NATURAL RESOURCES JOURNAL

Volume 49
Issue 3 *Summer-Fall*

Summer 2009

# Water Leasing: Evaluating Temporary Water Rights Transfers in New Mexico through Experimental Methods

Craig D. Broadbent

David S. Brookshire

Don Coursey

Vince Tidwell

CRAIG D. BROADBENT, DAVID S. BROOKSHIRE, DON COURSEY & VINCE TIDWELL*

# Water Leasing: Evaluating Temporary Water Rights Transfers in New Mexico Through Experimental Methods**

## ABSTRACT

*Rapid population growth coupled with stable or decreasing water supplies has further stressed already over-allocated water resources in the western United States. In this article, we consider the issues that lead to the further consideration of a water market. Specifically, we consider water markets that allow for the temporary transfer (lease) of a water right as one possible mechanism that could provide flexibility for water managers to fulfill water demands in fully or over-allocated watersheds. Using the Middle Rio Grande Basin located in central New Mexico as a backdrop, we develop a prototype coupled model that incorporates natural, physical, and engineering dynamics with an economic trading model where a variety of water users in the basin are represented. We explore the robustness of this prototype water leasing market and its ability to provide flexibility in water management. The empirical testing of the coupled model satisfies three necessary conditions: (1) efficient prices; (2) multiple transactions between user groups; and (3) minimal impact upon the natural, physical, and engineering system, as measured by water movement resulting from trading. Finally, we discuss how this trading structure might relate to a larger-scale application in the Middle Rio Grande Basin.*

---

* Respectively: Assistant Professor, Department of Economics, Illinois Wesleyan University, Bloomington, IL; Professor of Economics and Director of the Science Impact Laboratory for Policy and Economics, Department of Economics, University of New Mexico, Albuquerque, NM; Ameritech Professor of Public Policy, University of Chicago, Chicago, IL; Hydrologist, Geohydrology Department, Sandia National Laboratories, Albuquerque, NM.

** This material is based upon work supported by Sustainability of Semi-Arid Hydrology and Riparian Areas (SAHRA) under the Science and Technology Centers (STC) Program of the National Science Foundation, Agreement No. EAR-9876800, Sandia National Laboratories, Laboratory Directed Research and Development Program, and the U.S. Geological Survey funded Science Impact Laboratory for Policy and Economics (SILPE) at the University of New Mexico. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the U.S. Department of Energy National Nuclear Security Administration under contract DE-AC04-94AL85000.

## I. INTRODUCTION

Water management increasingly depends upon flexible institutions that allow for the efficient allocation of scarce water resources. In the semi-arid West, most watersheds are fully or over-allocated as water demand from population growth continues to increase and the supply of water is subject to uncertainty and variability. The complexity of this water allocation challenge is heightened by the increasing importance over recent decades to formally incorporate Native American rights and environmental concerns into the water management system.

These anthropogenic changes and possible climatic variations create a need to develop alternative institutional responses for water allocation such as water leasing markets. These market institutions must be efficient, fair, transparent, voluntary, temporally and spatially flexible, and must address hydrologic and engineering realities.

Support for water market institutions exists at both the national and state level. In 2005, the U.S. Department of the Interior released the publication, *Water 2025: Preventing Crises and Conflict in the West*.[1] This document "promotes the idea of working together for the sustainable and efficient use of western agricultural water supplies,"[2] and is based upon six principles that must be recognized to minimize or avoid water conflicts.[3] In addition, many western states (California,[4] New Mexico,[5]

---

1. Bureau of Reclamation, U.S. Dep't of the Interior, Water 2025 Preventing Crises and Conflict in the West (2005), *available at* http://biodiversity.ca.gov/Meetings/archive/water03/water2025.pdf; *see also* http://www.doi.gov/water2025 (for up-to-date information on "Water 2025").

2. *See* Bureau of Reclamation, *supra* note 1, at 31. R

3. *See id.* at 3. These six principles are: (1) solutions to complex water supply issues must recognize and respect state and federal water rights, contracts, and interstate compacts or decrees of the U.S. Supreme Court that allocate the right to use water; (2) existing water supply infrastructure must be maintained and modernized so that it will continue to provide water and power; (3) enhanced water conservation, use efficiency, and resource monitoring will allow existing water supplies to be used more effectively; (4) collaborative approaches and market based transfers will minimize conflicts between demands for water for people, for cities, for farms, and for the environment; (5) research to improve water treatment technology, such as desalination, can help increase water supplies in critical areas; and (6) existing water supply infrastructure can provide additional benefits for existing and emerging needs for water by eliminating institutional barriers to storage and delivery of water to other uses while protecting existing uses and stakeholders. *Id.*

4. Cal. Dep't of Water Res., California Water Plan, http://www.waterplan.water.ca.gov (last visited Feb. 1, 2010).

5. N.M. Off. of the St. Eng'r, New Mexico State Water Plan, http://www.ose.state.nm.us/publications_state_water_plans.html (last visited Feb. 1, 2010).

Nevada,[6] Utah,[7] and Wyoming[8]) have developed state-level water plans to address water management issues.

There are currently two broad categories associated with the wide spectrum of water market institutions: permanent transfers[9] of water rights and temporary transfers (leasing)[10] of water rights. While water markets concerning permanent transfers of water rights have been studied for the better part of the last four decades,[11] the use of a water market institution for the leasing of water rights has not been studied as intensely. In fact, most leasing studies have only recently appeared over the last 10 years.[12] As such, there is limited understanding of the feasibility of water leasing markets.

Effective water leasing markets must consider the relevant natural, physical, engineering, and economic (behavioral) factors in the decision-making process. As such, the market must deal with the complexity and interconnections within and between the natural and human environments. To allow for the efficient allocation of water resources, coupled modeling, within the context of a decision support system, provides a mechanism to integrate the natural, physical, and engineering dynamics of a watershed with the behavioral factors of users in that watershed. Such a framework captures the natural and engineering factors that demonstrate when a water supply is available and how it flows through the system. The coupled framework further integrates institutional factors such as the priority rights structure, population, market rules, and the market model.

In 2004, the Washington State Department of Ecology in conjunction with West Water Research released a report entitled, *Analysis of Water Banks in the Western States*,[13] that provides an analysis of then-current water marketing policies, legislation, and programs in 12 western

---

6. NEV. DIV. OF WATER RES., NEVADA STATE WATER PLAN, http://water.nv.gov/water planning/wat-plan/con-main.cfm (last visited Feb. 1, 2010).

7. UTAH DIV. OF WATER RES., UTAH STATE WATER PLAN, http://www.water.utah.gov/waterplan (last visited Feb. 1, 2010).

8. WYO. WATER DEV. OFF., WYOMING STATE WATER PLAN, http://waterplan.state.wy.us/history.html (last visited Feb. 1, 2010).

9. A permanent transfer of a water right is the permanent transfer of a water right from one user to another.

10. A temporary transfer, or lease, of a water right allows for a water right holder to provide for an intermediate use while retaining his ownership of the right for future use.

11. *See, e.g.*, MARKETS FOR WATER: POTENTIAL AND PERFORMANCE (K. William Easter et al. eds., 1998).

12. *See generally* WASH. DEP'T OF ECOLOGY, ANALYSIS OF WATER BANKS IN THE WESTERN STATES (2004), *available at* http://www.ecy.wa.gov/pubs/0411011.pdf (reviewing these markets).

13. *Id.*

states. One factor that has limited the effectiveness of the water leasing markets highlighted in this report is the rigidity of the trading rules. The markets detailed in the report have fixed prices or market-based pricing allowed only within a set interval. In addition, many of these water markets utilize a clearinghouse setting.[14] This clearinghouse system does not address the natural, physical, and engineering constraints of the watershed and also may not provide the flexibility of a real-time market. Further institutional constraints exist, including one-year limits on leases, which limit inter-temporal trading that might alleviate water problems during prolonged drought. In addition, only water that is stored can be brought to the market, or water can be purchased only for long-term groundwater storage with large participation or application fees that often deter potential buyers and sellers from entering the marketplace. Arguably, such constraints limit the number of transactions and the effectiveness of the market institution.

To examine the potential of a water leasing market, we develop and test through experimental economic techniques a coupled hydrologic, engineering, institutional, and economic market using the Middle Rio Grande Basin located in central New Mexico as a backdrop for developing a prototype water leasing market.[15] First, we develop a hydrologic model that represents the natural, physical, and engineering dynamics of the basin, and the outputs of this coupled model are integrated with a trading market. Second, we conduct laboratory market experiments[16] that use these hydrologic outputs as initial allocations to each participant. The coupled model reports the number of transactions during each trading period and provides detailed information on individual trades, such as who engaged in the transaction, the amount of water traded, the price paid per acre-foot, and the impact of water trading upon the physical system. This framework allows us to observe the number of transactions (a sign of market robustness), the volume of water traded, carriage gains and losses, the impact of water movement upon the physical sys-

---

14. In a clearinghouse framework, the bids for buying water are posted on bulletin boards managed by an irrigation or water management district. Transactions are conducted through negotiations between a single buyer and a single seller.

15. This prototype model is the first stage in a four-stage process to evaluate a water leasing market. The second stage develops an enhanced farming model; the third stage evaluates the potential of a futures contract, while the fourth stage examines third-party effects as a result of market transactions.

16. Experimental economics allows a researcher to test hypotheses by inducing values to participants. A properly designed economic experiment will be salient—meaning that participants perceive that they are paid based upon decisions they make—and the experiment will have parallelism—meaning it is constructed to resemble the natural decision-making process as closely as possible.

tem, the prices paid by user group, and the overall market price, all within the context of alternative climatic scenarios.

Part II of this article demonstrates the need for a water leasing market using the Middle Rio Grande Basin in New Mexico as an example. Part III discusses issues in designing water market institutions. Part IV provides a review of the current theoretical and empirical studies on existing water leasing markets. Part V details the coupled prototype leasing market and explains how to test whether this market is efficient; and Part VI reports the natural, physical, and economic findings of market transactions. Part VII offers conclusions and suggestions for future research.

## II. NEED FOR A WATER LEASING MARKET

Between 1990 and 2000 the U.S. Census Bureau reported population growth rates in the 12 western states to be 66 percent in Nevada relative to 9 percent in Wyoming.[17] The 10-year growth rates translate into a 7 percent annual growth rate in Nevada and a 1 percent annual growth rate in Wyoming. Recent estimates from 2000 to 2007 report further population growth rates from 28 percent in Nevada relative to 6 percent in Wyoming.[18] In fact, each of the western states has continued to experience population growth from 2000 to 2007.

Population growth places additional demands on existing water supplies. At the same time, these water supplies have not increased and are subject to climatic variability leading to considerable uncertainty from year to year. The Western Regional Climate Center has summarized this volatility by measuring and recording the monthly average precipitation for each state in the United States from 1931 to 2000.[19] For example, precipitation in New Mexico has varied from roughly 12.5 inches per year to 14.4 inches per year, while precipitation in Nevada has varied from 8.25 inches to 9.5 inches per year over this period. As demand for water resources continues to increase with uncertain water supplies, allocating scarce water resources becomes increasingly diffi-

---

17. *See* U.S. Census Bureau, Population Finder [hereinafter U.S. Census Bureau, Population Finder], http://factfinder.census.gov/servlet/SAFFPopulation?_submenuId=Population_0&_sse=ON (select a state to view its population) (last visited Apr. 14, 2010).

18. *See* U.S. Census Bureau, Annual Population Estimates [hereinafter U.S. Census Bureau, 2007 Population Estimates], http://factfinder.census.gov/servlet/DatasetMainPageServlet?_program=PEP (scroll down to and select 2007 population estimates) (last visited Apr. 14, 2010).

