



Winter 2007

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Recommended Citation

Fred O. Boadu, Bruce M. McCarl & Dhazn Gillig, *An Empirical Investigation of Institutional Change in Groundwater Management in Texas: The Edwards Aquifer Case*, 47 Nat. Resources J. 117 (2007). Available at: <https://digitalrepository.unm.edu/nrj/vol47/iss1/4>

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An Empirical Investigation of Institutional Change in Groundwater Management in Texas: The Edwards Aquifer Case

ABSTRACT

Texas Senate Bill 1477 changed the rules governing water appropriation in the Edwards Aquifer from a "rule of capture" to a "permit system." This article discusses some of the factors that explain the institutional change and empirically estimates the likely impact of the change. The article concludes that industrial and municipal water users benefited from the introduction of water marketing even though overall welfare declined. Also, the state's objective to protect endangered species was achieved with increased flows to key rivers, streams, bays, and estuaries in the aquifer region.

I. INTRODUCTION

Institutions are critical in promoting or hindering economic growth and welfare in a society, and one scholar has suggested that economic theory as a body of knowledge should be expanded to explicitly account for the role of institutions.¹ The term "institution" is used in two senses in economics literature. First, the term may refer to a physical organization that influences or regulates activity, such as a bank or a university or, for

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1. Feeny states that "the traditional three pillars of economic theory – endowments, technologies, and preferences – are incomplete. The fourth and implicit pillar is institutions." David Feeny, *The Demand for and Supply of Institutional Arrangements*, in RETHINKING INSTITUTIONAL ANALYSIS AND DEVELOPMENT: ISSUES, ALTERNATIVES, AND CHOICES 159, 159 (Vincent Ostrom et al. eds., 1988). Oliver Williamson has discussed the role of institutions in a market economy extensively. See OLIVER E. WILLIAMSON, *THE ECONOMIC INSTITUTIONS OF CAPITALISM* (1985).

the purposes of this discussion, the Edwards Aquifer Authority (Authority) and the San Antonio Water System (SAWS).² Second, the term may also refer to the "rules of the game"³ or "working rules,"⁴ encompassing the laws, regulations, customs, norms, mores, and conventions in a society.

The focus in this article is more on institutions as rules of the game as they govern groundwater use and determine the limits to economizing behavior by private parties. Since an understanding of the factors influencing change is needed to predict the path of future changes, a major concern in institutional analysis is whether the rules emerge as a result of private bargaining, government fiat, or a combination of bargaining among private parties and the government.

The sources of institutional change comprise a perennial issue in the scholarship on institutions. Historians, economists, and lawyers at the forefront of the research on institutional change agree that individual choice and wealth-maximizing behavior in response to new resource scarcity scenarios are primary sources of institutional change.⁵ Also important in institutional analysis is the recognition that institutional changes are defined by and occur because of the unique environment within which the change occurs.⁶ Given the diversity and number of societies, one could

2. Bromley goes to great lengths to make distinctions between institutions as organizations and as rules of the game. DANIEL W. BROMLEY, *ECONOMIC INTERESTS AND INSTITUTIONS: THE CONCEPTUAL FOUNDATIONS OF PUBLIC POLICY* 22-23 (1989). "One of the primary shortcomings of the model of induced institutional innovation arises over the treatment of institutions as both rules of organizations, and as the organizations themselves." *Id.* at 27.

3. See Lance Davis & Douglass North, *Institutional Change and American Economic Growth: A First Step Towards a Theory of Institutional Innovation*, 30 J. ECON. HIST. 131, 132 (1970).

4. This phrase was coined by John R. Commons, who defined institutions as "collective action in restraint, liberation, and expansion of individual action." BROMLEY, *supra* note 2, at 43.

5. For an analysis of institutional change in a historical context, see DOUGLASS C. NORTH & ROBERT PAUL THOMAS, *THE RISE OF THE WESTERN WORLD: A NEW ECONOMIC HISTORY* (1973). For contributions in a law and economics context, see A. ALLAN SCHMID, *PROPERTY, POWER, AND PUBLIC CHOICE: AN INQUIRY INTO LAW AND ECONOMICS* (1987) and Gary D. Libecap, *Economic Variables and the Development of the Law: The Case of Western Mineral Rights*, 38 J. ECON. HIST. 338 (1978).

6. In a series of case studies of how different societies designed institutions to deal with problems of resource depletion, Elinor Ostrom concluded,

The primary substantive lesson from these cases is that it is possible for humans to break out of the logic that yields a tragedy of the commons and to restructure the situation itself. Thus it is important for policy analysts to recognize the difference between making assumptions during an analysis and presuming these assumptions are immutable. There cannot be "one best way" of organizing the management of natural resource systems.

Elinor Ostrom, *Institutional Arrangements and the Commons Dilemma*, in *RETHINKING INSTITUTIONAL ANALYSIS AND DEVELOPMENT*, *supra* note 1, at 101, 119.

understand why there is such an extensive literature on the importance of institutional research to public policy making.

Changes in institutions governing groundwater resources, specifically the Edwards Aquifer in Texas, present an opportunity to revisit the issue of sources and impacts of institutional change.⁷ This article presents an empirical analysis of institutional changes to manage the aquifer and addresses two basic questions: (1) What demand and supply forces influenced the institutional change in the management of the aquifer? and (2) What is the jurisprudence of these institutional changes – the cost of the change, its distributional impacts, including the impacts on total welfare gains and losses, and endangered species protection? The results stemming from the study may be useful in exploring future sources and direction of change in the water sector in Texas.⁸

Section I concludes with a description of the aquifer and its importance to the central Texas region and a brief discussion of Texas groundwater law. Section II discusses various theories of the sources of institutional change. The first part of the discussion focuses on the property rights theory of institutional change since property rights concerns have been central to the discussion of aquifer water rights. The second part presents a generalized theory of the sources of institutional change. The discussion then pulls together critical elements from various theories of institutional change and how these apply in the context of the aquifer region. In section III, an aquifer level model, the Edwards Aquifer Simulator-River Model (EDSRM) is employed to explore the jurisprudence of the changes that occurred.⁹ The section compares the quantifiable and non-quantifiable costs associated with the change against computed welfare benefits and losses due to the change and other policy goals anticipated under the change. Conclusions and policy implications are presented in section IV.

7. This study will not be the first to examine the issue of institutional changes in the context of groundwater resources. *E.g.*, Ostrom, *supra* note 6, at 108–11 (providing a case study of institutional changes within the West basin in California). For a review of groundwater laws and regulations, see BONNIE COLBY SALIBA & DAVID B. BUSH, *WATER MARKETS IN THEORY AND PRACTICE: MARKET TRANSFERS, WATER VALUES, AND PUBLIC POLICY* (1987).

8. Davis and North have suggested that a useful model of institutional innovation must be able to predict two kinds of things:

(1) Given any established set of institutions and some disequilibrating force, the model ought to predict whether the newly emerging institutions will be purely individual, involve some form of voluntary cooperation, or rely on the coercive power of government; (2) It should provide some estimate of the period of time that is likely to elapse between the initiating disequilibrium and the establishment of the new (or mutated) institutions.

Davis & North, *supra* note 3, at 132.

9. *See infra* note 128.

A. The Importance of the Edwards Aquifer

The Edwards Aquifer extends through eight counties in central Texas,¹⁰ and the contribution of the aquifer to the economic development of the region is immense. With a population of over one million people—projected to double by the year 2050—the City of San Antonio and the surrounding metropolitan area are major users of water from the aquifer. In accord with population growth, municipal water demand is projected to more than double within the period.¹¹ Because San Antonio is heavily dependent on the aquifer for its water supply, pumping restrictions as a component of drought or overall aquifer management could have significant impacts on municipal and industrial water prices.

For example, analyses have shown that if pumping is limited to 340,000 annual acre-feet, municipal and industrial water prices would rise by about 37 percent by the year 2012. When pumping limits are further reduced to about 175,000 acre-feet per year, water prices nearly double from \$701 per acre-foot to about \$1,389 per acre-foot per year.¹²

As shown in Table 1,¹³ the aquifer is also critical to agricultural producers. Model predictions for agricultural impacts from aquifer pumping restrictions indicate that restricting pumping to 175,000 acre-feet per year will cause irrigated cotton, oilseeds, and other irrigated crops to disappear from the aquifer region. Irrigation-related employment will fall by as much as 50 percent in certain parts of the region. The gross regional product¹⁴ is also projected to fall by almost 50 percent with consequent losses for private businesses and local jurisdictions providing public

10. The Edwards Aquifer extends 180 miles from Brackettville in Kinney County to Kyle in Hays County. Edwards Aquifer Authority, *Our Aquifer: History*, <http://www.edwardsaquifer.org/pages/history.htm> (last visited Mar. 8, 2007). The counties are Atascosa, Bexar, Caldwell, Comal, Guadalupe, Hays, Medina, and Uvalde. Edwards Aquifer Authority Act art. 1, § 1.02(a), 1993 Tex. Gen. Laws 2350, 2351.

11. S. CENT. TEX. REG. WATER PLANNING GROUP, *SOUTH CENTRAL TEXAS REGIONAL WATER PLANNING AREA: REGIONAL WATER PLAN 2-12 (2001)* (total municipal use in the South Central Region in 1990 was 318,495 acre-feet per year (afy) and is projected to increase to 769,523 afy by 2050).

12. Lonnie L. Jones et al., *Economic Impacts of Edwards Aquifer Pumping Restriction Alternatives to Meet Habitat Conversion Plan Requirements 8-9* (Mar. 15, 2001) (unpublished manuscript, on file with author).

13. Compiled by the author based on data from TEX. AGRIC. EXTENSION SERV., *DISTRICT 10: ESTIMATED VALUE OF AGRICULTURAL PRODUCTION AND RELATED ITEMS, 1997-2000, 2001 PROJECTED (2001)*, and TEX. WATER DEV. BD., *WATER FOR TEXAS (1990)*.

14. Gross regional product (GRP) refers to the total value of all goods and services produced in the region in a given year.

services such as schools, health services, and police and fire protection.¹⁵ Table 1 also shows that restrictions on aquifer pumping would have a significant negative effect on farmers in Medina, Uvalde, and Hays counties.

Table 1: Basic Indicators of the Edwards Aquifer Region & Counties, 2001

County	Atascosa	Bexar	Caldwell	Comal	Guadalupe	Hays	Medina	Uvalde
Population	30,533	1,185,394	26,392	51,832	64,873	65,614	27,312	23,340
Agriculture ^a								
Total Production	77,861	59,755	42,464	10,710	44,319	30,845	45,624	84,423
Major Products	Beef	Beef	Poultry	Beef	Feed Crops	Nursery	Beef	Vegetables
Value Major Prod.	29,705	8,515	18,800	5,271.68	11,056	6,000	25,000	28,085
% of 4-year total	48.3	13.9	55.9	41.7	31.1	21.2	47.1	27.2
% of Nursery Prod.	25.4	58	0.4	13.2	20.4	21.2	0.0	0.0
Water ^b								
Total Demand	61,472	303,917	7,149	15,404	14,973	12,998	164,600	147,897
Irrigation	47,208	37,012	1,375	479	2,646	298	157,380	140,669
Manufacturing	0.0	14,049	0.0	3,248	1,661	57	286	557
Municipal	5,670	225,626	4,931	10,415	9,627	9,740	4,475	5,278
Steam/Elec.	6,036	24,263	0.0	0.0	0.0	0.0	0.0	0.0
Livestock	1,613	1,376	816	316	1,031	378	1,560	994
Mining	664	1,561	27	946	8	0.0	120	399

^a Agriculture production values are in thousands of dollars.
^b Water values are in acre-feet per year.

15. Jones et al., *supra* note 12, at 42.

Other studies have addressed the importance of habitat and species preservation, including recreational activities in the aquifer region. The aquifer supports five major springs: Leona, San Antonio, San Pedro, Comal, and San Marcos. Comal Springs at New Braunfels and San Marcos Springs at San Marcos are the largest, providing the base flow of the Guadalupe River and its tributaries. The springs support local tourist activities and amusement parks. San Marcos and Comal Springs are the only habitat of five federally listed endangered and threatened species: the fountain darter, the San Marcos gambusia, the San Marcos salamander, the Texas blind salamander, and Texas wild rice. The region is also home to two endangered birds: the golden-cheeked warbler and the black-capped vireo.¹⁶

Environmental concerns have been rising in the Edwards region. Recently, the San Marcos River Foundation filed an application for approximately 1.15 million acre-feet of instream water rights in the San Marcos River and the Guadalupe River. The goal is to guarantee adequate flows to bays and estuaries. The success of this application is dependent on the health of the aquifer because, while ordinarily the aquifer contributes about 50 percent of the base flow of the two river systems, this contribution could be as high as 90 percent during periods of extreme drought.¹⁷

The pressure for institutional change to address the human and ecological dependence on the aquifer is revealed in Figure 1, which shows aquifer discharge¹⁸ as a percentage of recharge from 1934 through 1999. A general conclusion that one could draw is that, over the period, recharge — “water entering an underground aquifer through faults, fractures, or direct absorption”¹⁹ — has declined relative to discharge. Well pumping has been quite dramatic over the years and has not been matched by natural recharge of the aquifer. Since 1934, observed spring flow per unit of recharge has fallen about one percent per year largely from the growth of water withdrawals, which have risen from 18 percent of long-run average recharge to 81 percent.²⁰ It is against this backdrop that the introduction of

16. Ben F. Vaughan IV & Peter M. Emerson, *Protecting the Edwards Aquifer: An Efficient and Ecological Alternative*, in *WATER MARKETING—THE NEXT GENERATION* 167, 168 (Terry L. Anderson & Peter J. Hill eds., 1997). The Edwards-dependent species are listed and defined at 50 C.F.R. §§ 17.11, 17.12 (2005).

