if there was certainty. For example, traditional decision models that assume certainty often require that the present value of known net benefits be maximized, when in fact it may be that benefits, costs, and the discount are all actually unknown, or at least involve risk.

As is common in decision theory, in this paper risk (with known probabilities) is distinguished from uncertainty, where probabilities cannot be easily, or even never can be known (e.g. Knight, 1921). Economic risk is often synonymous with probability. Other research disciplines often factor the severity of the outcome into the definition of risk, i.e. the "risk" of a disease that has mortality as a possible outcome is worse than one that has morbidity as a possible outcome, even if the probabilities are the same in each case. For psychologists, the definition of risk varies a great deal, and this matters, particularly when risk communication is the focus [see *Fischhoff*, 2009; *Nguyen et al.,* 2010]. Others distinguish between variable quantities, such as the load level of a toxic element in a river, which varies temporally or spatially in a known manner, and quantities which have a single, but unknown "true" value [e.g. *Smith et al.,* 1992].

The riskiness of a situation is fundamentally about the spread of a probability distribution. The distinction between the average and the spread is characterized nicely by considering the "risk" in jumping out of an airplane with a bad parachute. If the parachute is known to fail 99 out of 100 times, then one might actually say there is no "risk" involved with jumping: death is actually nearly certain.[2] Decision makers are often found to be averse to risk: if the average returns of two gambles are the same, people will prefer the one that has a tighter distribution and, therefore, less risk.

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[1] Shaw and Woodward are each Professors, Department of Agricultural Economics, and participants in the Graduate Program in Hydrologic Science and Policy, Texas A&M University. Shaw is also Research Fellow, Hazards Reduction and Recovery Group at A&M. Shaw acknowledges additional funding from the U.S.D.A. Hatch (W-2133) Grant Program. The authors thank Michael Kaplowitz and Frank Lupi for encouraging the paper and for hosting a seminar on this topic at Michigan State University, three anonymous reviewers, and the editor of this journal for comments which ultimately improved the paper. We have benefitted greatly in our discussions about uncertainty over the past years with Bob Berrens, David Bessler, Therese Grijalva, Glenn Harrison, Paul Jakus, Paan Jindapon, Mary Riddel, and Nat Wilcox. They are of course not responsible for anything we get wrong here.

[2] The authors credit Harris Schlesinger, from whom we took this example.

There is little consensus among economists regarding choice under uncertainty, when the probability distributions are not well understood by subjects, and perhaps even by experts. However, formal analysis and structured decision-making can proceed even in the face of pure uncertainty.

The most common approach to handling uncertainty is to convert the situation from one of uncertainty to one of risk. One way to do this is to create what is called a compound lottery, making a probability distribution itself depend on a second random variable and then averaging over the probabilities. Introducing uncertainty by considering multiple distributions can be implemented through relatively simple Monte Carlo analysis, often done to explore the effects of various risk assumptions. While standard Monte Carlo analysis is fairly standard in much research, simplistic analyses using this process have been criticized on several grounds [see *Smith, Ryan and Evans,* 1992].

For example, simple Monte Carlo exercises often involve multiple draws from the same class or family of probability distributions (continuous/normal), and functional forms are typically assumed to be known with certainty (Pindyck 2010). But real uncertainty may involve not having any idea of the family of distributions to consider. However, there are many other tools that allow analysis of at least some kind when uncertainty rules the day.

Below some of these uncertainty analysis tools are described, in their most recent form. Then, applications of these tools to several issues in the areas of water management are given. The final section offers a short discussion and list of policy recommendations that are for use by researchers, as well as people in the water resources community.

Methods in the Uncertainty Toolkit

Several water resource issues facing society today fit the characterization of pure uncertainty in which probabilities are not known. Such conditions can arise even if the status quo situation is well understood, since pursuing a project can introduce uncertainty. Some believe that nothing should be done about global warming, for example, because even the probabilities of outcomes (the timing and magnitude of impacts) are debated. Developing watersheds or aquatic habitats in manners that have irreversible consequences is another example. Society sometimes chooses to take a precautionary approach, investing in programs to reduce pollution or use of fossil fuels, even when the benefits in the distant future may be largely or completely uncertain.

Most tools of interest to water resource economists fall into categories of empirical-statistical methods, programming approaches, or optimal control techniques. Regardless of the approach taken, the usual decision framework is a variation on ex ante benefit-cost analysis. It is the benefits, not typically the costs, which are hard to estimate, ex ante. The most widely used theoretical framework to frame analysis of the benefits is the expected utility (EU) model, which potentially leads to the measurement of the option price (OP – see Graham 1981), the standard measure of benefits under risk. The EU framework helps greatly to explain why people undertake very risky gambles, or avoid gambles that appear to offer fair payoffs (i.e. turning down the offer to be paid $1.00 or $0, each with a fifty-fifty chance, in lieu of being paid $0.50 with certainty).

The EU-OP framework is one in which probabilities are presumed to be known. There are certainly situations involving such well-known risks in the water-resource arena. For example, flows of rivers are inherently random, but long data histories may allow characterization of annual or seasonal flows using probability distributions. Perhaps surprisingly however, there are relatively few economic studies in the literature that actually use data collected in a fashion that allows estimation of the OP for individuals in a sample. An exception in the water resources realm is the Monongehela River study by Desvousges et al. (1987), where subjects are told what risks are and the survey elicits their OP. To our knowledge, thus far no researcher has clearly estimated an OP using only a revealed preference valuation approach, i.e. one based on observed behavior.

Thus, stated preference methods are the only ones we have observed in the literature where researchers may have obtained a clear estimate of OP. Problems with getting a clear estimate of an individual's OP using stated preference methods are numerous. First, even if science-based estimates of risk are available, these must be presented to individuals in such a way that the researcher is sure that respondents are understanding them.

Risk communication can be quite difficult, at best, leading to the individual to over or underestimate risks as compared to the science community (see Riddel and Shaw 2006; or see a host of references in Fischoff 2009; or Nguyen et al. 2010). The problems seem most difficult when the best science suggests that risks are quite small, when the scientists themselves cannot agree, or when the public does not trust the source of the risk estimates. Mortality risk estimates, for example, are often much smaller than 1 in 1,000, prompting the question whether an individual can comprehend the meaning of these small probabilities (Manski 2004, is quite skeptical).

Second, even supposing that risk communication led to an unambiguous subjective probability distribution on the part of the individual which ends up being identical to the scientist's estimates, the next task is to phrase the willingness to pay (or willingness to accept) question in a manner that does not confuse the OP with all of the other valuation concepts (bequest, expected future use, option, and existence value). A thorough review is beyond the scope of this current paper, but many older papers that were scrutinized do not convincingly accomplish this task.

The use of subjective probability or risk estimates is quite important, and especially so when it is apparent that social behavior is being driven by subjective risks that are far different than science-based risks. For example, *Riddel and Shaw* [2006] found, even after trying to communicate science-based risks to their sample of respondents, that the sample's subjective risks of nuclear waste transport and shipping were thousands of times higher than the science-based estimates. In theory and in practice, it is certainly possible to use subjective estimates in empirically modeling behavior: this has been done dozens of times in the literature on cigarette smoking [e.g. *Viscusi,* 1990].

A less-explored problem that arises in subjective estimation of risks or probabilities relates to whether the individual providing the risk estimate is him or herself uncertain about them. A simple case arises when there might be two experts who offer their opinion of the risk of an event, and these widely diverge from one another, and subjects are aware of this divergence. *Savage* [1954] showed that a decision maker's choices could be explained by a model in which it is assumed that the individual takes the expected value of the two risk estimates, maximizing his or her "subjective expected utility." However, many psychologists and economists have demonstrated in laboratory experiments that subjects do not behave in this manner. One thought is that instead, individuals simply use decision heuristics to make complicated decisions, and that these depart greatly from the assumptions underlying the classic EU framework [see *Tversky and Kahneman,* 1974].

In response to concerns about the validity of the EU framework [e.g. *Smith,* 1969], a host of non-EU models have arisen that allow for a rich set of behaviors when individuals make decisions, and potentially allow for ambiguity [e.g. *Segal,* 1987]. Most of these models incorporate probability weights, including the cumulative prospect theory developed by *Tversky and Kahneman* [1992] and the rank-dependent expected utility model developed by *Quiggin* [1993]. These models account for the fact that compared to those science-based probabilities (p) in the standard EU model, individuals often place more weight on low probability outcomes, and less weight on common outcomes. This can be understood by a model in which probabilities are filtered through a probability weighting function (PWF) such as the inverse S shaped curve in Figure 1. If an individual's PWF lines up on the 45 degree line, then his or her treatment of the risks of a situation will coincide with the science-based estimates. When low probability events are given more weight, the weights, w(p), will take on an S-shape. Non-linearity in the pwf has been found in many studies that obtain them [e.g. *Gonzalez and Wu,* 1999].

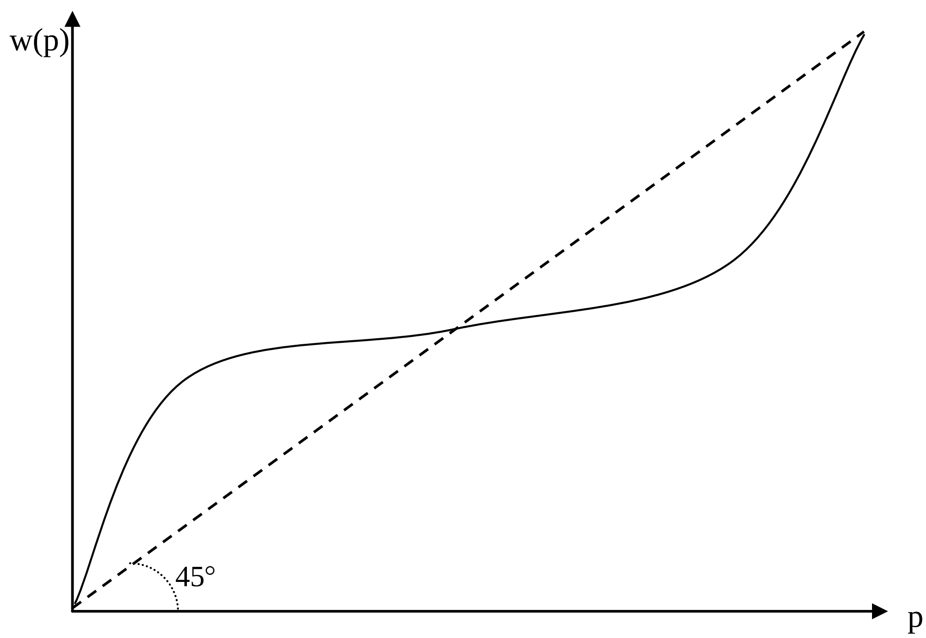

Figure 1: Probability Weighting Function (Inverse S shape)

There is substantial evidence that such non-linear probability weighting often occurs and this can relate to issues in water resource economics (see the focused discussion by *Shaw and Woodward* [2008], relating especially to environmental and resource economics issues). Actually estimating the probability weights is a substantial challenge. Recovering a PWF requires knowledge of weights throughout the spectrum of probabilities, for each individual in a study, and requires identification of each individual's utility function, and risk attitudes. An individual's choices must be observed making a series of similar decisions with gradually changing probabilities. Estimating such PWFs in the "real world," is very difficult, and some are skeptical that PWFs actually provide any improvement over models without weights that focus on reduction in error (see for example, Wilcox 2009). Several economists and decision theorists are leading the way in such methods using laboratory experiments [see *Tanaka, Camerer, and Nguyen*, 2010, for example].

Decision makers may face the problem of *ambiguity*, lacking knowledge about a probability reflecting risks. A simple characterization of at least some degree of ambiguity is the two-expert example above. In the laboratory, or on a survey questionnaire, an individual might be told that there are two "experts" who disagree with one another about their estimate of risks [*Woodward and Bishop,* 1997]. Ambiguity arises when the individual is unable to come to terms with how to treat these opposing views of risk. If an individual is comfortable simply averaging the two estimates of risk, then this is as a compound lottery that reduces the uncertainty to a situation of risk. The individual is thought to be making a decision under something approaching pure uncertainty when averaging does not happen.

The decision maker does not know the probabilities that define the situation with pure uncertainty. In experiments to evaluate choice under uncertainty, a researcher might make no effort at all to communicate the probabilities to individuals, or to elicit them. Subjects in a laboratory or in a survey might simply be informed that outcomes are uncertain, but be asked to proceed with making a choice. Choices in this case might be consistent with a variety of decision heuristics, including minimizing the regret they would experience by making the wrong choice (e.g. in their recent classroom experiment *Grijalva, Berrens,* and Shaw 2011, find that subjects' responses are consistent with this strategy).

In most laboratory experiments that have focused on pure uncertainty, individuals are shown to be averse to ambiguity involving monetary payoffs. Whether they would demonstrate similar traits when confronted with the problem of droughts or flooding has not been tested. Ambiguity, at least in some form, has been also considered now in several empirical models of behavior that do not involve laboratory experiments [see for example the survey-based research by *Viscusi and Magat*, 1992; *Riddel and Shaw,* 2006], and aversion to ambiguity is not always found.