19. Western Regional Climate Center, Average Statewide Precipitation for Western U.S. States, http://www.wrcc.dri.edu/htmlfiles/avgstate.ppt.html (last visited Apr. 14, 2010); *see also* NAT'L CLIMATIC DATA CTR., HISTORICAL CLIMATOGRAPHY, SERIES NO. 4-2, *available at* http://cdo.ncdc.noaa.gov/climatenormals/hcs/HCS_42.pdf.

cult. Not only has demand for water increased in recent years, but water resources must also serve traditional users such as Native American tribes and *acequias*, in addition to serving irrigated agriculture, municipal, industrial, and environmental interests.

To fully understand the effects of population growth with variability in water supply throughout the western United States, we turn to a portion of a single river basin as an example to illustrate these tensions: the Middle Rio Grande Basin[20] located in central New Mexico. This basin faces significant population growth and issues related to Native American water rights (i.e., adjudication of rights and litigation around Indian Pueblos' historic use rights), ecosystem maintenance of Bosque habitat as a corridor for migratory bird species, and maintenance of instream flows for endangered species such as the native silvery minnow (*Hybognathus amarus*).

Historically, New Mexico has experienced fluctuations in water supply as indicated by the reconstruction of stream flow data for the Rio Grande using tree-ring analysis.[21] This reconstruction displays both annual and inter-annual variability in stream flow. Further, since 1970, the U.S. Geologic Survey gage south of Cochiti Reservoir, just north of Albuquerque, has measured the wettest period on record, one of the driest years on record, and one of the longest drought sequences, which demonstrates the variability in western water supplies.[22]

The U.S. Census Bureau reported population growth of 20 percent for the State of New Mexico with the major metropolis, Albuquerque, experiencing a 17 percent growth rate from 1990 to 2000.[23] Recent population estimates from the U.S. Census Bureau show a further growth rate of 8 percent for New Mexico and 13 percent for Albuquerque from 2000 to 2007.[24]

As population continues to increase throughout the Middle Rio Grande Basin and existing demands for traditional and environmental water uses grow, the state is faced with a problem of how to satisfy each

---

20. We define the Middle Rio Grande Basin as the stretch of the Rio Grande located just south of Cochiti Reservoir to just north of Elephant Butte Reservoir.

21. TreeFlow, Streamflow Reconstructions from Tree Rings, Rio Grande Basin, http://treeflow.info/riogr/ (last visited Apr. 14, 2010). TreeFlow's web resource on tree ring reconstructions of streamflow and climate for the western United States is made available as a collaborative effort of researchers affiliated with three NOAA-funded Regional Integrated Sciences and Assessment (RISA) programs: Climate Assessment for the Southwest (CLIMAS) Western Water Assessment, and the Climate Impacts Group, TreeFlow, About TreeFlow, http://treeflow.info/about.html (last visited Apr. 14, 2010).

22. U.S. GEOLOGICAL SURVEY, WATER RESOURCES DATA, SURFACE WATER MONTHLY STATISTICS (2007).

23. *See* U.S. Census Bureau, Population Finder, *supra* note 17.

24. *See* U.S. Census Bureau, 2007 Population Estimates, *supra* note 18.

of these needs. In response, New Mexico has developed a state water plan of which sections C2 and C9 call for a water transfer plan. Specifically, "the State must develop well-defined voluntary water rights markets that will allow the identification and dedication of existing water rights to new uses either on a temporary or permanent basis."[25] In addition, "because water banks, when appropriately established and monitored, allow the temporary re-allocation of water among voluntary water bank participants without the need for a formal water rights transfer or a change of ownership, they have the potential to provide an efficient and timely alternative means to mitigate short-term shortages."[26] In the next Part, we consider the challenges of designing a real time water leasing system.

## III. CHALLENGES IN DESIGNING A LEASING INSTITUTION

Much of the published literature on water markets examines the permanent transfer of water rights via market transactions and has detailed potential obstacles in designing a water market institution. We summarize these potential obstacles into six keys issues in an effort to inform a leasing market design that is based on the criteria that it be efficient (with price as a robust signal), fair, transparent, voluntary, temporally and spatially flexible, and responsive to hydrologic and engineering reality. These six key issues involve the following: (1) well-defined, securable, and tradable property rights; (2) hydrologic and engineering reality; (3) environmental quality; (4) social/community and traditional uses; (5) transaction costs; and (6) third-party effects (i.e., the "no injury" rule).

For a water market to be effective, it must attempt to address most of these issues. First, property rights must be well-defined and tradable; they define the rules and relationships that individuals hold. Since Ciriacy-Wantrup's seminal article on the economic criteria for defining water rights,[27] other articles by Burness and Quirk,[28] Brajer et al.,[29] Mat-

---

25. *See* N.M. Off. of the St. Eng'r, *supra* note 5, at 16. R

26. *See* Nev. Div. of Water Res., *supra* note 6, at 45. R

27. S.V. Ciriacy-Wantrup, *Concepts Used as Economic Criteria for a System of Water Rights*, *in* Law of Water Allocation in the Eastern United States: Papers and Proceedings of a Symposium Held in Washington, D.C., October, 1956 531 (David Haber & Stephen W. Bergen eds., 1958).

28. H. Stuart Burness & James P. Quirk, *Water Law, Water Transfers, and Economic Efficiency: The Colorado River*, 23 J.L. & Econ. 111 (1980).

29. Victor Brajer et al., *The Strengths and Weaknesses of Water Markets as They Affect Water Scarcity and Sovereignty Interests in the West*, 29 Nat. Resources J. 489 (1989).

thews,[30] and Slaughter and Wiener[31] have discussed the need for changes to address the shortcomings of the appropriative rights system utilized in the western United States. The general consensus from these articles is that well-defined property rights will encourage individuals to seek out activities that will enhance the right holders' position. These activities can include, but are not limited to, temporary transfers within and across user groups.

The second issue of transaction costs arises from incurred costs of designing the institution and the costs incurred in transferring water. Transaction costs are generally characterized as any factor that can prevent a market from operating efficiently or from forming.[32] Large transaction costs can reflect multiple economic benefits of water and can also reflect the scarcity value of water. As Howe and Goemans[33] have found, transaction costs are higher in a water market with traditional water rights than they are in a proportional shares market. High transaction costs lead to fewer, albeit larger, average transfers. Because transaction costs can limit or even prohibit market transactions, one must acknowledge their existence in designing institutions and be able to predict these costs to inform decision-making and improve policy decisions, as Colby[34] and McCann and Easter[35] explain.

The third issue of hydrologic and engineering reality requires the use of a hydrologic model to determine when and where water is available, the impacts of market transfers upon the physical system, and whether it is physically possible to deliver the leased water. Anderson and Leal[36] address the need for incorporating the hydrology of the region into a market institution, while Matthews[37] explains why a market institution must address hydrologic reality. Currently, new and innovative

---

30. Olen Paul Matthews, *Fundamental Questions About Water Rights and Market Reallocation*, 40 WATER RESOURCES RES. W09S08 (2004).

31. Richard A. Slaughter & John D. Wiener, *Water, Adaptation, and Property Rights on the Snake and Klamath Rivers*, 43 J. AM. WATER RESOURCES ASS'N 308 (2007).

32. Bonnie G. Colby, *Transactions Costs and Efficiency in Western Water Allocation*, 72 AM. J. AGRIC. ECON. 1184, 1186 (1990).

33. Charles Howe & Christopher Goemans, *Water Transfers and Their Impacts: Lessons from Three Colorado Water Markets*, 39 J. AM. WATER RESOURCES ASS'N 1055, 1064 (2003).

34. Bonnie G. Colby, *Cap-and-Trade Policy Challenges: A Tale of Three Markets*, 76 LAND ECON. 638, 652 (2000).

35. Laura McCann & K. William Easter, *A Framework for Estimating the Transaction Costs of Alternative Mechanisms for Water Exchange and Allocation*, 40 WATER RESOURCES RES. 6 W09S09 (2004).

36. Terry Anderson & Donald R. Leal, *Building Coalitions for Water Marketing*, 8 J. POL'Y ANALYSIS & MGMT. 432, 434–36 (1989).

37. *See* Matthews, *supra* note 30, at 5.

approaches are being used to ensure that the hydrology of systems is recognized in reallocating water.[38]

Fourth, environmental quality concerns, such as maintaining instream flows to protect the natural system, are researched by Colby,[39] Colby,[40] Griffin and Hsu,[41] Lovell et al.,[42] Green and O'Connor,[43] Weber,[44] Landry,[45] and Burke et al.[46] In general, these articles detail the value of instream flows while examining a water market institution as a possible mechanism to meet environmental quality goals. This growing literature displays the need to include environmental quality goals in the design of a market to capture the value of environmental amenities. From this literature there are two possible methods of including these goals: either allocate water rights to environmental trustees and allow them to participate in market transactions, or design the market to include environmental goals as constraints.

Fifth, concerns exist over social/community and traditional uses of water. These uses have not received as much attention in the literature as environmental quality even though they are some of the oldest issues that exist in designing markets, as first explained by Trelease[47] and as later explained by Brajer and Martin[48] and Seldin.[49] In New Mexico, traditional values are of great importance because 23 Native American tribes and pueblos exist in the Rio Grande Basin. These social/commu-

38. *See* Olen Paul Matthews et al., *Marketing Western Water: Can a Process Based Geographic Information System Improve Reallocation Decisions?*, 41 NAT. RESOURCES J. 329 (2001).

39. Bonnie G. Colby, *Estimating the Value of Water in Alternative Uses*, 29 NAT. RESOURCES J. 511 (1989).

40. Bonnie G. Colby, *Enhancing Instream Flow Benefits in an Era of Water Marketing*, 26 WATER RESOURCES RES. 1113 (1990).

41. Ronald C. Griffin & Shih-Hsun Hsu, *The Potential for Water Market Efficiency When Instream Flows Have Value*, 75 AM. J. AGRIC. ECON. 292 (1993).

42. S. Lovell et al., *Using Water Markets to Improve Environmental Quality: Two Innovative Programs in Nevada*, 55 J. SOIL & WATER CONSERVATION 19 (2000).

43. Gareth P. Green & John P. O'Connor, *Water Banking and Restoration of Endangered Species Habitat: An Application to the Snake River*, 19 CONTEMP. ECON. POL'Y 225 (2001).

44. Marian L. Weber, *Markets for Water Rights Under Environmental Constraints*, 42 J. ENVTL. ECON. & MGMT. 53 (2001).

45. Clay Landry, *Buy that Fish a Drink: The United States' Approach to Environmental Protection in an Era of Water Marketing*, 12 WATER L. 240 (2001).

46. Susan M. Burke et al., *Water Banks and Environmental Water Demands: Case of the Klamath Project*, 40 WATER RESOURCES RES. W09S02 (2004).

47. Frank J. Trelease, *Policies for Water Law: Property Rights, Economic Forces, and Public Regulation*, 5 NAT. RESOURCES J. 1 (1965).

48. Victor Brajer & Wade E. Martin, *Water Rights Markets: Social and Legal Considerations*, 49 AM. J. ECON. & SOC. 35 (1990).

49. Chris Seldin, *Interstate Marketing of Indian Water Rights: The Impact of the Commerce Clause*, 87 CAL. L. REV. 1545 (1999).

nity and traditional uses (i.e., Native American rights, *acequias*, and public uses) must be considered to ensure that all users are properly represented within the market.

The final issue relates to third-party effects that arise from market transfers. Third-party effects can take multiple forms but are generally a function of return flows from irrigated agriculture as explained by Gould.[50] These effects have the potential to limit market transactions or block transactions if left unaddressed. In dealing with these effects, some states have incorporated a "no-injury" rule when it comes to water transfers.[51] "No-injury" rules are designed so that a water transfer cannot cause economic harm to other parties. Including these effects in the design of the market is necessary to ensure that transactions can occur, as Gisser,[52] Anderson,[53] Gould,[54] and Dragun and Gleeson[55] explain.

