WATER FROM A STONE:
THE LIMITS OF THE SUSTAINABLE DEVELOPMENT OF THE TEXAS EDWARDS AQUIFER

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The First Dissertation
Approved By
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February 23, 2000

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TEXAS EDWARDS AQUIFER

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ACKNOWLEDGEMENTS

"Every one to whom much is given, of him will much be required; and of him to whom men commit much they will demand the more."

Luke 12:48, The Bible (Revised Standard Version)

I wish to thank my advisor, mentor, and friend, Professor Joe G. Moore, Jr., from whom I have gained much. Thanks are also due my committee members and Professor Sally Caldwell for their advice and assistance.

Finally, I would like to thank my family for their unwavering faith, strength, and love. I dedicate this dissertation to the memory of Professor Susan Hadden, my former doctoral research advisor at The University of Texas at Austin, Lyndon Baines Johnson School of Public Affairs.

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ABSTRACT

WATER FROM A STONE: THE LIMITS OF THE SUSTAINABLE DEVELOPMENT OF THE TEXAS EDWARDS AQUIFER

by

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March, 2000

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A conflict over protection of threatened and endangered aquatic species has established the limits on the sustainable development of the Edwards (Balcones Fault Zone) Aquifer in south central Texas as the minimum discharges from Comal Springs in New Braunfels, Texas, and San Marcos Springs, in San Marcos, Texas. This conflict is aggravated by periodic droughts that increase the demand for water, while reducing recharge. This research demonstrates that in the fall, critically low spring discharge conditions can be predicted for the following summer allowing water conservation measures to be initiated in advance of critical periods. Conventional drought indices such as the Palmer Drought Severity Index and the Standard Precipitation Index were found to be unreliable indicators of hydrologic drought in the Edwards Aquifer region.

Regional drought management plans have attempted to restrict pumping from the aquifer based on changes in the levels of three regional groundwater index wells. This research determines that the levels of the groundwater index wells are poor proxies for spring discharge rates, necessitating the revision of regional drought management plans. In addition, it was determined that the aquifer can be more sustainably managed by diverting excess spring discharge during wet periods for storage to be used during droughts and periods of low recharge to reduce water demand from the aquifer. A system for storing excess spring discharge called the San Antonio Drought Reserve Project is proposed.

Keywords: Texas, Edwards Aquifer, groundwater, Endangered Species Act, common pool resources, transboundary dispute, drought, sustainable development, Palmer Drought Severity Index, Standard Precipitation Index.

LIST OF ABBREVIATIONS

1996 EWRP	*1996 Emergency Withdrawal Reduction Plan for the Edwards Aquifer*
AAG	Association of American Geographers
AG	Attorney General's Office
APA	Aquifer Protection Association
ASR	Aquifer Storage and Recovery
Bexar Met	Bexar Metropolitan Water District
BMA	Bexar - Medina - Atascosa Water Control and Improvement District No. 1
BRAC	Base Closure and Realignment Commission
CFR	Code of Federal Regulations
cfs	Cubic feet per second (ft^3/s)
CPMP	*Critical Period Management Plan*
CRWA	Canyon Regional Water Authority
CWB	San Antonio's City Water Board
DMP	*Demand Management Plan*
DOD	Department of Defense
DOJ	Department of Justice
EAA	Edwards Aquifer Authority
EARDC	Edwards Aquifer Research and Data Center
EDF	Environmental Defense Fund
EPA	Environmental Protection Agency
ESA	Endangered Species Act
ETJ	Extraterritorial jurisdiction
EUWCD	Evergreen Underground Water Conservation District
EUWD	Edwards Underground Water District
EWRP	*1994 Emergency Withdrawal Reduction Plan for the Edwards Aquifer*
FR	Federal Register
ft	Feet

gal/min	Gallons per minute
GBRA	Guadalupe - Blanco River Authority
gpcd	Gallon per capita per day
gpm	Gallons per minute
HCP	Habitat conservation plan
ITP	Incidental Take Permit
LCRA	Lower Colorado River Authority
LEPA	Low energy precision application
MALDEF	Mexican American Legal Defense and Education Fund
MCUWCD	Medina County Underground Water Conservation District
MGD	Million gallons per day
mi^2	Square mile
msl	Mean sea level
NBU	New Braunfels Utilities
NFH&TC	San Marcos National Fish Hatchery and Technology Center
NMFS	National Marine Fisheries Service
NRA	Nueces River Authority
NRCS	Natural Resource Conservation Service
Panel	Incidental Take Permit Application Panel
PDSI	Palmer Drought Severity Index
PHDI	Palmer Hydrological Drought Index
REWRP	*1995 Revised Emergency Withdrawal Plan for the Edwards Aquifer*
RWMP	*Regional Water Management Plan*
SARA	San Antonio River Authority
SAWS	San Antonio Water System
SCS	Soil Conservation Service
SCTWAC	South Central Texas Water Advisory Committee
SPI	Standard Precipitation Index
SWTSU	Southwest Texas State University

TAC	Texas Administrative Code
TBWE	Texas Board of Water Engineers
TOES	Texas Organization for Endangered Species
TNRCC	Texas Natural Resource Conservation Commission
TPWD	Texas Parks and Wildlife Department
TWC	Texas Water Commission
TWDB	Texas Water Development Board
TWQB	Texas Water Quality Board
UCUWCD	Uvalde County Underground Water Conservation District
U.S.C.	United States Code
USDA	U.S. Department of Agriculture
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
UST	Underground storage tanks
YTBD	yet to be determined
WSP	Withdrawal Suspension Program
WWTP	Wastewater treatment plant

1. INTRODUCTION AND STATEMENT OF THE ISSUES

> But the people thirsted there for water, and the people murmured against Moses, and said, "Why did you bring us up out of Egypt, to kill us and our children and our cattle with thirst?" So Moses cried to the LORD, "What shall I do with these people? They are almost ready to stone me." And the LORD said to Moses, "Pass on before the people, taking with you some of the elders of Israel; and take in your hand the rod with which you struck the Nile, and go. Behold, I will stand before you there on the rock at Horeb; and you shall strike the rock, and water shall come out of it, that the people may drink." And Moses did so, in the sight of the elders of Israel. And he called the name of the place Massah and Meribah, because of the fault-finding of the children of Israel, and because they put the LORD to the proof by saying, "Is the LORD among us or not?"
>
> Exodus 17:3 – 7, The Bible (Revised Standard Version)

And so it was also that the water flowed forth from the limestone fissures of the Edwards Aquifer for countless generations. Life found nowhere else on the Earth, flourished in the clear waters that flowed from the springs. Yet, as the thirst of humanity grew, the springs were stilled one by one until only the largest among them remained. On June 13, 1956, for the first time in recorded history, the mightiest of them, Comal Springs, became a trickle then ceased, succumbing to years of drought and years of slaking many thirsts. It would be 144 arduous days before water would begin to seep from the limestone again. While tragic, the region had been given a valuable gift, an insight into a future of water use without restraint. It would be seventeen years before the Endangered Species Act of 1973 (ESA) became law, yet the struggle to control the region's most important natural resource had already commenced.

An Emergency Exists

> The Edwards Aquifer region has finally reached the point where the Aquifer is unable to provide for the needs of all those who depend upon it during dry years, from persons directly over the Aquifer, to those persons and endangered species at Comal and San Marcos Springs. Without a fundamental change in the value the region places on fresh water, a major effort to conserve and reuse Aquifer water, and implemented plans to import supplemental supplies of water, the region's quality of life and economic future are imperiled. (*Sierra Club v. San Antonio et al.*, No. MO-96-CA-097, slip op. at 1 (W.D. Tex. Aug. 23, 1996)(Order Mandating Federal Management of the Aquifer))

Forty years after Comal Springs ran dry, on August 23, 1996, I drafted these words for Senior U.S. District Court Judge Lucius D. Bunton. The Judge's order mandated federal judicial management for the overtaxed Edwards Aquifer. The Order resulted from decades of political wrangling over water and endangered species, ending in stalemate among urban and rural interests, and between all levels of government following the events of 1956. Decades of litigation in state courts, five years of federal litigation, and one year of severe drought preceded the emergency order. Numerous attempts to mediate the dispute and craft a regional solution had failed. All of this preceded the U.S. District Court's attempt to keep the springs flowing to protect the endangered species and supply downstream water uses through a court-mandated drought management plan. With no recourse by way of state law or state courts, federal law and a federal court became the forum for first establishing, and then enforcing, the limits for the sustainable use of the Edwards Aquifer.

The plight of the Edwards Aquifer is not an isolated example of water resource shortages affecting competing water demands and endangered species. Across the western United States, the protection of endangered species is conflicting with the use of water resources with increasing frequency (Moore, Mulville, and Weinberg 1996, 319). In 1994, the Council on Environmental Quality reported that of approximately 1,033 species of native freshwater fish nationwide, 74 – 103 were endangered, 85 – 114 were vulnerable to extinction, 101 – 147 were rare, and 27 were already believed to be extinct (Council of Environmental Quality 1994, 222). In a 1996 survey of all 17 western states, agricultural activity was linked to the status of 50 fish species listed under the ESA. The same study identified 235 counties containing irrigated agriculture that rely on water from rivers containing a fish with protected status under the ESA (Moore, Mulville, and Weinberg 1996, 319).

For example, in the Pacific Northwest the listing of populations of salmon and trout has spawned an effort to reevaluate regional water resource management strategies. Apparently unaware of San Antonio's experience with the ESA, Seattle Mayor Paul Schell asserted that, "There has never been a listing with such consequences in a metropolitan area" (Landers 1999, 12). In New Mexico, protecting the endangered silvery minnow in the middle Rio Grande threatens to reallocate water from agricultural and municipal users to environmental needs (Dodd 1999, 6). In Nebraska's portion of the Platte River, the endangered pallid sturgeon could potentially limit the allocation of water for agricultural irrigation (Epstein 1999b, 7). In the eastern U.S., a major federal initiative to restore the Florida Everglades is a response, in part, to the needs of some 68 endangered species that have suffered from water control projects (Phinney 1999, 1). The Edwards Dam on the Kennebec River in Maine was recently removed, in part to restore runs of Atlantic salmon and other anadromous fish (Grant 1999, A19).

"Water defines 'the West' " (Western Water Policy Review Advisory Commission 1998, 2-1). As a result conflicts over endangered species and water use can be particularly controversial. Water shortages, such as those experienced in the Edwards Aquifer region, are problems of geographic distribution. In the western United States, the geographic distribution of water frequently differs from the geographic distribution of human population concentrations, due in part to technological developments and government policies that have encouraged growth in arid, semi–arid, and sub-humid regions. Here water consumers are concentrated in urban areas, where there is fertile soil, or where favorable climatic conditions exist. As natural sources of water are fully utilized, securing adequate water to sustain existing populations and facilitating future growth require more than conservation; meeting these needs requires additional supplies of water. However, water is dispersed geographically and is often in short supply. Because many dependable water sources have already been committed, new users are forced to develop less dependable water supplies (Slade and Asquith 1996, 3). With the reduction of technical and physical barriers, law and public policy are becoming the primary factors that determine the geographic distribution of water. These factors also define relationships between people and institutions. As people exhaust the available water, the welfare of human communities becomes more susceptible to natural hazards, such as drought. Humans respond to perceived resource shortage or environmental degradation by adjusting to the limits of natural environments (Kates 1995, 631). There are six types of human responses to natural hazards: (1) losses are endured; (2) losses are shared; (3) attempts are made to modify hazards; (4) attempts are made to prevent hazards; (5) resource use is changed; or (6) people move away from the hazard (Kates 1995, 631-632).

The sustainable development movement is one response to the increased human vulnerability to natural hazards caused by population increases and environmental deterioration, such as the lack of adequate water supplies of acceptable quality. Sustainable development has been defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development 1987, 43). However, because sustainable development has become a catchword for the concern that the fate of human populations on the Earth is somewhat precarious, it is more a political slogan than a basis for action (Wilbanks 1994, 541). In 1994, Association of American Geographers (AAG) president Thomas Wilbanks encouraged geographers to tackle the problem of sustainable development (Wilbanks 1994, 541). In 1995, AAG president Robert Kates also made sustainable development a priority for geographers (Kates 1995, 623).

Objectives

This research will examine the elements critical to the sustainable development of the Edwards Aquifer region and attempt to provide solutions to some of the problems identified as impediments to that sustainable development. I trace water development and use during the twentieth century in the Edwards Aquifer region of south-central Texas. The Edwards Aquifer is the primary source of water for the City of San Antonio. Relying exclusively on groundwater, the residents of this region have significantly reduced the flows from two of the largest springs in the southwestern United States, Comal and San Marcos Springs, which are also habitat for threatened and endangered species. Efforts made thus far to achieve the sustainable use of the aquifer will be chronicled and evaluated. Where appropriate, feasible alternatives will be discussed.

The three general questions this research seeks to answer are:

- Will the conservation measures proposed by the Edwards Aquifer Authority (EAA) to assure spring discharge at Comal and San Marcos Springs be initiated in advance of critical flows?

- Can a methodology be developed to predict in advance years in which spring discharge below levels necessary to protect endangered species are likely to occur?

- Is the management approach found in Senate Bill 1477, the Act of the Texas Legislature that created the management system for the Edwards Aquifer, the best way to assure optimum utilization of the water in the aquifer with minimum economic and human dislocation? If not, what approach is more likely to assure sustainable development and growth in the region?

The intent of this research is to evaluate whether the Edwards Aquifer is being managed on a sustainable basis. It is my hypothesis that the withdrawal limits in Senate Bill 1477 do not adequately consider the hydrologic characteristics of the Edwards Aquifer and will not guarantee the necessary minimum spring discharge (springflow) required to protect endangered species during a repeat of the drought of record. In some years, when recharge to the aquifer is high, restricting withdrawals to 450,000 acre-feet/year or 400,000 acre-feet/year (one acre-foot is equivalent to 325,851 gallons) could be too restrictive. However, in years following low annual recharge these same withdrawal limits could be too high and Comal Springs could cease to flow.

It is also my hypothesis that flow at Comal Springs and San Marcos Springs cannot be maintained above the level at which the endangered species are harmed with sustained minimum downstream supplies if water conservation measures are initiated by the trigger levels found in the EAA's May 1999 *Critical Period Management Plan* (CPMP). Predictors of future critical spring discharge, flows below which harm can occur to endangered species, are needed to apply water withdrawal restrictions in advance of likely periods of damaging critical low flows.

The theoretical basis of this research rests upon ideas expressed by Aldo Leopold concerning the role of humans in conserving natural resources upon which humans depend for their survival and well – being (Leopold 1949). The prospect that human population growth might exhaust the capacity of the Earth to supply man's needs receives periodic expression (Meadows and others 1972). Water is the quintessential resource. The Edwards Aquifer region in Texas is a microcosm of this prospect. Property rights in groundwater have been jealously guarded by those who believe they are entitled to them. The exploitation of the common pool resource, the Edwards Aquifer, has produced the "tragedy of the commons" of which Garret Hardin has so eloquently written (Hardin 1968). At the same time, property rights advocates have discovered that prior to state regulation their rights did not have the characteristics of an efficient property rights system – (1) universality; (2) exclusivity; (3) transferability; and (4) enforceability (Teitenberg 1992, 45 - 47). Flow in the Edwards Aquifer from point of percolation or infiltration to point of discharge produces classic transboundary disputes among various users and government entities. The theoretical basis of this research is presented in Chapter 2.

The research methodology is described in Chapter 3. An understanding of history should help prevent or overcome the mistakes of the past. In addition to an examination of the record of efforts to understand and resolve water supply disputes over Edwards Aquifer water use and misuse during the last fifty years, I have also reviewed the history of litigation involving allocations of aquifer water as between all pumpers, cities in which the springs are located and surface water users downstream on the Guadalupe River. Participants in the litigation were interviewed. I have also used statistical methods to analyze various aspects of drought prediction and management plans to determine whether they will achieve the intended purposes. Methods for predicting critical spring discharges in a following year, are explored. Current Edwards Aquifer Authority permitting procedures are examined to determine whether such policies will provide a sustainable basis for optimum economic benefit to the people of the region and downstream in the Guadalupe River basin.

The physical geography and land use in the Edwards Aquifer region – its surface and groundwater availability, climate and population growth provide the context within which the residents there have managed, or failed to mange, their water supply (Chapter 4). The results of their efforts impact water availability in neighboring watersheds and the surface and groundwater users within them. The areal extent of the impacts influences available options and practical decisions. The consequences of drought, aggravated because of the direct interconnection between surface and groundwater, shape reactions and plans.

The legal and institutional framework within which water and land use decisions must be reached constrain the range of alternative solutions (Chapter 5). There are the usual historical conflicts between urban, rural, and industrial interests and water users. Upstream – downstream animosities are present in three river basins as well as the disputes between those withdrawing groundwater at elevations higher than those of the springs – withdrawals which eventually reduce spring discharge. Texas wrestles with a bifurcated water allocation system determined by source – (1) the rule of capture for groundwater allowing unrestricted withdrawal by any landowner and (2) the appropriative water rights doctrine that requires state permits for withdrawal and use of surface water. The springs literally move water from one legal doctrine and political jurisdiction to others. Historical declines in spring discharge from increasing pumping of Edwards groundwater caused alarm among downstream surface water rights holders. The rule of capture fosters private property rights claims of pumpers threatened with withdrawal limits. Enter the 1973 Endangered Species Act (ESA) which allows the U.S. Fish and Wildlife Service (in this case) to name such species and protect their habitat by federal agency actions, enforceable in federal court.

Solutions of most natural resources issues, and particularly those related to water use, are restricted by their historical evolution (Chapter 6). Conflicts over the use of surface water from Canyon Dam on the upper Guadalupe River between San Antonio and the Guadalupe – Blanco River Authority poisoned their relationship for decades. Antagonisms between their respective residents still flourish. Negotiations and mediation attempts by several parties failed to resolve the claims of respective Edwards Aquifer groundwater pumpers and those surface water users dependent upon spring discharge failed. Litigation in state and federal courts followed. The judgment in a suit filed under the ESA finally compelled the Texas Legislature to modify the rule of capture for the Edwards Aquifer. Determination of the minimum mandatory spring discharge by the USFWS, reinforced by a regional authority charged with enforcing pumping limitations, may produce the indirect result of satisfying downstream surface water rights permits most of the time.

Availability of water can limit the sustainable development of the Edwards Aquifer region (Chapter 7). There are both potential economic and ecological consequences; a "bad water line" separating fresh groundwater from that too loaded with minerals could move into areas dependent on Edwards water if the aquifer is over-pumped. Depleted freshwater inflows to Texas bays and estuaries could adversely affect sports and commercial fisheries and the habitat of other endangered species such as the whooping crane. Continued litigation and potential intermittent shortage threaten the regional economy.

Droughts have historically aggravated the contention among various Edwards water users, and there have been repeated attempts at equitable allocation of the shortages among the users (Chapter 8). Various voluntary management plans were adopted prior to the ESA litigation with little success in application. Several more plans were developed in response to orders of the court during the ESA litigation; only one of these was actually ordered into effect, and that order was suspended by an appellate court before it was scheduled to be implemented.

The methods for triggering any management plan and the timing of its application are critical (Chapter 9). These matters are explored and proposals made to assure timely and equitable imposition of drought management plans in the future.

Ultimately there must be an integrated equitable plan that relies on proportionate use of the region's surface and groundwater, including aquifers other than the Edwards and all surface water basins over the Edwards, and possibly those outside of the region (Chapter 10). An enumeration of the possible alternatives melding available surface and groundwater in a San Antonio Drought Reserve Project demonstrate that the sustainable development of the Edwards Aquifer region can be assured for at least the next fifty years.

After such an investigation is detailed here, some observations and conclusions are appropriate (Chapter 11). These relate to (1) predictions of years in which low spring discharge are likely to occur; (2) triggers levels for drought management; (3) alternatives sources of water; (4) conjunctive use of surface and groundwater; (5) flexible pumping limits; (6) the drought reserve; and (7) maintaining sustainable development.

The appendices that follow the text contain much detailed information about the research presented in this dissertation.

2. THEORETICAL BASIS OF THE RESEARCH

Sustainable Development

In 1947, Aldo Leopold fused three ideas from his existing essays into a new vision of the landscape and the environment, *The Land Ethic*. These ideas are: (1) humans are citizens of the biotic community instead of its conqueror, taken from *The Conservation Ethic*; (2) there is the need for an ethical dimension to human societies' relationship with the natural environment, taken from *A Biotic View of Land*; and (3) there should be a sustainable use of the environment, taken from *The Ecological Conscience* (Meine 1988, 501). These ideas appear in the same essay because Leopold believed them to be complementary. For Leopold, man could be a citizen of the biotic community only if two precepts were accepted; first, as an ethical people, we have a moral responsibility to the biotic community, and secondly, only the sustainable use of the biotic community's elements could preserve the stability of that community.

Leopold was not a geographer, although he recognized that the concepts embodied in what he called "ecology" existed in the field of geography (Leopold 1949, 224). He was a forester by training, and an ecologist by practice. However, his ideas certainly represent a milestone in the conservation movement that has altered many aspects of American culture, including geography. Today, environmental and cultural geography are replete with references to Leopold's concepts of ethical land use and sustainability.

In the decade after the first Earth Day in 1970, the passage of environmental laws became a primary focus of the environmental movement. These laws often usurp the individual's responsibility for a more ethical relationship to the land and replace it with the machinery of government. However, most land in America is under private ownership. A system that removes the responsibility for the ethical management of land from the landowner and immediate community, and reassigns that responsibility to a government removed from the immediate community has disadvantages. Leopold recognized the failings of such a system for environmental regulation when he noted that, "There is a clear tendency in American conservation to relegate to government all necessary jobs that private landowners fail to perform" (Leopold 1949, 213). Leopold goes on to summarize, ". . . a system of conservation based solely on economic self-interest is hopelessly lopsided. . . . It tends to relegate to government many functions eventually too large, too complex, or too widely dispersed to be performed by government" (Leopold 1949, 214).

The question of an ethical dimension to our relationship with the environment has generated renewed interest recently. The concern for limitations to private property rights is now a key topic of debate about American public policy. The discussion has focused primarily on rights and often ignored responsibilities. Responsible use of the land is a part of what Leopold describes as an ethic. He writes, "An ethic, ecologically, is a limitation on freedom of action in the struggle for existence. An ethic, philosophically, is a differentiation of social from anti-social conduct. These are two definitions of one thing. The thing has its origin in the tendency of interdependent individuals or groups to evolve modes of co-operation" (Leopold 1949, 202). He explains that "Ethics are possibly a kind of community instinct in-the-making" (Leopold 1949, 203). Explicit in Leopold's definition of an ethic is a required limitation on the exercise of an individual's rights in the use and disposal of land and all of its attributes, including water. Leopold's preferred limitation is not one imposed by government, but rather individual restraint motivated by communal concern and responsibility. Also present in his writing is the idea that the community has a stake in the decisions made by individuals. This concept is contrary to the current trend in public policy that sees property rights as exclusively individual and not communal. This more autonomous view has significant implications for the landscape and culture; fragmentation of the land may result from the exercise of unfettered individual will selecting land uses detrimental to the human and biotic community.

Sustainable use is one of Leopold's ideas currently receiving much attention in the academic and international political communities. With regard to western water resources, the Western Water Policy Review Advisory Commission has concluded that:

> Sustainable development requires a new balance between consumptive and nonconsumptive uses. This is difficult to achieve because surface water supplies often are fully appropriated under state law. However, there is an increasing appreciation of the need to maintain more natural river and aquifer flow patterns to support wildlife and to maintain such landscape functions as upstream floodwater retention and natural filtration. One of the more striking developments in the past two decades is the increased recognition of the importance of nonconsumptive uses. Historically, nonconsumptive uses were what was left over after

consumptive demands were satisfied, but their importance is becoming better understood as we try to maintain and restore degraded aquatic ecosystems. We are struggling with the task of accommodating new consumptive water uses. We are beginning to define the baseline flows necessary for operative ecosystems. (Western Water Policy Review Advisory Commission 1998, 3-6)

Achieving sustainable groundwater use is one of the major water management challenges facing the West. This is primarily a state rather than a federal responsibility. Even though it is widely understood that ground- and surface-water resources are interrelated, most states continue to manage ground and surface water by different legal regimes. The majority of the western states administer surface waters under the doctrine or prior appropriation or by a mixed appropriative-riparian system. However, groundwater governance regimes display less uniformity and are typically far less well defined, making it more difficult for states to manage limited supplies. (Western Water Policy Review Advisory Commission 1998, 3-6)

Property Rights

The protection of private property was a concern of one of the first recognized Presidents to support conservation, Theodore Roosevelt, but even he did not view owners as having unfettered use of their property:

> The Constitution guarantees protections to property . . . We are face to face with new conceptions of the relations of property to human welfare, chiefly because certain advocates of the rights of property as against the rights of men have been pushing their claims too far. The man who wrongly holds that every human right is secondary to his profit must now give way to the advocate of human welfare, who rightly maintains that every man holds his property subject to the general right of the community to regulate its use to whatever degree the public welfare may require it. . . . I believe in shaping the ends of government to protect property as well as human welfare. Normally, and in the long run, the ends are the same; but whenever the alternative must be faced, I am for men and not for property . . . (Roosevelt 1910)

In Texas, rights to surface water evolved from rights to land; a grant of land, either explicitly or implicitly contained a grant of water to make productive use of the land. The rule of capture for groundwater confirms a property right in the landowner. Under the rule of capture, a landowner or lessee or assignee has the right to pump as much water as desired from beneath his or her land, provided the water is not willfully wasted, used maliciously to injure a third party, or pumped negligently.

Before endangered species became the focus of the conflict over water from the Edwards Aquifer, attention was focused solely on the question, to whom does this water belong? Do those who take the water from the artesian zone have the sole legitimate claim on the water under the rule of capture, or do those who have depended on the water flowing from the springs decades before the first well was drilled have a superior or equal claim? This question is intertwined with our concept of property and the legal rights to the water's use. The manner in which producers and consumers use resources depends on the property rights governing those resources. In neoclassical economic theory, a "property right" refers to a bundle of entitlements defining the owner's rights, privileges, and limitations for the use of a resource. Property as an institution encourages investment and careful use of resources; thus, property rights should be relatively stable. Such rights can be vested either in individuals, corporations, or the state. In addition, states share surface and groundwater resources that are sometimes regulated under differing legal doctrines, occasionally creating conflicts.

An efficient property rights system has the following characteristics:

1. Universality - All resources are privately owned, and all entitlements completely specified.
2. Exclusivity - All benefits and costs accrued as a result of owning and using the resources should accrue to the owner, either directly or indirectly.
3. Transferability - All property rights should be transferable from one owner to another in a voluntary exchange.
4. Enforceability - Property rights should be secure from involuntary seizure or encroachment by others. (Teitenberg 1992, 45 - 47)

An owner with a property right that has these four characteristics has a strong incentive to use that resource efficiently, because a decline in the value of that resource represents a financial loss. When well-defined property rights are exchanged, as in a market economy, this exchange facilitates efficiency. Because the seller has the right to prevent the consumer from consuming the product without paying for it, the consumer must pay to receive the product. Given a market price, the consumer will decide how much to purchase by choosing the amount that maximizes individual net benefit.

Exclusivity is one of the chief characteristics of an efficient property rights structure. This characteristic is frequently violated when agents making decisions do not bear all of the consequences of their actions. These property rights are said not to be well-defined. This situation produces an externality or spillover effect. An externality designates a benefit or a cost of a market transaction that is neither paid for nor received by those making the transaction, and is therefore not incorporated into the market demand or supply. Externalities that convey a benefit are called external economies, while externalities that result in damages are called external diseconomies (Teitenberg 1992, 53). The cost of not correcting the externality is known as the dead weight loss or excess burden. An externality exists whenever the welfare of some agent, either an individual, a firm or a household, depends directly on activities under the control of some other agent (Teitenberg 1992, 52).

Common Pool Resources

Property rights tend to evolve from poorly-defined to more well-defined as resources grow scarce, with the regulation of externalities evolving in a similar pattern (Rose 1994, 3). Incentives to overexploit communal resources exist where there is no system of well-defined property rights. Common pool, or common property, resources are those not exclusively controlled by one or more individuals or agents (Teitenberg 1992, 54). They can result from an improperly operating property rights system. If access to these resources is not controlled by one or more agents, the resource can be exploited on a first-come, first-served basis. Generally, under the rule of capture, Texas groundwater is a common pool resource. Other examples include migratory bird, fish, and animal populations. Large underground reservoirs of oil in Texas were once common pool resources. If the surface area of the property is less than the geographic coverage of the subterranean pool, several different entities could end up tapping the same pool of oil. If none of these entities had exclusive control over the oil field, the oil was a common property resource.

Garrett Hardin has written about the potential abuse of common property resources. He describes an unregulated public pasture where each shepherd reasons that his or her incremental increase in grazing animals is justified. Such reasoning eventually brings ruin of the public resource for all with its overexploitation (Hardin 1968, 1243-1244). In the commons, each individual would seem to be locked into a system that compels him or her to increase his or her consumption of resources without limit, in a world where resources are actually limited. The tragedy of the commons works in reverse in land, air and water pollution. Here, it is not a question of taking something out of the commons, rather, the tragedy occurs by adding something, such as dumping dangerous waste on the land, discharging sewage into the water, or releasing noxious emissions into the air. The rational individual can find that his or her calculation of utility is much the same as before. The freedom of unrestricted exploitation of the commons can ultimately bring tragedy to all.

Common pool resources may be exploited in ways that cause external harm to others, or negative externalities. Property owners may, unintentionally or intentionally, inflict harm or negative externalities on others through the exercise of their property rights. The relevant example here would be the withdrawal of groundwater to the extent that a neighboring well ceases to produce water.

Typically, the neoclassical economic approach to solving the problem of over - exploitation of common property resources has been to define and enforce property rights through institutional intervention (Tobin 1989, 127). A government entity protects property rights and manages the resource under goals that promote the public interest. Under a pure rule of capture system for water, property rights, in the economic sense, are an illusion. There is no protection for existing users against an adjacent plot of land being purchased and enough water withdrawn to lower the water table below the well intakes of surrounding landowners. Indeed, it was this type of unrestricted extraction of oil that ended the rule of capture for oil and gas in Texas.

Jacque Emel and Elizabeth Brooks have studied the changes in property rights institutions under threatened scarcity of groundwater in the High Plains overlying the Ogallala Aquifer (Emel and Brooks 1988). In response to this same type of unrestricted extraction of groundwater in Nebraska, Kansas, and Oklahoma, a pattern was found of replacing the judicial management of groundwater resources with effective local management, as groundwater resources became scarce. Administrative organizations replaced judges and courtrooms as the primary forum for defining rights and settling disputes. These changes resulted from a conscious preference for increased security at the price of reduced freedom in the exercise of property rights in groundwater.

Prior to regulation, the Edwards Aquifer manifested the characteristics of a common pool resource. Pumping was essentially unrestricted, and total annual pumping rose significantly over the last century in the absence of incentives or disincentives to conserve water through efficient technology. While not well owners, those dependent upon discharge from the springs of the aquifer were similarly affected by declining aquifer levels that resulted from increasing withdrawals and periodic droughts, much as a pumper whose well yield diminished through a neighbor's pumping. As the chapters that follow will demonstrate the over - exploitation of this common property resource resulted in conflict between different users.

Transboundary Disputes

Disputes over water rights and water use can occur between government entities as well as people. Olen Matthews describes a sequential power transboundary dispute, as a dispute between political jurisdictions resulting when water flows from one political jurisdiction to another (Matthews 1994, 375). The jurisdiction from which the flow travels can come into conflict with the jurisdiction into which the water flows. Matthews makes a basic, but critical, point about the consequence of the mobility of water. The property rights associated with water are unlike those associated with land. The conflicts between differing systems of water law become apparent when different political jurisdictions share a common source of water. Transboundary conflicts could be characterized as macro-scale property rights conflicts, in this context over water. Private property rights conflicts could be characterized as micro scale transboundary conflicts between individuals.

The theories discussed above are woven into the body of the research that follows. In the next chapter the methods used to answer the research questions outlined in Chapter 1 are discussed.

3. RESEARCH METHODOLOGY

Introduction

This chapter will outline the methodology used to answer the questions posed in Chapter 1. The benefits of the research are also enumerated.

Objective 1

Proposed and current Edwards Aquifer drought management plans are intended to prevent spring discharge at Comal and San Marcos Springs from diminishing below rates necessary to protect listed aquatic species. These plans influence the health of aquatic ecosystems of the Comal and San Marcos Rivers and essential downstream surface water uses sustained by the aquifer. The EAA uses the levels of three strategically located groundwater wells to trigger conservation measures during drought to avoid critical flows at Comal and San Marcos Springs. The use of these groundwater wells as proxies for the direct measure of spring discharge is evaluated.

I determine whether the trigger levels used in the EAA's proposed *Critical Period Management Plan* (CPMP) could have prevented critical flows at Comal and San Marcos Springs during historical periods of low rainfall and recharge and historical levels of withdrawals. The relationships between water levels of three groundwater wells -- one each in Uvalde, Medina, and Bexar Counties -- called index wells -- and the flow of Comal Springs and San Marcos Springs in cubic feet per second (cfs) are examined.

Bivariate Pearson correlation coefficients are calculated between flow from the springs and the index wells, one of which is 120 miles from the springs. Scatterplots of the three index well levels and spring discharge are produced with CPMP trigger levels indicated. Finally, the number of days during past low flow periods when the index well trigger levels would have initiated each stage of the proposed *Critical Period Management Plan* in each county are determined.

Objective 2

In 40% of the years after "the drought of record" ended in 1957 (1958 – 1999), critical spring discharge has occurred at Comal Springs. A risk assessment methodology to anticipate years when critical spring discharge might occur is needed to begin curbing water use in advance of the crisis to avoid potential harm to endangered species at Comal and San Marcos Springs and inadequate surface water flows downstream. In 1995, I developed a methodology that can anticipate in advance of each year, total withdrawals that might be allowed in that year while realizing; (1) optimum use of Edwards Aquifer groundwater, (2) protection of endangered and threatened species, and (3) adequate downstream surface water flows to meet legitimate needs in compliance with statutory mandates.

My hypothesis is that an analysis of Edwards Aquifer conditions prior to the beginning of any calendar year can be used to predict, with reasonable certainty, the occurrence of low flows at the springs during the following summer. In most years, flow from the springs increases during the fall, after withdrawals from the Edwards Aquifer peak during the summer and demand declines. If spring discharge remains diminished late into the fall, when the aquifer is normally replenished by recharge from seasonal rainfall, reduced spring discharge may foreshadow the possibility of "take" or "jeopardy" flows (defined in Chapter 5) for endangered species at the springs the following year and inadequate surface water downstream to meet essential needs. As the fall progresses with low rainfall, the likelihood declines that the substantial rainfall needed to replenish the aquifer will occur before withdrawals increase the following year.

To test my hypothesis and anticipate years when critical flows may occur, three measures of important hydrologic conditions are examined; (1) recharge, (2) springs discharge, and (3) withdrawals. U.S. Geological Survey (USGS) data for the period 1934 to 1996 is used (U.S. Geological Survey 1998). Similar data are available for other aquifers in other parts of the United States, offering the possibility that techniques developed in this research could be applicable for the management of other aquifers.

The minimum daily spring discharge rate for Comal and San Marcos Springs is determined for each year for the period of historical data. Annual recharge, spring discharge, and withdrawals from the Edwards Aquifer are determined. Recharge is subdivided into two independent variables, recharge from January to June, and recharge from July to December, to examine the influence of recharge that occurs before and after the period when spring discharge typically reaches its lowest levels in July and August. An additional independent variable, the difference between annual recharge and withdrawals, is determined.

I use multiple linear regression analysis to examine the relationships between critical spring discharge, recharge, and withdrawals from the Edwards Aquifer. Multiple linear regression can be used when two or more independent variables are used simultaneously to explain variations in a single dependent variable (Schroeder, Sjoquist, and Stephan 1986, 29). The independent variables are recharge, springs discharge, and withdrawals. The dependent variables are led by one year to determine if recharge, springs discharge, and withdrawals figures can be used to anticipate critical spring discharge at both Comal and San Marcos Springs in the following year. Leading replaces each value of a variable with the value of a subsequent case.

Objective 3

> We welcome anyone who can present us with a plan that will take all aquifer users into account – from the endangered species that still survive to the humans who deserve the same right.
>
> Michael Beldon, EAA Board Chairman (Beldon 1999b, 29A)

This research is intended to evaluate whether the Edwards Aquifer probably could sustain a higher level of economic activity and population growth than is likely under the EAA's anticipated current and proposed management plans, and plans developed by other entities within the region such as the Guadalupe – Blanco River Authority and the San Antonio Water System.

An analysis is made to determine whether the method the EAA proposes to manage the Edwards Aquifer will provide a sustainable basis for optimum economic benefit to the people of the region and downstream on the Guadalupe River now and in the future while assuring critical spring discharge. Through a literature review and interviews of key individuals, the creation of the EAA, as well as the litigation that led to its creation, is detailed. This analysis is used to evaluate whether the EAA is following the optimum management program under its authorizing statute, Senate Bill 1477 enacted in 1993, as amended. Based on this examination and the results drawn from Objectives 1, 2, and 3, I suggest an alternative management plan to ensure optimum use of Edwards Aquifer groundwater and adequate flow from Comal and San Marcos Springs for sustainable growth and economic development until alternative water supplies can be developed.

As a part of Objective 3, interviews of key individuals representing major interests in the Edwards region were conducted; however, some of the information collected during interviews benefited Objectives 1 and 2 (see Appendix 6. Interviews Requested and Completed). The interviews were conducted to obtain additional information that was not available through the literature search and statistical analysis. The interview questions were tailored to the subjects' areas of involvement with research, management, and use of the aquifer. However, while questions were prepared for each interview, the interviews typically consisted of an open conversation that was not restricted to the prepared questions. This was done to allow relevant new information to be introduced by the person being interviewed.

Benefits of the Research

This research:

- Contributes to the region's ability to manage ground and surface water conjunctively in the future to satisfy growing demands by multiple users;

- Suggests a means to reduce the severity of diminished surface water flow for uses in the Guadalupe River basin, minimizing the likelihood of future jurisdictional disputes between Guadalupe River surface water users and Edwards Aquifer groundwater users;

- Identifies effective management options and the conditions under which action should be taken to protect minimum flows at the springs. The knowledge gained may provide guidelines for the management of other aquifers with similar conditions;

- Demonstrates that a smaller quantity of supplemental water may be required than under the EAA's current approach;

- Improves the tools to preserve threatened and endangered species at Comal and San Marcos Springs, possibly avoiding additional Endangered Species Act litigation;

- Provides a basis for revised and more accurate trigger levels when developing an adequate *Critical Period Management Plan*;

- Provides concepts for the establishment of future groundwater regulatory districts in Texas when similar conflicts arise. A pattern has emerged in Texas of replacing the rule of capture with local regulation as conflicts erupt over scarce groundwater resources;

- Provides insight into alternatives that might reduce the increasing conflicts between the ESA and water use across the American West; and

- Proposes the conjunctive use of surface and groundwater for sustainable growth in the Edwards Aquifer region.

4. EDWARDS AQUIFER HYDROLOGY, CLIMATE, AND POPULATION

Introduction

This chapter will examine key characteristics of the Edwards Aquifer, including climate of the region, land use practices that affect the hydrology of the aquifer, and population growth within the region, all of which constitute the framework within which decisions concerning the sustainable development of the aquifer must be made.

Hydrology

Springs in Texas

As the growth of human communities in Texas has diverged from the geographic distribution of water, natural supply systems are being overtaxed to meet demand. During droughts, the human water needs frequently outstrip supply, which can damage the ecosystems that also require water during these stressful events. One category of these overtaxed natural systems is springs, where the physical and legal transformation of groundwater into surface water occurs. Scattered across the often-arid landscape of Texas are more than 1,000 springs, many of which are oases for unique plants and animals found nowhere else in the world (Brune 1981, 566).

Texas originally had 281 major freshwater springs, of which 139 issued from the Edwards (Balcones Fault Zone) and the Edwards-Trinity (Plateau) Aquifers (Brune 1975, abstract). Major springs are those with a flow of 1 cubic foot per second (cfs) or more, including those springs known to have discharged at rates of 1 cfs or more in the past, but that currently flow at lesser rates (Brune 1975, 5). Springs issue from underground formations of limestone, gypsum, sand, gravel, and other permeable formations. Faults, acting as subterranean dams, are important determinants in the location of springs by blocking the lateral flow of the water under hydrostatic pressure which then moves upward to overflow. The arching, doming, and cracking of rock layers cause the formation of springs.

Springs have been important to humans for thousands of years as documented by the bedrock mortars, middens, and rock paintings and carvings found in the vicinity of springs (Brune 1981, preface). Springs were stops for early explorers, stage coaches, and river boats. They provided power for mills, health-restoring minerals at spas, municipal water supplies, and recreational parks (Brune 1981, abstract, preface). Many battles were fought between pioneers and American Indians for possession of springs (Brune 1975, abstract). Numerous communities formed around springs, and they have been important recreational centers. The decline in springs probably began soon after the first colonization of Texas by Spain (Brune 1975, abstract). Unique ecosystems containing endemic plant and animal life, such as the Comanche Springs pupfish, have disappeared as the springs dried up (Brune 1981, preface).

Endemic species are species that occur in a particular place and are found only there (Wilson 1992, 397).

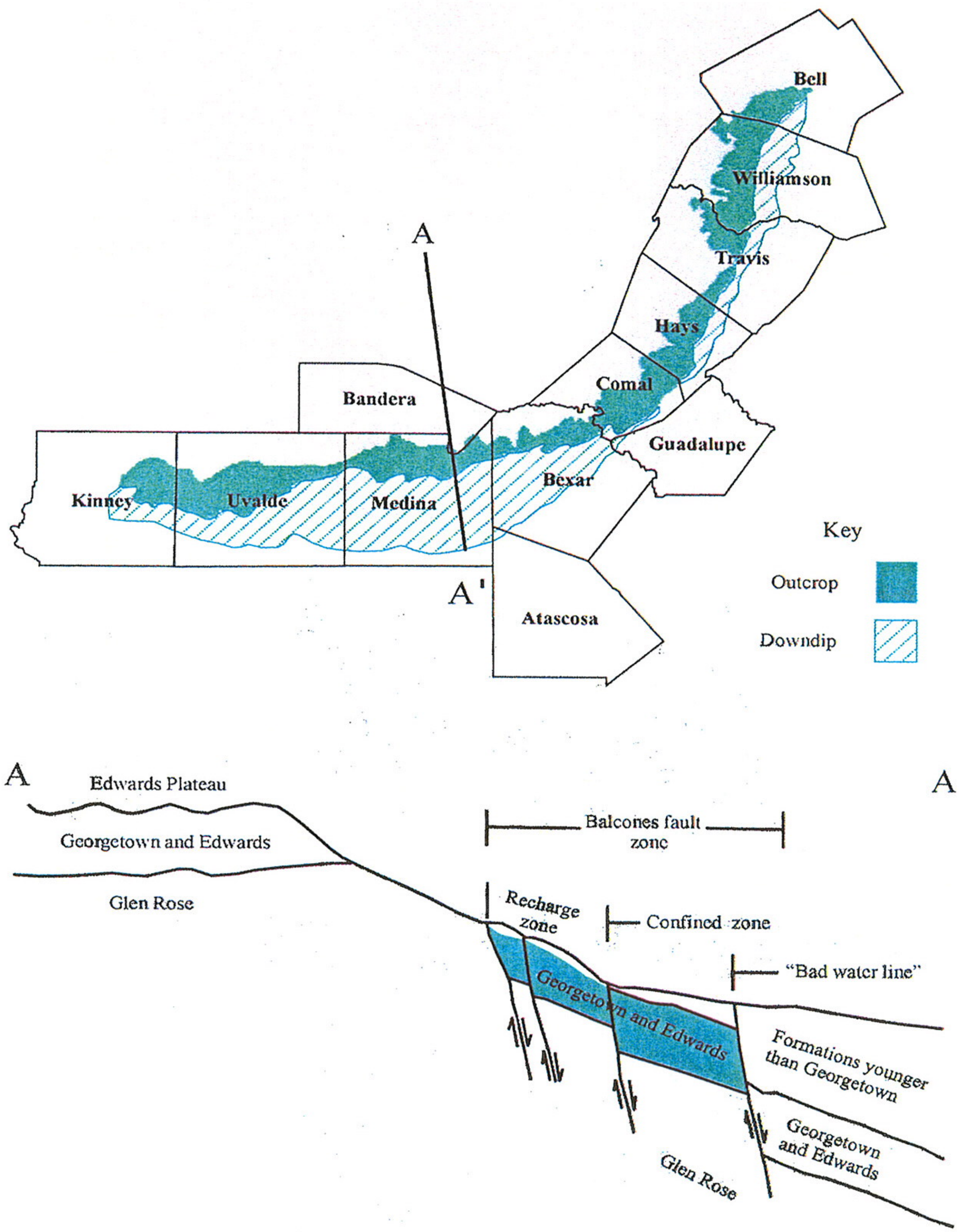
By 1981, sixty-three, or approximately 22%, of the major freshwater springs in Texas had completely failed primarily because of groundwater withdrawals (Brune 1975, abstract). The clearing of forested land and overgrazing has likely reduced recharge to springs (Brune 1975, abstract). In the mid-1800's, the drilling of many flowing wells greatly reduced the artesian pressure of some springs. Described by early explorers as natural 'fountains,' these prolific springs quickly disappeared with advances in well technology. Groundwater withdrawals for irrigation, municipal, commercial, industrial and other purposes have accelerated the decline of springs in Texas. While some springs have been inundated by surface reservoirs, others have experienced increased flow as the result of reservoir construction (Brune 1975, abstract). Many of the Edwards Aquifer's 139 springs still flow when the water level is high; however, many in Uvalde, Medina, and Bexar Counties ceased to flow or became intermittent during periods of low recharge because of groundwater withdrawals. All of the threats facing Texas' groundwater and springs result from increased water use due to population increases (Brune 1981, preface). Four Texas springs originally flowed at a rate greater than 100 cubic feet per second; by 1975 however, only two of the four, Comal and San Marcos Springs, continued to flow at or above this level (Brune 1975, abstract).

Description of the Edwards Aquifer

The Edwards (Balcones Fault Zone) Aquifer is a major Texas groundwater formation which stretches from Brackettville in Kinney County, east to San Antonio in Bexar County, and north through Austin in Travis County to Mills County northwest of Salado (Figure 1). It consists of three segments, the northern segment, the Barton Springs segment, and the southern or San Antonio segment. The boundaries of the northern segment are Mills County northwest of Salado and Austin to the south. The Barton Springs segment is the center segment, bounded by Austin to the north and Kyle in Hays County to the south. The southern or San Antonio segment (hereinafter referred to as the Edwards Aquifer) stretches about 200 miles from Brackettville, east to San Antonio, and north to Kyle. The Edwards Aquifer shown in Figure 2 is one of the most permeable and productive carbonate aquifers in the United States (U.S. Geological Survey 1997, 1). It is a complexly faulted karst groundwater formation encompassing a contributing zone of some 4,400 square miles, recharge zone of 1,500 square miles, and confined zone of 2,100 square miles, totaling some 8,100 square miles (Edwards Aquifer Authority undated, 2).

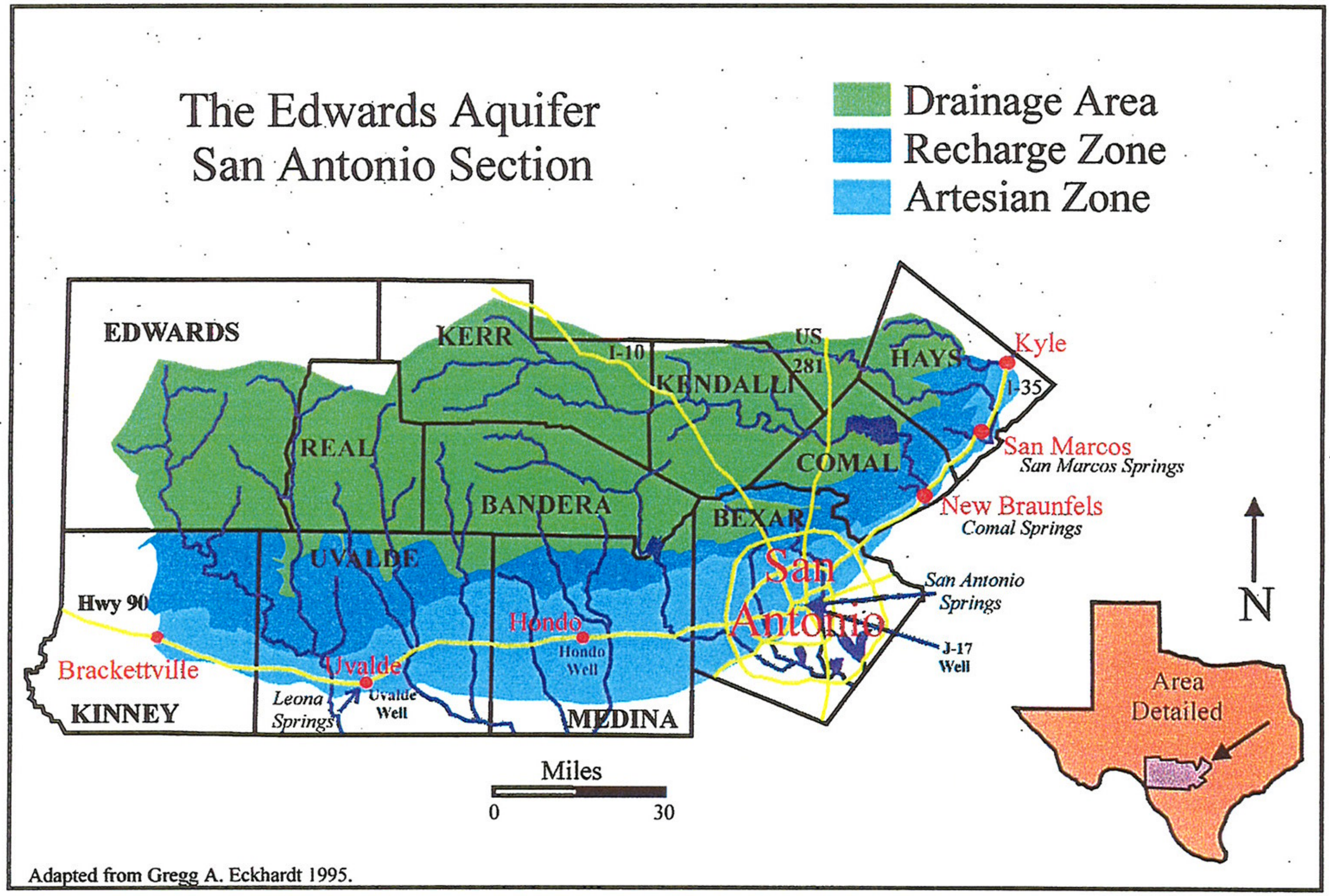
A simple analogy of the very complex aquifer likens it to a bucket with different sized holes that represent the springs at several levels from top to bottom. If the bucket is full of water, the water flows from all the holes at variable velocities depending upon the water level in the bucket and the size and elevation of the hole. As the water level declines, flow from each hole decreases until the lower edge of each downward hole is reached, and then flow ceases. San Antonio, Comal, and San Marcos Springs are examples of the holes in the

Figure 1. The Edwards (Balcones Fault Zone) Aquifer



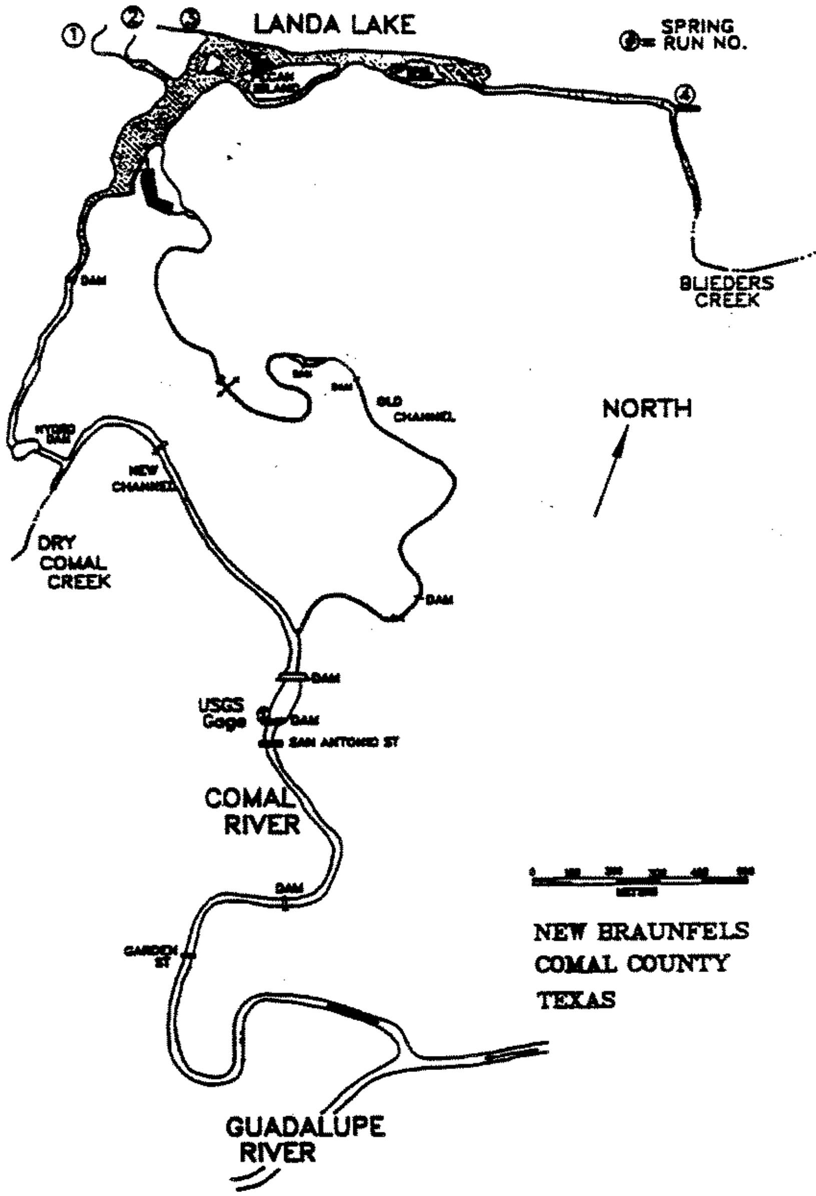
(Ashworth and Hopkins 1995, 14)

Figure 2. The San Antonio or Southern Section of the Edwards Aquifer



bucket that are also the sources of rivers of the same name, all of which eventually flow into, and provide much of the baseflow for the Guadalupe River from Gonzales, Texas to the Gulf Coast, a distance of about 90 river miles. Comal, and San Marcos Springs are the largest and second largest springs in the Southwest (Brune 1975, 39, 45). Comal Springs (Figure 3) actually consists of some 18 or more spring openings (Brune 1981, 131). Some of these are submerged under Landa Lake, while the remainder discharge into spring runs located at slightly higher elevations. About 20% of the discharge from Comal Springs comes from four spring runs, j, k l, and m, while the rest comes from the spring orifices under Landa Lake (Ozuna 1999). Hydrochemical investigations of the Comal and Hueco spring systems in Comal County, Texas were conducted by Rothermel and Ogden in 1982 and 1983 in an attempt to better understand the nature of recharge and flow to the springs (Rothermel and Ogden 1987, abstract). The study analyzed fracture and joint orientations using dye - tracing. Comal Springs was found to be a deep-flow conduit system with long transport distances, but with some local recharge during high water table conditions resulting from storm events (Rothermel and Ogden 1987, abstract). However, since Comal Springs was not observed to become turbid and showed no bacterial contamination after storms, local recharge must not occur very close to the springs or in large volumes (Rothermel and Ogden 1987, abstract). Rothermel and Ogden concluded that local recharge structures would not increase guaranteed flow from Comal Springs, but that its flow could only be preserved by restricting groundwater withdrawals. The principal recharge area for Comal Springs lies as much as 62 miles west of New Braunfels (Brune 1981, 130).