Another potential uncertainty tool is in the area of linear and non-linear programming. One common task is for the programmer to introduce risk. This is often done by simply letting there be two or three states of the world, each with a known probability, and engaging in stochastic optimization. Though this sounds simple, things quickly get complicated with many such states of the world as the computational complexity of the problem can grow geometrically, often leading to intractable problems. It is important that the modelers consider more than one specific probability distribution to add some uncertainty to a programming analysis. Ritten et al. (2010) consider a range of projections for precipitation in their analysis of optimal rangeland stocking problems. They recognize that climate change may lead to several possibilities for randomness in weather patterns, which is consistent with varying predictions from current scientific estimates.

Programmers can further introduce uncertainty using optimal control. Below is the standard expected utility maximization problem for a planner making a policy choice, *z*:

$$\max_{z} E_P u\left(z;\varepsilon\right), \qquad (1)$$

where ε is randomness in the environment that varies according to a known probability distribution *P* and E_P is the expectation operator for that distribution.

Many mathematicians have considered optimization problems with uncertainty [see *Schmeidler* [1989] and *Gilboa* [1987]]. A relationship between pure uncertainty and probability weighting can be formalized in this context by assuming that individuals make decisions as if they violate well-known properties that probabilities have. For example, consider the state-space corresponding to three outcomes, A, B, and C, with probabilities p(A), p(B), and p(C). It turns out that decision makers often act (i.e. make choices) as though probabilities do not sum up to one. Situations of both “sub-additivity” and “super-additivity” have been found to arise in experimental settings. Such unusual weighting has led to the framework known as Choquet-Expected Utility [*Diecidue et al.*, 2004]. It has been shown that for decision makers who are averse to ambiguity, choices that use nonlinear weighting or in other ways that violate the standard model can be “rational” in a rather rigorous sense of that word.

A particularly relevant extension of conventional optimal control is robust optimal control [see *Hansen and Sargent,* 2001*; Ben-Tal et al.,* 2009], often specified in dynamic economic models. A robust control optimization problem is used when there is a family of possible probability distributions, say **P**, and the decision maker is completely uncertain about which distribution is the correct one. The robust-control problem is

$$\max_{z} \min_{P\in\mathbf{P}} E_P u\left(z;\varepsilon\right). \qquad (2)$$

That is, the robust optimal policy is the one that is made assuming the worst possible probability from the set of possible distributions, **P**, so that the expected outcome will be at least as favorable as the worst case that is identified in (2).

When decision makers are averse to ambiguity, robust control is “rational” in that it is consistent with a set of reasonable axioms (Gilboa and Schmeidler 1989). The approach includes a term that allows for varying degrees of aversion to ambiguity, effectively determining the size of the set **P** in (2). At one extreme **P** is a single probability distribution and the model maximizes the standard discounted expected value. At the other extreme the model chooses as if only the worst-case scenario is relevant. Increasingly, robust control is used to solve applied problems in engineering though the computational complexity of this specification can be as burdensome as in the standard EU cases discussed above. The following sections offers attempts at using some of the above approaches.

Issues Involving Water Quantity, Risk and Uncertainty

Several pressing and important issues relating primarily to water quantity or scarcity are highlighted. These are limited to topics that are especially difficult to analyze because of risk or uncertainty. On many minds is regional population growth relative to water supply. This problem is typified by struggles in Arizona [see *CBO,* 2006], California [see *Hanemann*, 2002], and in

China [see *Dasgupta*, 2001 and *Gleick,* 2009]. A reviewer of this paper noted that population growth has been high in all three of these regions, but that future water availability and climate impacts are still uncertain in each. This highlights that the relationship between population growth and water allocation is complex. For example, migration can lead to population growth in those areas with the highest income [*Borjas et al.,* 1992]. Predicting population growth and its relationship to water availability is no doubt fraught with uncertainty.

How should water managers proceed to introduce uncertainty here? Consideration of both supply side (availability because of climate uncertainty) and demand side issues is merited. Most risk or uncertainty for natural resource economics of extraction, occurs in relation to extraction costs (e.g. the effect of unknown reserves and discovery), but it may be that future tastes and preferences are unknown as well. In the discussion below two water problems are given that involve risk or uncertainty, the problem of drought and global warming, and the management of instream flows.

Addressing Drought and Global Warming

Precipitation, by its very nature, involves risk, and is regularly characterized using a well-known probability distribution. An emerging issue is whether relatively recent precipitation data is sufficient to be informative regarding large deviations from some mean. Focusing on the use of time trends, *Milly et al.* 2008 recently pronounced the death of the use of such modeling in the area of climate change research . They offer suggestions for a model using nonstationary hydrologic stochastic variables, where these are used to develop probability density functions that do change over time. They note that the challenge in doing this will be daunting. Hundreds of hydrologic studies have focused on using more simple stochastic models of surface and groundwater flow. Economic analysis has built on optimal withdrawals under known risks with allowance for comparison to withdrawals when there is certainty.

Pullen and Colby [2008] illustrate connections between drought indicators and water prices. Their conclusion is that climate variability does affect water price, with some lag and that water markets may work reasonably well to adjust prices in response to scarcity in some contexts. Exacerbating the water allocation and planning problem with potential droughts now is the threat of severe consequences related to global warming. Some are already blaming some increase in droughts in China on climate change [see *Gleick,* 2009]. Augmented precipitation intensity and variability are projected to increase the risks of flooding and drought in many areas [*Bates et al.,* 2008]. Note that the word “risks” is used here by Bates et al., 2008, but many in the global warming science community might argue that impacts are more certain. For example, the head of the White House Council on Environmental Quality stated recently that preparations must be made for the “inevitable” effects of climate change (see Chipman 2010).

If risks related to global warming were well known, it would be possible to estimate the OP for water quantity-related changes. The 2008 IPCC report on climate change and water indicates that “climate change challenges the traditional assumption that past hydrological experience provides a good guide to future conditions [*Bates et al.,* 2008, p. 4].” *Schimmelpfennig* [1996] documents failures of climate change researchers to adequately model uncertainty. *Paté-Cornell* [1996] concludes that uncertainty, not risk, characterizes climate change estimates, and states that “Experts, however, tend to underestimate uncertainties…” (p. 148). Still, she and other climate change researchers call for better efforts to handle uncertainty.

Alternatively, one could focus on the agricultural sector and consider the role that climate risks play there in farming, or raising livestock. That is precisely what *Groom et al.* [2008] try to do. They develop a model assuming that farmers use a combination of inputs, and that irrigated water plays the key role in the analysis via an imposed quota during drought. The essential point of their paper is to allow for climate risk to affect crop yield and explore risk attitudes of farmers, demonstrating that allowance for this risk preference yields quite different results than a model that assumes certainty. Using a moment-based approach (i.e. a model that collapses to a simple examination of first (average), second (variance), third (skewness), or higher moments of profit), they are able to uncover risk-attitudes using cross sectional data, which they obtain from a survey of a sample of farmers in Cyprus.

One might criticize the above approach in that it allows for little heterogeneity in risk attitudes across farmers; yet, its attention to risk preferences is certainly a step in the right direction. What is especially relevant is their examination of a water quota or restriction under various sets of information available to water policy managers. *Groom et al.* [2008] illustrate that under a drought-induced water quota, the naive water manager who assumes risk neutrality on the part of farmers will incorrectly predict how inputs will be used. Results vary for different crops, but using vegetables as an example, the naive manager expects fertilizer use to go down as water is restricted, while the sophisticated one does the analysis and expects fertilizer use to go up. Failing to allow for risk aversion, therefore, may well lead to choose the wrong quota.

Two other studies are closely related to the agriculture and water relationship, and they have important ramifications for modeling decisions under risk or uncertainty. In the first, *Lybbert et al.* [2007] consider whether herders in developing countries act as Bayesians when they take in information on rainfall forecasts. Results suggest that they do, but only for below-normal rainfall expectations, not for above-normal rainfall. This study is interesting because it allows for subjective risks of rainfall to affect decisions to manage agriculture (livestock).

Ranjan and Shogren [2006] consider outcomes when farmers put probability weights on the losses of water rights under market transactions. Here again is an effort to introduce non-EU modeling, simulating what happens if farmers have nonlinear probability weighting functions. They show that if farmers overweight the probability of losses, then this results in undervaluing water resources. This is consistent with the fact that many farmers are reluctant to participate in markets such as found in states with drought water banks. Whether markets will work or not to allocate water supplies for growing populations is questionable. Markets likely do better in allocating resources when demand is known with certainty, and thus, water planners would at least wish that long range population projections were accurate.

There is still a great deal of uncertainty about impacts despite tremendous energy put into modeling global warming's impacts on precipitation and temperature. There are several competing global, ocean, and atmospheric models. Each produces results that vary as to the projected impacts and the probabilities associated with them. Most of the models predict that particular regions of the planet will be hotter, while others actually cooler; some will be wetter, and others drier. Consistent features of the models are that climate will be more variable and extreme events will be more violent. However, the probabilities of these outcomes differ considerably across the models.

Competing and differing estimates of the probability of certain outcomes is consistent with the way that several decision theorists and economists characterize pure uncertainty. Water managers and planners might best think of how to cope with uncertainty and not just risk.Iif they are continuing to rely on forecasts of demand or supply as if these are certain, they have a long way to go in catching up with climate change issues. The next section features the problem of instream flow and endangered species offering robust optimization as one leading approach to making choices in this uncertain environment.

Application of Robust Control: the Instream Flow Problem

Society may place considerable value on water left in a river or lake, or in the ground. This is in contrast to the notion that only water extracted from a river or lake can have value. Perhaps the latter arose only because it was much easier to assign values for extracted water using conventional economic approaches, than to do so for in-situ water or because residual flows were seen as virtually inexhaustible. But this is changing. Instream flow protection is being considered in a host of states in the U.S. today, in some instances because of the importance of aquatic habitat for endangered or threatened species. Such species and their habitat are protected under the Endangered Species Act (ESA), but there is considerable tension between parties wishing to withdraw water and those who support instream flow, especially when water resources are scarce, as during drought periods.

Several countries adopt the precautionary principle, or something along the lines of the Ciriacy-Wantrup's safe minimum standard [*SMS,* 1952]. Again here is the notion that under uncertainty, being cautious about protection is prudent. Models of behavior that generate support for the SMS can be found in the literature, and these incorporate uncertainty [e.g. *Ready and Bishop,* 1991*; Woodward and Bishop,* 1997*; Palmini,* 1999], but general support in economics for the SMS is not a given [see *Margolis and Naevdal,* 2008].

Woodward and Shaw [2008] recently considered the problem of water allocation when features of a species' growth function were uncertain. It turns out that much less is known about species stocks and their growth functions than one might assume. For example, what is the optimal stream flow level to support a certain species of fish? Biologists and hydrologists may not actually know. Even for relatively well-studied fish, oftentimes science still lacks knowledge of some of the most basic properties of the species' growth and reproduction.[3] The difference for policy purposes, between risk and uncertainty might be summarized in comparing Figures 2 and 3. In Figure 2, if policy A is pursued, the distribution for the stock is known, and a compareison can be made with policy B. In Figure 3, the distribution related to either policy is not known with certainty, so there is potential overlap in the tails of outcomes, depending on which of the distributions actually pertains.

[3] An example of this is found in the Rio Grande silver minnow (*Hybognathus amarus*) as discussed in U.S. Fish and Wildlife Service (2007).

Figure 2: Known Risk Distributions for Policy A and B

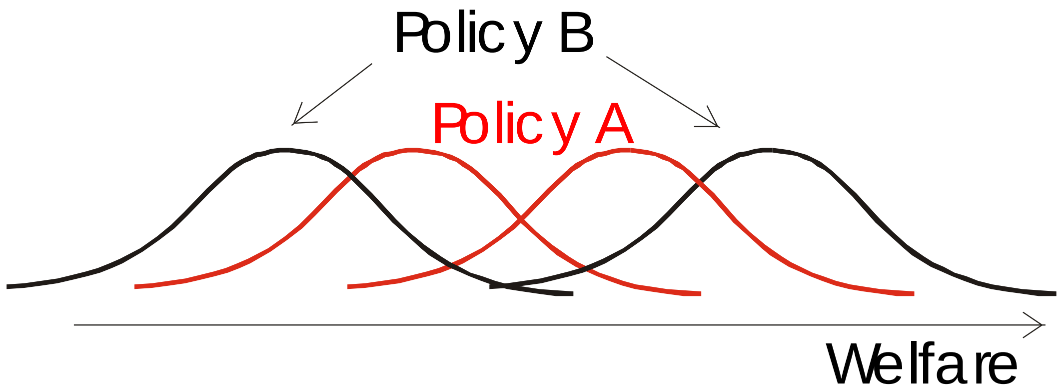

Figure 3: Ambiguity About Distributions for Policy A and B

As mentioned above, robust control is routinely used in engineering applications. For example, structural engineers would not find it acceptable to have a low probability of failure on average; there must be a low probability of failure in all possible scenarios. There are similarly strong intuitive arguments for applications to water management. *Roseta-Palma and Xepapadeas* [2004] apply the approach to the management of groundwater resources, where uncertainty can be substantial, especially in the face of climate change. They conclude that in the face of uncertainty the robust strategy will be to reduce use of groundwater resources. *Woodward and Shaw* [2008] apply the method to the problem of managing instream flows of water in a river in which an endangered species is present. Where there is profound uncertainty about the relationship between the stock's growth and the water level, the authors' show that, at least for a range of stock sizes above some critical minimum stock size, proceeding more slowly with extraction or use makes sense. Hence, the authors show that an SMS approach to management is intuitively attractive and consistent with a formal model of optimal choices under ambiguity.