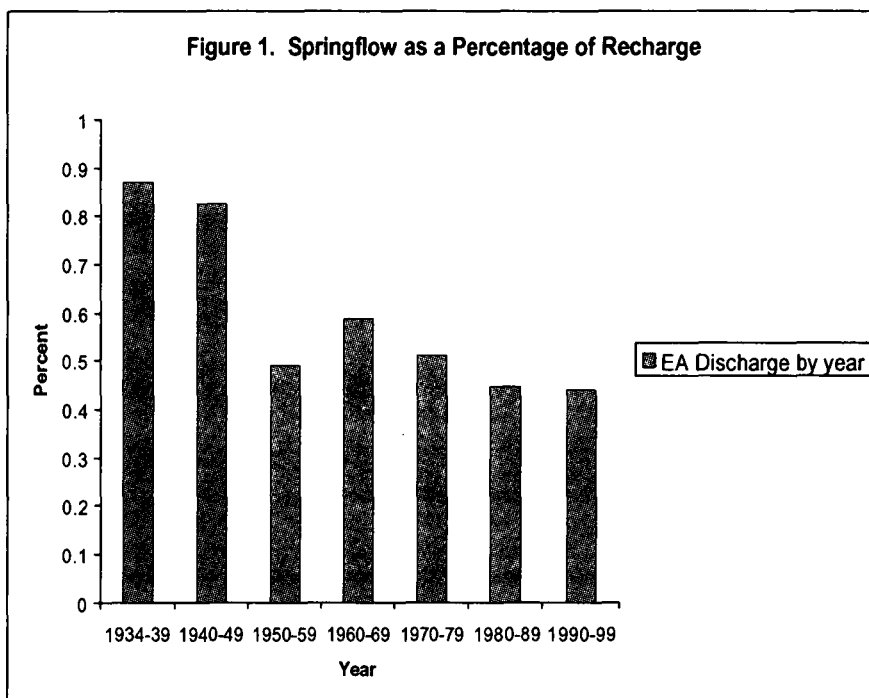
17. Letter from Dianne Wassennich, President, San Marcos River Foundation, to Fred Boadu, Professor of Agricultural Economics, Texas A&M University (Jan. 31, 2002) (on file with author).

18. Aquifer discharge consists of ground water that is pumped from the aquifer through wells and water that is discharged naturally as spring water.

19. Gregg Eckhardt, *Glossary of Water Resource Terms*, EDWARDS AQUIFER WEBSITE, <http://www.edwardsaquifer.net/glossary.html#R> (last visited Mar. 8, 2007).

20. ROBERT A. COLLINGE ET AL., TEX. WATER RESOURCES INST. REPORT No. TR-159, *THE EDWARDS AQUIFER: AN ECONOMIC PERSPECTIVE 1* (1993), available at <http://twri.tamu.edu/reports/1993/tr159/tr159.pdf>.

a catfish farm that relied on a well capable of yielding 40,000 gallons of water per minute raised so much alarm in the aquifer region.²¹



B. Groundwater Law in Texas

Texas has a dual water law regime. Surface water is owned by the State of Texas in trust for all citizens of the state.²² A party who wishes to

21. The Living Waters Artesian Catfish Farm was opened by Ron Pucek in Bexar County in 1991. The farm was pumping enough water to support about 250,000 households. The City of San Antonio was forced to purchase Pucek's water rights for \$9 million in order to protect the aquifer and have water available for use by households. Gregg Eckhardt, *Ron Pucek's Living Waters Catfish Farm*, EDWARDS AQUIFER WEBSITE, <http://www.edwardsaquifer.net/pucek.html> (last visited Mar. 8, 2007).

22. The Texas Water Code states,

(a) The water of the ordinary flow, underflow, and tides of every flowing river, natural stream, and lake, and of every bay or arm of the Gulf of Mexico, and the storm water, floodwater, and rainwater of every river,

appropriate surface water must obtain a permit from the Texas Commission on Environmental Quality (TCEQ).²³ On the other hand, ground water is private property owned by the person who brings the water to the surface, known as "the rule of capture."²⁴ Texas adopted the English Common Law rule in 1840 and in 1904, in the case of *Houston & Texas Central Railway Co. v. East*,²⁵ officially adopted the rule of absolute dominion and liability for use of groundwater resources.

Texas courts have held that the only limitations known under the rule of capture are that the owner may not "maliciously take water for the sole purpose of injuring his neighbor, or wantonly and willfully waste it."²⁶ The current application and limitations on the "rule of capture" are best stated in the case of *Friendswood Development Co. v. Smith-Southwest Industries*,²⁷ in which the Texas Supreme Court refused to abandon the rule²⁸

natural stream, canyon, ravine, depression, and watershed in the state is the property of the state.

(b) Water imported from any source outside the boundaries of the state for use in the state and which is transported through the beds and banks of any navigable stream within the state or by utilizing any facilities owned or operated by the state is the property of the state.

TEX. WATER CODE ANN. § 11.021 (Vernon 1999).

23. "The right to the use of state water may be acquired by appropriation in the manner and for the purposes provided in this chapter. When the right to use state water is lawfully acquired, it may be taken or diverted from its natural channel." *Id.* § 11.022.

24. "The ownership and rights of the owners of the land and their lessees and assigns in groundwater are hereby recognized, and nothing in this code shall be construed as depriving or divesting the owners or their lessees and assigns of the ownership or rights, subject to rules promulgated by a district." *Id.* § 36.002.

25. The Supreme Court of Texas stated the English Rule as follows:

That the person who owns the surface may dig therein, and apply all that is there found to his own purposes, at his free will and pleasure; and that if, in the exercise of such right, he intercepts or drains off the water collected from the underground springs in his neighbor's well, this inconvenience to his neighbor falls within the description of *damnum absque injuria*, which cannot become the ground of an action.

Houston & Tex. Cent. Ry. Co. v. East, 81 S.W. 279, 280 (Tex. 1904) (quoting *Acton v. Blundell*, (1843) 152 Eng. Rep. 1223 (Ex.)). Texas's adoption of the English Rule was reaffirmed in *City of Corpus Christi v. City of Pleasanton*, 276 S.W.2d 798, 800-01 (Tex. 1955).

26. *City of Corpus Christi*, 276 S.W.2d at 801.

27. 576 S.W.2d 21 (Tex. 1978).

28. Referring to its own previous ruling, the Supreme Court of Texas stated, "At a time when the trend in other jurisdictions was away from the English rule and toward the "reasonable use" rule, the English rule was reaffirmed by this Court in *City of Corpus Christi v. City of Pleasanton*. The Court said, "With both rules before it, this Court in 1904, adopted, unequivocally, the 'English' or 'Common Law' rule." The opinion in the case shows quite clearly that the court weighed the merits of the two rules—"The practical reasons upon which the courts base their conclusions [applying the 'English'

given the potentially large reliance costs²⁹ but was also willing to redefine the limits of applicability of the rule of capture.³⁰

Texas courts and commentators have said that the responsibility for regulating ground water lies with the legislature and not the courts.³¹ This view is grounded in the Constitution of Texas, which states, *inter alia*, "The conservation and development of all of the natural resources of this State...and the preservation and conservation of all such natural resources of the State are each and all hereby declared public rights and duties; and the Legislature shall pass all such laws as may be appropriate thereto."³²

Section 59(a) of the Texas Constitution was introduced at the height of a major drought in the 1900s.³³ Again in the 1990s when there was a major drought, the legislature answered with Senate Bill (SB) 1, which

rule] fully meet the more theoretical view of the New Hampshire Court [applying the 'American' rule] and satisfy us of the necessity of the doctrine" – and, whether wisely or unwisely, made a deliberate choice.

Id. at 26 (citations omitted) (alterations in original).

29. "The rule has been relied upon by thousands of farmers, industries, and municipalities in purchasing and developing vast tracts of land overlying aquifers of underground water." *Id.* at 29. "Reliance is, simply, the opportunity cost of the broken promise." CHARLES J. GOETZ, *CASES AND MATERIALS ON LAW AND ECONOMICS* 257 (1984). A sudden change in the rule would have imposed detrimental reliance costs on the farmers, ranchers, industries, and households that have made water consumption decisions based on the long-standing rule.

30. This case, however, gives the Court its first opportunity to recognize, and to encourage compliance with, the policy set forth by the Legislature and its regulatory agencies in an effort to curb excessive underground water withdrawals and resulting land subsidence. It also affords us the opportunity to discard an objectionable aspect of the court-made English rule as it relates to subsidence by stating a rule for the future which is more in harmony with expressed legislative policy. We refer to the past immunity from negligence which heretofore has been afforded ground water producers solely because of their "absolute" ownership of the water.

Friendswood Dev. Co., 576 S.W.2d at 29.

31. *Id.* at 26.

32. TEX. CONST. art. XVI, § 59. One commentator has made an observation about the incidence of droughts and legislative response:

Texas water law has evolved within a pattern of key litigation and legislation following major droughts. For example, after the 1996 drought, the Texas Legislature passed Senate Bill 1 in 1997. The Texas Water Development Board is the agency leading the effort to plan for future water supply needs of the state in line with this legislation.

Todd H. Votteler, *WATER: The Drought of Record, the Edwards Aquifer, and San Antonio's Water Future*, BUSINESS S.A., Sept. 1998, at 5, 7.

33. The *Glossary of Meteorology* defines droughts as "periods of abnormally dry weather sufficiently prolonged for the lack of water to cause a serious imbalance in the affected area." AM. METEOROLOGICAL SOC., *GLOSSARY OF METEOROLOGY* (1959). Article XVI, section 59(a) of the Texas Constitution was enacted in response to the droughts of 1910 and 1917. *See also* Votteler, *supra* note 32 (discussing "droughts of record").

significantly changed the procedure for water resource planning in the State.³⁴ While it is true that the legislature has responded to water scarcity over time, the failure to act to avoid the lengthy litigation that has characterized the management of the aquifer reflects the depth of the power of strategic groups in the supply of institutional change.

C. The Change in Institutional Arrangements

The major drought of the 1950s led to the creation of the Edwards Underground Water District (EUWD) in 1959. Charged with the responsibility of conserving and managing water in the aquifer,³⁵ the EUWD was quite limited in power, as it had no authority to limit pumping from the aquifer or to regulate the drilling of wells.³⁶

One explanation for this powerlessness may be the rather high bargaining cost associated with seeking consensus within a heterogeneous group with entrenched positions and conflicting interests.³⁷ There are some who may argue that the assessment of the EUWD is unduly harsh. Clearly from its statute, the EUWD was vested with considerable power to make a change in the management of the aquifer.³⁸ If the power of the EUWD was limited, it was because of the conflicting interests and not as a result of its statutory grant.

A turning point in institutional evolution occurred when the Sierra Club filed a lawsuit against the U.S. Fish and Wildlife Service for failure to enforce the Endangered Species Act (ESA) to protect the endangered species that depend on adequate flow of aquifer water.³⁹ The court ruled that, if unprotected, the Edwards-dependent species would be "taken" as

34. See Votteler, *supra* note 32, at 7.

35. See generally Gregg Eckhardt, *Laws and Regulations Applicable to the Edwards Aquifer*, EDWARDS AQUIFER WEBSITE, <http://www.edwardsaquifer.net/rules.html> (last visited June 11, 2007).

36. *Id.* ("However, [the EUWD] had no authority to restrict groundwater pumping, and for over 40 years it was mainly a data collection agency.").

37. See Linda L. Putnam & Tarla Peterson, *The Edwards Aquifer Dispute: Shifting Frames in a Protracted Conflict*, in MAKING SENSE OF INTRACTABLE ENVIRONMENTAL CONFLICTS 127, 130-31 (Roy Lewicki et al. eds., 2002) ("In the words of one environmentalist... 'The EUWD did not have the regulatory authority that even some other groundwater districts had to be able to manage withdrawal of water from the aquifer. They had many conflicting interests—political interests in San Antonio, agricultural interests in Uvalde and Medina, and springs interests in Hays and Comal counties—and no overall mechanism to reach any conclusions about how the aquifer should be managed. So it was pretty chaotic.'").

38. The EUWD was created to "manage, conserve, preserve, and protect the aquifer and to increase the recharge of, and prevent the waste or pollution of water in, the aquifer." Edwards Aquifer Authority Act § 1.08(a), 1993 Tex. Gen. Laws 2350.

39. *Sierra Club v. Lujan*, 36 ERC 1533, 1993 U.S. Dist. LEXIS 3361, 42, No. MO-91-CA-069, 1993 WL 151353, at 34 (W.D. Tex. Feb. 1, 1993).

defined under the ESA. The court ordered the State of Texas to limit pumping from the aquifer and threatened to develop and implement its own scheme if this was not done.⁴⁰

The Texas Legislature responded to the judge's order with the passage of Senate Bill 1477, the Edwards Aquifer Authority Act (Act),⁴¹ which imposed significant changes in the management of the aquifer. First, the Act set up the Authority, a new institution to manage water withdrawals from the aquifer.⁴² Second, while the Act did not extinguish the rights of existing landowners,⁴³ it subjected water withdrawals from the aquifer to a permitting scheme similar to the rules governing surface water.⁴⁴ Third, to protect against the adverse effects of droughts and to remedy the adverse environmental impacts of excessive withdrawals from the aquifer, the Act placed pumping limits on water withdrawals,⁴⁵ mandated minimum springflows to protect endangered species,⁴⁶ and laid

40. See Eckhardt, *supra* note 35 (suggesting that the implementation of the court's plan would mean that the federal government would be in charge of the aquifer).

41. Edwards Aquifer Authority Act, 1993 Tex. Gen. Laws 626.

42. "A conservation and reclamation district to be known as the Edwards Aquifer Authority is created in all or part of Atascosa, Bexar, Caldwell, Comal, Guadalupe, Hays, Medina, and Uvalde counties. A confirmation election is not necessary. The authority is a governmental agency and a body politic and corporate." Edwards Aquifer Authority Act art. 1, § 1.02(a) "[The] authority is created under and is essential to accomplish the purposes of Article XVI, Section 59, of the Texas Constitution." *Id.* art. 1, § 1.02(b). See also *supra* notes 23 and 24 for the proposition that changes in laws regulating the use of ground water in the State of Texas are the responsibility of the legislature. See *infra* Part II of this article for a detailed analysis of the EAAA and the demise of the EUWD, a parent institution to the Edwards Aquifer Authority. Edwards Aquifer Authority Act art. 1, § 1.41.