## IV. REVIEW OF WATER LEASING MARKETS

The utilization of a market to conduct formal leasing of water rights has received attention since Howe et al.,[56] Howe et al.,[57] and Gould[58] dedicated sections of their articles to temporary water rights transfers. Since then, articles have been published detailing: the benefits of water leasing in the hydropower industry by Hamilton et al.,[59] environmental purposes by Turner and Perry;[60] agricultural practices by

---

50. George A. Gould, *Transfer of Water Rights*, 29 NAT. RESOURCES J. 457, 463 (1989) [hereinafter Gould, *Transfer of Water Rights*].

51. *See id.* at 463–68.

52. Micha Gisser, *Groundwater: Focusing on the Real Issue*, 91 J. POL. ECON. 1001, 1016–18 (1983).

53. Terry L. Anderson, *The Market Alternative for Hawaiian Water*, 25 NAT. RESOURCES J. 893, 898 (1985).

54. George A. Gould, *Water Rights Transfers and Third Party Effects*, 23 LAND & WATER L. REV. 1, 13–22 (1988).

55. Andrew K. Dragun & Victor Gleeson, *From Water Law to Transferability in New South Wales*, 29 NAT. RESOURCES J. 645, 653–56 (1989).

56. Charles W. Howe, Paul K. Alexander & Raphael J. Moses, *The Performance of Appropriative Water Rights Systems in the Western United States During Drought*, 22 NAT. RESOURCES J. 379, 384 (1982).

57. Charles W. Howe, Dennis R. Schurmeier & W. Douglas Shaw, Jr., *Innovative Approaches to Water Allocation: The Potential for Water Markets*, 22 WATER RESOURCES RES. 439, 443 (1986).

58. *See* Gould, *Transfer of Water Rights*, *supra* note 50. R

59. Joel R. Hamilton et al., *Interruptible Water Markets in the Pacific Northwest*, 71 AM. J. AGRIC. ECON. 63 (1989).

60. Brenda Turner & Gregory M. Perry, *Agriculture to Instream Water Transfers Under Uncertain Water Availability: A Case Study of the Deschutes River, Oregon*, 22 J. AGRIC. & RESOURCE ECON. 208 (1997).

Calatrava and Garrido;[61] municipal use by Smith and Marin,[62] Characklis et al.,[63] and Characklis et al.;[64] and the preexisting conditions of a water market institution and its evolution by Carey and Sunding,[65] Howe and Goemans,[66] and Calatrava and Garrido.[67] Further, Shupe et al.[68] supports a water leasing market and describes how it "can be an attractive option for both parties because it maintains continuity, preserves ownership by the holder of the right for future use, and accommodates an intermediate use. . . ."

In addition to these theoretical studies, empirical studies have analyzed the available price data for permanent and temporary water rights transfers in the western United States and southeastern Australia. Articles concerning the western United States by Yoskowitz,[69] Czetwertynski,[70] Yoskowitz,[71] Loomis et al.,[72] Adams et al.,[73] Howitt and Hansen,[74] Brown,[75] and Brewer[76] typically analyze temporary transfers

---

61. Javier Calatrava & Alberto Garrido, *Spot Water Markets and Risk in Water Supply*, 33 AGRIC. ECON. 131 (2005).

62. Mark Griffin Smith & Carlos M. Marin, *Analysis of Short-Run Domestic Water Supply Transfers Under Uncertainty*, 29 WATER RESOURCES RES. 2909 (1993).

63. Gregory W. Characklis et al., *Improving the Ability of a Water Market to Efficiently Manage Drought*, 35 WATER RESOURCES RES. 823 (1999).

64. Gregory W. Characklis et al., *Developing Portfolios of Water Supply Transfers*, 42 WATER RESOURCES RES. W05403 (2006).

65. Janis M. Carey & David L. Sunding, *Emerging Markets in Water: A Comparative Institutional Analysis of the Central Valley and Colorado-Big Thompson Projects*, 41 NAT. RESOURCES J. 283 (2001).

66. *See* Howe & Goemans, *supra* note 33. R

67. Javier Calatrava & Alberto Garrido, *Difficulties in Adopting Formal Water Trading Rules Within Users' Associations*, 40 J. ECON. ISSUES 27 (2006).

68. Steven J. Shupe et al., *Western Water Rights: The Era of Reallocation* 29 NAT. RESOURCES J. 413, 417 (1989).

69. David W. Yoskowitz, *Spot Market for Water Along the Texas Rio Grande: Opportunities for Water Management*, 39 NAT. RESOURCES J. 345 (1999).

70. MARIELLA CZETWERTYNSKI, THE SALE AND LEASING OF WATER RIGHTS IN WESTERN STATES: AN OVERVIEW FOR THE PERIOD 1990–2001 (2002) (Water Policy Working Paper #2002-002, Ga. St. Univ.), *available at* http://www.h2opolicycenter.org/pdf_documents/water_workingpapers/2002_002.pdf.

71. David W. Yoskowitz, *Price Dispersion and Price Discrimination: Empirical Evidence from a Spot Market for Water*, 20 REV. INDUS. ORG. 283 (2002).

72. John B. Loomis et al., *Expanding Institutional Arrangements for Acquiring Water for Environmental Purposes: Transactions Evidence for the Western United States*, 19 WATER RESOURCES DEV. 21 (2003).

73. JENNIFER ADAMS ET AL., THE SALE AND LEASING OF WATER RIGHTS IN WESTERN STATES: AN UPDATE TO MID-2003 (2004) (Water Policy Working Paper No. 2004-004, Ga. St. Univ.), *available at* http://www.h2opolicycenter.org/pdf_documents/water_workingpapers/2004-004.pdf.

74. Richard Howitt & Kristiana Hansen, *The Evolving Western Water Markets*, 20 CHOICES 1, 59–63 (2005).

for the entire western region because the available data is not rich enough to analyze each basin independently, except for water markets in the Lower Rio Grande in Texas, the Central Valley Project, and the proportional shares market for the Colorado Big Thompson (CBT).[77]

Articles concerning southeastern Australia by Crase et al.,[78] Bjornlund,[79] Bjornlund,[80] Crase et al.,[81] and Turral et al.[82] differ from the articles covering the western United States as they analyze permanent and temporary water rights transfers in one basin, the Murray-Darling Basin. Each of the five articles for southeastern Australia utilizes existing data to provide empirical insights for the Basin as a whole[83] or for one specific state within the Basin.[84] The data available for southeastern Australia contains a larger number of transactions on a basin scale than the data available for the western United States.[85] This richer data for southeastern Australia allows for an examination of a market for one specific basin rather than a large region with different physical conditions, as is the case for the western United States.

The final empirical study for temporary water rights markets is by Hadjigeorgalis and Lillywhite[86] in northern Chile. They analyze the differences in homogenous water rights across irrigation districts and find

---

75. Thomas C. Brown, *Trends in Water Market Activity and Price in the Western United States*, 42 WATER RESOURCES RES. W09402 (2006).

76. JEDIDIAH BREWER ET AL., WATER MARKETS IN THE WEST: PRICES, TRADING, AND CONTRACTUAL FORMS 1 (2007) (Working Paper Series No. 13002, Nat'l Bureau of Econ. Res.).

77. Data from these studies is predominately available from the journal, *Water Strategist*, published by Stratecon, Inc. Only Yoskowitz's data comes from another source—the Rio Grande Water Masters Office.

78. Lin Crase et al., *Water Markets as a Vehicle for Water Reform: the Case of New South Wales*, 44 AUSTRALIAN J. AGRIC. & RESOURCE ECON. 299 (2000).

79. Henning Bjornlund, *Farmer Participation in Markets for Temporary and Permanent Water in Southeastern Australia*, 63 AGRIC. WATER MGMT. 57 (2003).

80. Henning Bjornlund, *Formal and Informal Water Markets: Drivers of Sustainable Rural Communities?* 40 WATER RESOURCES RES. W09S07 (2004).

81. Lin Crase et al., *Water Markets as a Vehicle for Reforming Water Resources Allocation in the Murray-Darling Basin of Australia*, 40 WATER RESOURCES RES. W08S05 (2004). [hereinafter Crase et al., *Murray-Darling Basin of Australia*].

82. H.N. Turral et al., *Water Trading at the Margin: The Evolution of Water Markets in the Murray-Darling Basin*, 41 WATER RESOURCES RES. W07011 (2005).

83. *See id.*; *see also* Bjornlund, *supra* note 79; Bjornlund, *supra* note 80; Crase et al., *supra* note 78.

84. *See* Crase et al., *supra* note 78.

85. The data for these studies comes from personal contact with the Water Analysis and Audit Unit, the Department of Natural Resources and Environment, and the Goulburn-Murray Water Register.

86. Ereney Hadjigeorgalis & Jay Lillywhite, *The Impact of Institutional Constraints on the Limari River Valley Water Market*, 40 WATER RESOURCES RES. W05501 (2004).

**TABLE 1: Summary of Empirical Studies**

| Study | Year | Trade Type | Time Horizon | Number of Leases | Location | Finding |
|---|---|---|---|---|---|---|
| Yoskowitz | 1999 | Temporary | 1993–1998 | 1504 | Texas | Municipalities pay more than irrigators; mining industry pays 27 times that of municipalities. |
| Crase et al. | 2000 | Permanent, Temporary | 1983–1998 | 7581 | Southeastern Australia | Only 5% of all transfers are permanent transfers. Few permanent transfers result in under investment. |
| Czetwertynski | 2002 | Permanent, Temporary | 1990–2001 | 552 | Western U.S. | Larger volume of water is leased than is sold in most of the western states. |
| Yoskowitz | 2002 | Temporary | 1993–2000 | 1330 | Texas | Price discrimination and dispersion exist in a temporary market. |
| Bjornlund | 2003 | Permanent, Temporary | 1992–2002 | In ML | Southeastern Australia | Growing demand for the temporary market. Water is just another input in farming operations. |
| Loomis et al. | 2003 | Permanent, Temporary | 1995–1999 | 52 | Western U.S. | Marginal values for environmental purposes may have surpassed marginal values in irrigation. |
| Adams et al. | 2004 | Permanent, Temporary | 1990–2003 | 752 | Western U.S. | Irrigators are sellers or leasers of water; prices have increased in areas with strained water supply. |
| Bjornlund | 2004 | Permanent, Temporary | 1998–2003 | In ML | Southeastern Australia | Markets have helped to shift risk positions for irrigators and manage supply uncertainty. |
| Crase et al. | 2004 | Permanent, Temporary | 1983–2003 | In ML | Southeastern Australia | Temporary markets might slow the exit of less efficient water users. |
| Hadjigeorgalis and Lillywhite | 2004 | Permanent, Temporary | 1987–1997 | 176 | Northern Chile | Institutional restrictions create price differentials across districts for homogenous water rights. |
| Howitt and Hansen | 2005 | Permanent, Temporary | 1999–2002 | 752 | Western U.S. | Temporary trades allow states to meet environmental concerns during supply uncertainty. |
| Turral et al. | 2005 | Permanent, Temporary | 1990–2001 | In $M^3$ | Southeastern Australia | Temporary trading has increased to meet short-term overestimates or underestimates. |
| Brown | 2006 | Permanent, Temporary | 1990-2003 | 319 | Western U.S. | The number of temporary transfers has doubled. Prices for municipal water higher than irrigation. |
| Brewer et al. | 2007 | Permanent, Temporary, Multi-Year | 1987-2005 | 3232 | Western U.S. | Higher prices for agriculture to urban trading than within agriculture trading. States with growing populations have a higher number of transfers. |

that water rights are tied to property rights. This attachment to property rights prohibits the sale or leasing of water rights across different basins.

Collectively, these empirical studies demonstrate the attention that water leasing has been receiving on a national and international basis. Concerns about water availability are not unique to the western United States; rather, these concerns exist throughout the world. Each of these empirical studies is summarized in Table 1 (above).