<u>Conclusions and Policy Recommendations</u>

Water managers have often been characterized as a "risk averse group" [e.g. *Carbone and Dow*, 2005]. This may suggest that most have indeed abandoned the use of certainty models in preparing for the future, although a paper that tries to assess the average strategy of water managers, nation-wide, remains to be seen.

Hopefully, at the very least planners and managers are strategizing by assuming that risk prevails over certainty. They can then at least adopt an EU framework for decision making (e.g. Graham 1981). What they would probably wish for is more information that at least allows for updating and more precision in estimating risks, or in pinning down probability distributions. Risk models are conducive to updating, as learning happens (e.g. Groom et al. 2008; Lybbert et al. 2007). But such additional information and learning from it may not happen for a long while in some cases, and in others, may not ever happen.

However, for many issues, the incorporation of risk into their decision calculus is not sufficient. Better incorporation of not only risk, but also uncertainty needs to come at the initial planning stage. This may be true when considering investments into new storage or treatment facilities. In cases where pure uncertainty is high, adopting a worst-case scenario, something along the lines of safe minimum standards, may be not only be prudent, but an economically rational approach to a difficult problem.

In a world of uncertainty it is prudent to draw on the growing theoretical and empirical research on choice under true uncertainty as society wrestles with tough issues ahead (e.g. using maxmin EU models or robust optimal control as in Diecidue et al. 2004; Gilboa 1987; Gilboa and Schmeidler 1989; Grijalva et al. 2010; Hansen and Sargent 2001; Palmini 1999; Roseta-Palma and Xepapadeas 2004; Schmeidler 1989; Woodward and Shaw 2008). These models are not easy to understand, but they are not impossible to implement (see the experiment by Grijalva et al. 2010).

At the very least, even if such models are not tractable, non-expected utility models should be integrated into decision-making. These types of models allow for something to influence decisions that relates to more than just mean risk, and often allow for ambiguity, and possible probability weighting (Gonzalez and Wu 1999; Ranjan and Shogren 2006; Segal 1987; Tanaka et al. 2010; Tversky and Kahneman 1974; 1992; Viscusi and Magat 1992). As a easily implementable first step, water managers that rely on models that only incorporate risk should consider different possible distributions in the way of a sensitivity analysis, as results may vary wildly, depending on the distribution (e.g. Ritten et al. 2010).

Taking such approaches may be costly, but may also tend to diminish the threat of crises. A crisis in the water arena can mean conflicts over water supplies from competing users, morbidity or even mortality for humans and other living organisms from inadequate water supplies at times of drought. By using a decision-making process that explicitly recognizes the inherent uncertainties that are faced, water managers might better be able to reduce the threat of the worst crises.

This all comes at a price, and water managers who adopt a safe strategy will no doubt be criticized for over-reacting, as they already are today when wet years make surplus storage capacity appear wasteful. Ideally, it would be convenient to be able to focus on those problems with known and stable risks where that can be done. However, this seems possible only in geographical regions that can expect very small climate change impacts to arise, if any such places exist.

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Innovations for Supply Reliability: Role of Inter-jurisdictional Agreements

Bonnie G. Colby, Michael O'Donnell and Rosalind Bark[1]

Introduction

Rapid growth of western cities, full appropriation of dependable river flows, declining groundwater levels, and growing concern for the environment all lead to competition for water and pressure to resolve uncertainties and disputes. The frequent recurrence and the costs associated with water disputes are well documented and significant (Wolf, 2002, D'Estrée and Colby, 2004). Less recognized are the windows of opportunity to create more flexibility in water management. Negotiations to resolve conflicts have given groups who are traditionally marginalized in state level water policy making, such as environmental organizations and tribes, an opportunity to exert levels of influence they are unable to wield with state legislatures. The outcomes of these negotiations have broadened equity, in the form of access to water for interests were not awarded water rights when the region was being settled.

In this article, several innovations in western U.S. water management arising through inter-jurisdictional agreements are reviewed, highlighting provisions relevant to maintain water supply reliability under climate change. This article highlights opportunities that conflicts present to introduce new supply reliability tools into western water policy.

Economists evaluate changes in policies on the basis of efficiency and equity considerations. Efficiency (defined simply for this brief article) considers whether the stream of benefits over time outweighs the stream of costs associated with a particular policy change (benefits and costs measured in present value terms) . Equity considers how the distribution of benefits and costs shifts among different interest groups as a result of the policy change under consideration. For the policy innovations described in this article, a brief commentary is provided for each on their potential efficiency and equity implications.

Western water law tends to evolve slowly in the absence of the pressures for policy change that such conflicts produce. Although innovations become increasingly urgent as the western U.S. grapples with challenges presented by a changing regional climate, water policies tend to be resistant to fundamental change, an inertia which provides security to water right holders but also limits adaptability. This limited adaptability is primarily a consequence of resistance to change from established right holders under the prior appropriation water rights framework.

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Under the doctrine of prior appropriation, water entitlements are sequentially conferred upon water appropriators, meaning that appropriators who are first-in-time have the highest seniority and greatest security against future shortage. Later appropriators have junior rights in this system and in times of drought their entitlements might not be delivered. Additionally, the prior appropriation doctrine developed such that water entitlements could be lost if not beneficially used. This was done to encourage development in the arid west as well as to minimize the incentive to speculate in water. Currently, however, an appropriators' fear of losing access to water by not beneficially using it encourages inefficient use of the resource.[2] While the doctrines of prior appropriation and beneficial use were consistent with the developmental goals as the West was being settled, policymakers of that era could not anticipate the modern challenges of providing water for ecosystem services or facilitating climate change adaptation.

While water management has always been carried out amidst uncertainty, climate change requires adding new strategies to old approaches. Climate change and climate variability are associated not only with a projected increase in average temperature, but also increased frequency and severity of droughts and floods and an increasing portion of precipitation falling as rain rather than as snow – reducing the length of the snow storage season (Natural Resources Defense Council, 2008). These supply-side changes pose a daunting challenge to western water managers when combined with increased water demand for agricultural crops, growing populations, energy generation and urban landscape uses as temperatures rise. Aridity and increasing demand for water resources make the region's water supplies highly vulnerable (Colby and Frisvold, 2011). While a century of investment in dams and reservoirs means that many parts of the West are not much affected by year to year changes in precipitation, extended drought cycles and higher temperatures will exacerbate already intense competition for water (Colby and Bark, 2011). Innovations introduced through crafting inter-jurisdictional water agreements provide valuable tools to maintain supply reliability in the face of climate change.

Interstate water compacts and tribal water settlement are the two categories of inter-jurisdictional agreements discussed in this article. Both of these become legally binding agreements, once ratified by the necessary federal and state authorities (including the US Congress), and have the full force of federal, state and tribal law.

Native American tribes control large amounts of land in the western states, and significant entitlements to water can be associated with these land reservations. Efforts to clarify and quantify Native American water entitlements often result in protracted, costly litigation. However, in a number of cases government-to-government negotiations (tribes, states and federal agencies) or Native American water rights settlements, have generated creative solutions to seemingly intractable problems and more integrated management of regional water resources. Starting in the 1970s, tribal and non-Indian water users pioneered workable negotiation procedures and substantive approaches (Colby, Thorson and Britton, 2006). Over two dozen tribal water settlements have been ratified by Congress over the past quarter century, and dozens of settlement processes are underway.

[2] The term beneficial use is broad and often includes uses such as domestic, municipal, recreation, agricultural, mining, power and others. Some states also allow wildlife uses to be considered beneficial (For example, *see* Arizona Revised Statutes, California Water Code)

Interstate compact disputes are the second class of inter-jurisdictional conflict discussed here. Most of the rivers of the United States flow across one or more state boundaries and many are governed by interstate water compacts. The over two dozen interstate water compacts in the United States vary tremendously in their complexity. Interstate compacts evolved first in the West during the 1920s and focused on dividing up water in a shared river among the relevant states. States found to be in violation of compact provisions are subject to significant enforcement action (Hall, 2010). Nevertheless, it is not uncommon for one state to claim another has violated compact provisions, resulting in lengthy litigation and/or negotiations. Schlager and Heikkila (2009) examine 14 interstate water compacts in the western U.S. They find a regular pattern of disputes arising over compact interpretation and compliance, as well as resolution of these disputes through various mechanisms, including negotiated agreements between the compact member states.

Inter-jurisdictional agreements to address tribal and interstate water disputes shape the economies and futures of communities throughout the western United States. The costs of such conflicts, and of implementing agreements to resolve them, appear in the form of higher water costs, increases in property taxes and shifting of government spending away from other programs. Along with these costs, some agreements have introduced new ways of managing water that are proving valuable as the region adapts to climate change.

Water Management Innovations for Supply Reliability

In this section a number of innovative water management tools are discussed. Some of these are now actively used in multiple locations throughout the western United States, yet were first introduced through inter-jurisdictional agreements created to resolve interstate and tribal-state water conflicts. Here we discuss regional water banks, groundwater protection zones and shortage-sharing arrangements.

Regional Water Banks

A water bank is an institutional mechanism to create a more reliable water supply during dry years through voluntary trading and water storage (O'Donnell and Colby, 2009, Clifford, et al. 2004). Water banks are administered by federal and state agencies and private firms, and range in geographic scale from a specific urban area to several states. Water banks can make water available for future use through storage in either a reservoir or an aquifer. Water accounts are then maintained in which water is banked and withdrawn at varying locations and time periods (Howe and Weiner 2002). Provided that the appropriate legal structure exists, water banks can allow an appropriator to bank water without the fear losing access under the use-it-or-lose-it provision of the prior appropriation doctrine. In a setting where the bank facilitates trades between willing suppliers and willing demanders, it can also provide efficiencies in trade by reducing search costs of demanders as well as promotional/advertisement costs of suppliers. The centralized framework can operate as a clearinghouse that reduces the costs of bringing a trade to fruition.

Colorado River Interstate Conflicts and Water Bank Development

The Arizona Water Banking Authority, developed as a response to conflicts over the waters of the Colorado River, stores excess water for: higher priority subcontractors of the Central Arizona Project (CAP); Native American water rights settlements; and for interstate contractors. This recharged water will be recovered in times of shortage.

The Colorado River is sourced in the Rocky Mountains and flows through Colorado, Utah, Arizona, Nevada, and California south into northern Mexico. Wyoming and New Mexico also contain portions of the river's watershed and are parties to the Colorado River Compact. Major southwestern cities depend on water from the Colorado and large dams provide reliable municipal and agricultural supplies and generate hydropower. About 90 percent of water diverted from the river is used for irrigation. The seven basin states developed the Colorado River Compact after a 1922 U.S. Supreme Court decision (*Wyoming v. Colorado,* 259 U.S. 419) caused concern among the slower developing states that fast growing California would quickly divert (and thus gain rights to) most of the unclaimed water of the basin. The Compact divides the Colorado River Basin into an upper and lower basin at Lees Ferry; with Colorado, New Mexico, Utah and Wyoming as upper division states, and Arizona, California, and Nevada as the lower division states. The Compact apportions the waters of the Colorado River between the two basins, with each basin allocated 7,500,000 acre-feet of water per year (*Colorado River Compact*, Articles II and III). The Compact's apportionment has proven flawed as it was based on water supply measurements taken during an unusually wet period. This results in the lower division states having larger and more reliable water supplies in dry years than the upper division states. This is a source of ongoing conflict that is being partially addressed through water banking and new shortage sharing mechanisms.

As a consequence of the Colorado River Compact of 1922, water entitlements to the Colorado are divided into pre-1922 rights (senior rights) and post-1922 rights (junior rights). The junior water rights are the ones to be curtailed in the event of extended drought and a compact call by the lower division states (*Colorado River Compact*, Article 3(d)). The impacts of such a call are widely held to be widespread and damaging to Colorado. To provide flexibility in addressing such a situation, a water bank has been proposed to facilitate temporary water transfers and provide post-1922 water users with supply reliability (Iseman, 2009). If they purchase and store water under the bank, they can access that water in times when their allocations would otherwise be curtailed. This proposed bank would proactively assess future supply shortfalls and manage the threat of water use curtailment under the Compact (Water Information Program, 2008). Meetings to discuss this proposal are ongoing.