43. The ownership and rights of the owner of land and the owner's lessees and assigns, including holders of recorded liens or other security interests in land, in underground water and the contract rights of any person who purchases water for the provision of potable to the public or for the resale of potable water to the public for any use are recognized....

Edwards Aquifer Authority Act art. 1, § 1.07.

44. "Except as provided by Sections 1.17 and 1.33 of article 1, a person may not withdraw water from the aquifer or begin construction of a well or other works designed for the withdrawal of water from the aquifer without obtaining a permit from the authority." *Id.* art. 1, § 1.15 (b).

45. "[F]or the period ending December 31, 2007, the amount of permitted withdrawals from the aquifer may not exceed 450,000 acre-feet of water for each calendar year." *Id.* art. 1, § 1.14 (b); "[F]or the period beginning January 1, 2008, the amount of permitted withdrawals from the Aquifer may not exceed 400,000 acre-feet for each calendar year." *Id.* art. 1, § 1.14 (c).

46. [B]y June 1, 1994, the authority...shall implement and enforce water management practices, procedures, and methods to ensure that, not later than December 31, 2012, the continuous minimum springflows of the Comal Springs and the San Marcos Springs are maintained to protect endangered and threatened species to the extent required by Federal law.

Id. art. 1, § 1.14(h).

the foundation for water marketing.⁴⁷ Reading these provisions together leads to the conclusion that SB 1477 effectively ended the institutional arrangement—the rule of capture as applied to the aquifer—and replaced it with a permit system that promoted water marketing.

II. THE SOURCES OF INSTITUTIONAL CHANGE

The institutional changes that have occurred with regard to the Edwards Aquifer are not of a spontaneous origin. Since 1952 when the City of San Antonio tried to address its water problems by joining in the construction of Canyon Lake, an ongoing battle has raged between strategic hierarchies and coalitions over what to do about water from the Aquifer.⁴⁸ In the end, a long-standing groundwater rule, “the rule of capture,” gave way to a new institutional arrangement under which the aquifer is subject to administrative management and water marketing as the preferred governance mechanism to determine groundwater allocation. Indeed, institutions for the management of aquifer water are still evolving and present an opportunity to empirically test some of the major hypotheses that have been advanced to explain institutional change.

There are three main theoretical explanations of institutional change:⁴⁹ (1) the Property Rights Model, (2) the Induced Technological Change Model, and (3) the Davis and North Transaction Cost Model. David Feeny has synthesized these three models to develop a general demand and supply framework for explaining institutional change. The three basic models are briefly discussed and Feeny’s generalized framework is adapted for an empirical analysis of the factors influencing institutional change within the aquifer region.

A. Property Rights Model

Under the Property Rights Model, new institutions emerge for individuals to take advantage of new opportunities that arise from new knowledge, technological change, information, aspirations, and changes in

47. A permit holder may lease permitted water rights, but a holder of a permit for irrigation use may not lease more than 50 percent of the irrigation rights initially permitted. The user’s remaining irrigation water rights must be used in accordance with the original permit and must pass with transfer of the irrigated land. Edwards Aquifer Authority Act art. 1, § 1.13(c).

48. The first attempt to form the Edwards Underground Water District was in 1955.

49. The description of the various models of institutional change is based largely on BROMLEY, *supra* note 2, and Feeny, *supra* note 1.

market values.⁵⁰ According to the proponents of this model, changes in society present individuals with new cost-benefit opportunities. Those in strategic positions may seek to capture the benefits from the change if the benefits of capture outweigh its cost.

The distinguishing characteristic of the property rights model is that it advocates the superiority of private property rights over other forms of institutional arrangements. According to one author, a system of efficient private property rights—characterized by universality, exclusivity, and transferability—is superior to other institutional arrangements, at least in terms of efficient resource allocation.⁵¹

The issue of property rights was central in the debate over the aquifer. First, as it applies to ground water in Texas, the “rule of capture” acknowledges private property rights to water. The courts in Texas seem to have also blessed private ownership of ground water.⁵² Second, some debate continues as to what exactly constitutes a property right in ground water. One school of thought is that the landowner has a property interest only after the water has been brought to the surface and is in possession of the landowner. Another school of thought is that the landowner actually has property interest in the water even while the water is in the ground.⁵³

50. Harold Demsetz is generally credited with articulating the theory of property rights. As he explained it,

Changes in knowledge result in changes in production functions, market values, and aspirations. New techniques, new ways of doing the same things, and doing new things—all invoke harmful and beneficial effects to which society has not been accustomed....[T]he emergence of new property rights takes place in response to the desires of the interacting persons for adjustment to new benefit-cost possibilities....[P]roperty rights develop to internalize externalities when the gains of internalization become larger than the cost of internalization.

Harold Demsetz, *Toward a Theory of Property Rights*, 57 AM. ECON. REV. 347, 350 (1967); see also RICHARD POSNER, *THE ECONOMICS ANALYSIS OF LAW* (2d ed. 1977).

51. “The proper incentives [for economic efficiency] are created by the parceling out among the members of society of mutually exclusive rights to the exclusive use of particular resources” BROMLEY, *supra* note 2 (citing POSNER, *supra* note 50, at 10).

52. “It is of some importance to note that in the laws authorizing these regulatory Underground Water Districts and the Harris-Galveston Coastal Subsidence District, the Legislature specifically confirmed private ownership of underground water.” See *Friendswood Dev. Co. v. Smith-Sw. Indus.*, 576 S.W.2d 21, 27 (Tex. 1978). See also *Denis v. Kickapoo Land Co.*, 771 S.W.2d 235, 236 (Tex. App.—Austin 1989) (“groundwater percolating beneath the soil is the property of the owner of the surface who may, in the absence of malice, appropriate such water while on his premises and make whatever use of it as he pleases”) (citing *City of Corpus Christi v. City of Pleasanton*, 276 S.W.2d 798 (1955)).

53. At a water law conference held in Texas several years ago, the issue of property rights in ground water was discussed. One expert argued that

[w]hat the landowner has absolute ownership of...is the water after he has removed it from the soil and reduced it to possession. How can the landowner be said to be the absolute owner of the ground water beneath the

While recent property rights advocates seem to prefer the latter position, a more accurate view is that the "property right" is the right to "capture and use," and not a right in the water in the ground per se. What is popularly referred to as a "water right" should properly be called a "pumping right." This debate reveals a rather ironic aspect of the institutional change that has occurred in the aquifer region. The granting of pumping rights to a specified quantity of ground water provides the security of property rights to water that was not available under the rule of capture.

It is important at this point to clarify what has been labeled a "property rights" group in the aquifer debate since the group represents diverse interests and issues. The district court in the *Sierra Club* case split amici briefs into two groups: those in favor of protecting the rule of capture, translated by the group to mean no restrictions on pumping rights and the protection of property rights,⁵⁴ and those advocating a change in the rule of capture to one of managed governance.⁵⁵

surface of his land if the law gives him no remedy whatsoever for the protection of that water against the acts of others?...[H]e does not even have any property interest.

A.W. Walker, Jr., *Theories of Ownership and Control of Oil and Gas Compared with Those of Ground Water*, PROC. WATER LAW CONFERENCE, UNIV. OF TEX., 121, 125 (1956) (quoted in WELLS A. HUTCHINS ET AL., *THE TEXAS LAW OF WATER RIGHTS* 572 (1961) (internal quote marks deleted). *Contra* Joe R. Greenhill, *Well Spacing*, PROC. WATER LAW CONFERENCE, UNIV. OF TEXAS 146, 146 (1956) ("the owner of the surface *does*, with minor exceptions, own the water under it just as he owns the oil and gas") (quoted in HUTCHINS, *supra* at 572) (internal quote marks deleted).

54. The following groups were generally in favor of retention of the rule of capture and filed amici in support of their position: City of Houston; Texas Council of Forest Products Manufacturers; Texas Water Conservation Association; Texas Groundwater Association; Texas Alliance of Groundwater Districts; Edwards Aquifer Authority; North Plains Ground Water Conservation District No. 2; American Land Foundation; Riverside and Landowners Protection Coalition; Texas Justice Foundation; Texas and Southwestern Cattle Raisers Association; Texas Cattle Feeders Association; Texas Association of Nurserymen, Inc.; and Texas Farm Bureau.

55. Amici generally in favor of abandonment of the rule of capture included Aqua Water Supply Corporation (AWSC), Environmental Defense Fund, and National Spring Water Association (NSWA).

AWSC is a Texas non-profit corporation started in the 1970s when the U.S. Farm and Home Administration extended loans and grants to spur start-up water systems all over the United States to provide safe drinking water at reasonable prices to rural areas. Today AWSC serves rural residents in a 910-square mile area in six counties, including most of Bastrop, Lee, and Caldwell counties, and parts of eastern Travis, Fayette, and Williamson counties. *See* Aqua Water Supply Corporation, <http://www.aquawsc.com/> (follow "About Us" hyperlink).

The NSWA was established in 1993. Its membership consists of natural spring owners, spring water bottlers, groundwater professionals, environmentalists, and interested members of the public. The main purpose behind forming the organization was to protect and encourage the protection of natural spring water resources and to promote the spring water business, encourage sustained resource management, and inform the public of the differences between true spring water and other waters. E-mail from Bill Miller, President, NSWA, to Fred Boadu, June 19, 2007, 4:40 PM (on file with author).

The property rights position is most associated with farmers, landowners, and irrigators, who seek to maintain the rule of capture as a way to have access to unlimited pumping rights. On the other hand, the interest of a rule of capture advocate such as the City of Houston is not immediately clear. One commentator has suggested that some of the parties were probably more concerned about the change in groundwater use liability rules in general than about an interest in property rights to water per se.⁵⁶ This is a plausible explanation, especially in light of the opinion in the *Friendswood* case, in which the court signaled the demise of the no liability rule when harm is caused by groundwater withdrawals.⁵⁷ A similar argument could be made regarding the support of the rule of capture by an organization such as the Texas Justice Foundation (TJF) since it does not directly use water from the aquifer. The TJF by its own mission statement is set up to defend constitutional rights, free markets, parental rights, and “property rights” whenever they find these rights threatened.⁵⁸

Another complication is the extent to which the position of the property rights groups changed over time. A study of the aquifer problem as a case of conflict management shows how the positions of the various groups changed over time.⁵⁹ According to the study, while the early stages of the aquifer conflict were dominated with *interest-based* frames as depicted in defending the sacred principle of “private property rights,” preserving

56. E-mail from Todd Votteler, Ph.D., Executive Manager of Intergovernmental Relations and Policy, Guadalupe-Blanco River Authority, to author (Mar. 20, 2002) (on file with author).

57. See *Friendswood Dev. Co.*, 576 S.W.2d 21.

58. The TJF has been involved in several property rights litigations including *Bragg v. Edwards Aquifer*, 71 S.W.3d 729 (Tex. 2002), where TJF brought suit against the Edwards Aquifer Authority (EAA), claiming that EAA’s denial of Bragg’s pumping rights was unconstitutional and would put the clients out of business (the court found the EAA’s well permitting rules void because the EAA failed to prepare a Taking Impact Analysis as required by the Texas Real Property Rights Preservation Act); *Davidson v. Babbitt*, where TJF represented a couple denied the right to build a home on their land because of a golden cheeked warbler (couple finally is allowed to build a home); *Medearis v. Brazoria County Drainage District No. 4*, Dist. Ct. Brazoria County, 149th Judicial Dist. Tex. (1995) (No. 95-M-2313), brought under the Texas Real Property Rights Preservation Act of 1995 (the court held that the drainage district had exceeded its authority and acted unconstitutionally by committing a taking under the Texas Constitution). See The Justice Foundation, www.tjxf.org/ (go to “Landmark Cases,” “Property Rights”).

59. Putnam and Peterson have applied a model of conflict framing to the dispute over the Edwards Aquifer. Framing refers to how people interpret or make sense of experiences and the way they talk about what is most important or least important in a situation. The authors focused on identity and characterization framing. Identity framing refers to statements or phrases that reflect how the parties in a conflict describe their role, who they are, what is important to them, and how their identity becomes vested in the conflict. Characterization refers to the way that parties describe other people involved in the conflict—ways they see the others as positive, negative, or neutral. See Putnam & Peterson, *supra* note 37, at 150–58.

the springs, and protecting local economies, these identities became *place-based* as a battle between rural and urban counties. Later, when there was a move to declare the aquifer an “underground river,” identities shifted to *institutional domains*, and stakeholders considered the jurisdictions of federal, state, regional, and local authorities as frames for their own identities.⁶⁰

To understand the shifts in identity one has to examine the hydrogeology and movement of water in the aquifer. Imagine a large “bowl” that is buried underground and stretches from west to east. Water collects in this bowl but due to differences in elevation the water flows from west to east. What is known as the “Knippa Gap” is a narrow barrier fault that controls the flow of water from the west side of the aquifer to the eastern side. The nature of the gap prevents huge amounts of water from flowing quickly through the gap, so water piles up in storage units behind it, causing water levels in wells to the west to display much less variability than wells to the east.⁶¹ The western portion of the aquifer is in Uvalde and parts of Medina counties, two major agriculture-based (primarily vegetables) counties. Bexar County is to the east of the gap, and the major water user is the City of San Antonio. With a distinct advantage over access to large quantities of water, residents to the west of the Knippa Gap (rural) have been resistant to changes in pumping rules, while those to the east of the gap (urban) have supported controls over pumping to ensure adequate water flows to the east.

The previous paragraphs suggest that an appropriate quantitative index of the property rights model is the position of farmers (irrigators), who have consistently opposed restrictions on water rights. The position of the Farm Bureau is typical: “in areas of the state without groundwater conservation districts, delegates supported the common law doctrine rule of capture”; “[g]roundwater captured by a landowner should, by law, be owned and fully controlled by the landowner and protected from seizure by eminent domain”; and “[w]e oppose any state control of groundwater.”⁶² In terms of water marketing, the property rights advocates provide a classic example of identity frame shift. At their convention in year 2000, delegates were generally supportive of water marketing as part of a water management plan in the aquifer region: “District rules should not unreason-

60. *See id.*

61. This description of the aquifer and water movement is based on Gregg Eckhardt, *Hydrogeology of the Edwards Aquifer*, EDWARDS AQUIFER WEBSITE, edwardsaquifer.net/geology.html#movement (last visited June 11, 2007).