While these studies represent a significant advancement in understanding current water marketing practices in the western United States, southeastern Australia, and northern Chile, the water markets they address lack the coupled modeling components that allow for an examination of the impact of temporary water rights transfers upon the natural and physical setting. Further, these water markets are situations where most transfers experience long lags in the approval process that often deter potential participants from entering the marketplace. Current studies have typically focused on trades within a sector (i.e., agriculture, industry, environment, urban) and rarely on trades between sectors, and have not incorporated the natural and physical setting into the market studies. In what follows, we present a market design that addresses many of the issues raised in the aforementioned literature.

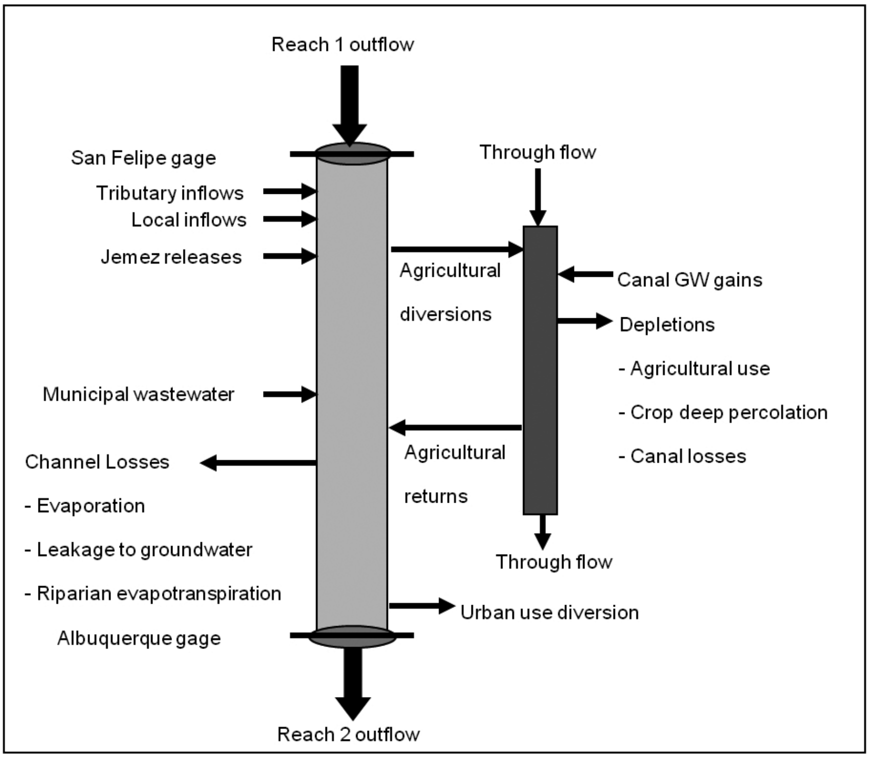
## V. MARKET DESIGN

Recognizing the limitations of current temporary transfer markets described in Part IV and the issues in designing a market institution as outlined in Part III, we develop a coupled market utilizing the Middle Rio Grande Basin as a backdrop from which to capture the natural and physical dynamics in a hydrologic model that is then coupled with a market framework to create a prototype water leasing market. This model is based upon the six issues set forth in Part III and explicitly incorporates the following four issues: (1) well-defined property rights; (2) hydrologic and engineering reality; (3) environmental quality; and (4) inclusion of social/community and traditional uses into the hydrologic model and trading market. This type of market design is unique in that it presents water managers with flexibility in planning, as the natural, physical, and engineering dynamics of the region are coupled with its behavioral characteristics.

The objective of this model is to address the feasibility of a water leasing market using the techniques of experimental economics.[87] A properly designed experiment will be salient and have parallelism, meaning it is realistic to the participants and replicates the decision-mak-

87. *See* DOUGLAS D. DAVIS & CHARLES A. HOLT, EXPERIMENTAL ECONOMICS (1993).

**FIGURE 1: SCHEMATIC OF THE HYDROLOGIC MODEL FOR ONE REACH OF THE MIDDLE RIO GRANDE**




ing process as closely as possible.[88] To ensure saliency and parallelism in the coupled market, the natural, physical, and engineering dynamics of the Middle Rio Grande Basin are modeled through three steps. The first step is to create a hydrologic model that simulates the physical dynamics of the Middle Rio Grande Basin. The second step is to obtain outputs for the amount of water available in the region under different climatic conditions using the developed hydrologic model. The third step is to integrate these outputs with a marketplace where student subjects motivated by monetary payoffs are allowed to trade water with other participants as they seek to maximize their own monetary reward.

This design process is unique and robust; previous research has not utilized a coupled model to design a water market to the best of our knowledge, and the model reports data for the number of transactions during each round and provides detailed information on individual

88. *See id.* at 14–18.

trades. Data obtained includes who is engaging in each transaction, the amount of water being traded, the price per acre-foot, and the impact of these transactions upon the physical system.

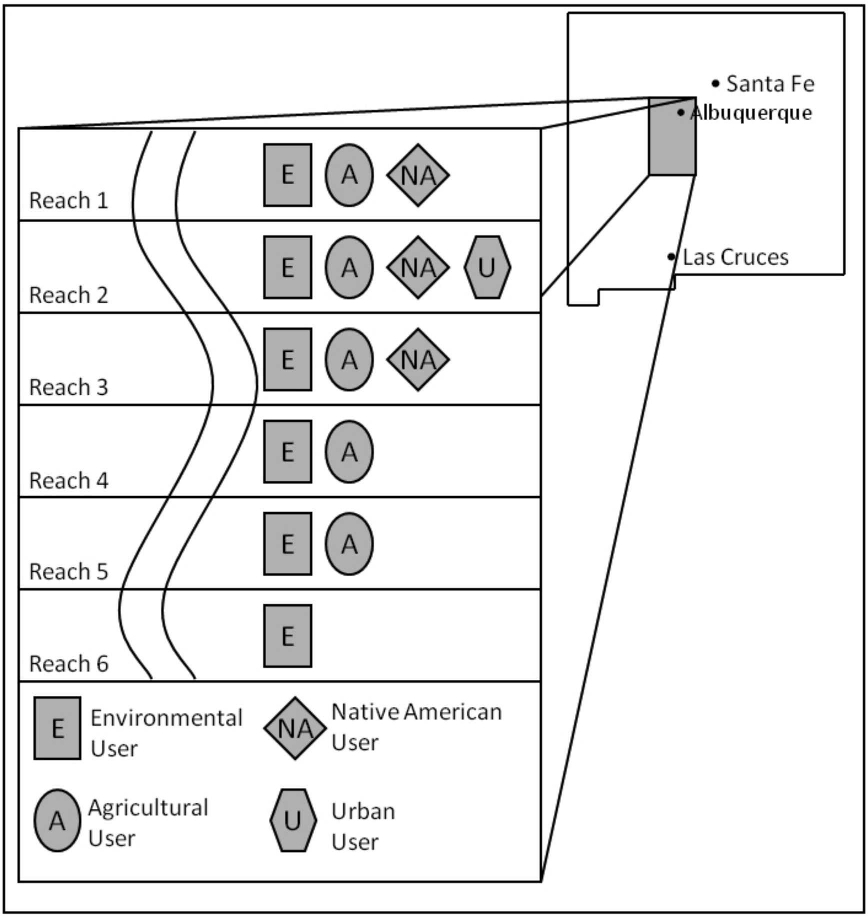
The outputs of this coupled model allow for a full examination of the efficiency of a prototype water leasing market. For a water leasing market to be efficient, it should have minimal impact upon the natural and physical system and the observed market price should not be statistically different from the expected market price. The hydrologic outputs detail the impact of market transactions upon the physical system, and because of the use of induced values,[89] the observed price per acre-foot can be tested against the value given to the participants (expected price).

In developing the first step—designing a model that addresses hydrologic and engineering reality—we base the model upon the physical dynamics of the Middle Rio Grande Basin. The region is subdivided into six distinct reaches delineated by the major gages on the Rio Grande. The basic hydrologic model elements include surface and groundwater supplies balanced against municipal, agricultural, environmental, and Native American demands (Figure 1, above). Surface inflows include the main stem of the Rio Grande, tributary flows, inter-basin transfers from the Colorado River, and wastewater returns. Losses from the surface water system include evaporation from the river, transpiration from the riparian corridor, groundwater-pumping-induced river leakage, and agricultural, municipal, and Native American consumption. Groundwater inflows include mountain-front recharge, inter-basin flows and river leakage, while withdrawals include groundwater pumping and discharge to the river and shallow aquifer.

Evaporative losses from the river are a function of climatic conditions, while river leakage is a function of river discharge and groundwater pumping. The sum of these gains or losses is denoted as carriage gains/losses. The model accounts for these carriage gains/losses at the reach-specific scale. As water is traded across reaches, carriage gains/losses are tracked and assessed to the lessee's trade. Tracking carriage gains/losses adds a spatial component to the marketplace. Carriage gains/losses are assessed on a per-acre-foot-of-water-traded basis and are calculated for each reach based on 25-year averages and taken as constants to facilitate their representation in market transactions. Our expectation is that including carriage gains/losses in the marketplace will

89. Induced values reflect the structure of an experiment whereby individual participants in the market experiment are told how much each unit (in this case, an acre-foot of water) is worth to them. These induced values (expected values) can then be compared against the behavior of the participant.

**FIGURE 2: LAYOUT OF USERS**




motivate participants to lease water upstream in order to capture water that otherwise would be lost.

The second step is to run the hydrologic model to determine how much water is available for a growing season. The hydrologic model developed in the first step is based upon historic gage data for the region. Water for the basin originates in the Rocky Mountains of Colorado during the winter months as snowpack. The Rio Grande Compact[90] has been established between the three states that draw water from the Rio

90. Rio Grande Compact (1938), N.M. STAT. ANN. § 72-15-23 (2008), Act of May 31, 1939, ch. 155, 53 Stat. 785, *available at* http://www.ose.state.nm.us/PDF/ISC/ISC-Compacts/Rio_Grande_Compact.pdf.

Grande (Colorado, New Mexico, and Texas). In any given year the formula determines the allocation of water for the Middle Rio Grande Basin. The formula uses four stream gages in the Rocky Mountains of Colorado to determine snowpack runoff. From this runoff, Colorado is committed to deliver quantities of water at different times throughout the year depending upon the quantity of water calculated from the four stream gages. Using the historic water data, the hydrologic model is run to determine the amount and availability of water to each of the participants in the market experiments. The outputs of these hydrologic model runs represent the initial allocations for users in the experiments.

The third step is to integrate the outputs of the hydrologic model (initial conditions) into a marketplace where participants can seek out transactions to maximize their monetary reward. The marketplace is a simplistic representation of how water rights are distributed throughout the six reaches of the region (Figure 2, above). Aggregating all water rights in the region into four distinct categories—irrigated agriculture (A), municipalities (U), environmental (E), and Native American (NA)—creates 15 different representative traders in the marketplace. Before participants are allowed to engage in transactions, the first run of the hydrologic model is performed to determine the initial allocation of water to each user. Market trading is then allowed where water rights are assumed to be homogenous.[91] The coupling of the hydrologic model into the marketplace allows the model to track specific users who are engaging in transactions and the magnitude of each transaction. After trading concludes for a round, the hydrologic model performs a second run to determine the impact of market transactions upon the physical setting (i.e., carriage gains/losses). This same process is carried out for 10 trading periods.

The double auction market framework is utilized to facilitate market transactions.[92] This framework displays all bids and offers simultaneously and all transactions for the current round to all participants via an online trading interface. A transaction is formalized in the market when two individuals voluntarily agree upon a standing price and quantity. Each participant is motivated to maximize his or her monetary payout

91. We assume homogeneity of water rights for the experiments based upon the New Mexico Regional Water plan where the bulk of the water rights for the basin are presumed to be pre-1907 water rights. *See* WATER ASSEMBLY, MID-REGION COUNCIL OF GOVERNMENTS, MIDDLE RIO GRANDE REGIONAL WATER PLAN 2000–2050, chs. 2, 5 (2004), *available at* http://www.waterassembly.org/waterplan.htm.