The Arizona Water Bank Authority (AWBA) has been operating for a number of years, also in response to conflicts involving interstate water sharing and the compact. The CAP, a key component of Arizona's water supply, delivers approximately 1.5 million acre-feet of Colorado River water annually to municipal, agricultural, and Native American interests in central Arizona. California's reluctant support of the project was contingent on Arizona accepting a junior CAP priority status, meaning CAP water users would be among the first to experience reduced deliveries in the event of shortage on the Colorado River system. The AWBA was established in 1996 to protect Arizona against Colorado River shortage and CAP supply disruptions by storing unused apportionment in underground aquifers within the state (Arizona Water Banking Authority, 2008). The AWBA purchases excess CAP water and effluent and stores it as accrued long-term storage credits. AWBA also participates in an interstate water management function with Nevada and California. Arizona is storing available portions of Nevada's Colorado River entitlement (up to 1.25 million acre feet) underground in Arizona. Nevada receives credits for this banked water and can use these storage credits to withdraw a portion of Arizona's Colorado River entitlement directly from Lake Mead. Arizona, in turn, withdraws the banked water from its groundwater aquifers (Garrick and Jacobs, 2006). Nevada paid Arizona $100 million in 2005, and is making 10 annual installments of $23 million until the entire 1.25 million acre-feet allowable is used (Southern Nevada 2009). California also can participate with similar arrangements.

Klamath Basin Tribal and Interstate Conflicts and Development of Water Banking

The Klamath River flows through southern Oregon and northern California before reaching the Pacific Ocean. Agriculture accounts for most of the water demand and the river also is used for hydropower generation and recreation. The basin is prime habitat for federally listed salmon species. California and Oregon entered into the Klamath River Basin Compact to divide the Basin's water among the two states and various tribal and federal water needs in the basin.

Many parties, including the Klamath Tribes, had long been concerned about precipitous declines in salmon populations. In 2001, the Fish and Wildlife Service (FWS) and National Marine Fisheries Service (NMFS) issued Biological Opinions that required maintaining higher instream flows for fish recovery. As a consequence, Reclamation was unable to release normal volumes of irrigation water to farmers and a widely publicized crisis of fish versus farmers ensued. In response, Reclamation issued a new Operating Plan and a finalized 2002 NOAA-Fisheries Biological Opinion was issued which established specific flow requirements and directed Reclamation to develop a water bank to meet seasonal flow requirements.

The Klamath Pilot Water Bank, created in 2003, does not store water for later use but rather allows for transfer of forborne irrigation water to instream flows without jeopardizing irrigators' water rights. Banking operations evolved over time to include not only "crop idling" but also "groundwater substitution" and contingency contracts for "groundwater pumping." Groundwater substitution occurs when irrigators use well water instead of river water for farm irrigation and groundwater pumping is a program in which irrigators pump well water and divert the water into irrigation canals for use by others. The Klamath Water Bank also switched from a fixed offer price to a bidding system and was able to obtain water from irrigators more cost effectively.

There also is a seasonal aspect to the program. Instream flow requirements are high in spring and early summer while fallowing generates the most conserved water later in the summer. The bank allows Reclamation to "borrow" water from short-term storage supplies in the late spring and replace that water later with foregone irrigation water (GAO, 2005). While the program creates environmental benefit through stream flow restoration, there is a concern that farmers have unsustainably increased their use of groundwater to offset their reduced surface water use (USGS, 2005). Implementation of the functions served by the Bank was transferred from the U.S. Bureau of Reclamation to the Klamath Water and Power Authority in 2009.

Water Banks As A Supply Reliability Strategy

While only a few water banks are reviewed here, there are over a dozen now operating in the western U.S., most of which originated as a response to an inter-jurisdictional water conflict. Water banks allow for adaptability that is difficult to achieve in the traditional state water law framework for transferring water to other users or uses. The flexibility to transfer water quickly, and at low transaction costs, to locations and purposes that otherwise would suffer losses due to the variability climate change brings, makes water banks, in various forms, an important adaptation mechanism. Water banks, can reduce the transaction costs of participating in water trading as compared the costs of individuals negotiating trades on their own without the services provided by bank. This can enhance efficiency, by facilitating trades that produce positive net benefits but otherwise would not occur due to higher transaction costs. A bank which succeeds in reducing transaction costs also would allow a broader array of interest groups to participate in trades, parties who otherwise might be barred from trading due to higher transaction costs.

Groundwater Protection Zones

While surface water is more obviously susceptible to climate change impacts, more prolonged and severe droughts will also affect groundwater supplies as appropriators switch away from the more variable surface flows. Below are highlighted several innovative arrangements for protecting groundwater levels on behalf of cultural resources and to preserve groundwater as a buffer supply when surface water is limited. In the cases below groundwater has been protected by regulation (Taylor, Contor and Hamilton, 2010).

Groundwater Regulation to Restore Cultural Resources – the Zuni Heaven Settlement

The Pueblo of Zuni is located in New Mexico but members of the Zuni Tribe undertake a regular pilgrimage over 110 miles to perform religious ceremonies in "Zuni Heaven," a marshy riparian area of the Little Colorado River in Arizona. Congress passed a law in 1984 to acquire lands around the religious site for Zuni Pueblo. However, the site was much altered due to construction of an upstream dam which trapped sediment and caused the river to abandon its historical floodplain with rapid destruction of the wetlands. Groundwater pumping by nearby non-Indians exacerbated the destruction, along with introduction of non-native plants and cattle grazing.

The dominant focus of four-years of settlement negotiations was assuring adequate water to restore the cultural site. The cornerstone of the negotiated settlement, ratified by Congress in 2003, is a voluntary acquisition of water rights so the Zuni can irrigate the site and restore its original wetland habitat (Act Approving Settlement of the Water Rights Claims of the Zuni Indian Tribe, Pub. L. No. 108-34, June 23, 2003). To further protect the wetlands, two large utility companies agreed to "non-interference" groundwater compacts with the tribe and smaller parties to the settlement also agreed to limit their nearby groundwater pumping. These "Pumping Protection Agreements" effectively create buffer zones surrounding the religious site based on limiting groundwater use by non-Indians in that area (Williams, 2001).

Groundwater Protection Zones in Arizona Water Settlements Act

The Arizona Water Settlements Act, 2004, (AWSA, Pub. L. 108-451) has 35 signatories and over 85 side agreements, with several innovative features, see Bark and Jacobs, 2009. The AWSA created groundwater protection zones around the Gila River Indian Community (GRIC) Reservation, within which groundwater pumping by non-Indians is limited and must be replenished. This protection zone protects the groundwater water rights of GRIC from over pumping by neighboring water users. In addition to compensate for past excessive pumping around the boundaries of the reservation, which has drawn down groundwater supplies on the Reservation, the State must replenish groundwater on the southern border of the reservation and implement ongoing rules to restrict and replenish groundwater pumping in five protection zones (AWSA, Title II, Sec 207(c)(1)(i). Southside Replenishment Program, A.R.S. §45-2602 (A) as amended by HB 2728).

Maintaining Groundwater Levels As A Supply Reliability Strategy

These two examples are policy instruments designed to address the impacts of pumping on groundwater reserves for the environment and as a backup water supply when surface water supplies are curtailed during drought. While neither of these cases had climate change as their primary consideration, groundwater protection zones will likely become a more important management tool as water users seek to diversify their supply portfolios and spread their supply risks across multiple water sources and concurrently seek protection from the pumping of those outside of these arrangements.

The issue of efficiency as related to policies that seek to maintain groundwater levels is complex and has been usefully modeled by economists as a dynamic optimization problem over time (Brozovic et al, 2010, Shaw, 2005).The efficiency question of whether the present value of benefits from maintaining groundwater levels by restricting pumping outweighs the costs can only be answered by looking at site-specific information. However, it is clear that the groundwater protection policies can play an important equity role. In the two cases summarized here, maintaining the groundwater table at levels higher than would occurred without the policy intervention serves to protect specific tribal values against diminishment by neighboring non-Indian pumping.

Shortage-sharing Arrangements

Shortage-sharing agreements are voluntary negotiated arrangements in which a senior entitlements holder agrees to forgo their senior position so that another water user will have more reliable supplies during a time of shortage. For instance, in some basins, a tribe's full use of its senior rights during regional drought would cut off junior non-Indian water users. In these instances, shortage sharing agreements have proven to be attractive to both tribes and junior non-Indian water users. Under such agreements, a tribe consents to share shortages with non-Indian water users rather than to exercise the full seniority of the tribal right, thereby protecting non-Indian water users during dry years. A similar reasoning applies to agreements whereby a senior non-Indian water entitlement holder, such as an irrigations district, agrees to share shortages in some manner other than straight application of the priority system. This section discusses one example involving a tribe, another involving a shortage sharing mechanism established among the Colorado River Lower Basin States and a third example (AWSA) that includes exchanging water sources of varying quality and reliability levels.

Exchanges among water sources can provide improved reliability, efficiency, and a better match of water quality with water user needs. Trades involving water from rivers with differing drought cycles and between groundwater, surface water and treated wastewater are becoming more common around the West. Many of the policy mechanisms that facilitate such exchanges originated as a response to entered jurisdictional conflicts.

Navajo Nation and San Juan Chama Project

The water supply arrangements associated with the Navajo Indian Irrigation Project (NIIP), negotiated in the 1960s, provides water storage for the Navajo Reservation and other nearby water users and also laid the framework for the San Juan-Chama Project (CJCP), a trans-basin diversion which supplies the Rio Grande Basin of New Mexico. The Navajo Nation, which holds the most senior water rights on the San Juan River, agreed to share shortages proportionally with the SJCP during times of drought in order to obtain federal authorization for the NIIP. While not a comprehensive water rights settlement, this is an early example of a negotiated arrangement between an Indian nation and non-Indian water users (Colby, Thorson and Britton, 2005). In return for federal funding commitments to build a large new irrigation project on their reservation, the Navajo Nation agreed not to oppose New Mexico's 110,000 acre-foot annual diversion through the SJCP for the Rio Grande Basin.

Intentionally Created Surplus – Lower Colorado River Basin

The Secretary of the Interior must annually evaluate the water supply situation on the Colorado River for the Lower Division States and declare each year to be either surplus, normal, or shortage. Regulations and operating criteria had been defined for normal and surplus conditions, but shortage criteria and consequences were not explicitly defined until the culmination of formal process to develop shortage sharing guidelines for the Lower Basin (Department of Interior, 2007).

Increasing pressure on supply, drought, and the corresponding drawdown of the Colorado River system's two main storage reservoirs (Lake Powell and Lake Mead) prompted the negotiation of a new agreements and federal rules for how shortage conditions will be declared, managed, and shared. The new rules include coordinated management guidelines for the major system reservoirs under low reservoir conditions; allow more flexibility in storage and delivery of water and formalize a mechanism called "Intentionally Created Surplus" (Department of Interior, 2007).

The Intentionally Created Surplus (ICS) program provides a way for Colorado River water users in the Lower Basin to generate ICS credits to be stored in Lake Mead by engaging in four types of activities, of interest here, are extraordinary conservation and system conservation. The chief methods of extraordinary conservation are irrigation forbearance agreements, canal lining, and desalination programs. Each year when annual water orders are placed for the following year, states with ICS credits can request the recovery of those credits in addition to their water order for the year. Various ICS projects are underway in each of the three Lower Division States. ICS creates flexibility in the time of use and can serve to defer or lessen the severity of involuntary curtailment of water supplies under the more frequent and severe drought scenarios anticipated with climate change, by augmenting storage and thus Lake Mead elevations (Department of Interior, 2007).

Arizona Water Settlements Act

The AWSA includes and strengthens an important supply resilience mechanism: diversifying portfolios of water types and priorities. While long-term (99 years) water leases between the Gila River Indian Community (GRIC) and central Arizona cities are key to the AWSA, the innovation feature highlighted here is a complex array of exchanges among water sources. GRIC negotiated lease and exchange agreements with a large mining company to enable tribal CAP water to be used and exchanged in lieu of alternative surface and groundwater supplies (Bark, 2009). This set of exchanges gives GRIC, the mining company and other water users in the watershed more drought proof supplies and reduced supply costs compared to the original allocation of water sources.

Another AWSA side agreement exchanges reclaimed urban wastewater for CAP water between cities and GRIC, with the tribe receiving reclaimed urban water. These exchanges are implemented on a 4-to-5 ratio: the cities receive 20% less CAP water for their reclaimed water (Bark, 2009; Bark and Jacobs, 2009). However, the economic benefit to the cities lies in exchanging reclaimed water for potable water, and the tribe receives reclaimed water as a drought-proof supply for their agricultural and golf resort businesses.

Shortage-sharing Agreements As a Supply Reliability Strategy

Traditional state water law relies on the priority system to determine which users are cut off in times of shortage. The more flexible types of arrangements just discussed allow adaptation with less bureaucratic procedures and lower transaction costs than the primary flexibility provided in traditional water right systems - which is to go out and purchase more senior water rights if one desires increased supply reliability. In principle, voluntary shortage sharing arrangements can promote efficiency by allowing the most reliable supplies to be available to those water users that value supply reliability most highly and are able and willing to pay for access to more reliable supplies. Any type of voluntary trading can raise the equity concern that certain parties, such as those interested in acquiring supplies to support habitat, have less financial resources with which to bid for more reliable supplies. In recognition of this concern, public agency dollars are sometimes dedicated to acquiring water for environmental purposes along with funds raised by nonprofit groups (Berrens et al, 1996, Colby, 1990).