62. *Water, Farm Income Top Convention Issues*, TEX. AGRIC., Dec. 15, 2000, <http://www.txfb.org/TexasAgriculture/2000/121500water.htm> (statements by delegates at the Texas Farm Bureau’s 67th Annual Meeting).

ably or unconstitutionally prohibit landowners from exercising their private property right to use or market groundwater.”⁶³

This is a fundamental shift in position from 1993 when the Authority legislation was being discussed: “farmers would support a drought plan to limit pumping, but they opposed a permanent cap on pumping and marketing provisions for buying and selling water rights.”⁶⁴ As stated by the president of the Uvalde County Water Conservation Association, “You start buying water rights up and you are going to kill the economy.”⁶⁵ Today landowners are fully in support of water marketing and are even threatening legal action to remove a requirement in SB 1477 that is intended to prevent stripping land of all water rights. To understand the genesis of this issue, one must read sections 1.16 (e) and 1.34 (C) of the Act together. Under section 1.16 (e), an irrigation user may obtain a permit after demonstrating beneficial use for a “historical period” or shall receive a permit “for not less than two acre-feet a year for each acre of land the user actually irrigated in any calendar year during the historical period.” Under section 1.34 (C), “a holder of an irrigation permit may not lease more than 50 percent of the irrigation rights initially permitted. The user’s remaining irrigation water rights must be used in accordance with the original permit and must pass with the transfer of the irrigated land.” In short, there must be at least one acre-foot of water left with each acre of land. This acre-foot of water is called the “Base Acre-Foot.” Conversations with experts at the regulatory agencies seem to suggest that irrigators want the restriction on the base acre-foot removed. The only problem according to one expert is the transaction costs facing a single irrigator interested in starting a movement to challenge the restriction, a classic example of the “free rider problem.”⁶⁶

B. The Induced Institutional Change Model (Ruttan-Hayami)

The Ruttan-Hayami Model explicitly recognizes the interaction of both demand and supply factors in institutional change. On the demand side, individuals seek institutional change because the interaction of technical change, factor endowments, and product demand brings forth a new constellation of appropriable income. Increases in domestic water demand coupled with new demands for protection of endangered species and recreational uses have been important sources of pressures for change in institutional arrangements. However, the appropriation of perceived

63. *Id.*

64. Putnam & Peterson, *supra* note 37, at 139.

65. *Id.* (citing SAN ANTONIO EXPRESS NEWS, Apr. 29, 1993).

66. Personal Communication with Greg Ellis, General Manager, Edwards Aquifer Authority (Jan. 10, 2002).

benefits does not occur in a vacuum but rather depends on the supply of institutional innovation.

On the other hand, the supply of institutional innovation depends on the cost to political entrepreneurs who design new institutions to minimize costs associated with the political competition between strategic coalitions that stand to gain from institutional change. If the private return to the political entrepreneurs differs from the social return, institutional change would not occur or, if it does, would not be supplied at a "socially optimal level."⁶⁷

C. The North Model of Institutional Change

The North Model of Institutional Change distinguishes between changes that occur to improve efficiency and those that redistribute income.⁶⁸ The model focuses on efficiency-promoting change that increases the net social benefit and identifies the four possible sources for increasing incomes: market failure, economies of scale, externalities, and risk. Other exogenous factors such as constitutional amendments, expansion in franchises, or shifts in a community's preferences between public and private solutions to problems may also lead to institutional changes.

Bromley has suggested that the North Model seems to fit a situation where "there are few, if any, existing institutional arrangements in place to organize a new economic activity...[where] there [is] an institutional vacuum."⁶⁹ Citing the evolution of the Prior Appropriation Doctrine in Western water law in support of this view, Bromley explains that the Riparian Rights Doctrine that was imported from England did not protect a water user who wanted to invest in technology to carry water over long distances for irrigation purposes. What was missing was an institutional arrangement that guaranteed the security of investments in water technology to encourage individuals to invest. The Prior Appropriation Doctrine that replaced the Riparian Rights Doctrine provided the needed security of tenure and made it possible for the needed investments in water development to take place.⁷⁰

67. BROMLEY *supra* note 2, at 20 (citing Hayami & Ruttan).

68. When institutional change occurs to improve efficiency, at least one party (person initiating change) is made better off under the change but no one is made worse off. Where the outcome of institutional change is distributional, a party gains only at the expense of some other party. *Id.* at 28.

69. *Id.* at 29.

70. *Id.*

D. Generalized Demand and Supply Model of Institutional Change

David Feeny has combined the three models of institutional innovation to develop what he describes as a “heuristic framework of the demand for and supply of institutional change.”⁷¹ He cautions that the “framework identifies general categories of variables that must in turn be given concrete form relevant to the particular historical or contemporary institutional change being considered.”⁷²

1. Demand for Institutional Change

The underlying factor driving the demand for institutional change is the desire to capture benefits made possible through (1) technology and changes in relative product and factor prices, (2) the constitutional order, and (3) the size of the market.

a. Technology and Changes in Relative Product and Factor Prices

The performance of the agriculture and water economies in the aquifer region supports the proposition that changes in relative product and factor prices have played an important role in the demand for institutional changes. Largely due to population increases and dependence on the aquifer as the sole source of its water supply, the City of San Antonio has experienced significant increases in water rates over time.⁷³ The projected water needs have led to a search for options and practices that rely on the application of new technology to lower the cost of water to consumers.⁷⁴ To meet increasing demands in the near term, water authorities in San Antonio are developing recharge enhancement projects, recycling of wastewater for non-drinking purposes, aquifer storage and recovery programs, and

71. “The framework builds explicitly on the previous work of Davis, Hayami, North, Ruttan, and Thomas.” Feeny, *supra* note 1, at 173, 176; see also BROMLEY, *supra* note 2, at 12, 14, 18–31 (the Hayami and Ruttan model [induced institutional change model] is discussed and critiqued extensively along with North and Thomas’s Transaction Cost model).

72. The flexibility made possible by a general framework is especially useful for adaptation to specific circumstances. The framework is in effect consistent with the observations made in *RETHINKING INSTITUTIONAL ANALYSIS AND DEVELOPMENT*, *supra* note 1.

73. San Antonio’s water needs are projected to double by the year 2050. The Edwards Aquifer will remain the main source of water for the foreseeable future. See SAN ANTONIO WATER SYSTEM, *PLANNING OUR FUTURE FOR THE NEXT FIFTY YEARS*, http://web.archive.org/web/20041012175657/www.saws.org/our_water/future/ (last visited July 7, 2007).

74. Cf. Feeny, *supra* note 1, for the proposition that population increases that led to a decline in real wages combined with technological changes in machinery and fertilizer use that led to yield increases created disequilibria between harvest-share wage and prevailing agricultural wage, and consequently led to demand for institutional change to restore equilibrium.

sustainable withdrawals from nearby aquifers.⁷⁵ Technology is also driving the search for new sources of water to meet long-term needs. A system of river diversions and water treatment projects has been planned to meet the water needs of the SAWS service area.⁷⁶

Water users within the SAWS service area will pay higher prices for water as a result of increasing demand. The San Antonio City Council has approved a multi-year funding mechanism for the development of additional water resources for the SAWS service area.⁷⁷ The new graduated fee schedule adds about three cents per 100 gallons in year 2001, rising to about 13 cents per 100 gallons in year 2005. The revenue is earmarked specifically for water development and represents a separate line item from a consumer's regular water bill. Faced with rising water costs, one can understand why authorities in the SAWS service area would demand institutional changes that support the acquisition of rights to a greater share of the Edwards Aquifer water.⁷⁸

75. Approximately 7,000 acre-feet of sustained yield is expected to be available through recharge by 2007 and roughly twice that amount over the longer term. Recycling of treated wastewater effluent for irrigation and industrial uses will provide 35,000 acre-feet of non-drinking water. Sustainable withdrawals from a portion of the Cow Creek formation of the Trinity Aquifer in northern Bexar County could add about 4,500 acre-feet per year. SAWS has acquired property in southeastern Bexar County for the Aquifer Storage and Recovery (ASR) project using the Carrizo Aquifer as a storage facility. Water would be injected into this sand-based aquifer during periods of rainfall excess and withdrawn during dry periods. This process will yield an additional 30,000 acre-feet. See SAN ANTONIO WATER SYSTEM, SHORT-TERM WATER SUPPLIES, http://web.archive.org/web/20041019113212/http://www.saws.org/our_water/future/short_term.shtml (last visited July 7, 2007).

76. Successful diversion from the lower part of the Guadalupe River basin near the Gulf Coast could yield approximately 60,000 to 70,000 acre-feet. The purchase and transfer of 150,000 acre-feet may be available to SAWS from the Lower Colorado River Authority (LCRA) at Bay City, while acquired ground water from the Simsboro Aquifer in Milam and Lee counties could yield about 55,000 acre-feet. Desalination of seawater is also being considered. See SAN ANTONIO WATER SYSTEM, LONG TERM WATER SUPPLIES, http://web.archive.org/web/20041019112354/http://www.saws.org/our_water/future/long_term.shtml (last visited July 7, 2007).

77. See San Antonio, Tex., Code 92753 (2000) (renumbered as §§ 34-1431 to 34-1439). This amends chapter 34 of the City Code of the City of San Antonio by adding a new article IX, *Water Supply Fee*; SAN ANTONIO WATER SYSTEM, QUARTERLY REPORT ON WATER RESOURCES (City of San Antonio), July–September 2005, available at http://www.saws.org/our_water/waterresources/watersupply/.

78. San Antonio water authorities expect a permit from the Edwards Aquifer Authority that would allow them to withdraw about 135,000 acre-feet of water per year through 2007 and 120,000 acre-feet per year thereafter. These withdrawals are to be supplemented with up to about 50,000 acre-feet of additional Edwards Aquifer pumping rights by purchase or lease of water rights from irrigators. For a summary of SAWS water pumpage and aquifer levels, see San Antonio Water System, http://web.archive.org/web/*/http://www.saws.org/our_water/future/short_term.shtml.

While consumers in urban areas are facing a water price squeeze, irrigators are experiencing a different phenomenon. The behavior of relative product and factor prices in the agricultural sector within the aquifer region followed the national pattern of performance of agriculture. While farm receipts were falling, farm costs were rising.⁷⁹ One immediate impact of falling product prices is to increase the willingness on the part of farmers to lease or sell water rights. There are two main reasons why there has not occurred widespread sale or lease of water rights by farmers. First, the implementing regulations for use of aquifer water have not been finalized. But more importantly, farmers rationally suspect the existence of considerable rents in the water market and are willing to wait for the day when water lease prices rise to the amount of the rent. The argument is that, should a major increase in urban water demand occur as a result of a drought or population increase, the City of San Antonio, for example, can meet this demand only through new water development projects. These projects would make water prices much higher than the current water lease price of \$80 per acre-foot.⁸⁰ Some have intimated that a water lease price of about \$800 per acre-foot is a possibility.⁸¹ This divergence in the current and potential lease price of water has encouraged the emergence of a private agency to market water in the aquifer region.⁸²

b. Constitutional Order

The demand for new institutional arrangements is also influenced by the constitutional order. The constitutional order is the "set of fundamental political, social, and legal ground rules that establishes the basis for production, exchange, and distribution."⁸³ One can point to at least two fundamental changes in constitutional rules that have influenced the demand for institutional change governing water use in the aquifer region. One such change in the constitutional order was the creation of the EUWD

79. For example, using the base period 1990 to 1992, the All Farm Products Index of Prices Received by Farmers in October 2001 "dropped a record 10 points (9.5 percent) to 95 percent from the September Index." "On the other hand, the October Index of Prices paid by farmers for production inputs such as Commodities and Services, Interest, Taxes, and Farm Wage Rates (PPITW) was 123 percent of the 1990-92 base period average. Prices paid by farmers represent the average costs of inputs purchased by farmers and ranchers to produce agricultural commodities." Jose G. Peña, *Continuing Weak Agriculture Outlook Requires Careful Planning for Survival*, 17 AG-ECO NEWS, Nov. 7, 2001, at 1.

80. Telephone interview with Jose Peña, Extension Economist, Uvalde County (Feb. 22, 2002).

81. See edwardswater.com, <http://edwardswater.com/>.

82. *Id.*

83. LANCE E. DAVIS & DOUGLASS C. NORTH, INSTITUTIONAL CHANGE AND AMERICAN ECONOMIC GROWTH 6 (1971).

by the Texas Legislature in 1959.⁸⁴ The EUWD was not the first district to be created in Texas,⁸⁵ and even though it lacked the typical authority that underground water authorities have,⁸⁶ its creation marks a significant event in the evolution of institutions within the aquifer region. As Putnam points out, "Even though the District consisted of representatives from the five major counties linked to the aquifer, it lacked the authority to limit pumping or even to require people to register their wells."⁸⁷ Despite its obvious deficiency, the formation of the EUWD "brought together stakeholders who represented many different interests in this dispute."⁸⁸ Also, by demonstrating the possibility for consensus-building, the EUWD reinforced the long-standing practice of local control of water resources as opposed to a broad statewide rule to control ground water in the region.⁸⁹ The significance of the EUWD is that it laid a foundation for what later became the Authority, the primary agent responsible for the management of the aquifer.⁹⁰

For over two decades there has been a marked increase in the number of environment-related lawsuits brought by private parties and environmental groups. One plausible explanation for the increase in suits is the change in constitutional rules in the form of standing rules.⁹¹ Some

84. See Feeny, *supra* note 1, at 180, for a discussion of how the extension of suffrage in the 1800s (a change in constitutional rule) influenced demand for new institutional arrangements in the form of property rights to land and the resulting change in land holdings from a regime of large land ownership to a regime of small holdings.