Figure 3. Comal Springs

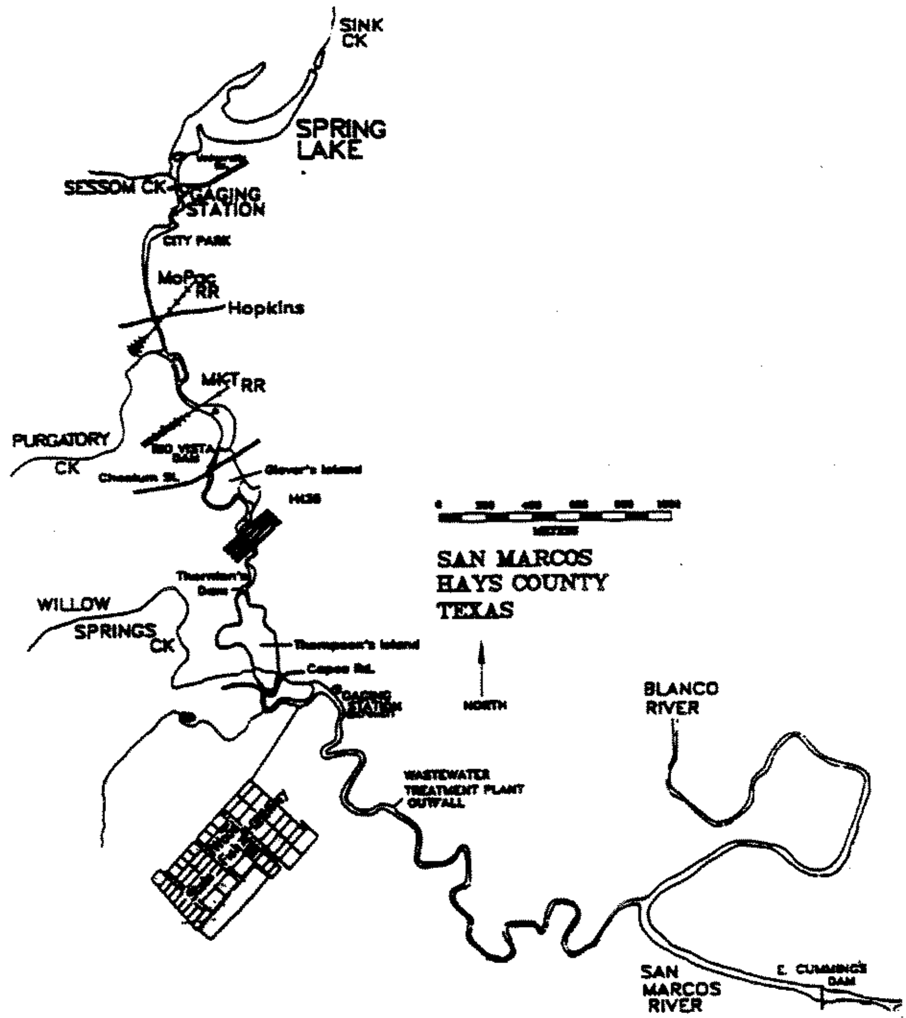


(U.S. Fish and Wildlife Service 1996, 12)

San Marcos Springs (Figure 4) consists of some 200 springs that originate from three large fissures, and many small openings, at the bottom of Spring Lake (Brune 1981, 223). The largest component of recharge to San Marcos Springs is from groundwater flow past Comal Springs and the next largest is local recharge (Rothermel and Ogden 1987, 138, 139).

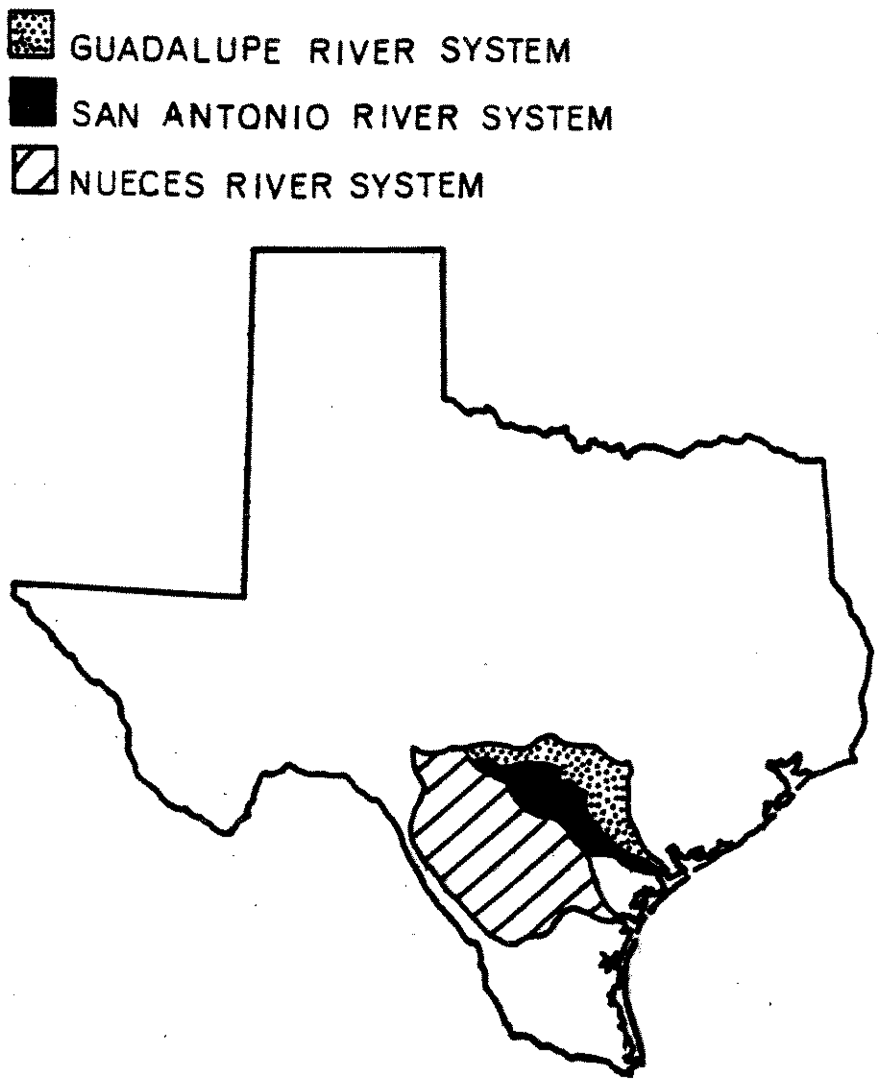
The total volume of circulating water in the Edwards Aquifer is not known with great certainty, but has been estimated at 45 million acre-feet (U.S. Geological Survey 1996, 1). However, much of this water is at depths that make its use uneconomical (U.S. Geological Survey 1996, 1). The aquifer is very transmissive due to the highly permeable and porous Edwards limestone. Most of the aquifer's permeability results from secondary porosity from joints, fractures, vugs, and solution channels that are interconnected (Klemt and others 1979, 36). Aquifer levels are dependent upon highly variable annual rainfall and the rate of withdrawals to satisfy multiple demands. Much of the recharge to the aquifer occurs as the result of brief, but intense storms that supply water to the mostly perennial streams that recharge the aquifer. Rainfall across the region averages 22 to 36 inches annually, with 22 to 29 inches falling over the key recharge Counties of Kinney, Medina, and Uvalde (Illgner 1993, 1.2). From USGS data, I calculated that approximately 70% of the recharge to the aquifer occurs west of San Antonio in Kinney, Medina, and Uvalde Counties (U.S. Geological Survey 1998, 2). This recharge occurs where three river basins (Figure 5), the Nueces (Figure 6), the San Antonio (Figure 7), and Guadalupe (Figure 8), cross the aquifer recharge zone. By basin, approximately 51% of the recharge occurs in the Nueces, 37% in the San Antonio, and 12% in the Guadalupe River basin (Todd Engineers 1999, 9).

Figure 4. San Marcos Springs



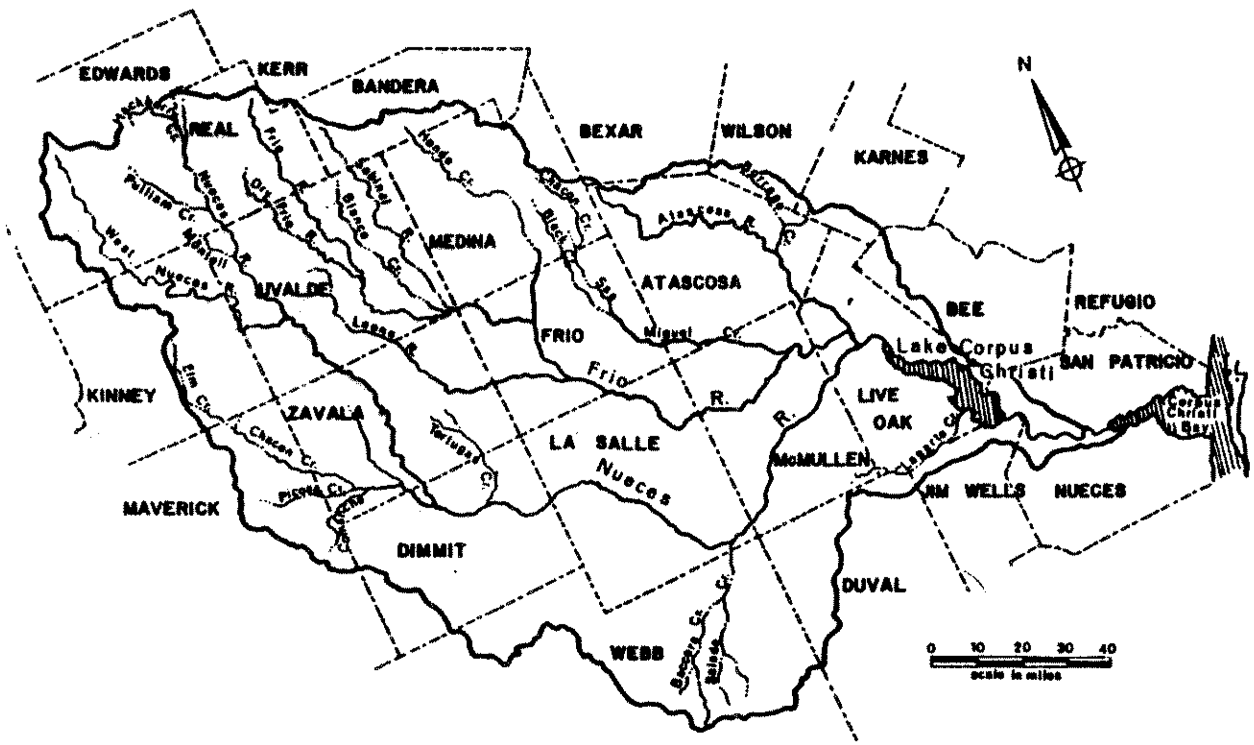
(U.S. Fish and Wildlife Service 1996, 14)

Figure 5. The River basins that Overlay the Edwards Aquifer



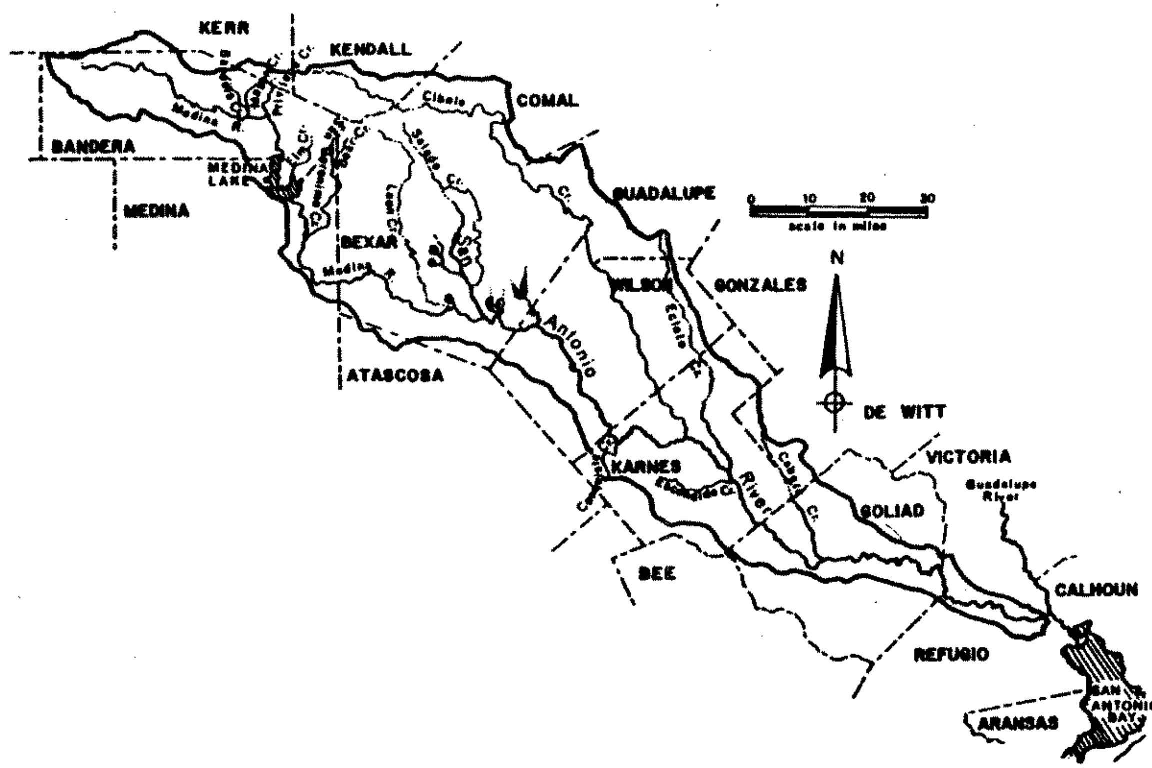
(Young and others 1973, 4)

Figure 6. The Nueces River Basin



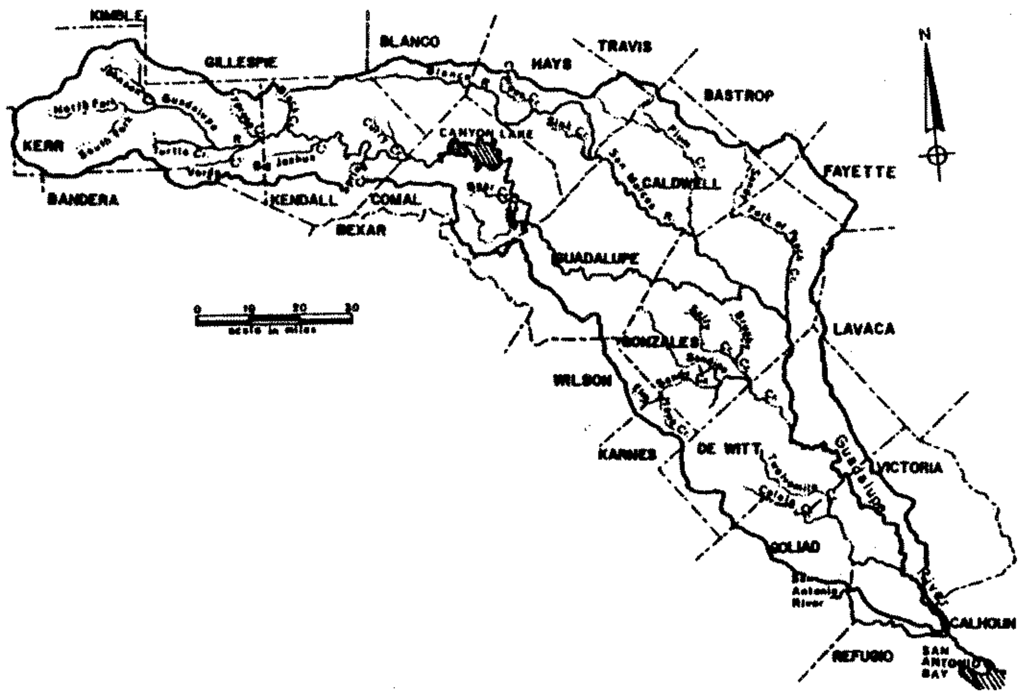
(Young and others 1973, 18)

Figure 7. The San Antonio River Basin



(Young and others 1973, 12)

Figure 8. The Guadalupe River Basin



(Young and others 1973, 5)

Because the Edwards Aquifer is primarily recharged west of San Antonio and the water reemerges east of San Antonio at Comal and San Marcos Springs, the aquifer has been characterized as an enormous trans-basin diversion (Nevola 1989, 11-12). Water enters the aquifer west of San Antonio as runoff from storms that collect into the streams and rivers of the Nueces River basin that flow generally south across the recharge zone where it comes into direct contact with the porous Edwards limestone. Water enters the aquifer and generally flows south and southeast within precipitous hydraulic gradients and low permeabilities to the confined zone (Klemt and others 1979, 23). The hydraulic gradient becomes low and permeability becomes high as water moves generally east and northeast to the springs at San Antonio, New Braunfels, and San Marcos as well as others (Klemt and others 1979, 23). As the water flows east, wells intercept a significant portion of the aquifer's annual recharge.

The presence of a faultline west of Hondo, Texas and east of Uvalde, Texas, which includes the Haby Crossing and Medina Lake Faults, tends to temporarily 'pile up' water behind these faults. The flow of water is redirected through the Knippa Gap, an ill - defined geologic feature that restricts, to an unknown degree, the flow of water to the east (Todd Engineers 1999, 16). This feature influences the movement of water through the aquifer much as a spillway does for a surface reservoir (Todd Engineers 1999, 16). Table 1 indicates that the average annual recharge to the aquifer over the period of record from 1934 to 1998 has been 683,100 acre-feet (U.S. Geological Survey 1999, 4). Record high and low recharge amounts have varied from 2,485,700 acre-feet in 1992 to 43,700 acre-feet in 1956 respectively (U.S. Geological Survey 1999, 2). Withdrawals from the

Table 1. Edwards Aquifer Water Characteristics

An Acre-Foot	325,851 gallons of water
Average Annual Recharge (1934 – 1998)	683,100 acre-feet
Median Annual Recharge (1934 – 1998)	556,100 acre-feet
Record Lowest Recharge (1956)	43,700 acre-feet
Record Highest Recharge (1992)	2,485,700 acre-feet
Annual Discharge from Comal and San Marcos Springs in 1998 (80% of all Edwards Aquifer springs discharge)	371,100 acre-feet
Average Annual Discharge from all Edwards Aquifer Springs (1934 – 1998)	365,300 acre-feet
Record High Withdrawals (1989)	542,400 acre-feet

Source: (U.S. Geological Survey 1999, 2, 3, 4).

Edwards have increased from approximately 100,000 acre-feet in 1934, to a peak of 542,400 acre-feet in 1989 (U.S. Geological Survey 1999, 3). As withdrawals from the Edwards Aquifer have increased, the possibility that Comal and San Marcos Springs may become intermittent, or cease to flow altogether, has increased. Waters discharging from these springs comprise a significant, but variable, portion of the surface water available downstream in the Guadalupe River basin.

Since the 1960s, the Edwards Aquifer region generally has been in a wet cycle. The total recharge in the decades of the 1970s, 1980s, and 1990s has exceeded the 1934 – 1998 annual average (Table 2). Despite two serious droughts in 1996 and 1998, the 1990 -1998 period has the highest total recharge of any decade during the period of record, 9.2 million acre-feet. With one year left for the 1990's data, recharge for this decade has nearly equaled the total recharge for the decades of the 1940's and 1950's combined. This current period of generally high recharge is unlikely to be sustained indefinitely.

During this period of high recharge, withdrawals from the aquifer have reached their highest levels (Figure 9). Much of the population growth in the Edwards Aquifer region has occurred during the wet cycle that has characterized the last three decades. There are some parallels in the Edwards situation to the homesteading of the arid and semi-arid portions of the Great Plains during a wet cycle, and the allocation of Colorado River of the West among its contributing states, water volumes based on estimates derived during a wet period. John Wesley Powell, leader of the U.S. Geographical and Geological Survey of the West and second director of the USGS, cautioned against the mass settlement of the arid and semi-arid portions of western North America because of the lack of

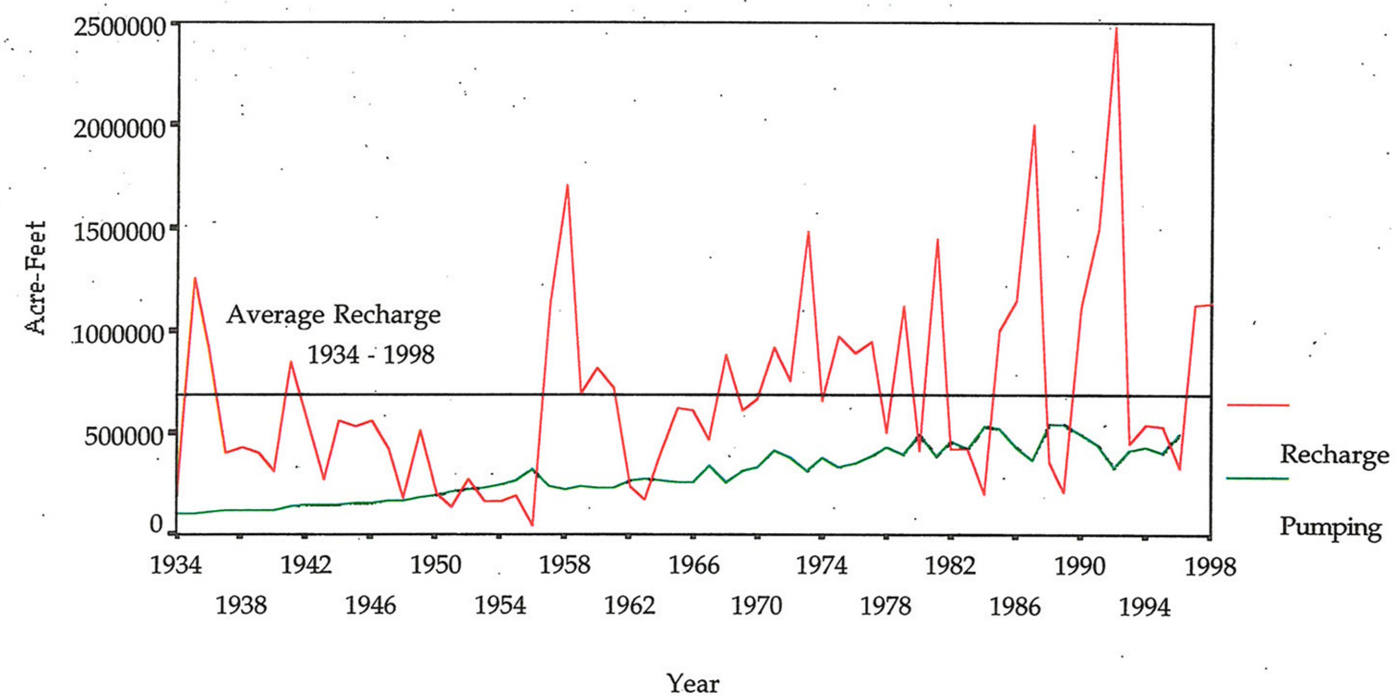
Table 2. Average Recharge to the Edwards Aquifer by Decade Compared to Average Rainfall for San Antonio by Decade

Decade	Average Annual Recharge in acre-feet	Average Annual Rainfall in Inches*
1940 – 1949	470,000	30.67″
1950 – 1959	470,000	24.73″
1960 – 1969	560,000	27.98″
1970 – 1979	890,000	34.24″
1980 – 1989	760,000	29.89″
1990 through 1998	920,000	35.22″

*Recorded at San Antonio International Airport.

Source: Prepared by author based upon U.S. Geological Survey 1999, 2.

Figure 9. Total Annual Recharge vs. Total Annual Withdrawals, 1934-1998



water (Martin and James 1993, 159, 160). These regions were settled anyway, and when the drought cycle returned, the new inhabitants found that the agricultural techniques they had brought from the East could not sustain them. The allocation of water rights in the western Colorado River, between states that share that river, was based on flows recorded during a period of high rainfall and runoff. Under the *Law of the River*, the Colorado River states of Arizona, Nevada, and California share a surplus of water in years when a surplus is declared and one of the states does not use all of the water it has been allocated (Epstein 1999a, 18). California has relied on this surplus to meet its water needs in the southern portion of the state. The *Law of the River* was recently renegotiated in part because of a fear that the weather patterns that have created 20-years of above average rainfall in that region will end (Epstein 1999a, 18).

Historical Uses of Edwards Aquifer Water

Edwards Aquifer springs were an important resource for early inhabitants of the region. San Antonio Springs in San Antonio was visited by Cabeza de Vaca in 1535 (Brune 1975, 33). It eventually supplied water for irrigation through acequias (community irrigation ditches) built around Spanish missions there (Kaiser 1987, 43). The area around San Pedro Springs in San Antonio was established as a public park in 1729 by King Philip V of Spain, making it the second oldest park in the United States (Haurwitz 1997b, 21A). Neither of these springs has a regular or reliable flow today because of pumped withdrawals.

The Tehuacana Indians once occupied the Comal Springs area (Brune 1981, 38). In 1845, German immigrants led by Prince Carl Solms-Braunfels settled the area, eventually establishing New Braunfels, in part because Comal Springs provided a source of water to power mills (Wimberley 1998).

San Marcos Springs had been occupied by Tonkawa Indians for 600 years before the Spanish arrived (Wimberley 1998). It was also the location of a Spanish mission from 1755 to 1756 (Wimberley 1998). Uvalde, Texas was established because of the existence of Leona Springs (Wimberley 1998). These cities formed around the springs long before wells were drilled into the aquifer.

The use of artesian wells from the aquifer dates back to at least 1884 when the first irrigation well was completed in Bexar County (Texas Board of Water Engineers 1961, 14). The withdrawal of groundwater began in earnest during the 1950s (Wimberley 1997b, 1). Until the record drought in that decade, the aquifer was so prolific, and the demand so small, that pumping from the wells appears to have made little difference with regard to spring discharge. Today, many of the springs, such as San Antonio Springs, rarely flow unless a flood fills the aquifer. The San Antonio River adjoining the River Walk, a central feature of downtown, would be dry within the city limits if not for water pumped into it from the aquifer (Texas Water Development Board 1991b, 19).

The Edwards Aquifer is currently the sole source of water for almost 2 million persons, including all residents of the City of San Antonio (Watkins and McKinney 1999, 17). San Antonio is the only major city in the United States that obtains its entire water supply from a single aquifer (Texas Water Development Board 1991b, 19). Water from the aquifer also supports the economies of agriculture - based counties west of the city, Comal and Hays Counties to the east, and communities in the Guadalupe River basin all the way to the Texas Gulf Coast. Permits issued by the state to surface water rights holders in the

Guadalupe River basin are based, in substantial part, on flows from the aquifer. Most permits for Guadalupe River water were issued before withdrawals from the aquifer reached significant levels.

The importance of the Edwards Aquifer as a water supply was recognized by the federal government in 1975 when the U.S. Environmental Protection Agency (USEPA) declared it the nation's first 'sole source aquifer' under the Safe Drinking Water Act of 1974 (SDWA) (Public Law 93-523). That statute's provision allowing such designations was inserted in the SDWA at the insistence of San Antonio Congressman Henry B. Gonzales (Rosenberg 1999). That Act provides that special protection may be given upon petition or by decision of the USEPA if:

> (A)n area has an aquifer which is the sole or principal drinking water source for an area, and which if contaminated would create a significant hazard to public health. [Safe Drinking Water Act, § 1424(e)].

In the absence of state underground injection controls, Congress intended to provide interim protection to the critical aquifers through the sole source aquifer provision of the SDWA, including specifically the Edwards Aquifer (Arbuckle and others 1991, 180). The quality and quantity of water supplied throughout most of the history of the region have been so high that San Antonio has relied on the aquifer as its only source of water. The infrastructure necessary to deliver treated surface water to supply the city in the event of a prolonged drought or to accommodate future growth has not been built. Even though the city is located at the edge of a semi-arid region, Table 3 indicates that the cost of

Table 3. Average Monthly Residential Water and Sewer Bills for Selected Municipalities in Texas

City	Monthly Residential Water and Sewer Bill
Austin	$58
Dallas	$50
Fort Worth	$46
Houston	$64
San Antonio	$28

Source: (San Antonio Express-News 1999, 5B).

water in San Antonio has, until recently, been among the lowest of any major metropolitan area in Texas (San Antonio Water System 1994, 49).

The use of water by San Antonio's largest water purveyor, the San Antonio Water System (SAWS), was very inefficient in the past, but has become more efficient in recent years. Water use in the late 1980's was 285 gallons per capita per day (gpcd), while in the late 1990's 155 gpcd are being used (Thuss 1999). Much of these efficiency gains have resulted from SAWS' leak detection and repair program for its water delivery infrastructure, as well as its promotion of water saving appliances and practices (San Antonio Water System 1993, Table 21). Until the ESA litigation (discussed in Chapter 6) there was little incentive for SAWS, or any other pumper, to spend money plugging leaks. It was simply cheaper to pump greater amounts of free water from the Edwards Aquifer to overcome transmission losses.

From 1989 to 1998, withdrawals have varied annually from 327,300 acre-feet to 542,400 acre-feet (U.S. Geological Survey 1998, 3). Municipal use in the five years of highest withdrawals since 1980 (1984, 1985, 1988, 1989 and 1990) accounted for more than 50% of all withdrawals from the Edwards Aquifer (Votteler 1996, 9). During average climatic conditions, outdoor watering, including lawn and ornamental watering, and, to a much lesser extent, outdoor car washing and water for pools, accounts for between 30% and 40% of total of water withdrawn from the aquifer (Thuss 1999). Over the last 50 years, the use of Edwards water for irrigated agriculture has increased significantly. Because the cost of water to the farmer has been only the cost of the well and the energy to pump water from the aquifer, few incentives have existed to encourage farmers to adopt the most efficient irrigation methods. Withdrawals for irrigated agriculture vary according to rainfall over the region. However, in 1967 withdrawals for irrigated agriculture exceeded 100,000 acre-feet per year for the first time, and then peaked in 1985, exceeding 200,000 acre-feet per year (U.S. Geological Survey and Edwards Underground Water District 1994). Irrigation withdrawals have stabilized over the last decade.

A similar pattern has emerged elsewhere. Nationwide, total surface and groundwater withdrawals have remained relatively constant since the mid 1980's after increasing in each year from 1950 to 1980 (Solley, Pierce, and Perlman 1998, iii). Freshwater consumptive uses in the West are approximately 47% of all freshwater withdrawals, while the estimate is 12% in the East (Solley, Pierce, and Perlman 1998, 1). A higher percentage of use in the West is consumptive, because 90% of water withdrawals are for irrigation (Solley, Pierce, and Perlman 1998, 1). From 1990 to 1995, nationwide irrigation withdrawals decreased by 2%, while irrigated acres increased by 1% (Solley, Pierce, and Perlman 1998, 32). The decrease in irrigation water use was attributed to the use of more efficient irrigation techniques and increases in rainfall during this period (Solley, Pierce, and Perlman 1998, 32). Irrigated acres in the West decreased from 1980 to 1995, because irrigated acreage was replaced with urban development and dry land farming, and irrigation water rights were sold to municipal water suppliers (Solley, Pierce, and Perlman 1998, 62, 63).

Surface Environmental Changes Influencing Hydrology

Access to Edwards groundwater has allowed the land above the aquifer to be reshaped. The land surface, especially vegetation, on the Edwards confined, recharge, and contributing zones at one time was very different from that today. Prior to settlement by Europeans, fires were a common feature of the landscape. Natural fires were triggered by lightning strikes, and American Indians who regularly set fires (Texas A&M University Research Station 1994, 4). These fires swept across the mixed tallgrass prairie confining woody species such as ashe juniper (*Juniperus ashei*), mesquite (*Prosopis glandulosa*), and other brush with high evapotranspiration rates to the escarpments and more mesic areas. As central Texas was settled, fire was suppressed. Overgrazing also suppressed fires by degrading rangeland to the degree that the remaining grasses could not carry fire to the brush under normal conditions. Brush with high evapotranspiration rates has now overtaken former grasslands because of overgrazing and fire suppression. Mesquite roots can penetrate down 65 feet or more to reach groundwater (Jensen 1988, 1-6). Fire will kill junipers, but generally it only slows mesquite growth (Pinchak, Ansley, and Teague 1995). In areas of the contributing and recharge zones where juniper, mesquite and other water absorbing brush have replaced former grasslands, springs and once perennial streams are now intermittent, flowing only during wet periods. Ecosystems that would have been indefinitely sustained by those streams have perished or been altered significantly. In these same areas, wetlands have been lost, and the riparian zone has declined as these areas were developed for agriculture. As woody species thrived and grasses diminished, soil erosion increased because the grassless understory in juniper thickets allowed soil to be eroded. The result has been increased sedimentation and less recharge to the Edwards Aquifer as evapotranspiration has increased.

Beavers (*Castor canadensis*) once occupied the Edwards Aquifer region (Davis 1960, 166, 167). They depended on the numerous cottonwoods that once lined the regional watercourses for food and habitat. They are a keystone species that build dams allowing wetlands to spread out behind them, creating habitat for numerous other species (Outwater 1996, 21). With elimination of beaver and the loss of riparian habitats, the duration and timing of recharge to the aquifer may have been altered. Wetlands acted as sites for recharge much like artificial recharge dams already constructed and proposed. The loss of riparian habitats also may have altered the amount of recharge by reducing the ability of water to enter the aquifer. With the loss of riparian habitat, water may move across the recharge zone faster, reducing the time in which it is in contact with the porous Edwards limestone. This could result in a larger percentage of the recharge having to occur in less time without wetlands to absorb flood flows. As riparian areas have been lost, total recharge to the aquifer is probably being reduced. The restoration of wetlands over the recharge zone could allow water to percolate slowly into the aquifer. Wetlands in the contributing zone could store water and slowly release it downstream so that more recharge occurs during drier periods. This consequence could reduce peak flows at Comal and San Marcos Springs as the rise in hydrostatic pressure is distributed over a longer period, and the time the springs flow above the mean increases. Other keystone species that affect the local hydrology were present across the contributing and recharge zones at one time. Both American bison (*Bison bison*) and black-tailed prairie dogs (*Cynomys ludovicianus*) were present (Zim and Hoffmeister 1955, 134, 135) (Davis 1960, 132, 133). Bison wallows and prairie dog burrows have been identified as significant contributors to groundwater recharge (Outwater 1996, 73, 75, 76).

Urban growth in New Braunfels, San Antonio, and San Marcos is altering the contributing and recharge zones of the aquifer. As the regional population increases, the pressure to build over the recharge zone is also increasing, and agricultural land is being converted to commercial, residential, and industrial uses. As more land is paved, the area available to recharge the aquifer is decreasing as impervious cover increases. By 1998, approximately 72% of the 119 square miles of recharge zone in Bexar County remained undeveloped, while residential and commercial development was increasing in this area (Ockerman, Petri, and Slattery 1999, 1). Construction over the contributing and recharge zones also increases the flow of sediment into the creeks and rivers that are the sites for much of the recharge to the Edwards. As this transport of sediment across the recharge zone increases, sediment can enter the aquifer, filling the cracks and fissures in the limestone, eventually reducing both recharge rate and total aquifer storage capacity. Wetlands can trap sediment in transport within the water column before it can clog recharge features (Mitsch and Gosselink 1993, 598). The future yield of the aquifer could decrease at the same time that the demand for aquifer water is increasing to accommodate the additional population.

The risk of floods over the recharge and contributing zones, as well as downstream, has increased as riparian areas are destroyed. The vegetation of wetlands slows the movement of water to reduce flooding. Eliminating stream and river meandering increases the speed at which water moves downstream, which increases flooding. The Edwards Plateau and the Gulf Coastal plain are frequently inundated by heavy rainfall from tropical depressions, storms and hurricanes that move across the area from the Gulf of Mexico.

As agriculture spread across the contributing and recharge zones in the 20th century, chemical pollutants, primarily in the form of fertilizers, agricultural pesticides and herbicides, began to wash into the aquifer. Water quality is also being reduced by the chemical pollutants washed into the aquifer with the sediment. Wetlands could absorb some of the nitrogen, phosphorus, pesticides, and herbicides to prevent these pollutants from entering the streams and rivers (Mitsch and Gosselink 1993, 598).

Karst aquifers such as the Edwards are poor at filtering pollution, contrary to public opinion (Ozuna 1999). Increased sediment and pollution flows can significantly degrade the water quality at Comal and San Marcos Springs and could impact the endangered species, as well as the entire aquatic ecosystem found there and downstream. Development of the recharge zone will also bring more underground storage tanks (unless restrictions are enacted), increasing the possibility of aquifer contamination from their leaking, as well as from any industrial facility that might be built over the recharge zone.

Climate

Climate in the Edwards Aquifer Region

Texas is located along the 30° North latitude where many of the Earth's deserts are found (Jensen 1996, 1). John Wesley Powell recognized the significance of this line of demarcation (Lowry 1959, 66 quoting W.G. Hoyt). Powell cautioned Congress that the lands west of Minnesota were arid and, for the most part, could not be used for agriculture except with irrigation (Lowry 1959, 66 quoting W.G. Hoyt). The far western portion of Texas has a desert climate, the far eastern portion has a humid climate, and between them lies an intermediate zone that is nether arid nor humid. This intermediate zone shifts from year to year with variations in rainfall. Annual rainfall in Texas varies from 8 inches in El Paso to 56 inches along the Texas - Louisiana border (Texas Water Development Board 1991b, 2). Generally, the west has a deficit of water, while the east has a surplus. Interstate Highway 35 divides the state between the 20% of the population to the west that uses 44% of the water (85% for irrigation), and the 80% of the population that lives to the east and uses 56% of the water (36% for irrigation) (Texas Water Development Board 1991b, 9). Texas receives most of its moisture from the Gulf of Mexico with lesser amounts contributed from the Pacific Ocean (Jones 1991, 514).

As with most of Texas, precipitation across the Edwards region varies seasonally, with some sources indicating that April and May being the wettest months as the result of thunderstorm activity from successive weak frontal systems (Jones 1991, 514). However, other sources indicate that June has been the wettest month for San Antonio in recent decades (Table 4). A secondary peak of rainfall generally occurs in September and October from tropical cyclones originating in the Gulf of Mexico and Caribbean Sea (Jones 1991, 514). Droughts in Texas occur primarily from shifts of the Bermuda High portion of the subtropical high-pressure zone which drifts latitudinally and becomes fixed over the southern U.S. (Jones 1991, 514).

Table 4. San Antonio Climate Summary: 1961-1990

Month	Average Rainfall (inches)	Average High Temperature (°F)	Average Low Temperature (°F)
January	1.71	61	38
February	1.81	66	41
March	1.52	74	50
April	2.59	80	58
May	4.22	85	66
June	3.71	92	73
July	2.16	95	75
August	2.54	95	75
September	3.41	89	69
October	3.17	82	59
November	2.62	72	49
December	1.51	64	41
Annual Average	**30.97**	**80**	**58**

Source: (National Oceanic and Atmospheric Administration 1999).

Drought

Drought has been called the most complex, but least understood, of all natural hazards, affecting more people than any other hazard (Wilhite 1996, 230). However, it is a normal, recurrent feature for nearly all climatic regimes (Wilhite 1996, 231). Drought is the most damaging of weather related natural hazards (Kogan 1995, 15). In the 25 year period prior to the 1990s, drought affected 1.4 billion of the 2.8 billion people who suffered from weather-related disasters, resulting in 1.6 million deaths (Obasi 1994, 1661). There are several definitions of drought. The problem of arriving at a standard definition is the result of conflicting concepts held by different academic fields which have persisted for years (Dracup, Lee, and Paulson 1980, 297). Drought is usually considered relative to some long-term average condition of balance between precipitation and evapotranspiration in a particular area, referred to as normal (Wilhite 1996, 231). It differs from other natural hazards in important ways. Drought is not often recognized as a natural hazard, because it develops slowly with beginning and ending times difficult to determine; its definition varies; and its impacts are often spread over a large area (Wilhite 1996, 232).

There are several major categories of drought. These include: meteorological (degree of dryness); socioeconomic (associates the supply and demand of some economic good with meteorological or hydrological drought, for example water, crops, or hydroelectric power); and hydrological (effects of precipitation shortfalls on water supplies) (Wilhite 1996, 232-233). Some authorities indicate that, depending on duration and intensity, a drought can have a meteorological, a socioeconomic, and a hydrological phase, developing and terminating in that order (Galvan 1999, 1). The variety of drought definitions requires an analyst to specify the particular type of drought to be studied (Dracup, Lee, and Paulson 1980, 301). Hydrologic drought can be produced artificially by pumping excessive amounts of groundwater from an aquifer. For this research, the focus is hydrologic drought.

Drought in the Edwards Aquifer Region

Drought is a significant natural hazard in the Edwards Aquifer region. To understand past drought magnitude and duration, the paleoclimatic record must be examined (Woodhouse and Overpeck 1998, 2693). Historical documents, tree ring analysis, archeological investigations, lake sediments, and geomorphic data demonstrate that twentieth century droughts pale in magnitude and duration to previous droughts during the last 2000 years (Woodhouse and Overpeck 1998, 2693). Major multiyear droughts affecting the Great Plains (including the Edwards region) have occurred once or twice a century for the last 400 years (Woodhouse and Overpeck 1998, 2698). Paleoclimatic data suggest that droughts across the Great Plains during the period 1 – 1600 AD occurred on scales that have not recurred since European colonization (Woodhouse and Overpeck 1998, 2704). Droughts of the scale experienced in the 1930s and 1950s have occurred regularly over the past 400 years, and are moderate in severity and short in duration compared to those occurring 1 – 1600 AD (Woodhouse and Overpeck 1998, 2706). These findings suggest that twentieth century droughts have been moderately severe, and of relatively short duration, when compared to past droughts. Those in the twentieth century have occurred on a temporal scale of seasons to years, while previous droughts have occurred on a scale of decades to centuries (Woodhouse and Overpeck 1998, 2708). This raises a concern that future droughts could last longer and be more severe than have been experienced since 1600, resulting in natural disasters on a scale unknown during this century (Woodhouse and Overpeck 1998, 2706, 2709). Variations in drought magnitude and duration result from differences in the large-scale patterns of atmospheric circulation, and interactions between the atmosphere and oceans which alter regional precipitation patterns from decades to centuries (Woodhouse and Overpeck 1998, 2708). General circulation models developed to estimate the effects of global climate changes in the mid- to late twenty-first century generally indicate lower humidity and precipitation for the Great Plains and an increase in the frequency and duration of extreme droughts (Woodhouse and Overpeck 1998, 2710).

A review of droughts from 1931 to 1985 by the Texas Water Commission found that a three-month drought is likely to occur in at least one Texas climatic region every nine months (Riggio, Bomar, and Larkin 1987, 58). A drought of six months to a year is more likely to occur somewhere in Texas than six months to a year of average to above average precipitation (Riggio, Bomar, and Larkin 1987, 61). Droughts lasting six months or longer are likely once every sixteen months, and year-long droughts are likely once every thirty-three months (Riggio, Bomar, and Larkin 1987, 61).

The area of Texas that experienced the fewest droughts of any duration from 1931 to 1985 was the Edwards Plateau region. It experienced the fewest three-month droughts from 1931 to 1985. The fewest severe to extreme six-month droughts occurred over southwest Texas in the western Edwards Plateau region, with Uvalde, Texas recording the fewest such droughts (Riggio, Bomar, and Larkin 1987, 42). Normal three-month precipitation events were found to occur most often over the Edwards Plateau region (Riggio, Bomar, and Larkin 1987, 40, 53). The area where six-month 'wet events' were found to occur most frequently included the Edwards Plateau (Riggio, Bomar, and Larkin 1987, 53). Normal twelve-month precipitation events also occurred more often over the Edwards Plateau.

Some global factors have been studied as influences on droughts in Texas. The El Niño – Southern Oscillation (ENSO) is a warming of sea surface temperatures in Pacific Ocean waters west of Peru. It has occurred in 31% of the last 50 years (Suplee 1999, 81). A La Niña event is a cooling of the sea surface temperatures in Pacific Ocean waters west of Peru and has occurred in 23% of the last 50 years (Suplee 1999, 81). El Niño and La Niña have been identified as two of the principal global scale environmental factors affecting Atlantic season hurricane activity (Gray and others 1998, 6). El Niño events suppress, while La Niña events tend to enhance, hurricanes (Gray and others 1998, 6). Some authors conclude that sea surface temperatures in the Pacific influence Great Plains drought-associated circulation patterns (Woodhouse and Overpeck 1998, 2708), whereas others have found that the link between winter precipitation in the Southwest and ENSO might be minor (Earl and Harrington 1994). One study concluded that strong El Niño events typically cause wetter than average winters and springs in Texas, while La Niña events typically cause a drier climate (Cleaveland and Stahle 1994, 21).

Other factors may influence large-scale weather patterns and cause drought. The 22–year Hale double – sunspot cycle and the 18.6 – year lunar cycle appear related to the occurrence of droughts (Longley 1994, 2). During the 22–year sunspot cycle, droughts of various intensities have occurred over the Edwards Aquifer region during recent cycle peaks in 1932, 1954, and 1998.

The Drought of Record

The critical drought period used for planning and management purposes is called the drought of record. The drought of record generally refers to the worst drought that has occurred in a region since detailed records have been kept. For the state, and the Edwards Aquifer, the drought of record is the drought from 1950 to 1957 (Texas Water Development Board 1997, 2-36). By the end of 1956, about 94% of Texas' 254 counties were classified as disaster areas (Texas Department of Water Resources 1984, II-1). Comal Springs ceased to flow for 144 days in 1956, and the Bexar County groundwater index well, J-17, declined to a record low 612.5 feet (ft) above mean sea level (msl) on August 17, 1956 (Longley 1995, 113). The drought ended with state-wide flooding in 1957. Another drought, occurring between 1916 and 1919, is considered almost as severe as the drought of record (Texas Department of Water Resources 1984, II-1). On average, a similar drought can be expected to occur once in every 50 to 80 years (Jones 1991, 518); (Texas Water Development Board 1997, 2-36). Other researchers indicate a recurrence interval of 90 to 100 years (Stahle and Cleaveland 1988, 72).

While the drought of record is generally considered to be 1950-1957, some sources select the period 1947-1956 (Longley 1995, 111). However, recharge to the aquifer was below average for each of the fourteen years during the span from 1942 to 1956, with an annual average recharge for the same period of 300,600 acre-feet, compared to 683,100 acre-feet for the period of record, 1934 - 1998. This indicates that hydrologic drought could have existed for the aquifer from 1942 until 1957, which suggests that the drought of record for the Edwards should be redefined as beginning in 1942 and ending in 1957. Recharge to the aquifer in 1956 was only 43,700 acre-feet (U.S. Geological Survey 1998, 2), or 6% of average, when Comal Springs dried up for 144 days. In the most severe year of the extended drought, withdrawals from the aquifer surpassed 300,000 acre-feet for the first time, reaching 321,100 acre-feet (U.S. Geological Survey 1998, 3). Compare this to the relatively short drought in 1996, when withdrawals for the much more populous region with more irrigated agriculture totaled 493,600 acre-feet (U.S. Geological Survey 1998, 3), total recharge was 50% of average, and Comal Springs continued to flow, although at a diminished rate.

Regions underlain by karst aquifers, particularly those that provide nearly all of an area's water supply, are distinctively vulnerable because they can experience noticeable effects even from droughts of short duration (Texas Water Development Board 1997, 2-37). This situation applies to the Edwards Aquifer region. During the drought of record, industries that depended on the flow from Comal and San Marcos Springs and flood runoff into the Guadalupe River continued to operate only with the implementation of emergency measures such as recirculating water systems (Lowry 1959, 34).