Conclusions

A number of valuable innovations, now becoming widespread, were first introduced into western water management as a part of negotiations to resolve inter-jurisdictional conflicts. These new arrangements would have been difficult to insert into traditional state water policies, absent the urgency to settle pressing disputes with tribes and other states. The inter-jurisdictional water agreements discussed are remarkable in many important respects. Through these arrangements, states, tribes and federal agencies collaborate on management of their region's water resources. Such policy innovations also raise both equity and efficiency issues, which need to be evaluated within the site-specific context in which the policy is being implemented.

Over a century of western U.S. experience with addressing interstate and tribal-state conflicts demonstrates that innovative approaches can be employed to settle disputes and to plan for the future. Fundamentally, inter-jurisdictional water agreements are an ongoing process. Rather than providing finality, such agreements typically need to be modified over time, adding new strategies to meet unexpected circumstances and changing needs. Flexibility to address unanticipated problems and conflicts becomes even more essential in the face of climate change. Policy innovations originally developed for other purposes are likely to be an important part of regional strategies to adapt to increased water supply variability under climate change.

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Water Markets and Water Rights Markets in the Western United States

Kristiana Hansen[1]

Introduction

Supply reliability is the most important issue facing water agencies in the arid western United States (US). Shortages of firm water supply stem from three sources. First, population pressure and rising environmental water needs are increasing average demand. Second, many climate change scenarios forecast that average supplies will decrease in many parts of the western US, compounding the problem (Kundzewicz *et al*. 2007). Third, the western US is characterized by substantial inter- and intra-annual variability in supply, both of which are also forecasted to increase under many climate change scenarios (Kundzewicz *et al*. 2007). Water agencies have historically dealt with supply risk and increased demand by building additional storage capacity. Now that the best reservoir sites have been taken, water managers are increasingly turning to improved water management institutions to address anticipated shortfalls in supply. One such institution that has gained popularity in recent years is water markets.

Water can be transferred in one of two ways. First, a water right may be transferred from one user to another.[2] Second, a water right may be leased to another user for a set period of time (perhaps the buyer receives a pre-specified quantity of water each year for the duration of the contract), but the underlying water right does not change hands. A transfer may be an isolated, bilateral market exchange of water or a water right. In other instances, water and/or water rights are transferred relatively frequently within close geographical proximity. Both water transfers (leases) and water rights transfers with varying degrees of market activity are considered here.

Water markets and water rights markets allow for the reallocation of water from low to high valued uses, thereby increasing overall efficiency. These theoretical benefits of water markets have been demonstrated (Hartman and Seastone 1970). The empirical costs and benefits vary, depending on hydrology, geography, institutions, and history. This article is an overview of water and water rights markets in the western US, specifically when and where they work well and why. Western water law and institutions are introduced, followed by a discussion of impediments to water market development and the range of institutions found in the western US. The impacts of transfers on other rights-holders and interested parties are discussed, as are recent trends in western US water and water rights markets.

Institutional Background

Prior appropriation is the law that governs water allocation in most states in the western US. The governing principle of prior appropriation is "first in time, first in right." The first to claim

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[2] When a water right is transferred, the new rights-holder must submit an application to the state to change the use of the water. Many water rights are transferred from agricultural use to municipalities that have purchased the water to meet future projected growth. The water could remain in agriculture for some period of time, though the city owns the underlying water right.

water on a particular river or other body of water has the most senior right to the water. In dry years, senior rights are satisfied before more junior rights receive any water. If a water right is not used for a number of years (as specified by state law), the water right is forfeit (Getches 1997).

Water may not be wasted under prior appropriation. Water may only be put to uses that are considered beneficial under state law. Prior appropriation states generally consider domestic, municipal, agricultural, and industrial uses of water to be beneficial. Some states have further defined stock watering, power generation, mining, recreation, and/or fish and wildlife to be beneficial uses. Modern interpretations of beneficial use generally prohibit inefficient use of water. A common example is that irrigators may not apply more water than their crops need (Getches 1997).

The law of prior appropriation developed organically. When settlers first moved to the western US, they initially adopted riparian water rights, inherited from states in the Eastern US and ultimately from English common law. Under riparian rules, water users had the right to as much water as they could take from waterways adjoining their land. Migration into the western US, water lead to land becoming relatively scarce, increasing the marginal benefit of establishing firmer property rights. Miners in California employing hydraulic mining to extract gold, found that they needed a property rights regime more conducive to their purpose. Prior appropriation developed from the miners' need to use water on public land and at some distance from existing waterways, neither of which would have been possible under the riparian system of water rights (Hundley 2001; Anderson and Hill 2004). A number of western states possess a hybrid of riparian and prior appropriation water law.[3] This generally occurs when a state with riparian water law has transitioned to prior appropriative rights but still recognizes existing riparian rights. The riparian rights are converted to appropriative rights and must now be put to beneficial use, even if they were not before the transition to prior appropriation (DOI 2001).

Property rights evolve in response to technological innovation, the opening of new markets and changes in relative factor market scarcities. Anderson and Hill (2004) place this evolution within an economic framework by observing that people invest in establishing and protecting property rights for natural resources as long as the costs do not outweigh the benefits. One example they provide to support their model is the development of water law in the western United States described above.[4]

Over the past thirty years, there has been another shift in property rights for water; they have become more transferable. Due to population pressures and society's growing belief in the importance of environmental and recreational water use, water has become an increasingly valuable resource. The differential between water rights-holders who are using water in relatively low-value uses and those who do not have sufficient water but are willing to pay large sums of money to acquire it has led to pressure to make property rights for water more transferable. Several modest, recent examples are a 2007 Arizona law (HB2488) that allows water to be transferred out of a groundwater basin in a drought emergency situation (*Water*

[3] Western states with hybrid water law doctrine are California, Kansas, Nebraska, North and South Dakota, Oklahoma, Oregon, Texas, and Washington.

[4] Another example that Anderson and Hill give is that of land ownership on the Great Plains. As population increased in the latter half of the 19th century, stockgrowers' associations began to attempt to restrict entry onto their grazing lands and to lobby for restrictions on land use. It was only with the invention of barbed wire in the 1870's that it became possible to enforce exclusive ownership of grazing land in a cost-effective manner.

Strategist 2007); an Oregon law (SB 89) that extends an existing pilot program allowing several irrigation districts to approve temporary water transfers within district boundaries (*Water Strategist 2007)*; a 2008 Colorado law (HB1141) that water rights leased or temporarily donated to the Colorado Water Conservation Board are not subject to abandonment (*Water Strategist* 2008); and a Utah law (HB 117) allowing water rights-holders to lease water out for up to 10 years, to protect or restore habitat for several fish species (*Water Strategist* 2008).

Impediments to Trading and Market Institutions

In spite of changes to state law that have facilitated water and water rights transfers, market activity is rarer than one might expect, given the high value differential that often exists between potential buyers and sellers. Young (1986) discusses the very large extent to which water's distinctive characteristics impede transfers. Water's mobility makes it difficult to contain and measure; an exclusive, transferable property right can consequently be difficult to establish. Water also exhibits economies of scale in conveyance, distribution, and storage, making its allocation through natural monopoly likely. Further, although water is a precious resource, it is expensive to transport.[5] The costs of transportation and delivery can be significant. As an extreme example, of the $250/acre-foot the Metropolitan Water District of Southern California paid in 2002 for delivered water, 55% was for the cost of conveying the water from northern California, through the environmentally sensitive San Joaquin–Sacramento Valley Delta, to the Los Angeles Basin (DWR, 2004).

Another cost of trading water are transaction costs. According to Dahlman (1979), these are the costs of search and information, bargaining and decision, and policing and enforcement. Colby (1990) defines transaction costs to be the costs associated with acquiring regulatory approval for a transfer. She lists examples of these policy-induced transaction costs: attorneys' fees, engineering and hydrologic studies, court costs, and fees paid to state agencies. In some states, these costs are high because new laws to facilitate water and water rights transfers have not been implemented; regulatory transaction costs are high through inertia. In other cases, these costs may be intentionally high so as to minimize the transfer of water. Transaction costs tend to be higher for water rights transfers than they are for leases (Howitt 1998). Colby (1990) notes that transaction costs tend to be higher in states where there is more pressure on existing water supplies. She asks should public policy minimize the cost of transferring water. Alternatively might transaction costs have a role in facilitating efficient reallocation by taking into account the social costs of transfers that are costly to delineate and incorporate explicitly.

There is much variation across states in the institutions governing water and water rights transfers. , Water rights transfers must be approved by the State Engineer in many states, who heads the administrative body in charge of water policy implementation; whereas rights transfers in Colorado are evaluated by basin-specific water courts. Several states' water codes require the State Engineer (or other relevant decision-maker) to consider some aspects of public welfare in deciding whether to approve a rights transfer, though "public interest" is not generally defined in state statutes. By contrast, Colorado water courts do not consider economic or social impacts resulting from a rights transfer, and the state of Oregon only allows protests which claim injury to another water right. In some western states (for example, California,

[5] One exception is water banks located on reservoirs, where the cost of transporting water from one member to another is effectively zero.

Colorado, Idaho, and Nevada), water rights are real property, meaning that they can be owned separately from the land on which the water is used or diverted. In other western states (for example, Arizona, Montana, New Mexico, Oregon, Wyoming), a water right is appurtenant to the land (DOI 2001). This attachment can limit transferability, though some states, Arizona in particular (Colby 1990), have witnessed land transfers occurring for the sole purpose of acquiring the associated water. Quantification of the amount of a water right that can be transferred such that other rights-holders are not harmed can be expensive. It is easier to transfer irrigation water in New Mexico or within groundwater management areas in Arizona, where the portion of a water right that can be transferred is administratively defined, than it is to transfer a water right in Colorado, where quantification is determined on a case-by-case basis (Colby 1988). Such differences in state law affect the ease with which water and water rights can be transferred.

The nature of the institutions that govern water trades in a region have an enormous impact on how water markets develop. Carey and Sunding (2001) explore this issue by contrasting water market formation on two very different water projects: the Central Valley Project of California (CVP) and Colorado-Big Thompson (CBT). Although the situation in California is changing, CVP trades are generally short-term lease transactions within the agricultural sector. By contrast, water markets (both lease and rights transfers) on the CBT are active, commonly anonymous, mediated by brokers, and transacted at a well-established price. Historical circumstances are largely responsible for these differences in present-day markets. The CBT operates as a single water district, encompassing both agricultural and urban areas, which lowers trading costs significantly compared to the more jurisdictionally fragmented CVP. Proportional water rights in the CBT make transfer of short-term and permanent rights easy compared to the CVP, where a priority rationing system requires that water be quantified and potentially adjudicated before it is traded away. Downstream users in the CBT have no right to instream flows, which severely limits the legal recourse of third parties who are harmed by a water rights transfer. By contrast, California state law contains a number of provisions for the protection of downstream users.

Direct and Secondary Impacts

Water and water rights transfers generally affect more than just the two parties who sign a contract. Water's mobility and non-exclusivity make it likely that there are interactions and dependencies among users. Further, the statutes of all western states establish state or public ownership of waters within state boundaries (Getches 1997).[6] States' statutory authority to manage water to the benefit of society and the popular perception of water as a public natural resource mean that changes in water allocation attract attention from a number of affected parties. Affected parties fall into two groups: those who are directly affected by a water or water rights transfer, and those for whom the impacts are secondary.

Direct Impacts

Transferring water from one location to another affects other water users and the riparian ecosystem, by changing water quality, flow volumes, or the timing of flows. Direct impacts of water and water rights transfers are the effects of the transfer on other water users that are not accounted for in the market transaction. Such externalities are virtually inevitable in water and water rights transfers, due to the fact that multiple users can often utilize the same water

[6] The statutes of all 19 US states with prior appropriation water law or a combination of prior appropriation and riparian water law establish that water "belong[s] to the public," is the "property of the people of the state," or something similar. Private rights are thus considered use rights only (Getches 1997).

simultaneously. For example, an agricultural producer who practices flood irrigation creates a wetland which may benefit migratory birds. This producer has created a positive externality. Multiple users may also use the same water in sequence. If an upstream user sells water or a water right to another party outside the drainage, availability of water to the downstream user is likely be negatively affected. Such environmental and physical externalities can be either positive or negative, as in the two examples provided here. They ought to be taken into account when evaluating the social efficiency of a trade. Externalities affecting other rights-holders and the environment are generally addressed (or should be) in the state regulatory approval process.

Secondary Impacts

The term secondary impacts refers to the economic harm that communities in an exporting region experience due to a water transfer. These impacts are generally measured in terms of diminished income, increased unemployment, and reduced property and sales tax revenues. A common example is an irrigation district that exports water out of the basin rather than using it as an input to agricultural production. Although the irrigation district and its member farmers may benefit financially from the transaction, the fields left fallow for lack of water signify fewer workers hired and fewer secondary processing firms employed in the exporting basin.