92. There are other market frameworks that could facilitate transactions. The double auction framework is employed because it leads to robust predictions of the competitive price when compared to other market frameworks. *See* Vernon L. Smith, *An Experimental Study of Competitive Market Behavior*, 70 J. POL. ECON. 111 (1962).

by deciding how to utilize the water allotment given to him or her. Participants are given three choices: first, they can use their water allotment to fulfill the specific interests of the user they are assigned; second, they can lease water to other users; or third, they can lease water from other users. Participants are able to choose among these three alternatives in the manner they believe will best maximize their own monetary payout. Participants are allowed to engage in as many transactions as they desire during each round with the constraint that participants cannot trade more water than they are allotted and they cannot have negative dollar balances.

Each of the user groups was given a unique payout[93] and demand[94] function. Upon a review of the water demand literature for the western United States we found the highest value use of water to be in the urban or municipal sector followed by the environmental sector and agriculture. The payout and demand functions that follow are a representation of the activities that dominate(d) each of the main user groups in the Middle Rio Grande Basin based upon the highest-valued-use hierarchy. Thus, we have represented, to the best of our ability, the major user groups in the Middle Rio Grande Basin by constructing demand and payout functions for each of the user groups based upon the highest-valued-use hierarchy. We assume that irrigators and Native American users are engaging in irrigated agricultural practices, and that these users need a minimum amount of water for crop production. For simplicity, we assume that the payout and demand functions for these two users are the same.[95] Participants who represent environmental interests receive different payout and demand functions than the agricultural users.[96] These users are modeled as protecting environmental interests such as endangered species or riparian habitat. Unlike the previous three user groups, the municipal user is given a positively sloped payout func-

---

93. A payout function displays the relationship between the dollars a participant can earn and the amount of water in acre-feet necessary to earn those dollars.

94. A demand function displays the relationship between the amounts of money a participant is willing to spend to obtain a specific quantity in acre-feet of water.

95. If these participants achieved 3 acre-feet, they would be paid $9, anything less then 3 acre-feet would yield them a payout of $0. These participants' demand function told them that they should be willing to pay up to $3 per acre-foot to achieve the 3 acre-feet necessary to obtain a $9 payout.

96. If these participants achieve 2 acre-feet, they would receive a payout of $10 and anything less then 2 acre-feet would result in a punishment of $1. The demand function for these participants told them they should be willing to pay $5 per acre-foot to obtain the 2 acre-feet and the $10 payout to avoid the $1 punishment.

tion and a downward-sloping demand function[97] rather than simple step functions.[98] This urban user is modeled to incorporate the metropolis of Albuquerque and its outlying municipalities. Lumping all these municipalities creates one large urban user in the experimental marketplace.

Due to the different marginal values[99] of water that are constructed for the different user groups from the payout and demand functions, we expect to observe price differentials between the four user groups if we do not allow arbitrage[100] in the market. As Gary D. Libecap explains, "the persistence of large water price differentials between agricultural and urban and environmental uses reflects the lack of extensive, routine market trades that would otherwise arbitrage to narrow those differences."[101] For simplicity in these market experiments, we allow for arbitrage and incorporate homogenous[102] water rights rather than a priority rights structure. We expect that the marketplace will function smoothly, narrowing price differentials between the different user groups, leading to a uniform market price.

Market experiments were conducted over the summer of 2005 using student subjects at the University of New Mexico. Twelve experimental sessions were conducted under four climatic scenarios (baseline,[103] decreasing,[104] increasing,[105] and dry[106]) with three sessions per scenario. Under each scenario, participants were not given a forecast

---

97. This participant was given a positive sloped payout function of $ = 8*acre-feet–(acre-feet)^$^{3/2}$ showing diminishing marginal returns for each acre-foot obtained. The demand function for this participant is Price = 8–(acre-feet)^$^{0.5}$.

98. A step function is a function only on real numbers, also known as a staircase function. The payout and demand functions for the agricultural, Native American, and environmental user groups are step functions.

99. A marginal value is the value associated with a one-unit (acre-foot) change.

100. We define "arbitrage" here as meaning that participants are allowed to purchase and re-sell water without actually putting the water to "beneficial use."

101. GARY D. LIBECAP, THE PROBLEM OF WATER 4 (Nat'l Bureau of Econ. Research & Hoover Inst. 2005), *available at* http://www.aeaweb.org/annual_mtg_papers/2006/0108_1300_0702.pdf.

102. We define a homogenous water right to be a water right where all rights holders have the same priority date.

103. The baseline scenario provides a representation of average water years for the basin where participants were given an initial allotment that would allow them to fulfill their specific interests.

104. The decreasing scenario represents the basin entering a drought, where the initial allotment starts above the baseline allotment and ends below the baseline allotment.

105. The increasing scenario represents the basin exiting a drought, where the initial allotment starts below the baseline allotment and ends above the baseline allotment.

106. The dry scenario represents a prolonged drought where participants are given an initial allotment that is below the allotment needed each period to fulfill their specific users' interests.

of what the future might hold; rather, the future was left uncertain. In total, 180 individuals participated in the market experiments.

The market reports the number of transactions each trading period and details information on individual trades such as who engaged in the transaction, the amount of water traded, the price per acre-foot, and the impact of water trading upon the physical system, all within the context of alternative climatic scenarios. Using a Student t-test[107] we are able to test the observed market price against the expected or induced market price for each user group and for the market as a whole.

## VI. RESULTS

Due to space considerations, the results of the market experiments are presented for each scenario rather than for each individual experiment. The first result of the market experiments is the number of lease transactions in which each user group engaged and the volume of water that was leased from these transactions. Tables 2, 3, 4, and 5 report the number of lease transactions and the volume of water traded from these transactions for the agricultural, environmental, Native American, and urban users, respectively. Each of these tables reports the transactions and volume of water leased by the respective user groups from other user groups for each of the four different climatic scenarios. For example, Table 2 (APPENDIX) displays from whom the participants representing agricultural users leased water (i.e., other agricultural, environmental, Native American, or urban users).

The findings shown in Table 2 suggest that while the participants representing agricultural users engaged in multiple transactions with the other user groups, the bulk of these transactions occurred with the participants representing environmental users. In addition, these agricultural users leased more water when water was scarce in the decreasing and dry scenarios than when water was abundant in the increasing and baseline scenarios. This finding may be a result of these participants seeking to fulfill their specific user interests from their payout functions rather then just arbitraging water.

Table 3 (APPENDIX) illustrates that while the participants representing environmental users engaged in multiple transactions with the other user groups, the majority of environmental users' transactions oc-

---

107. The test statistic is

$$t = \frac{\bar{X} - \mu_0}{s/\sqrt{n}}$$

where $\bar{X}$ is the observed weighted average price, $\mu_0$ is the expected market equilibrium, $s$ is the standard deviation, and $n$ is the sample size.

curred with other environmental participants. Some large rounds of trading occurred at the start of each scenario with the agricultural users, and a large number of transactions occurred with the Native American users throughout the baseline scenario. The volume of lease transactions was relatively constant for the environmental users, indicating that environmental users tried to fulfill their specific user interests from their payout functions in water scarce years and arbitraging water when water was plentiful.

Table 4 (APPENDIX) illustrates that while the participants representing Native American users engaged in multiple transactions across the user groups, the majority of their lease transactions occurred with the agricultural and environmental users. In addition, these participants engaged in more transactions with a larger volume of water being leased when water was scarce in the decreasing and dry scenarios as these participants sought to fulfill their specific user interests from their payout functions.

Table 5 (APPENDIX) illustrates that while the participants representing urban users engaged in multiple transactions with the other users, the volume of these lease transactions is relatively small when compared to the lease transactions by the other user groups displayed in Tables 2, 3, and 4. These urban representative participants engaged in more lease transactions with a larger volume of water traded when water was plentiful in the baseline and increasing scenario, and with fewer transactions and a smaller volume of water traded in the water scarce years of the decreasing and dry scenarios.

Of interest from the transactions summarized is whether water is captured and put to use as a result of market transactions. Specifically, if trades tend to move water use upstream, then less water is lost to evaporation and river leakage (i.e., carriage loss), making more water available for use.

Figure 3 (APPENDIX) displays the aggregate carriage gains/losses as a percent of the water available to participants at the beginning of each trading round. Our expectation was that the inclusion of carriage losses would result in water being traded upstream rather than downstream, which would result in more water available. The results in Figure 3 demonstrate that this expectation does not hold true. Rather, we find carriage losses in five of the 10 periods for the decreasing scenario, six of the 10 periods for the dry scenario, four of the 10 periods for the increasing scenario, and six of the 10 periods for the baseline scenario. However, these losses are minimal; the largest loss—close to 5 percent of the total water allocated to the participants—is found in the baseline scenario, trading period four, while the largest gain—close to 2 percent of total water allocated to the participants—is found in the last round of the increasing scenario. While we expected to see carriage gains from market transactions, we find mixed results leading us to believe that the price per acre-foot was a larger determining factor in how water was traded than was the inclusion of carriage gains/losses in the marketplace. However, these carriage gains/losses are relatively small, thus displaying minimal impact upon the natural and physical system.

Figure 4 (APPENDIX) displays the change in water delivered for each of the six river reaches as a result of market transactions. For example, in round one of the dry scenario, users in reach one observed a 9 percent decrease in water use relative to their initial allocation. This means that the participants in this reach leased 9 percent of their total water allocation to other reaches. At the same time, users in reach six utilized 25 percent more water than their initial allocation. This means that the users in this reach leased 25 percent more water than they were allocated. Figure 4 displays the movement of water on a reach-specific basis for rounds one, four, seven, and 10 of market trading for the four scenarios. The results shown in Figure 4 suggest that the market transactions lead to a redistribution of water throughout the basin. That is, some reaches end up using more water while others use less, and there does not appear to be any strong redistribution trends across the different scenarios.

Table 6 (APPENDIX) summarizes the results for the weighted average price per acre-foot for each of the user groups by scenario. From the way the market was constructed, it was expected that if price differentials did exist, participants who represented agricultural users and Native American users would be willing to pay three dollars per acre-foot, while participants who represented environmental interests would be willing to pay five dollars per acre-foot. The willingness to pay for each acre-foot for a participant representing urban users was dependent upon the amount of water that participant was seeking to obtain. However, if a unique market price per acre-foot does exist, we would expect this unique price to fluctuate depending upon the supply of water allocated to the participants in the different scenarios and to minimize the price differential between user groups.

A Student t-test is used to test the hypothesis that the observed weighted average price for each of the user groups is equal to the expected price for these user groups. The results of these tests are displayed in Table 6. If the observed weighted average price is significant, then we are able to reject this hypothesis, concluding that the observed price is different from the expected price, meaning that the participants did not effectively take on the role of the user group they were assigned.

As illustrated in Table 6, the participants who represented agricultural users effectively took on their assigned role in the baseline and decreasing scenarios; however, in the dry and increasing scenarios the observed price was significantly different from the expected price. This could be due to the scarcity of water in the dry and increasing scenarios. Participants who represented Native American users effectively took on their assigned role in the baseline scenario; however, the results are mixed in the dry, decreasing, and increasing scenarios. Again, these results may be mixed due to the scarcity of water in some of these scenarios, driving the observed market price higher. Participants who represented the environmental users effectively took on their assigned role in the baseline and dry scenarios, but exhibited mixed results in the increasing and decreasing scenarios. Finally, participants representing the urban users effectively took on their assigned role in the baseline scenario with mixed results in the dry scenario and only one insignificant finding in the decreasing and increasing scenarios. The mixed results by each of the users groups could be attributed to the scarcity of water in the water scarce scenarios.