The detrimental effects of a repeat of the drought of the 1950s would probably be far greater today, because growth in the size of the economy and the greater efficiency of water use renders the region more vulnerable. For example, the impacts of water shortages during a drought can be more severe for efficient municipal water systems (Natural Resources Law Center 1997, 41). The Texas economy also is more water dependent today. Agricultural losses from the relatively brief 1996 drought in Texas have been estimated at $2.1 billion, and overall state losses at $5 billion (Western Governors' Association 1996, 12). Factors contributing to increasing societal vulnerability to water shortages in Texas include:

- Population and water needs are growing at a rapid rate;
- Depletion of usable groundwater sources continues;
- It is increasingly difficult to permit new surface reservoirs;
- Increasing legal and regulatory requirements concerning environmental issues will reduce water available for other needs; and
- The high costs of new water supplies, and supply limitations, will probably result in greater "risk acceptance" assumptions into water supply planning and permitting decisions. (Water Demand/Drought Management Technical Advisory Committee of the Consensus State Water Plan 1998, 5)

As withdrawals have increased from the Edwards Aquifer over time, on average less intense and shorter duration droughts cause the water level to decline to the point that the springs are threatened with the cessation of flow (Longley 1995, 113). As use of scarce water resources becomes more efficient, the lead-time for implementing drought management plans increases.

Over time, as more water has been withdrawn from the aquifer, the threshold for droughts that can cause discharge from the springs to approach zero has declined. Eventually, unchecked withdrawals will create artificial hydrologic drought conditions. With fully utilized water resources monitoring, incremental short-term changes in the water budget become more important in a fully appropriated system. For this reason, methods that predict potential shortfalls and monitor day-to-day changes are needed. This is true for the Edwards as well as anywhere water resources are fully developed.

Droughts have driven the development of Texas water management policies, programs, and law. Major water legislation and litigation have followed droughts. For example, the Edwards Underground Water District was created in the 1959 legislative session following the end of a drought. The recent case that sought to modify Texas groundwater law, *Sipriano et al. v. Great Spring Waters of America, Inc.*, resulted from the 1996 drought, as did the passage of the 1997 Senate Bill 1 water planning legislation.

In water supply planning, the question is not how much water can be supplied from a particular source during periods of average rainfall; rather the question is, how much water can be supplied during droughts? In subhumid to semiarid regions, such as the Edwards, with a dry climate, runoff tends to be more variable than in regions which receive more rainfall (Leopold 1994, 96). Wide variations in recharge make water supply planning very difficult in the Edwards region (Table 1). The challenge for those who depend on Edwards water is made even greater in the absence of readily available water supply alternatives. Most of the storage in Texas surface water supply reservoirs is permitted on a firm yield basis, with the firm yield volume being the maximum quantity of water available during a critical drought period (Water Demand/Drought Management Technical Advisory Committee of the Consensus State Water Plan 1998, 4). While the drought of record is the event which water supply planning strategies are designed to withstand, at least ideally, droughts worse than the drought of record have occurred in the past and await somewhere over the horizon. Currently, no one can be certain that any drought is worse than the drought of record until several years of drought have passed, or the drought is over. If a drought is worse than the drought of record, by the time the drought has ended, it may be too late to make appropriate management decisions to avoid water shortages (Kabir 1991, 1). A preferable approach would be to take measures in the early stages of a drought, assuming it has the potential to be worse than the drought of record (Kabir 1991, 1).

Population and Water Demand

As the demand for water increases, and available supplies diminish, drought-induced natural disasters could increase, not because droughts are occurring more often, but because of increasing vulnerability to extended periods of below normal rainfall. If the population and economy of the Edwards Aquifer region are to continue to grow, projected water demands must be satisfied. Should the groundwater supply be significantly curtailed without substitute supplies, it is unlikely that this expected growth can be sustained.

Population projections are used by local, regional and state planners as the basis for determining future water requirements, particularly municipal water demand. The current standard Texas water planning horizon is 50 years established by state statute with projections produced at ten – year intervals to coincide with the national ten - year census (Sec. 16.051, Texas Water Code). Estimates are made assuming there will be no limit on the available water supply to support the expected population and the economic activity on which it depends for livelihood (Sec. 16.051, Texas Water Code).

The first statewide water planning effort was the *1961 Texas Water Plan* issued by the Texas Board of Water Engineers (TBWE) [predecessor to the Texas Water Development Board (TWDB)]. Beginning in 1965, the TWDB has prepared population estimates and water demand for 50 – year plans issued in 1968, 1984, 1990, 1992, and 1997. The contents of these plans for the Edwards Aquifer are discussed in Chapter 8. The methodology used by the TWDB for these projections is explained in *Water for Texas* prepared by the TWDB, Texas Natural Resource Conservation Commission (TNRCC), and the Texas Parks and Wildlife Department (Texas Water Development Board 1996). The technical appendix of Water for Texas contains the following the statement, "The development of the consensus population projections incorporated a number of data files and information based on the 1990 Census, provided by Steve Murdock, Ph.D., Chief Demographer for the State Data Center" (Texas Water Development Board 1997, 2-15).

In 1992, the TWDB initiated a special planning effort, known as the Trans–Texas Water Program, covering selected portions of the state expected to experience water shortages that might require transfer of surface water from one river basin to another, known as a transbasin diversion. Because the *Sierra Club et al. v. Babbitt et al.*, Endangered Species Act litigation (discussed in Chapter 6) was underway during this planning effort, special population and water demand data were developed and published for the Edwards Aquifer region by the TWDB's contractor, HDR Engineering, Inc. The assumptions for these projections are given on pages 1 – 4 and 1 - 5 of that report (HDR Engineering 1998). These data for population and water demand are shown in Table 5 and Table 6. The reason for using these data for projected population and water

Table 5. Population Projections – Edwards Aquifer Area*, Trans – Texas Water Program, West Central Study Area

County	Total in 1990	Projection 2000	Projection 2010	Projection 2020	Projection 2030	Projection 2040	Projection 2050
Atascosa (part)	1,567	2,312	2,718	3,113	3,477	3,762	4,070
Bexar (all)	1,182,643	1,470,422	1,771,697	2,124,142	2,483,130	2,808,166	3,072,461
Medina (all)	27,312	33,349	38,069	42,299	44,945	46,969	49,556
Uvalde (all)	23,340	26,466	29,756	32,788	35,595	38,087	40,565
Comal (part)	30,981	43,647	57,488	75,667	96,839	112,766	130,945
Hays (part)	36,095	44,358	54,522	65,185	78,887	95,155	111,871
Guadalupe (part)	39,217	53,509	71,996	91,375	116,003	135,441	159,347
Caldwell (part)	19,782	23,702	27,569	31,193	33,732	33,690	33,658
Total	1,360,937	1,697,765	2,053,815	2,465,762	2,892,608	3,274,036	3,602,473

*As specified in Senate Bill 1477, Texas Legislature, 73rd Session, 1993, as amended.

Source: (HDR Engineering 1998, Table 2-2, 2-5).

Table 6. Total Water Demand Projections – Edwards Aquifer Area*, Trans - Texas Water Program, West Central Study Area

County	Total Use in acre-feet 1990	Projection in acre-feet 2000	Projection in acre-feet 2010	Projection in acre-feet 2020	Projection in acre-feet 2030	Projection in acre-feet 2040	Projection in acre-feet 2050
Atascosa (part)	1,802	2,003	1,943	1,924	1,938	1,942	1,953
Bexar (all)	303,586	404,291	436,383	483,931	548,644	609,441	656,013
Medina (all)	164,600	176,094	164,583	158,107	152,131	146,307	140,833
Uvalde (all)	147,897	144,315	139,328	134,509	130,355	126,341	122,592
Comal (part)	11,218	20,233	22,678	26,114	31,099	32,898	35,847
Hays (part)	7,882	10,674	12,013	13,411	15,884	18,882	22,136
Guadalupe (part)	6,509	10,831	12,929	14,925	18,371	21,159	24,730
Caldwell (part)	4,275	4,911	5,101	5,271	5,555	5,473	5,409
Total	647,769	773,352	794,959	838,191	903,976	962,443	1,009,512

*As specified in Senate Bill 1477, Texas Legislature, 73rd Session, 1993, as amended.

Source: (HDR Engineering 1998, Table 2-5, 2-11), taken from original source Most Likely Case, below normal rainfall and advanced water conservation (Texas Water Development Board 1996).

demand is that their use facilitates comparisons for the 50-year period. The population of the area is estimated to increase from 1.4 million in 1990 to 3.6 million in 2050, while water demand is expected to grow from 648,000 acre-feet to 1 million acre-feet during the same period assuming "Most Likely Case, below normal rainfall and advanced water conservation" as stated at the bottom of Table 6.

In 1990, water use in Bexar, Medina, and Uvalde Counties totaled 616,083 acre-feet or 95.2% of the use in all of the Edwards Aquifer area (calculated from data in Table 6). The Trans – Texas study compiled data showing 1990 water use and annual groundwater supplies for the entire 32 county West Central Study Area (HDR Engineering 1998, Table 2-7, 2-15). This data indicates there will be at least a 200,000 acre-feet water supply shortage for these three counties in the year 2010 when annual withdrawals from the Edwards are limited to 400,000 acre-feet or less (see Table 7).

Since groundwater yields in the Edwards Aquifer counties are already fully utilized and surface water supplies require further development, the annual shortage could be as large as ±575,000 acre-feet in the Edwards Aquifer region by 2050 (calculated from data in Table 6 and Table 8; 2050 demand of 1,009,512 acre-feet from Table 6 minus 438,774 acre-feet of supply from Table 8). Additional tables reflecting population and water demand data are included in the Appendix 1. Population, Water Use, and Water Demand Tables.

Table 7. Estimated 2010 Water Supply Shortage in Bexar, Medina, and Uvalde Counties, Using only Sources in those Counties and 1990 Surface Water Use Data

County	Groundwater Supply in 2010, in acre-feet, Non Edwards Aquifer*	Groundwater Supply in 2010, in acre-feet, Edwards Aquifer **	Surface Water Use in 1990,in acre-feet	Total, in acre-feet	Estimated Demand in 2010, in acre-feet	Estimated Shortage in 2010, in acre-feet
Bexar	19,125	206,342	34,412	259,879	436,383	176,504
Medina	7,826	64,079	81,091	152,996	164,583	11,587
Uvalde	8,213	110,884	3,375	122,472	139,328	16,856
Total Shortage						204,947

*Includes Carrizo-Wilcox, Trinity, Edwards – Trinity, Queen City and Sparta Aquifers.

**400,000 acre-feet prorated among EAA counties in the same proportion as each county's pumpage was of total pumpage in 1990: 51.6% to Bexar, 27.7% to Uvalde, and 16.0% to Medina (the remainder, 4.7% allocated to parts of Atascosa, Comal, Hays, Guadalupe, and Caldwell Counties).

Source: Calculated by author from [HDR Engineering, 1998 #454, Table 2-5, 2-11; and Table 2-7, 2-15].

Table 8. Total Annual Groundwater Supply Available in the Edwards Aquifer Region, 2000 – 2050, in acre-feet per year.

County	Non-Edwards Aquifer Groundwater in acre-feet	Edwards Aquifer Groundwater in acre-feet	Total, in acre-feet
Atascosa (part)	*	1,385	1,385*
Bexar (all)	19,125	206,342	225,467
Medina (all)	7,826	64,079	71,905
Uvalde (all)	8,213	110,884	119,097
Comal (part)	1,800	8,633	10,433
Hays (part)	1,810	6,065	7,875
Guadalupe (part)	*	2,286	2,286*
Caldwell (part)	*	326	326*
Total	38,774	400,000	438,774

* Non – Edwards Aquifer groundwater insignificant in portion of county within Edwards Aquifer Region.

Source: (HDR Engineering 1998, 2-11, Table 2-7, 2-15), taken from original source (Texas Water Development Board 1992).

While both population and water demand projections developed at intervals since 1961 generally reflect grossly overstated water use in the latter decades of each 50-year set of projections, the data confirm that the region has exhausted its options other than additional conservation, reuse, other groundwater sources or surface water development.

Not until the *1984 Texas Water Plan* was conservation considered a major means for demand reduction. While water reuse has been practiced for limited low quality water uses, it has not been applied extensively in metropolitan areas. The prevailing philosophy of Texas water planners since the 1950's has usually favored new surface water reservoirs over other alternatives. That approach has changed as the construction of reservoirs has become more controversial. Planning for more extensive use of groundwater has been hampered by the rule of capture discussed in the next chapter.

5. TEXAS GROUNDWATER LAW AND AQUATIC ENDANGERED SPECIES

Introduction

Texas water law and the federal Endangered Species Act influence the use of Edwards Aquifer groundwater. Decisions that determine how future population growth and economic activity can be sustained are impacted. This chapter will trace the history of the litigation attempting to resolve regional transboundary disputes over groundwater use and describe the ecological limitations placed upon the use of the aquifer. This chapter will establish the historical context in which the research questions will be examined.

The Rule of Capture Encourages the Groundwater Use at Rate that is Unsustainable

As the population of Texas continues to grow and the need for water increases, the demand for groundwater will continue to rise. In 1997, groundwater accounted for about 57% of the water used in Texas; 80% of this total was used for agriculture (Texas Water Development Board 1997, 3-15). Texas has nine major and twenty minor aquifers (Texas Water Development Board 1997, 3-202). The TWDB defines major aquifers as those supplying large quantities of water over large areas of the state, while minor aquifers either supply large quantities of water in small areas or small quantities of water over large areas (Texas Water Development Board 1997, 3-202). Major and minor aquifers are found beneath 81% of the state's land surface (Texas Water Development Board 1997, 3-202). The Edwards Aquifer is considered a major aquifer.

In the previous chapter I discussed how population growth in the Edwards Aquifer region (Table 5), is projected to increase demand for groundwater (Table 6 and Table 7). Historically, there has been almost no limit to groundwater withdrawals from the Edwards Aquifer. Generally, groundwater in Texas is governed by the English common law concept known as the rule of capture, also known as the right of capture, the law of absolute ownership, and other names. In accordance with this rule, underground water is the exclusive property of the owner of the overlying land, unless a state statute specifies otherwise. Remedies in tort law [a private or civil wrong or injury (Black 1990, 1489)] are unavailable to a landowner who has a well that is affected by someone else's pumping. Surface water in Texas is governed by the appropriative water rights doctrine common to most western states. Under this doctrine, water is held in trust by the state for the benefit of all the people, subject to a granted right to use. Those who are "first in time" are "first in right" to take or divert water from a surface watercourse or reservoir and apply it to a beneficial use (Kaiser 1987, 43); he or she must "use it or lose it." However, water required for a single household's domestic and livestock use is always senior to any other appropriative right (Cisneroz 1996, Section 2, 3).

As coexisting legal frameworks, prior appropriation and the rule of capture can encourage incompatible behavior by water users depending upon the source. They contribute to the deleterious effects of droughts by treating ground and surface water as separate legal entities. This separation ignores the fundamental hydrologic connection between them and provides no incentives for their efficient conjunctive use. The *1968 Texas Water Plan* describes the disconnection between ground and surface law, "The situation is paradoxical when one realizes the actual interrelationship of ground and surface water development for future state needs and the necessity of adequate ground water supplies to meet future municipal and domestic requirements in certain areas" (Texas Water Development Board 1968a, II-29).

While it is one of the most groundwater dependent states, Texas has been described as a "bad case with regard to wise use" of groundwater because of its piecemeal approach to management that relies primarily on voluntary measures (Tobin 1989, 127, 128). The Western Water Policy Review Advisory Commission has expressed a similar opinion:

> . . . Three of the largest groundwater-using states – California, Nebraska, and Texas – do not allocate groundwater by the law of prior appropriation or acknowledge the potential for groundwater uses to deplete surface supplies. The net result is that state laws commonly allow groundwater overdraft – the depletion of an aquifer at a rate faster than the natural rate of recharge. (Western Water Policy Review Advisory Commission 1998, 3-6)

The origin of the rule of capture is the same common law that governs the possession of animals of *ferae naturae* [animals of a wild nature or disposition (Black 1990, 619)]. As it applies to property rights in wild animals, the most famous U.S. case dates from 1805 in the State of New York, *Pierson v. Post* (Craft 1995, 698, 699). In that case a dispute arose when ". . . *Post*, being in possession of certain dogs and hounds under his command, did, 'upon a certain wild and uninhabited, unpossessed and waste land, called the beach, find and start one of those noxious beasts called a fox,' and whilst there hunting, chasing and pursuing the same with his dogs and hounds, and when in view thereof, *Pierson*, well knowing the fox was so hunted and pursued, did, in sight of *Post*, to prevent his catching the same, kill and carry it off" [*Pierson v. Post*, 3 Cai R. 175 (N.Y. Sup. Ct. 1805)]. Under the rule of capture, a landowner must bring a resource within his or her possession to claim absolute ownership, i.e. reduce it to possession.

Application of the rule to groundwater was first enunciated in a decision by an English court, *Acton v. Blundell*, 152 Eng. Rep. 1223, 1235 (Ex. Ch. 1843). The court found that Roman law provided no rule for the ownership of groundwater, and that groundwater was different from surface water and should be governed under a separate principle:

> . . . [W]hich gives to the owner of the soil all that lies beneath his surface; that the land immediately below is his property, whether it is solid rock, or porous ground, or venous earth, or part soil, part water; 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 water collected from underground springs in his neighbor's well, this inconvenience to his neighbor falls within the description of *damnum absque injuriâ*, which cannot become the ground of action. *Acton v. Blundell*, 152 Eng. Rep. 1235 (Ex. Ch. 1843)

This decision was cited by the Ohio Supreme Court in an 1861 case, *Frazier v. Brown*, 12 Ohio St. 294, 311 (1861) in which the court ruled on the question of whether a property owner has the same absolute right to water beneath his or her land as he or she has to rocks, minerals and material that constitutes the substance below the surface. The court stated, the "movement and course of such waters, and the causes which govern and direct their movements, are so secret, occult and concealed, that an attempt to administer any set of legal rules in respect to them would be involved in hopeless uncertainty, and would be, therefore, practically impossible" [*Frazier v. Brown*, 12 Ohio St. 294, 311 (1861) (Emphasis added)].

The rule of capture governed groundwater in almost every state during the nineteenth century. In the twentieth century it was adopted for Texas in *Houston & Texas Central Railway Co. v. East* (*East*) at a time when it had already been abandoned by much of the eastern U.S. (Tarlock 1993, 4-8). In the 1904 *East* case, the Texas Supreme Court adopted the rule of capture, borrowing the "secret, occult and concealed" language in *Frazier v. Brown* to describe groundwater movement [*East*, 81 S.W. 281 (Tex. 1904)]. However, what was "secret, occult, and concealed" in 1861 was better understood by 1904, and is well understood today. Cases such as these reveal the importance of water to livelihood in the West, the problems of applying common law in arid regions, and the separation of law from common sense and science (Wimberley in press, 1-2). Although the majority of states in the western U.S. retained the rule of capture well into the twentieth century, by 1992 it still existed in its pure form only in Texas, along with the states of Connecticut, Louisiana, Maine, and Rhode Island where there is less reliance on groundwater (Tarlock 1993, 4-7). As of 1998, one authority asserted that Texas was the only state to retain the rule of capture (Skillern 1998, 197).

In 1949, the Legislature chose local groundwater districts with limited powers to prescribe spacing of wells as the preferred method for managing groundwater under the rule of capture, and the Senate Bill 1 water planning legislation passed in 1997 retained the rule [S.B. 1 and H.B. 5, 75th Leg., Regular Sess. (Tex. 1997)]. However, by the beginning of 1999, only 42 local groundwater districts covering a small percentage of the state had been created [*Sipriano et al. v. Great Spring Waters of America, Inc.*, concurring opinion (Tex. 1999)]. The Legislature has made two extensive exceptions to the rule of capture as the result of two different problems resulting from overdrafting of aquifers.

In 1975, the Legislature created the Harris-Galveston Coastal Subsidence District to limit pumping from the Gulf Coast Aquifer because pumping had caused land to subside in portions of the area by as much as 10 ft (Callaway 1985, 1). The District was created, "to provide for the regulation of the withdrawal of groundwater within the boundaries of the District for purpose of ending subsidence which contributes to or precipitates flooding, inundation or overflow of any area within the District, including without limitation rising water resulting from storms or hurricanes" (Callaway 1985, 2). The constitutionality of the District was upheld in *Beckendorff v. Harris-Galveston Coastal Subsidence District*, 558 S.W. 75 (Tex.Civ.App. – Houston (14th Dist.) 1977).

The second example is the creation of the Edwards Aquifer Authority in 1993 to limit withdrawals to protect endangered species and guarantee minimum flows of groundwater from Comal and San Marcos Springs into the Guadalupe River. As a result of the judgment in *Sierra Club et al. v. Babbitt et al.* the Federal District Court contributed to the end of the rule of capture in the Edwards

Aquifer by forcing the Legislature to create a pumping regulatory scheme (discussed in detail in Chapter 6).

Despite its adoption 95 years ago, the Texas Supreme Court acknowledged in 1978 that the rule of capture is in some respects "harsh and outmoded," and invited the Legislature to provide "a more sensible rule" [*Friendswood Development Co. v. Smith-Southwest Industries*, 576 S.W.2d 21 (Tex. 1978)]. On May 6, 1999, the Texas Supreme Court unanimously decided in *Sipriano et al. v. Great Spring Waters of America, Inc.* (*Ozarka*) to retain the rule as the standard governing the use of groundwater. A concurring opinion in the *Ozarka* case by Justices Hecht and O'Neill concluded:

> I agree with the Court that it would be inappropriate to disrupt the processes created and encouraged by the 1997 legislation [Senate Bill 1] before they have had a chance to work. I concur in the view that, for now – but I think only for now – *East* should not be overruled. [*Sipriano et al. v. Great Spring Waters of America, Inc.*, concurring opinion (Tex. 1999)] .

The Environmental Defense Fund (EDF), which filed an amicus brief [a filing by someone who is not a party to the litigation, but who has an interest on the subject matter of the action (Black 1990, 82)] in the *Ozarka* case, opposed the rule because, "under the rule of capture it is difficult to protect ecosystems dependent upon springflow" (Taylor 1999). Amicus briefs were filed in favor of keeping the rule of capture by the Texas Farm Bureau, the City of Houston, the Texas Groundwater Districts Association, the Texas Water Conservation Association, the Texas Justice Foundation, the Texas and Southwestern Cattle Raisers Association, the Edwards Aquifer Authority, and others [*Sipriano et al. v. Great Spring Waters of America, Inc.*, (Tex. 1999)]. The EAA supported the rule of capture even though the rule no longer strictly applies to the Edwards Aquifer. Specifically, the EAA supports the rule of capture as vesting property rights (Buckner 1999).

> The EAA was 'thrilled' with the Supreme Court's decision in the Ozarka case. The rule of capture is not a property law; it is a tort law. You still can't sue your neighbors in the Edwards or the Gulf Coast Aquifer for pumping too much water even though the rule of capture is gone (Ellis 1999).

The EAA was created to supervise the transition from the rule of capture to a permit system [*Sipriano et al. v. Great Spring Waters of America, Inc.*, No. 98-0247 at 2 (Tex. 1998) (Amicus Edwards Aquifer Authority Brief on the Merits)]. If individual well owners were to have the ability to sue each other for damages when levels of the aquifer declined below well intakes, it could potentially undermine the authority of the EAA to regulate the aquifer on a holistic basis.

Property Rights and Common Property Resources

The Edwards Aquifer is a common pool resource undergoing a transition to a regulated resource at a time when the aquifer is unable to satisfy all demands for domestic, municipal, industrial, commercial, agricultural, recreational, and environmental uses. Prior to regulation, overlying land ownership was the sole legal requirement for participation in the common property system that is the Edwards Aquifer. Conflicts over regulating common resources, often produce a crisis that requires the intervention of the state or federal government:

> In the 1930's martial law had to be declared to restore order in the East Texas [oil] Field. The regulation of fishing of [sic] the redfish brought protestors and demonstrators to the steps of the State Capitol. And fights over grazing rights were settled with pistols before they were settled by law. (Testimony of Ronald Luke, J.D., Ph.D., Edwards Aquifer Hearings, June 30, 1992, 6)

The state, in its brief for the Texas Supreme Court in *Barshop, et al. v. Medina County Underground Water Conservation District, et al.*, recognized that the Edwards Aquifer is a common pool resource and compared unregulated withdrawals to a tragedy of the commons in the making:

> Underground water in Texas is private property, although of an unusual kind, because despite being 'absolutely owned in place' by the surface owner, it is subject to the rule of capture allowing others to take it. The Edwards Aquifer Act affects that property much as a local zoning ordinance containing a grandfather clause affects surface land. Historical users of Aquifer water, who range from cities to manufacturing companies to farmers irrigating maize, will have the broadest rights of continued use. It is only fair and reasonable (and constitutional) for historical *non*-users -- persons whose only 'use' during the 21 years from 1972-93 has been to leave 'their' water in the ground, available for withdrawals by others -- to be limited in their future uses. No owner's use is entirely barred.
>
> The Edwards Aquifer Act is as least as constitutionally sound as city zoning ordinances and as the time-honored Texas systems for controlling oil and gas well drilling and production rates -- far-reaching regulatory regimes which have marked effects on private property yet have withstood attacks from several directions.
>
> Plaintiff-appellees and the district court slighted these analogies and over-extended the property concepts shaping underground water law. Their approaches, which would recognize a constitutional right in each surface owner to drill as many wells as he or she wants and pump nonwastefully from them as much water as he or she wants, suffer from a false naiveté overlooking the commonalty of the Edwards Aquifer and its vulnerability to the collective effects of individual actions.
>
> When a shared, limited resource is involved, some kind of use control is needed.
>
>> Picture a pasture open to all . . . [E]ach herdsman will try to keep as many cattle as possible on the commons . . .

> [M]ore or less consciously, he asks, 'What is the utility to *me* of adding one more animal to my herd? . . .' [T]he rational herdsman concludes that the only sensible course is for him to add another animal. . . . And another and another. . . . [T]his is the conclusion reached by each and every herdsman sharing a commons. . . . Each man is locked into a system that compels him to increase his herd without limit. . . . Freedom in a commons brings ruin to all.

> Garrett Hardin, *The Tragedy of the Commons*, 162 Science 1243, 1244 (1968)(emphasis in original). This article's proposed solution is a regime of mutual coercion mutually agreed upon - in other words, some form of institutional control. In our democracy, no institution is better positioned to assert control than the legislative branch of the state government. (*Barshop, et al. v. Medina County Underground Water Conservation District, et al.*, No. 95-0881 at 8-9 (Tex. 1996) (Brief of Appellant, State of Texas))

Interests opposed to the end of unrestricted withdrawals from the Edwards Aquifer claimed that their individual private property rights had become impaired. Some have contended that the regulation of Edwards groundwater through the ESA is a taking of private property rights.

> In 1989, in Sierra Club v. Babbitt, the ESA was used as a weapon to take property rights, in this instance Water [sic], from private landowners. . . . We have invested thousands of dollars of our membership dues [paid to the Texas Farm Bureau] in an attempt to protect a sacred property right in Texas known as a 'rule of capture'. To this day, there has been no satisfactory resolution to this lawsuit. However, under the threat of federal intervention, the State legislature has taken individual's property rights by restricting their right to pump water from beneath their own land. (Stallman 1995, 1)

The responses of many pumpers in the Edwards Aquifer illustrate the "prisoners dilemma" (Olson 1971). In the Logic of Collective Action, Olson (1971) argued that individual incentives discourage collective action because members of groups, such as Edwards Aquifer pumpers under the rule of capture have a powerful incentive not to cooperate and to violate rules established to limit withdrawals for the common good, if by doing so, their personal welfare is increased (Table 9). The dilemma is that either A or B is far better off by defecting when the other cooperates. The benefit of defecting is more attractive than cooperating because of the potential for the greatest payoff. As a result, both players usually defect. Without supervision and substantial penalties, individuals can claim a disproportionate share of resources while allowing others to carry the burden of compliance. This is the same logic that undermines the ability of cartels to control effectively the price of resources such as oil.

The Endangered Species Act Restricts the Amount of Water Available for Irrigation, Industrial, and Municipal Uses

Endangered, Threatened, and Candidate Species Dependent on the Edwards Aquifer

While the water needs of the growing population of the Edwards region were once the sole determinant of the allocation of groundwater, a concern for the aquifer's unique ecology is now an important competing consideration. The Edwards Aquifer is considered one of the most diverse aquifer ecosystems in the world (Longley 1981, 123). Within the aquifer, species exist that are found nowhere else and of which little is known. Blind catfish (species), such as the widemouth blindcat, are occasionally pumped from the aquifer from wells almost 2,135 feet deep (Longley and Karnei 1978, 6).

Table 9. The Prisoners' Dilemma

	A cooperates	**A defects**
B cooperates	A wins, B wins	A wins greatly, B loses greatly
B defects	A loses greatly, B wins greatly	A loses, B loses

Source: (Olson 1971).

The U.S. Fish and Wildlife Service (USFWS) in the U.S. Department of the Interior considers the Comal and San Marcos Springs ecosystems to contain one of the greatest known diversities of organisms of any aquatic ecosystem in the Southwest (U.S. Fish and Wildlife Service 1996, 6). In part, the constant temperature and flow of the high quality waters of the aquifer create unique ecosystems that support a high degree of endemism. Comal and San Marcos Springs are the remaining major natural discharge points from the Edwards Aquifer, as well as habitat for one threatened and seven endangered species listed by USFWS (Table 10 and Table 11). All species are aquatic and inhabit ecosystems dependent on the Edwards Aquifer. The San Marcos salamander (*Eurycea nana*) is listed as threatened. The San Marcos gambusia (*Gambusia georgei*), Texas wildrice (*Zizania texana*), fountain darter (*Estheostoma fonticola*), Texas blind salamander (*Typhlomolge rathbuni*), Comal Springs riffle beetle (*Heterelmis comalensis*), Comal Springs dryopid beetle (*Stygoparnus comalensis*), and Peck's cave amphipod (*Stygobromus pecki*) are listed as endangered. Historically, San Marcos gambusia populations were sparse (U.S. Fish and Wildlife Service 1996, 28). Originally listed in 1980, no individuals were collected during sampling in at least 15 attempts between 1982 and 1995, raising the possibility that the gambusia is extinct (U.S. Fish and Wildlife Service 1996, 28). The fountain darter and Comal Springs riffle beetle are the only species listed at both Comal Springs and San Marcos Springs. All but the subterranean Texas blind salamander occur in spring-fed systems (U.S. Fish and Wildlife Service 1996, Executive Summary).

Table 10. Required Spring Discharge for Threatened and Endangered Species at Comal Springs

Species	Status	Conditions	Minimum Flow To Avoid Take	Minimum Flow To Avoid Jeopardy	Minimum Flow To Avoid Habitat Modification
Fountain Darter	Endangered	Current Conditions	200 cfs	150 cfs for short, undefined periods	--
" "	" "	Rams-horn Snail Controlled	150 cfs	60 cfs for short, undefined periods***	--
Comal Springs riffle beetle	Endangered	--	YTBD**	YTBD	--
Comal Springs dryopid beetle	Endangered	--	YTBD	YTBD	--
Peck's cave amphipod	Endangered	--	YTBD	YTBD	--

*cfs = cubic feet per second

**YTBD = yet to be determined

***This figure was omitted from a similar table in the Recovery Plan (U.S. Fish and Wildlife Service 1996).

Sources: U.S. Fish and Wildlife Service, April 15, 1993 and June 15, 1993 letters filed with the U.S. District Court, Western District of Texas, Judge Lucius D. Bunton, and 62 Fed. Reg. 66295 (1997).

Table 11. Required Spring Discharge for Threatened and Endangered Species at San Marcos Springs

Species	Status	Special Conditions	Minimum Flow to Avoid Take	Minimum Flow To Avoid Jeopardy	Minimum Flow To Avoid Habitat Modification
San Marcos Salamander	Threatened (CH)	Current Conditions	60 cfs*	60 cfs	60 cfs
Fountain Darter	Endangered (CH)	Current Conditions	100 cfs	100 cfs	100 cfs
" "	" "	Aquifer Management Plan & Control of Exotics	--	An undefined cfs <100, for short, undefined periods	An undefined cfs <100, for short, undefined periods
San Marcos Gambusia	Endangered (CH)	Current Conditions	100 cfs	100 cfs	100 cfs
" "	" "	Aquifer Management Plan & Control of Exotics	--	An undefined cfs <100, for short, undefined periods	An undefined cfs <100, for short, undefined periods
Texas Blind Salamander	Endangered	Current Conditions	50 cfs	50 cfs	--
Texas Wild-Rice	Endangered (CH)	Current Conditions	100 cfs	100 cfs	100 cfs
" "	" "	Aquifer Management Plan & Control of Exotics	--	An undefined cfs <100, for short, undefined periods	An undefined cfs <100, for short, undefined periods
Comal Springs riffle beetle	Endangered	--	YTBD**	YTBD	--

CH = Critical habitat designated. CH is the geographical area including, but not limited to, the area occupied by the species, for which special management considerations are required (Endangered Species Act of 1973, Sec. 3(5)(A).
*cfs = cubic feet per second.
**YTBD = yet to be determined.
Sources: U.S. Fish and Wildlife Service, April 15, 1993 and June 15, 1993 letters filed with the U.S. District Court, Western District of Texas, Judge Lucius D. Bunton, and 62 Fed. Reg. 66295 (1997).

The USFWS recovery priority for these species indicates that each faces a high degree of threat and a low potential for recovery, and the survival of each species is in conflict with development projects or other forms of economic activity (U.S. Fish and Wildlife Service 1995, 27). Critical habitat has been designated only at San Marcos Springs [Endangered and Threatened Wildlife and Plants, 45 Fed. Reg. 47,355 (1980)], and is designated for all listed species, except the Texas blind salamander and the Comal Springs riffle beetle.

In addition to the threatened and endangered species, there are other rare and endemic species dependent on the Edwards Aquifer classified by the USFWS as candidates for listing (Table 12). Category 1 species are taxa for which the Service has on file enough substantial information on biological vulnerability and threats to support proposals to list them as endangered or threatened. Proposed rules are anticipated for these species, but have not been issued because other listings are given a higher priority. Category 2 species are taxa for which information indicates that proposing to list the species as endangered or threatened is possibly appropriate, but for which conclusive data on biological vulnerability and threat are not currently available to support proposed rules. In 1997, the USFWS redesignated category 1 species as 'candidate species' and category 2 species as 'species of concern' (Seawell 1999c).

Table 12. Candidate Species Dependent on the Edwards Aquifer

COMMON NAME	SCIENTIFIC NAME	STATUS
Cagle's map turtle	*Graptemys caglei*	c
San Marcos saddle-case caddisfly	*Protoptila arca*	soc
Texas cave diving beetle	*Haideoporus texanus*	soc
Widemouth blindcat	*Satan eurystomus*	soc
Toothless blindcat	*Trogloglanis pattersoni*	soc
Comal Springs salamander	undescribed *Eurycea*	soc
Texas salamander	*Eurycea neotenes*	soc
Comal blind salamander	*Eurycea tridentifera*	soc
Blanco (Robust) blind salamander	*Typhlomolge robusta*	soc

c = Species for which the Service has on file enough substantial information to warrant listing as threatened or endangered.

soc = Species for which there is some information showing evidence of vulnerability, but not enough data to support listing at this time.

Sources: (Moore and Votteler 1995a, 89) and (U.S. Fish and Wildlife Service 1999, 1, 2, 3, 4).

During dry periods, when withdrawals from the aquifer increase, flow from the springs diminishes to critical levels; aquatic habitat is impacted causing "takes" of species listed under the Endangered Species Act; and the flow of surface water downstream in the Guadalupe River decreases. Take means "to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or to attempt to engage in any such conduct" [16 U.S.C. § 1532 (19)]. Take is an event that may pertain to as few as one individual of the species. Extremely low, or no flow, from these springs places the species in "jeopardy." The term "jeopardy" refers to a situation where the survival of the entire species is in peril. Under the ESA, the take of a threatened or endangered species by any person subject to the jurisdiction of the United States, including private citizens, agencies and any other individual or group, constitutes a violation of the Act. Withdrawals from the Edwards Aquifer for municipal, industrial, agricultural, recreational, and other uses contribute to the reduction of spring discharge at Comal and San Marcos Springs which causes take of the listed species. Other threats include nonnative species, recreational activities, predation, direct or indirect habitat destruction or modification by humans, and factors that decrease water quality (U.S. Fish and Wildlife Service 1996, Executive Summary). These latter include dam construction, bank stabilization, and the control of aquatic vegetation (U.S. Fish and Wildlife Service 1996, Executive Summary).

In 1975, a study was commissioned by the TWDB to determine the minimum spring discharge required to ensure the continued existence of the unique physical and biological character of the Comal and upper San Marcos Rivers (Espey 1975). At the time, the projected future demands on the waters of the Edwards Aquifer resulted in an expectation that spring discharge would drop significantly within the next several decades. The study examined the relationships between spring discharge and selected biological parameters in an effort to estimate the necessary spring discharge for preserving the unique biological community. The second goal was to gather data on the physical and chemical characteristics of these systems to evaluate the possibility of compensating for the decline in spring discharge by augmenting flows using pumped well water (Espey 1975, introduction). This study was one of the earliest attempts to establish what spring discharge rate was necessary to protect endangered species at Comal and San Marcos Springs, thereby helping to establish the limit on total annual withdrawals from the Edwards Aquifer.

In 1993, during *Sierra Club, et al. v. Bruce Babbitt, et al.* litigation over the protection of endangered species, the USFWS provided the U.S. District Court in Midland, Texas, with its "best professional judgment" of the flow/discharge rates at which take and jeopardy occur for the species of concern at Comal and San Marcos Springs (U.S. Fish and Wildlife Service 1995, 17). These take and jeopardy levels are summarized for Comal Springs in Table 10 and for San Marcos Springs in Table 11. These thresholds are characterized by the USFWS as conservative, and a statement was added to the flow determinations that the judgments may change to reflect more accurately the best available scientific and commercial information as that information becomes accessible:

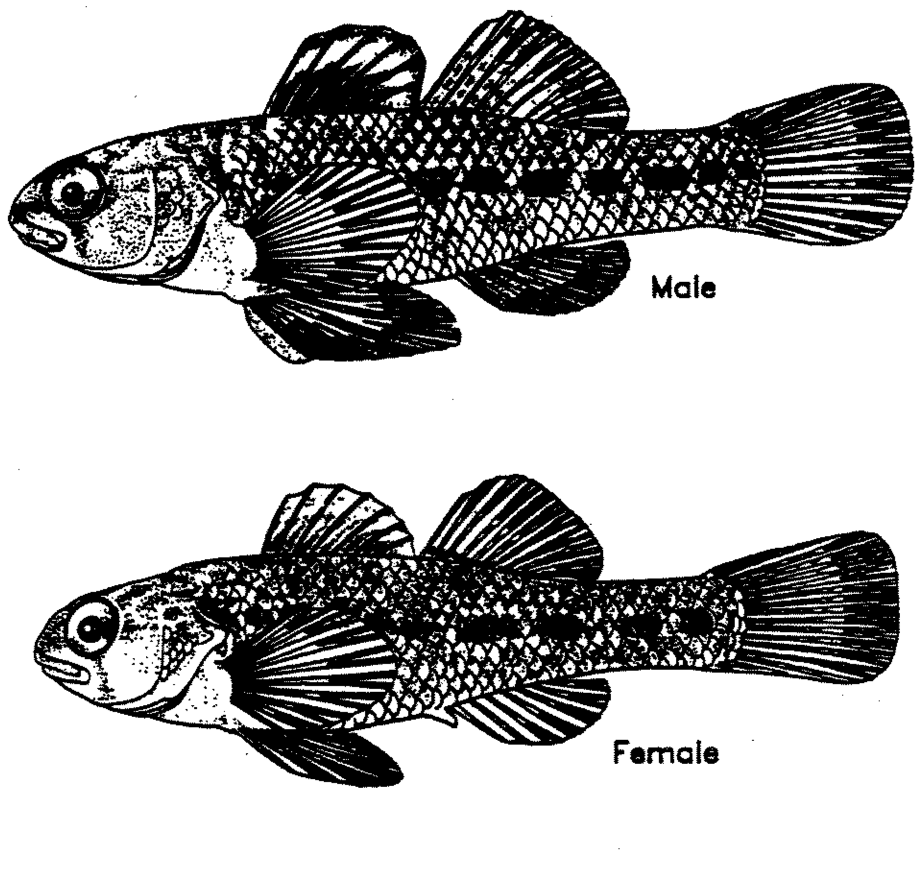
> In reviewing available information and interviewing various experts, the Service found more data available for basing flow level determinations for some of the listed species than for others. In addition, there are significant gaps in knowledge upon which to base minimum flow level findings for all of the species. Because this evaluation was conducted with much less data than are normally available, this document renders the Service's best professional judgement on the levels where

> "take" occurs. If sufficient data are not available, the Service acts conservatively to be certain that irrevocable harm to listed species is unlikely to occur from the action(s) being evaluated. (Shockey 1993a, 1)

Presumably, the USFWS would be required to file a notice with the U.S. District Court to modify these determinations since the Recovery Plan is one of the items that was required to satisfy the judgment and bring *Sierra Club et al. v. Babbitt et al.* to an end.

A review of USGS spring discharge data confirms that Comal Springs typically declines below the critical 200 cfs level before San Marcos Springs declines below the critical 100 cfs level. For this reason, the fountain darter (Figure 10) at Comal Springs is typically the first species to be affected by declining spring discharge, and therefore the population of the darter serves as an indicator of stress to the Edwards Aquifer system. A flow rate of 200 cfs at Comal Springs, below which "take" occurs, is the presumed tripwire for an ESA enforcement action. Recall the earlier bucket analogy. Any water in the aquifer above the elevation of the San Marcos Springs, 574 ft msl, is only in temporary storage since the San Marcos Springs are the lowest surface outlet for the aquifer. Since the sustained flow of 200 cfs from the Comal Springs is critical for protecting the fountain darter, the elevation of those springs, 623 ft msl, plus a flow of 200 cfs, becomes the significant benchmark aquifer level for purposes of protecting the endangered species.

Figure 10. The Fountain Darter



Male and female length approximately 1.1 inches.

(U.S. Fish and Wildlife Service 1996, 31)

The original population of fountain darters was extirpated from the Comal Springs ecosystem when the springs ceased to flow in 1956. Fountain darters from San Marcos Springs were reintroduced into Comal Springs in 1975 and 1976; however, the darters at Comal Springs are not classified as an experimental population (Arsuffi and others 1990, 4).

As for San Marcos Springs, there is no record that it has ceased to flow over the last 11,000 years. Three points have been cited to support this conclusion: (1) no known record exists indicating flow has ever ceased; (2) the development of great biological diversity and unique endemic plants and animals; (3) and the archeological record of continuous human habitation going back at least as early as 9200 BC (Longley 1991, 1). When fountain darters are being "taken," flows from the aquifer through the springs are diminishing as well to downstream ecosystems and users in the Guadalupe River. The Guadalupe River also provides freshwater inflows for the Guadalupe Estuary, winter home of the only migratory flock of endangered whooping cranes (*Grus americana*) in the world. In 1999, an attempt to establish a second migratory population of whooping cranes in Idaho and New Mexico was abandoned (Associated Press 1999b, 73A).

Additional water could be withdrawn from the Edwards Aquifer in low rainfall years if the giant rams-horn snail (*Marisa conuarietis*) were controlled. The rams-horn snail is a large discoidal snail native to northern South America and southern Central America that has been sold by pet dealers for aquariums. It is likely that specimens were released into the Comal and San Marcos Rivers by aquarists (Arsuffi and others 1990, 10 - 11). Areas of Landa Lake, into which Comal Springs flow, supported large masses of aquatic plants until recently. The vegetation in the lake has been severely denuded by the snails, resulting in a loss of cover, refuge, and food supply, making fountain darters more susceptible to predation. The rams-horn snail population probably increases during periods of diminished spring discharge. The snails could indirectly be the biological agent responsible for the demise of fountain darters as well as other species. If the population of snails were reduced, the USFWS take and jeopardy levels for Comal Springs could fall to 150 and 60 cfs respectively, allowing as much as 65,000 acre-feet of additional water to be withdrawn from the aquifer before takes begin during droughts (Moore and Votteler 1995a, 108).

The Endangered Species Committee

Under Section 7(e) of the ESA, actions proposed by federal agencies that are determined to result in jeopardy to a listed species can be exempted from the ESA if the members of the federal Endangered Species Committee determine (1) that the action is of regional or national significance, (2) that the benefits of the action clearly outweigh the benefits of conserving the species, (3) and that there are no reasonable and prudent alternatives to the action. The Endangered Species Committee consists of the Secretary of Agriculture; the Secretary of the Army; the Chairman of the Council of Economic Advisors; the Administrator of the National Oceanic and Atmospheric Administration; and one individual from each affected state, chaired by the Secretary of the Interior [Endangered Species Act, Section 7(e)(1)(2)(3)]. An application for an exemption from the ESA may be made by a federal agency, a permit or license applicant, or by a governor of a state in which an action would occur. The Endangered Species Committee has only met a few times to deliberate the fate of a listed species, yet the use of the Committee for the Edwards Aquifer species has become the subject of increasing informal discussion. It was invoked in the case of the snail darter and the Tellico Dam in Tennessee which eventually was brought before the U.S. Supreme Court (National Research Council 1995, 21).

Mean Versus Minimum Spring Discharge

Spring discharge varies considerably during the day, with Comal regularly varying by some 20 to 30 cfs during the summer (Ozuna 1999). The mean flow is calculated at the end of the day. The mean flow calculation can mask the fact that flows are descending to take and jeopardy levels during a 24-hour day, as well as the degree to which the flows are descending below the critical levels during the portions of some days. The *Amended Findings of Fact and Conclusions of Law* in *Sierra Club et al. v. Babbitt et al.* includes statements by the USFWS Regional Director and other personnel that it is the minimum discharge from the springs that determines take and jeopardy [*Sierra Club et al. v. Babbitt et al.*, No. MO-91-CA-069, slip op. at 45, 46 (W.D. Tex. May 26, 1993)(Amended Findings of Fact and Conclusions of Law)]. Federal filings on April 15, 1993, and June 15, 1993, concerning take and jeopardy spring discharges as well as the Recovery Plan for the species also state that flow determinations are minimums (Shockey 1993a, 1); (Shockey 1993b, 1); and (U.S. Fish and Wildlife Service 1996, 17).

The USGS reports of daily spring discharge at Comal and San Marcos Springs are the daily mean; however harm to the listed species may potentially begin when minimum spring discharge fall below the thresholds established by USFWS. Minimum and maximum daily spring discharge data have not been processed by the USGS for the Comal Springs, but the necessary information to produce these data could be in the database (Ozuna 1999). As for San Marcos Springs, a short span of minimum spring discharge data was available from the USGS website in 1998; however, they were removed in 1999. This issue is not trivial, because according to the filings in *Sierra Club et al. v. Babbitt et al.*, it is the minimum flow that determines take.

As stated earlier, the limits to the sustainable development of the Edwards Aquifer were determined by the "best professional judgment" of the USFWS in letters filed with the court in *Sierra Club et al. v. Babbitt et al.* These letters define the minimum flow rates at Comal and San Marcos Springs for protecting the endangered species. The research supporting this judgment is likely to receive renewed scrutiny concerning any proposed alteration of these limits. A recent study of spring discharge that included participation by USFWS biologist from the Ecological Field Office in Austin reported that for the fountain darter in the Comal River, "Analysis results indicate that due to the temperature effects, fountain darter habitat drops precipitously as flow-rates decline below 100 cfs" (Bartsch, Hardy, and Connor 1999, 121). For the fountain darter in the San Marcos River the study reported that, "During summer months this increases water temperature resulting in a lower weighted useable area at modeled flow-rates at or below 65 cfs" (Bartsch, Hardy, and Connor 1999, 122).

There is another issue concerning minimum flows, the threshold of the established take and jeopardy levels.

> In terms of protecting endangered species, the specification of a stated minimum flow is unrealistic. If, for example, a limit of 100 cfs were required for a given spring, does that imply that with a flow of 99 cfs for one day, certain species will suffer great damage or loss? More realistically one should work within a range of minimum flows applicable to all endangered species and recognizing that the limits of the range can be lowered as the duration of low flow decreases. One of the contributions that biologists plan to make by means of the EAA research studies is to provide water resource planners with realistic estimates of minimum flows for the two major springs, recognizing that a guidance range of flows applicable to all species will be most useful. (Todd Engineers 1999, 18, 19)

If take at Comal Springs begins at 200 cfs and continues to 151 cfs, is the effect upon the fountain darter the same at 200 cfs as 151 cfs? The use of thresholds is necessary primarily for practical management purposes. If there were not a minimum threshold, the initiation of conservation measures during critical low flow periods would be difficult.

6. KEY EVENTS SHAPING THE SUSTAINABLE DEVELOPMENT OF THE EDWARDS AQUIFER

Introduction

This chapter will examine the history of efforts to manage the available water supply in the Edwards Aquifer region to meet competing and changing water demands. The major events that have shaped the current use and management of the aquifer are discussed. These events provide the context with in which efforts to sustainably develop the aquifer region must be formulated.

The Fight over Canyon Reservoir

More than a decade before the Endangered Species Act became law in 1973, competition over the water in the Edwards Aquifer existed among regional interests. The vulnerability of San Antonio residents to future water shortage has been known since the historic drought of the 1950's. A newspaper article in 1956 headlined "San Antonio could be out of water by 1966," began, "In 10 years San Antonio may well face a major catastrophe which could destroy its entire economy" (Thompson 1956, 2C). San Antonïo failed to act in time to take advantage of the period from the 1930s to 1980s of generous federal subsidies for water development, while other Texas cities decided to build reservoirs.

Instead, San Antonio's initial attempt to obtain significant amounts of surface water focused on Canyon Reservoir, which was under construction in the 1950's in the Guadalupe River basin. The primary motivation for the construction of the Canyon Dam was flood control. However, water conservation was also a major consideration because the reliability of future spring discharge from the Edwards Aquifer was already a concern, which is apparent in this statement by Senator Lyndon Baines Johnson before the Senate Public Works Subcommittee:

> Water conservation also is of tremendous importance in connection with this project. Failing spring flow and a steadily increasing demand for water for municipal, industrial and agricultural purposes have caused an acute water shortage in the Guadalupe River Basin. Further industrial and irrigation development depends on an increase in water supply – such an increase as would be provided by the building of Canyon Dam and Reservoir. (Johnson 1955, 2)

Canyon Reservoir was once considered San Antonio's solution to its potential water shortages: "Engineering studies show that San Antonio's great hope for preventing a water crisis in the years immediately ahead lies in the planned Canyon Dam and reservoir north of New Braunfels on the Guadalupe" (Thompson 1956, 2C). However, this attempt to obtain water from Canyon Reservoir initiated a major transboundary dispute over water.

If June 13, 1956, the day Comal Springs ceased to flow, is when the struggle over the control of the Edwards Aquifer began, then July 5, 1957 is the day when the struggle became bitter. On that day, the Texas Board of Water Engineers (TBWE) granted an application by the Guadalupe – Blanco River Authority (GBRA) to appropriate 50,000 acre-feet of water from Canyon

Reservoir for municipal use, while denying a similar application by San Antonio for 100,000 acre-feet [*City of San Antonio et al. v. Texas Water Commission et al.*, 407 S.W.2d 754 (Oct. 26, 1966)]. San Antonio had planned to withdraw the water at the reservoir in Comal County and pipe it to the San Antonio River in Bexar County.