Secondary impacts are pecuniary externalities. They are the effects of a transfer on other people resulting from the market transaction itself (and the resulting change in resource prices) rather than from direct physical effects on other users' water availability. Secondary impacts are controversial. If an agricultural input such as water can be more productively utilized elsewhere, then the resource reallocation resulting from water exports increases overall efficiency. However, transfers create both winners and losers, as secondary impacts can be quite disruptive to the exporting region. In their analysis of Colorado water exports from the Arkansas River Valley, Howe, Lazo and Weber (1990) find that exporting communities are harmed by the transfer but that the overall benefits to the state more than offset these losses. Other researchers studying ag-to-urban transfers in Colorado and California have found similar results (Howe and Goemans 2003; Howitt 1994). In short, while a trade may cause decreased income and higher unemployment in the exporting region, such losses are generally more than offset by gains in the purchasing region. Indeed, if overall efficiency were not increased by a transfer, it would likely not take place.

Although economic theory does not recognize the legitimacy of such pecuniary externalities, the reality is that trades often do not receive regulatory approval without allowances for such economic impacts. Many water transfers provide for some compensation (National Research Council, 1992; Howe, 2000; Hanak, 2005). For example, recent long-term ag-to-urban transfers in southern California (between the Metropolitan Water District of Southern California and Palo Verde Irrigation District and between the San Diego County Water Agency and the Imperial Irrigation District) both include compensation for third parties in the form of funding for local community improvement programs (MWD 2004, SDCWA 2007). How much compensation is appropriate and how best to use this money to assist exporting communities can be controversial, as shown by the San Diego/Imperial Irrigation District transfer in particular.

The extent to which secondary impacts are significant depends in part on the value of the ceased agricultural production that facilitates the water transfer. Economic theory predicts that the least productive agricultural land will be removed from production, which would tend to minimize secondary impacts. Charney and Woodard (1990) find this to be the case in their analysis of early land and water purchases in Arizona, though they also suggest that water exports might draw upon more productive land if municipal purchasers are interested in acquiring rights with higher seniority or easy access to transport.

Research into the effects of the 1990 California Drought Bank shows that secondary impacts can be minimized through advance planning. Dixon, Moore, and Schechter (1993) find that farmers who participated in that temporary water market used revenues from water exports to increase farm investment, which partially offset the negative impacts of the Bank. They suggest that farmer participation in multi-year fallowing programs should be rotated, since there is likely a limit to how much on-farm investment any one farmer can make over time. Spreading fallow acreage geographically and across crops minimizes negative economic impacts on any one business or sector of the farm economy, thereby reducing overall impacts (Dixon, Moore and Schechter 1993; Howitt 1994). Howitt (1994) found that on-farm employment reductions were lower than anticipated, as many farmers preferred to maintain their work force at a loss rather than re-hire at the conclusion of the Bank.

Issues and Trends in Water and Water Rights Trading

A number of studies have used actual water market transaction data to compare water market institutions and development across the western United States (Loomis *et al*. 2003; Brookshire *et al*. 2004; Howitt and Hansen 2005; Brown 2006; Brewer 2007; Hansen 2008). Although the studies differ in scope and focus, several themes emerge from them collectively. First, water markets tend to work well in places for which some or all of the transaction costs and institutional constraints discussed above are minimized. Markets are more likely to occur in locations with well-developed conveyance systems that can facilitate the physical transfer of water. Water market activity is greater in locations where water rights have been fully defined through an adjudication process (Brookshire *et al*. 2004 in particular make this point). State laws that allow water to be sold separately from the land also facilitate market activity (Easter *et al*. 1999).

Second, leases of water rights are far more common than water rights transfers. (This is true regardless of whether volume transferred under long-term leases and sales is counted once in the transaction year or cumulatively during the duration of the contract.) Hadjigeorgalis and Lillywhite (2004) observe that regulatory constraints on permanent transfers tend to increase lease activity. The analysis of Hansen (2008) suggests that much lease activity may be a response to temporary need rather than institutional constraints on permanent transfers.

Third, water markets are increasingly used to augment environmental flows, to improve wildlife habitat, and for recreational use. Loomis *et al*. (2003) document significant transfers to these environmental purposes across the western United States in the late 1990’s. Reallocation of water from existing users to environmental purposes by administrative fiat can be contentious; voluntary transfers through markets are far less so. Loomis *et al*. (2003) point out that the marginal value of water for environmental use must now exceed the value of water in agricultural production in some parts of the western United States; if this were not the case, these transfers would not be occurring. Generally speaking, the environment, recreation, and wildlife have not historically been considered beneficial uses of water. Thus, state laws must change before water can be purchased or leased for these purposes. Landry (1998) summarizes the diversity of states’ experiences with instream flow laws and regulations. He explains that since 1987, the states of California, Idaho, Montana, Oregon, and Washington have all enacted legislation allowing public agencies and private individuals to purchase water and/or water rights. In 1986, Colorado, Utah, and Wyoming each enacted legislation allowing specific public agencies to purchase instream flow rights. (Colorado also permits leasing of water rights.) By contrast, Arizona, New Mexico, and Nevada do not have legislation allowing for market transfers of water rights for environmental protection. However, court decisions in all three states have established instream flow rights, to varying degrees.

Finally, a growing trend in water markets is the transfer of water from agriculture to municipal use. Water markets are driven by the high value differential between low-value agricultural producers and municipal agencies needing to acquire a firm supply of water. Long-term agriculture-to-urban leases and rights transfers are common in the growing metropolitan regions of Arizona, California, Colorado, Nevada, New Mexico, and Texas in particular. Municipalities' water rights acquisitions are a risk management strategy, as water is often leased back to irrigators until such time as the municipalities need the water to satisfy projected demand increases.

Another type of ag-to-urban transfer is dry-year options, where the buyer pays a premium for the right to lease water after supply risk has been resolved. Real-world data on options are scarce. Watters (1995) and Villinski (2003) each used existing water transfer prices to calculate option value. However, more recent water options literature tends to be either simulation-based (Gómez -Ramos and Garrido 2004; Characklis *et al*. 2006; Brown and Carriquiry 2007, to name a few) or experimental (Hansen, Kaplan, and Kroll 2010). Dry-year options have a significant political advantage over rights transfers and leases in that they provide a way to transfer water in dry years, when value to the buyer is greatest, without permanently shutting down agriculture in the exporting region (Howitt 1998). However, growth in water options is hindered by the fact that municipalities acquiring water to meet growing urban demand are acutely concerned with reliability of supply. They perceive that ownership of a water right is more secure than a long-term lease or dry-year options and are consequently willing to pay a premium for water rights, on an annualized basis (Hansen 2008).

Concluding Thoughts

Markets give water managers additional flexibility to acquire water resources in a cost-effective manner. Flexible contract arrangements such as leases and dry-year options further augment the range of options available to water managers and are likely to become increasingly important in western water markets. This is especially true if average precipitation levels decrease and variability in timing and volume of flows increases, as expected. However, the strong preference of municipal water users for acquiring water rights over leases and options may temper development of these latter types of markets, at least in some parts of the West.

Water markets may also provide an indirect benefit to society by encouraging better water management. When the opportunity cost of water is clearly signaled with a market price, water is more efficiently utilized. It remains to be seen whether the institution of prior appropriation, with the relatively new development of more easily transferable property rights, will be flexible enough to reallocate water in a world with higher demands and a possibly decreased, more variable supply.

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Hedonic Price Modeling to Value Irrigated Agriculture Across a River Basin

Steven Shultz[1]

Introduction

The need to quantify the economic value of irrigation associated with production agriculture has become essential in evaluating the economic feasibility of various water management options in many areas of the Central and Western U.S. This paper summarizes two alternative approaches to value irrigation in an area such as Nebraska which relies on both ground and surface water resources: relying on existing surveys of real estate experts and hedonic price modeling.

The geographic focus of this research is the Niobrara River Basin which extends 486 miles across Nebraska from Wyoming in the West to the confluence of the Missouri River in the East (Figure 1) and encompasses 7.6 million acres of pasture/grazing/livestock production, wet meadows, and both dry and irrigated cropland production from both ground and surface water sources. The National Scenic River portion of the River is heavily used for recreational floating from June to August with flow levels being influenced by both overland (stream) and aquifer hydrologic connections meaning that recreational flow levels may be influenced by out-of-stream water uses, particularly irrigated agriculture across the Basin. The Nebraska Game and Parks Commission is studying irrigation values in the Basin as part of their evaluation of the merits of an in-stream flow request for recreation on the River. As well, several lawsuits are ongoing in the Basin that require an estimation of regarding the fair market value of irrigation associated with subjugated water rights. Finally, in other watersheds of Nebraska (such as the Platte and the Republican Basins), and in many other Western states, the need for accurate estimates of the value of irrigation is necessary to help both policy makers and landowners determine the highest and best use for scarce water resources and to determine fair market prices for the purchase and/or leasing of water rights, and/or to resolve compensation cases associated with damaged or lost water rights.

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Figure 1 Location Map of the Niobrara Basin

Previous Studies and Approaches to Valuing Irrigation

In many western states that rely on surface water irrigation, and which have active markets for trading water surface water supplies, economists and appraisers simply report observed selling prices (usually auctions and exchanges) while adjusting for transaction costs (Landry, 1999; Pritchett, James, Thorvaldson, and Frasier, 2009; Basta and Colby, 2010). However, in other central and western states (such as Nebraska and Kansas) that rely either on groundwater or a mix of groundwater and surface water supplies for irrigation, and where there is often not a formal market for trading surface water rights, agricultural economists have generally relied on the 'Land Value Approach' to value irrigation.

The principal assumption underlying the 'Land Value' approach for determining the contributory value of irrigation is that buyers and sellers of agricultural land are able to differentiate the factors of production as they relate to future profits when agreeing to sale prices for agricultural land. Therefore, real estate prices reflect revealed preferences for particular land characteristics, including irrigation, while holding all other land condition factors constant.

There are three different ways to utilize the 'Land Value Approach' for valuing irrigation: All rely on real estate market transaction data but differ in relation to data specificity, sample sizes of market transactions, geographical scale, and level of analytical complexity. These alternatives are: 1) Pairwise/comparable sales analyses (the approach preferred and most utilized by fee appraisers); 2) Observed price differentials between aggregated and survey based land value data; and 3) The hedonic valuation method (HVM) which is a multiple regression based technique based on parcel specific data which is often collected through the use of geographic information system (GIS) based technologies and spatially related databases.

The pairwise/comparable sale based approach to valuing irrigation most often relies on comparing paired sales. In the case of valuing irrigation, price differentials would be calculated between irrigated and non-irrigated agricultural sale parcels which are otherwise very similar if not identical (Derbes, 2005). A limitation of this approach is that it is often difficult to identify identical agricultural sale parcels that differ only with respect to irrigation activity. Land which is developed for irrigation usually has superior bio-physical characteristics than nearby (i.e.

'comparable') non-irrigated land parcels which often have inferior soil characteristics, field slopes, and/or water supplies required for irrigation. These non-comparability issues are potentially remedied by individual appraisers making price adjustments for differences across parcels but these estimates are potentially subjective and/or subject to valuation errors, particularly when based on small samples of compared sales.

A variation of the comparable sales/pairwise appraisal approach is to compare the average values of large numbers irrigated versus non-irrigated land sales derived from annual surveys and/or local real estate expert opinions. Producer surveys that collect land value information include the June Agricultural survey by the National Agricultural Statistics Service (NASS), or the agricultural census (both by the U.S. Department of Agriculture). Both of these collect uniform data nationally, and it has been demonstrated in at least two studies that this data is relatively accurate (Gertel, 1995, Shultz, 2006). However, a major drawback associated with the Federal Land Value data is the level of analysis at which it is released (States or occasionally counties) or the infrequency in which more detailed data is released (e.g. County level land value data from the Agricultural Census which is only conducted every 10 years. As an alternative, numerous state-level land value surveys have been developed over the years to elicit agricultural market transaction values from bankers, appraisers, and other real estate experts. Often, they are conducted by faculty working in State Land Grant Universities and or staff of Federal Reserve Banks (particularly in Midwest States).

State land value surveys intended to gauge expert opinions are often aggregated within regions of a State intended to represent fairly generalized agricultural land market segments. For example the Nebraska annual land survey by the University of Nebraska-Lincoln (UNL) is conducted within eight unique regions (Johnson and Lukassen, 2009). However, these regions are often very large and in many cases do not accurately correspond to watershed boundaries which is often required for irrigation policy decision making, particular in a State like Nebraska where many irrigation management activities are undertaken by locally empowered Natural Resource Districts whose jurisdicti9ns are based on watershed boundaries.

Expert opinion surveys often have relatively low sample sizes which limits an evaluation of statistical significance of reported land values. Also, when used to estimate irrigation values by comparing irrigated and non-irrigated land values, this approach suffers from the same problem as pairwise analyses in that the bio-physical characteristics (aside from irrigation status) are not always similar. This is particularly a problem in dry areas where, due to insufficient rainfall, irrigation is required for corn and other cropland production. In these areas most land that has suitable characteristics for irrigation (i.e. relatively good soil productivity, level slopes, and water availability) has already been irrigated while non-irrigated land is usually unsuitable for irrigation anyway. Some of the state surveys, including the University of Nebraska-Lincoln survey, attempt to conduct such mismatched comparisons by comparing irrigated land values with 'dry land sales *that have the potential for irrigation'*. However, it is not clear whether there exist enough of the sales described as 'dry land with irrigation potential' in many surveyed markets. Thus, it is difficult for experts to provide accurate survey data on this type of land valuation.