To fully examine whether price differentials were present in the marketplace, the observed market price is compared to the expected market price.[108] Table 7 (APPENDIX) presents the observed market prices with their associated standard errors. A Student t-test was used to test the hypothesis that the observed market price equals the expected market price. Rejecting this hypothesis leads to the conclusion that the observed market price does not equal expectations, which could be a sign that price differentials do exist. The results in Table 7 illustrate that this hypothesis can only be rejected in three instances in the decreasing, dry, and increasing scenarios. All of these instances occur when water is scarce except for round four of the decreasing scenario and round six of the increasing scenario, meaning that in water scarce years participants tend to pay a higher price for water due to the scarcity of the resource.

The results of Table 7 in conjunction with the results of Table 6 suggest that price differentials exist in very few instances, meaning that the inclusion of homogenous water rights allowing for arbitrage did, in fact, narrow price differentials, and that the marketplace is efficient in most instances where participants effectively took on the role of their assigned user groups. The instances where participants did not effectively take on the role of their assigned user groups typically occurred in periods of water scarcity.

While these results are based upon the empirical realities described in Part V, we realize that not all property rights are well defined and would foresee the price formation process changing in the market-

108. The expected market price is obtained by horizontally summing the demand functions of each user group.

place as property rights are better defined. Better-defined property rights should lead to more transactions, which should lead to lower prices and higher levels of economic welfare gains. Thus, the breadth of the market will expand with and parallel the breadth of the established property rights.

In addition, we have assumed in our experimental work that our subjects are motivated to maximize their own monetary reward. There are times in real situations where other non-monetary values may be expressed and could influence the prices observed in the actual marketplace. For example, traditional agricultural users and Native American users may have cultural and spiritual values for water. These values could lead these users to be less likely to participate in market transactions. Fewer transactions would result in less water brought to the marketplace, a higher market price, and lower levels of economic welfare gains then observed in our experimental treatments.

Further, in our experimental treatments we placed an environmental user in each reach of the river that was modeled to protect instream flows and/or riparian habitat protection for that reach of the river. Different outcomes would occur in the market if fewer environmental users were placed in the system, and these outcomes would depend upon the placing of these users. For instance, if only one environmental user is placed in the market and they are in the sixth reach—or the bottom of the river—any leasing of water by this user from other users would result in a minimum instream flow goal being met throughout the river system. However, if this user is placed in the first reach—or the top of the river—any leasing of water by this user from other users would ensure a minimum instream flow goal for that reach only. While the placement of the environmental user has implications upon the system, the number of environmental users placed in the system also has an effect. With fewer environmental users, less water is brought to the market, leading to a higher market price and lower economic welfare gains then observed in our experimental treatments.

Finally, the institution presented in this article is only one type of institution in which transactions could occur. In reality, the water users in the Middle Rio Grande Basin may prefer a modified structure of these institutional rules. The important factor is that many market institutions have been shown to increase the efficiency of resource utilization and allocation.

## VII. CONCLUSIONS AND FUTURE RESEARCH

As populations continue to grow in the western United States, there will be increased pressure on already scarce water resources to fulfill municipal, environmental, irrigated agriculture, cultural, and traditional uses. Water managers will need flexibility in planning to ensure that these demands are met with minimal conflict. Allowing for the leasing of water rights through coupled markets that recognize the natural, physical, and engineering dynamics of the system and include behavioral characteristics of market participants is one possible mechanism to provide water managers with flexibility.

In this research, a hydrologic model is developed using the Middle Rio Grande Basin in central New Mexico as a backdrop, and the outputs of this prototype model are coupled within a water leasing market framework to create a prototype market in which to better understand the impact of lease transactions upon the natural, physical, and engineering system. From this marketplace we are able to gather rich data to demonstrate the minimal impact of water leasing upon the basin and the efficiency of the market when arbitrage is allowed using homogenous water rights.

While this model is based upon the hydrologic and economic realities of the Middle Rio Grande Basin, it provides insights into the potential for a water leasing market for any basin. We caution against the broad use of our model in other basins, since a water leasing market for any basin needs to be based upon the hydrologic realities of that particular basin. However, the results of a leasing market in other basins should lead to similar results observed in our model, again noting the breadth of the market will expand with and parallel the breadth of established property rights.

In this article, six primary issues are identified in designing a water market from existing literature: well-defined property rights, hydrologic reality, environmental quality, social/community and traditional uses, transaction costs, and third-party effects. The prototype marketplace developed here is designed specifically to address four of these issues: well-defined property rights, hydrologic reality, environmental quality, and social/community and traditional uses. Further research is necessary to fully understand how the issues of transaction costs and third-party effects might inhibit or limit transfers. While the redistribution of water from market transactions has the potential to induce third-party effects, adjustment of reservoir and ditch delivery schedules may be sufficient to satisfy instream flow and water deliveries challenged by market transactions. Further research is necessary to truly understand these third-party effects and possible mechanisms for amelioration.

In conclusion, this research demonstrates the effectiveness of incorporating the outputs of the natural, physical, and engineering system with the behavioral characteristics of a basin's users into a prototype marketplace. Findings demonstrate the impact of transactions upon the physical system to be minimal as carriage gains/losses are generally at or below 1 percent of the initial allocation to the system. In addition, the model proved to be robust as multiple lease transactions occurred in each trading period with arbitrage leading to a narrowing of price differentials and a uniform price observed where most participants effectively took on the role of their assigned user group. This work suggests that addressing property rights issues in a timely fashion could lead to a situation where voluntary exchange leaves both parties to the exchange better off.

[APPENDIX FOLLOWS]

**TABLE 2: From Whom Agricultural Users Leased Water**

| | *Agricultural* | | | | *Environmental* | | | | *Native American* | | | | *Urban* | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Round | Dec | Dry | Inc | Base | Dec | Dry | Inc | Base | Dec | Dry | Inc | Base | Dec | Dry | Inc | Base |
| 1 | 11 | 7 | 6 | 9 | 20 | 14 | 11 | 12 | 7 | 6 | 3 | 2 | 3 | 3 | 0 | 0 |
| | *6.14*[a] | *5.20* | *3.54* | *9.18* | *10.38* | *9.80* | *6.24* | *7.80* | *3.34* | *4.88* | *1.84* | *1.20* | *1.73* | *2.23* | *0* | *0* |
| 2 | 15 | 15 | 11 | 2 | 22 | 21 | 20 | 16 | 10 | 7 | 6 | 9 | 4 | 9 | 0 | 2 |
| | *9.64* | *4.87* | *3.39* | *1.22* | *8.04* | *12.14* | *10.51* | *11.73* | *5.50* | *2.87* | *3.78* | *6.70* | *3.46* | *1.78* | *0* | *1.46* |
| 3 | 10 | 7 | 13 | 9 | 24 | 21 | 16 | 19 | 8 | 11 | 6 | 14 | 1 | 4 | 2 | 2 |
| | *6.77* | *4.93* | *7.37* | *3.54* | *12.69* | *9.11* | *6.63* | *10.70* | *3.38* | *6.32* | *3.85* | *7.45* | *0.93* | *2.04* | *0.32* | *0.30* |
| 4 | 11 | 17 | 22 | 10 | 17 | 11 | 16 | 12 | 6 | 12 | 7 | 9 | 1 | 5 | 1 | 2 |
| | *7.88* | *8.29* | *7.34* | *5.60* | *6.38* | *7.49* | *6.95* | *6.60* | *2.54* | *7.57* | *3.55* | *6.34* | *0.67* | *2.73* | *0.20* | *1.19* |
| 5 | 18 | 11 | 15 | 5 | 12 | 17 | 13 | 17 | 12 | 7 | 4 | 11 | 5 | 2 | 3 | 1 |
| | *10.67* | *6.71* | *7.07* | *2.89* | *4.79* | *8.06* | *4.02* | *6.73* | *5.82* | *5.71* | *1.87* | *9.33* | *5.36* | *0.40* | *0.40* | *1* |
| 6 | 9 | 9 | 15 | 9 | 19 | 26 | 14 | 19 | 8 | 8 | 4 | 7 | 1 | 3 | 3 | 0 |
| | *4.62* | *5.25* | *4.73* | *4.54* | *8.07* | *13.7* | *3.72* | *6.38* | *4.01* | *5.56* | *0.75* | *5.02* | *1.12* | *1.54* | *0.29* | *0* |
| 7 | 12 | 11 | 5 | 3 | 16 | 17 | 7 | 11 | 16 | 10 | 4 | 11 | 2 | 3 | 1 | 4 |
| | *6.03* | *5.53* | *1.10* | *0.98* | *6.69* | *11.48* | *1.57* | *4.46* | *4.90* | *5.29* | *2.06* | *6.62* | *1.32* | *1.26* | *0.08* | *0.69* |
| 8 | 16 | 10 | 11 | 8 | 22 | 9 | 8 | 12 | 13 | 7 | 1 | 9 | 1 | 8 | 1 | 1 |
| | *7.19* | *5.85* | *2.93* | *1.78* | *7.76* | *7.08* | *2.02* | *5.67* | *3.42* | *5.48* | *0.41* | *5.61* | *0.11* | *1.93* | *0.20* | *0.50* |
| 9 | 10 | 11 | 8 | 12 | 16 | 20 | 4 | 11 | 9 | 12 | 3 | 8 | 2 | 6 | 0 | 2 |
| | *5.88* | *3.95* | *1.76* | *5.36* | *7.98* | *9.23* | *0.88* | *6.33* | *4.69* | *7.19* | *1.67* | *2.98* | *1.27* | *4.09* | *0* | *0.60* |
| 10 | 14 | 12 | 5 | 2 | 18 | 12 | 5 | 4 | 9 | 7 | 3 | 5 | 1 | 6 | 0 | 0 |
| | *6.54* | *5.27* | *6.87* | *1.66* | *7.35* | *7.74* | *2.07* | *2.21* | *12.48* | *3.73* | *1.89* | *4.00* | *0.89* | *2.90* | *0* | *0* |