The City of San Antonio and the San Antonio Water Board of Trustees (predecessor to the San Antonio Water System) filed two appeals of the decisions by the TBWE in the 98th District Court of Travis County. The first appeal concerned the TBWE's order granting the GBRA 50,000 acre-feet, and the second appeal was for the denial of its own application. When these appeals were filed, every major city in the Guadalupe River basin joined the GBRA as defendant intervenors, as well as Calhoun and Refugio Counties, DuPont and Union Carbide Corporations, and Central Power and Light. The drought of record was just coming to an end at a moment when San Antonio's preferred future source of water was eliminated. It is likely that the prolonged effects of drought of record, only recently ended, generated concern among residents of the Guadalupe River basin causing them to unite to protect water that they perceived to be theirs, while at the same time creating an equal level of anxiety in San Antonio to secure the crucial amounts necessary for its current and future needs.

On October 26, 1966, the Texas Supreme Court sided with the TBWE and the residents of the Guadalupe River basin, denying San Antonio's appeals [*City of San Antonio et al. v. Texas Water Commission et al.*, 407 S.W.2d 752 (Oct. 26, 1966)]. San Antonio's first attempt to secure an additional source of water was frustrated by the GBRA. The resultant rift between the GBRA and San Antonio has never fully healed.

The Edwards Underground Water District

Management of the Edwards Aquifer has been a controversial and divisive issue since the Canyon Reservoir litigation. As a result of the concerns raised by the drought of record, the Edwards Underground Water District (EUWD) was created by the Texas Legislature in 1959, two years after the drought ended. The EUWD was a special district with an elected board charged with conserving and protecting water in the aquifer, and increasing its recharge. The District's initial jurisdiction included Bexar, Comal, Hays, Medina, and Uvalde Counties.

The District was unlike local groundwater districts found on the Texas High Plains overlying the Ogallala Aquifer. The movement of water through the Edwards Aquifer is so much faster than through the Ogallala in Texas that the management model developed for that region was unlikely to work for the Edwards, where pumping by individuals can have a more immediate influence on the water level of neighboring wells. The EUWD also differed from the typical groundwater districts studied by Stephensen (1996). He found that local groundwater districts in Nebraska, controlled by agricultural interests, could manage the resource effectively (Stephenson 1996, 761). However, unlike Nebraska, the EUWD, and later the Edwards Aquifer Authority, was governed by a board that contained a minority representing agricultural interests. Also, unlike the local districts in Nebraska, the EUWD did not have authority to restrict groundwater pumping:

> While not regulatory in nature, the Edwards Underground Water District is in the continuous process of developing and carrying out projects to increase the recharge to the Edwards Aquifer. Comments by the EUWD, 45 Fed. Reg. 47359 (1980)

The need to regulate pumping became apparent in the 1980's when withdrawals began regularly to exceed 500,000 acre-feet annually, approaching the median annual recharge, which is now 556,100 acre-feet. When the EUWD tried to obtain the authority to regulate pumping by legislative action, the District disintegrated.

The *1961 Texas Water Plan* and the Edwards Aquifer

In addition to the creation of the EUWD, the effects of the drought of record spurred Texas to begin a major planning effort to provide for the state's water needs to meet the challenges of a repeat of the 1950s drought. Periodic *Texas Water Plans* in 1961, 1968, 1984, 1990, 1992, and 1997 constitute the state's outline for water resources development (Texas Water Development Board 1997, 2-1, 2-2). While not enacted as law or adopted as mandatory plans, they do establish the state's priorities for future water development projects and contain a tremendous amount of technical information concerning water quality and quantity issues. These plans address future water supply, water quality protection, water conservation, flood protection, and other water-related needs of the state. Potential projects and the associated costs to protect water quality, and supply water to meet future water needs, are identified. The plans describe existing water resources and water uses, projections of future water requirements, and estimates of future water supplies in regional and statewide perspectives. They typically include specific details of current water uses, current water development plans, future water needs, and potential water sources to meet projected demands in each river and coastal basin in the state. Information is based upon Texas water use and availability, and demographic, economic, and technical data. Projections of future needs take into account estimates of future trends in economic conditions and in available technologies.

The *1961 Texas Water Plan* was the first blueprint for meeting the state's needs during a repeat of the drought of record. Some major cities that were short of water, such as Dallas and Fort Worth, built reservoirs as recommended in the plan. For San Antonio, the plan discouraged over-reliance on the Edwards Aquifer and noted that irrigation was depleting groundwater supplies for future municipal use (Texas Board of Water Engineers 1961, 26). The plan stated that to meet its 1980 water needs, additional regional water supplies would be required, requiring the construction of new surface water reservoirs:

> However, assuming that future water levels will not be drawn lower than those which occurred in 1956 [when 321,000 acre-feet were withdrawn] and also projecting the increased irrigation pumping in Bexar, Medina, Uvalde, and Kinney Counties, it appears that only about 75,000 to 100,000 acre-feet of water will remain available to the city of San Antonio annually from the Edwards limestone (fault zone) under 1980 conditions. It is thus expected that, in order to meet the 1980 municipal and industrial water requirements, it will be necessary for San Antonio to obtain surface-water supplies. (Texas Board of Water Engineers 1961, 152)

Small and large reservoir projects were suggested, including East, Cibolo, and Ecleto Reservoirs, with some water coming from the Guadalupe River basin. The only one of these reservoirs constructed was East, now named Calaveras, which is used by City Public Service (San Antonio's electric utility) as cooling water for power generation. Goliad was to be built farther south on the San Antonio River to supply Corpus Christi as a trade for Guadalupe River water upstream that would go to San Antonio. The plan encouraged the "importation of water from the east", but the Guadalupe River basin was recognized as not being a basin of surplus for San Antonio on a long-range basis, suggesting that the Colorado, or basins further east, were the ultimate source of supply (Texas Board of Water Engineers 1961, 146, 152).

The *1966 (Preliminary) and 1968 Texas Water Plans* and the Edwards Aquifer

The Texas Water Development Board's update to the *1961 Texas Water Plan* was the 1966 preliminary plan. The 1966 plan also described how San Antonio could be provided with the water it would need for the next drought of record. In addition to reservoirs in the Colorado River basin, the TWDB proposed a preliminary schedule of reservoir construction that would complete all of the major reservoirs projects suggested for San Antonio within the first of three phases between 1967 and 1979 (Texas Water Development Board 1966, 17). This list of projects included Cuero I, Cuero II, Goliad, Cibolo, and Cloptin Crossing (Texas Water Development Board 1966, 17). By placing all of the major reservoirs for San Antonio in the first phase, the ambitious program of statewide reservoir construction clearly placed a priority on the early construction of reservoirs to meet San Antonio's needs ahead of the remainder of the state.

The most significant contribution of the *1968 Texas Water Plan* is the determination that, based upon historical rates of recharge, storage, and hydrologic characteristics, withdrawals should not exceed 400,000 acre-feet annually if water levels in the Edwards Aquifer were to recover following dry periods and a safe yield was to be ensured (Texas Water Development Board 1968a, I-15). Although the Plan does not explain the origin of this limit, 400,000 acre-feet is approximately 80% of the average annual recharge to the Edwards Aquifer from 1934 to 1967, or 503,500 acre-feet. The Plan acknowledges that, at 400,000 acre-feet, the flow of Comal and San Marcos Springs would be eliminated part of the time (Texas Water Development Board 1968a, I-15). The Plan provides that the total of 400,000 acre-feet withdrawn annually would be distributed as shown in Table 13. Five years before there was an Endangered Species Act, the TWDB stated that it was "considered to be desirable by the Board" to maintain some amount of flow from the springs to among other goals provide "part of downstream surface water supplies . . . as well as enhance the scenic, cultural, and recreational value of the area" (Texas Water Development Board 1968a, I-15). Thus, justification for guaranteeing minimum flow from the springs initially arose from the generation of economic and aesthetic benefits in New Braunfels, San Marcos, and downstream.

The 400,000 acre-feet figure has survived the test of time. This limit was later revived in a 1992 letter from USFWS Director Michael Spear to Texas Water Commission (TWC) Chairman John Hall, which recommended,

Table 13. Recommended Amount of Edwards Aquifer Groundwater to be Withdrawn Annually by Basin in the *1968 Texas Water Plan*

Basin	Amount Available/Year	Conditions
Nueces River	90,000 acre-feet	Available annually
San Antonio River	260,000 acre-feet	Under present conditions
Guadalupe River	50,000 acre-feet	Available as perennial yield
Total	400,000 acre-feet	

Source: Totals derived from (Texas Water Development Board 1968a, IV-54, IV-59, IV-64).

"Within 10 years, direct pumpage from the Aquifer shall be reduced by 50,000 acre-feet to 400,000 acre-feet per calendar year" (Spear 1992, 2). Finally, the 400,000 acre-feet limit was eventually adopted in Senate Bill 1477 as the ceiling for annual withdrawals from the Edwards Aquifer after 2007 (Act of May 30, 1993 73rd Leg., R.S., ch. 626, 1993 Tex. Gen. Laws 2355, §1.14(c)).

While the *1968 Texas Water Plan* allocated the 400,000 acre-feet between pumpers in the three river basins, it also acknowledged that pumping would need to be "reduced somewhat below 400,000 acre-feet annually" to maintain some flow from both Comal and San Marcos Springs (Texas Water Development Board 1968a, I-15). A limit of less than 400,000 acre-feet was eventually recommended by Director Spear as the limit to guarantee flow from both springs:

> In order to protect flows at San Marcos and Comal Springs, a special drought management plan must be developed and implemented during extreme drought. Specifically, the drought management plan must reduce direct pumpage from the Aquifer to a rate of 350,000 acre-feet per year at any time the water level in the J-17 index well in Bexar County falls below 625 feet msl. (Spear 1992, 2)

To meet projected annual 2020 municipal and industrial water needs in Bexar County, the Plan recommended 220,000 acre-feet of surface water supplies and 215,000 acre-feet of withdrawals from the Edwards (Texas Water Development Board 1968a, I-15). The Plan acknowledged that water development in the San Antonio region would require the cooperation of the EUWD, the GBRA, the San Antonio River Authority (SARA), the City of San Antonio, and the TWDB. The TWDB concluded that the most feasible alternative for supplemental surface water supplies was development in the San Antonio and Guadalupe River basins, including Goliad, Cuero 1, Cuero 2, and Cibolo Reservoirs. Even with construction of these reservoirs, withdrawals from the aquifer for the San Antonio area would be limited to 215,000 acre-feet annually. Construction of reservoirs over the recharge zone (Concan on the Frio River, Sabinal on the Sabinal River, and Montell on the Nueces River) were recommended to promote conjunctive use of ground and surface water (Texas Water Development Board 1968a, I-15, I-16). Long range water supply alternatives for the region included the importation of water from the Colorado River through a transbasin diversion in the vicinity of Austin to San Antonio for municipal and industrial water uses.

The Purchase of Water from Canyon Reservoir is Rejected

After years of litigation, San Antonio finally reached a tentative agreement to purchase Canyon Reservoir water from the GBRA. A 1976 draft contract between the GBRA and San Antonio would have provided 30,000 acre-feet of raw surface water for $1 million, or $33.33 per acre-foot (Specht 1999). Another 20,000 acre-feet would eventually come from a new reservoir to built in the basin. Although it was not mandatory that the agreement be approved by the San Antonio City Council, it was submitted to them anyway. The purchase, along with future purchases from the GBRA, was rejected by one vote (Specht 1999). The former general manager of the GBRA has stated that this sale could have supplied San Antonio with an alternative water source and avoided nearly a decade of Endangered Species Act litigation over the Edwards Aquifer (Specht 1999).

After voting against water from the Guadalupe as a councilman in 1976, Mayor Henry Cisneros in 1984 approached the GBRA about buying water (Specht 1999). He was told that there was no longer enough for all of San Antonio's needs. The GBRA suggested a joint study of the region's needs, which was completed in 1986 by Espey Huston and Associates (Specht 1999).

The *1984 Texas Water Plan* and the Edwards Aquifer

The TWDB concluded in its 1984 plan:

> The San Antonio River Basin is projected to experience water shortages before the year 1990 if no additional water supply sources are developed. . . . Studies of the Edwards (Balcones Fault Zone) Aquifer have indicated that limitations on withdrawals of ground water from the aquifer will be needed to maintain spring flow in the Guadalupe River Basin at San Marcos Springs and to avoid possible degradation of water quality in the aquifer. Such pumpage limits will necessitate, at some future time, the curtailment of additional development by some users of the aquifer and must involve Bexar County, as municipalities and industry in Bexar County are the largest users of water from the Edwards. If economic growth in Bexar County is not to be inhibited by water shortages, then alternative water supplies must be developed from the most economically available sources. The most likely future water sources for Bexar County are surface-water supplies in the Guadalupe and San Antonio River Basins. (Texas Department of Water Resources 1984, III-19-9)

In 1974, Cibolo Reservoir was authorized by the U.S. Congress to be constructed by the U.S. Army Corps of Engineers (Public Law 93-943). Originally, it was projected that the reservoir could supply 22,000 acre-feet annually, of which 20,000 acre-feet would be piped to Bexar County (Texas

Department of Water Resources 1984, III-19-13). San Antonio was granted a permit for Applewhite Reservoir on the Medina River in 1982; the firm annual yield covering a repeat of the drought of record was estimated to be 15,000 acre-feet (Texas Department of Water Resources 1984, III-19-9). A shortage in 1990, which was anticipated to be 56,900 acre-feet could be met from the Lindenau Reservoir in the Guadalupe River Basin (Texas Department of Water Resources 1984, III-19-13). The TWDB estimated any further shortage in 2030 could be supplied from the proposed Goliad Reservoir on the San Antonio River with associated pumping facilities (Texas Department of Water Resources 1984, III-19-13).

The 1984 plan contemplated the amounts found in Table 14 would be pumped from the Edwards Aquifer in 2030. The TWDB also stated, "through the application of a mathematical model of the Carrizo-Wilcox Aquifer, it was concluded that approximately 40 thousand acre-feet could be pumped annually from the artesian zone of the aquifer in Wilson County, in the Guadalupe River Basin, over a 50 – year period without dewatering the aquifer" (Texas Department of Water Resources 1984, III-19-13).

Medina and Uvalde Counties Withdraw from the Edwards Underground Water District

In 1987, the Legislature authorized the EUWD in House Bill 1942 to develop a *Regional Water Management Plan* (RWMP) and a *Drought Management Plan* (DMP) (Templer and Jonish 1993, 60).

Table 14. Recommended Amount of Edwards Aquifer Groundwater to be Withdrawn Annually by 2030, by Basin in the *1984 Texas Water Plan*

River Basin	**Acre-feet**
Guadalupe	38,200
San Antonio	285,100
Nueces	101,700
Total	425,000

Source: (Texas Department of Water Resources 1984, III-18-9, 10; III-19-8; III-21-9).

Appendix 3, Item 2. Summaries of the Texas Water Commission's Emergency Conservation Proposals, contains the details of the resulting *Drought Management Plan*. The RWMP would have given the EUWD the authority to restrict withdrawals and issue permits for new wells, while limiting irrigation for each irrigator to the maximum number of acres irrigated in any year between 1979 and 1985 (Jensen 1988, 1-6). The RWMP and DMP were not implemented because the proposed enabling legislation, The Edwards Aquifer Administration Act, failed to pass in the 1989 Texas legislative session (Templer and Jonish 1993, 60). Faced with possible limits on withdrawals for irrigation, Medina and Uvalde Counties seceded from the EUWD early in 1989 (House Research Organization 1994, 37). In that same year, the Medina and Uvalde County Underground Water Conservation Districts were created to represent pumpers in those counties.

Aftermath of the Failure of Local Control

The aftermath of the drought of record and the inability of the Edwards Districts (including the EUWD and Medina and Uvalde Underground Water Conservation Districts) to reduce the volume of pumping has been described:

> Central Texans had pinned their hopes for a sustainable and unlimited groundwater source on the technology of recharge dams under the District's guidance. Instead of accepting the reality of natural limitations on the aquifer's ability to provide unlimited water to all, Edwards users sought to protect their individual, unlimited access indefinitely. Many apparently believed that technology would develop to allow them to continue using the resource as they wished. Few seemed willing to accept daily conservation as a part of their futures, or to consider altering their lifestyles to accommodate their physical surroundings. Simultaneously, the voters of the Edwards district, refused to invest tax dollars in developing these technological fixes. The District faced difficulty in

> financing recharge facilities in the 1960s and completed only four within twenty-five years of its formation. City officials, state agencies, the Edwards Districts, and river authorities, now aware to an even greater extent of their opponents in a contest to claim, control, and protect their access to water, continued to fight each other over the aquifer and the surface streams in the area. The lack of power in the district permitted those entities with rule-making ability, such as cities, counties, river authorities, and state agencies, to continue efforts at self-protection without fear of reprisal from the district. Representatives within the Edwards District hierarchy also showed mistrust and an inability to cooperate for the region's good. The constituencies of the Edwards District remained leery of one another. Suspicious of, and contemptuous of, each county's use of the groundwater, District members cooperated minimally at best. (Wimberley 1997a, 6)

The attempt to apply the lessons learned from the drought of record through the EUWD failed. Wimberley's discussion of the apathy of the citizens of the Edwards region explains how they failed to address its future water needs:

> The Edwards District, the most obvious and long-lasting result of South Central Texans' conservation efforts and cooperative ventures during the Great Drought, failed to solve the problems revealed by those events. The District and the drought both faded from public consciousness as rain returned to Texas. After the drought, occasional editorials or water rate fights would pique interest in the aquifer temporarily, but concern faded quickly. New residents continued to pour into the area in the 1960s; many remained unconcerned about their water source - accepting on faith that when they turned on the tap, water would flow. Conservation and public education efforts lapsed, to be awakened again when dry times returned and water scarcity loomed. In those intervals, people remembered the "Great Drought." And as the majority did in the 1950s, the people of South Central Texas would once again resist accepting their situation, reluctantly undertake conservation efforts, and struggle against recognizing their regional interdependence. (Wimberley 1997b, conclusion)

The *1990 Texas Water Plan* and the Edwards Aquifer

The *1990 Texas Water Plan* was the first revision of the state's strategy for meeting the water needs of the Edwards region after Medina and Uvalde Counties had withdrawn from the EUWD. The projected future use of the aquifer in this plan is found in

Table 15. The 2000 projection will probably underestimate actual pumping by 50,000 to 80,000 acre-feet, if current trends continue. The Plan noted that the TWDB's computer model of the Edwards Aquifer indicated that, if total pumping is limited to slightly over 424,000 acre-feet annually and the "assumed recharge sequence occurs" (this is undefined), San Marcos Springs could be expected to continue to flow (Texas Water Development Board 1990, 3-88). What would happen at Comal Springs is not discussed; however, the TWDB noted that other research indicated that even a 424,000 acre-feet pumping limit might not adequately protect spring discharge at San Marcos Springs (Texas Water Development Board 1990, 3-88).

Attempts to Declare the Aquifer an Underground River

In 1989, a suit filed by the Guadalupe-Blanco River Authority sought to designate the Edwards Aquifer as an underground river (*Adjudication of Rights to Water in the Edwards Aquifer*, No. 89-0381). While the case did not move forward in 1989, it was still pending as of 1999 (Nevola 1999). This case suggested a procedure to regulate the aquifer that could circumvent the rule of capture. This strategy was to be revived by the TWC in 1992.

Table 15. Projected Future Use of Edwards Aquifer Groundwater by River Basin in the *1990 Texas Water Plan*

Basin	Projected Use in 2000	Projected Use in 2040
Nueces River	115,189 acre-feet	120,352 acre-feet
San Antonio River	269,001 acre-feet	294,264 acre-feet
Guadalupe River	32,722 acre-feet	33,176 acre-feet
Total	416,912 acre-feet	447,792 acre-feet

Source: Derived by the author from (Texas Water Development Board 1990, 3-42, 3-44, 3-46).

The narrow configuration and rapid flow and recharge characteristics of the aquifer encouraged the view that it is a well-defined underground stream (Pressley 1991, 42-59). Under Texas water law an underground river must have certain characteristics defined in case law (listed below). However, designating underground rivers is problematic:

> The high standard of proof required to establish underground streams limits the utility of the use of the subsurface stream doctrine to coordinate ground and surface water rights; findings of subsurface streams are likely to be comparatively rare. (Tarlock 1993, 3-27)

In 1991, the TWC requested that Attorney General Dan Morales review a 1941 opinion by a predecessor that Section 28.011 of the *Texas Water Code* was not a constitutional delegation of rule-making authority over groundwater (House Research Organization 1994, 12). Section 28.011 of the *Texas Water Code* states:

> 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. (West Publishing Company 1996, 746)

Without addressing the scope of 28.011, in November 1991, Morales overruled the 1941 opinion, in opinion DM-54, and determined that 28.011 did provide sufficient standards to constitute the necessary delegation of legislative authority (House Research Organization 1994, 12). However in March 1992, Attorney General Morales reversed his opinion that had provided the TWC with the necessary authority to take control of the Edwards. This time Morales ruled that ". . . the opinion would be insufficient legal authority for the Commission to attempt to regulate the use of groundwater on the basis of sec. 28.011" (House

Research Organization 1994, 12). Morales concluded that opinion DM-54 did not delineate the scope of authority that the Legislature had delegated to the TWC under 28.011 (House Research Organization 1994, 12).

Despite the reversal by Morales, the TWC moved forward on April 15, 1992, adopting the Guadalupe Blanco River Authority's idea and relying on this seldom used provision of the Texas Water Code to support its claimed authority. The TWC found that the Edwards had the following unique characteristics necessary to be classified an underground river:

> 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.
> (Templer and Jonish 1993, 61)

The TWC concluded that these characteristics subjected the Edwards to Chapter 11 of the *Texas Water Code*, concerning surface water rights and adjudication, and Chapter 26, concerning water quality (Templer and Jonish 1993, 61). The TWC based its decision to take control of the Edwards on an emergency basis on the following grounds: "1) no regional water management plan had been adopted after four decades of disagreement by regional interests; 2) uncontrolled pumping of the aquifer; 3) the absence of progress by San Antonio in developing a supplemental surface water supply; and 4) the threat of federal intervention under the pending litigation, *Sierra Club et al. v. Babbitt et al.*" (Templer and Jonish 1993, 61). The designation would have allowed the TWC to ignore the rule of capture for the Edwards Aquifer and regulate withdrawals in a system parallel to that used for surface lakes, rivers, and streams. The TWC's action was later overturned by a State District Court in August, 1992 (*Danny McFadden & Texas Farm Bureau v. Texas Water Commission*, No. 92-05214 (Dist. Ct. of Travis County, 331st Judicial District of Texas)).

The *1992 Texas Water Plan* and the Edwards Aquifer

The 1992 update of the *Texas Water Plan* retains essentially the same figure for the cap on annual pumping from the Edwards Aquifer, 425,000 acre-feet as in the 1990 plan (Texas Water Development Board 1992b, 94). However, the TWDB states that pumping should be limited to 165,000 acre-feet during a repeat of the drought of record to guarantee 100 cfs of flow at Comal Springs and 50 cfs at San Marcos Springs (Texas Water Development Board 1992b, 94). These estimates were produced a year before the USFWS filed the take and jeopardy flow determinations with the U.S. District Court as required by the judgment in *Sierra Club et al. v. Babbitt et al.* discussed below.

San Antonio Citizens Twice Reject Applewhite Reservoir

After deciding against purchasing water from Canyon Reservoir, the city placed its hope on construction of the Applewhite Reservoir, covering 2,500 acres along the Medina River some 11 miles south of San Antonio (Bauer, Frye, and Spain 1991, 98). During special referenda in 1991 and 1994, the citizens of San Antonio voted not to complete Applewhite Reservoir, already under construction on the latter date. The successful campaign to defeat the reservoir project was coordinated by a citizen's organization that had originally formed to successfully prevent fluoride from being added to San Antonio's drinking water (Wimberley 1998).

The elimination of the Applewhite Reservoir significantly expanded *Sierra Club et al v. Babbitt et al.* (which was underway in 1994) and the involvement of the federal court in the regional water dispute. The process of developing the first draft regional habitat conservation plan for the Edwards Aquifer was a direct result. The defeat of Applewhite had a more important effect upon San Antonio's neighbors. It spawned the sentiment that San Antonio was unjustified in seeking new water supplies outside the city's immediate vicinity, contributing to the persistent opinion that, if San Antonio could not develop its own water resources, why should it be allowed to develop projects elsewhere; "They have refused to do it in their own back yards. I don't want it in my front yard" (Cooper 1999, 1).

The Texas Water Commission's Edwards Aquifer Plans

When the Texas Water Commission attempted to declare the Edwards Aquifer an underground river in 1992, it developed two management plans (summarized in Appendix 3, Item 2. Summaries of the Texas Water Commission's Emergency Conservation Proposals). While these plans were rejected by the major parties, Senate Bill 1477 incorporates some of the elements of TWC's plans (McCarl and others 1993, executive summary). Since the Texas

Legislature considered the adoption of plans similar to the TWC plans, a study was undertaken to evaluate the hydrologic and economic implications of the TWC plans. The Texas Water Resources Institute (TWRI) study claimed that the two plans developed to curb withdrawals would not have maintained flow at Comal Springs through a repeat of the drought of record without additional measures (McCarl and others 1993, executive summary). Instead the TWRI study extolled markets as a way for economic agents to seek out the highest valued uses of scarce groundwater, while compensating those reducing their usage (McCarl and others 1993, executive summary). The study suggested that simultaneously implementing water market mechanisms to allow water use reallocation along with pumpage restrictions was desirable (McCarl and others 1993, executive summary). It found that, without changing the allocation of withdrawals among different water uses, the result is a growing disparity in sectoral water values as demand grows. The simultaneous imposition of withdrawal limits, allocation of water rights, and creation of a water market appeared necessary to maintain economic efficiency.

The Catfish Farm

Under the rule of capture, gross misallocations of resources can occur. Much like the tragedy of the commons (Hardin 1968), each individual user of Edwards water who wished to maximize profits was compelled to increase consumption of water without limit, so long as such use was profitable or needed. For example, in 1991 the Living Waters Artesian Springs Farm (the catfish farm), 15 miles southwest of San Antonio, began using as much as 40 million gallons (123 acre-feet) of aquifer water per day to raise catfish, discharging the water directly into the Medina River (House Research Organization 1994, 19). At that time, on an annual basis, this usage equaled approximately 25% of the City of San Antonio's total water use from the aquifer (Illgner 1993, 4.3). When the catfish farm was in operation, well levels in adjacent portions of the aquifer declined 3 to 10 feet (Templer 1996, 3). The San Antonio Express-News called the catfish farm's action ". . . clearly and absolutely an outrage. It is property rights carried to the nth degree, the public be damned. It violates the spirit of the law. It defies common sense" (San Antonio Express-News 1995, B-4). The catfish farm's water use demonstrated in a single example that the cumulative impacts of additional pumping could eventually lead to the overexploitation of the aquifer. The controversy over the catfish farmer's withdrawals drew attention to unrestricted pumping that might have gone unnoticed if many individuals had incrementally increased withdrawals by a similar total amount. The catfish farm operated for 8 months before litigation forced it to close temporarily in 1991; it briefly began operating again in 1996 before the prospect of additional litigation forced another shutdown (Templer 1996, 3).

Sierra Club et al. v. Babbitt et al. – The ESA Mandates Pumping Limits

As Melvin Marcus said in his 1979 address as AAG president, the alteration of the Earth has created problems so large that they cannot be left to lawyers, engineers and other decision makers (Marcus 1979, 529). Yet the most important decisions regarding the management of the Edwards Aquifer as of 2000 have been made either in court, or in direct response to court decisions. The most significant case was *Sierra Club et al. v. Babbitt et al.* The Edwards Aquifer litigation under the provisions of the Endangered Species Act has been motivated by two desires on behalf of the plaintiffs: (1) to protect the unique species found in the Comal and San Marcos Springs ecosystems; and (2) to protect the surface water resources of the Guadalupe River Basin downstream of the springs. The second motivation is an example of a sequential power transboundary dispute (Matthews 1994, 375). In the Edwards Aquifer region, as surface water enters the aquifer recharge zone it leaves the jurisdiction of the state, as well as that of the Nueces, San Antonio, or Guadalupe – Blanco River Authorities. It becomes groundwater by percolating into the Edwards limestone. Prior to creation of the EAA the groundwater was governed solely by the rule of capture. When the groundwater discharges from Comal and San Marcos Springs it again becomes surface water, subject to appropriation under the jurisdiction of the GBRA and the state. On its journey the water passed from regulated, to unregulated, and then back to regulated jurisdictions.

A sequential power conflict could explain the motives of entities such as the GBRA with regard to the ESA litigation. In 1980, the GBRA, the EUWD, and the Nueces River Authority all opposed the listing of critical habitat for the fountain darter, San Marcos gambusia, San Marcos salamander, and Texas wild rice at San Marcos Springs (45 Fed. Reg. 47357 (1980)). The GBRA stated that:

> Based on numerous studies by the Authority [GBRA], the Texas Department of Water Resources [then containing the Texas Water Development Board], the U.S. Water and Power Resources Service [U.S. Bureau of Reclamation] and others, water supply to meet future municipal, industrial, and agricultural needs in the Guadalupe River Basin and adjacent river basins will require the full use of the Edwards Aquifer and the development of all surface water sources to supplement existing ground water resources. The commitment of a major portion of the Edwards Aquifer water supply to habitat maintenance in the San Marcos springs area would have a drastic effect on those people presently dependent on the Aquifer, would require the immediate development of additional surface water resources and would preclude future economic development and growth in the region. 45 Fed. Reg. 47358 (1980)

Former GBRA general manager John Specht has stated that the GBRA's motivation in *Sierra Club et al. v. Babbitt et al.* was to protect the water resources of the Guadalupe River basin, as contrasted with the Sierra Club's interest in protecting the species (Specht 1999). However, he stated that the GBRA's action was not taken at the expense of others who were using the aquifer. GBRA believed action had to be taken before another crisis similar to the drought of record occurred. Some GBRA board members, whose primary interest was preventing construction of Cuero I and II Reservoirs on the Guadalupe River, decided that the litigation was actually an effort to create a need in San Antonio for surface water that would ultimately result in the construction of these reservoirs (Specht 1999). On the contrary, the goal was to assure that, during a repeat of the drought of record, while Comal Springs might cease to flow for a short period of time, San Marcos Springs would continue to flow (Specht 1999). GBRA officials met with SAWS officials before the trial and thought they would reach an agreement, but SAWS could not commit to this very limited guarantee. When this last negotiation failed, the lawsuit proceeded. Specht has stated that the GBRA knew ahead of time that it would probably suffer retribution by state officials if it proceeded with the litigation, but believed it had little choice. The GBRA approached the Sierra Club about becoming involved with the litigation, because it was believed that the Sierra Club could maintain the litigation even if the GBRA were forced to withdraw (Specht 1999).

In 1991, the Sierra Club, along with Zoology Professor Clark Hubbs of The University of Texas at Austin, filed a suit in the U.S. District Court in Midland, Texas, alleging that the Secretary of the Interior and the USFWS had allowed takings of endangered species by not ensuring a water level in the Edwards Aquifer adequate to sustain the flow of Comal and San Marcos Springs. Originally styled *Sierra Club et al. v. Lujan et al.*, the Sierra Club, Guadalupe-Blanco River Authority, and other plaintiffs requested that the defendant (USFWS) be enjoined to restrict withdrawals from the Edwards Aquifer under certain conditions, and to develop and implement recovery plans for certain endangered and threatened species found in the aquifer and at Comal and San Marcos Springs [*Sierra Club et al. v. Lujan et al.*, No. MO-91-CA-69, 1993 WL 151353, (W.D. Tex. Feb. 1, 1993)].

A number of entities joined the lawsuit as plaintiffs with the Sierra Club, including the Bexar Metropolitan Water District and the Cities of San Marcos and New Braunfels. Several local and state agencies, and individuals joined the USFWS as defendant intervenors including: the City of San Antonio; the Attorney General's Office representing, the TNRCC, the Texas Parks and Wildlife Department (TPWD), and the Texas Department of Agriculture; as well as agricultural irrigators. The style of the case was later changed to *Sierra Club et al. v. Babbitt et al.* when Bruce Babbitt succeeded Manual Lujan as the Secretary of the Interior.

A non-jury trial was held in the U.S. District Court, Western District of Texas, in Midland, Texas, in November 1992 (Bunton 1999, 310). On February 1, 1993, the presiding Judge, Lucius Bunton, ruled in favor of the plaintiffs, and required the USFWS to determine the minimum spring discharge requirements to avoid take and jeopardy of the listed species in both springs.

> I felt I had to do a great deal of research about water and water rights and the laws applicable thereto in order to make a proper ruling. After studying and hearing a lot of testimony in court, I became convinced that Texas is too big a state, geographically speaking, to have one system of laws relating to water. (Bunton 1999, 312)

Bunton ruled that, if the Texas Legislature did not adopt a management plan to limit withdrawals from the aquifer by the end of its then-current session, the plaintiffs could return to the court and seek additional relief. The Sierra Club indicated that, if it had to return to the District Court, it would seek regulation of the aquifer by the USFWS, placing the aquifer under federal judicial control.

In the 1993 Legislative session, the GBRA was put under review by the Texas Sunset Commission, which could have resulted in the agency's abolition. Governor Ann Richards decided that Specht had to be replaced (Specht 1999); he was able to negotiate his retirement that year (Specht 1999). Retribution had indeed occurred. However, the GBRA ultimately achieved its goal of protecting the interests of water rights holders in the Guadalupe River basin through the establishment of minimum spring discharges while, at the same time, preserving endangered and threatened species. Indeed, the GBRA never dreamed that the lawsuit would result in the 200 cfs minimum at Comal Springs (Specht 1999).

I entered my judgment in January 1993 and essentially found that the overpumping from the Edwards Aquifer could indeed endanger the species that I had previously found were endangered in the Comal and San Marcos Springs. In the finding I expressly stated that the solution should be by the state rather than the federal government, and I would give the state an opportunity to address the matter in the coming session of the Texas Legislature.

The Legislature passed an act, but after the session was over, the legislation was submitted to the Attorney General of the United States, and it was found that the act violated the Voting Rights Act. The Legislature didn't meet again for two years. In the early '90s this delay did not make a lot of difference because it was raining on the aquifer, and the yards and farms on the aquifer were not using as much water as in times of drought.

In April 1994 the Sierra Club (because the land was getting dry) filed a motion to expand the lawsuit and wanted me to declare an emergency and take control of the aquifer. Needless to say, this really grabbed the attention of the people of San Antonio.
(Bunton 1999, 310, 311)

Senate Bill 1477: Pumping Regulations Become State Law

The next session of the Texas legislature offers the last chance for adoption of an adequate state plan before the 'blunt axes' of Federal intervention have to be dropped. Finding 196, Amended Findings of Fact and Conclusions of Law, *Sierra Club et al. v. Babbitt et al.* (May 26, 1993)(emphasis in original)

Senate Bill 1477, adopted by the Legislature on May 30, 1993, one day before the deadline for threatened federal action, created a conservation and reclamation district, named the Edwards Aquifer Authority (EAA). The EAA is to regulate groundwater withdrawals pursuant to the Conservation Amendment in the Texas Constitution, Article XVI, § 59, modifying the rule of capture in five counties and portions of three others, with a permit system. The Authority replaced the EUWD, which at that time covered only three counties overlying the aquifer. Under Senate Bill 1477 withdrawals are eventually to be limited to 450,000 acre-feet before December 31, 2007, and 400,000 acre-feet thereafter, unless drought conditions require more severe restrictions [Ch. 626, 1993 Tex. Gen. Laws 2355, §1.14(b) and (c)]. By December 31, 2012, "the authority [EAA] . . . shall ensure that . . . 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" [Ch. 626, 1993 Tex. Gen. Laws 2355, §1.14(h)]. The EAA is specifically charged by Senate Bill 1477 with protecting threatened and endangered species [Act of May 30, 1993 73rd Leg., R.S., ch. 626, 1993 Tex. Gen. Laws 2355, §1.14(a)(6)].

The EAA is authorized to achieve the required limits on withdrawals by purchasing and retiring permitted withdrawal rights. When the cap goes from 450,000 acre-feet to 400,000 acre-feet, downstream users in the Guadalupe River basin will contribute to the money needed to purchase the 50,000 acre-feet reduction (Thuss 1999). Domestic and livestock pumping was excluded from the 450,000 and 400,000 acre-feet caps (Buckner 1999). Agricultural irrigators were guaranteed 2 acre-feet of water per acre of irrigated cropland. The export of groundwater across county lines was limited.

After the Legislature adjourned, an objection to the make – up of the governing board under the federal Voting Rights Act prevented the EAA's activation. Under § 5 of the federal Voting Rights Act, in fourteen states with a past history of discrimination against minority voters, any change affecting voters or elections in political subdivisions must be submitted to the U.S. Department of Justice (USDOJ) for preclearance. The Mexican American Legal Defense and Education Fund (MALDEF) opposed preclearance of the procedure for choosing EAA board members. On November 19, 1993, USDOJ's Civil Rights Division agreed with MALDEF and objected to the new law ". . . insofar as it replaces the previously elected governing body [of the Edwards Underground Water District] with an appointed board [for the EAA]" (House Research Organization 1994, 2). The USDOJ was concerned that Hispanic voters in the former Edwards Underground Water District would not have the same opportunity to be represented on the appointed EAA board.

A Monitor is Appointed

Late in 1993, with the EAA in limbo, the Sierra Club returned to the District Court and requested that a Monitor be appointed in the case. In February, 1994, Judge Bunton appointed Joe G. Moore, Jr. as the Court Monitor to ". . . gather, summarize, and evaluate information necessary to allow the Court to take appropriate action to prevent violations of the Endangered Species Act" [*Sierra Club et al. v. Babbitt et al.*, MO-91-CA-069, at 1 - 2 (W.D. Tex. Feb. 25, 1994) (Order Appointing Joe G. Moore, Jr. as Monitor)].

The Monitor prepared two drought management plans for the court, the first in 1994 and the second in 1995 (see Appendix 3. Regional Drought Management Plans Developed for the Edwards Aquifer). A third such plan was generated by a lawyer's panel appointed by the Judge in the spring of 1995; it was adopted by the court in June 1995 on a stand – by basis for use in the event of critical low spring discharge in the summer of 1995.

The City of San Antonio had represented to the federal court that the construction of Applewhite Reservoir as a surface water supply demonstrated its intent to reduce its dependence on the aquifer. When the second referendum halted construction of the Applewhite Reservoir in August 1994, the Monitor suggested that the city and other pumpers apply for an Endangered Species Act §10(a) Incidental Take Permit (ITP).

Prior to 1982, non-federal parties faced penalties under the Act when their otherwise legal activities resulted in the take of a species. In that year, Congress amended the ESA to allow the "taking" of federally listed species when the taking is the inadvertent result of a legal activity by obtaining an incidental take permit (ITP) under Section 10(a) of the Act. An ITP would allow withdrawals to continue from the Edwards Aquifer that may be responsible for the take of listed species at Comal or San Marcos Springs until the jeopardy spring discharge levels are reached. In return, protective measures are devised to prevent lowering the Edwards to the level where jeopardy occurs for the species of concern, and extinction of the endangered species could result.

Development of a habitat conservation plan (HCP) is required for an ITP. The Edwards Aquifer HCP would have been a water conservation and supply plan for the sustainable development of the region, used to secure a twenty-year permit authorizing incidental takes by those entities and individuals who signed the application. Holders of the ITP would have been protected from an ESA enforcement action when Comal Springs drops below 200 cfs until the 150 cfs jeopardy level is reached. The difference between these flows, 50 cfs, would allow additional withdrawals of approximately 36,200 acre-feet annually in dry years. As noted earlier, if the population of the giant rams-horn snail were controlled the estimate of additional withdrawals allowed could rise another 65,000 acre-feet annually in dry years (Moore and Votteler 1995a, 108).

The Monitor recommended to Judge Bunton that a panel be convened to review and discuss the available water supply and conservation options that could preserve the endangered species and assure minimum flows downstream in the Guadalupe. The panel would be chaired by the Monitor and initially be composed of named professional staff members representing seven major water conservation or development organizations from the Edwards region; the GBRA, SAWS, SARA, EUWD, the Nueces River Authority (NRA), the Medina County Underground Water Conservation District (MCUWCD), and the Uvalde County Underground Water Conservation District (UCUWCD). Two additional panel members were representatives of the New Braunfels Utilities and the City of San Marcos, where Comal and San Marcos Springs respectively are located. The Judge responded with an Order creating the Incidental Take Permit Panel (Panel) [*Sierra Club, et. al. v. Bruce Babbitt, et. al.*, MO-91-CA-069, at 3-4 (W.D. Tex. Sep. 30, 1994) (Order Directing the Monitor to Create a Panel)].

A total of eleven Panel meetings were held over four months across the Edwards Aquifer region. Representatives from state and federal agencies, water purveyors, major water users, elected officials, academic institutions, and engineering firms gave presentations before the Panel. The accumulated information was evaluated and incorporated into the draft HCP wherever appropriate.

In June 1995, a 330-page draft of the HCP was released. The primary themes of the HCP were the conservation and reuse of existing water supplies, and the introduction of additional ground and surface water supplies to the region to reduce withdrawals from the aquifer (Moore and Votteler 1995a, 4). A sufficient number of alternatives, totaling 250,000 to 350,000 acre-feet annually, were proposed in the HCP to protect the endangered species and assure downstream minimum flows in the Guadalupe River during droughts. No new reservoirs were included.

Water for San Antonio Military Bases

While they do not use significant quantities of Edwards water as a percentage of annual withdrawals, military bases represent major contributors to Bexar County's economy. During the litigation, the Base Closure and Realignment Commission (BRAC) was considering the fate of the five military bases in San Antonio. These local bases had previously received adverse ratings by the BRAC for their sole reliance on the Edwards Aquifer. The Endangered Species Act "requires that each Federal agency shall consult with the USFWS to insure that any action authorized, funded, or carried out by such agency is not likely to jeopardize the continued existence of any threatened [or endangered] species or result in the adverse modification of habitat of such species" [16 U.S.C. § 1536(a)(2) (1988)]. The threat of formal consultation confronted four of the five San Antonio bases and could have influenced the decision to keep the bases open.

Early in April 1995, the Monitor met with the principals of five water purveyors to discuss a Letter of Intent to be executed by these parties to assure the transport of 15,000 acre-feet of Guadalupe River water to the military bases. An agreement was reached, and arrangements were made so that a public announcement and a signed document could be released simultaneously by the governing boards of the GBRA, SARA, Canyon Regional Water Authority, the Bexar Metropolitan Water District (Bexar Met), and SAWS on April 19, the day before a visit by BRAC representatives to San Antonio. A copy was delivered to the San Antonio military bases for use during the BRAC meeting on April 20. As a result, it was hoped the water supply for the bases would no longer be a factor in the BRAC's deliberations to consider closing the bases in San Antonio. However, Kelly Air Force Base was added, eventually, to the base closure list for other reasons.

The Recovery Plan for the Threatened and Endangered Species

The work of the Monitor was stayed by the U.S. Fifth Circuit Court of Appeals in October 1995. Sierra Club et al. v. Babbitt et al. was eventually ended on February 26, 1996, after the USFWS published the *San Marcos and Comal Springs and Associated Aquatic Ecosystems (Revised) Recovery Plan* (Recovery Plan) for the threatened and endangered species at Comal and San Marcos Springs. The Appellate Court concluded that all action required by Judge Bunton's 1993 amended judgment had been fulfilled. To satisfy the judgment in this case, the Recovery Plan or a notice of the availability of the plan, was to be published in the *Federal Register*. The legal counsel for the USFWS stated in a letter to the

Circuit Court that, "The FWS will publish a Federal Register Notice as to the availability of the plan shortly" (Shockey 1996, 1). In September 1999, a search of the *Federal Register* failed to locate any notice that the Recovery Plan had, in fact, been published.

The Recovery Plan acknowledges that the key issue to survival of the listed species is the conservation of the aquatic ecosystems at Comal and San Marcos Springs, as well as the aquifer itself (U.S. Fish and Wildlife Service 1996, 51). The Recovery Plan lists first among the actions needed to protect the listed species:

> 1. Assure sufficient water levels in the Edwards aquifer and flows in Comal and San Marcos Springs to maintain habitat for all life stages of the five listed species [three more species were added afterwards] and integrity of the ecosystem upon which they depend. (U.S. Fish and Wildlife Service 1996, Executive Summary)

One of the measures described in the recovery plan is the establishment of "refugium" for endangered species. Soon after the Recovery Plan was released in 1996 the National Biological Service attempted to close the San Marcos National Fish Hatchery and Technology Center which served as a primary refugium. The Sierra Club filed suit in the U.S. District Court to keep the hatchery open, and Judge Bunton ruled in their favor preventing the hatchery from being closed [*Sierra Club v. Bruce Babbitt and the National Biological Service*, MO-96-CA-19 (W.D. Tex. Apr. 4, 1997) (Order)].

Senate Bill 1477 is Constitutional

After the Voting Rights Act defects were corrected during the 1995 Legislative session, board members of the EAA, who were named in the amending statute, were scheduled to be sworn into office on August 28, 1995. On August 23, 1995, the Medina and Uvalde County Underground Water Conservation Districts (MCUWCD and UCUWCD), representing pumpers in the two counties west of San Antonio in which the majority of pumping for irrigation occurs, filed suit in the 38th State District Court in Hondo, Medina County, against the EAA board members (who had yet to be sworn in) [*Barshop, et al. v. Medina County Underground Water Conservation District, et al.*, No. 95-0881 at 5-6 (Tex. Jan. 19, 1996) (Brief of Appellees, Medina County Underground Water Conservation District)]. The brief for the appeal to the Texas Supreme Court filed by Medina County Underground Water Conservation District, et al. argued that:

> MCUWCD and UCUWCD exist to protect the aquifer and the rights of those who use the aquifer, and they take their job very seriously. Plaintiff-Appellees are not for waste or destruction of the resource. They are for protection of the resource and the property rights of those above it. [*Barshop, et al. v. Medina County Underground Water Conservation District, et al.*, No. 95-0881 at 3 (Tex. 1996) (Brief of Appellant, Medina County Underground Water Conservation District)]

The plaintiffs contended the Acts creating the EAA were unconstitutional, because the Legislature took vested property rights in water under their land. Therefore, Senate Bill 1477, as amended, was unconstitutional as a taking of private property without due process of law.

A temporary restraining order was granted by Hondo County Judge Mickey Pennington to prevent the EAA board members from taking office, and to extend the life of the EUWD. A trial was held beginning on October 11, 1995. In the Court's ruling, the defendant EAA board members were barred from implementing Senate Bill 1477; however, they were permitted to be sworn in and to organize for the purpose of defending the legislation. The Court eventually held that Senate Bill 1477 was unconstitutional, with the exception of the provision validating the creation of the Uvalde County Underground Water Conservation District, one of the plaintiffs.

Because a water supply emergency for the Edwards Aquifer appeared imminent in 1996 as the result of a drought, the Texas Attorney General's Office obtained an expedited appeal of the State District Court ruling to the Texas Supreme Court, bypassing the State Court of Appeals. The brief filed by Medina County Underground Water Conservation District and others argued that Senate Bill 1477 must be declared unconstitutional because no other water regulation entity quite like the EAA currently existed in Texas and that the regulation of groundwater was a violation of private property rights. The MCUWCD made reference to the state's common property resources argument (tragedy of the commons).

> . . . The question is whether the legislature's novel attempt to abrogate the rule of capture on both a prospective and retroactive basis is constitutional. . . . The purpose of the state's regulation under the Conservation Amendment is to protect the common owners and preserve, to the maximum extent possible, each of their individual ownership interests. . . . While reasonable regulation to protect correlative rights is certainly permissible and desirable, the courts have never allowed the legislature or the commission [Texas Railroad Commission] to absolutely cut off or unreasonably restrict landowners' right to capture a fair share of

> the oil, gas, minerals or water beneath their land, even under the Conservation Amendment. See, e.g., *Marrs v. Railroad Comm'n*, 177 S.W.2d 941, 947-949 (Tex. 1944). The legislation in issue here does precisely that, in several obvious ways.
>
> Appellants also seem to agree that the legislation is intended to deprive landowners' of their property and dedicate the water in the reservoir 'for the benefit of the public.' Statement p. 2. No clearer demonstration can be made that the legislation takes property without compensation. [*Barshop, et al. v. Medina County Underground Water Conservation District, et al.*, No. 95-0881 at 6 (Tex. 1996) (Brief of Appellant, Medina County Underground Water Conservation District)]

To counter, the state argued that the power to create entities to regulate groundwater is an established fact in Texas law. The state arguments prevailed, resulting in a unanimous decision by the Texas Supreme Court on June 28, 1996, that Senate Bill 1477 was indeed constitutional. The Texas Supreme Court added, "If an individual landowner's property is taken [by action of the EAA] and no compensation is provided, that landowner may then bring a challenge to the Act as it is applied or pursue other possible remedies" [*Barshop, et al. v. Medina County Underground Water Conservation District, et al.*, No. 95-0881, slip op. 20 (Tex. June 28, 1996)]. Thus, any individual pumper who feels inadequately compensated by the EAA can still sue under the takings and due process clauses of the U.S. and Texas Constitutions.

Sierra Club v. Glickman et al.

While the case against the USFWS was underway, a second case was initiated by the Sierra Club. On April 28, 1995, the Sierra Club filed a complaint in the U.S. District Court in Midland, Texas, this time against Secretary Dan Glickman and the U.S. Department of Agriculture (USDA). Aquifer withdrawals for agricultural irrigation averaged 127,000 acre-feet per year from 1982 to 1996 (Keplinger and others 1998, 6). In 1992, the Texas Water Commission (TWC) estimated that conservation efforts in the Edwards Aquifer area could reduce withdrawals for irrigated agriculture by 40,000 to 52,000 acre-feet per year (Texas Water Commission 1992, 8). Three-counts were alleged. First, the Sierra Club charged that the Agricultural and Water Policy Coordination Act provisions establishing the USDA Council on Environmental Quality and the Bankhead-Jones Farm Tenant Act, required the USDA to prevent adverse environmental impacts rising from agricultural activities, and that these had been violated [*Sierra Club v. Glickman et al.*, No. MO-95-CA-091, at 12 – 13 (W.D. Tex. Apr. 28, 1995)]. Count II alleged the USDA violated both ESA § 7(a)(1) and § 7(a)(2) by failing to consult with the USFWS and by failing to develop programs to conserve the listed species at Comal and San Marcos Springs [*Sierra Club v. Glickman et al.*, No. MO-95-CA-091, at 13 – 14 (W.D. Tex. Apr. 28, 1995)]. Count III alleged that the USDA violated ESA § 7(a)([illegible]) by subsidizing irrigation dependent on Edwards Aquifer water without formally consulting with the USFWS or insuring that its actions would not cause jeopardy to the listed species [*Sierra Club v. Glickman et al.*, No. MO-95-CA-091, at 15 – 20 (W.D. Tex. Apr. 28, 1995)]. On July 2, 1996, Judge Bunton ruled in favor of the Sierra Club and on September 19, 1996, entered a judgment finding that USDA had failed to consult with USFWS [*Sierra Club v. Glickman et al.*, No. MO-95-CA-091, at 1 (W.D. Tex. Sep. 19, 1996) (Judgment)]. The USDA was ordered to, among other things, develop and implement programs to protect water quality, to preserve natural resources, and to protect fish and wildlife through land conservation and use [*Sierra Club v. Glickman et al.*, No. MO-95-CA-091, at 2 (W.D. Tex. Sep. 19, 1996) (Judgment)].

The judgment was appealed and a stay of Judge Bunton's order was granted by the U.S. Fifth Circuit Court of Appeals on October 23, 1996 [*Sierra Club v. Glickman et al.*, No. 96-50677, No. 96-50778, at 5 (5th Cir., Sep. 24, 1998)]. On September 24, 1998, a three-judge panel of the U.S. Fifth Circuit Court of Appeals ruled on the appeal. Among the appellate court's findings was that the ESA requires federal agencies not only to avoid actions that jeopardize listed species, but also that federal agencies are required to consult with the USFWS and develop programs to conserve endangered species consistent with the agency's real authority over species-related issues [*Sierra Club v. Glickman et al.*, No. 96-50677, No. 96-50778, slip op. at 10 (5th Cir., Sep. 24, 1998)].