For these reasons, the most reliable and widely accepted approach among economists to value irrigation is the multiple regression-based 'Hedonic Valuation Method' (HVM). The HVM is also known as a hedonic price model (the terminology used for the remainder of this present study), or a 'price attribute model' or a 'mass appraisal technique'. The hedonic approach was formerly established by Rosen (1974) and has been used to value a full range of factors influencing real estate prices. The approach was refined and applied specifically to agricultural land sale prices by Palmquist (1989 and 1991) and is based on the assumption that producers are able to differentiate factors of production as they relate to profits when purchasing agricultural land under the following conditions:

$$P(q,s,z,i) = \int_0^\infty R(q,s,z,i)e^{-rs}ds$$

where the price of agricultural land (P) is specified a function of agricultural rent *R* based on soil quality characteristics q, location *z*, time *s*, the ability to irrigate *i*, and the interest rate *r*.

The marginal price of irrigation (both rights and potential bundled together) on sale prices is indicated by the coefficient of a variable measuring the percentage of a sold parcel that is irrigated. This can be considered the price differential between an irrigated versus a non-irrigated parcel while taking into account (controlling) for other factors (productivity measures). This irrigation value represents buyers and sellers opinions regarding the discounted net value of irrigation over time. Therefore, to convert such irrigation values to an annual basis, it is necessary to multiply hedonic based irrigation values by a capitalization rate (the ratio of annual rental rates to sale prices).

Recent estimates of irrigation value tied to real estate almost always rely on hedonic price modeling. Crouter (1987) estimated a linear regression equation for 53 real property sales near Greeley, CO with the irrigation variable represented as acre-feet of surface water delivered to the parcel and a dummy indicating the presence of a well. An index of soil quality available from the NRCS was used to proxy for the physical characteristics of the parcel. Overall, the value of an acre-foot of delivered water was shown to be just under $100 depending on the model used. Crouter (1987) also notes that this relatively low irrigation value may be due to the absence of an explicit water market in the area which leads to higher transaction costs. Torell, Libbin, and Miller (1990) extend this research to the agricultural production in areas served by the Ogallala Aquifer and determined that irrigation was on average worth $545 per acre-foot.

Faux and Parry (1999) using hedonic pricing found that irrigation values in Oregon ranged from $514 to $2,551 per acre (or from $147 to $729 per acre foot of water) with the highest values being associated with the highest quality land. Petrie and Taylor (2007) used hedonic pricing to determine that irrigation well moratoriums and pumping restrictions had significant impacts on irrigation values in Georgia. Finally, Butsic and Netusil (2007) estimated a hedonic price model based on 113 land sale transactions in rural county in southwester Oregon which was used to determine that irrigation was on average worth $1,850 per acre (a 26% premium over dry land values) which corresponds to $261 per acre-foot of irrigation water. It should be noted that that none of the above summaries of hedonic based irrigation values have not been adjusted to present dollars.

Common shortcomings or limitation with many of these previous hedonic studies of irrigation value are that they are based on relatively small samples of sales and/or that they are missing key bio-physical information describing sold land parcels. Field slope, and water pumping capacity are frequently missing from these models and even more serious common omission is the inability to quantify the precise number of sold irrigated acres. That is, researchers have often had to assume that all of the land associated with an irrigated land sale was irrigated when in fact it is likely that only portions of sold parcels were actually irrigated.

A Summary of Irrigation Valuation Approaches of the Present Study

In this present study, the value of irrigation across the Niobrara Basin based on real estate transaction data will involve two alternative approaches and data sources. First readily available real estate transaction data and survey-based values associated with both irrigated and non-irrigated land are compared to land value survey data (a single Basin-wide value). Second, these irrigation value estimates are compared to irrigation values derived from hedonic price modeling within specific sub-regions (markets) in the Basin.

The land survey data is based on the annual University of Nebraska-Lincoln Agricultural Land Value Survey conducted by Bruce Johnson of the Department of Agricultural Economics and hereafter referred to as the 'UNL/Johnson Survey data'. Such information quantifies inherent (or implied) irrigation values by subtracting the value of irrigated versus non-irrigated land
The hedonic modeling approach relies on the use of multiple regression to estimate the marginal price of irrigation (defined as the contribution that irrigation makes to sale price on a per acre basis). But it first requires the time consuming and difficult process of mapping and analyzing the geo-spatial characteristics of all sold agricultural parcels (contained in the State of Nebraska agricultural sale transaction database known as the '521' database of the Department of Property Transaction).

Irrigation Values Based on Surveys of Real Estate Experts

Land value estimates based on the UNL/Johnson agricultural land value survey (administered to real estate experts segregated by eight regions statewide) are summarized in Figure 2 for the North and Central regions combined (which provide the best available geographical overlap with the Niobrara Basin). In particular the following categories of reported land values are represented and analyzed: Irrigated cropland, dry cropland, pasture land, and dry cropland with irrigation potential. Later the estimation of the contributory value of irrigation based on these reported land values will be made by calculating 'net irrigation values' as the value of irrigation land minus the value of dry land.

The Non-Irrigated cropland with irrigation development potential values are of particular interest as subtracting this value from reported irrigated land values would generate a much more realistic estimate of the contributory value of irrigation per se as it would not be based on comparing irrigated land with land with no potential for irrigation. However, a potential limitation of relying on this category of land value for estimating net irrigation values is that very few sales of dry cropland with irrigation potential may exist making it difficult for surveyed 'experts' to accurately report such values on an annual basis and/or for specific areas.

Figure 2 demonstrates irrigated cropland values are consistently higher than non-irrigated cropland values and pasture land values over time (on average 62%). This differential increased sharply between 2005 and 2010 when the value of pivot irrigation land increased by 11% per year while dry land increased 9% per year. Dry cropland and pasture land values are very similar, and, as expected, dry cropland values are higher than dry cropland without irrigation potential.

Net irrigation values shown in the graph are calculated by subtracting irrigated land values from the average of pasture and dry cropland and are therefore in between (the average) of these classes of land values. Over the 10-year period they are on average $655/acre.

The two most serious limitations or drawbacks associated with these survey based net irrigation values are that the elicited values are likely based on a relatively low number of sales of 'dry cropland with irrigation potential', and that the estimated values are not specific to different study areas throughout the Basin (i.e. NRDs and/or irrigation districts). In fact, there was no Basin-wide specific value reported (instead this study had to use average values across two distinct survey regions).

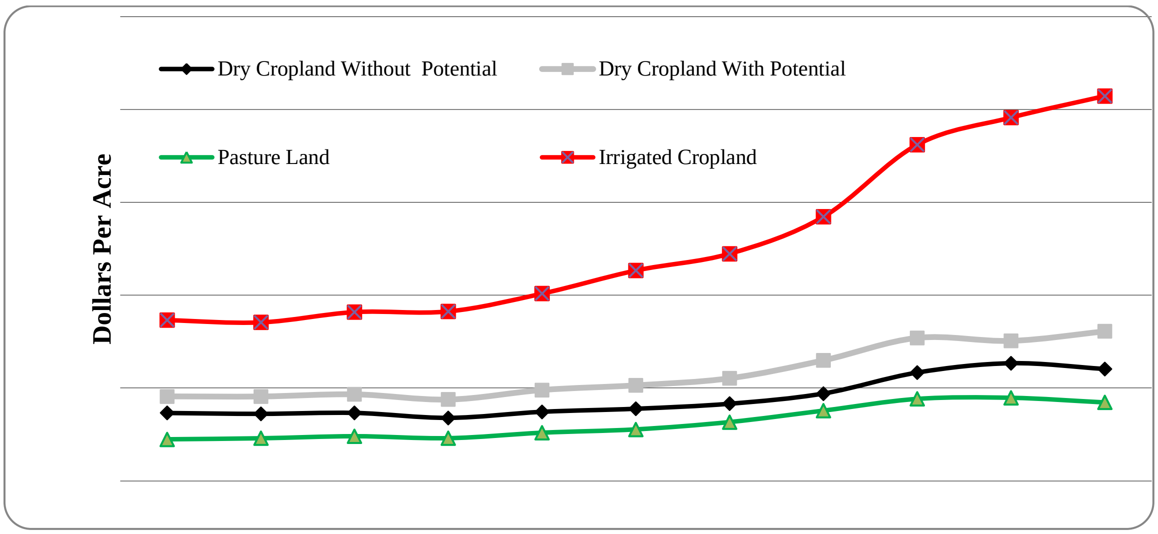

Figure 2. Land Values in the 'North' and 'Central' Regions: 2000-2010 (Based on UNL/Johnson Land Value Surveys of Real Estate 'Experts)

GIS-Based Hedonic Analyses of Irrigation Values

The data source for the estimation of hedonic models to quantify irrigation values in the Basin are recorded agricultural land sales transaction data contained in the 'Form 521' database maintained by the Nebraska Department of Revenue (Property Taxation Division). The '521 Sales' data is compiled by County Assessors and provided to the State for the purposes of evaluating the accuracy and fairness (equity) of tax assessments. A major advantage of these sales is that they include all arms-length transactions, and they account for non-land assets included in sales such as irrigation pivots or other farm equipment included with sales.

These sales were geo-spatially referenced (digitized within a GIS) using available legal descriptions of sold parcels along with National Agricultural Aerial Imagery Program (NAIP) field imagery and common land unit (CLU) boundaries of farm parcels as compiled by the Farm Service Agency of the U.S. Department of Agriculture. This was required to estimate irrigation values in specific sub-regions of the Basin in this case Natural Resource Districts, and to accurately quantify the extent of irrigation within sold parcels and measure the bio-physical characteristics of irrigated acreage.

Most (94%) of all sales were successfully digitized into a GIS database. Some (around 4%) of the sales were excluded as a result of the inability to digitize some sale parcel boundaries due to confusing, missing and/or incorrect legal descriptions, or because key sales transaction data were missing or incorrect. And approximately 1% of the digitized sales were classified as being uncharacteristic outliers and excluded based on comments made by local appraisers and/or assessors related to their a-typical nature. In most cases these were lands purchased for recreational activities by non-agricultural producers.

Digitized parcel boundaries of 94% of all arms-length sales (916 sales over the 2000 to 2008 time period), were spatially overlaid with a year 2005 land use database for the region (CALMIT 2005 and Dappen et al., 2007) in order to quantify both the irrigation status and crop type (cropland versus pasture) of all sold acres. The sale parcels were also spatially overlaid with a variety of other GIS databases including stream and well data from the U.S Geological Society (USGS) and the Nebraska Department of Natural Resources (NE DNR), a soil rating for plant growth (SRPG) measure USGS digital soils (SSURGO) data project (USGS 2010), and finally mean field slopes calculated from USGS digital elevation maps (USGS, 2009).

The frequency of sales across the Basin from 2000 to 2008 are shown in Figure 3 and summarized by land cover type in Table 2. Dry cropland sales are less than 5% of all sales, and additional inquiries indicated that only about 10% (i.e. five) of these sales had the potential to be irrigated (with similar characteristics as nearby irrigated sales). This shortage of dry cropland sales with irrigation potential may limit the accuracy of the earlier discussed UNL/Survey based estimates of net irrigation values which are based on comparing irrigated sale prices with cropland with irrigation potential prices. In other worlds if such sales are extremely infrequent it is not clear how experts can accurately relate their opinions about the value of such sales.