[a] Values in *italics* are the volume of acre-feet traded by the transactions

**TABLE 3: From Whom Environmental Users Leased Water**

| | *Agricultural* | | | | *Environmental* | | | | *Native American* | | | | *Urban* | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Round | Dec | Dry | Inc | Base | Dec | Dry | Inc | Base | Dec | Dry | Inc | Base | Dec | Dry | Inc | Base |
| 1 | 16 | 11 | 11 | 17 | 15 | 18 | 15 | 15 | 12 | 10 | 10 | 8 | 5 | 3 | 0 | 4 |
| | *10.27*[a] | *5.52* | *6.14* | *10.24* | *11.44* | *10.92* | *6.87* | *11.18* | *6.52* | *4.94* | *6.79* | *3.23* | *4.04* | *2.07* | *0* | *2.16* |
| 2 | 15 | 20 | 34 | 27 | 15 | 20 | 26 | 35 | 9 | 10 | 17 | 12 | 4 | 2 | 0 | 6 |
| | *12.53* | *7.41* | *15.50* | *13.56* | *6.55* | *10.95* | *12.27* | *19.26* | *4.48* | *7.29* | *10.30* | *10.41* | *1.89* | *0.23* | *0* | *3.77* |
| 3 | 10 | 27 | 28 | 25 | 11 | 16 | 22 | 23 | 19 | 6 | 20 | 13 | 3 | 4 | 1 | 6 |
| | *7.32* | *9.98* | *10.50* | *11.90* | *4.62* | *9.76* | *11.81* | *11.57* | *6.79* | *2.51* | *6.83* | *9.97* | *1.28* | *2.06* | *1.00* | *1.96* |
| 4 | 11 | 24 | 26 | 15 | 12 | 12 | 22 | 13 | 12 | 10 | 15 | 11 | 4 | 6 | 0 | 4 |
| | *4.32* | *6.73* | *9.18* | *7.44* | *4.05* | *5.30* | *9.67* | *5.74* | *3.97* | *5.87* | *8.08* | *8.19* | *0.65* | *1.20* | *0* | *2.11* |
| 5 | 15 | 16 | 22 | 12 | 13 | 24 | 16 | 20 | 9 | 5 | 4 | 9 | 1 | 6 | 2 | 5 |
| | *6.30* | *5.84* | *11.30* | *7.09* | *4.19* | *12.13* | *9.35* | *8.65* | *1.69* | *2.64* | *2.55* | *3.08* | *0.10* | *0.71* | *0.96* | *2.74* |
| 6 | 20 | 17 | 18 | 15 | 5 | 22 | 11 | 21 | 10 | 6 | 12 | 12 | 1 | 10 | 4 | 1 |
| | *7.65* | *4.75* | *8.52* | *5.98* | *2.61* | *9.44* | *3.46* | *8.66* | *4.12* | *1.99* | *6.10* | *9.08* | *0.41* | *2.32* | *1.96* | *0.46* |
| 7 | 24 | 21 | 14 | 9 | 8 | 23 | 9 | 7 | 7 | 3 | 7 | 10 | 6 | 6 | 4 | 1 |
| | *6.79* | *5.99* | *5.17* | *5.66* | *2.74* | *9.78* | *1.77* | *3.04* | *1.88* | *0.79* | *3.50* | *9.75* | *1.90* | *1.15* | *1.42* | *0.46* |
| 8 | 13 | 14 | 17 | 12 | 12 | 17 | 6 | 21 | 7 | 5 | 4 | 13 | 2 | 3 | 1 | 5 |
| | *5.00* | *5.14* | *6.08* | *6.76* | *4.67* | *5.86* | *2.20* | *6.90* | *1.63* | *2.97* | *2.37* | *6.70* | *0.64* | *0.83* | *0.18* | *1.98* |
| 9 | 13 | 15 | 13 | 12 | 9 | 14 | 5 | 22 | 7 | 5 | 6 | 13 | 0 | 4 | 1 | 7 |
| | *3.86* | *5.49* | *5.51* | *6.55* | *3.14* | *4.12* | *1.22* | *7.29* | *2.46* | *1.08* | *3.94* | *6.92* | *0* | *0.99* | *0.16* | *2.36* |
| 10 | 16 | 8 | 8 | 6 | 15 | 12 | 8 | 16 | 12 | 2 | 4 | 5 | 3 | 4 | 0 | 4 |
| | *3.76* | *4.32* | *2.92* | *4.02* | *4.50* | *7.23* | *2.35* | *5.04* | *4.34* | *0.76* | *3.41* | *1.97* | *1.02* | *1.31* | *0* | *2.55* |

[a] Values in *italics* are the volume of acre-feet traded by the transactions

**TABLE 4: From Whom Native American Users Leased Water**

| | *Agricultural* | | | | *Environmental* | | | | *Native American* | | | | *Urban* | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Round | Dec | Dry | Inc | Base | Dec | Dry | Inc | Base | Dec | Dry | Inc | Base | Dec | Dry | Inc | Base |
| 1 | 4 | 8 | 8 | 8 | 6 | 14 | 4 | 6 | 5 | 1 | 1 | 1 | 2 | 1 | 0 | 1 |
| | *3.12*[a] | *4.88* | *4.72* | *5.69* | *3.43* | *6.13* | *1.02* | *1.35* | *4.19* | *0.50* | *0.96* | *0.99* | *1.72* | *0.40* | *0* | *0.20* |
| 2 | 11 | 16 | 12 | 12 | 13 | 18 | 12 | 11 | 3 | 3 | 0 | 4 | 3 | 4 | 2 | 2 |
| | *6.21* | *9.39* | *5.55* | *6.05* | *6.98* | *8.52* | *7.76* | *8.60* | *2.38* | *1.56* | *0* | *2.19* | *1.29* | *1.10* | *1.27* | *2.01* |
| 3 | 15 | 15 | 14 | 12 | 16 | 21 | 8 | 10 | 5 | 7 | 0 | 5 | 4 | 2 | 2 | 1 |
| | *6.98* | *6.58* | *5.47* | *8.28* | *7.91* | *8.37* | *3.45* | *6.78* | *1.51* | *3.19* | *0* | *3.60* | *0.71* | *1.51* | *0.59* | *0.10* |
| 4 | 15 | 14 | 8 | 8 | 4 | 19 | 8 | 13 | 3 | 3 | 3 | 6 | 1 | 1 | 3 | 0 |
| | *6.38* | *7.39* | *3.50* | *4.18* | *2.45* | *10.24* | *3.71* | *7.56* | *0.88* | *1.70* | *2.33* | *3.50* | *0.10* | *0.30* | *0.79* | *0* |
| 5 | 9 | 8 | 12 | 9 | 13 | 18 | 4 | 13 | 9 | 1 | 5 | 5 | 1 | 5 | 2 | 1 |
| | *4.93* | *4.84* | *5.40* | *5.74* | *4.45* | *7.38* | *1.70* | *6.09* | *2.89* | *1.02* | *2.62* | *3.65* | *0.10* | *1.00* | *1.10* | *0.10* |
| 6 | 7 | 12 | 6 | 8 | 9 | 13 | 8 | 8 | 2 | 3 | 6 | 1 | 1 | 2 | 2 | 2 |
| | *2.62* | *8.02* | *2.41* | *4.26* | *3.40* | *6.86* | *2.90* | *3.20* | *0.30* | *1.61* | *4.22* | *0.99* | *0.10* | *0.40* | *0.20* | *0.88* |
| 7 | 12 | 14 | 7 | 6 | 12 | 14 | 9 | 10 | 1 | 5 | 0 | 1 | 2 | 5 | 0 | 0 |
| | *4.02* | *4.49* | *2.87* | *4.80* | *3.46* | *6.51* | *3.66* | *4.65* | *0.10* | *3.26* | *0* | *0.50* | *0.91* | *1.60* | *0* | *0* |
| 8 | 12 | 9 | 5 | 9 | 7 | 18 | 3 | 11 | 4 | 6 | 1 | 3 | 2 | 1 | 0 | 1 |
| | *4.02* | *5.87* | *3.66* | *5.39* | *2.41* | *10.79* | *1.06* | *3.14* | *1.57* | *2.37* | *1.01* | *1.02* | *1.21* | *0.10* | *0* | *0.20* |
| 9 | 7 | 9 | 2 | 11 | 18 | 20 | 5 | 8 | 4 | 6 | 3 | 1 | 2 | 1 | 0 | 1 |
| | *2.50* | *4.51* | *1.82* | *2.70* | *3.56* | *8.23* | *2.65* | *2.48* | *1.65* | *3.41* | *2.52* | *0.20* | *2.03* | *0.20* | *0* | *0.20* |
| 10 | 7 | 6 | 4 | 4 | 20 | 13 | 2 | 9 | 2 | 6 | 3 | 6 | 6 | 4 | 0 | 2 |
| | *2.69* | *3.74* | *2.57* | *2.97* | *6.60* | *7.79* | *1.98* | *2.74* | *0.93* | *2.43* | *2.51* | *2.49* | *3.02* | *1.31* | *0* | *1.11* |

[a] Values in *italics* are the volume of acre-feet traded by the transactions

**TABLE 5: From Whom Urban Users Leased Water**

| | *Agricultural* | | | | *Environmental* | | | | *Native American* | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Round | Dec | Dry | Inc | Base | Dec | Dry | Inc | Base | Dec | Dry | Inc | Base |
| 1 | 3 | 1 | 2 | 3 | 2 | 2 | 2 | 2 | 0 | 0 | 1 | 6 |
| | *1.65*[a] | *0.94* | *1.82* | *2.80* | *2.04* | *1.02* | *0.61* | *1.15* | *0* | *0* | *0.50* | *4.48* |
| 2 | 2 | 1 | 2 | 5 | 5 | 2 | 0 | 3 | 1 | 1 | 4 | 7 |
| | *0.30* | *0.29* | *2.03* | *2.29* | *1.58* | *1.12* | *0* | *3.15* | *0.98* | *0.10* | *3.94* | *6.13* |
| 3 | 4 | 4 | 4 | 4 | 2 | 5 | 2 | 2 | 1 | 0 | 2 | 3 |
| | *2.43* | *1.61* | *1.42* | *2.54* | *0.99* | *2.57* | *0.55* | *1.54* | *0.99* | *0* | *1.97* | *1.50* |
| 4 | 3 | 3 | 3 | 7 | 1 | 1 | 6 | 2 | 1 | 2 | 2 | 2 |
| | *1.18* | *0.69* | *1.46* | *3.30* | *0.98* | *0.12* | *4.25* | *1.34* | *0.10* | *0.71* | *1.94* | *1.20* |
| 5 | 3 | 2 | 4 | 6 | 3 | 0 | 4 | 4 | 2 | 2 | 2 | 3 |
| | *2.38* | *0.40* | *0.56* | *3.80* | *1.00* | *0* | *2.02* | *0.43* | *0.61* | *0.50* | *1.98* | *2.51* |
| 6 | 3 | 3 | 6 | 2 | 2 | 2 | 5 | 10 | 0 | 1 | 4 | 5 |
| | *1.60* | *2.19* | *3.27* | *1.92* | *0.87* | *0.41* | *2.82* | *2.04* | *0* | *0.59* | *3.88* | *1.81* |
| 7 | 1 | 0 | 7 | 6 | 3 | 1 | 7 | 5 | 1 | 0 | 4 | 4 |
| | *0.93* | *0* | *2.24* | *2.06* | *0.91* | *0.10* | *4.87* | *1.72* | *0.49* | *0* | *2.77* | *1.92* |
| 8 | 2 | 1 | 5 | 4 | 1 | 0 | 9 | 8 | 1 | 0 | 7 | 1 |
| | *1.18* | *0.39* | *2.33* | *1.54* | *0.30* | *0* | *4.51* | *2.59* | *0.30* | *0* | *5.75* | *1.00* |
| 9 | 3 | 1 | 10 | 9 | 4 | 0 | 6 | 3 | 0 | 0 | 5 | 7 |
| | *1.25* | *0.20* | *4.76* | *2.21* | *1.73* | *0* | *3.72* | *1.33* | *0* | *0* | *3.30* | *3.89* |
| 10 | 3 | 1 | 19 | 7 | 3 | 0 | 13 | 6 | 0 | 0 | 7 | 6 |
| | *1.60* | *0.20* | *11.20* | *5.55* | *1.13* | *0* | *3.30* | *2.50* | *0* | *0* | *4.94* | *2.80* |