Sierra Club v. San Antonio et al.

In the latter half of 1995 and into 1996 much of Texas and the Edwards Aquifer region suffered the effects of a severe drought. Flow from both Comal and San Marcos Springs reached the jeopardy levels in May 1996. In June 1996, the Texas Supreme Court ruled that the statute creating the EAA (Senate Bill 1477) was constitutional [*Barshop, et al. v. Medina County Underground Water Conservation District, et al.*, No. 95-0881, slip op. (Tex. June 28, 1996)]. In June, the director of the USFWS office in Austin, Texas, stated before the San Antonio City Council that the USFWS would take no action against pumpers to reduce withdrawals from the aquifer (Needham 1996, 1C). Later in June, the Sierra Club filed a class action suit under § 9 of the ESA in Judge Bunton's Court alleging that pumpers from the aquifer were causing takes of endangered species [*Sierra Club* *v. San Antonio et al.* No. MO-96-CA-097, (W.D. Tex. 1996)]. The Sierra Club sought to include everyone withdrawing from the aquifer, as many as one thousand individuals, organizations and corporations, into representative defendant classes to manage the litigation. By July, flows at both springs were well below the jeopardy levels, and the possibility of total cessation of flows at Comal Springs loomed. The reduced flow from both the Comal (85 cfs) and San Marcos Springs (79 cfs) comprised almost all of the remaining flow in the Guadalupe River at Victoria, Texas near the coast (Guadalupe - Blanco River Authority 1996, Exhibit 2).

On July 31, 1996, the EAA declined to declare an emergency to reduce withdrawals from the aquifer to maintain spring discharge to protect endangered species habitat and downstream water rights in the Guadalupe River basin. The Authority began to perform its duties, following a delay of three years due to voting rights issues and litigation in state court, in the midst of a severe drought. Some of the statutorily named board members were facing their first election in November 1996, which influenced their decisions (Buckner 1999).

Consequently, the Court appointed the author as Special Master on August 1, 1996, under Rule 706 [*Sierra Club v. San Antonio, et al.*, No. MO-96-CA-097, slip op. at 1 (W.D. Tex. Aug. 16, 1996)]. Judge Bunton ordered the Special Master to produce a draft plan to reduce withdrawals from the aquifer within 10 days. With neither the federal nor state government agencies willing or able to reduce withdrawals from the aquifer, Judge Bunton issued an order on August 23, 1996, drafted by me, setting a deadline of October 1, 1996 for the implementation of the *1996 Emergency Withdrawal Reduction Plan for the Edwards*

Aquifer (1996 EWRP) (Appendix 3. Regional Drought Management Plans Developed for the Edwards Aquifer). The 1996 EWRP concluded that:

> The Edwards Aquifer can no longer adequately provide for the needs of all those who depend upon it in years of high withdrawals and low recharge to the Aquifer. As a consequence some uses of Edwards Aquifer water must be given priority over other uses. Using Aquifer water for lawns and landscaping is of lower priority than the use of water for human consumption, health, and safety.
>
> The longer the region delays conservation and reuse of Edwards Aquifer water and the development of water supplies to supplement its dependence on the Edwards Aquifer, the scarcer supplemental supplies will become and the higher their cost will be. (Votteler 1996, at 1)

The plan was designed to allow individual municipalities as much flexibility as possible to achieve the required reductions mandated by the Court. While unpopular in San Antonio, the 1996 EWRP received letters or resolutions of support from entities in the Guadalupe River basin, including the Guadalupe–Blanco River Authority, the City of Seguin, the Board of Trustees of the New Braunfels Utilities, the Luling Area Chamber of Commerce, and the Comal and Hays County Board Members of the EAA.

On the day the 1996 EWRP was adopted by the Court, rain began to fall, providing temporary relief from the drought. In September, Judge Bunton's August 23rd Order was stayed by the U.S. Fifth Circuit Court of Appeals. A hearing was held on December 4, 1996, while flow from Comal and San Marcos Springs remained below take levels. On April 30, 1997, after the crisis had passed, the Fifth Circuit annulled Judge Bunton's August 23, 1996, order, finding that the Court should have abstained from acting until the EAA had an opportunity to resolve the matter. A three judge panel of the Fifth Circuit, in a 2-1 vote, ruled:

> Because we hold that the Sierra Club did not establish a substantial likelihood of success on the merits, in light of the abstention doctrine enunciated in *Burford v. Sun Oil Co.* (319 U.S. 315 (1943), we vacate the injunction. . . . [W]e state no bar against the Sierra Club, either in pursuing the merits or in ultimate efforts to protect the water and darters if the State of Texas fails to do so. [*San Antonio*, 112 F.2d 789, 791 – 92, 797 (5th Cir. 1997), cert. denied, 118 S.ct. 879 (1998), (2-1 decision)]

The Sierra Club appealed the decision to the U.S. Supreme Court, which declined to intervene. Fortunately, in 1997 heavy spring rains temporarily quenched the region's thirst, providing the region with a reprieve.

The next cycle of drought began in 1998. This time the USFWS warned pumpers that the agency was prepared to file civil lawsuits or bring criminal charges against pumpers to protect species in danger of dying from diminished spring discharge (Needham 1998h, 1A). In response to the drought, the EAA implemented its first *Critical Period Management Plan*, which restricted certain uses of water (Appendix 3. Regional Drought Management Plans Developed for the Edwards Aquifer). The EAA also turned to less traditional means to combat the drought, seeking a permit from the state for a $500,000 cloud seeding program to increase precipitation in selected areas (Needham 1998b, 1B).

Flow at Comal Springs fell below the take level, but the USFWS did not file suit or bring enforcement actions against pumpers or the EAA. Fortunately, rainfall in August from tropical storms Charlie and Francis recharged the aquifer and diminished the rates of withdrawals, raising spring discharge at Comal Springs significantly above the take level. Prior to this rainfall, the mean flow at Comal Springs was below the take level of 200 cfs for a total of 38 days. As in 1996, once again a crisis at the springs was averted by an unusually wet August, with rainfall over the recharge zone far in excess of normal for what is typically one of the driest and hottest months.

Preparation for New Litigation

On August 14, 1998, the Sierra Club notified the EAA and USFWS of its intent to sue over violations of the ESA resulting from the "failure" of those entities to limit withdrawals from the aquifer as required by Senate Bill 1477 and to enforce the Recovery Plan (Notice of Violations of the Federal Endangered Species Act and Notice of Intent to Sue, Sierra Club, Aug. 14, 1998). The EAA and USFWS are not defendants in *Sierra Club v. San Antonio, et al.*, but could be added to the litigation or be the subject of a new suit.

As a response to the threat of renewed ESA litigation, State Representative John Shields, whose district includes portions of San Antonio, filed suit against the Secretary of the Department of the Interior, Bruce Babbitt, the director of the USFWS, Jamie Rappaport Clark, and the Sierra Club [*Shields v. Babbitt et al.*, No. SA-98-CA-0774 at 1 (W.D. Tex. Aug. 28, 1998)]. Among other charges, Representative Shields alleged that the ESA has taken the private property of pumpers from the aquifer, and that the ESA does not apply to the species listed at Comal and San Marcos Springs because they are "wholly intrastate species" residing completely within the boundaries of Texas and that no issue involving the interstate commerce clause of the U.S. Constitution was present [*Shields v. Babbitt et al.*, No. SA-98-CA-0774 at 6 (W.D. Tex. Aug. 28, 1998)]. In 1999, Shields was dismissed from the case, which he is appealing, and the case has been transferred to Judge Bunton's court. It is still pending.

On September 14, 1998, the Environmental Defense Fund issued a notice of its intent to sue the EAA over violations of the ESA as a result of the EAA allowing withdrawals from the aquifer "in quantities great enough so as to reduce spring flows at Comal and San Marcos Springs to the point that listed species are harmed and harassed" (Notice of Violations of the Federal Endangered Species Act and Notice of Intent to Sue, Environmental Defense Fund, Sep. 14, 1998). No subsequent action had been taken as of February 2000.

Why Attempts to Negotiate a Regional Solution Failed

The controversy over the aquifer has been called an intractable environmental dispute in which the key parties have considered their best alternative to a negotiated agreement to be additional litigation (Putnam and others 1998, 3). Indeed, there have been four decades of litigation over interrelated issues in state and federal courts. Water users in the Edwards Aquifer region and the Guadalupe River basin have disagreed over the apportionment of water from the Edwards Aquifer since the drought of record in the 1950's. As the demand for water increased, the disagreement moved into the courts. For the Edwards Aquifer region, the competition for surface and groundwater resources has resulted in decades of disagreement, negotiation, mediation attempts, and litigation. The conflict has been primarily between those dependent upon Guadalupe River surface water and those who pump groundwater from the Edwards.

There have been several attempts to find a compromise among the major regional interests. Throughout at least the 1970s and 1980s, attempts to negotiate voluntary management plans to restrict withdrawals were unsuccessful, even though demand was projected to exceed average recharge around the end of the century (McCarl and others 1993, executive summary). Attempts to manage the Edwards Aquifer or develop a plan for conjunctive use of surface and groundwater had thus far been unsuccessful. These efforts included a legislative effort in 1989, a mediator sponsored by the Texas Water Development Board in 1991, the chairman of the Texas Water Commission in 1992, the Mayor of Austin in 1992, an effort by the U.S. District Court in 1994 and 1995, and, more recently, the USFWS in 1996.

There is a range of opinions by those involved as to why a regional solution that could have avoided litigation was not achieved. Outside San Antonio, the local politics of the city and the reluctance of farming and ranching interests to accept limits have been cited:

> A regional solution was not achieved because of two reasons, politics and sacrifices. San Antonio did not recognize the problem, and was not concerned about the endangered species. Edwards water is cheap and new sources would be expensive. There was also distrust between the farmers and San Antonio. The situation is similar today, although slightly improved. Some farmers believed they would get rich by selling their water to San Antonio. (Lewis 1999)

Others cite the tragedy of the commons, and the triumph of short-term economic interests (Nevola 1999). Politicians today are generally against raising money for water development (Nevola 1999).

> A question exits of whether the long-term economic incentives outweigh the short-term political incentives of waging a political battle to authorize and fund the development of reservoirs and other water supply alternatives. The length of local political terms is short, yet it takes decades to construct and fill a reservoir after a decision is made. For example, in San Antonio, Mayors are limited to two terms of two years each. Also, pumping interests did not believe they could lose the pending ESA litigation. (Specht 1999)

Within San Antonio, there is the opinion that a resolution was not achieved because of strong regional feelings about the access to water (Peak 1999). However, there is also an opinion that confrontations over water inevitably generate lawsuits, and the litigation causes people to think about water issues; thereby promoting activities that can eventually resolve the conflicts (Thuss 1999). San Antonio has also been influenced by strong opposition to the use of surface water. The anti-surface water groups organized twice to defeat the construction of Applewhite Reservoir. San Antonio Mayor Howard Peak has stated that the efforts of these groups have had the following effects on achieving a regional solution:

- Negative – They delayed action on developing alternatives, increased costs of future alternatives, and limited the city's options. They succeeded by capitalizing on the public's natural fears and suspicions about government; and
- Positive – They taught San Antonio city leaders to be open about water development and to include the public in planning. (Peak 1999)

The Edwards Aquifer Authority

The Authority is committed to manage and protect the Edwards Aquifer system and work with others to ensure the entire region of a sustainable, adequate, high quality and cost-effective supply of water, now and in the future.

Edwards Aquifer Authority Mission Statement, 1999

The Edwards Aquifer Authority's Initial Attempt to Allocate Groundwater

Senate Bill 1477 ended unrestricted pumping under the rule of capture for the aquifer, and included all pumpers over the confined zone of the aquifer, with the exception of portions of Kinney County, under one management agency. It limits access to aquifer water to historical users. Pumpers are able to lease or sell quantities of permitted groundwater subject to limitations. Key legislators have expressed the view that, "The EAA was never intended to be a centralized bureaucracy dictating the allocation among water rights holders within the aquifer, nor was it intended to act as a Rio Grande-style watermaster. An underlying premise of the Act is to allow voluntary exchanges of available water among the various water users without EAA interference in order to provide low cost water for users while protecting property rights" (Counts 1997, 2). Others have indicated that the role of the EAA is essentially that of a watermaster (Knowles and Mullican 1999).

Senate Bill 1477 establishes an Edwards Aquifer Authority board of directors of seventeen members. Fifteen of the members are elected and represent fifteen districts within Bexar, Medina, Uvalde Counties and portions of Atascosa, Caldwell, Comal, Guadalupe, and Hays Counties. The EAA directors are elected for four-year terms, with district elections staggered so that about half of the terms expire every two years. In addition to the fifteen elected board members, there are also two non-voting appointed directors; one to represent the interests of Medina and Uvalde Counties and one to represent the interests of downstream water users. The Medina and Uvalde County director is appointed to serve a four-year term by the Commissioner's Court of either Medina or Uvalde County on an alternating basis. The South Central Texas Water Advisory Committee (SCTWAC), which was established by the Act to advise the board of directors of downstream water rights and other issues, is responsible for appointing the second non-voting director who serves a four-year term.

There are four major interest blocks represented on the EAA board. The legislature originally created the EAA with an appointed board, but changed Senate Bill 1477 as the result of the Voting Rights Act litigation. The irrigators in Medina and Uvalde Counties fear that San Antonio will take away their water without adequate compensation. They have opposed restrictions and have maintained that they are isolated geologically from the rest of the aquifer by the geologic fault, the "Knippa Gap." The Bexar County delegation is divided between those who do not want San Antonio's use of Edwards water restricted and do not want the city to invest in costly supplemental surface water supplies, and those who recognize the time has come to restrict water use and invest in conservation and development of some new water sources. Those east of San Antonio in Comal and Hays Counties, and those in the Guadalupe River basin, want withdrawals from the aquifer limited to ensure adequate flow from the springs, and have generally opposed those in Bexar, Medina, and Uvalde Counties who would prefer unrestricted pumping. EAA board members have been elected to enforce a statute that requires those primarily representing San Antonio and the west, to limit their constituent's access to the resource (water) for the preservation of springs to the east and of surface water downstream in the Guadalupe River. Constituents in Bexar, Medina, and Uvalde Counties could elect a majority of individuals opposed to the provisions and goals of the statute they are bound to enforce. Thus, the goals of the statute could be frustrated by the Board intended to implement it.

Statutory provisions of Senate Bill 1477 governing the allocation of groundwater pumping permits are contained in Appendix 2. Senate Bill 1477 Provisions on Initial Groundwater Allocation (Act of May 30, 1993, 73rd Leg. R.S. ch. 626, 1993, Tex. Gen. Laws 2355, Sec. 1.16). Wells from which water is used exclusively for domestic use or watering livestock are exempt from metering and permit requirements if no more than 25,000 gallons per day is pumped, but the owner must report annual quantities pumped [Act of May 30, 1993, 73rd Leg. R.S. ch. 626, 1993, Tex. Gen. Laws 2355, Sec. 1.33(a)(b)]. An initial regular permit may be issued to every other pumper equal to the user's maximum beneficial use of water without waste during one calendar year beginning June 1, 1972 through May 31, 1993; special provisions govern pumpers who have pumped for shorter periods [Act of May 30, 1993, 73rd Leg. R.S. ch. 626, 1993, Tex. Gen. Laws 2355, Sec. 1.16(a)]. If the total amount of such permits exceeds the amount available for permitting, the authority shall adjust the amount of water authorized for withdrawal proportionately to meet the amount available [Act of May 30, 1993, 73rd Leg. R.S. ch. 626, 1993, Tex. Gen. Laws 2355, Sec. 1.16(e)]. An existing irrigation user shall receive a permit for not less than two acre-feet a year for each acre of land the user actually irrigated in any one calendar year from June 1, 1972 through May 31, 1993.

For the Edwards, those interests in the best position to capture the common resource do so, while the demands of less advantageously positioned interests go unsatisfied (Keplinger and McCarl 1996, 64). This results in a misallocation of water and a market failure, since those who are in the best position to capture the resource are not those applying the resource to the highest valued use (Keplinger and McCarl 1996, 64). Agricultural irrigators are geographically and politically well positioned to capture water because they are numerous and were not effectively regulated under the rule of capture (Keplinger and McCarl 1996, 64). Those eastern interests at the springs, and downstream of the springs, are at the greatest disadvantage to capture the resource since spring discharge is a residual of recharge and storage minus withdrawals, and can only be protected by limiting withdrawals or increasing recharge, activities over which eastern interests had little control until the ESA litigation (Keplinger and McCarl 1996, 64).

On April 29, 1998, the EAA notified permit applicants how much water it intended to approve in permits for withdrawals from the aquifer (Needham 1998j, 6A). The total proposed amount was 484,600 acre-feet for 694 applicants from a total of 1,004 applicants requesting 852,800 acre-feet (Needham 1998j, 6A). The proposed total withdrawals exceeded the 450,000 acre-feet cap in Senate Bill 1477, by some 34,600 acre-feet, which does not include the amount being pumped for domestic and livestock wells, possibly as much as 30,000-50,000 acre-feet. The water use statistics for the 1972 - 1993 historical period are found in Table 16. A comparison of the proposed amounts for irrigation, municipal,

Table 16. Calculated Edwards Aquifer Water Use in 1,000 acre-feet per year, 1972-1993.

WATER USE	1972	1973	1974	1975	1976
Municipal	190.5	177.1	174.6	182.5	182.1
Agriculture (Irrigation)	128.8	82.2	140.5	96.4	118.2
Industrial Use	21.1	18.8	15.1	15.3	14.7
Domestic Supply, Stock, and Miscellaneous	30.8	32.3	33.5	33.6	34.6
Subtotal of Water Uses	371.2	310.4	363.7	327.8	349.6

WATER USE	1977	1978	1979	1980	1981	1982	1983
Municipal	205.3	214.2	208.9	256.2	231.8	268.6	249.2
Agriculture (Irrigation)	124.2	165.8	126.8	177.9	101.8	130.0	115.9
Industrial Use	13.0	11.5	15.2	13.7	12.6	15.0	14.7
Domestic Supply, Stock, and Miscellaneous	38.1	40.3	40.7	43.3	40.9	39.5	38.8
Subtotal of Water Uses	380.6	431.8	391.6	491.1	387.1	453.1	418.6

Source: (Moore 1994) and (U.S. Geological Survey and Edwards Underground Water District 1994).

Table 16 (continued). Calculated Edwards Aquifer Water Use in 1,000 acre-feet per year, 1972-1993.

WATER USE	1984	1985	1986	1987	1988	1989	1990
Municipal	287.2	263.7	266.3	260.9	286.2	285.2	254.9
Agriculture (Irrigation)	191.2	203.1	104.2	40.9	193.1	196.2	172.9
Industrial Use	15.2	16.5	16.8	18.7	18.8	22.9	23.7
Domestic Supply, Stock, and Miscellaneous	36.2	39.2	42.0	43.5	41.9	38.2	37.9
Subtotal of Water Uses	529.8	522.5	429.3	364.0	540.0	542.5	489.4

WATER USE	1991	1992	1993
Municipal	240.5	236.5	252.0
Agriculture (Irrigation)	88.5	27.1	69.3
Industrial Use	67.5	29.0	36.1
Domestic Supply, Stock, and Miscellaneous	39.5	34.8	49.9
Subtotal of Water Uses	436.0	327.4	407.3

Source: (Moore 1994) and (U.S. Geological Survey and Edwards Underground Water District 1994).

and industrial uses, with the average amount that has been pumped during the historical period specified in Senate Bill 1477 is presented in Table 17.

As shown in Table 17, proposed initial permits were heavily skewed in favor of agricultural irrigation when compared to historical use. The proposed total available for irrigation on an annual basis was 237,200 acre-feet, which is greater than the maximum 203,100 acre-feet pumped for irrigation in 1985 (U.S. Geological Survey and Edwards Underground Water District 1994). In 1996 and 1997, Edwards Aquifer withdrawals reported for irrigation for Bexar, Comal, Hays, Medina, and Uvalde Counties, totaled 169,418 acre-feet and 116,841 acre-feet respectively (Texas Water Development Board 1999a). In 1996, the region experienced a significant drought during the prime irrigation season, and in 1997 the region experienced above average rainfall during the irrigation season. Pumping for irrigation averaged 127,000 from 1982 to 1996 (Keplinger and others 1998, 6).

The proposed total allocation for municipal use on an annual basis was 219,000 acre-feet, which is less than the maximum 287,200 acre-feet pumped for municipal use in 1984 (U.S. Geological Survey and Edwards Underground Water District 1994). Proposed municipal permits were slightly less than what was used on average during the historical period. However, proposed industrial permits were less than half of the record year, 1991, which includes the pumping for the catfish farm.

These initial permits were voided in December 1998 when the Travis County District Court invalidated the EAA's permit rules. The new permit rules are likely to be substantially the same as the rules that were invalidated by the Travis County District Court (Beldon 1999a).

Table 17. Comparison of Proposed Annual Allocation of Edwards Aquifer Pumping with Reported Pumping from 1972 to 1993

	Annual Amount Proposed by EAA in 1998, in Acre-feet and Percentages	Average Annual Amount Withdrawn from 1972 – 1993, in Acre-feet and Percentages	Maximum Annual Amount, with Year, Withdrawn from 1972 – 1993, in Acre-feet and Percentages
Irrigation	237,200 (49%)	121,500 (33%)	203,100 (36%), 1985
Municipal	219,000 (45%)	225,000 (62%)	287,200 (52%), 1984
Industrial	28,400 (6%)	19,400 (5%)	67,500 (12%), 1991*
Total	484,600 (100%)	365,900 (100%)	557,800 (100%)

*Includes pumping by Living Waters Artesian Springs catfish farm in 1991.

Sources: (Beldon 1998b, Figure 11) and (U.S. Geological Survey and Edwards Underground Water District 1994).

The following are a range of opinions regarding how Senate Bill 1477 allocates water among competing uses:

> Irrigators come out of Senate Bill 1477 in terrific shape. The irrigators should build a statue of Billy Clayton [the irrigator's lobbyist and former Speaker of the Texas House] out in Uvalde (Beldon 1999a).
>
> [Is Senate Bill 1477 a good deal for irrigators?] Yes, a very good deal. They hit a home run, a grand slam (Ellis 1999).
>
> Municipalities generally were hurt; they will get their average use. Industries were hurt the most because their wells were unmetered. They only have numbers for 1988 to 1993 of the 1972 to 1993 period. They had zero for 1972 to 1987. If the farmers received 1.5 acre-feet per acre, most of the municipalities and industries could have gotten what they needed. This is the price of regulation (Ellis 1999).
>
> Senate Bill 1477 is a good deal for irrigators, all in all. The irrigators are likely to be permitted about twice what they are currently using. Most irrigators are satisfied with the 2 acre-feet per acre minimum. Some thought that they should receive more. A new set of permit rules could change the averaging formula used to determine permit amounts. Some irrigators supported Senate Bill 1477 because of the security it would provide against encroachment on their pumping, but none did so publicly (Buckner 1999).
>
> Municipal growth is the problem. Industrial users were not all metered, and that was a problem. With the new rules, all are likely to get more across the board, agriculture, municipal, and industrial (Buckner 1999).

Senate Bill 1477 also favors agricultural water use over other water uses through the annual fees charged to pumpers. Section 1.29(e) of Senate Bill 1477 provides that agricultural fees will not exceed 20% of the rate for municipal users [Act of May 30, 1993, 73rd Leg. R.S. ch. 626, 1993, Tex. Gen. Laws 2355, sec. 1.29(e)]. The EAA chose a 19.5% rate for agricultural users in 1999. The 1999 aquifer management fee for municipal and industrial water users was $18.50 per acre-foot, and for agricultural water users it was $3.60 per acre-foot (Edwards Aquifer Authority Board of Directors 1998, 2).

EAA Board Chairman Mike Beldon has stated that an annual pumping limit of 450,000 acre-feet is too low, and that 650,000 acre-feet is probably closer to what the aquifer can support (with the optimization program discussed in Chapter 10), but that this amount could not be pumped in every year (Beldon 1999a). When the permitting process continues, the total permits of 484,000 acre-feet proposed in 1998 are likely to increase to 525,000 acre-feet eventually (Beldon 1999a) and (Ellis 1999). The EAA could issue permits with a high number, a middle number that would be similar to a junior surface water right that could be pumped in high recharge years, and a low number that would be the equivalent to a senior surface water right (Ellis 1999). These various levels within the permit would all be subject to reductions under the CPMP.

If the EAA issues permits totaling 525,000 acre-feet, a total clearly in excess of the 450,000 acre-feet limit in Senate Bill 1477, it would need to offset the difference by reducing pumping 75,000 acre-feet. Some irrigators and environmentalists are in agreement on how the reduction can be accomplished (Buckner 1999). The Conservation Reservoir Enhancement Program (CREP), a program administered by the U.S. Department of Agriculture, may have money available to pay the costs of reducing water withdrawal to 450,000 acre-feet. This program was brought to the EAA's attention by Melinda Taylor, attorney for the Environmental Defense Fund (Buckner 1999). The goal would be to retire 30,000 acres of irrigated agricultural land and the water rights that go with them (60,000 acre-feet using the 2 acre-feet minimum per acre of land). Under CREP, the USDA would fund 80% of the costs of temporarily taking out of production agricultural land that is environmentally sensitive, while the EAA would issue bonds to finance the remainder (Needham 1999c, 1). An alternative to limiting pumping to 450,000 acre-feet would be to buy and retire the excess 75,000 acre-feet in rights which could cost $50 – $100 million (Ellis 1999). Simply using a multiplier to reduce proportionally the permitted amounts would initiate a political fight (Ellis 1999). Using the CREP to buy down the total to 450,000 acre-feet could avoid a political fight. Under CREP, the land could not be farmed or ranched; however, it could be used for hunting to provide an additional revenue source. The program would retire the land for 15 years, but some of the water rights might possibly be retired permanently (Needham 1999c, 1). However, consensus has not been reached on the efficacy of this program. There are concerns among irrigators that it would result in serious adverse economic impacts to the communities in Medina County, where most of the program would be focused.

Leasing or Selling Agricultural Irrigation Water Rights

Article 1, Section 1.34(c) of Senate Bill 1477 limits the lease of agricultural water rights to 50% of the permitted right:

ARTICLE 1, SECTION 1.34
TRANSFER OF RIGHTS

(a) Water withdrawn from the aquifer must be used within the boundaries of the authority.

(b) The authority by rule may establish a procedure by which a person who installs water conservation equipment may sell the water conserved.

(c) 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. (Act of May 30, 1993 73rd Leg., R.S., ch. 626, 1993 Tex. Gen. Laws 2355, *as amended by* Act of May 29, 1995, 74th Le., R.S., ch. 261, 1995 Tex. Gen. Laws, §1.34.)

The 50% limitation on leasing was sought by some of the irrigators during the crafting of Senate Bill 1477, even though it would seem to be a violation of the unfettered exercise of individual property rights. Using the April 1998 proposed permit total, the agricultural water leasing limitation would equal 50% of 237,200 acre-feet, or 118,600 acre-feet, if the EAA rules were applied. Leasing large amounts of water permitted for irrigation could result in little reduction in actual irrigation, given the 50% limitation on leasing, the recent average amount for irrigation, and an immediate surplus of permitted irrigation water. If the 50% limitation on leasing were lifted, the incentive to conserve the remaining 118,600 acre-feet through the use of more efficient irrigation technology would increase, but it also might eventually result in the virtual elimination of irrigation from the Edwards as the demand for municipal and industrial water rises. An alternative might be to reduce the 50% limitation in stages over 25 years to 25%. As cumulative irrigation efficiencies rise, some level of reduction might allow the agricultural sector to prosper, while reducing the need for additional sources of water outside of the region. This provision could actually encourage urbanization as investors purchase agricultural land for conversion to urban use and immediately take advantage of the removal of the 50% limit.

> The 50% limitation will probably be challenged in court and found unconstitutional. Currently, if the land use changes from agricultural to something else, the 50% limitation no longer applies (Buckner 1999).

Restricting the amount of water withdrawn from the Edwards, has increased the need to reallocate the uses of water withdrawn from the aquifer to meet future growth. The water use most likely to be reallocated is a portion of the amount annually withdrawn for agricultural irrigation. Water used for irrigation generally can be sold for a high price to be used for municipal or industrial use. The process of shifting from an agriculturally based economy to an economy based on supplying water, has already begun as some irrigators are maneuvering to supply San Antonio residents and businesses. For example, U.S. Filter, a water services company, has purchased land and water rights in the Edwards Aquifer (Casey 1997, 2A). Irrigators have been responding to the potential profits to be had from selling water to San Antonio and other municipal, industrial, and commercial users (Haurwitz 1997a, A15). An acre of farmland with a 2 acre-foot water right is worth about $2,000; however, without the water right (dry land farming) the land is worth $500 per acre (Ellis 1999). Despite the fact that final permits have not been issued, water is already being leased and sold. SAWS was by far the largest potential customer buying or leasing water rights. It has found a healthy interest among farmers to lease or sell their rights. The San Antonio Water System estimates that the value of the Edwards groundwater leased for irrigation is $50 per acre-foot (Thuss 1999). In 1999, SAWS leased Edwards Aquifer water for $75 an acre-foot and bought permanent water rights for $700 an acre-foot (Thuss 1999). At this price, SAWS is currently leasing water for 3 to 5 years in Medina and Uvalde Counties (Needham 1999b, 7B). The large amount of water likely to be finally permitted to irrigators under the 2 acre-foot minimum in Senate Bill 1477 will provide a large supply for lease and could keep the cost of leasing water from irrigators low until the next prolonged drought.

With permits that can be traded, leased, and sold, two strategies may develop:

- Long-term sales and leases, a low risk strategy: A modest price per acre foot is agreed upon for a extended period of time, and is not subject to fluctuations from annual variations in recharge and pumping; and

- Short-term sales and leases, a high risk strategy: The price per acre foot is subject to annual pumping and recharge conditions and takes advantage of price increases during times of stress. In wet years, the price is low, but water could be purchased at discounted prices on a short-term basis by those who want to store it for droughts. In dry years, prices are high, with the price rising as the length and intensity of the drought increases.

Once the EAA issues regular final permits, there is a possibility that additional regular permits could be issued under §1.18 if additional water is made available through the EAA's optimization projects. Those issued the original regular permits will generally have an incentive to oppose attempts to issue additional permits because the additional permits will allow more pumping, decreasing the value of the original permits.

The EAA's Permit Rules are Void

Thus far, the EAA has been unable to fulfill all the statutory requirements found in Senate Bill 1477, primarily as a result of suits filed against it in State District Courts (already reviewed). "The EAA's progress over the first 3 years has been 'bumpy'. Administratively, the EAA has done everything it could do" (Ellis 1999).

On August 5, 1998, a State District Court in Travis County issued a temporary injunction, enjoining the EAA from implementing or enforcing its rules that relate to the filing and processing of permit applications in a suit filed by the catfish farmer [*Living Waters Artesian Springs, LTD. v. Edwards Aquifer Authority*, No. 98-02644, at 1 (Dist. Ct. of Travis County, 353st Judicial District of Texas, Tex. Aug. 5, 1998) (Order Granting Temporary Injunction)]. The injunction resulted from concerns that rules adopted by the EAA would treat some users of Edwards water arbitrarily when allocating withdrawal rights. Living Waters (the catfish farm) applied for 47,043 acre-feet annually and received a proposed permit for 6,934 acre-feet (Needham 1998i, 3B). The EAA was to begin enforcing the withdrawal cap on January 1, 2000 (Needham 1998j, 6A). By the time the injunction was in place, the EAA was still tallying the hundreds of challenges to the proposed permits it had received from pumpers (Needham 1998d, 5B). On December 1, 1998 Travis County District Court Judge Joseph Hart found that the rules of the EAA which limit withdrawals, as well as the EAA's *Critical Period Management Plan* rules, were invalid because their adoption did not adhere to the Administrative Procedures Act (Needham 1999a, 8A). As the only local government subject to the Administrative Procedures Act

(APA), about 33% of the EAA's budget now goes to review rules to make them comply with the APA (Ellis 1999).

A second ruling in *Glenn and JoLynn Bragg v. Edwards Aquifer Authority and Gregg Ellis*, No. 98-07-14535CV (Tex. Sep. 11, 1998), this time by 38th State District Court Judge Mickey Pennington, in Hondo, enjoined the EAA from enforcing its rules and found that the EAA violated the Texas Private Real Property Rights Preservation Act by failing to conduct a takings – impact assessment of its proposed rules as required by the Act (Needham 1998a, 3B). Because the EAA believes it is exempt from this Act, it has appealed the ruling in the Bragg case to the 4th Texas Court of Appeals. Oral arguments were held on September 21, 1999, and the Courts of Appeals in San Antonio overturned Judge Pennington's ruling and sided with the EAA *Edwards Aquifer Authority and Gregg Ellis, Appellants, v. Glenn and JoLynn Bragg, Appellees,* No. 2000 WL 35582 (Tex.App.-San Antonio, Jan. 19, 2000).

The EAA, as the result of these rulings, is faced with the costs of takings impact assessments and small business impact assessments. The EAA hired a consulting firm on May 11, 1999 to conduct an in-depth assessment of whether the draft of the agency's new rules to replace those invalidated by Judges Hart and Pennington, are in compliance with the APA and the Texas Private Real Property Rights Preservation Act (The Devine News 1999, 20). The consulting firm is scheduled to finish the assessments by October 2000.

Prior to the rulings in *Living Waters Artesian Springs, LTD. v. Edwards Aquifer Authority* and *Glenn and JoLynn Bragg v. Edwards Aquifer Authority and Gregg Ellis*, key legislators had expressed concerns with regard to the EAA's interpretation and implementation of its rules for allocating groundwater.

Chairman David Counts of the Texas House Natural Resources Committee criticized the EAA for not implementing Senate Bill 1477 as intended:

> I feel it is necessary and appropriate for me to express my concern about recent actions and statements by the EAA that appear to be contrary to your enabling statute. There are growing concerns that EAA's approach may be to see how far it can "bend" the statute rather than carry out the intent of the Legislature as written. This course of action is particularly troubling at a time when you are seeking additional emergency funding for your operations. (Counts 1997, 1)

Chairman Counts cited the concerns that the EAA had not limited withdrawals to 450,000 acre-feet, while providing a minimum of 2 acre-feet for each agricultural irrigator; some applicants were being treated unequally; and that property rights were not being respected (Counts 1997, 1, 2). While concerned that the original EAA rules might allocate water in the Edwards Aquifer in excess of the first statutory limit to meet legitimate claims of all applicants, it was later reported that the EAA staff had determined that under the existing original rules, applicants might actually be limited to less than 450,000 acre-feet (Beldon 1997, 1), (Hooper and others 1997, 1, 2). Senator Ken Armbrister, Senate sponsor of Senate Bill 1477 and Chairman of the Texas House and Senate's joint Edwards Aquifer Oversight Committee concluded in a letter to Chairman Beldon that:

> Last spring your staff proposed new rules that appeared to violate the legislative intent of SB 1477. I, along with several other legislative colleagues, notified you and other board members of the illegality of those rules and how they failed to bring permitted pumping under 450,000 acre-feet, failed to treat all regions fairly, and hindered water transfers so that all entities and regions in need of additional permit rights could acquire them. It's my understanding that the newly proposed rules equally violate the provisions of SB 1477. . . . I urge the Edwards Aquifer Authority Board not to publish or adopt the staff's proposed rules at this time. They violate SB 1477, they invite federal take over of the aquifer, and they

> sacrifice regional support. The Texas Legislature has labored for six long years on the issue of the Edwards Aquifer Authority. (Armbrister 1997, 1, 2)

In a subsequent letter from Senator Armbrister and Representative Counts to Mr. Ronnie Pucek, owner of the catfish farm, the senator and representative made the following comments:

> We did not intend to create a priority system based on years of use. We did not intend for the statute's goals to be met at the disproportionate expense of a small group of new pumpers. We expect all existing users, including you, to be treated fairly. It is our understanding that San Antonio and other long term pumpers will receive a minimum up to 85% of their historic use. There is simply no reason for you to receive less. (Armbrister and Counts 1998, 1)

EAA Chairman Beldon responded to the flurry of correspondence from the legislators, noting that the EAA's proposed rules had been published in *The Texas Register* and each legislator had been given the opportunity to comment, and concluded:

> You mentioned in your letter that we were to "limit the withdrawal of water from the Edwards Aquifer to 450,000 acre feet [sic] a year immediately." We disagree with that position. Had such been the intent of the legislature, there would have been no need for the section on interim authorization which clearly gives us the authority to permit whatever amounts we feel are appropriate for the interim period. . . . Chief among these contradictions is Section 116(e) of the legislation, which sets out the minimums or floors for certain applicants. The sum of these minimums exceeds the 450,000 acre foot cap, both in the original applications and as proposed by the General Manager. (Beldon 1998a, 1)

The *1997 Texas Water Plan* and the Edwards Aquifer

The TWDB in its 1997 plan acknowledged the pumping limits of 450,000 acre-feet "through the year 2007" and 400,000 acre-feet beginning in 2008 as well as the further limit of whatever is required "to protect endangered species to the extent required by Federal law at Comal Springs . . . and San Marcos Springs . . . (Texas Water Development Board 1997, 3-215). The TWDB added, "model results currently indicated that a regional level of pumpage of 225,000 acre-feet per year is required to protect endangered species under historic recharge conditions, including a recurrence of the drought of record" (Texas Water Development Board 1997, 3-215).

7. WATER AS A LIMIT ON THE SUSTAINABLE DEVELOPMENT OF THE EDWARDS AQUIFER REGION

Introduction

This chapter will examine the crucial role that water plays in the sustainable development of the Edwards Aquifer region. The potential consequences of failing to manage the aquifer on a sustainable basis are examined.

Establishing a Limit on the Sustainable Development for Edwards Aquifer Groundwater

In 1980, Dr. Clark Hubbs, who extensively researched aquatic species dependent on flows from the aquifer, made the following observations about the sustainable development of the Edwards Aquifer region:

> I am deeply troubled by the opposition to the proposed Critical Habitat designations for the Texas wild rice, San Marcos salamander, San Marcos gambusia, and fountain darter (March 19, 1980; 45 FR 17888 – 17891 as amended by 45 FR 27457 – 27458). Much of that opposition stems from the philosophical position that economic growth must take precedence over the integrity of biological systems. That philosophy overlooks the inevitable need to maintain a viable environment and comments such as those contrasting the welfare of a million humans with that of a river forget that eventually the environmental resources will be exhausted and the welfare of two million humans would then be

> impacted. Those hard decisions will eventually have to be made and deferral will not make that decision any easier.
>
> The central issue of all of the debate is whether it is best to insure a minimum flow rate in the San Marcos River. Those individuals opposing critical habitat designation do that on the assumption that the demise of the river is a foregone conclusion. [45 Fed. Reg. 47357 (1980)]

With regard to the aquifer, sustainable development means that pumping should be managed in a way that provides for the current and future needs of all those who rely on the aquifer, even those downstream of the springs, and for the needs of the environment, including spring discharge and freshwater inflow to bays and estuaries. The drought of record is the event that defines the limits of the sustainable development of the Edwards Aquifer. More specifically, the filings of spring discharge determinations by the USFWS in *Sierra Club et al. v. Babbitt et al.* (required under the *Amended Judgment*) codify these limits (see Table 10 and Table 11). These documents define, and will continue to define until modified, the maintenance of the various flows necessary to prevent takes of the threatened and endangered species, and, consequently, the potential limits to growth that water resource planners will have to consider to avoid violations of the ESA. The flows established in this case are also shaping the future growth, development, and preservation of the Edwards Aquifer and the lifestyle of people and the economy that supports them in the overlying area and downstream on the Guadalupe River. In addition, the future growth and development of areas to the east of the Guadalupe are also being shaped as surface and groundwater resources in the Colorado and Brazos River basins are considered for diversion to the west.

As take limits, 200 cfs at Comal and 100 cfs at San Marcos Springs are easy to observe and monitor. Since the fountain darter is typically the first of the listed species to be harmed by declining spring discharge, the survival of the fountain darter in the wild, like the canary in the coal mine, provides the limit against which alteration of the environment presses.

The minimum flows prescribed by the USFWS to protect endangered species in its letters of April 15, 1993, and June 15, 1993, also fix the limits of water use for the Edwards Aquifer. By the date of the second letter Senate Bill 1477, providing pumping limits of 450,000 and 400,000 acre-feet had been enacted by the Texas Legislature (Table 18). A constant flow rate of 200 cfs, below which takes occur at Comal Springs, equals 144,800 acre-feet of water over one year. The minimum 100 cfs flow rate below which take and jeopardy occur at San Marcos Springs equals 72,400 acre-feet over one year. The total combined minimum discharge of 300 cfs from both springs for one year equals 217,200 acre-feet, which ultimately flows into the Guadalupe River. Thus, total permitted annual withdrawals plus minimum spring discharges through December 31, 2007, should be as much as 667,200 acre-feet; beginning in 2008, the total should be as much as 617,200 acre-feet until December 31, 2012 after which pumping must be restricted to whatever level is required to "protect endangered and threatened species to the extent required by federal law" [Ch. 626, 1993 Tex. Gen. Laws 2355, §1.14(h)]. Thus, the permitted pumping plus minimum flows is somewhat less than the <u>average</u> annual aquifer recharge of 683,100 acre-feet per year (see Table 1).

Table 18. The Evolution of Pumping Limitations for the Edwards Aquifer, 1961 – 2000

YEAR	SOURCE	ANNUAL AMOUNT, ACRE-FEET	STATUS	DEADLINE
1961	TBWE	Unspecified limit on pumping	Recommended	
1968	TWDB	400,000	Recommended	
1984	TWDB	425,000	Recommended	
1990	TWDB	425,000	Recommended	
1992	TWDB	425,000	Recommended	
1992	USFWS	450,000	Recommended	1993
		400,000	Recommended	2002
1993	SB 1477	450,000	Required	12-31-2007
		400,000	Required	1-1-2008
		Whatever is required by the ESA	Required	1-1-2012
1999	USFWS	450,000	Recommended	2001 –2002
		400,000	Recommended	2003 - 2008
		300,000	Recommended	2009 - 2011
		Whatever is required by the ESA	Recommended	1-1-2012

Sources: (Texas Board of Water Engineers 1961, 26), (Texas Water Development Board 1968, I-15), (Texas Department of Water Resources 1984, III-18-9, 10; III-19-8; III-21-9), (Texas Water Development Board 1990, 3-88), (Texas Water Development Board 1992, 94), (Spear 1992), Ch. 626, 1993 Tex. Gen. Laws 2355, §1.14(b) and (c), (Seawell 1999, 9).

Avoiding Disaster

Avoiding Disaster was the title chosen by the Texas Water Commission for its 1992 plan to manage the Edwards Aquifer. Given the potential problems that could occur if the region were unprepared for a return of a drought similar in magnitude to the drought of record, the title seems appropriate. A review of USGS data beginning in 1927 indicates that the flow at Comal Springs had not fallen below the 200 cfs take level established for the fountain darter prior to June 30, 1951. Since the drought of record, Comal Springs has fallen below 200 cfs in each of the following years: 1951 - 1957; 1962 - 1967; 1971; 1980; 1983 - 1985; 1989 - 1991; and 1996 – 1998. Flow at Comal Springs fell below the take level in 40% of the years, and below jeopardy (150 cfs or lower) in 19% of the years from 1958 to 1999. Withdrawals from the Edwards Aquifer have substantially increased since the drought of record. Total withdrawals for 1950 – 1956 were about 1,677,000 acre-feet, or an annual average of approximately 239,500 acre-feet. Withdrawals appear to have peaked at 542,400 acre-feet in 1989. From 1990-1996 withdrawals totaled approximately 2,978,000 acre–feet, or an annual average of approximately 425,000 acre-feet. Table 1 and Figure 9 show that recharge to the Edwards Aquifer is highly variable, while Table 2 and Figure 9 indicate that, since the drought of record, the Edwards Aquifer region has generally experienced higher than usual rainfall with high recharge. If the trend of above average rainfall were to end, and if withdrawals were not limited, the frequency of take and jeopardy flows at Comal Springs would increase significantly. A stochastic drought analysis of the Edwards Aquifer determined that there is a 78% probability that recharge will be less than 229,000 acre-feet, or 34% of the 1934 – 1998 average, at least once in every ten years (Wanakule 1993, 22).

For decades, it has been recognized that if increasing levels of unrestricted withdrawals from the aquifer were to continue, eventually flows at Comal and San Marcos Springs would become intermittent or cease altogether (Rothermel and Ogden 1987, 137). It has been predicted that Comal Springs would cease to flow permanently by the year 2020, or sooner, with unrestricted withdrawals (Klemt and others 1979, 88). A summary of estimates of when San Marcos Springs (assumes Comal Springs ceases to flow first, since it is at a higher elevation) would cease to flow under scenarios of both low and high water demand are given in Table 19. At the very least, in the absence of withdrawal limits, the possibility has increased that Comal, and eventually San Marcos, Springs could cease to flow during one of the relatively mild droughts that occur in the Edwards region.

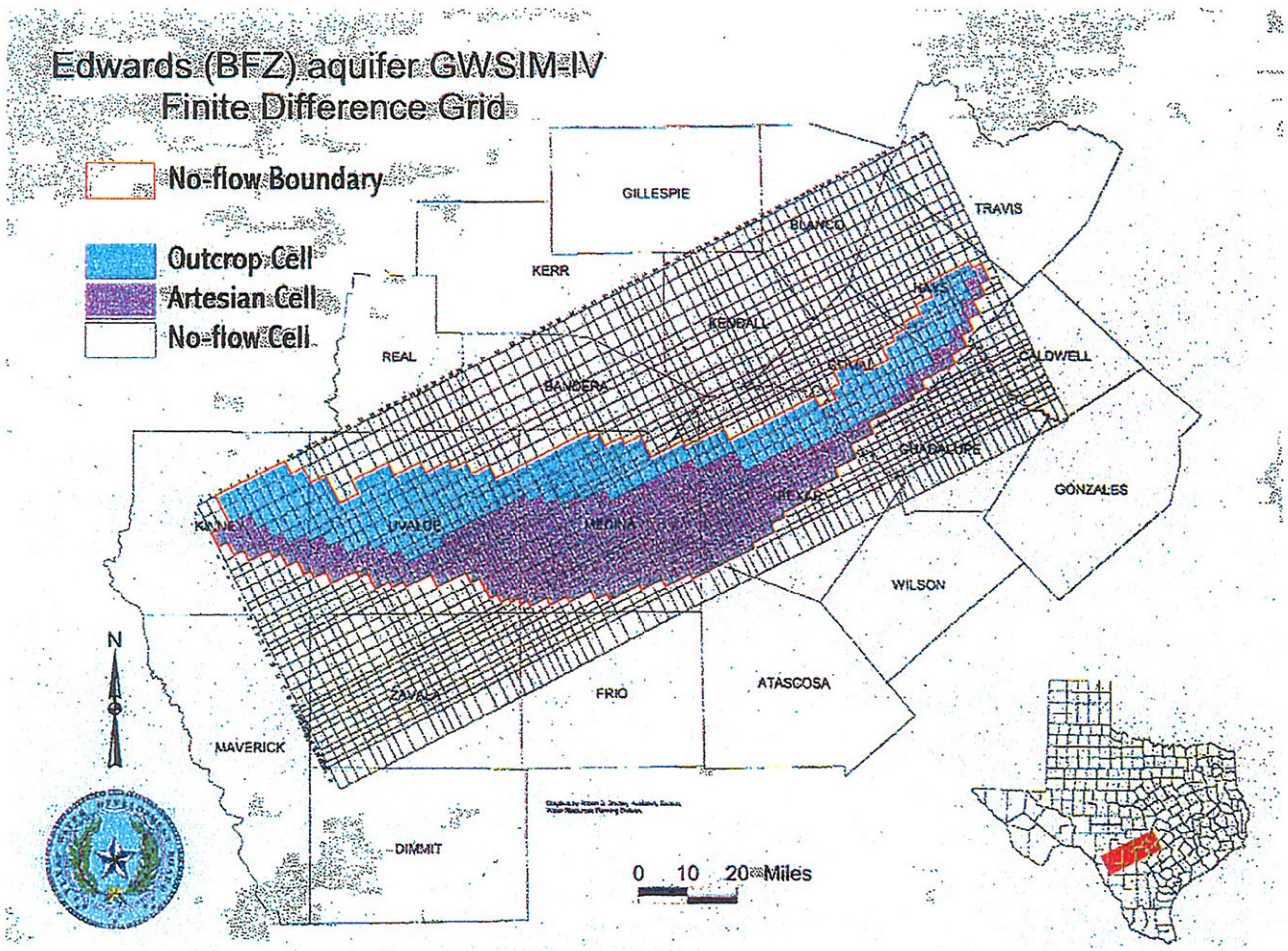
The TWDB has developed a computer model showing how the aquifer responds under various scenarios of recharge and withdrawal, the GWSIM-IV model (Texas Water Development Board 1992a). The TWDB's Edwards (BFZ) Aquifer flow model (Figure 11) is a mathematical representation of the aquifer that subdivides the aquifer into small areas or cells using a grid system (Knowles 1995, Attachment, 3). Each cell is assigned parameters consistent with the physical characteristics of the aquifer at that location, which allows flows to be computed and water levels simulated (Knowles 1995, Attachment, 3).

Table 19. Projected Year of Termination of Flow for San Marcos Springs under Low and High Edwards Aquifer Water Demand Scenarios

Study Source	Year of Termination for San Marcos Springs with Low Demand	Year of Termination for San Marcos Springs with High Demand
Bureau of Reclamation	After 2020	2001
Texas Water Development Board	After 2020	2005
Coastal Ecosystems Management, Inc.	2015	2005

Source: (Coastal Ecosystems Management 1975, 283).