85. For a detailed analysis of water districts in Texas, see FRANK F. SKILLERN, *TEXAS WATER LAW* 191-260 (1991).

86. Districts may regulate well spacing, enjoin wasteful water practices such as allowing water to flow into roadside ditches, and conduct public education programs. See RONALD A. KAISER, *HANDBOOK OF TEXAS WATER LAW* 32-33 (1986).

87. Putnam & Peterson, *supra* note 37, at 130 (citing N. Wolf, *Mayor: An Inside View of San Antonio Politics, 1981-1985*, *SAN ANTONIO EXPRESS NEWS*, 1997). See also *supra* notes 32-34.

88. Putnam & Peterson, *supra* note 37, at 132.

89. Former Mayor of San Antonio Henry Cisneros described the plan developed by the EUWD management team as "the finest example of consensus building." *Id.* (citing *SAN ANTONIO LIGHT*, July 29, 1988). It is notable that local control of water resources was also the position of the Texas Farm Bureau and most of the Parties that filed Amici in the Sierra Club Case. See Correspondence from Greg Ellis, Edwards Aquifer Authority (Jan. 7, 2002) (on file with author).

90. Even though Article 1, Section 1.42 (a) of the Act repealed the EUWD, (b) through (e), read together, suggest that the Edwards Aquifer Authority is to be a successor agency to the EUWD.

91. The Supreme Court has articulated the constitutionally imposed requirements for associational standing. In *Warth v. Seldin*, 422 U.S. 490 (1975), the court held that [e]ven in the absence of injury to itself, an association may have standing solely as the representative of its members.... The association must allege that its members, or any one of them, are suffering immediate or threatened injury as a result of the challenged action of the sort that would make out a justiciable case had the members themselves brought suit.... So long as this

commentators have pointed to the inconsistency and unpredictability of the Supreme Court's standing rules until recently.⁹² Environmental groups were particularly alarmed by the Supreme Court ruling in the case of *Lujan v. Defenders of Wildlife*,⁹³ where the Court refused to apply the "injury-in-fact" requirement in determining standing. The Defenders of Wildlife filed suit seeking the application of the Endangered Species Act to activities funded by the United States in foreign countries. In this case, U.S. funds were to be used to fund an irrigation project in Sri Lanka and to rebuild the Aswan Dam on the Nile River in Egypt. The project in Sri Lanka threatened the endangered elephant found in the region, and the project on the Nile River threatened an endangered crocodile. The Supreme Court ruled that the Defenders had failed to show that one or more of their members would be "directly" affected from their "special interest" in the subject.⁹⁴

The ruling in *Lujan* cast doubt on what most considered to be the standing rule as implied by a previous ruling in the case of *Sierra Club v. Morton*.⁹⁵ The Court in *Morton* denied standing to the Sierra Club because it failed to show that any of its members would be adversely affected by the development complained about. In effect, the High Court was willing to grant standing to an organization that demonstrates that its members would be adversely affected by failure of a governmental agency to comply with an environmental statute. It is in light of this "injury-in-fact" standing rule that the *Lujan* ruling sent shock waves through the environmental movement community.⁹⁶ Thus, when the Supreme Court granted standing to an environmental group, Friends of the Earth (FOE), in the case of *Friends of the Earth v. Laidlaw*, environmental groups were reinvigorated.⁹⁷

The change in constitutional rules in the form of citizens' standing clearly enhanced the chances of a successful challenge by the Sierra Club against the rule of capture. One important change brought about by the

can be established, and so long as the nature of the claim and of the relief sought does not make the individual participation of each injured party indispensable to proper resolution of the cause, the association may be an appropriate representative of its members, entitled to invoke the court's jurisdiction.

Id. at 511.

92. See Hudson P. Henry, Case Note, *A Shift in Citizen Suit Standing Doctrine: Friends of the Earth Inc. v. Laidlaw Environmental Services*, 28 *ECOLOGY L.Q.* 233 (2001).

93. 504 U.S. 555 (1992).

94. *Id.* (citing *Sierra Club v. Morton*, 405 U.S. 727, 735, 739 (1972)).

95. *Morton*, 405 U.S. 727.

96. Henry, *supra* note 92, at 236-37.

97. *Id.* at 252. Although the continuing compromise between private and public law models of standing and separation of powers issues remains a source of uncertainty, *Laidlaw* signifies a much more predictable and progressive citizen suit standing doctrine. After years of marginal usefulness, environmental citizen suits have been given new life. *Id.*

Laidlaw decision is that the “injury-in-fact” requirement for standing was extended to include a plaintiff’s relationship with the environment and an examination of congressional intent in legislation.⁹⁸ Prior to this decision, several environmental suits had been dismissed because Plaintiffs could not prove any direct injury, and their claim of injury due to their special relationship with the environment had been considered “speculative.”

In the Texas *Sierra Club* suit, the Plaintiff’s key witness was Professor Clark Hubbs, the Regents Professor Emeritus of Zoology at the University of Texas, Austin, who has spent a lifetime of teaching and research on the ecology and fish life in Texas rivers and lakes. Professor Hubbs’ background and his contribution to our understanding of the ecology of rivers and fish in the State of Texas, and the potential “injury” to him should the Edwards-dependent species be destroyed, clearly meet the “injury-in-fact” standard announced in *Laidlaw*. Indeed, after over 35 years of study of aquatic life in the Edwards region, even a *Morton* or *Lujan* court would have been hard pressed to find Professor Hubbs’ interest “speculative.”⁹⁹ The willingness of the court to recognize the recreational interest as basis for granting standing, as in the situation in *Laidlaw*, and the research and professional interest as in *Sierra Club*, is an example of a change in constitutional rule that lowers the transaction costs facing environmental groups in bringing lawsuits to enforce environmental laws. It is in this sense that a change in constitutional rule could encourage the demand for institutional changes that allow individuals to take advantage of opportunities in the society.

c. Size of the Market

The size of the aquifer water market is an important factor in the demand for institutional change to manage water in the region.¹⁰⁰ An

98. One FOE member, Kenneth Lee Curtis, averred that he lived near the facility and occasionally drove over the river. Curtis stated that he would like to “fish, camp, swim, and picnic in and near the river between 3 and 15 miles downstream from the facility.” *Friends of the Earth, Inc.*, 528 U.S. at 181–83. Other plaintiff group members attested to similar concerns. See *id.* Citizens League for Environmental Action Now member Gail Lee averred that her home near *Laidlaw*’s facility “had a lower value than similar homes located further from the facility, and that she believed the pollutant discharges accounted for some of the discrepancy.” *Id.*

99. In conversations with the *Sierra Club*’s (Plaintiff) attorney, Mr. Stuart Henry, he pointed out that he could not foresee any existing standing rule that would have defeated Mr. Hubbs’ credentials. Interview with Professor Clark Hubbs, Regents Professor Emeritus of Zoology, University of Texas, Austin (June 4, 2002).

100. See Feeny, *supra* note 1 (suggesting that the introduction of general laws of incorporation, especially limited liability laws, as a new institutional arrangement was in response to an expansion in the size of the market made possible through improved transportation and economies of scale due to technological advances and how the limited liability company made it possible to obtain capital for investment purposes from several individuals).

expansion in the size of the market allows fixed costs to be spread over a large number of transactions, leading to economies of scale.¹⁰¹ The resulting economies of scale means that fixed costs become less of an impediment to institutional innovation and interested parties may take advantage of the lower market entry costs to seek changes in institutions.¹⁰²

The Texas water code contains a ranking of the preferences for water uses in the State.¹⁰³ The ranking gives some indication of what may be considered the "water market" in Texas. While recreational use is included, albeit as a low priority preference, one may argue that a broader specification of preferences may be useful in light of events that led to the observed institutional innovation. Concerns about domestic, municipal, industrial, and irrigation uses of water are of the highest priority and essentially defined the water scarcity sources of the institutional changes that occurred in the aquifer region. However, it was concern about a much lower priority use that dealt a blow to the rule of capture. Under the Water Statute, recreational use of water is of low priority, and use for environmental protection is not even mentioned. One could argue that the catchall priority – public welfare – captures environmental use priority. But even in this case, environmental use is treated only as a residual priority even though primarily environmental concerns led to a change in institutional arrangements in the aquifer region.¹⁰⁴ The problem in including environmental use as a component of the water market is valuation. For example, how much is an endangered species worth? The difficulty in placing monetary values on some of the benefits of institutional change is an important consideration in quantitative analysis of institutional change.¹⁰⁵

The market for aquifer water also includes instream uses even though such use is not extensively discussed in the literature. Water recreation related expenditures in the Guadalupe region generated over \$155 million in 1995.¹⁰⁶ Inshore and offshore commercial fish landings in the Guadalupe Estuary generated an estimated \$20 million and about 497 jobs.¹⁰⁷ The San Marcos River Foundation has applied for a water right

101. *See id.*

102. *See id.*

103. TEX. WATER CODE ANN. § 11.024 (Vernon 1983).

104. The series of lawsuits filed by the Sierra Club have all been concerned with the protection of the Edwards Aquifer-dependent species.

105. *See infra* Part III for further discussion of non-quantifiable benefits and costs in the jurisprudence of institutional change.

106. Recreational activities include boating, fishing, and birdwatching. LONNIE L. JONES & AYSEN TANYERI-ABUR, IMPACTS OF RECREATIONAL AND COMMERCIAL FISHING AND COASTAL RESOURCE-BASED TOURISM ON REGIONAL AND STATE ECONOMIES 7 (Tex. Water Resources Inst., TR-184, 2001).

107. *Id.* at 16.

permit intended to keep over a million acre-feet of water in the Guadalupe River to protect estuaries and bays.¹⁰⁸

2. *The Supply of Institutional Change*

The interaction between political actors, strategic groups, and key institutional players like the courts determines the supply of institutional changes in a constitutional democracy.¹⁰⁹ The threshold issue is the capability and willingness of the major actors to supply institutional change.¹¹⁰ There are considerable degrees of freedom in defining those factors that affect a supply curve. Some of the key factors influencing the willingness and capability to supply institutional change include the existing stock of knowledge, the costs of institutional design, the implementation of new arrangements, and the expected net benefits to powerful elite decision makers who exercise positions of dominance.¹¹¹

a. *Stock of Existing Knowledge and Technology*

Scientific knowledge about groundwater resources has contributed in important ways to the evolution of institutions governing ground water in Texas. Generally, new knowledge and technology have the effect of lowering the marginal cost curve for institutions, thereby increasing the supply of institutions.

It is significant that the historical adoption of the rule of capture was to an extent determined by knowledge and technology. In the early case of *Houston & Texas Central Railway Co. v. East*,¹¹² the court's rationale for adopting the rule of capture was based primarily on the lack of knowledge about the hydrology of ground water.¹¹³ Decisions in several subsequent cases have been greatly influenced by new knowledge about the hydrology

108. The permit requests about 1.3 million acre-feet of water, an amount of water estimated by the Texas Parks and Wildlife to be what is needed to satisfy the biological needs of the Guadalupe estuary. The Foundation has also applied for 157,000 acre-feet to protect the San Marcos River. Kevin Carmody, *Foundation Hopes to Protect Rivers with Water Rights*, AUSTIN AM. STATESMAN, July 28, 2001, at B1. The Guadalupe River is an integral component of the Edwards region water market.

109. See Feeny, *supra* note 1, at 183 (the supply of institutional changes depends on the capability and willingness of the political order to provide new arrangements).

110. *Id.*

111. Here we have limited ourselves to those factors considered most critical in the Edwards Aquifer context.

112. 81 S.W. 279 (Tex. 1904).

113. Because the existence, origin, movement, and course of such waters, and the causes which govern and direct their movements, are so secret, occult, and concealed[,] an attempt to administer any set of legal rules in respect to them would be involved in hopeless uncertainty, and would, therefore, be practically impossible.

Id. at 281.

of ground water. For example, in the case of *Denis v. Kickapoo Land Co.*, the court used knowledge of groundwater hydrology in making a distinction between the “underflow” of a water course and “percolating” ground water, which is the object of the rule of capture.¹¹⁴ In the *Denis* case, the court concluded that a spring from which a landowner withdrew water had the characteristics of a surface stream subject to state control.¹¹⁵

New scientific information about the relationship between groundwater withdrawals and land subsidence has been a source of change in the groundwater rule of capture. The primary change has been a movement away from the pure English rule of no liability for injury to a landowner caused by groundwater withdrawals to a rule that recognizes some basis for recovery for such injury. Also, new knowledge has been used to regulate land use practices such as well spacing and drilling. The leading case is *Friendswood Development Co. v. Smith-Southwest Industries*, in which the Supreme Court of Texas explicitly acknowledged the importance of new scientific knowledge in the regulation of groundwater resources in Texas.¹¹⁶ Once legislators were supplied with new knowledge about the hydrology of ground water, the cost of supplying institutions change was lowered, thereby increasing the supply of institutional change. The availability of new knowledge in combination with the Supreme Court’s recognition of the constitutional authority of the legislature to regulate groundwater production in the state led one commentator to conclude that the *Friendswood* ruling offers an “invitation to the state legislature to take further action.”¹¹⁷ The passage of SB 1477 was in effect a predictable event.

The *Denis* case also highlights the role of new knowledge in defining groundwater rules.¹¹⁸ In *Denis*, a downstream landowner filed an action to stop an upstream landowner from using water adjacent to a spring for irrigation purposes. The upstream landowner had drilled a well adjacent

114. See HUTCHINS ET AL., *supra* note 53, at 564.

115. *Denis v. Kickapoo Land Co.*, 771 S.W.2d 235, 236 (Tex. Ct. App. 1989) (writ denied). The subterranean watercourse must have the same characteristics as a surface watercourse — beds, banks forming a channel, and a current of water. *Id.* (citing C. KINNEY, A TREATISE ON THE LAW OF IRRIGATION AND WATER RIGHTS § 1195, at 2167 (2d ed. 1912)).

116. 576 S.W.2d 21 (Tex. 1978).