Table 1. The Frequency of Agricultural Sales by Type* (2000-2008)

	Number	Proportion of All Sales
Dry Cropland	45	5%
Irrigated Cropland	213	23%
Pasture	418	46%
Mixed Sales	240	26%
Total	916	100

** Derived from spatial overlays of sale parcels with a land use cover database for 2005*

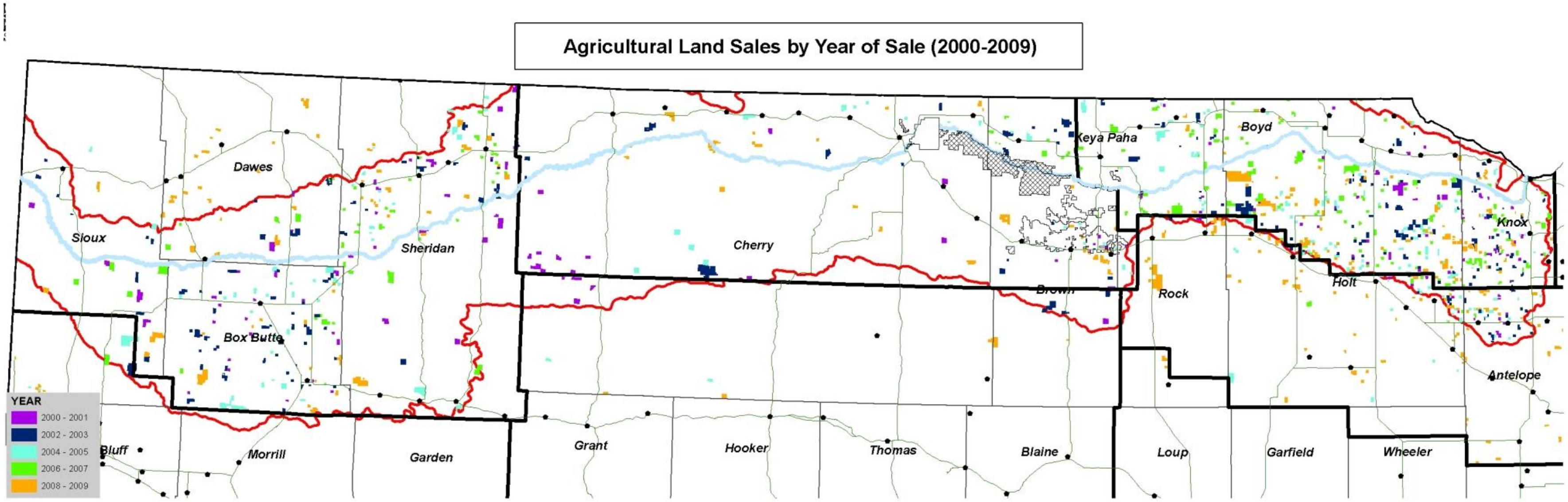

Figure 3. The Location of Agricultural Land Sales Across the Niobrara Basin (2000 to 2008*)
**** including 8 sales which occurred in early 2009***

The mean price of irrigated land sales across the Basin was $1,333/acre whereas the mean sale price for non-irrigated land was $375/acre. Based on this agricultural land sales information classified by irrigation status it is possible to conduct a quick and simple calculation of net irrigation values by subtracting non-irrigated (dry) land values from irrigated values. The caveat here is that the non-irrigated land parcels evaluated may not actually have any irrigation potential so these resulting net irrigation values should be considered an exaggerated (or high end) range of actual (likely) irrigation values. In this case they average $928/acre across the entire Basin with a range of value by NRD from $418/acre to $1027/acre

The general form of the hedonic price model to more accurately estimate irrigation values is:

$$(Price / Acre)_i = \beta_0 + \sum_{i=1}^{n} \beta_q Q_{ij} + \beta_s S_{ij} + \beta_z Z_{ij} + \beta_c I_i + u$$

where the of price per acre is a function of a vector of physical characteristics **Q**, a time trend matrix of dummy variables **S**, location dummies **Z**, a vector representing the presence of a irrigation rights and ability **I**, and a random error term u.

More specifically, this hedonic price model involves regressing sale prices on a per acre basis against the size of sold parcels, the percentage of a parcel that is wetlands or wet meadows which are incompatible with irrigated agriculture, the proportion of a parcel that is irrigated, the average soil productivity of a parcel (SRPG), the reciprocal of the average slope of a parcel[2], the distance from sold parcels to towns containing a population of 2000 persons or greater, time trend variables representing the year in which sales occurred, and finally dummy variables (yes/no) indicating the NRD in which a sale was located and whether or not it was in an fully appropriated area. These variables along with their summary statistics (means and standard deviations) are summarized in Table 2.

Alternative functional forms including semi-log, log-log, and quadratic specifications were experimented with and estimated. The hedonic models were first estimated basin-wide and then separately for unique market segments (NRDs and NRDs north and south of the Niobrara River) to evaluate the extent to which whether irrigation values vary spatially across the Basin. It is hypothesized that such market segment variables are important for accurate estimates of irrigation values this hedonic price model because Niobrara Basin covers such a large area with heterogeneous bio-physical conditions and land use practices. That is, the market segments are expected help account for variations in land characteristics across the study area as well as omitted variables within particular areas. As well, such NRD specific irrigation valuation estimates are considered relevant to policy makers and land owners as irrigation activities (development policies and water allocations) are managed autonomously in each of these NRD based market segments.

The estimated coefficient of most interest is the proportion of a sold parcel that is irrigated because this represents the marginal price of irrigation (both rights and potential bundled together). Again, this is considered the effect of changing irrigation status on an acre of land.

[2] Reciprocal function forms for explanatory and variable B_1 are represented by $Y = B_o + B_1 \ 1/X_1$. Such a functional form is commonly used for modeling variables with a satiation or a minimum acceptable level (such as the slope of a field at which the use of a pivot irrigation is infeasible. The marginal effect of a reciprocal variable (X) is interpreted as $- B_1 \ 1/X_1$ (that is, the sign of estimated coefficient needs to be reversed for interpreting its effect on Y).

Conceptually this can be considered to be equivalent to the price differential between an irrigated versus a non-irrigated parcel while taking into account (controlling) for other factors (productivity measures) and hence the marginal implicit price of irrigation on a per acre basis.

Table 2. Variables in the Basin-Wide Hedonic Price Model

Variable	Description	Mean	Std. Dev.
Price_Acre	Sale Price Per Acre (the dependent variable)	$693	$538
Totalac	Sold Acres	339	549
P_Wet_Meadows	Proportion (%)of the Sold Parcel Comprised of Wet Meadows and/or Wetlands (considered non-irrigatable)	2%	7%
P_Irrigated	Proportion (%) of the Sold Parcel Irrigated	26%	36%
SRPG	Soil Rating For Plant Growth	35.1	11.6
rSlope	Parcel Slope	3.5	3.1
d_u_nrd	If in the Upper Niobrara-White NRD	27%	0.44
d_m_nrd	If in the Middle Niobrara NRD	13%	0.33
d_l_nrd	If in the Lower Niobrara NRD	47%	0.50
d_2001	If sold in 2001	8%	
d_2002	If sold in 2002	11%	
d_2003	If sold in 2003	14%	
d_2004	If sold in 2004	13%	
d_2005	If sold in 2005	6%	
d_2006	If sold in 2006	12%	
d_2007	If sold in 2007	5%	
d_2008	If sold in 2008 or early 2009	22%	
Dist_Town_2000	Distance from Sold Parcel to Nearest Town of 2000 persons or more (Miles)	29	15
d_Fully_App	If in a Fully appropriated Area	56%	

The baseline hedonic model that specified sale prices ($/acre) to be a function of bio-physical characteristics of sold parcels, the year of the sale and the NRD in which the sale is located had a R^2 value of 0.67 meaning that 67% of the variation in sale prices are explained by the variables in the model. This is reflected in a statistically significant F-value and most of the explanatory variables having t-values that are statistically significant and with expected signs (positive or negative impacts on sale prices).
The estimated coefficients for this model are summarized in Table 3.

Estimating the hedonic model using alternative functional forms (semi-log, log-log and quadratic) did not result in any significant improvements to the explanatory powers of the model nor did they substantially change the direction, statistical significance, or magnitude of any of the estimated coefficients, particularly the coefficient representing irrigation value.

The variable measuring the percentage of a sold parcel that was irrigated has a statistically significant and positive impact on sales prices at the 99% confidence level. Each additional acre of irrigation adds $827 to total sale prices which is $273/acre or 26% higher than net irrigation value estimates based on expert surveys, but $101/acre (11%) lower than non-hedonic based net irrigation estimates calculated through comparisons of GIS-confirmed irrigated and dry land sale values.

As expected, wet meadows and parcel slope have statistically significant and negative impacts on sale price. Similarly, as expected, soil productivity (SRPG) has a statistically significant positive impact on sales price. Finally, as expected, proximity to towns of greater than 2000 people (i.e. only relatively large towns in the Basin) had a positive and statistically significant impact on sale price.

Somewhat unexpectedly, sale parcel size does not have a statistically significant impact on price per acre meaning that prices on per acre basis are not lower for large sales as has been demonstrated in other hedonic price studies of agricultural land sales. This may be a result of most sales in the Niobrara Basin being relatively large (i.e. a mean sale size of 339 acres).

Whether or not a sale was located in a fully appropriated area (where no new irrigation developments are permitted) had a statistically significant and negative ($91/acre) impact on sale price which is about tenth of the magnitude of the impact of irrigation itself on sale prices.

Each of the four market segment variables (NRD's) had a statistically significant impact on sale prices which reinforces the hypothesis that distinct market segments exist and are not accounted for only with the other explanatory variables in the model. Finally, time trend values only from 2005 to 2008 have a statistical significant impact on sale prices.

Table 3. Estimated Coefficients for the Basin-Wide Hedonic Price Model

	Coef.	Std. Err.	T	P>t
Totalac	0.00	0.02	-0.21	0.83
P_Wet_Meadows	-235.12	143.01	-1.64	0.10
P_Irrigated	827.36	35.16	23.53	0.00
SRPG	3.20	1.05	3.03	0.00
recip_Slope	62.69	14.77	4.24	0.00
d_u_nrd	-354.37	47.26	-7.5	0.00
d_m_nrd	-211.92	49.93	-4.24	0.00
d_l_nrd	-93.95	32.88	-2.86	0.00
d_2001	-2.92	51.15	-0.06	0.96
d_2002	9.31	47.95	0.19	0.85
d_2003	25.41	46.14	0.55	0.58
d_2004	74.49	46.86	1.59	0.11
d_2005	345.19	54.47	6.34	0.00
d_2006	360.54	47.68	7.56	0.00
d_2007	478.16	57.17	8.36	0.00
d_2008	232.43	43.94	5.29	0.00
Dist_Town_2000	-2.91	0.92	-3.16	0.00
d_Fully_App	-91.08	33.68	-2.7	0.01
_cons	473.05	66.83	7.08	0.00

Hedonic-based estimates of the marginal value irrigation estimated separately for specific sub-markets of the Niobrara Basin are summarized in Table 4. Marginal irrigation prices were successfully estimated for each of the NRDs in the Basin (i.e. all models having statistically F-tests, relatively high R^2 values and statistically significant irrigation coefficients). The resulting irrigation values range from $596/acre in the Upper Niobrara NRD to $909/acre in the Lower Niobrara NRD.

Within even more specific market segments (NRD segments classified by whether they are north or south of the Niobrara River), marginal irrigation prices were again successfully in all cases and the resulting irrigation values display an even wider range, from $412/acre in the Middle Niobrara/North of River NRD market segment to $985/acre in the middle Niobrara/South of River NRD market segment. This is a result of marked geological variations in land north and south of the River which directly impacts the biophysical characteristics and productivity of agricultural lands. The marked variation in irrigation values in different market segments of the Basin demonstrated the dangers of using a single (Basin-wide) irrigation value to policy making activities.

Table 4. Hedonic Marginal Irrigation Values by Market Segments (2000-2008)

	Sales	**R^2 Value (hedonic model)**	**Marginal Value of Irrigation**
Entire Basin	916	.68	$827*
By NRD Market Segments			
Upper Niobrara	247	.62	$596
Middle Niobrara & Upper Loup	114	.54	$909
Lower Niobrara	409	.74	$911
Upper Elkhorn	125	.49	$807
By Detailed NRD Market Segments			
Upper Niobrara-White North	104	.57	$701
Upper Niobrara-White South	141	.70	$578
Middle Niobrara North	37	.66	$412
Middle Niobrara South	77	.61	$985
Lower Niobrara North	70	.61	$496
Lower Niobrara South	342	.73	$916

** In contrast the value of irrigation based on expert surveys was $655/acre*

Conclusions

This study has compared two alternative approaches to valuing irrigation across a large river basin where irrigators rely on a mix of both ground and surface water supplies and where there is not an active surface water exchange market. These included relying irrigation value estimates derived from surveys of local real estate experts, and the estimation of a parcel level hedonic price model.

The advantage using survey data is that at least in States where it is collected, it is readily available thanks to the hard-work of the persons who conduct and report these surveys (and the experts who answer them). The limitations of relying on surveys to value for irrigation is whether there are enough sales of dry cropland with irrigation potential for direct comparisons to irrigated sale values. Also the statistical significance of the results cannot be tested, and the results are usually just available as a single value Basin or region wide.

In contrast, the use of hedonic price modeling to value irrigation is considerably more time consuming as sale parcels need to be digitized into a GIS, parcel level data collected, and hedonic models estimated. But the advantages of such hedonic based estimates of irrigation values are many. First they are based on actual market transactions and the statistical validity of irrigation estimates can be tested. More importantly such irrigation values based on this approach take into account the different characteristics of sold parcels to ensure that irrigation itself is being valued. In this case hedonic price estimates generated slightly higher irrigation value estimates than values derived from expert opinion surveys.
A final advantage of the hedonic approach is that allows irrigation values to be estimated within specific sub-markets of the Basin in this case NRDs that are based on sub-watershed boundaries and where bio-physical conditions vary markedly and where irrigation activities are managed autonomously. Such NRD specific irrigation values are expected to useful in ongoing and future efforts that will compare the relative values and tradeoffs between in and out-of-stream water uses in specific areas of the Niobrara Basin.

Such parcel level hedonic studies require that county and/or state authorities carefully track and disseminate information regarding agricultural land sales. It also requires that legal descriptions of land sales be accurately recorded, and that researchers make significant efforts to digitize such sales so that they can be integrated with other spatially related data using GIS technologies. These are costly and time consuming endeavors but as demonstrated by this study, they are deemed necessary for making accurate estimates of irrigation values.

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