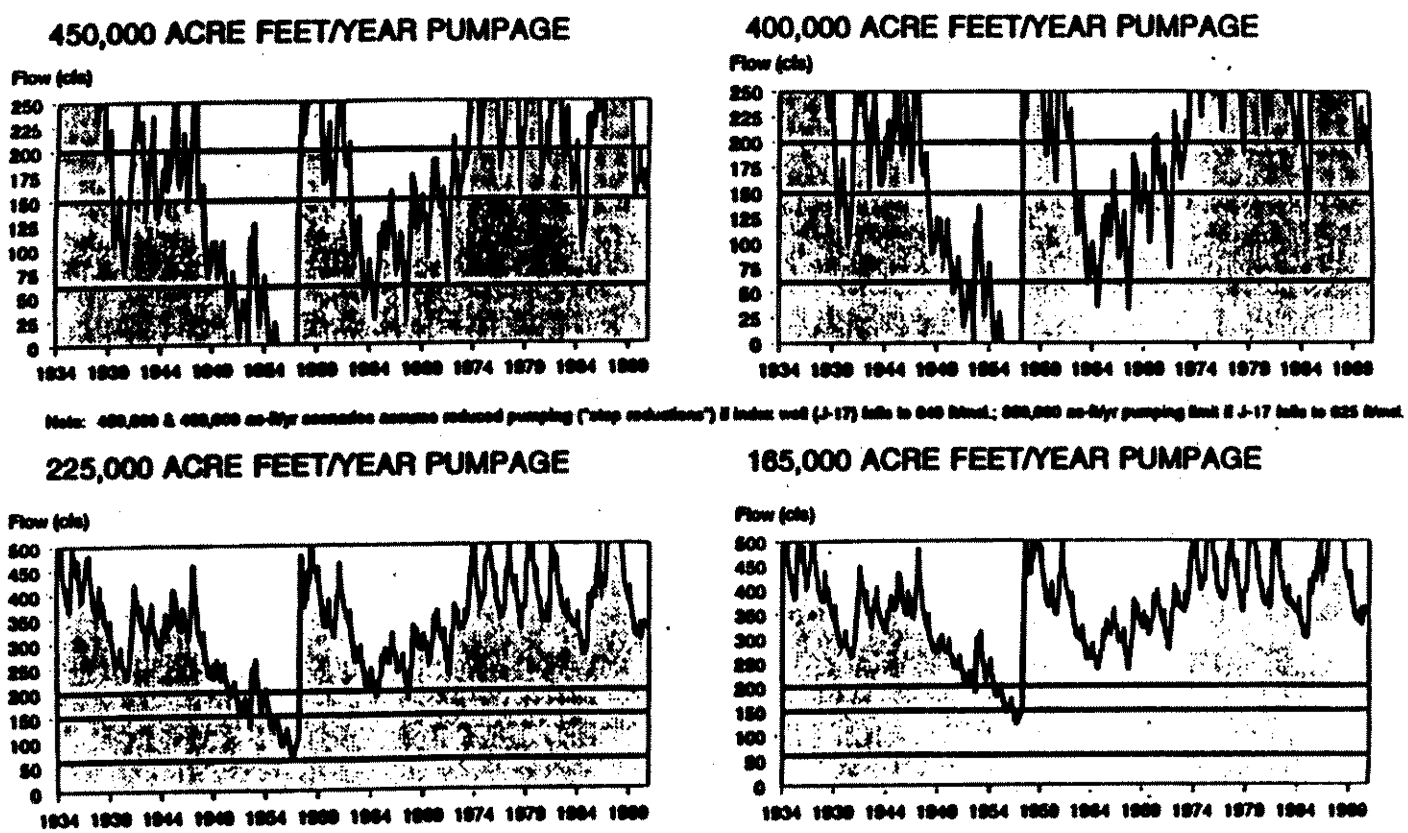
Figure 11. Edwards (BFZ) Aquifer GWSIM-IV Finite Difference Grid



(Kabir, Bradley, and Chowdhury 1999).

Figure 12 shows the TWDB estimated Comal Springs flows for the 1934 - 1989 period under four annual pumpage withdrawal limits -- 450,000, 400,000, 225,000 and 165,000 acre-feet/year - - developed in 1994 (House Research Organization 1994, 10). These estimates of the maximum amount that could be pumped under four scenarios are still considered to be accurate according to the model (Knowles and Mullican 1999). Only at a withdrawal rate of 165,000 acre-feet/year is the jeopardy level of 150 cfs at Comal Springs assured for most of the period, but not throughout the entire drought of record (Moore 1994, 3). With aggressive rams-horn snail control, the jeopardy level of 60 cfs is protected at 225,000 acre-feet/year, but just barely, during the drought of record. The 200 cfs take level without rams-horn snail control is not assured during the drought of record under any of the four TWDB scenarios. None of these scenarios demonstrates what might have happened with timely initiation and full enforcement of a drought management plan, such as the EAA's proposed *Critical Period Management Plan*, or the Withdrawal Suspension Program (Chapter 9). The TWDB model compares proposed management systems against the historical drought of record, assuming no conservation measures or pumping controls are implemented as the drought increases in severity. The EAA is developing its own model as an alternative to that used by the TWDB (Ellis 1999).

Figure 12. Estimated Comal Springs Discharge 1934 – 1989 Under Four Hypothetical Pumping Scenarios



(House Research Organization 1994, 10).

With the projected growth (Table 5 - Table 6), the current demands for aquifer water will exceed the amounts authorized by Senate Bill 1477 (Table 7). If the drought of record were repeated and a cap of 450,000 acre-feet of pumping were in place, an annual shortfall of 285,000 acre-feet could occur based on the TWDB model output, assuming jeopardy is prevented at Comal Springs (see Table 20). If the drought of record were repeated and a cap of 450,000 acre-feet of pumping were in place, and the giant rams-horn snail were controlled, a shortfall of 225,000 acre-feet could occur based on the TWDB model output, assuming jeopardy is prevented at Comal Springs. These estimates do not reflect the savings that might be achieved with the early implementation of measures such as a strict regional drought management plan and the Withdrawal Suspension Program.

By 2030, with withdrawals under non-drought conditions and the Senate Bill 1477 cap of 400,000 acre-feet in place, I have projected the shortage for the Edwards Aquifer area to be as high as 575,000, while others have projected a shortage of 574,500 acre-feet by 2050 (HDR Engineering 1994, Figure ES-6, ES-19). The region would have to reduce its pumping during a repeat of the drought of record by more than half to meet the 225,000 acre-feet limit. Water from the aquifer will have to be supplemented from conservation, reuse, and other sources, if projected water demands are to be satisfied and the limits in Senate Bill 1477 are to be met. Low spring discharge means repeated and increasingly low surface water flow downstream in the Guadalupe River and the coastal estuary. Today, as compared to the 1950's, even relatively mild droughts in the contributing and recharge zones can reduce flows at Comal and San Marcos

Table 20. Edwards Aquifer Withdrawal Limitations and Potential Deficits Under the Current Scenario

1. Amount of Aquifer withdrawals applied for	852,800 acre-feet
2. Annual withdrawal limit as of December 1999	792,000 acre-feet
3. Record annual withdrawals in 1989	542,400 acre-feet
4. Total withdrawals proposed by the EAA in 1998	484,600 acre-feet
5. Withdrawal limit in Senate Bill 1477 before 2008	450,000 acre-feet
6. Withdrawal limit in Senate Bill 1477 as of 2008	400,000 acre-feet
7. Withdrawal limit in Senate Bill 1477 as of 2013, the amount ensuring continuous minimum flow of Comal and San Marcos Springs to protect listed species as required by the Endangered Species Act	Whatever is necessary.
8. Total the TWDB model estimates can be withdrawn during a repeat of the drought of record while preventing jeopardy to both springs	165,000 acre-feet
9. Given a withdrawal limit of 450,000 acre-feet before 2008, the amount of additional water that would be needed during a repeat of the drought of record to avoid jeopardy (row # 5 minus row # 8)	285,000 acre-feet

10. Total amount the TWDB model estimates can be withdrawn during a repeat of the drought of record while preventing jeopardy to both springs (assumes control of the giant rams-horn snail)	225,000 acre-feet
11. Given a withdrawal limit of 450,000 acre-feet before 2008, the amount of additional water that would be needed during a repeat of the drought of record to avoid jeopardy, with control of the giant rams-horn snail (row # 5 minus row # 10)	225,000 acre-feet

Sources: Act of May 30, 1993 73rd Leg., R.S., ch. 626, 1993 Tex. Gen. Laws 2355, *as amended by* Act of May 29, 1995, 74th Le., R.S., ch. 261, 1995 Tex. Gen. Laws, §1.14(b), (c) and (h); (House Research Organization 1994, 10); (Needham 1998j, 6A); (Needham 1999a, 8A).

Springs below critical levels. Given the increasing efficiency with which water from the aquifer is used and the much greater regional demand, it would require enormous political will to limit withdrawals to either 165,000 or 225,000 acre-feet. Using a new federal court decision under the ESA to limit withdrawals might work if (a) the litigation were filed early enough; (b) a judge were to rule in favor of the plaintiffs; (c) the U.S. Fifth Circuit Court of Appeals were to allow it; and (d) the public were persuaded to comply with a drought management plan that substantially limits withdrawals.

If the drought of record occurred over the next seven years, it is unlikely that pumping from the aquifer could be restricted to anywhere near 225,000 acre-feet. Compared to 1956, Comal Springs could be dry for much longer during a repeat of the drought of record. All species at Comal might be extirpated from their natural habitats. Fountain darters would almost certainly be eliminated, since they were eliminated during 144 days without flow in 1956. What about the invertebrates, Comal Springs riffle beetle, Comal Springs dryopid beetle, and Peck's cave amphipod, recently listed at Comal Springs (Table 10 and Table 11)? No take and jeopardy flows have been specified for these invertebrates, nor has critical habitat been designated by USFWS at Comal Springs.

There is no indication that San Marcos Springs has ever ceased to flow, as Comal Springs did in 1956; however, with withdrawals significantly higher than during the 1950's, would a repeat of the drought of record cause San Marcos Springs to cease to flow for the first time in recorded history? If San Marcos Springs ceased to flow for an extended period, some species at the springs that have short life spans, and those for which reproduction in captivity has been unsuccessful (such as the San Marcos salamander), would face extinction. With little or no flow from the Comal and San Marcos Rivers to the Guadalupe, downstream water users would be severely impacted.

After such a prolonged drought, with the fountain darter eliminated from Comal Springs, how would a region that had just emerged from a devastating natural disaster react if USFWS tried to reintroduce darters again as it did in 1975? What if the listed species were eliminated at both springs? If the species are extirpated from both springs, how could those pumping excessively be subjected to future ESA penalties when the springs are nearing zero flow? Would the introduced species be classified as an experimental population to allow reintroduction to proceed? This designation would likely result in reduced protection under the ESA. Would the USFWS be sued to prevent reintroduction after such a drought as the region demands access to more water in the Edwards that lies below the level necessary to maintain flow from both springs, 574 msl at San Marcos? The effects of a drought of record on an unprepared region might result in voiding the pumping limits agreement struck in Senate Bill 1477, particularly if the species are extirpated from one or both spring ecosystems, and if the region is faced with the cost of new water supplies all at once, as could happen if the development of large amounts of additional water does not begin soon.

How would surface water rights holders on the Guadalupe River fare under such a scenario? Would there be no freshwater inflows to the Guadalupe Estuary for a number of years? If the limits in Senate Bill 1477 were not enforced, and if ESA remedies were unavailable with the elimination of listed species at the springs, only Texas water law would remain. With the exception of renewing the litigation over the underground river concept, no remedy exists under the rule of capture.

There are regulatory mechanisms, such as drought and *Critical Period Management Plans* and the EAA, which can prevent a repeat of the unrestricted pumping that occurred during the drought of record. Understanding when and how pumping limits should be imposed to avoid the catastrophic effects of the drought of record is an essential determination. Unfortunately, even weather forecasting experts cannot tell when a drought starts until it is well underway; nor can they tell when it ends until it is over.

Some Potential Hazards if Comal and San Marcos Springs Cease to Flow

Hydrologic and Economic Consequences

The hydrologic connection between the Edwards Aquifer and surface water flow makes the sustainable development of the region inseparable from the sustainable development of the Guadalupe River basin. Since significant withdrawals from wells began, spring discharge has periodically declined to critical levels, or, as Comal Springs did in 1956, ceased altogether. If withdrawals continue to increase, Comal Springs will go dry intermittently even without a major drought, as average withdrawals approach average recharge. The purpose of the ESA litigation over the Edwards Aquifer has been characterized as the preservation of threatened and endangered species. In reality, this is only half the motivation; the other purpose is protection of the economies and surface water rights of individuals, businesses and communities at Comal and San Marcos Springs and downstream along the Guadalupe River all the way to the Gulf of Mexico. Reduced flows in the Guadalupe River can cause economic losses for those individuals, corporations, municipalities and other entities who hold these rights. Reduced freshwater flows to the Guadalupe Estuary could seriously impact the coastal ecology, as well as the commercial seafood industry there.

The *1968 Texas Water Plan* described the potential consequences if a supplemental source of water were not developed for the Edwards region:

> Unless supplemental surface water supplies are made available to the San Antonio area for use at an early date, continuation of the historic rate of irrigation development and associated ground water pumpage, together with steadily increasing pumpage of ground water from the Edwards (Balcones Fault Zone) Aquifer for municipal and industrial use in the area, will result in:
>
> (1) Marked seasonal fluctuations in water levels in the aquifer, as well as severe declines during drought periods;
>
> (2) significant reduction in the quantity of ground water available to all users in the area on an annual dependable safe yield basis; and
>
> (3) more frequent and probably prolonged periods of time during which little or no flow will occur from the numerous and important natural springs in the area, the largest of which are Comal Springs near New Braunfels and San Marcos Springs at San Marcos. (Texas Water Development Board 1968a, I-14, I-15)

The most serious potential result of lowering aquifer levels and the cessation of spring discharge could be limits on population and economic growth dependent upon groundwater. One report even warned that lowered aquifer levels could result in large numbers of people moving out of the area and never returning (Coastal Ecosystems Management 1975, 405). Commercial enterprises in New Braunfels and San Marcos could suffer major economic losses, possibly bringing about the demise of recreational businesses (Coastal Ecosystems Management 1975, 403). Support facilities and local merchants would suffer proportionately (Coastal Ecosystems Management 1975, 403).

During the USFWS deliberations on designating critical habitat, Dr. Clark Hubbs made the following observations about the effect of no spring discharge upon the City of San Marcos:

> As a biological (and recreational) resource it [San Marcos River ecosystem] has enormous financial and aesthetic value. That value cannot be overlooked in your consideration. No opponent has addressed the question 'Why is the city of San Marcos there?' The answer is self evident. 45 Fed. Reg. 47357 (1980)

The Bad Water Line

In addition to the water quantity issues affecting the Edwards, there are also water quality issues. Lowering the water levels of the aquifer below the historic lows of 1956 could result in the intrusion of "bad water" into the freshwater zones of the aquifer. There is general agreement that somewhere south of the Edwards Aquifer downdip, a "bad water line" separates the area of usable groundwater from the area where wells produce water of unacceptable quality. The possibility of saline water intrusion has been a concern since the drought in the 1950s, when residents reported that some freshwater wells on the southern edge of the aquifer experienced an intrusion of highly mineralized water. The *1961 Texas Water Plan* states that:

> In the years just preceding 1956, a combination of a severe drought with reduced recharge to the reservoir [Edwards Aquifer], discharge from

> the springs, and increased pumping reduced the water stored in the underground reservoir to such a level that Comal Springs ceased to flow in the summer of 1956. While the quality of the Edwards limestone (fault zone) water is very good, water of very poor quality occurs in a line generally along the southern edge of the underground reservoir. As water levels declined, preceding the summer of 1956, a shifting of this "good water-bad water" line seems to have occurred. Subsequently, with the large amounts of recharge into the formation during 1957-1958, the "good water-bad water" line apparently returned to its previous position. (Texas Board of Water Engineers 1961, 152)

While the bad water line has not been precisely delineated, it exists in close proximity to both Comal and San Marcos Springs. The *1968 Texas Water Plan* cites the possibility that water containing high levels of salt and hydrogen sulfide could enter the freshwater portion of the aquifer, if the water level is lowered below 612 ft msl at Bexar County index well J-17 and the springs cease to flow (Texas Water Development Board 1968a, I-15, II-8). Today, there is disagreement among knowledgeable persons as to the risk of this line moving as the result of withdrawing large quantities of water from the Edwards during dry years. Research regarding the bad water line has produced conflicting conclusions. Both those who fear the intrusion of bad water and those who contend it is not a problem cite as their authority the same USGS publication (Perez 1986) that describes its existence. Recently, the EAA has initiated a long-term study on the bad water line that will last 40 years with the first results due in 20 years (Thuss 1999).

While there is disagreement over the likelihood of the bad water boundary shifting, the potential of a contaminated water supply in some portions of the aquifer is not worth the risk. Over time, if withdrawals from the Edwards Aquifer continue to rise while cyclical droughts come and go, lowering the aquifer to levels below those experienced in the past amounts to a massive uncontrolled experiment with unknown consequences upon the future of the San Antonio region.

Water Rights in the Guadalupe River Basin

A 1998 report tabulates 258,098 acre-feet of consumptive run of river water rights downstream of Canyon Reservoir from the Guadalupe River (HDR Engineering 1998, 2-20). These include the cities of Victoria and Goliad, and Du Pont and Union Carbide Chemicals as well as irrigators.

> Reductions in springflows from the Comal and San Marcos springs would have a severe impact on the ability of existing water-right holders to obtain flows which they have historically used, and would also have a severe impact upon the flows into bays and estuaries. Likewise, the yields of Canyon Reservoir and any proposed reservoir projects would be significantly reduced by this reduction in flow, should springflows continue to diminish. Future policy decisions by the City of San Antonio and others regarding withdrawals from the Edwards Aquifer will therefore significantly impact the development of future reservoir projects. (Espey 1986, 5)

Releases from Canyon Reservoir might be available to sustain flows in the Guadalupe River to satisfy water rights holders within the basin when the level of the reservoir is high enough. Minimum spring discharge of 200 cfs at Comal and 100 cfs at San Marcos Springs produce 217,200 acre-feet annually, an amount inadequate to supply all 258,100 acre-feet of downstream surface water rights without contributions from the flow of other tributaries to the Guadalupe River. Should there be a Section 10(a) Incidental Take Permit in effect, pumping could increase and minimum spring discharge could decrease another 36,200 acre-feet, producing 181,100 acre-feet of spring discharge annually.

Endangered and Threatened Species

As spring discharge at Comal and San Marcos Springs declines, the habitat for seven endangered and one threatened species shrinks. The most prominent of these species is the fountain darter, the first to be harmed at Comal Springs. The results of Comal and San Marcos Springs becoming intermittent could be the extinction of some of the wild populations of the listed threatened and endangered species as well as the destruction of their natural habitat. These species serve as one of the important indicators of the health of the Edwards Aquifer. While some of the species could be maintained in refugia, others such as the San Marcos Salamander do not reproduce in captivity at a rate that could sustain a population indefinitely (Schleser 1995).

Freshwater Inflows to Bays and Estuaries

The aquifer's natural discharge at the springs provides significant baseflow to the San Antonio and Guadalupe Rivers; it also provides crucial freshwater inflows to the coastal Guadalupe Estuary. Bays and estuaries are impacted by droughts as freshwater inflows decline. Spring discharge from the Edwards Aquifer can become almost the sole source of water flowing downstream into the Guadalupe River during droughts; recall that at one point during the summer of 1996 it accounted for 81.7% (Guadalupe - Blanco River Authority 1996, Exhibit 2).

Before the construction and filling of Canyon Reservoir, as much as 70% of the flow in the Guadalupe at Victoria, Texas, was derived from Comal and San Marcos Springs (Bureau of Reclamation 1978, 219, 220). The annual average combined freshwater inflow to the San Antonio - Guadalupe Estuary from 1941 to 1987 was 2,344,140 acre – feet (Longley 1994, viii). The average monthly inflow was 195,000 acre – feet (Longley 1994, 26). Drought effects on freshwater inflows include (1) reduced nutrients and sediments, (2) higher salinity levels, and (3) uncontrolled marine predators, parasites, and diseases (Water Demand/Drought Management Technical Advisory Committee of the Consensus State Water Plan 1998, 7).

During times of drought, recharge to the aquifer declines, withdrawals from the aquifer for agricultural, municipal, industrial and other uses rise, flow from the springs diminishes, causing flow downstream in the Guadalupe River to decline. Reducing flow in the Guadalupe River and its tributaries could result in irreversible changes in vegetation that could favor nuisance fish species over game fish species (Coastal Ecosystems Management 1975, 403). The reduction in freshwater inflows to the San Antonio – Guadalupe estuary would increase salinity and lower nutrient levels which could lower primary productivity below what is necessary to sustain commercial seafood species (Coastal Ecosystems Management 1975, 403 - 404). Salinity could reach hypersaline levels, since the evaporation rate, on average, exceeds the rainfall rate for the San Antonio – Guadalupe Estuary (Bureau of Reclamation 1978, 122). However, commercial seafood production could rise again as the change in salinity levels results in different species filling the newly created niches (Coastal Ecosystems Management 1975, 404). Reduced freshwater flows to the Guadalupe Estuary could allow saltwater to migrate up the Guadalupe River to points where municipal, industrial, and agricultural water is withdrawn. An inflatable barrier is maintained on the Guadalupe River by the Guadalupe – Blanco River Authority between the San Antonio – Guadalupe Estuary and the freshwater intake of Victoria and downstream industries on the River to prevent the entry of saltwater into water intakes when freshwater flows in the river diminish. However, the reduction in flow from the springs might not be limited to the Guadalupe Estuary. The reduction in flow could also negatively impact the Mission – Aransas and Lavaca – Colorado Estuaries since between 25% to 33% of the freshwater that flows out of the San Antonio – Guadalupe Estuary discharges into those estuaries (Jensen 1994, 3).

The Regional Economy and Perpetual Litigation

> Given what is known about the limits of firm yield from the Edwards, it is imprudent even today for municipalities to rely on the Edwards for their total water supply. The State should not be distracted from the long-term problem by the current high levels in the aquifer. As the uncertainty of the water supply becomes more widely understood, the risks San Antonio and other cities are taking can be expected to reduce their attractiveness to employers and increase the risk premium in their municipal bond interest rates. This will cost jobs, reduce family incomes, and increase the cost of public services. (Luke, 1986, 12)

In addition to the potential for contaminating the aquifer by the movement of the bad water line, San Antonio could also suffer from the additional ESA litigation that would likely result from the springs ceasing to flow. Continued litigation renewing the specter of inadequate water supply will likely discourage some industries from locating in San Antonio or expanding existing operations, particularly water intensive industries. If San Antonio does not grow, other regional cities are unlikely to grow given the interrelationship of the regional economy (Thuss 1999). Two incidents in 1995 demonstrate San Antonio's economic vulnerability. The first was the meeting of the Base Closure and Realignment Commission to consider the fate of five military bases in San Antonio, which was discussed in Chapter 6. These bases have been the foundation of San Antonio's economy. In the second incident, San Antonio Mayor Bill Thornton traveled to Japan to encourage Japanese companies to locate in San Antonio. While he was in Japan, the Mayor Thornton was asked by an executive of the Sony Corporation if San Antonio had a water problem (Dilanian 1996, 1A). If an executive in Japan is aware of San Antonio's vulnerability, other U.S. cities are likely aware as well and could be using this fact against San Antonio when competing to attract new, and retain existing, industry.

Comanche Springs: An Example of the Failure to Sustainably Develop a Texas Aquifer

The elimination of Comanche Springs in Fort Stockton, Pecos County, Texas, chronicles a failure to sustainably develop a Texas aquifer. Flowing from the Edwards Trinity Plateau Aquifer, Comanche Springs created an oasis that was once an important resource for American Indians, explorers such as De Vaca, and settlers (Brune 1981, 357). Like Comal and San Marcos Springs, a unique ecosystem existed at Comanche Springs. Vast marshes created by the springs that bounded Comanche Creek for 15 miles attracted large numbers of waterfowl and other wildlife (Brune 1981, 357). At one time Comanche Springs supported a thriving tourism and agriculture-based economy much as the springs of the Edwards Aquifer do today (Brune 1981, 223).

Throughout the late nineteenth and early twentieth centuries, Fort Stockton boosted itself as the "fruit-growing capital of the world," "The Spring City of Texas" which came to an abrupt end in the late 1950s when Comanche Springs dried up (Wimberley 1994, 2). Heavy groundwater pumping from the Edwards Trinity Plateau Aquifer for agricultural irrigation eliminated the springs. For the Fort Stockton area as a whole, the destruction of Comanche Springs altered the community. Newspaper editor Glen Larum remarked in 1993, "Fort Stockton went from being an oasis in the desert to just a place where you got gas on your way from San Antonio to El Paso" (Wimberley 1994, 9).

A Sample of Opinions on the Effects of a Repeat of the Drought of Record

- The springs are at greater risk of running dry now than before the ESA litigation, because of increased regional growth (Thornhill 1999);
- It is more likely that Comal Springs would dry up today in a repeat of the drought of record than in the 1950's. There was little irrigation in the 1950's and the population over the aquifer has tripled. In a repeat of the drought of record, Comal Springs would dry up for a longer period of time today (Ozuna 1999);
- With a repeat of the drought of record, there is a chance that the springs could be saved if the timing is right. The result of Sierra Club et al. v. Babbitt et al. is a marginal improvement that the springs won't dry up again. The courts are now more familiar with the issue and more likely to take action. Pumpers have received notice of the need for pumping restrictions (Nevola 1999);
- If a repeat of the drought of record began today, San Antonio would not fare well, and its economy would suffer. Comal Springs would dry up again, but the region would be moved along toward a regional solution (Specht 1999);

- The EAA will eventually be successful in assuring minimum discharge from the springs during low rainfall years (Specht 1999); and

- San Antonio is not prepared for a repeat of the drought of record. I lived in San Antonio during the drought of record and I fear that the event could be devastating for the city. The city has not been able to deal with a need for balance between growth and water development (Peak 1999).

8. RESPONDING TO DROUGHTS IN THE EDWARDS AQUIFER REGION

Introduction

This chapter will analyze regional attempts to respond to the natural hazard of drought. Current drought management strategies will be discussed under the sustainable development limitations resulting from the Endangered Species Act litigation and state law.

Drought Management Plans

The Western Water Policy Review Advisory Commission has concluded that:

> An interagency task force should be established to develop an integrated national drought policy and plan that emphasizes a preventative, anticipatory, risk management approach to drought management and promotes self-reliance. (Western Water Policy Review Advisory Commission 1998, xxiii)

Senate Bill 1 in 1997 added a new provision to the Texas Water Code, §11.1272, which directs the TNRCC to adopt rules for irrigation districts and water suppliers to develop drought management plans (Personett 1998, 157).

These plans are essentially water rationing plans. They can target specific uses or set overall percentage reduction goals for water programs.

In 1998, major Texas groundwater conservation districts, including the High Plains Underground Water Conservation District No. 1 (Wyatt 1998) and the Harris – Galveston Coastal Subsidence District (Harris - Galveston Coastal Subsidence District 1998, 70), had yet to develop drought management plans. However, as a result of the concern over providing water for the Guadalupe River from springs discharges and the presence of the endangered species in Comal and San Marcos Springs, several regional groundwater drought management plans had been developed for the Edwards Aquifer region prior to Senate Bill 1. As the result of ongoing ESA litigation, different regional drought management plans have been developed by entities such as the Edwards Underground Water District, the Edwards Aquifer Authority, U.S. Fish and Wildlife Service, and the U.S. District Court in Midland, Texas (see Appendix 3. Regional Drought Management Plans Developed for the Edwards Aquifer, in chronological order). The priorities in water use reductions found in these plans may provide precedents for drought management plans developed for other parts of the state.

When targeting specific uses, typically those uses considered the least critical to local economies and the least opposed by the general public are selected for the first reductions. While percentage reductions in water use can be mandated, the public's perception of the crisis is possibly the most important factor in achieving reductions, since substantial voluntary compliance is essential. Lawn and landscape watering are the initial targets for drought management plans, since this use is considered discretionary. "Possibly the best application of water rationing would be to limit irrigation of lawns. This is perhaps the most nonessential use that present ground-water supplies have been utilized for" (Coastal Ecosystems Management 1975, 411). Most Edwards drought management plans focus upon the largest single use, municipal consumption, which peaks in July and August when spring discharges are usually at their lowest. If restrictions are imposed to reduce withdrawals very early in a drought year, then reductions can be relatively less restrictive during the most critical summer months during a short-term drought. To protect endangered species dependent upon the Edwards during droughts, management plans must be implemented before spring discharges fall below the take and jeopardy levels, and ideally, far in advance to reduce the possibly abrupt severity of the necessary reductions. While protecting the species, these restrictions also have the secondary effect of assuring minimum surface water flows downstream in the Guadalupe River and into coastal estuaries. They can also reduce sequential power conflicts among the GBRA and the EAA, and those whom the EAA regulates. To trace the development of drought management plans for the Edwards Aquifer, I will examine selected plans representing a cross-section of drought management approaches. This examination is necessary prelude to the analysis of the drought management plan trigger levels found later in this chapter.

The EUWD's Drought Management Plans

The EUWD developed the first regional drought management plans for the Edwards Aquifer. With the exception of the 1995 EUWD plan, the 1988, 1989, and 1992 plans were all triggered by declines in the water level of the J-17 index well in Bexar County or the Uvalde index well in Uvalde County (see Appendix 3, Item 1. Summaries of the Edwards Underground Water District's 1988 and 1989 Drought Management Plan; Item 3. A Summary of the Edwards Underground Water District's 1992 Demand Management Plan; and Item 6. A Summary of the Edwards Underground Water District's 1995 Demand Management Plan). The withdrawal reductions to be achieved were all described as 'goals', raising concern that these limitations were voluntary, as opposed to mandatory, in nature. The EUWD also began the practice of using different hydrologic indicators with different triggers for subregions within the District's jurisdiction, a practice continued by the EAA.

The U.S. District Court's Drought Management Plans

In the summer of 1994, declines in the discharge rate from Comal Springs prompted the Sierra Club requested that the Court direct the Monitor appointed in *Sierra Club v. Babbitt* to prepare an emergency plan to reduce withdrawals from the aquifer. On July 3, 1994, the Court ordered the Monitor to prepare the plan by August 1 [*Babbitt*, MO-91-CA-069, at 7-8 (W.D. Tex. Jun. 3, 1994) (Order on Motion for Additional Relief)]. This document (see Appendix 3, Item 4. A

Summary of the Monitor's Proposed *1994 Emergency Withdrawal Reduction Plan for the Edwards Aquifer*) was not only a drought management plan, but also an attempt to educate the public about aquifer management issues at the center of the litigation. The *Emergency Withdrawal Reduction Plan for the Edwards Aquifer* (EWRP) did not apply to small sections of Atascosa, Caldwell, Guadalupe, and Kinney Counties above the aquifer. It provided staged reductions for withdrawals of municipal and industrial uses of groundwater. The EWRP, like each of the following plans developed for the Court, was intended to maintain flow at Comal Springs above the 150 cfs jeopardy level for fountain darters, using measures based on the current hydrologic conditions and existing regulatory authorities governing the aquifer and its users. The plan relied on percentage reductions in discretionary water uses, triggered by declining flows of Comal Springs (a reference to nondiscretionary reductions under stage V was a misprint). However, with the end of heavy summer withdrawals from the aquifer and fall rains, the need for the Court to implement the EWRP was averted in 1994.

In March 1995, the *Revised Emergency Withdrawal Reduction Plan* for the Edwards Aquifer (REWRP) was produced for the Court in anticipation of decreased spring discharge later in the year (Moore and Votteler 1995b). The REWRP (see Appendix 3, Item 5. A Summary of the Monitor's Proposed *1995 Revised Emergency Withdrawal Reduction Plan for the Edwards Aquifer*) incorporated information on water conservation collected during the Incidental Take Permit Panel meetings. Like the previous plan, the REWRP's various stages were to be triggered by declining discharge rates at Comal Springs. Unlike the EWRP, the REWRP based reductions on a base period monthly water use. Base period monthly water use (for military, municipal and industrial water users) was defined as the total water use in millions of gallons in the immediate preceding calendar year, minus three times the winter average water use, divided by nine (Moore and Votteler 1995b, 32). Winter average water use was defined as the average quantity of water used by a customer of a water purveyor in the three lowest consecutive monthly billing periods during the preceding period from November through March (Moore and Votteler 1995b, 42). Using the base period was an attempt to avoid targeting nondiscretionary water uses for reductions. As an alternative, Judge Bunton directed attorneys representing various interests in the litigation to meet and develop their recommendations for maintaining spring discharge above the 150 cfs jeopardy level at Comal Springs. The result was referred to as the *Lawyer's Panel Plan* with the stages triggered by the J-17 index well rather than spring discharges (details of this plan are described within Appendix 3, Item 7. A Summary of the U.S. District Court's 1996 Emergency Withdrawal Reduction Plan for the Edwards Aquifer), announced in June 1995; this plan was later accepted and approved by the Court [*Babbitt*, MO-91-CA-069, at 3-4 (W.D. Tex. Jun. 14, 1995) (Order on Summer 1995 Emergency Withdrawal Reductions)]. However, as in 1994, the end of heavy summer withdrawals and autumn rains averted the need for the Court to implement the *Lawyer's Panel Plan* in 1995.

During *Sierra Club v. San Antonio et al.* litigation in 1996, another emergency drought management plan was developed for the court (see Appendix 3, Item 7. A Summary of the U.S. District Court's *1996 Emergency Withdrawal Reduction Plan for the Edwards Aquifer*). *The 1996 Emergency Withdrawal Reduction Plan* (1996 EWRP) was based on the restrictions agreed to in the

Lawyer's Panel Plan by representatives of the Edwards Underground Water District, the City of San Antonio, the Green Valley Special Utility District, Atascosa Rural Water Supply Corporation, the City of New Braunfels and New Braunfels Utilities, and irrigators. This choice was made to minimize the opposition to the use of the 1996 EWRP, since several of the major parties to the litigation had originally developed the basic restrictions. The 1996 EWRP reduction stages were triggered by either spring discharges or the J-17 index well. The draft of the plan was developed between August 1 and August 10. It was released for public comment, revised, and on August 23, 1996, ordered into effect; it became the only plan adopted by the court to date. The 1996 EWRP was scheduled to be implemented beginning October 1, 1996, so that entities required to comply would have time to make preparations; however, the order of August 23, 1996, was stayed by the U.S. Fifth Circuit Court of Appeals in September.

The plans developed for the U.S. District Court differed from those developed by other entities on two key issues. First, the various stages of the plans would be initiated by declines in the flow of Comal Springs, although declines in the level of the Bexar County index well, J-17, could initiate restrictions under the 1996 EWRP only if these declines occurred prior to declines at Comal Springs. Second, the enforcement of these plans would have been backed by the authority of the U.S. District Court had that been necessary.

The EAA's *Critical Period Management Plans*

Under its statutory authority, the EAA has proposed two primary means for addressing droughts. These are the EAA's proposed *Critical Period Management Plan* (CPMP) which is a drought management plan, and the Withdrawal Suspension Program (WSP), a program under which farmers are paid with funds from area water purveyors (and therefore by their customers) not to irrigate with water from the aquifer in a given year.

Because the onset of drought conditions can occur after the planting of irrigated crops has commenced in the spring, a CPMP is currently the primary mechanism for reducing withdrawals from the aquifer during critical periods that develop after spring planting. If the EAA correctly evaluates the hazard that drought poses to the endangered species at Comal and San Marcos Springs in any year, the EAA's *Critical Period Management Plan* will be initiated sufficiently early to assure that take and jeopardy do not occur at the springs. As of February 2000, all versions of the CPMP as proposed by the EAA would be initiated when the levels of three groundwater wells -- one each in Uvalde, Medina, and Bexar Counties -- called index wells, decline to specified levels.

The EAA developed the *Critical Period Management Plan* to meet the Senate Bill 1477 requirement:

> The authority shall prepare and coordinate implementation of a plan for critical period management . . . . The mechanisms must:
>
> (1) distinguish between discretionary use and non-discretionary use;
>
> (2) require reductions of all discretionary use to the maximum extent feasible;

(3) require utility pricing, to the maximum extent feasible, to limit discretionary use by the customers of water utilities; and

(4) require reduction of non-discretionary use by permitted or contractual users, to the extent further reductions are necessary, in the reverse order of the following water use preferences:

(A) municipal, domestic, and livestock;

(B) industrial and crop irrigation;

(C) residential landscape irrigation;

(D) recreational and pleasure; and

(E) other uses that are authorized by law.

(Act of May 30, 1993 73rd Leg., R.S., ch. 626, 1993 Tex. Gen. Laws 2355, *as amended by* Act of May 29, 1995, 74th Le., R.S., ch. 261, 1995 Tex. Gen. Laws, §1.26).

The EAA's first CPMP relied on well J-17 (for Bexar, Comal, Hays, Guadalupe, and Caldwell Counties), the Hondo well (for Medina and Atascosa Counties), and the Uvalde well (for Uvalde County) to initiate stages containing certain drought measures (see Appendix 3, Item 9. A Summary of the Edwards Aquifer Authority's *1998 Critical Period Management Plan*). In December 1998, the State District Court for Travis County voided EAA's rules for granting permits as well as the *1998 Critical Period Management Plan* [*Living Waters Artesian Springs v. Edwards Aquifer Authority*, No. 98-02644, slip op. (D.C. Travis County, TX Dec. 17, 1998)].

The EAA's May 1999 CPMP lowered the trigger for initiating the second stage in Bexar, Caldwell, Comal, Hays and Guadalupe Counties. The mandated water use reductions were substantially greater than in the 1998 CPMP, and were similar to those in the 1995 *Lawyer's Panel Plan* and *1996 EWRP*.

The USFWS Drought Management Recommendations

Appendix 3, Item 8. A Summary of the USFWS Recommendations to the Edwards Aquifer Authority for Trigger Levels, provides the USFWS recommendations to the EAA for a drought management plan (DMP). These recommendations represent the type of possible requirements now that a single regional entity is regulating withdrawals from most of the aquifer. The plan is linked to the discharge rate from Comal Springs and has mandatory reductions instead of voluntary reductions. The most important feature is the lack of specific requirements regarding which water uses are to be limited to achieve the required reductions. If no EAA CPMP were in place, the use of this approach would provide the EAA with flexibility in meeting the required reductions, when compared with plans that target specific uses. However, a description of the base period on which the reductions are to be based is essential -- for example, a 10% reduction in water use from the total withdrawals in June.

A drought management plan for the San Antonio military bases (Appendix 3, Item 11. A Summary of the 1999 Department of *Defense Drought Management Plan* approved by US. Fish and Wildlife Service) was approved by USFWS in November, 1999 as part of a biological opinion (Frederick 1999). In this plan the USFWS approved the use of a trigger level of 80 cfs at San Marcos Springs, below the 100 cfs jeopardy level. The USFWS also notes:

> The existing DMPs allow flows at Comal to go to about 160 cfs during level I and down to 60 cfs before level V (the emergency level) is

> implemented. During litigation procedures, *Sierra Club, et al. v. Lujan, et al.* (it would later become *Sierra Club, et al. v. Babbitt, et al.*), No. MO-91-cA-069, Joe G. Moore, Jr., Court Monitor for Judge Lucius D. Bunton, U.S. District Court, Western District of Texas was appointed and made the recommendation to the Court in August 1, 1994, and in a revised plan on March 31, 1995, that to assure necessary flows for listed species at Comal and San Marcos Springs, spring flow rates at Comal (and possibly San Marcos) should be used as triggers instead of the J-17 index well. The Service is concerned that during low springflows the J-17 well levels and springflows do not correlate well and existing DMP stages do not provide enough protection to protect spring flows and avoid jeopardy. Therefore, the Service concurs with the court monitor's suggestion that suggestion that springflows should be used and reductions should be started much earlier (for example, by 250 cfs at Comal Springs). (Frederick 1999, 18)

The Use of Spring Discharge v. Index Well Levels to Trigger Drought Management Plans

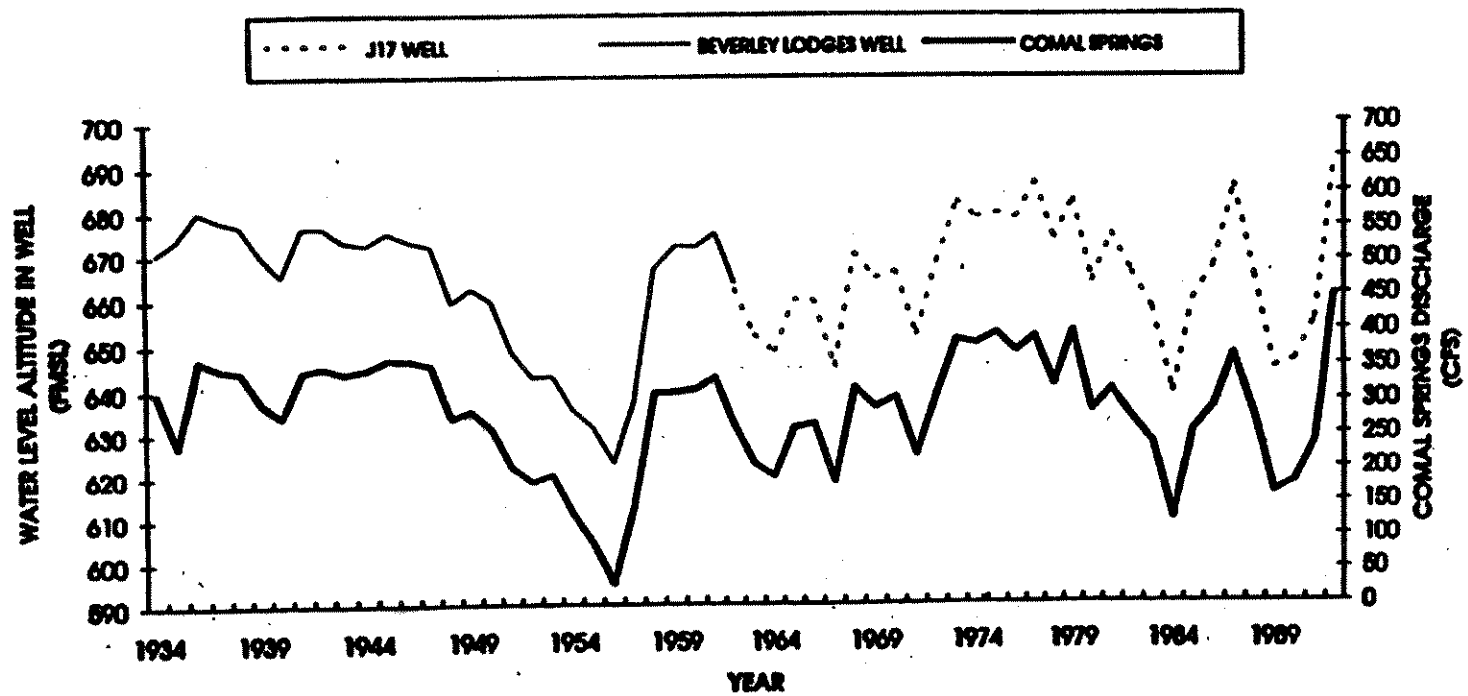
Together, the *May 1999 Critical Period Management Plan* and the Withdrawal Suspension Program of the EAA address the two primary uses of Edwards Aquifer water, municipal and agricultural, typically some 80% to 90% of total withdrawals during periods of low rainfall. The EAA's May 1999 CPMP addresses the largest use, municipal consumption, which peaks in July and August when spring discharges are usually at their lowest. To assure minimum human water needs; to protect endangered species at Comal and San Marcos Springs during droughts; and to assure minimum downstream flows, the CPMP must be implemented, and irrigation must be curtailed, before spring discharges approach the take and jeopardy levels. Determining when these actions are necessary could be accomplished by identifying precursors to diminished spring discharges as triggers to initiate the *Critical Period Management Plan* and the WSP. This section will examine the practice of using index wells to trigger drought management plans. In the chapter that follows, I examine techniques for anticipating when critical flows are likely to occur. Such techniques could be used to determine when measures, such as the WSP, should be initiated.

Index well J-17 near Fort Sam Houston in San Antonio, Bexar County (formerly identified as the Beverley Lodges Well), was used by water purveyors and the EUWD as the indicator well for triggering drought management plan reductions because of the apparent close correlation between mean annual water levels in this well and the mean annual flows from Comal Springs. Figure 13 is a graph of such correlation for the period 1934 through 1992. Analysis of the data on other than an annual basis reflects significant differences.

The majority of the drought management plans previously developed for the Edwards Aquifer are initiated by trigger levels based either on the level of one of three groundwater index wells, or on the flow of Comal Springs. Given that violations of the ESA at Comal and San Marcos Springs are linked to the discharge rates specified in Table 10 and Table 11, the use of indirect measures such as groundwater wells, instead of the direct measure of spring discharges, should be evaluated to determine if the groundwater well levels will always initiate a drought management plan so as to prevent take and jeopardy of endangered species. This evaluation requires the examination of the relationship between groundwater levels measured at the index wells, and discharges measured at the springs.

The EAA's May 1999 *Critical Period Management Plan* is triggered by designated levels in the following groundwater wells using a water - level recorder: J-17 index well (state designation AY-68-37-203) near Fort Sam Houston in Bexar County; the Uvalde, Texas index well (YP-69-50-302) in Uvalde County;

Figure 13. Mean Annual Relationship Between Water Level in J-17 and Beverley Lodges Observation Wells and Comal Springs Discharge, 1934 - 1992



(USGS, 1990).

and the Hondo, Texas index well (TD-69-47-306) in Medina County (Figure 1). Reported index well readings are daily highs, while reported spring discharges are the daily mean; for example, the J-17 water level is the highest number recorded for that day, usually around 7:30 A.M., provided it does not rain during the day after the daily high occurs (U.S. Geological Survey and Edwards Underground Water District 1994); (Walthour 1999).

The discharge of Comal Springs is measured by the U.S. Geological Survey water - stage recorder at gauging station 08168710, then the data are transmitted by a satellite telemeter to the USGS. Measurements of the Comal River flow at this station are designated as 08169000; in the past, data reported as Comal Springs discharge has been assigned this same USGS number, producing some confusion between spring discharge data and Comal River flow data (U.S. Geological Survey and Edwards Underground Water District 1994). The data are collected from a weir in the Comal River upstream of the San Antonio Street bridge in New Braunfels with spring discharge estimates calculated from these measurements. Estimated runoff, if any, from the watershed area above the weir is deducted. Daily spring discharge at Comal Springs can vary by as much 30 cfs or more during the day (Ozuna 1999). San Marcos Springs flow is measured at gauging station 08170000. Detailed information on the measurements of spring discharge at Comal and San Marcos Springs, as well as the three EAA indicator wells used in the statistical analysis that follows, are found in Appendix 5. A Data Dictionary of Selected Edwards Aquifer Metadata (metadata are descriptive information about data).

Other studies (Texas Department of Water Resources 1979) and (Rothermel and Ogden 1987) have correlated the water levels in selected groundwater wells and flows from major springs in the Edwards Aquifer, such as Comal and Hueco Springs. However, these studies have not examined the relationship between Comal and San Marcos Springs discharge and the three EAA index wells. Studies have attempted to correlate flows of Comal Springs and San Marcos Springs with water levels in groundwater index wells (Wanakule 1988, introduction). Wanakule concluded that flows at Comal Springs can be predicted by the level of well J-17 in San Antonio (Wanakule 1988, introduction). This supports conclusions that water use in San Antonio has a substantial direct correlation with flows at Comal Springs. Water use in the San Antonio area, at times, contributes significantly to diminishing spring discharges.

Correlations Between Comal Springs Flows and the EAA Index Wells

The flow from Comal Springs is controlled primarily by the piezometric surface (the height above the pressurized aquifer corresponding to its hydrostatic head) of the aquifer between San Antonio and Comal Springs. I have calculated that the mean daily discharge for Comal Springs from December 19, 1927 to June 3, 1998, to be 283 cfs. This includes 144 days of zero discharge during the drought of record.

A summary of the Pearson bivariate correlations coefficients that I calculated between Comal Springs discharge and the levels of the EAA's indicator wells is found in Table 21. Over the long-term, the daily discharge rate of Comal Springs was found to have a strong positive correlation, .9740, with the level of well J-17, approximately 30 miles to the southwest. The daily discharge

Table 21. Pearson Bivariate Correlation Coefficients (2-tailed Significance) between Comal Springs and All Three EAA Indicator Wells

	J-17	Hondo	Uvalde
Comal Springs	.9740	.9546	.7183
Number of Cases	22993	3839	19879
Significance Level	.000	.000	.000

rate of Comal Springs has a strong positive correlation, .9546, with the level of the Hondo well, approximately 70 miles to the southwest. The daily discharge rate of Comal Springs has a strong positive correlation, .7183, with the level of the Uvalde well approximately 110 miles to the southwest, although the correlation is not so strong as the correlations with J-17 and Hondo, which are closer to Comal Springs and are not influenced by the Knippa Gap constriction on flow.

I did an additional analysis to determine whether the correlation between Comal Springs discharge and the index wells varied with different ranges of flows at the springs. Table 22 through Table 24 show the results of correlations at ranges corresponding to greater than 200 cfs (above take flows), 151 – 200 cfs (during take flows), and 150 cfs or less (during jeopardy flows). These results show that the correlation between the level of the index wells and the flow of Comal Springs can decrease significantly over specified ranges from the entire span of data shown in Figure 14. For the three index wells, the correlation with Comal Springs declined substantially when Comal Springs discharge was between 151 cfs and 200 cfs. This reduction in the strength of the correlation within this range is important, because the CPMP and other drought management plans are designed for use during periods of low flows at Comal Springs, when the usefulness of the index wells as trigger mechanisms apparently declines.

Table 22. Pearson Bivariate Correlation Coefficients (2-tailed Significance) between Comal Springs and the J-17 Indicator Well for Specified Ranges

	Comal Springs ≥201 cfs	Comal Springs 151 – 200 cfs	Comal Springs ≤150 cfs
J-17	.9390	.5630	.9523
Number of Cases	19200	1665*	2114
Significance Level	.000	.000	.000

*One outlier case eliminated.

Table 23. Pearson Bivariate Correlation Coefficients (2-tailed Significance) between Comal Springs and the Hondo Indicator Well for Specified Ranges

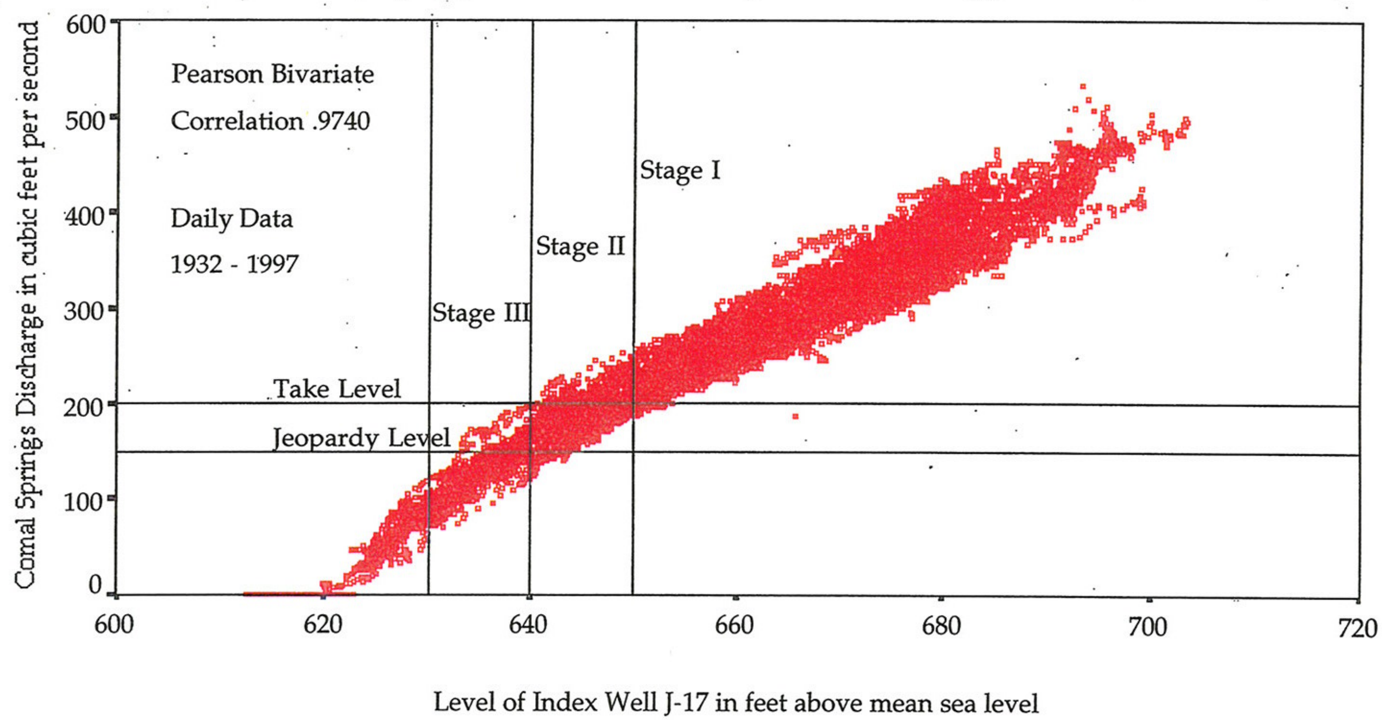
	Comal Springs ≥201 cfs	Comal Springs 151 – 200 cfs	Comal Springs ≤150 cfs
Hondo	.9250	.4409	.3897
Number of Cases	3066	428	343
Significance Level	.000	.000	.000

Table 24. Pearson Bivariate Correlation Coefficients (2-tailed Significance) between Comal Springs and the Uvalde Indicator Well for Specified Ranges

	Comal Springs ≥201 cfs	Comal Springs 151 – 200 cfs	Comal Springs ≤150 cfs
Uvalde	.5076	.0278	.4018
Number of Cases	16325	1460	2083
Significance Level	.000	.288	.000

Figure 14. Scatterplot of Comal Springs Flow and Well J-17 Level

Take and Jeopardy Levels and EAA May 1999 CPMP Trigger Levels Indicated



An Evaluation of the Trigger Levels in the May 1999 CPMP relating to Comal Springs

I have examined the EAA's May 1999 draft CPMP to determine whether the trigger levels adopted by the EAA would have restricted groundwater withdrawals from the aquifer prior to take and jeopardy flow levels at Comal Springs during the historical period for which data exist. Table 25 summarizes the range of flows at Comal Springs that correlate to index well trigger levels for the May 1999 CPMP based upon the scatterplots in Figure 14 through Figure 16. The scatterplot in Figure 14 shows that Comal Springs discharge have ranged from 180 cfs to 250 cfs when J-17 is at 650 ft msl, the trigger for Stage I conservation measures. For Stage II take or jeopardy levels have occurred in the past when J-17 was at 640 ft msl. For Stage III Comal Springs experiences jeopardy flows when J-17 is at 630 ft msl. Figure 15 shows that for all three CPMP stages using the Hondo index well, take, and for Stages II and III most likely jeopardy, would have been occurring at Comal Springs. For Comal Springs and the Uvalde well, it is difficult to find a range of corresponding flows for any of the CPMP Stages, although Figure 16 shows that when the Uvalde Well is at 875 ft msl or less, take and jeopardy could be occurring at Comal Springs.