As heretofore mentioned, the Legislature has entered the field of regulation of ground water withdrawals and subsidence. This occurred after geologists, hydrologists, and engineers had developed more accurate knowledge concerning the location, source, and measurement of percolating underground waters, and after legislators became aware of the potential conflicts inherent in the unregulated use of ground water under the English rule of ownership.

Id. at 29.

117. 3 WATERS AND WATER RIGHTS § 20.07(a), at 20–39 (Robert E. Beck ed., 1991) (2003 repl. vol.).

118. *Denis*, 771 S.W.2d 235.

to the spring and in so doing limited the amount of water that flowed from the spring to the downstream user. The downstream user argued for the water from the well to be treated as an underground stream and therefore subject to regulation by the state. An Appeals court relied primarily on the scientific evidence presented by two hydrologists and concluded that the groundwater source did not have the characteristics of a stream to be subjected to regulation by the State.¹¹⁹

Prior to the *Denis* case, the Guadalupe-Blanco River Authority (GBRA) had filed an action seeking to declare the aquifer an underground river.¹²⁰ As one commentator put it, the narrow configuration and rapid flow and recharge characteristics of the aquifer encouraged the view that it is a well-defined underground stream.¹²¹ In 1991, the Texas Water Commission (TWC) picked up the thread started by the GBRA and sought a ruling from the Attorney General of Texas on whether they had the legislative authority under section 28.011 of the Texas Water Code to declare the aquifer an underground stream.¹²² Even though the attorney general did not find any legal basis to support TWC's claim to delegated legislative authority, the TWC still went ahead to declare the aquifer an underground stream subject to state control.¹²³ The TWC felt that they had enough knowledge about the hydrology of ground water to support the declaration.¹²⁴ The TWC decision was overturned by the district court of Travis County.¹²⁵

b. The Cost of Design and Implementation of Institutional Change

Feeny has suggested that the cost of groundwater institutions that originate from within a community are generally lower than those imposed

119. The subterranean watercourse must have the same characteristics as a surface watercourse — beds, banks forming a channel, and a current of water. *Id.* at 236.

120. See *In Re Adjudication of Rights to Water in the Edwards Aquifer*, No. 89-0381 (Dist. Ct. Hays County 1989).

121. Robert Pressley, *Alternative Legal Bases for Managing the Edwards Aquifer*, 22 ST. B. TEX. ENVTL. L.J. 42, 46 (1991).

122. TEX. WATER CODE ANN. § 28.011 (Vernon 1993) ("Except as otherwise provided by this code, the commission may make and enforce rules and regulations for protecting and preserving the quality of underground water.").

123. See 31 TEX. ADMIN. CODE § 298 (1992) for the TWC Emergency rule declaring the Edwards Aquifer an underground stream, and 31 TEX. ADMIN. CODE § 298 (1992) for the permanent rules.

124. Knowledge of the unique characteristics of the Aquifer included (1) well-defined boundaries, (2) well-defined sources of water, (3) rapid flow in a well-defined direction, (4) well-defined destinations of the aquifer water to discharge at the springs, and (5) the presence of fish and other aquatic life. See Votteler, *supra* note 32, at 121.

125. See *McFadin v. Tex. Water Comm'n*, No. 92-05214 (Dist. Ct. Travis County 1992).

by a governmental bureaucracy.¹²⁶ A rational explanation for the lower cost is that since the institutions developed by the community are based on consensus, compliance and enforcement costs would be lower than the costs associated with institutions imposed by fiat. Arguing along these lines, one would conclude that the cost of the factors of production in institutional design in the aquifer region is lower than an alternative system that would have entailed extensive governmental control. Texas has used the groundwater conservation district management framework to promote local control of resources. As one commentator has argued, the primary reason some opposed the abandonment of the rule of capture was to ensure local control of water resources. The rule of capture promotes the creation of groundwater conservation districts as opposed to a statewide regulatory scheme.¹²⁷

Non-quantifiable costs may also be significant, including process costs, such as costs of assembling parties in negotiation, discussing a particular aquifer management plan, and making decisions about alternatives.

Sometimes also, rules and regulations may overlap and raise compliance costs. Parties in negotiations may adopt costly holdout tactics and may also over-invest to prevent opportunism. Special interest influence may also increase costs, especially where such influence leads to the creation of capturable rents by parties in strategic positions to do so.

c. Benefits of Institutional Change as the Source of Supply

The creation of an aquifer management entity and the requirements of permits for the withdrawal of ground water effectively ended the common law rule of capture as it pertains to the aquifer. The benefit of this transition may be examined from both procedural and substantive perspectives.

As a procedural matter, prior to the institutional change, one acquired groundwater water rights incident to the acquisition of land. Under the rule of capture, the owner of a well had no assurance that water would be available. The rules under the new regime remove this uncertainty by establishing one management entity with clearly defined jurisdiction. In addition, the new rules have established procedures for public input, hearings, notices, and comment on proposed regulations.¹²⁸

126. See Feeny, *supra* note 1 (comparing the cost of groundwater institutions in California that were designed by voluntary organizations and those in Arizona where the institutions were of a bureaucratic origin. Feeny concluded that the California system was cheaper.)

127. Interview with Greg Ellis, General Manager, Edwards Aquifer Authority (Jan. 7, 2002).

128. All enforcement proceedings under the Act are subject to the Administrative Procedure and Texas Register Act, TEX. GOV'T CODE ANN. ch. 2001 (Vernon 1988). See Edwards Aquifer Authority Act § 1.37(r).

Considerable substantive welfare benefits to the aquifer region and the State of Texas are created under the new rules. Simulation results based on a mathematical programming model quantitatively assess the welfare benefits of the institutional changes that occurred within the aquifer region.¹²⁹

III. QUANTITATIVE ASSESSMENT OF INSTITUTIONAL CHANGE

Both the demand and supply of institutional changes depend on whether the benefit of the change exceeds the cost. In the context of the aquifer, the question arises as to whether benefits associated with the change from the common law rule of capture to a regulated groundwater regime exceed the cost.

In its findings and declaration of policy, the Texas Legislature declared the aquifer to be a distinctive natural resource. The legislature also emphasized the need to protect the interests of the various publics that depend on the aquifer through the formation of the Edwards Aquifer Authority.¹³⁰ Whether the legislature made the right decision in entrusting the management of the aquifer to the Authority is not easy to ascertain because of several complex and sometimes difficult dilemmas. For example, how should the Authority balance the protection of a valued natural resource against the possible extinguishment of the hallowed principle of private property rights? Or how well have groundwater and surface water linkages been exploited to support an efficient water management system? These complexities are not fatal to a systematic examination of the real costs and benefits associated with the observed institutional change.

A. Quantifiable Costs Associated with the Institutional Change

This study employed a simple technique to obtain some estimates of the substantive and procedural costs associated with the institutional change. According to the Legislative Budget Board, the total budget for the administration and enforcement of the Act is between \$10 and \$14 million.¹³¹ Litigation and court costs incurred by various strategic parties to the dispute were added to the estimated administrative and enforcement costs. One agency official put its overall agency costs to date at \$5 million. Using a published base cost figure for this agency, we calculated a cost

129. See Interview with Greg Ellis, *supra* note 127.

130. Edwards Aquifer Authority Act § 1.01.

131. See St. of Tex. Legis. Budget Board, Fiscal Note, 73rd Regular Sess. (1993) (memo from Jim Oliver, Director, to Honorable Bill Sims, Chair, Committee on Natural Resources (Tex. Senate Chamber) (May 10, 1993).

inflation index as the ratio of this agency's published 1990 cost to its current cost. This index was used as the common factor to estimate the current costs for other agencies based on their known 1990 costs. The current costs for the City of San Antonio, SAWS, the GBRA, and the EUWD were included in the calculation.¹³² The estimated current total cost for these stakeholders is about \$25 million. An additional amount of about \$50 million was included in the initial EDSMIR model to account for in-house process costs and costs incurred by various non-governmental agencies involved in the aquifer dispute.¹³³ Adding it all up yields a total cost of about \$84 million. Clearly, this is a considerable over-estimate of what may be termed the transaction costs associated with the institutional change that occurred with respect to the aquifer. The assessment of benefits is made against this estimated cost.

B. Non-quantifiable Costs of the Institutional Change

There are several non-quantifiable costs associated with all institutional changes. In the context of the aquifer, some of these costs may indeed be more important than the quantified costs.

1. Process Costs

Since 1970, when the Texas Water Quality Board (TWQB) first issued a "Board Order" for aquifer protection, numerous public hearings, referenda, and meetings have been held, generating organizational costs that cannot be captured in any reasonable manner. Based on a chronology of the aquifer debate, one could reasonably conclude that these organizational costs exceed the quantified costs associated with litigation and administration.¹³⁴

2. Regulatory Dissonance

The costs associated with operating a system that depends on the interface of federal, state, and local laws and regulations is likely to raise compliance costs and pose significant challenges in implementation. The

132. The 1990 costs for the key stakeholders were City of San Antonio (\$371,000); San Antonio City Water Board (\$272,000); the Guadalupe Blanco River Authority (\$221,000); the Edwards Underground Water District (\$173,000). See *TWC Brokers Compromise in Edwards Aquifer Lawsuit, Legal Fees to \$1 Million*, 3 NEWWAVES (Newsl. of the Tex. Water Resources Inst.), Mar. 1990, at 9, 9-10. The source of the base estimate of \$5 million is intentionally omitted.

133. This is obviously a very high figure but we chose to err on the side of caution and to deflect any implication of underestimation of what may be considered the "transaction costs" associated with the institutional change.

134. Between 1970 and 1993 when the Edwards Aquifer Bill was passed, there were over 50 major events organized by councils, local organizations, task forces, planning commissions, boards, and technical committees.

Corps of Engineers has participated in the construction of dams and reservoirs.¹³⁵ These surface water resources directly influence negotiations on the use of groundwater resources. Various state water agencies have also been active in monitoring both the quality and quantity of water from the aquifer, while local organizations such as the EUWD have also been active in the debate over water from the Aquifer.

3. *Holdouts*

One could argue that bargaining costs more so than litigation costs have been very high.¹³⁶ The chronology of the aquifer is replete with instances of holdouts, delays, and threats by groups. For example, in January 1989, Uvalde and Medina Counties voted to pull out of the Edwards District, and later formed their own District, which was later declared illegal.¹³⁷ Various attempts to mediate the allocation of aquifer water also failed.

4. *Special Interest Influence*

A major difficulty in assessing the costs associated with the institutional changes in the aquifer region is the inability to accurately determine what costs and whose costs to count. In those situations where interest groups directly participate in litigation or indirectly as amici, it is often not difficult to determine costs. However, where interest groups work to influence the nature of statutory criteria or wording of a particular legislation, the costs are more challenging to quantify. Since the wording of the statutory criteria influences future interpretation of a statute, groups incur significant costs to influence the criteria ab initio. There is no reasonable way to determine the extent of these costs even though they may be substantial.

IV. THE BENEFITS OF THE INSTITUTIONAL CHANGE

The welfare benefits of institutional change were estimated using a model that depicts the interdependencies between the aquifer water and surface water flows from the Nueces, San Antonio, and Guadalupe rivers.¹³⁸

135. For example, the Corps of Engineers joined with GBRA in the construction of Canyon Lake and in 1974 Congress passed Public Law 93-943 authorizing the construction of Cibolo Reservoir. See SAN ANTONIO WATER SYSTEM, HISTORY & CHRONOLOGY, http://www.saws.org/who_we_are/chrono/chronol50.shtml (last visited Mar. 19, 2007).

136. Putnam described the debate over the Edwards Aquifer as "intractable," suggesting very high bargaining costs. Putnam & Peterson, *supra* note 37, at 158.

137. SAN ANTONIO WATER SYSTEM, *supra* note 135.

138. This model is referred to as *The Edwards Aquifer Simulation Model (EDSIMR)*. See Dhazn Gillig et al., *An Economic, Hydrologic, and Environmental Assessment of Water Management Alternative Plans for the South Central Texas Region*, 33 J. AGRIC. & APPL. ECON. 59, 61-71 (2001).

The U.S. Geological Survey's (USGS) data on river/reservoir reaches gathered from stream gauges were combined with data from a private engineering firm, HDR Engineering, Inc., for use in the simulation analysis.¹³⁹

The combination of groundwater and surface water data in the model reflects the hydrological inter-connectedness between the river systems and the aquifer through aquifer recharge, spring discharge, and return flow. The model includes data on return flows from municipal and industrial uses since return flows from agriculture are negligible.¹⁴⁰ It is assumed that the rate of return flow for municipal water is 55 percent and for industrial water 34 percent.¹⁴¹ The return flow rates are calculated as an average across the counties in the region based on 1995 USGS *National Water-Use Data Files*.¹⁴² The model reflects the weather and climate conditions in Texas to a remarkable degree by considering several alternative weather and climate patterns.¹⁴³ The model also captures the Texas weather cycle and its effects on water availability in the aquifer by using recharge data covering the period 1934 to 1996.¹⁴⁴ The theoretical details and structure of the model are discussed in the Appendix.

The beginning point in measuring the benefits of the institutional change is to examine the legislative intent to effect the institutional changes in the aquifer region. The intent was to (1) protect terrestrial and aquatic life; (2) protect domestic, municipal, and industrial water supplies; and (3) promote the economic development of the state.¹⁴⁵ The legislature also endorsed water marketing as a means of putting water to its most valued use.¹⁴⁶

139. *Id.* at 71.

140. *Id.* at 61.

141. HDR ENG'G, INC. & GERAGHTY & MILLER, INC., NUECES RIVER BASIN REGIONAL STUDY (technical report prepared for the Edwards Aquifer Underground Water District, San Antonio, Tex. 1993).

142. See USGS, <http://water.usgs.gov/watuse/wudata.html> (follow link to "USGS Water Use in the United States" and "Download 1995 data for counties and watersheds").

143. "EDSIMR operates across a ten-state representation of the probability distribution of recharge and associated precipitation ranging from very dry to very wet years." Gillig et al., *supra* note 138, at 62.

144. The years included, ordered from most dry to most wet, are 1956 (annual recharge at 43,758 acre-feet), 1951, 1963, 1989, 1952, 1996, 1974, 1976, 1958, and 1987 (annual recharge at 2,003,643 acre-feet).