[a] Values in *italics* are the volume of acre-feet traded by the transactions

FIGURE 3: CARRIAGE GAINS/LOSSES AS PERCENTAGE OF INITIAL ALLOCATION

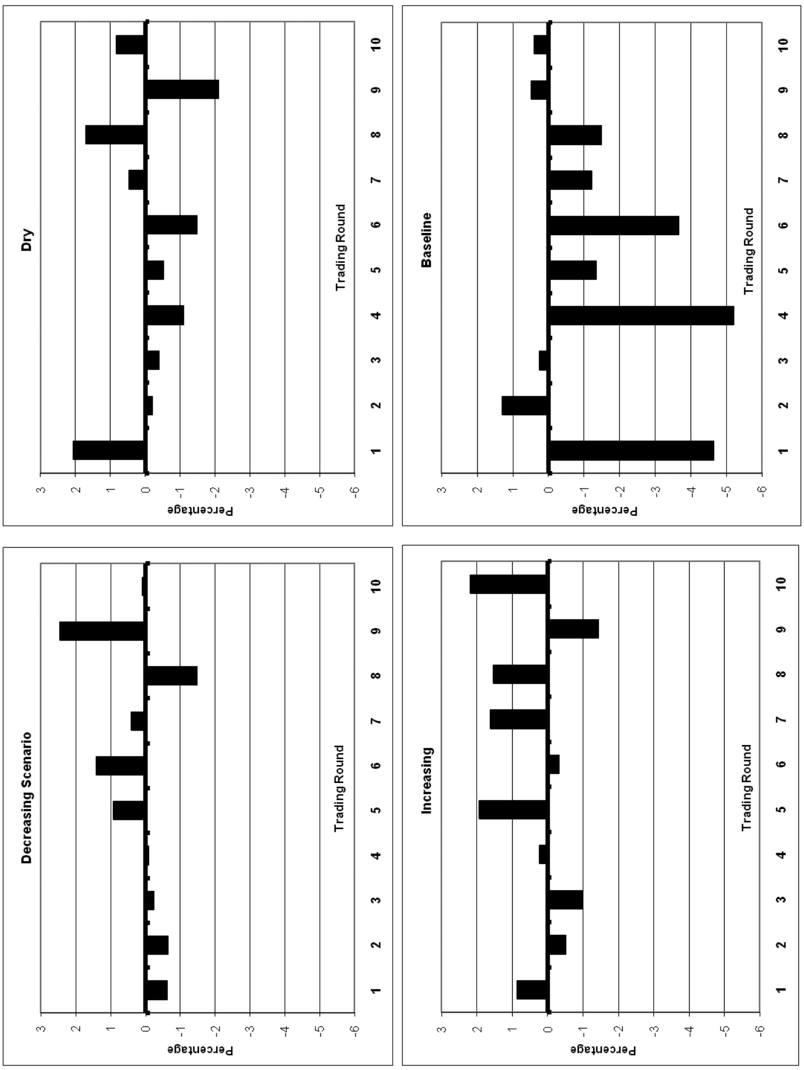


FIGURE 4: PERCENTAGE OF WATER LEASED FROM OR TO A REACH

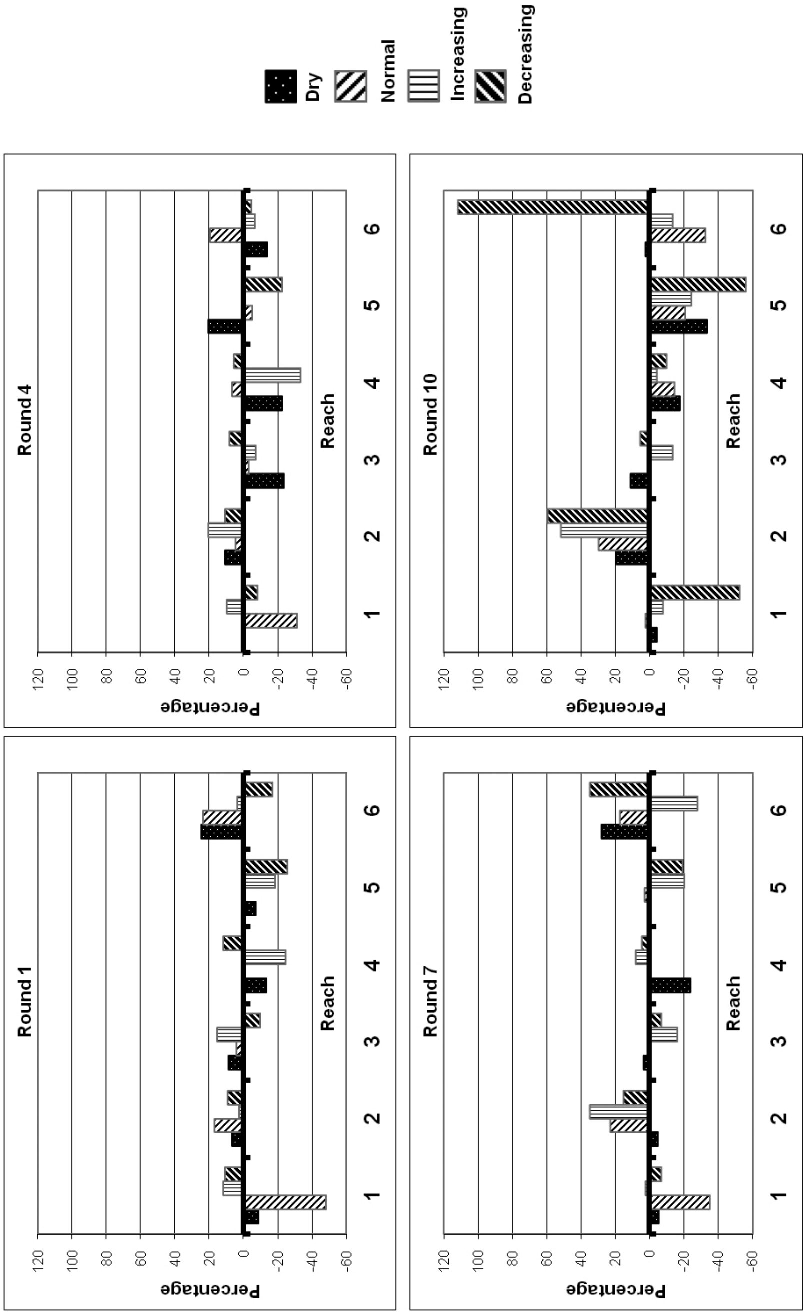


**TABLE 6: Weighted Average Price Per Acre-Foot by Lessee**

| Round \| Scenario | Agricultural | | | | Environmental | | | | Native American | | | | Urban | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Dec | Dry | Inc | Base | Dec | Dry | Inc | Base | Dec | Dry | Inc | Base | Dec | Dry | Inc | Base |
| 1 | 7.62 | 13.58* | 5.30 | 5.45 | 5.38 | 5.55 | 5.12 | 5.39 | 6.90 | 6.42 | 7.98 | 5.52 | 5.15 | 6.98 | 6.48 | 5.19 |
| | (3.02)[a] | (3.68) | (2.51) | (2.97) | (2.94) | (1.96) | (1.61) | (2.99) | (2.58) | (2.28) | (2.82) | (1.78) | (1.60) | (3.89) | (0.84) | (2.75) |
| 2 | 9.83 | 8.89* | 8.48* | 7.69 | 6.75 | 8.21 | 9.11* | 7.77 | 8.71* | 8.61 | 7.57* | 5.33 | 10.59 | 22.35* | 4.61 | 7.77 |
| | (3.84) | (2.06) | (2.11) | (4.13) | (2.92) | (3.28) | (1.99) | (3.55) | (2.66) | (2.96) | (2.05) | (3.15) | (2.27) | (2.58) | (1.85) | (4.04) |
| 3 | 9.77 | 10.49* | 11.72* | 10.13 | 7.51 | 11.35 | 12.63* | 9.31 | 8.88* | 9.03* | 15.86* | 5.69 | 6.39 | 10.66 | 10.91* | 8.15 |
| | (4.79) | (2.42) | (3.53) | (4.70) | (2.40) | (3.49) | (3.67) | (3.67) | (2.53) | (2.56) | (4.46) | (3.46) | (3.11) | (4.09) | (1.16) | (5.76) |
| 4 | 10.80 | 10.09* | 12.14* | 10.33 | 10.08* | 12.31 | 13.93 | 8.48 | 9.13 | 7.91 | 12.51* | 5.67 | 8.19 | 13.09 | 4.49 | 11.50 |
| | (4.17) | (2.30) | (3.31) | (5.10) | (2.44) | (4.58) | (4.57) | (3.75) | (3.02) | (2.79) | (3.60) | (2.79) | (3.23) | (3.69) | (1.22) | (3.32) |
| 5 | 6.79 | 11.03* | 12.36* | 6.71 | 10.94* | 13.50 | 12.82 | 8.23 | 8.71 | 7.32 | 13.42 | 6.06 | 6.89 | 20.07* | 6.14 | 9.79 |
| | (3.46) | (3.24) | (3.76) | (2.91) | (2.49) | (5.04) | (5.04) | (2.52) | (2.98) | (2.95) | (5.28) | (2.55) | (1.90) | (1.39) | (1.69) | (4.52) |
| 6 | 8.82 | 10.49* | 14.87* | 6.93 | 10.79* | 11.90 | 11.56 | 7.60 | 10.17* | 7.38* | 11.02* | 7.86 | 10.93 | 14.64* | 6.13 | 9.22 |
| | (3.27) | (3.15) | (3.11) | (2.44) | (2.77) | (4.19) | (3.37) | (2.52) | (2.39) | (1.96) | (2.98) | (2.41) | (2.77) | (3.39) | (1.96) | (2.78) |
| 7 | 9.10 | 11.07* | 10.85* | 7.20 | 10.13* | 10.85 | 10.57 | 6.22 | 12.57* | 10.44* | 10.99 | 4.15 | 11.37* | 8.73 | 5.26 | 7.81 |
| | (3.35) | (2.20) | (1.88) | (2.95) | (2.20) | (4.12) | (3.57) | (3.01) | (2.25) | (2.57) | (4.03) | (1.32) | (1.74) | (2.34) | (2.27) | (1.70) |
| 8 | 9.35* | 9.15* | 8.48* | 6.54 | 9.37 | 12.20 | 8.24 | 6.78 | 8.44* | 6.88 | 7.42 | 7.25 | 8.99 | 8.67* | 4.25 | 9.94 |
| | (2.86) | (2.63) | (1.55) | (2.33) | (2.21) | (4.50) | (2.59) | (2.74) | (2.22) | (3.11) | (4.79) | (2.16) | (1.63) | (0.86) | (2.15) | (3.47) |
| 9 | 8.90 | 9.22* | 9.26* | 7.73 | 9.33* | 9.82 | 6.70 | 8.24 | 9.75* | 8.21* | 4.66 | 9.30* | 11.24 | 4.45 | 4.93 | 7.99 |
| | (3.03) | (2.43) | (2.13) | (2.73) | (1.69) | (3.01) | (2.24) | (3.04) | (2.46) | (2.01) | (2.84) | (1.54) | (2.25) | (1.16) | (2.61) | (3.18) |
| 10 | 9.42* | 8.63* | 7.01* | 4.34 | 9.75* | 9.14 | 5.62 | 5.15 | 8.98* | 7.27* | 4.72 | 5.15 | 7.51 | 4.95 | 3.19 | 5.53 |
| | (3.15) | (2.36) | (1.67) | (2.80) | (1.77) | (4.08) | (2.39) | (2.36) | (2.40) | (2.00) | (2.59) | (1.73) | (1.56) | (1.43) | (1.31) | (2.65) |

* denotes value is significantly different from expectations at the 5% level
[a] values in parentheses are standard errors

**TABLE 7:**
**Weighted Average Price Per Acre-Foot by Scenario**

| Round \| Scenario | Dec | Dry | Inc | Base |
|---|---|---|---|---|
| 1 | 6.33 | 6.21 | 5.74 | 5.40 |
| | (2.86)[a] | (2.74) | (2.11) | (2.79) |
| 2 | 8.5 | 9.13 | 8.32 | 7.29 |
| | (3.24) | (2.80) | (2.02) | (3.70) |
| 3 | 8.62 | 10.62* | 12.75* | 8.62 |
| | (3.48) | (3.07) | (3.67) | (4.09) |
| 4 | 10.05* | 10.54* | 12.05* | 8.66 |
| | (3.35) | (3.51) | (3.97) | (4.09) |
| 5 | 8.15 | 11.91 | 12.26 | 7.40 |
| | (2.96) | (4.14) | (4.62) | (2.90) |
| 6 | 9.86 | 10.96 | 10.99* | 7.61 |
| | (2.90) | (3.62) | (3.08) | (2.50) |
| 7 | 10.22* | 10.70* | 9.11 | 6.24 |
| | (2.71) | (3.33) | (3.16) | (2.61) |
| 8 | 9.14* | 10.00 | 6.68 | 7.12 |
| | (2.49) | (3.75) | (2.67) | (2.61) |
| 9 | 9.36 | 8.77 | 6.02 | 8.17 |
| | (2.60) | (2.59) | (2.37) | (2.78) |
| 10 | 9.28 | 8.26 | 4.45 | 5.09 |
| | (2.46) | (3.25) | (1.93) | (2.35) |

[a] values in parentheses are standard errors
* denotes value is significantly different from expectations at the 5% level