Cumulative frequencies for flows corresponding to the May 1999 CPMP Stages were calculated by separating data for each index well into ranges represented by the dummy variables found in Table 26.

Figure 15. Scatterplot of Comal Springs Flow and Hondo Well Level

Take and Jeopardy Levels and EAA May 1999 CPMP Trigger Levels Indicated

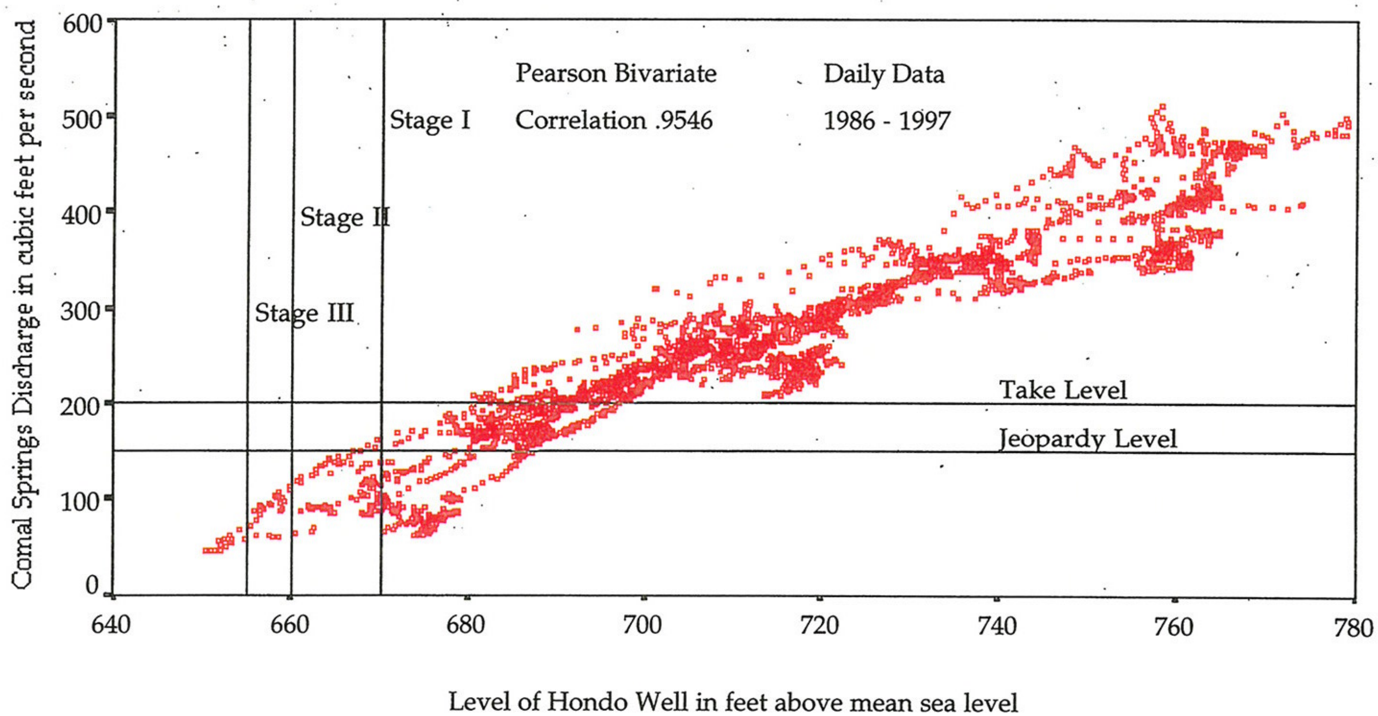


Figure 16. Scatterplot of Comal Springs Flow and Uvalde Well Level

Take and Jeopardy Levels and EAA May 1999 CPMP Trigger Levels Indicated

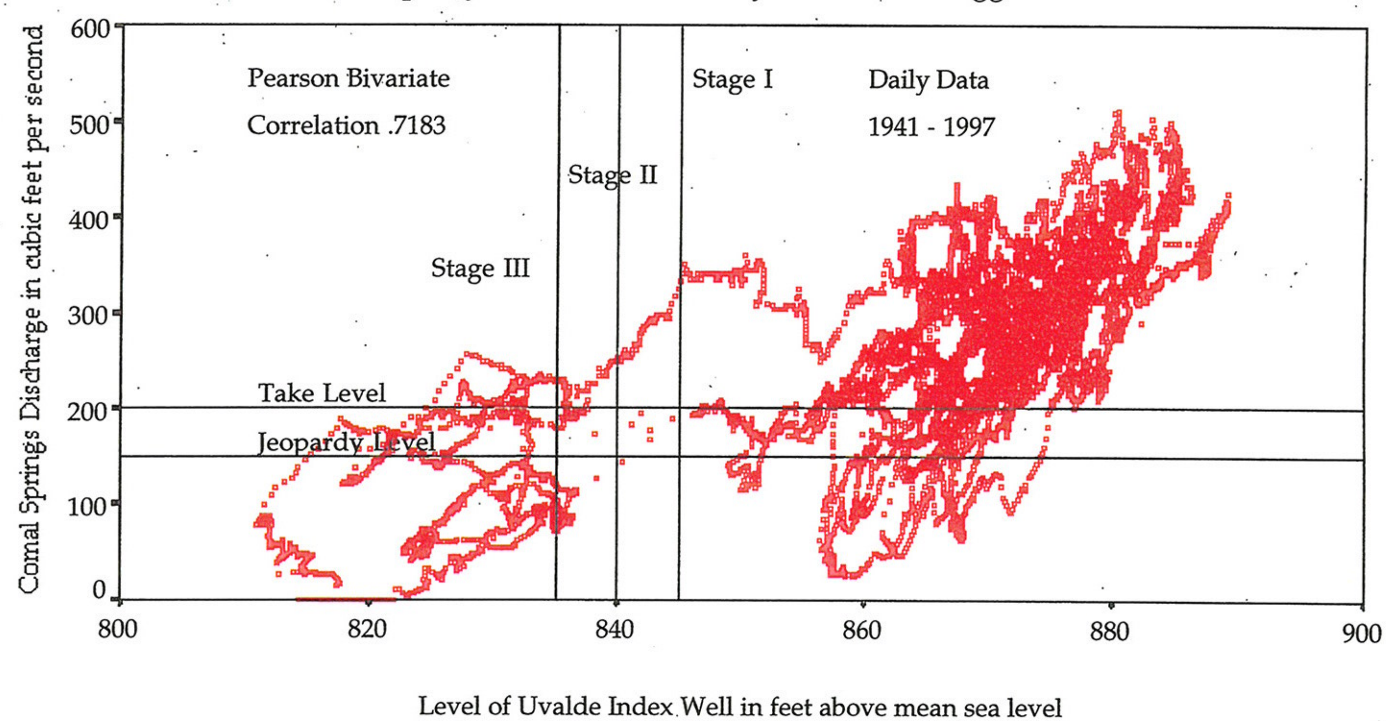


Table 25. Range of Flows at Comal Springs Corresponding to Key Trigger Levels in the EAA's May 1999 CPMP

Index Well	Stage	Trigger Level	Comal Springs
J-17	I	650	180 – 250
J-17	II	640	115 – 200
J-17	III	630	55 – 120
Hondo	I	670	80 – 160
Hondo	II	660	50 – 125
Hondo	III	655	50 – 70
Uvalde	I	845	UTD
Uvalde	II	840	UTD
Uvalde	III	835	UTD

UTD = Unable to determine

Table 26. Ranges Corresponding to Dummy Variables used to Calculate Crosstabulations of Groundwater Index Well Data and Spring Discharge Data

Index Well	Stage	Trigger Level	Dummy Variable
J-17	Before Triggering	>650	1.0
J-17	Stage I	≤650, >640	2.0
J-17	Stage II	≤640, >630	3.0
J-17	Stage III	≤630	4.0
Hondo	Before Triggering	>670	1.0
Hondo	Stage I	≤670, >660	2.0
Hondo	Stage II	≤660, >655	3.0
Hondo	Stage III	≤655	4.0
Uvalde	Before Triggering	>845	1.0
Uvalde	Stage I	≤845, >840	2.0
Uvalde	Stage II	≤840, >835	3.0
Uvalde	Stage III	≤835	4.0

A dummy variable is one that can assume one of two possible values, where one value represents the existence of a certain condition and the other value indicates that the condition does not exist (Keller, Warrack, and Bartel 1990, 840). For each dummy variable the number of days during which Comal Springs discharge was above the 200 cfs take level, within the range of take discharge 151 - 200 cfs, and within the range of jeopardy flows 150 cfs or less, were tabulated. The results of these crosstabulations are presented in Table 27 through Table 29. In Table 30 the May 1999 CPMP trigger levels are compared to historical low flow periods at Comal Springs to demonstrate which stages of the plan would have been triggered for each section of the aquifer during past periods when Comal Springs was below 200 cfs.

Table 22 through Table 24 show that the correlation between all of the index wells and Comal Springs decreases significantly when the Comal Springs discharge rate is between 151 and 200 cfs. For J-17 the correlation for all days in the record is .9740, but decreases to .5630 for days with flows between 151 and 200 cfs. For Hondo the correlation for all days in the record is .9546, but decreases to .4409 for days with flows between 151 and 200 cfs. For Uvalde, which is west of the Knippa Gap, the correlation for all days in the record is .7183, but decreases to .0278 for days with flows between 151 and 200 cfs. The decrease in the correlation between 151 and 200 cfs may be the result of a groundwater discontinuity somewhere between Comal Springs and J-17 in Bexar County, since correlations with all three wells are influenced within this range. This may be the discontinuity that Wanakule speculated existed at 639 feet msl for J-17 (Wanakule 1988, 14).

Table 27. Crosstabulation of Number of Days of Key Comal Springs Flows and Key Levels of J-17 Index Well, November 1932 – December 1997

	J-17 >650 ft msl	Stage I: J-17 ≤650, >640 ft msl	Stage II: J-17 ≤640, >630 ft msl	Stage III: J-17 ≤630 ft msl	Row Total
Comal >200 cfs	18509	691	0	0	19200
Comal 151–200 cfs	88	1404	174	0	1666
Comal ≤150 cfs	0	89	1081	944	2114
Column Total	18597	2184	1255	944	22980

Table 28. Crosstabulation of Number of Days of Key Comal Springs Flows and Key Levels of Hondo Index Well, September 1986 – December 1997

	Hondo >670 ft msl	Stage I: Hondo ≤670, >660 ft msl	Stage II: Hondo ≤660, >655 ft msl	Stage III: Hondo ≤655 ft msl	Row Total
Comal >200 cfs	3066	0	0	0	3066
Comal 151–200 cfs	425	3	0	0	428
Comal ≤150 cfs	211	92	24	16	343
Column Total	3702	95	24	16	3837

Table 29. Crosstabulation of Number of Days of Key Comal Springs Flows and Key Levels of Uvalde Index Well, January 1941 – December 1997

	Uvalde >845 ft msl	Stage I: Uvalde ≤845, >840 ft msl	Stage II: Uvalde ≤840, >835 ft msl	Stage III: Uvalde ≤835 ft msl	Row Total
Comal >200 cfs	15902	67	111	245	16325
Comal 151–200 cfs	1120	5	60	275	1460
Comal ≤150 cfs	866	1	97	1119	2083
Column Total	17888	73	268	1639	19868

Table 30. A Comparison of the EAA's May 1999 CPMP Trigger Levels and Critical Flows at Comal Springs

The (x) denotes each stage of the CPMP that would have been initiated historically using the trigger levels in years when Comal Springs was below 200 cfs or 150 cfs.

Stage/ Trigger Level	1951	1952	1953	1954	1955	1956	1957	1962	1963	1964	1965	1966	1967	1971	1980	1983	1984	1985	1989	1990	1991	1996	1997
	T170	T263	T150	T 62	T 0	T 0	T 73	T 15	T111	T109	T 10	T 4	T 49	T 72	T 28	T 37	T 61	T 19	T 46	T195	T 41	T139	T 42
	J 0	J 45	J 54	J 245	J 365	J 366	J 185	J 0	J 48	J 66	J 0	J 0	J 123	J 64	J 0	J 0	J 222	J 0	J 180	J 51	J 0	J 117	J 0
Stage I, J-17 ≤ 650, > 640	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Stage II, J-17, ≤ 640, > 630		X	X	X	X	X	X		X	X			X	X			X		X	X		X	
Stage III, J-17, ≤ 630				X	X	X	X						X	X			X		X	X		X	
Stage I, Hondo, ≤ 670, > 660	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	X	X		X	
Stage II, Hondo, ≤ 660, > 655	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA		X		X	
Stage III, Hondo, ≤ 655	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA		X			
Stage I, Uvalde, ≤ 845, > 840		X	X	X	X	X	X																
Stage II, Uvalde, ≤ 840, > 835		X	X	X	X	X	X																
Stage III, Uvalde, ≤ 835			X	X	X	X	X																

T = Number of days below 200 cfs take level. J = Number of days below 150 cfs jeopardy level. NA = Hondo Well level measurements available beginning 1986.
Note: J-17 triggers water conservation measures in Bexar, Caldwell, Comal, Hays and Guadalupe Counties; the Hondo well triggers measures in Hondo and Atascosa Counties; and the Uvalde well triggers measures in Uvalde County.

Table 27 shows that there were 88 days when J-17 was higher than 650 ft msl and Comal Springs was below 200 cfs. On a percentage basis prior to Stage I take conditions would have occurred less than 1% of the time, historically. This demonstrates that take would rarely already have been occurring for the fountain darter at Comal Springs before the initial conservation stage in the EAA May 1999 CPMP would have been triggered. However, with Stage I in effect, Comal Springs would have been at or below at the take level for some 1,404 days, and above the take level on only 691 days. Jeopardy flows would have been occurring on 89 days during Stage I. Historically, 64% of the days when J-17 would have been in Stage I of the EAA's May 1999 CPMP, Comal Springs was already at take, or 4% of the time jeopardy. For Stage II, Comal Springs has ranged from 115 cfs to 200 cfs when J-17 is at 640 ft msl. On a percentage basis during Stage II take conditions would have occurred 14% of the time and jeopardy 86%, historically. Stage III is initiated when J-17 reaches 630 ft msl, which corresponds to 55 cfs to 120 cfs at Comal Springs. On a percentage basis during Stage III jeopardy conditions would have occurred 100% of the time historically. This would appear to refute a conclusion by Wanakule that Comal Springs flow can be predicted using J-17 alone (Wanakule 1988).

For Comal Springs and the Hondo index well, take or jeopardy conditions already would have existed when Stage I was initiated (Table 28). On a percentage basis prior to Stage I take conditions would have occurred 11% of the time and jeopardy 6%, historically. On a percentage basis during Stage I take conditions would have occurred 3% of the time and jeopardy 97%, historically. When Stages II and III are reached using the Hondo well, jeopardy would have been occurring 100% of the time historically. Because measurements are only available from the Hondo well beginning in 1986, significantly fewer data are available than for the J-17 and the Uvalde well analyses.

For Comal Springs and the Uvalde well, it is difficult to find a range of corresponding flows for any of the May 1999 CPMP Stages because of their nonlinear relationship; however, Table 30 shows that if the trigger levels used in the May 1999 CPMP had been in effect during the years when flows were less than 200 cfs, the May 1999 CPMP would have been triggered in Uvalde County only from 1952 through 1957 during the drought of record, a drought with a probable 50 to 100-year recurrence interval or longer. This indicates that the burden for reduced pumping under the May 1999 CPMP would have been placed disproportionately upon Edwards Aquifer users in Bexar, Caldwell, Comal, Hays and Guadalupe Counties, and to a lesser extent in Medina and Atascosa Counties. As a result pumping reductions would come primarily from municipal water instead of agricultural water use. Table 29 provides similar results, showing that the Uvalde index well has very rarely declined to the levels selected by the EAA to trigger the May 1999 CPMP in that County.

For each of the groundwater index wells, take conditions have occurred prior to the initiation of each stage of the May 1999 CPMP using the designated trigger levels. Historically, 77% of the days when Comal Springs was at take, and 42% of the days when Comal Springs was at jeopardy, would have occurred prior to the Uvalde well triggering Stage I of the EAA's May 1999 CPMP. On a percentage basis of the days during Stage I take conditions would have occurred 7% of the time and jeopardy 1%, historically. On a percentage basis of the days during Stage II take conditions would have occurred 22% of the time and jeopardy 36%, historically. On a percentage basis of the days during Stage III take conditions would have occurred 17% of the time and jeopardy 68%, historically.

Correlations Between San Marcos Springs Flows and EAA Index Well Levels

I have calculated that the mean daily discharge for San Marcos Springs from May 26, 1956 to September 29, 1998, was 167 cfs. The correlations between San Marcos Springs flows and the EAA's May 1999 CPMP indicator wells are found in Table 31. The discharge rate of San Marcos Springs has a positive correlation, .6963, with the level of well J-17, approximately 45 miles to the southwest. The discharge rate of San Marcos Springs has a positive correlation, .6821, with the level of the Hondo well, approximately 85 miles to the southwest. The discharge rate of San Marcos Springs has a weak positive correlation, .3934, with the level of the Uvalde well, which is west of the Knippa Gap, approximately 120 miles to the southwest. The correlations between the indicator wells and San Marcos Springs are not so strong as the correlation between the indicator wells and Comal Springs. This result is expected, since local recharge is a larger component of the flow of San Marcos Springs than at Comal Springs (Rothermel and Ogden 1987, 138, 139). The discharge from San Marcos Springs consists of water passing underneath the Comal Springs area and from local recharge in northern Comal and Hays Counties (Texas Department of Water Resources 1979, 61). This local recharge is not intercepted by withdrawals in Bexar County. The spring openings at Comal Springs are higher then at San Marcos Springs, 612 ft msl as opposed to 573 ft msl. Therefore, the San Marcos Springs can continue to receive flow from the western

Table 31. Pearson Bivariate Correlation Coefficients (2-tailed Significance) between San Marcos Springs and All Three EAA Indicator Wells

	J-17	Hondo	Uvalde
San Marcos Springs	.6963	.6821	.3934
Number of Cases	15107	3839	14618
Significance Level	.000	.000	.000

portions of the aquifer after Comal Springs has ceased to flow. This fact was confirmed when Comal Springs ceased to flow during the drought of record in 1956, while San Marcos Springs continued to flow, although at a significantly reduced rate. Wanakule (1988, 27) also concluded that the "groundwater flow paths between Comal and San Marcos Springs are complex and contain discontinuities due to faults and differences in elevation of the major flow channels."

I did an additional analysis to determine whether the correlation between San Marcos Springs and the index wells varied with different ranges of flows at the springs. Table 32 through Table 34 show the results of correlations at ranges corresponding to greater than 100 cfs (above both take and jeopardy conditions) and 100 cfs or less (during take and jeopardy conditions). These results show that the correlations between the level of the Hondo and Uvalde index wells and the flow of San Marcos Springs varied significantly over specified ranges. When San Marcos Springs was less than 100 cfs, the correlation with the Hondo well decreased substantially below the correlation over the entire range of flows (Table 33). This reduction in the strength of the correlation when San Marcos Springs is 100 cfs or less is significant, because the May 1999 CPMP and other drought management plans are designed for use during periods of low flow at the springs, when the effectiveness of this index well as trigger mechanism declines. For the Uvalde well the correlation when San Marcos Springs was 100 cfs or less increased significantly above the correlation for the entire range of flows (Table 34).

Table 32. Pearson Bivariate Correlation Coefficients (2-tailed Significance) between San Marcos Springs and the J-17 Indicator Well for Specified Ranges

	San Marcos Springs ≥101 cfs	San Marcos Springs ≤100 cfs
J-17	.6122	.6663
Number of Cases	13593	1514
Significance Level	.000	.000

Table 33. Pearson Bivariate Correlation Coefficients (2-tailed Significance) between San Marcos Springs and the Hondo Indicator Well for Specified Ranges

	San Marcos Springs ≥101 cfs	San Marcos Springs ≤100 cfs
Hondo	.6224	.1390
Number of Cases	3413	426
Significance Level	.000	.004

Table 34. Pearson Bivariate Correlation Coefficients (2-tailed Significance) between San Marcos Springs and the Uvalde Indicator Well for Specified Ranges

	San Marcos Springs ≥101 cfs	San Marcos Springs ≤100 cfs
Uvalde	.2306	.7377
Number of Cases	13103	1515
Significance Level	.000	.000

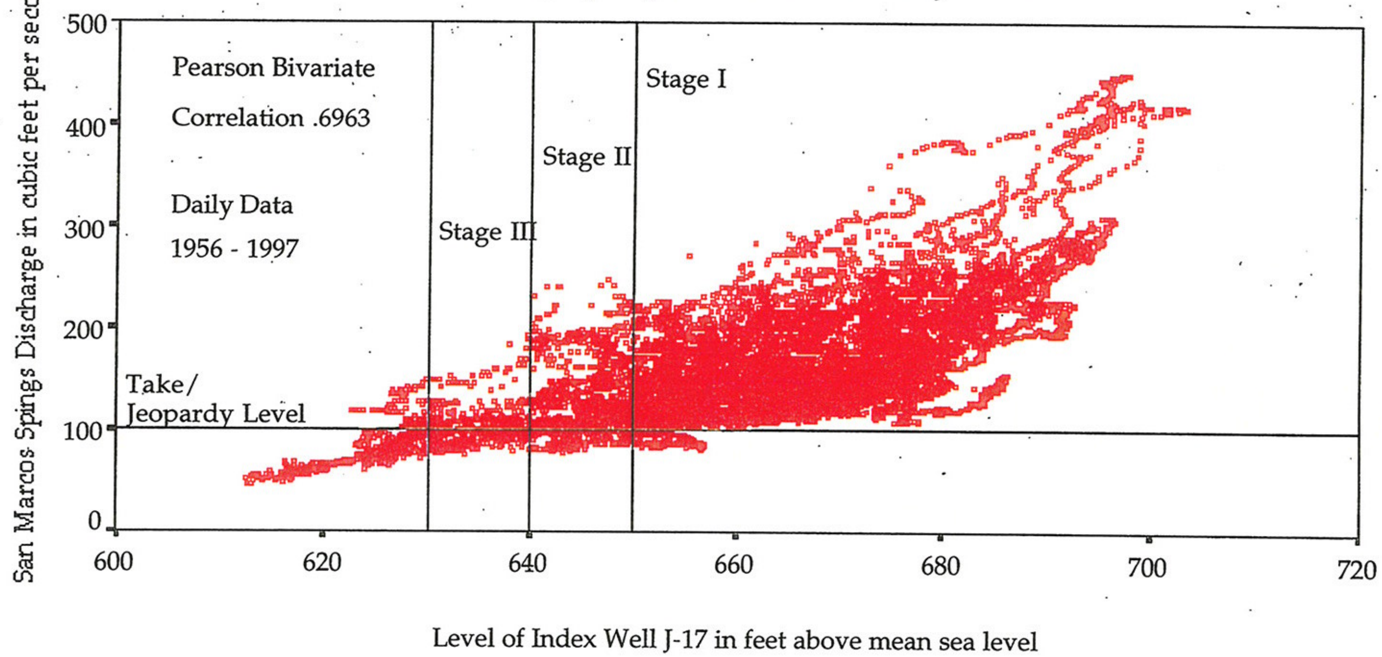
An Evaluation of the Trigger Levels in the May 1999 CPMP Relating to the San Marcos Springs

I have examined the EAA's May 1999 CPMP to determine whether the trigger levels adopted by the EAA would have restricted groundwater withdrawals from the aquifer prior to take and jeopardy flow levels at San Marcos Springs during the historical period for which data exist. In Table 35 the range of San Marcos Springs discharge rates based on the scatterplots in Figure 17 through Figure 19 are summarized. When the flow from San Marcos Springs diminishes below 100 cfs, take and jeopardy for the endangered fountain darter can occur (Table 11). For J-17, Table 35 shows that San Marcos Springs flow has ranged from 85 cfs to 230 cfs when J-17 is at 650 ft msl, the trigger for Stage I conservation measures. Table 35 shows that San Marcos Springs flow has ranged from 80 cfs to 210 cfs when J-17 is at 640 ft msl, the trigger for Stage II conservation measures. It also shows that San Marcos Springs flow has ranged from 75 cfs to 150 cfs when J-17 is at 630 ft msl, the trigger for Stage III conservation measures. For each of the groundwater index wells, take and jeopardy conditions would have occurred in some years prior to the initiation of each stage of the May 1999 CPMP using the proposed trigger levels.

Cumulative frequencies for flows corresponding to the May 1999 CPMP stages were calculated by separating data for each index well into ranges represented by the dummy variables found in Table 26. For each dummy variable, the number of days during which San Marcos Springs discharge was above the 100 cfs take and jeopardy level, and within the range of take and jeopardy flows of 100 cfs of less, was tabulated.

Figure 17. Scatterplot of San Marcos Springs Flow and Well J-17 Level

Take and Jeopardy Levels and EAA May 1999 CP



MP Trigger Levels Indicated

Figure 18. Scatterplot of San Marcos Springs Flow and Hondo Well Level

Take and Jeopardy Levels and EAA May 1999 CPMP Trigger Levels Indicated

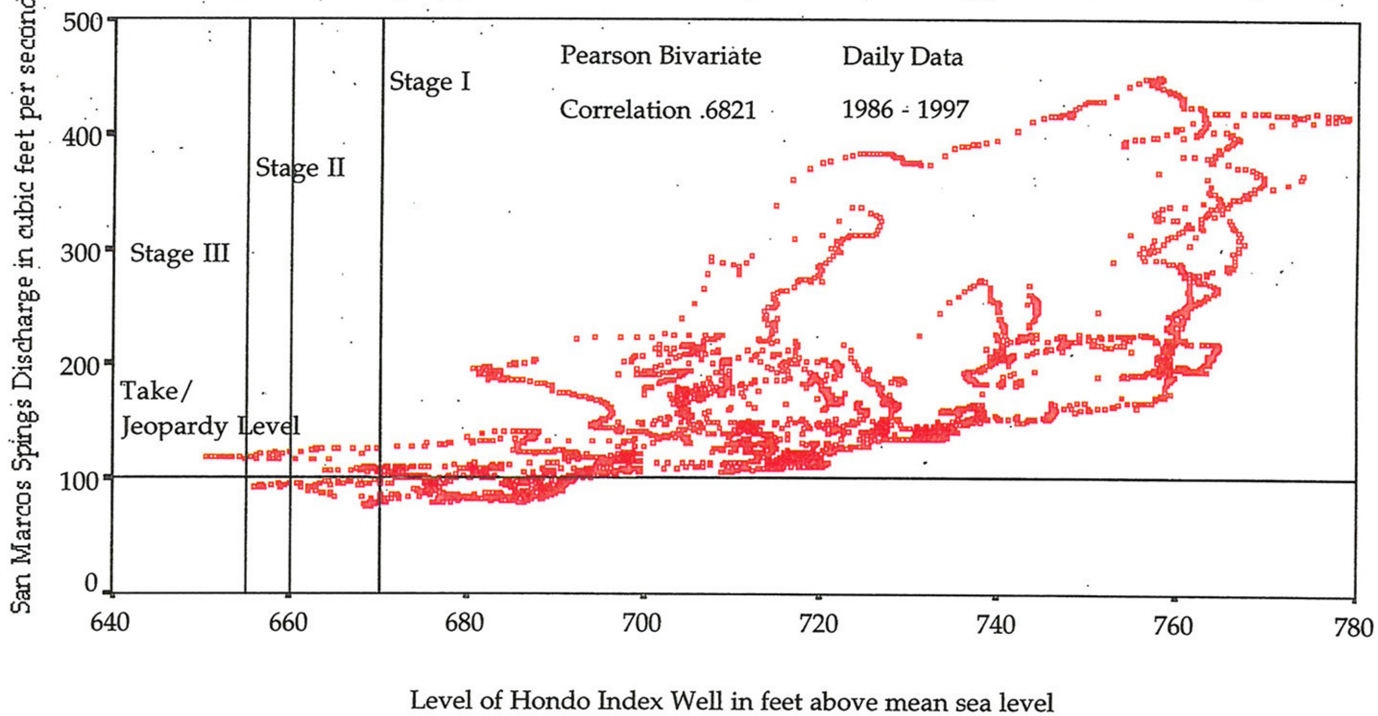


Figure 19. Scatterplot of San Marcos Springs Flow and Uvalde Well Level

Take and Jeopardy Levels and EAA May 1999 CPMP Trigger Levels Indicated

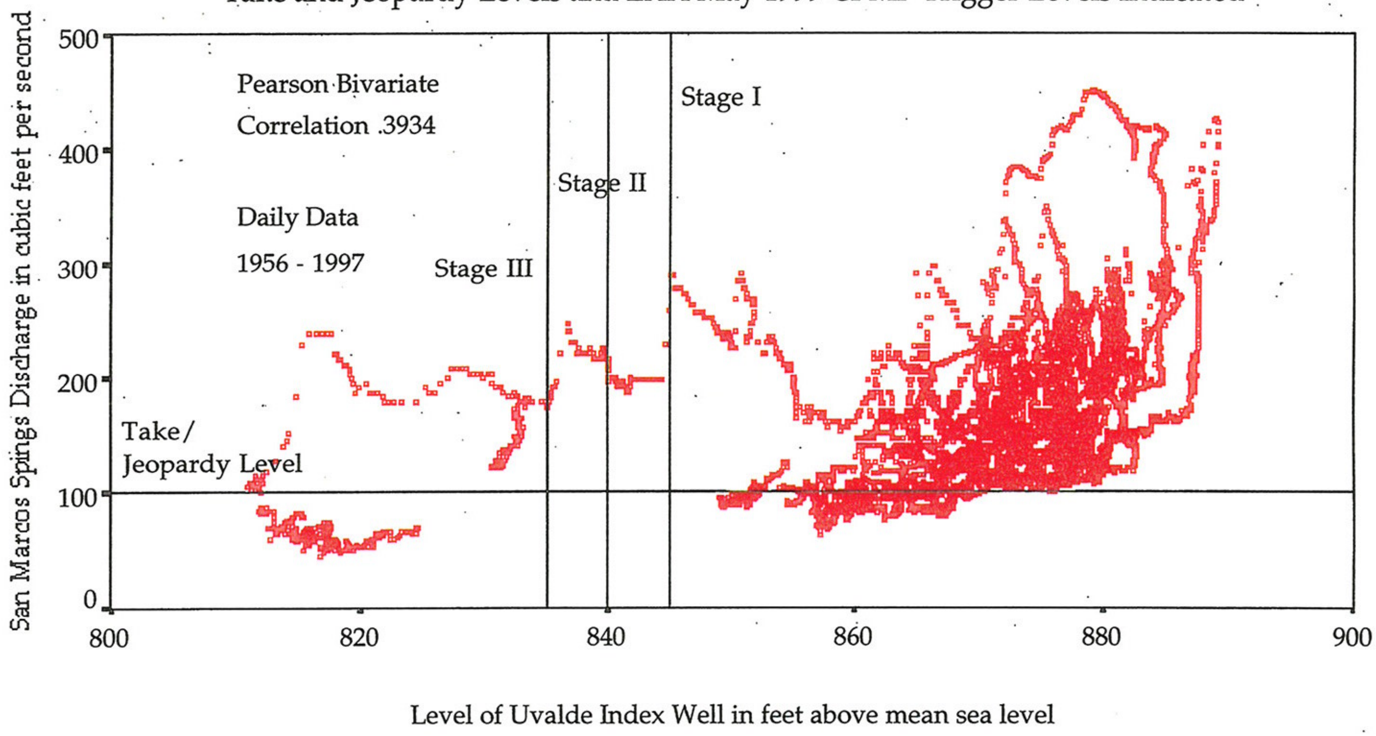


Table 35. Range of Flows at San Marcos Springs Corresponding to Key Trigger Levels in the EAA's May 1999 CPMP

Index Well	Stage	Trigger Level	San Marcos Springs
J-17	I	650	85 - 230
J-17	II	640	80 - 210
J-17	III	630	75 - 150
Hondo	I	670	80 -125
Hondo	II	660	90 - 120
Hondo	III	655	UTD
Uvalde	I	845	UTD
Uvalde	II	840	UTD
Uvalde	III	835	UTD

UTD = Unable to determine

The results of these crosstabulations are contained in Table 36 through Table 38. Table 32 through Table 34 show that the correlations between all of the index wells and San Marcos Springs do not decrease at critical flows in a similar pattern as do those found between the index wells and Comal Springs discharge when the flow rate is between 151 and 200 cfs. This result does not contradict Wanakule's conclusion that the discontinuity exists at 639 feet msl for J-17, since San Marcos Springs is located at a lower elevation (Wanakule 1988, 14).

Table 36 shows that there were 284 days during the period 1956 through 1997 when J-17 was higher than 650 ft msl and San Marcos Springs flow was below 100 cfs. This indicates that jeopardy conditions would have been occurring for the fountain darter at San Marcos before the initial CPMP stage would have been triggered. Historically, 19% of the days when San Marcos Springs was at or below 100 cfs (jeopardy), J-17 would not yet have reached Stage I of the EAA's May 1999 CPMP. With Stage I in effect and J-17 between 650 and 640 ft msl, San Marcos Springs would have been at the jeopardy level on some 365 days. On a percentage basis during Stage I jeopardy conditions would have occurred 26% of the time historically. For Stage II, San Marcos Springs has ranged from 80 cfs to 210 cfs when J-17 was at 640 ft msl. On a percentage basis during Stage II jeopardy conditions would have occurred 57% of the time historically. Stage III would have been initiated when J-17 reached 630 ft msl which corresponds to 75 cfs to 150 cfs at San Marcos Springs. On a percentage basis during Stage III jeopardy conditions would have occurred 82% of the time historically.

Table 36. Crosstabulation of Number of Days of Key San Marcos Springs Flows and Key Levels of J-17 Index Well, May 1956 – December 1997

	J-17 >650 ft msl	Stage I: J-17 ≤650, >640 ft msl	Stage II: J-17 ≤640, >630 ft msl	Stage III: J-17 ≤630 ft msl	Row Total
San Marcos >100 cfs	12191	1019	269	114	13593
San Marcos ≤100 cfs	284	365	357	508	1514
Column Total	12475	1384	626	622	15107

Table 37. Crosstabulation of Number of Days of Key San Marcos Springs Flows and Key Levels of Hondo Index Well, September 1986 – December 1997

	Hondo >670 ft msl	Stage I: Hondo ≤670, >660 ft msl	Stage II: Hondo ≤660, >655 ft msl	Stage III: Hondo ≤655 ft msl	Row Total
San Marcos >100 cfs	3346	39	12	16	3413
San Marcos ≤100 cfs	358	56	12	0	426
Column Total	3704	95	24	16	3839

Table 38. Crosstabulation of Number of Days of Key San Marcos Springs Flows and Key Levels of Uvalde Index Well, May 1956 – December 1997

	Uvalde >845 ft msl	Stage I: Uvalde ≤845, >840 ft msl	Stage II: Uvalde ≤840, >835 ft msl	Stage III: Uvalde ≤835 ft msl	Row Total
San Marcos >100 cfs	12764	67	68	204	13103
San Marcos ≤100 cfs	1215	0	0	300	1515
Column Total	13979	67	68	504	14618

Figure 18 shows the relationship between San Marcos Springs and the Hondo index well. Historically, 84% of the days when San Marcos Springs was at or below 100 cfs (jeopardy), the Hondo well would yet to have reached Stage I of the EAA's May 1999 CPMP. Stage I and Stage II would not always have been initiated prior to jeopardy conditions. Table 37 shows that for Stage I, 59% of the days when the Hondo index well would have been at Stage I, jeopardy would have been occurring at San Marcos Springs. The percentage is 50% for Stage II. However, because measurements are only available for the Hondo well beginning in 1986, significantly less than for J-17 and the Uvalde well, only a small number of days satisfying the necessary conditions are available for analysis.

For San Marcos Springs and the Uvalde well, there is a very wide range of corresponding flows to the CPMP Stages, but this was to be expected given the relatively low positive correlation between the two. Historically, 80% of the days when San Marcos Springs was at or below 100 cfs (jeopardy), the Uvalde well would yet to have reached Stage I of the EAA's May 1999 CPMP. Stage I and Stage II have always have been initiated prior to jeopardy conditions. During Stage III jeopardy conditions would have occurred 60% of the time historically. However, Table 39 shows that if the trigger levels used in the May 1999 CPMP had been in effect during the years when flows were less than 100 cfs, the CPMP would have been triggered in Uvalde County only during the last two years of the drought of record in 1956 and 1957, but not since. This indicates that, as with Comal Springs, the burden for reducing pumping under the CPMP to protect endangered species in San Marcos Springs would have been placed disproportionately upon Edwards Aquifer users in Bexar, Caldwell, Comal, Hays and Guadalupe Counties, and to a lesser extent in Medina and Atascosa Counties. As a result pumping reductions would come primarily from municipal water instead of agricultural water use. Table 39 provides similar results showing that it is an extremely rare event for the Uvalde index well to have declined to the levels selected by the EAA to trigger the May 1999 CPMP in that county.

Discussion

In the event of a repeat of the historical record of Edwards Aquifer conditions, trigger levels for conservation measures proposed by the Edwards Aquifer Authority in its May 1999 CPMP will likely fail to achieve the desired result of protecting minimum Comal and San Marcos Springs and downstream flows in some years. These analyses for Comal and San Marcos Springs demonstrate that the EAA's May 1999 CPMP will rarely trigger conservation measures across the aquifer in advance of violations of the ESA at either of the springs. Further, during periods of critical low flows, the Comal Springs flow is the most reliable trigger for pumping reductions. In addition, Table 30 and Table 39 raise the question why such high levels were chosen to initiate conservation measures in Uvalde County when such measures would not have been initiated when Comal or San Marcos Springs were historically below take and jeopardy flows, with the exception of the final years of the drought of record.

Table 39. A Comparison of the EAA's May 1999 CPMP Trigger Levels and Critical Flows at San Marcos Springs

The (x) denotes the CPMP stages that would have been initiated historically using the trigger levels in years when San Marcos Springs was below 100 cfs.*

Stage/ Trigger Level	1956 T/J 220*	1957 T/J 80	1963 T/J 156	1964 T/J 231	1965 T/J 19	1967 T/J 154	1978 T/J 2	1971 T/J 19	1984 T/J 193	1989 T/J 148	1990 T/J 87	1996 T/J 180	1997 T/J 46
Stage I, J-17 ≤ 650, > 640	X	X	X	X	X	X	X	X	X	X	X	X	X
Stage II, J-17, ≤ 640, > 630	X	X	X	X		X		X	X	X	X	X	
Stage III, J-17, ≤ 630	X	X				X		X	X	X	X	X	
Stage I, Hondo, ≤ 670, > 660	NA	NA	NA	NA	NA	NA	NA	NA	NA	X	X	X	
Stage II, Hondo, ≤ 660, > 655	NA	NA	NA	NA	NA	NA	NA	NA	NA		X	X	
Stage III, Hondo, ≤ 655	NA	NA	NA	NA	NA	NA	NA	NA	NA		X		
Stage I, Uvalde, ≤ 845, > 840	X	X											
Stage II, Uvalde, ≤ 840, > 835	X	X											
Stage III, Uvalde, ≤ 835	X	X											

*Springflow data for San Marcos Springs available from the USGS beginning 1956.
T/J = Number of days below 100 cfs take and jeopardy level.
NA = Hondo Well level measurements available beginning in 1986.
Note: J-17 triggers water conservation measures in Bexar, Caldwell, Comal, Hays and Guadalupe Counties; the Hondo well triggers measures in Hondo and Atascosa Counties; and the Uvalde well triggers measures in Uvalde County.

Article 1, §1.26(4) of Senate Bill 1477 requires that the CPMP reduce nondiscretionary industrial and crop irrigation water use to a greater extent than municipal, domestic, and livestock use. The May 1999 CPMP apparently does not satisfy this provision because, during most historical periods when Comal and San Marcos Springs were below critical levels, the CPMP would not have been triggered in Uvalde County using the water levels proposed for the Uvalde index well. This places the burden for pumping reductions primarily upon Bexar, Comal, and Hays Counties where conservation measures are triggered by the J-17 index well, and to a lesser extent on Medina and parts of Atascosa County, triggered by the Hondo index well. This research demonstrates that during droughts, the May 1999 CPMP will reduce municipal water use, primarily in San Antonio, rather than crop irrigation, particularly in Uvalde County. The results also contradict the claim made by irrigators that the Knippa Gap isolates their actions from impact on flows at the springs; and that therefore, the pumping of those west of the Gap should not be regulated or be subject to the Endangered Species Act to maintain adequate spring discharge. Groundwater pumpers in Medina and Uvalde Counties, primarily irrigators, benefit by using local index wells to avoid water use reductions during many low spring discharge periods.

The focus for management plans should be flow at Comal and San Marcos Springs as direct measures of aquifer conditions as opposed to using less effective indirect indicators because using the index well levels will not trigger reductions prior to critical spring discharges being reached. Variations in spring discharges corresponding to the index wells' water levels clearly illustrate the problems of using well levels as proxies to initiate conservation measures. Even though the correlation in some instances is very high, for example between the annual means of Comal Springs and J-17, substantial variations exist, which appear to increase as Comal Springs flow declines. It is when the discharge rate is declining that the relationship between the springs and the index wells becomes critical for triggering conservation measures. Because of the wide range of spring discharges corresponding to specific index well levels, simply raising the index well trigger levels is not an adequate solution. Raising the index well trigger levels would significantly increase the number of instances when the CPMP would be initiated when spring discharge is far above the take and jeopardy levels. As previously discussed in Chapter 6, Senate Bill 1477 clearly states that the EAA is to comply with the ESA. Restrictions on withdrawals are designed, in part, to protect the endangered species and guarantee minimum flows in the Guadalupe River basin. The use of index wells rather than spring discharge as trigger levels calls into question the chosen method to assure this compliance. The USFWS has recommended to the EAA that CPMP, "Trigger levels should be based on springflow rates at Comal (and possibly San Marcos), rather than index well levels" (Frederick 1998). The trigger flow rates and reduction rates that the USFWS proposed are in Appendix 3 (Item 8. A Summary of the USFWS Recommendations to the Edwards Aquifer Authority for Trigger Levels); they should be adopted for use with the EAA's CPMP. This research supports the use of spring discharges rates over index wells to minimize future EAA conflicts with the USFWS' application of the ESA. There is simply no significant practical reason why Comal Springs flow, and possibly San Marcos Springs, cannot be used to trigger various stages of drought management plans.

For example, during the occasional instances when San Marcos Springs reaches jeopardy before Comal Springs reaches take, conservation measures should be initiated.

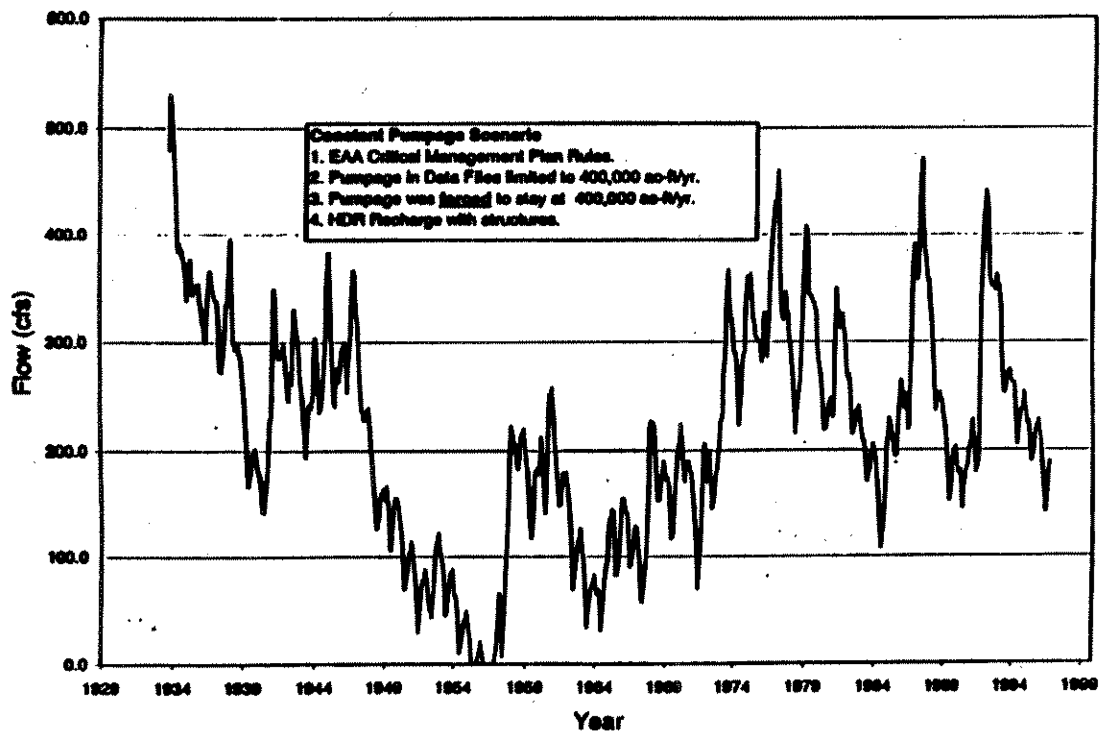
Finally, in 1994, New Braunfels Utilities switched from dependence upon Edwards groundwater to surface water from the Guadalupe River (Moore and Votteler 1995a). While the pattern of rainfall was responsible for the manner in which the springs responded during 1999, it might be that the reduction of pumping by New Braunfels has significantly influenced the relationship between Comal Springs and pumping from the aquifer west of Comal County. In April 1996, San Marcos entered into an agreement with the GBRA for a regional project to supply up to 5,000 acre-feet per year of treated water to the city and adjacent water utilities through a diversion and transmission facilities from Lake Dunlap (Votteler 1996, 12). The treatment plant has been completed and is operational. San Marcos will begin using surface water as its primary source in 2000 (Moore 1999). Once both cities are using surface water and enough time has accumulated for significant data to be collected, the relationships between Comal and San Marcos Springs and the index wells should be reexamined to determine whether a difference still exists.

The GWSIM-IV Model and the CPMP

The EAA's 1998 CPMP (outlined in Appendix 3, Item 9) was modeled by the TWDB using their GWSIM-IV model (Kabir, Bradley, and Chowdhury 1999). The assumptions in the model run included recharge estimates developed by HDR Engineering, Inc. as opposed to those calculated by the USGS. The HDR estimates were generally higher than those of the USGS (Bradley 1999). The assumptions used in the first model runs forced pumping to be limited in each year to 400,000 acre-feet, which required permitted irrigation water use to be reduced to 59% of what the EAA proposed in April 1998, and apparently did not include allowance for any pumping for domestic and livestock use (Kabir, Bradley, and Chowdhury 1999). The TWDB estimated that without reducing irrigation to 59% of the proposed amount, pumping would have been 496,699 acre-feet. Actual historical annual pumping did not reach 400,000 acre-feet until 1971 (U.S. Geological Survey 1999, 2). This figure includes all irrigation pumping, plus estimated domestic and livestock pumping of 12,000 acre-feet, which is probably less than actual pumping for this category of water use. The period included in the runs was 1934 to 1996. This run resulted in Comal Springs ceasing to flow throughout more of the drought of record than what actually occurred, with zero flow during portions of 1955, 1956 and 1957 (Figure 20). Comal Springs flow was less than 200 cfs during much more of this simulated run than during the actual period of record. For example, the model results frequently show jeopardy flows during the entire 1947 to 1957 period for Comal Springs, while, in reality, jeopardy flows occurred only in 1956 and 1957. While San Marcos Springs continued to flow, it frequently declined below the 100 cfs jeopardy level throughout the 1956 – 1996 period.

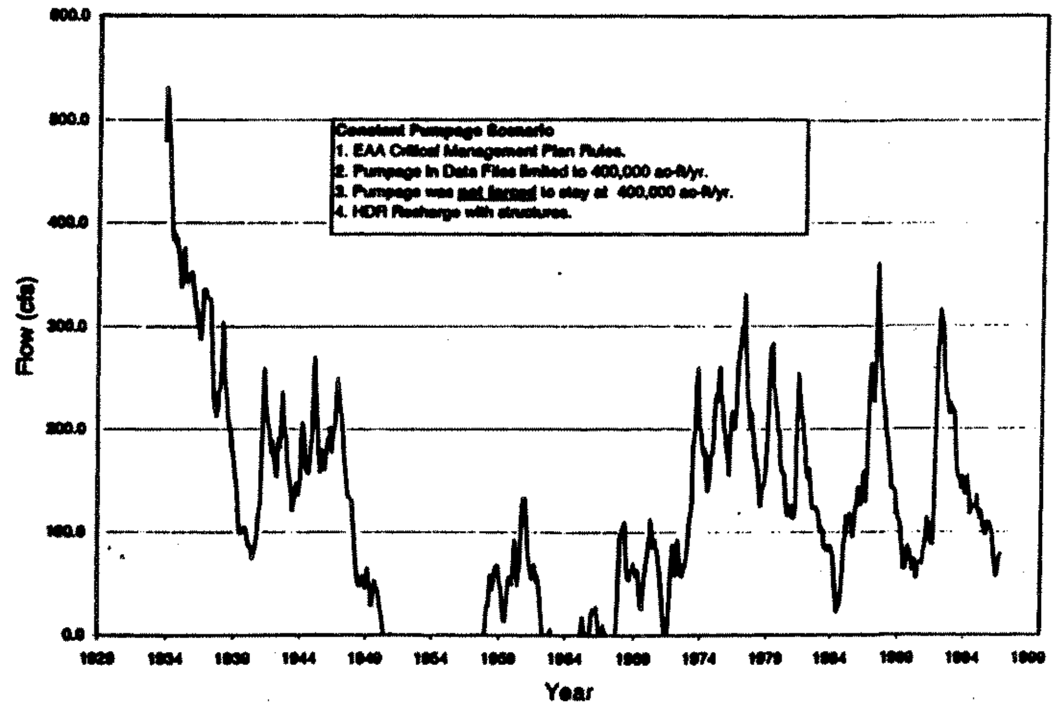
The second run (Figure 21) also was based upon the EAA's 1998 CPMP. In this simulation, pumping was not forced to remain at 400,000 acre-feet. This run demonstrated that under the 1998 CPMP, pumping actually increased to 500,000 acre-feet or more during almost the entire period from 1934 to 1999 when the CPMP was activated. This resulted in zero flow at Comal Springs throughout

Figure 20. 1998 *Critical Period Management Plan* Simulated Flow at Comal Springs, with Annual Pumping Artificially Constrained to 400,000 acre-feet



(Kabir, Bradley, and Chowdhury 1999).