145. Edwards Aquifer Authority Act art. 1, § 1.01 (2003).

146. *Id.* art. 1, § 1.34(c).

A. Protection of Terrestrial and Aquatic Life

Simulation results show that the goal to protect terrestrial and aquatic life has been achieved. Table 2 shows the elevations at the aquifer, springflows at the Comal and San Marcos springs, and water flows to the Calhoun and Corpus bays. The simulations are undertaken under alternative pumping limits as mandated under the Act. The implications of introducing water marketing are also presented. The simulation projects water use to the year 2012, based on legislative directives. The legislature directed the Authority to "implement and enforce water management practices, procedures, and methods to ensure that not later than December 31, 2012, the continuous minimum springflows of the Comal Springs and San Marcos Springs are maintained to protect endangered and threatened species to the extent required by Federal law."¹⁴⁷

Prior to the change in institutional arrangements, the most environmentally sensitive spring, the Comal Spring, was almost dry.¹⁴⁸ The model results show that springflow in both the Comal Spring and San Marcos Spring are adequate to protect the habitat for the one threatened and seven endangered species listed by the U.S. Fish and Wildlife Service (USFWS). Under the "no water market" scenario, springflow exceeds both the minimum "take" and "jeopardy" springflow levels defined by the USFWS.¹⁴⁹

147. *Id.* art. 1, § 1.14(h).

148. Under the rule of capture, the "status quo" in Table 1, the model results yield a zero cubic-feet per second (cfs) flow in the Comal Spring.

149. The minimum springflow to avoid "take" in the Comal is 200 cfs, and the minimum to avoid "jeopardy" is 150 cfs. SAN MARCOS/COMAL RECOVERY TEAM & U.S. FISH & WILDLIFE SERV., SAN MARCOS & COMAL SPRINGS & ASSOCIATED AQUATIC ECOSYSTEMS (REVISED) RECOVERY PLAN 17 (1996).

Table 2. Simulation Results for Elevations, Springflows, and Bay Flows: With and Without Water Marketing Under Alternative Pumping Restrictions for Projected Year 2012 Water Demand

			Water Market			No Water Market		
			Mandated Pumping Limit Imposed			Mandated Pumping Limit Imposed		
Environmental Attribute	Unit ^b	Status Quo ^c	400 ac/ft.	340 ac/ft.	175 ac/ft.	400 ac/ft.	340 ac/ft.	175 ac/ft.
J-17 Elevation ^a	feet	552.6	629.4	657.9	735.7	657.6	671.9	736.0
Sabinal Elevation	feet	655.9	740.4	772.7	861.2	772.6	788.8	861.3
Comal Springflow	Cfs	0.0	69.2	234.7	689.0	239.8	323.6	690.0
San Marcos Springflow	Cfs	20.5	67.2	85.3	134.5	86.1	95.3	135.0
Calhoun Bay Flow	10 ³ ac/ft	141.8	246.5	315.0	497.7	302.0	337.1	488.8
Corpus Bay Flow	10 ³ ac/ft	74.0	50.5	50.5	50.5	74.0	74.0	74.0

^a The Index Well for the Edwards Aquifer is well J-17.

^b Cfs is cubic-feet per second and measures the rate of flow of water in a stream.

^c Status quo refers to the conditions of the Edwards Aquifer prior to the institutional changes.

Table 3. Simulation Results for Water Consumption by Major Stakeholders: With and Without Water Marketing Under Alternative Pumping Restrictions for Projected Year 2012 Water Demand

			Water Market			No Water Market		
			Mandated Pumping Limit Imposed			Mandated Pumping Limit Imposed		
Water Consumption	Unit ^a	Status Quo ^b	400 ac/ft.	340 ac/ft.	175 ac/ft.	400 ac/ft.	340 ac/ft.	175 ac/ft.
EA Agricultural Pumping	10 ³ ac/ft	84.8	75.7	75.7	75.7	86.3	86.4	75.7
EA M&I Pumping	10 ³ ac/ft	467.8	324.1	264.2	99.2	252.6	222.2	92.1
Water Transfers	10 ³ ac/ft	-	119.26	90.1	9.5	-	-	-
Value of Water Market	\$10 ⁶	-	190.6	173.5	-0.4	-	-	-

^a Cfs is cubic-feet per second and measures the rate of flow of water in a stream.

^b Status quo refers to the conditions of the Edwards Aquifer prior to the institutional changes.

Table 4. Simulation Results for Economic Welfare of Major Stakeholders: With and Without Water Marketing Under Alternative Pumping Restrictions for Projected Year 2012 Water Demand

			Water Market			No Water Market		
			Mandated Pumping Limit Imposed			Mandated Pumping Limit Imposed		
Economic Welfare	Unit ^a	Status Quo ^b	400 ac/ft.	340 ac/ft.	175 ac/ft.	400 ac/ft.	340 ac/ft.	175 ac/ft.
Agricultural Income ^a	\$10 ⁶	23.1	22.0	23.0	23.8	24.4	24.5	24.2
Agricultural Income ^c	\$10 ⁶	-	33.4	29.7	24.3	-	-	-
M & I Welfare	\$10 ⁶	953.5	876.5	783.3	288.2	706.3	622.3	289.7
Total Welfare	\$10 ⁶	976.6	909.9	813.0	312.5	730.7	646.8	313.9

^a Cfs is cubic-feet per second and measures the rate of flow of water in a stream.

^b Status quo refers to the conditions of the Edwards Aquifer prior to the institutional changes.

^c Measured in US \$millions.

B. Agricultural, Municipal, and Industrial Water Consumption

Read together with Table 2, simulation results in Table 3 support some of the hypotheses offered to explain the sources of institutional change. The two tables reveal the objectives for the major stakeholders: environmentalists, municipal users, and irrigation users. In addition to satisfying the environmental demand, increased municipal demand for water as a result of population growth has significantly raised the scarcity value of water relative to the value of water for irrigation purposes. By introducing water marketing as an institutional innovation, water for municipal use has been reallocated to restore equilibrium. Thus, Table 2 shows that, in the absence of a water market, irrigation use of water is not significantly different from the status quo, while with the introduction of water market institutions, irrigation use declines while municipal use increases above the scenario with no market institutions. The phenomenon is consistent with the induced institutional innovation explanation of institutional change.

The results also explain why municipal users and environmental groups advocated for abandonment of the rule of capture, and irrigation users advocated for retention of the rule. The later shift in the position of the irrigation users in support of water marketing is also consistent with the property rights school that considers changes in institutions to be the result of perceived opportunities made possible through technological change.

C. Welfare Benefits to Major Stakeholders

Table 4 presents the simulation results for total welfare benefits and benefits to the major stakeholders in the aquifer region. Total welfare declines with the introduction of pumping limits. The decline with no water marketing is about \$145.9 million at the threshold-pumping limit of 400 acre-feet. This decline is measured using the status quo welfare measure as reference. When water marketing is allowed, however, the decline in welfare is \$66.7 million. The introduction of water marketing leads to a gain of about \$79.2 million. This represents a real gain if one considers the fact that the \$66.7 million loss does not take into account gains in springflows to protect endangered species and the value of downstream uses such as recreation.

With only a minor difference, the distribution of economic welfare among the major stakeholders follows the pattern observed for total welfare. Using the status quo as a reference point, irrigation users (agriculture) gain slightly (about \$1 million) under all pumping limits scenarios when there is no water marketing. Under the full institutional change (pumping limits with water marketing), agriculture suffers a slight loss (about \$1.1 million) when the pumping limit is 400 acre-feet, but there is a slight gain (less than \$1 million) under the 340 acre-feet and 175 acre-feet pumping limit scenarios.

The pattern of economic welfare outcomes for municipal and industrial users is different. There are welfare losses under all pumping limits scenarios (market and no-market) for municipal and industrial users. However, losses under the market scenarios are smaller than under the non-market scenarios. In a sense, the municipal and industrial users gained when market transfers are introduced even though they suffer welfare losses when water marketing is not permitted.

What emerges from the simulated welfare outcomes is that the institutional change from the rule of capture to a managed system with water marketing leads to both total welfare losses and losses to the major stakeholders in the aquifer region. This conclusion, however, must be interpreted within the context of what the suppliers of institutional change sought to do.

First, the legislature explicitly stated an interest in protecting the "terrestrial and aquatic" life that is dependent on the aquifer.¹⁵⁰ While the simulated model results show that springflows and bay flows are adequate to satisfy the legislative directive, the model does not provide empirical monetary values to permit a comparison of benefits and costs. Studies indicate that benefits from springflows in the Comal and San

150. Edwards Aquifer Authority Act art.1, § 1.01.

Marcos rivers and flows to the Calhoun and Corpus bays for the protection of "terrestrial and aquatic" life could be quite substantial. One study has estimated that fish landings in the Guadalupe estuary generated about \$20 million, providing about 497 jobs in 1995. The same study estimated that recreational travel spending in the region reached about \$154 million.¹⁵¹ This admittedly rough estimate suggests that, when all benefit sources are considered, one would conclude that economic welfare did not decline as a result of the institutional change. This is true under the 400 acre-feet pumping limit, with or without water marketing.

It is quite plausible that the simulated economic welfare results underestimate the benefits of the institutional change. The water market in the aquifer is best characterized as a monopsony, that is, a single buyer facing a group of perfectly competitive sellers. SAWS is by far the largest buyer of water rights in the aquifer region.¹⁵² SAWS sets the purchase price of water and buys water rights from a large number of landowners in the region. As the dominant or sole buyer of water rights with the ability to set the price of water, a permit holder has to either sell to SAWS or hold the permit. While the cost of water development is a critical factor in setting water price, SAWS' monopsony position allows it to offer prices below competitive price levels and in the end to capture economic rents or economic factor (water) rents.¹⁵³

One implication of the observed water market structure is that economic welfare estimates may be low due to deadweight losses.¹⁵⁴ Some of the deadweight loss is transferred to the monopsonist in the form of higher profits but most is lost as a result of fewer water permits than optimal being made available. It is well known that landowners in the aquifer region are unwilling to offer their land for lease or for sale because the price for water permits being offered by SAWS is too low and not reflective of the true price of permits. SAWS is currently paying between

151. The reader may note that Calhoun County lies in the Guadalupe estuary, and what is referred to as the Calhoun estuary is part of the larger Guadalupe estuary. See LONNIE L. JONES & AYSAN TANYERI-ABUR, *IMPACTS OF RECREATIONAL AND COMMERCIAL FISHING AND COASTAL RESOURCE-BASED TOURISM ON REGIONAL AND STATE ECONOMICS* 7, 16 (Texas Water Resources Institute, TR-184, 2001).

152. SAWS is currently spending approximately \$1.87 million per year on water lease payments. Interview with Gene Camargo, Water Resources Department, SAWS (Aug. 28, 2002).

153. Economic rent represents payments for water in excess of what would be necessary to get water permit holders to offer them to the marketplace. See BRIAN R. BINGER & ELIZABETH HOFFMAN, *MICROECONOMICS WITH CALCULUS* 455 (1985).

154. The deadweight loss from monopsony is due to losses in consumer and producer welfare as a result of having fewer than the optimal number of water transfers occurring in the Edwards region. Cf. definition of deadweight loss due to monopoly. See *id.* at 460.

\$75 to \$80 per acre-foot per year for leases.¹⁵⁵ The price for outright sale of water rights has been in the range of \$1,200 to \$4,400.¹⁵⁶

Some have argued that the price offered by SAWS for its leases is too low because the economic price of water is not the price of water in its current use, that is, for irrigation purposes, but rather the price of water based on developing an alternative source to meet demand. The position of water permit holders is that, if SAWS were to meet its current and future water needs using non-aquifer sources, it would have to pay much higher prices for water than the \$80 per acre-foot that it is currently paying. According to estimates by a regional planning group, the lowest per acre cost of alternative water for SAWS is about \$590 per acre-foot for water out of the Carrizo Aquifer, while the per acre-foot price could be as high as \$1,407 for desalinated water.¹⁵⁷ The monopsonistic position of SAWS makes it difficult to determine the extent of deadweight losses and hence the size of economic benefits in the aggregate and to strategic groups.

V. CONCLUSIONS AND POLICY IMPLICATIONS

A major institutional change occurred in the Texas water sector with the implementation of Senate Bill 1477, which created the Edwards Aquifer Authority Act to manage water withdrawals from the Edwards Aquifer. The Act places pumping limits on water withdrawals, mandates minimum spring flows to protect endangered species, lays the foundation for water marketing, and subjects water withdrawals from the aquifer to a permitting scheme similar to the rules governing surface water. Implementation of SB 1477 effectively ended the institutional arrangement – the rule of capture as applied to the aquifer – and replaced it with a permit system that promoted water marketing.

This article found the existing stock of knowledge, the technological change, the constitutional order, the size of the market, and the changes in relative product and factor prices to be important determinants of the demand and supply of institutional change within the

155. See [Edwardswater.com](http://EDWARDSWATER.com/), <http://EDWARDSWATER.com/>.

156. *Id.*

157. These estimates are based on studies by the South Central Texas Regional Water Plan (SCTRWP). Other alternatives and corresponding per acre-foot costs are the Simsboro Aquifer (\$707) (S. Central Tex. Region Water Supply Options, Option Data Sheet, Option No. SCTN-3c (Dec. 31, 1999)); Lower Guadalupe water (\$788) (S. Central Tex. Region Water Supply Options, Option Data Sheet, Option No. SCTN-16b (Dec. 6, 1999)); Colorado River water (\$677) (S. Central Tex. Region Water Supply Options, Option Data Sheet, Option No. C-17A (Nov. 2, 1999)). The group also estimated the price of water for irrigation purposes to be between \$51 and \$80 per acre-foot.

Edwards Aquifer region. There is evidence of considerable impact of technological changes and new knowledge on institutional changes with respect to the aquifer. For example, new knowledge about well spacing and improvements in drilling technology to avoid land subsidence all combined to restrict the rule of capture.

Institutional change in the Edwards Aquifer region has also been influenced by the size of the water market and changes in the constitutional order. Until recently, water for the protection of endangered species and instream flows was not considered as important as other sectors of the water market. Today, this is not the case. Several environmental groups are pressuring for changes in water laws to facilitate water flows to Texas's bays and estuaries. This expansion in the water market has been made possible through changes in the constitutional order in the form of *standing rules*.

The analysis shows that the switch from the rule of capture to a permit system responds adequately to the policy goal of SB 1477 to protect a valuable state resource, the aquifer. The results also show that the policy objective to protect the endangered and threatened species in the aquifer region was also achieved. Thus, the results show increased flows in the San Marcos and Comal springs, the home of several endangered species, compared to the situation before institutional changes occurred.

A major follow-up study that would shed more light on the sustainability of the institutional changes within the Edwards Aquifer and other regions in Texas is a just-completed interbasin water transfer model, TEXRIVERSIM, which covers 21 out of 23 river basins in Texas.¹⁵⁸ TEXRIVERSIM allows a user to evaluate proposed interbasin water transfers in Texas. The model integrates stochastic flow, non-agricultural demand, agricultural demand, climate effects, dryland/irrigation system choice, instream flow, estuary inflow, multiple basins, development project fixed costs and capacity, and reservoir operation, among other factors. Combined with the *Edwards Aquifer Simulation Model (EDSIMR)* discussed in this article, there is an opportunity to dig deeper to examine the implications of conjunctive water policy planning and implementation in the State of Texas.

158. Bruce A. McCarl et al., *Towards a Sustainable Water Policy in Texas: Developing Capacity to Evaluate Transfers (2006)* (funded by the Texas Higher Educational Coordinating Board, Advanced Research/Advanced Technology Program and the Texas Agricultural Experiment Station).

APPENDIX

Model Development¹⁵⁹

The model used in this article is the Edwards Aquifer Simulation Model (EDSIM) linked to a river model. The river model includes surface water flows and aquifer interdependencies in the Nueces, San Antonio, and Guadalupe Rivers.¹⁶⁰ The linked model is the Edwards Aquifer Simulation Model—River (EDSIMR). Monthly flows in the rivers are incorporated in the form of a network flow model depicting flow between river/reservoir reaches that were specified based on data from U.S. Geological Survey (USGS) stream gauges and data provided by HDR Engineering, Inc.¹⁶¹ The river systems are hydrologically connected to the aquifer through aquifer recharge, spring discharge, and return flow. Only return flows from municipal and industrial uses are considered since return flows from agricultural use are minor or non-existent.¹⁶² The rate of return flow is assumed to be 55 percent and 34 percent for municipal and industrial use, respectively. This return flow rate is calculated based on 1995 USGS data as an average across the counties in the region.¹⁶³

EDSIMR operates across a ten-state representation of the probability distribution of recharge and associated precipitation ranging from very dry to very wet years. The probability distribution is an empirical distribution based on the historical recharge of the Edwards Aquifer data for the period 1934 to 1996. The years included, ordered from most dry to most wet, are 1956 (annual recharge at 43,758 acre-feet), 1951, 1963, 1989, 1952, 1996, 1974, 1976, 1958, and 1987 (annual recharge at 2,003,643 acre-feet).¹⁶⁴

Theoretical Structure

EDSIMR is a price-endogenous mathematical program composed of about 100,000 continuous variables and 35,000 constraints in a General Algebraic Modeling System (GAMS).¹⁶⁵ The objective function maximizes

159. With only minor wording changes, this appendix is reproduced from our earlier study, Gillig et al., *supra* note 138.

160. See McCarl et al., *supra* note 158.

161. HDR ENG'G, INC. & GERAGHTY & MILLER, INC., *supra* note 141.

162. See *id.*

163. See USGS, *supra* note 142.

164. TEX. WATER DEV. BD., SURVEYS OF IRRIGATION IN TEXAS 1958, 1964, 1969, 1974, 1979, 1984, 1989, 1994 AND 2000 (Report 347, 2001).

165. RICHARD A. ROSENTHAL, GAMS: A USER'S GUIDE (1992), available at http://www.gams.com/dd/docs/bigdocs/GAMUsersGuide_nolinks.pdf.

the expected *net* benefits (benefits minus costs) of water use by municipal, industrial, and agricultural sectors. Water use is drawn from regional ground water or surface water depending upon availability at a particular site. The region is subdivided into east and west for use from the aquifer along with 52 river reaches and two other regions for use of non-aquifer water. Demand curves are specified for municipal and industrial (M&I) water based on estimates by Griffin and Chang and Renzetti, and by county with discretionary and non-discretionary uses differentiated in Bexar County (where San Antonio is located).¹⁶⁶ Agricultural use and demand is developed using 65 regional linear programming models defined for particular river reaches or groundwater usage areas, which could pursue irrigated and/or dryland crop production.

EDSIMR is implemented through the use of a two-stage or discrete stochastic programming model considering variability in yields and resource usage.¹⁶⁷ The stochastic events are defined by recharge and associated weather/crop yields.

Eleven water management options identified by the HCP, which are consistent with SCTRWPG, are included in EDSIMR as integer variables. These decisions – whether or not water management strategies should be adopted – are depicted as integer variable choices, build or not build, with annual costs and capacities involved. The amount of water that can be drawn from each water management strategy is limited by the capacity of each water management strategy, and its corresponding annual cost is considered in the objective function.

The model contains constraints on ground/surface water demand and supply availability, agricultural crop mixes, pumping lift formation, possible springflow or water use regulations, and nonnegativity conditions.

Maximization Procedure

With a set of water management options incorporated, EDSIMR chooses options to maximize net regional economic value. The model is set up under projected 2012 water demand and no pumping limit versus a 400,000, 340,000, and 175,000 acre-feet per acre pumping limit. Regional economic value is derived from a combination of perfectly elastic demand for agricultural products, agricultural production costs, price elastic municipal demand, price elastic industrial demand, and lift sensitive

166. Ronald C. Griffin & Chan Chang, *Seasonality in Community Water Demand*, 16 W.J. AGRIC. ECON. 207 (1991); S. Renzetti, *An Economic Study of Industrial Water Demands in British Columbia, Canada*, 24 WATER RES. RESEARCH 1569 (1988).

167. George B. Dantzig, *Linear Programming Under Uncertainty*, 1 MGMT. SCI. 197 (1955).

pumping costs. The municipal demand elasticity is drawn from Griffin and Chang, while the industrial elasticity is obtained from Renzetti.¹⁶⁸ Following Griffin and Chang, the quantity demanded by municipal users depends on rainfall and climatic conditions. The following section presents the specific objective function and constraints.

Objective Function

The objective function maximizes the expected *net* benefits (benefits minus costs) of water use by municipal, industrial, and agricultural sectors. Water use within each sector is drawn from either ground or surface water (w). Benefits from using ground and surface water in municipal and industrial sectors are determined by the areas under the constant elasticity municipal and industrial demand curves whereas benefits from using ground and surface water in the agricultural sector are represented by the net agricultural income derived from irrigated and dryland crop production (*CROPPROD*). Total water costs consist of pumping/diverting costs for the agricultural and non-agricultural sectors and water management plan costs. Fixed costs associated with each water management alternative option (p) incur only if that water management alternative option is adapted (*BUILDPLAN*), whereas variable costs depend on the amount of water used (*NEWWATER*). This objective function is maximized subject to a set of constraints including ground/surface water demand and supply balance (both existent and newly developed supplies), agricultural production activities (c), hydrologic regressions, nonnegative conditions for decision variables, and binary conditions for water development decisions. The objective function is probabilistically weighted by the state of nature or weather conditions (r) to reflect the stochastic nature of weather. Variables are in upper case and parameters are in lower case.

$$\begin{aligned} \sum_r \text{prob}_r \cdot & \left(\sum_c \sum_w (\text{irrincome}_{rcw} \text{CROPPROD}_{rcw}) \right. \\ & + \sum_w \int \text{MUN}_{rw} \text{dMUN} + \sum_w \int \text{IND}_{rw} \text{dIND} \\ & - \sum_m \sum_c \sum_w \text{agcost}_{cw} * \text{AGWATER}_{mrcw} - \sum_w \text{micost}_w * (\text{MUN}_{rw} + \text{IND}_{rw}) \\ & \left. - \sum_p \text{annualcost}_p * \left(\sum_m \text{NEWWATER}_{mp} \right) \right) \end{aligned}$$

168. Griffin & Chang, *supra* note 166; Renzetti, *supra* note 166.

Initial Edwards Aquifer Elevation

The initial Edwards Aquifer elevation (*INITIALLEVEL*) measured at J17 and Sabinal well indices is the average of the ending Edwards Aquifer elevation (*ENDLEVEL*) weighted by the probability associated with each state of nature in order to allow the Edwards Aquifer level to fluctuate with the weather.

$$INITIALLEVEL_i = \sum_r (prob_r * ENDLEVEL_{ir}) \quad \forall i = \text{J17 and Sabinal well indices.}$$

Ending Edwards Aquifer Elevation

The ending Edwards Aquifer elevation is a function of the initial elevation, the Edwards Aquifer groundwater use (*EDUSE*), and the Edwards Aquifer recharge (*recharge*). The a_i represents the regression parameter that was previously estimated in the Edwards Aquifer model using the GWSIM-IV Edwards Aquifer Simulation Model

$$ENDLEVEL_{ir} = \alpha_0 + \alpha_1 recharge_r + \alpha_2 \sum_m EDUSE_{mr} + \alpha_3 INITIALLEVEL_i \quad \forall i \text{ and } r.$$

Springflow Regression

Springflows are generated by a regression, which is a function of the initial Edwards Aquifer elevation levels at J17 and Sabinal index wells, the Edwards Aquifer monthly recharge, and the aggregated Edwards Aquifer water use. w and represent the regression parameters that were previously estimated in the EDSIMR

$$SPRING_{imr} = w_0 + w_i INITIALLEVEL_i + \alpha_1 recharge_{mr} + \alpha_2 EDUSE_{mr} \quad \forall i, m \text{ and } r.$$

Crop Mixes

A crop mix constraint implies that a farmer's crop production decision is a convex combination of crop mix (*CROPMIX*) in which all of the lands used (irrigated or dry land) for a crop grown within a county follows the historical crop mixes (*mixdata*) observed on irrigated and dry land acres by crop and county from the years 1975 to 1996 as well as crop mixes obtained from the 1994 farm program survey indicating what would happen if the farm program were eliminated.

$$CROPPROD_{rcw} = \sum_y (mixdata_{ycw} * CROP MIX_{ycw}) \quad \forall r, c \text{ and } w.$$

Irrigated Land

The constraint limits irrigated crop production to irrigated land acres (*LAND*) available but allows irrigated land acres to be converted to dryland (*TODRY*)

$$\sum_y \sum_c mixdata_{ycw} \cdot CROP MIX_{ycw} = land_w - TODRY_w \quad \forall w.$$

Dryland

This constraint limits dryland acres to those available plus those converted from irrigated acres (sprinkler or furrow)

$$\sum_y \sum_c mixdata_{ycw} \cdot CROP MIX_{ycw} = land_w - TODRY_w \quad \forall w.$$

Irrigation Water Demand

The irrigated crop water demand by type of water is also limited to be less than or equal to water available for irrigation by type of water

$$\sum_m watrequire_{mrcw} \cdot CROPPROD_{rcw} \leq \sum_m AGWATER_{mrcw} \quad \forall r, c, \text{ and } w.$$

Edwards Aquifer Pumping Balance

The total water demand for agriculture, municipality, and industry using the ground water pumped from the Edwards Aquifer is limited to be equal to the total amount of the ground water pumped from the Edwards Aquifer. In general, the amount of water pumped from the Edwards Aquifer (*pump*) is unlimited but is limited to 400,000, 340,000, and 175,000 acft per year when the pumping limit is imposed

$$EDUSE_{mr} = seasonal_{m'mur} * MUN_{r'ed} + seasonal_{m'ind} * IND_{r'ed} + \sum_c AGWATER_{mrc'ed}$$

$$MUN_{r'ed''} + IND_{r'ed''} + \sum_m \sum_c AGWATER_{mrc'ed''} \leq pump_r$$

$$\begin{aligned} &\forall m \text{ and } r. \\ &\forall r \end{aligned}$$

Irrigated Water

A water demand and supply balance limits water demand to less than or equal to the total amount of supply available for each water type (*watsupply*)

$$\sum_{m,c} AGWATER_{mrcw} \leq watsupply_{rw} \quad \forall r \text{ and } w$$

River System

The river system portrays a hydrological relationship among upstream (*up*), downstream (*s*), as well as instream flows, reservoirs/lakes release and spill, diversions, system channel loss, return flow, aquifer recharge, springflow, and water transfers where seasonal refers to municipal and industrial monthly seasonal distribution.

$$FLOW_{smr} + seasonal_{m'mun} MUN_{r'sur} + seasonal_{m'ind} IND_{r'sur} + \sum_c AGWATER_{mrc'sur}$$

$$+ \sum_{upriver} LOSS_{smr} + RECHARGE_{smr} - \sum_{up} Flow_{up,mr} - INFLOW_{smr} - RETURNFLOW_{smr}$$

$$- SPRING_{smr} - \sum_p NEWWATER_{mrp} \leq 0 \quad \forall m, r, \text{ and } s.$$

Water Management Alternative Plan

The decision whether a water management strategy, *p*, should be adapted is viewed as a binary choice, to adapt or not to adapt. If adapted, a water management strategy's variable cost is considered in the objective function. The amount of water that can be drawn from each water management strategy is limited by the capacity of each water management strategy (*capacity*)

$$BUILDPLAN_p \in \{0,1\}$$

$$\sum_m NEWWATER_{mrp} \leq capacity_p * BUILDPLAN_p \quad \forall r \text{ and } p$$

Other Features and Constraints

There are a number of other features and constraints used in the study but not presented in the Appendix. For example, the pumping lift constraint is set as a function of J17 and Sabinal wells ending elevation level. A full description of the model can be found in McCarl et al.¹⁶⁹

169. McCarl et al., *supra* note 158.