Figure 21. 1998 *Critical Period Management Plan* Simulated Flow at Comal Springs, Without the Annual Pumping Limit Constrained



(Kabir, Bradley, and Chowdhury 1999).

most of the drought of record as well as much of the 1960's, with flow ceasing from 1951 to 1958 and much of the period from 1962 to 1968, and again in 1972. Comal Springs flow was less than 200 cfs and 150 cfs during much more of this simulated run than during the actual period of record. San Marcos Springs continued to flow, but it was below 100 cfs for much of the period from 1947 to 1973 and occasionally thereafter.

9. PREDICTING CRITICAL SPRING DISCHARGE PERIODS AND TAKING PREEMPTIVE ACTION

Introduction

This chapter examines methods for predicting years of critical spring discharge before they occur. The previous chapter demonstrated that critical spring discharge rates are good indicators of low groundwater levels in the Edwards Aquifer. Potential predictors of diminished spring discharge rates are examined. The ability to forecast critical period years at the springs would aid in the sustainable management of the aquifer and could help to avoid violations of the Endangered Species Act and transboundary disputes during low rainfall and recharge periods. The analysis focuses primarily on indicators related to Comal Springs.

Existing Drought Prediction Tools

A component of drought prediction is the identification of indicators of emerging hydrologic drought conditions or early warning indicators. The lack of appropriate early warning indicators has been identified as one of the deficiencies in the crisis management approach to drought assessment, mitigation, preparation, and response (Wilhite 1996, 231). Attempts have been made to predict droughts in the Edwards region. For example, predictions that a repeat of the drought of record was to begin between 1978 and 1981 were incorrect (Coastal Ecosystems Management 1975, 4).

Several drought indices have been developed for use in monitoring droughts. The Palmer Drought Severity Index (PDSI) and Standard Precipitation Index (SPI) are two indices that measure deviations in precipitation from historically established norms (Hayes 1996, 1). PDSI and SPI are often referred to as meteorological drought indices. However, these indices do not consider human impacts on the water balance associated with hydrologic drought (Hayes 1996, 2). The most widely used drought index in the U.S. is PDSI developed in 1965 (Hayes and others 1999, 429). PDSI responds to abnormally wet or dry weather conditions (Hayes 1996, 2). It is based on anomalies in the supply and demand reflected in the water balance equation (Hayes and others 1999, 430). On a weekly or monthly basis, data for precipitation, temperature, and soil moisture conditions are collected and standardized and regional differences rationalized to allow comparison of PDSI values among different parts of the country (Hayes and others 1999, 430). Some states use PDSI values to trigger drought management plans (Hayes and others 1999, 430). However, PDSI values have several significant limitations for monitoring droughts, including: (1) the timescale makes PDSI preferable for monitoring agriculturally related impacts rather than long-term hydrological impacts; (2) all precipitation, even snow, is treated as rainfall, and frozen soil conditions are not considered, making winter PDSI values questionable; (3) runoff is underestimated because the natural lag between rainfall and runoff is not considered, and no runoff occurs until the water capacities of the surface and subsurface soil layers are full; (4) severe and extreme PDSI classifications vary widely depending on location; (5) PDSI does not work well in areas where there are extremes in the variability of rainfall or runoff; (6) PDSI can respond slowly to developing drought conditions; and (7) PDSI can retain values reflecting drought long after a climatological recovery from drought has occurred (Hayes and others 1999, 430); (Smith, Hutchinson, and McArthur 1993, 11, 12). The Palmer Hydrological Drought Index (PHDI), a variation of the PDSI, is a hydrologic, instead of a meteorological, index based on moisture inflow (precipitation), outflow, and storage (Hayes 1996, 3). PHDI has been criticized for not taking into account long-term trends (Hayes 1996, 3). Also, man-made changes such as increased irrigation, new reservoirs, and added industrial water use are not included in PHDI (Longley 1995, 110).

In 1993, a new index, the Standardized Precipitation Index, was developed at Colorado State University to address some of the problems with PDSI (Hayes and others 1999, 429, 430). The SPI is a simple index for use in all seasons as a supplement to the PDSI and another drought index, the Surface Water Supply Index (Hayes and others 1999, 430). SPI is based solely on precipitation and can be calculated for many time scales for any location where monthly precipitation data are available for 30 years or more (Hayes and others 1999, 430). SPI can be used to monitor short-term and long-term water supply conditions, including groundwater (Hayes and others 1999, 430). However, like PDSI, SPI also has significant limitations, including: (1) limited coverage in the western U.S. where terrain differences increase spatial variability of climatic variables; (2) inability to identify drought prone regions; (3) knowledge of regional climatology is required before SPI can be applied; and, important for the Edwards Aquifer, (4) SPI maps for the previous months are usually unavailable until the second or third week of the following month (Hayes and others 1999, 432).

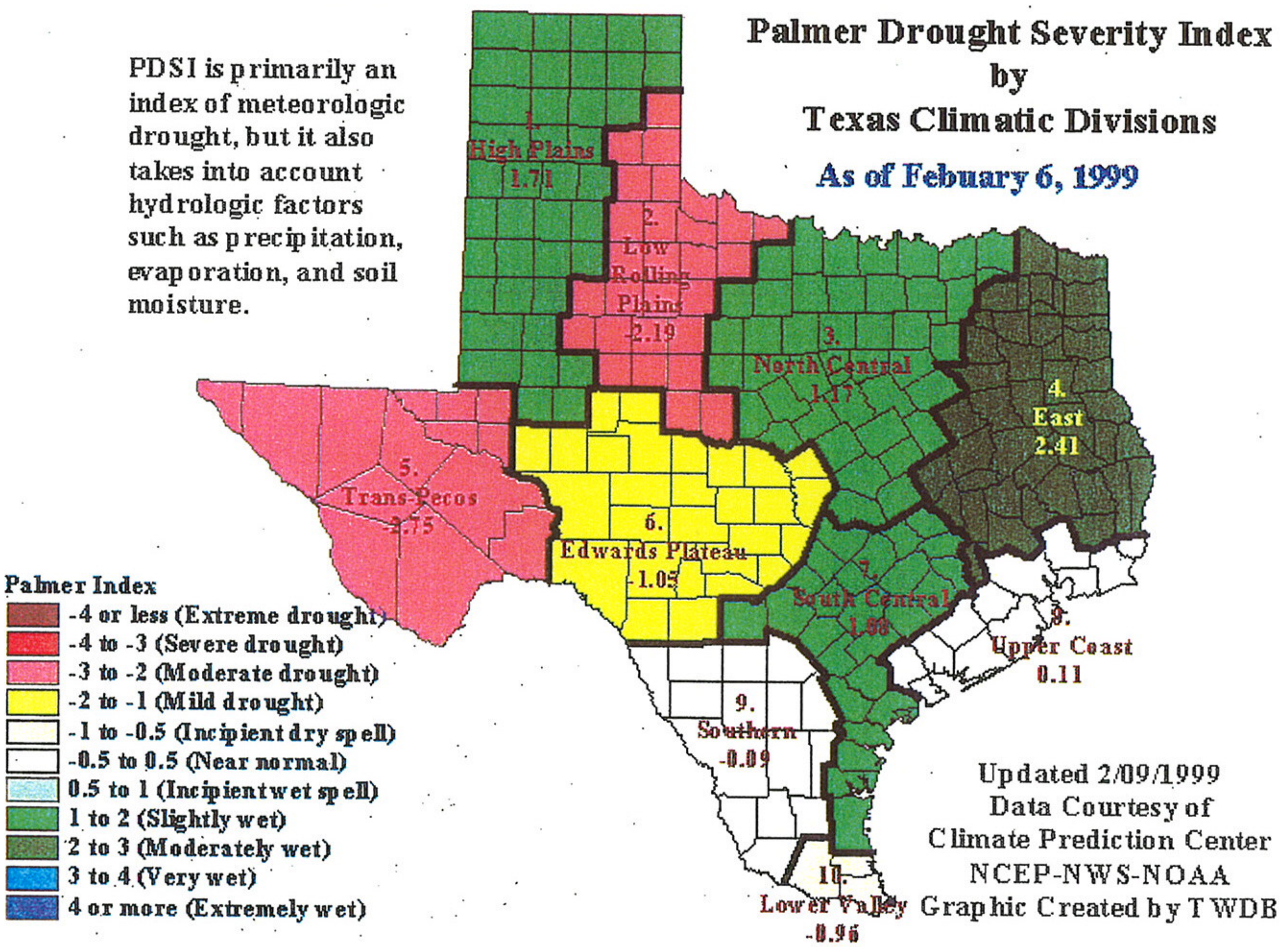
The older index, PDSI, has been used more widely to trigger drought management plans than SPI (Hayes 1996, 3, 6). The surface conditions reflected in PDSI and SPI can be a clue to future groundwater pumping rates as the demand for water for agricultural and ornamental plant irrigation increases; however, I am specifically interested in the Comal and San Marcos Springs, not the Edwards Aquifer as a whole. Drought indices and predictors of low spring discharge are not the same. Drought indices do not consider the antecedent hydrologic conditions of the aquifer, and are therefore, less reliable predictors of low spring discharge. Because PDSI does not measure hydrologic drought, it has limited use for the current conditions within an aquifer. PDSI and SPI can indicate the presence of drought while there is no hydrologic drought. An example is a year when rainfall has been minimal and soil moisture conditions are low, but excessive recharge in a previous year has fully recharged the aquifer, such as occurred in the Edwards Aquifer in 1993 and 1994 after the record recharge in 1992 and in 1999 after flooding across the region in 1998. These indicators can also indicate that drought does not exist when hydrologic drought conditions are present. An example is a year when rainfall has been sufficient to return soil moisture conditions to near normal, but the aquifer has not been fully recharged.

One study has compared the six month SPI map for October 1995 through March 1996 with the PDSI map for March 30, 1996 (Hayes and others 1999, 433, 434). The comparison showed that SPI values generally declined during this period across the Edwards Plateau Climatic Division, while the PDSI map did not show that drought conditions had begun (Hayes and others 1999, Figure 1, 433, 434). However, in April 1996, flow at Comal and San Marcos Springs had reached critical levels. The PDSI map did not reflect the true severity of the 1996 drought until mid-May (Hayes and others 1999, 434).

By contrast, in Figure 22, the February 1999 PDSI map showed the Edwards Plateau Climatic Division in mild (almost moderate) drought and the South Central Texas Climatic Division as slightly wet, at a time when the discharge rates at Comal and San Marcos Springs were far above normal (National Climate Data Center 1999). In Figure 23 the February 1999, one-month SPI values for the Edwards Plateau and South Central Texas Climatic Divisions indicated severely dry conditions (National Drought Mitigation Center 1999a). For February 1999, two-month SPI values for the Edwards Plateau and South Central Texas Climatic Divisions indicated extremely dry conditions (National Drought Mitigation Center 1999c). The February 1999, three-month SPI value for the Edwards Plateau Climatic Division indicated severely dry conditions (National Drought Mitigation Center 1999d). The February 1999, three-month SPI value for the South Central Texas Plateau Climatic Division indicated extremely dry conditions (National Drought Mitigation Center 1999d); yet on February 10, 1999, discharge from Comal Springs was 366 cfs (117% of the monthly norm) and from San Marcos Springs was 296 cfs (185% of the monthly norm) (Guadalupe - Blanco River Authority 1999b, 1).

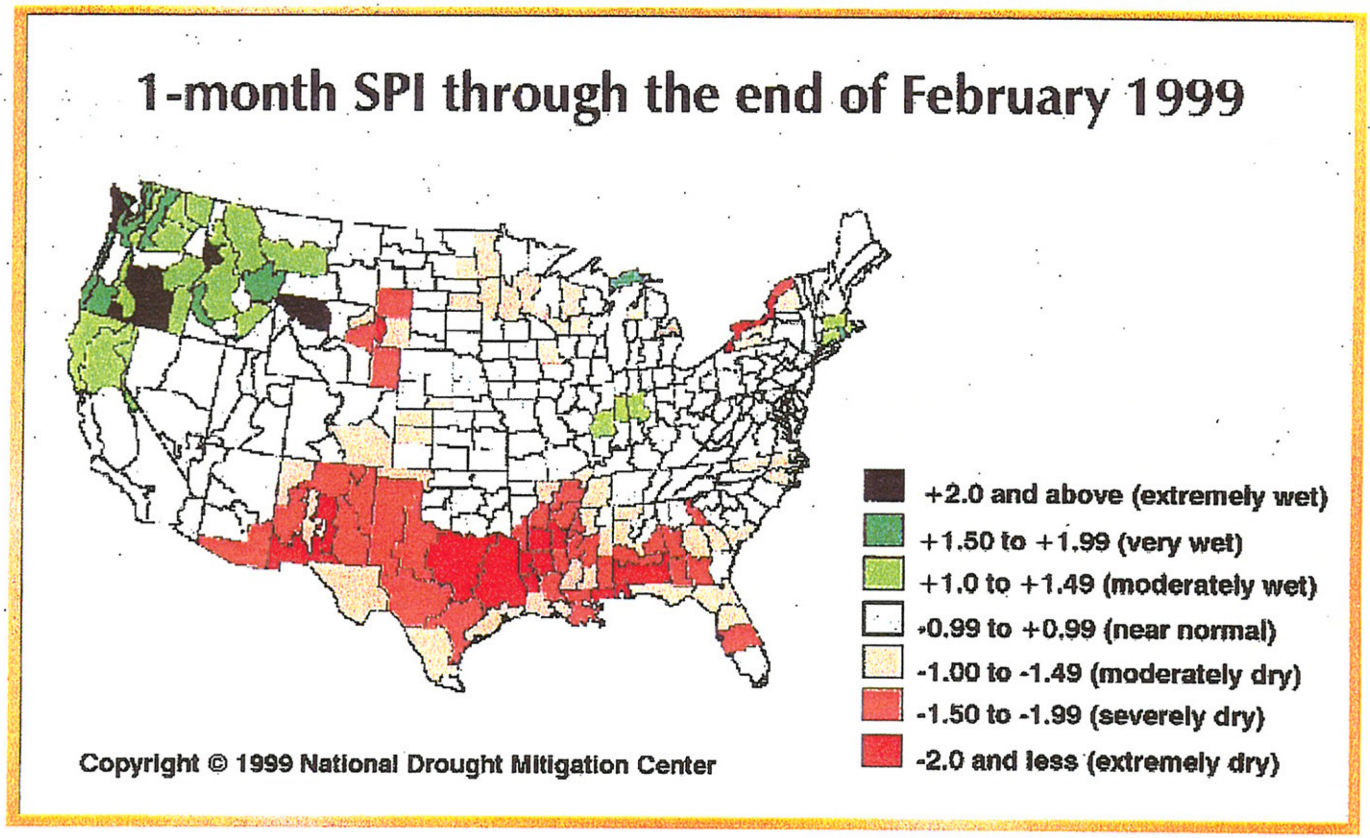
As another example, on August 14, 1999, the PDSI map showed the Edwards Plateau and South Central Texas Climatic Divisions in mild drought (National Climate Prediction Center 1999), yet the discharge rate at Comal Springs was still above normal. On August 11, 1999, discharge from Comal

Figure 22. Palmer Drought Severity Index Map for February 1999



(National Climate Data Center 1999)

Figure 23. Standardized Precipitation Index Map for One Month through February 1999



(National Drought Mitigation Center 1999a)

Springs was 323 cfs (130% of the monthly norm) and from San Marcos Springs was 151 cfs (91% of the monthly norm) (Guadalupe - Blanco River Authority 1999a, 1). The July 1999, one-month and three-month SPI values (two-month values were not available) for the Edwards Plateau and South Central Texas Climatic Divisions indicated near normal conditions (National Drought Mitigation Center 1999b); (National Drought Mitigation Center 1999e).

Some authors have suggested the use of the PDSI to anticipate droughts in South Texas (Stahle and Cleaveland 1988); (Longley 1995). Longley (1995) examined Palmer Drought Indices and concluded that severe droughts occurred over the Edwards Aquifer watershed in 1902, 1909-11, 1917-18, 1925, 1934, 1939, 1951-57, 1962-64, 1967, 1971, 1974, 1978, 1980, 1984 and 1989 (Longley 1995, 111). Yet droughts and periods of low spring discharge are not always the same. When comparing the same years identified by Longley with years when Comal Springs declined to the critical flow level of 200 cfs or less, I found that Comal Springs flow was not below that critical level in many of those years. From discharge data available beginning in 1927, critical flows were not reached in the following years identified as experiencing severe drought; 1934, 1939, 1974, and 1978. Withdrawals during 1934 and 1939 had not yet reached the 300,000 acre-feet level; however, in 1974 and 1978 withdrawals were 377,400 and 431,800 acre-feet respectively (U.S. Geological Survey 1998, 3). In addition, the following years, not identified by Longley (prior to 1995) as severe drought years using PDSI, experienced critical flows at Comal Springs: 1983, 1985, 1990, and 1991. During the 1980's withdrawals from the aquifer reached their highest levels.

Indicators designed specifically for the Edwards Aquifer are needed, because specific predictors based on characteristics of the aquifer could be more accurate than a general tool, such as PDSI or SPI, designed for comparing regional conditions across the U.S. Indicators designed specifically for the Edwards Aquifer region have advantages because they:

- Minimize the costs of inaccurate predictions that might cause the premature initiation of drought measures;
- Allow management decisions to be made sufficiently in advance to minimize transboundary disputes between groundwater pumpers and surface water users in the Guadalupe River basin; and
- Facilitate the use of groundwater on a sustainable basis.

The potential consequences of Comal and San Marcos Springs ceasing to flow, which were identified in Chapter 8, make it imperative that indicators be developed to signal to those dependent upon the aquifer when measures to reduce withdrawals from the aquifer should be initiated. I have identified variables to anticipate future periods of critical spring discharges so that conservation measures can be initiated sufficiently in advance to avoid critically low spring discharges.

Different measures are needed to cope with droughts of differing lengths and severity. The 1996 drought began a year to 18 months before the summer of 1996. In 1998, a brief drought occurred after the beginning of the year with the sudden cessation of above average rainfall at the conclusion of 1997. Droughts, such as that of 1996, can be mitigated in advance with the full range of available tools (drought management plans, withdrawal suspension, etc.) provided the effort is started early enough. The effects of severe short-term droughts like that in 1998, which develop during the irrigation season, are currently addressed primarily through the *Critical Period Management Plan*. The indicators discussed here pertain primarily to hydrologic drought conditions that are developing prior to January of any year.

The Withdrawal Suspension Program

If drought conditions are anticipated in the upcoming year, and the threat of critical spring discharges looms, there is currently one program available in addition to the use of the CPMP for the Edwards Aquifer, a program that reduces irrigation water use for an upcoming year. In 1992, the TWC proposed a program of water use curtailment originally known as the dry-year option, and currently known as the Withdrawal Suspension Program or WSP:

> The essence of the Commission's recommended curtailment plan is that non-agricultural users, and downstream surface water users, would make temporary purchases of agricultural groundwater rights, to be left in place for the purpose of aquifer level and spring flow maintenance during periods of low recharge. The benefit of the program is that it will allow immediate and substantial reductions in groundwater withdrawals, only when necessary, at a cost that is well below the estimated cost for other water supply options. Most important, the dry-year option will lessen the magnitude of demand curtailment required by non-agricultural users and thereby protect the bulk of the region's population and economy. (Texas Water Commission 1992, 12-13)

The program was designed to maintain or raise the level of the aquifer, sustain or increase spring discharge, and provide municipalities with relief during droughts by paying farmers not to irrigate in critical spring discharge years. One significant advantage of the WSP is that irrigators are compensated for their reductions in profits when production is curtailed.

The WSP addresses the second largest use, irrigation. The majority of withdrawals for irrigation typically occur in the months of April, May, and June, with the peak irrigation period typically ending around the beginning of July (Ozuna 1994). Municipal usage is highest in June, July, August, and September, typically peaking in August (Moore and Votteler 1995b, 18). Table 4 shows that July and August are the hottest, and two of the relatively drier, months. An examination of spring discharge data confirms that July and August are most often the months of greatest concern for critical spring discharges. Thus, significant water reductions in total annual withdrawals will be realized only if reductions begin before April 1 for irrigation water use and before June 1 for municipal water use (Moore and Votteler 1995b, 18).

The WSP was initiated for the first time in 1997 (Keplinger and others 1998, 4). Those who wished to participate had to have been irrigating for the two years immediately prior to 1997 (Buckner 1999). In this way, those irrigators who were likely actually to pump their groundwater allocation were part of the program. A weighting system was used that gave preference to pumping locations closest to the springs (Buckner 1999). Some 37 individuals with 9,669 acres of irrigated land were enrolled for a median per acre cost of $240 (Keplinger and others 1998, 10). While the potential existed to reduce irrigation withdrawals by 23,206 acre-feet, the drought was ended by heavy late-winter and spring rains in 1997 (Keplinger and others 1998, 12). An examination of USGS discharge data for Comal Springs reveals that, at the time the WSP was initiated in 1997, Comal Springs was already slightly below the 200 cfs take level.

In December 1996, a hearing concerning the appeal of the U.S. District Court's temporary injunction in *Sierra Club v. San Antonio et al.* occurred, placing pressure on the EAA to act. The WSP was then, and still would be, initiated by a decision of the EAA board (Ellis 1999). For summer 2000 the EAA proposed initiating the WSP when J-17 reached 650 feet msl and Uvalde 845 feet msl (Ellis 2000), levels at which critical spring discharge rates are likely at both springs.

Uncertainty remains as to when the WSP should be initiated when conditions are not so severe as they were at the beginning of 1997. To implement the WSP and other measures, conditions warranting timely reductions in water use must be identified. Determining the conditions that warrant initiation of the WSP is an exercise central to the sustainable use of the aquifer. Critical period indicators, if available, could be used to determine in advance the years when the Withdrawal Suspension Program should be implemented. It is important that these indictors be reliable enough that the unwarranted initiation of the WSP is minimized to reduce unnecessary economic loss or to prevent public confidence in the program being undermined.

Take and Jeopardy Early Warning Indicators

In the absence of information on future aquifer levels and spring discharge, predictions can be based in part on the expected precipitation for a particular month (Table 4). Based upon the pattern of historical recharge and withdrawals, a lower rate of spring discharge in June is of greater concern than the same rate of low flows in August. This is because of the potential for rapid declines in spring discharge as the hottest and generally drier period of the year passes, along with peak pumping for the year. If the spring discharge rate is declining during April, May, and June, it could signal an increasing potential for critical spring discharges later in the year because April, May, and June comprise the high rainfall period that typically replenishes the aquifer before the hot and relatively dry months of July and August, when recharge is low and total withdrawals are the highest. After June, the influence of rainfall associated with frontal weather systems diminishes across the region, and more variable and less predictable tropical systems become a major source of recharge to the aquifer (Jones 1991, 514).

An examination of spring discharge data shows that, during most fall seasons, discharge at Comal and San Marcos Springs increases once withdrawals from the Edwards Aquifer decline after the peak summer demand period and fall rains begin. As the fall progresses, the likelihood that substantial rainfall will replenish the aquifer diminishes as the traditional months of high rainfall pass and the relatively dry winter months in this region commence (see Table 4).

This observation suggests that the spring discharge in the fall could be an important indicator of future spring discharge conditions. The period I examined for the court in 1995 as Special Master in *Sierra Club v. San Antonio et al.* began with the end of the drought of record, 1957. Prior to that year, pumping from the aquifer had yet to reach 300,000 acre-feet annually. Comal Springs flow was chosen for the analysis because Comal Springs is at a higher elevation than San Marcos Springs and typically declines below critical levels before similar declines at San Marcos Springs.

I found that since 1957, Comal Springs declined below 200 cfs in a majority of the years when discharge was less than 300 cfs throughout the fall of the previous year (Table 40). Jeopardy occurred in at least one third of the following years under the same conditions. Table 40 provides the cumulative frequency of the percentage of years that take or jeopardy occurred when flow at Comal Springs was below a specified level at the end of October, November, and December of a current year. The percentages were calculated for October, November, and December because of the necessity to prepare to implement a program to reduce irrigation, such as the WSP, at the beginning of the upcoming calendar year which also signals the irrigation season of pre-watering.

Table 40 was first used successfully in 1995 to provide the U.S. District Court with the likelihood of critical spring discharge in 1996. On November 1, 1995, the court was informed that the Comal Springs discharge rate of 247 cfs on October 31 corresponded to a historical probability of take of 75%, and for jeopardy 42%, in the approaching year (Moore 1995). The minimum discharge rate in 1996 reached 83 cfs, below the rate at which jeopardy begins. By comparison, an estimate of future spring discharge provided to the court in October, 1995, estimated that Comal Springs would remain above the 150 cfs jeopardy level through the summer of 1996 in the absence of any additional recharge during the intervening period (LBG - Guyton Associates 1995).

Table 40. Take and Jeopardy Early Warning Indicator Flows, 1995 (Cumulative Frequency)

	Comal Springs Less than 325 cfs		Comal Springs Less than 300 cfs		Comal Springs Less than 275 cfs		Comal Springs Less than 250 cfs	
Years: 1957 - 1994	In the Following Year		In the Following Year		In the Following Year		In the Following Year	
	Take	Jeopardy	Take	Jeopardy	Take	Jeopardy	Take	Jeopardy
On October 31	50%	29%	60%	35%	69%	38%	75%	42%
On November 30	55%	32%	63%	37%	79%	43%	89%	56%
On December 31	67%	39%	85%	54%	82%	55%	100%	63%

Source: (Votteler 1995).

Using December 31 as the fail-safe date for the initiation of irrigation conservation measures, I have examined the performance of the Take and Jeopardy Early Warning Indicators developed in 1995 (Table 40). Using 300 cfs as the Comal Springs discharge rate to initiate conservation would have resulted in an accurate prediction of critical springflows in all four years (100%) since this method of prediction was developed. Comal Springs was below 300 cfs on December 31 for each of the years prior to years in which flows reached take (200 cfs):

- On December 31, 1995, the Comal Springs discharge rate was 272 cfs, and in 1996 the minimum discharge rate was 83 cfs;
- On December 31, 1996, the Comal Springs discharge rate was 196 cfs, and in 1997 the minimum discharge rate was 193 cfs (minimum discharge occurred early in the year); and
- On December 31, 1997, the Comal Springs discharge rate was 296 cfs, and in 1998 the minimum discharge rate was 168 cfs; 1998.

Comal Springs was above 300 cfs on December 31 prior to a year in which flows remained above take (200 cfs) in the following year:

- On December 31, 1998 Comal Springs was above 382 cfs and Comal Springs remained above 200 cfs throughout 1999.

I have revised the estimates developed in 1995 based on three years of additional information. Table 41 contains new early warning indicators developed using

Table 41. New Take and Jeopardy Early Warning Indicator Flows, 1999 (Frequency)

	Comal Springs ≥400 cfs		Comal Springs 350 – 399 cfs		Comal Springs 300 – 349 cfs		Comal Springs 250 – 299 cfs		Comal Springs 200 – 249 cfs		Comal Springs 0 – 199 cfs*	
Years: 1958 – 1999	The next year: Take#	Jeopardy	The next year: Take	Jeopardy	The next year: Take	Jeopardy	The next year: Take	Jeopardy	The next year: Take	Jeopardy	The next year: Take	Jeopardy
On October 31	0%	0%	0%	0%	9%	0%	40%	10%	71%	57%	100%	33%
On November 30	0%	0%	0%	0%	17%	0%	60%	30%	83%	50%	100%	50%
On December 31	0%	0%	10%	0%	17%	0%	71%	43%	100%	67%	100%	33%

*The category 0 – 99 cfs was not included in Table 40 because there were no springflow measurements less than 100 cfs on the target dates during the period 1958 – 1999.

#In each year that jeopardy flows occurred, take flows also occurred.

data beginning with 1958 (the first complete year after the drought of record ended), and concluding with 1999. This table is not a cumulative frequency table, but instead provides the percentage of years when Comal Springs reached take or jeopardy when discharge was within a specific range during October, November, and December of the preceding year.

Identifying Additional Indicators that Could be Used to Initiate the Withdrawal Suspension Program

Previous analyses have suggested tentative measures that appear consistently to foretell reduced spring discharge at Comal Springs in any year since the end of the drought of record in 1957 (Moore and Votteler 1995b). In 1995, I developed other indicators to anticipate years when take or jeopardy may occur. These indicators were:

> Indicator 1. A negative balance between recharge and withdrawals from the aquifer during the preceding calendar year (i.e. more water was withdrawn than was recharged); and
>
> Indicator 2. Recharge to the Edwards Aquifer during the last six months of the preceding year (July through December) of less than 230,000 acre-feet (or approximately 60% of normal). This indicator reflects recharge after the majority of withdrawals for agricultural irrigation and peak municipal use have concluded during the year and is a measure of the recovery of water levels in the Aquifer.
> (Moore and Votteler 1995b, 27)

The recharge that occurs from July through December after the period of peak withdrawals ends is a measure of recovery in aquifer levels after the peak period of summer pumping as reflected by spring discharge. The balance between recharge and pumping from the aquifer (i.e. more water was withdrawn than was recharged) is a measure of the general balance of inputs and outputs from the aquifer. I have identified other variables as potential triggers for the WSP. They are the following:

Independent Variables:

PUMPING = annual pumping in acre-feet (1934 – 1996)
RECHARGE = annual recharge in acre-feet (1934 – 1996)
REJANJUN = recharge January through June in acre-feet (1934 – 1996)
REJUD_1 = recharge July through December of the previous year (1934 – 1996)
BALANCE = annual difference between recharge and withdrawals in acre-feet (1934 – 1996)

Pumping data are published on an annual basis. PUMPING, which represents USGS estimates of annual withdrawals from the Edwards Aquifer are compiled from: (a) spring discharge data collected by the USGS; (b) withdrawal data for municipal supply, and military and industrial uses collected by the TWDB; (c) withdrawal data for irrigation estimated by the USGS using irrigated-acreage data supplied by the Natural Resources Conservation Service (a division of USDA); and (d) withdrawal data for domestic supply, stock, and miscellaneous uses estimated by USGS (Brown, Petri, and Nalley 1992, 7).

Recharge data are also published on an annual basis and are represented by the variable RECHARGE (see U.S. Geological Survey 1999). USGS measurements of Edwards Aquifer recharge are calculated using surface-water stream-flow gauging stations for the San Antonio area consisting of discharge data for streams and springs and contents data for reservoirs located in all major Edwards Aquifer watersheds, as well as the assumptions that relate the runoff characteristics of gauged areas to ungauged areas (Brown, Petri, and Nalley 1992, 6-7).

By special request, the USGS provided me with recharge estimates subdivided into six month periods, REJANJUN and REJUD_1. Another independent variable, BALANCE, was created by subtracting annual pumping data from annual recharge data. These independent variables were regressed with two different dependent variables representing the minimum measurement of spring discharge at Comal (COMALLOW) and San Marcos Springs (SANMARLO) recorded during each year, which I identified by examining spring discharge data collected by the USGS. USGS measurements of springs discharge are calculated using surface water - stream flow gauging stations for major springs (see detailed discussion in Appendix 5. A Data Dictionary of Selected Edwards Aquifer Metadata).

<u>Dependent Variables</u>:

COMALLOW = the lowest daily mean discharge rate measured at Comal Springs in cfs in each year (1934 – 1996); and

SANMARLO = the lowest daily mean discharge rate measured at San Marcos Springs in cfs in each year (1957 – 1996)

Table 42. Comparison of Dependent Variable COMALLOW Regressions with the Individual Independent Variables

Variable	R	R^2	F/Sig. F	T/Sig. T
PUMPING	-.36	.13	9.30/.003	-3.05/.003
RECHARGE	.37	.13	9.53/.003	3.09/.003
REJANJUN	.41	.17	12.72/.001	3.57/.001
REJULD_1	.44	.20	14.79/.000	3.85/.000
BALANCE	.47	.22	17.39/.000	4.17/.000

Table 43. Comparison of Dependent Variable SANMARLO Regressions with the Individual Independent Variables

Variable	R	R^2	F/Sig. F	T/Sig. T
PUMPING	-.24	.06	2.39/.131	-1.55/.131
RECHARGE	.62	.38	24.29/.000	4.93/.000
REJANJUN	.63	.40	25.45/.000	5.05/.000
REJULD_1	.64	.40	26.48/.000	5.15/.000
BALANCE	.65	.42	27.86/.000	5.28/.000

Figure 24. Scatterplot of Dependent Variable COMALLOW and Independent Variable PUMPING

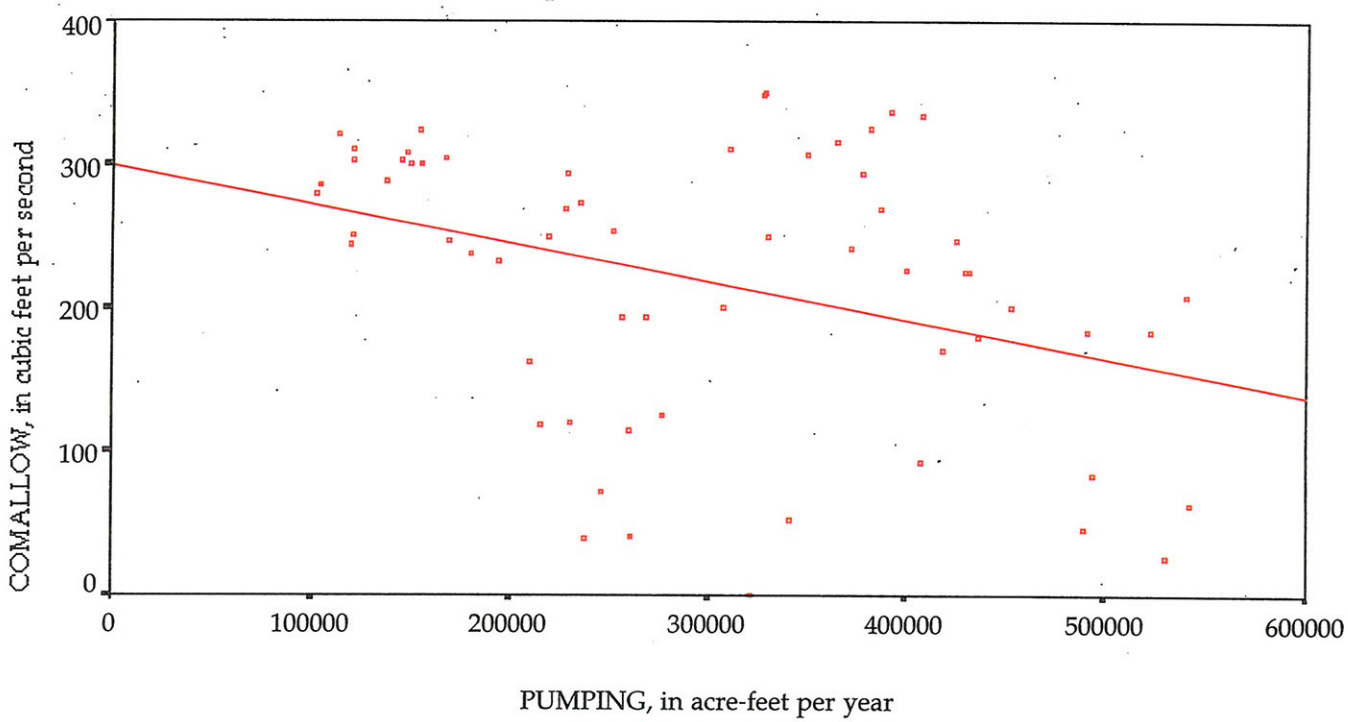


Figure 25. Scatterplot of Dependent Variable COMALLOW and Independent Variable RECHARGE

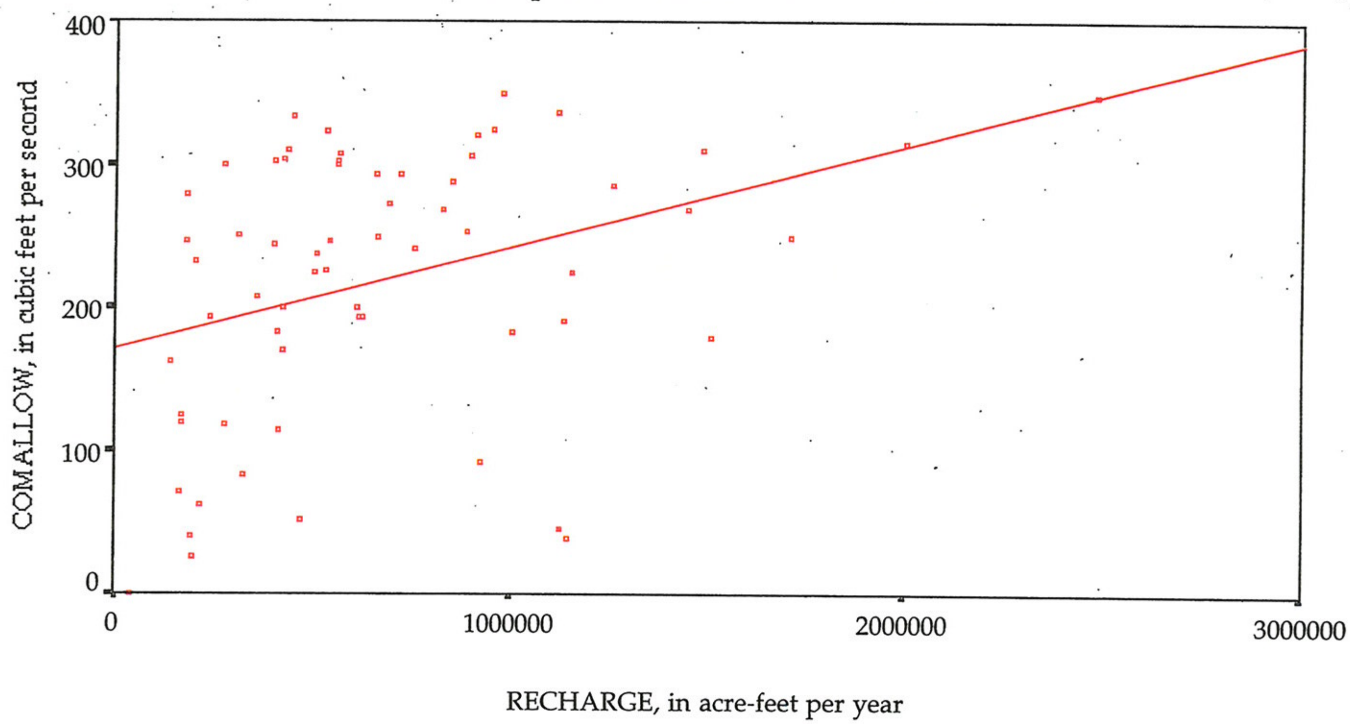


Figure 26. Scatterplot of Dependent Variable COMALLOW and

Independent Variable REJANJUN

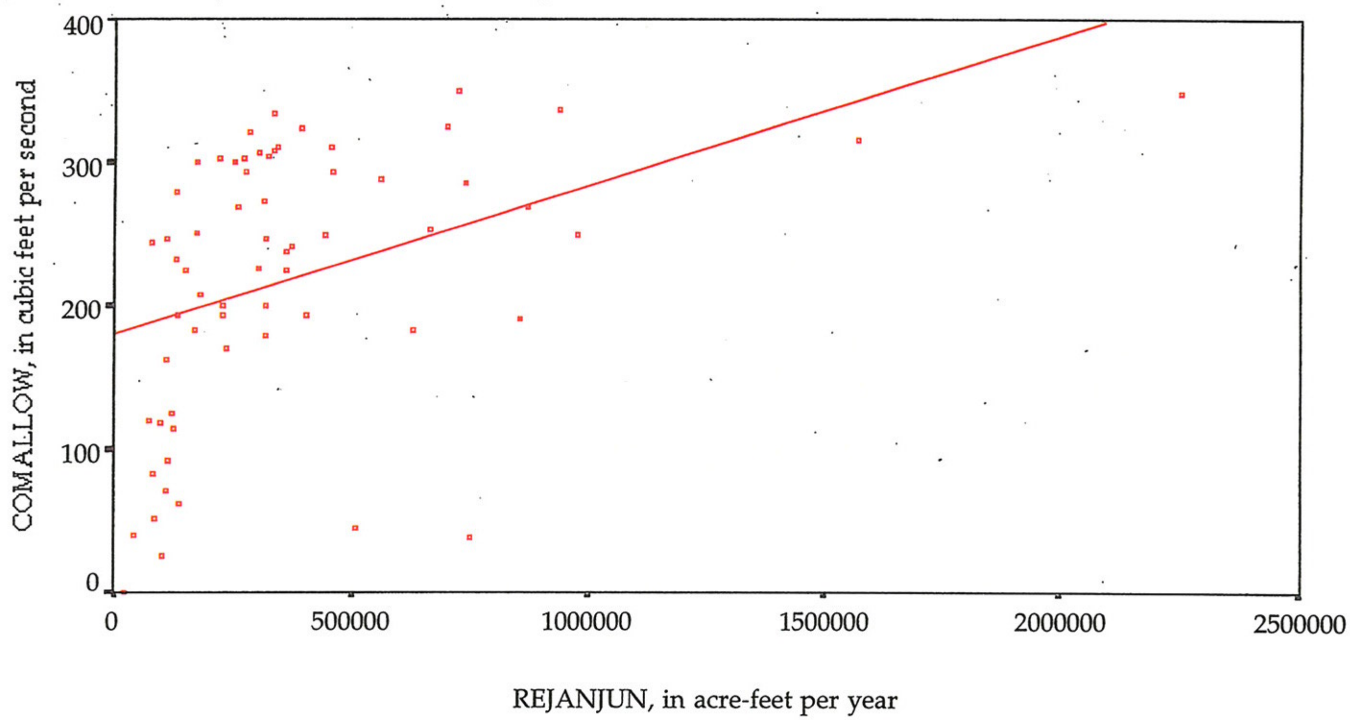


Figure 27. Scatterplot of Dependent Variable COMALLOW and Independent Variable REJULD_1

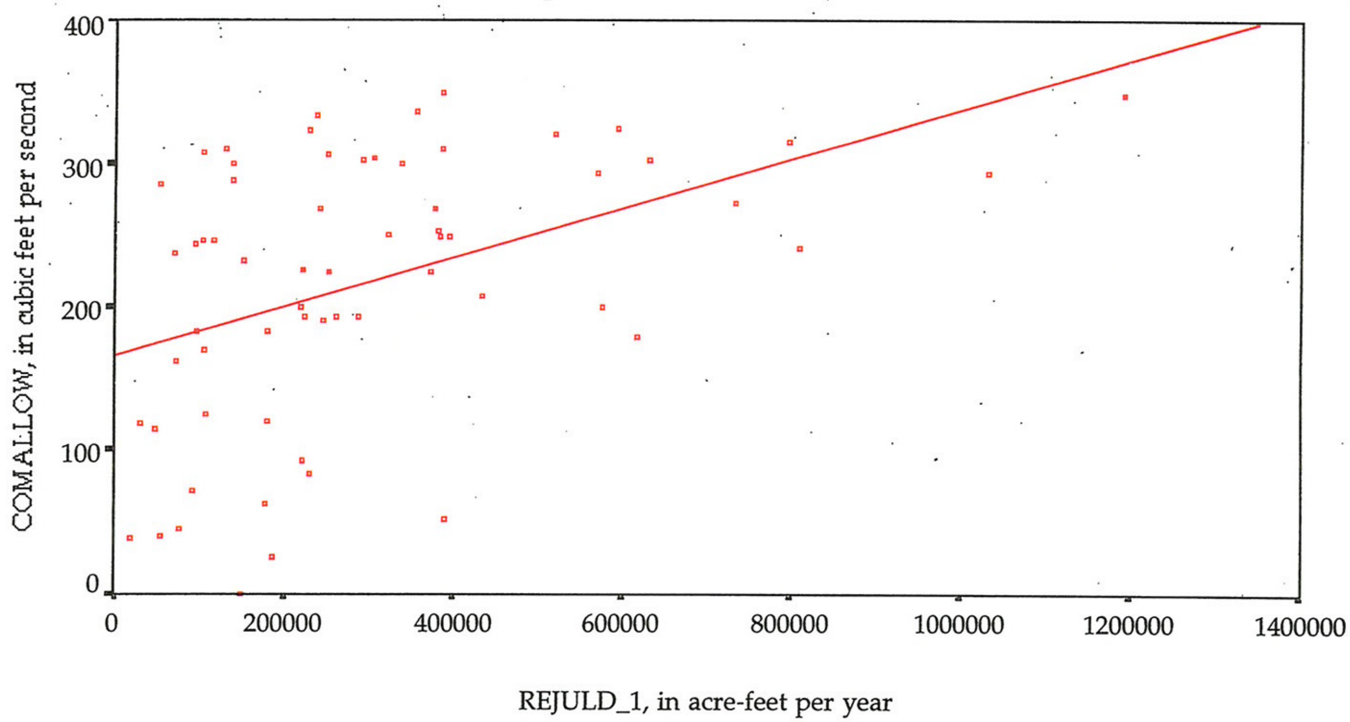


Figure 28. Scatterplot of Dependent Variable COMALLOW and

Independent Variable BALANCE

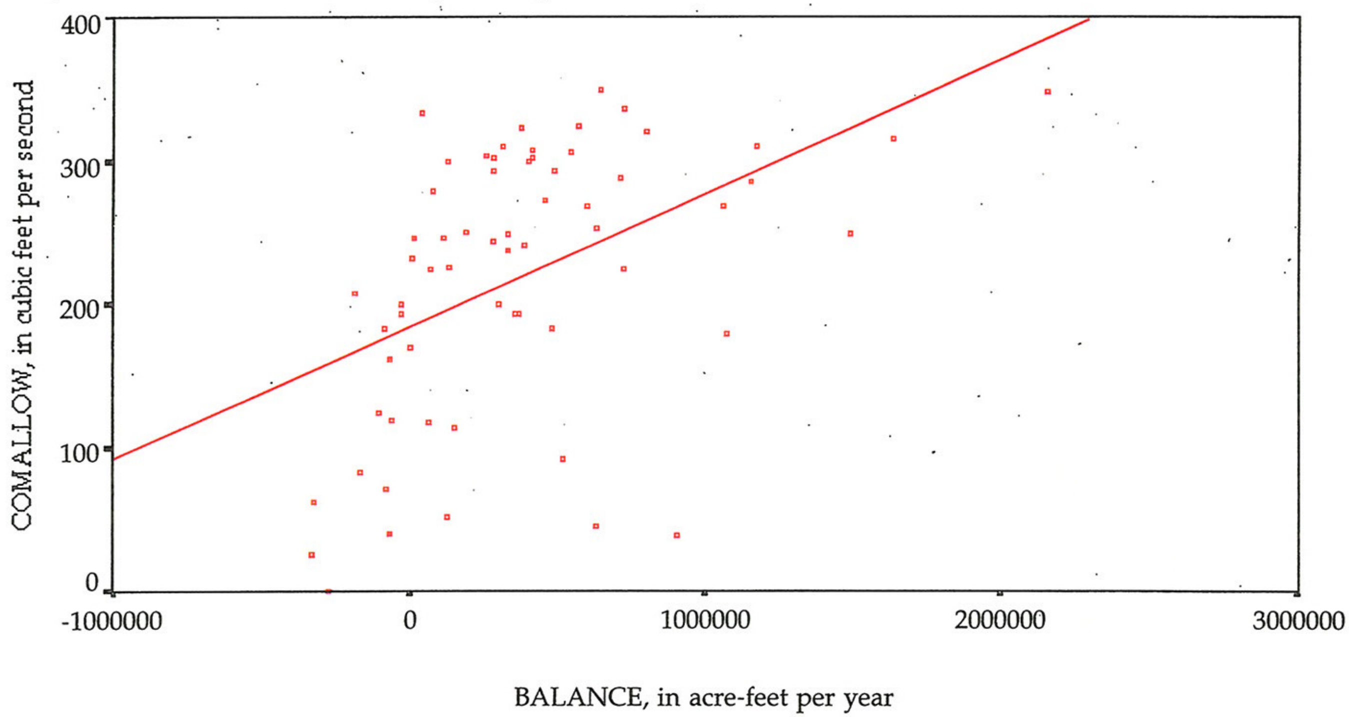


Figure 29. Scatterplot of Dependent Variable SANMARLO and Independent Variable PUMPING

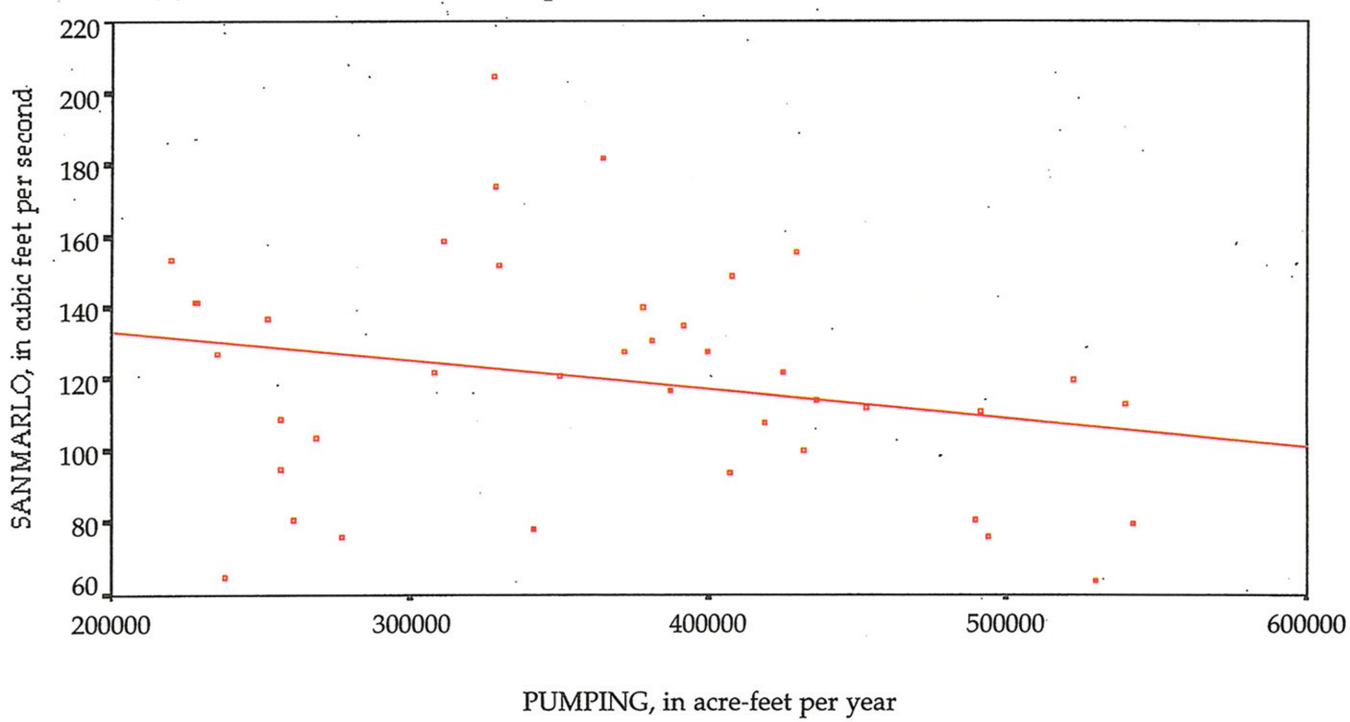


Figure 30. Scatterplot of Dependent Variable SANMARLO and Independent Variable RECHARGE

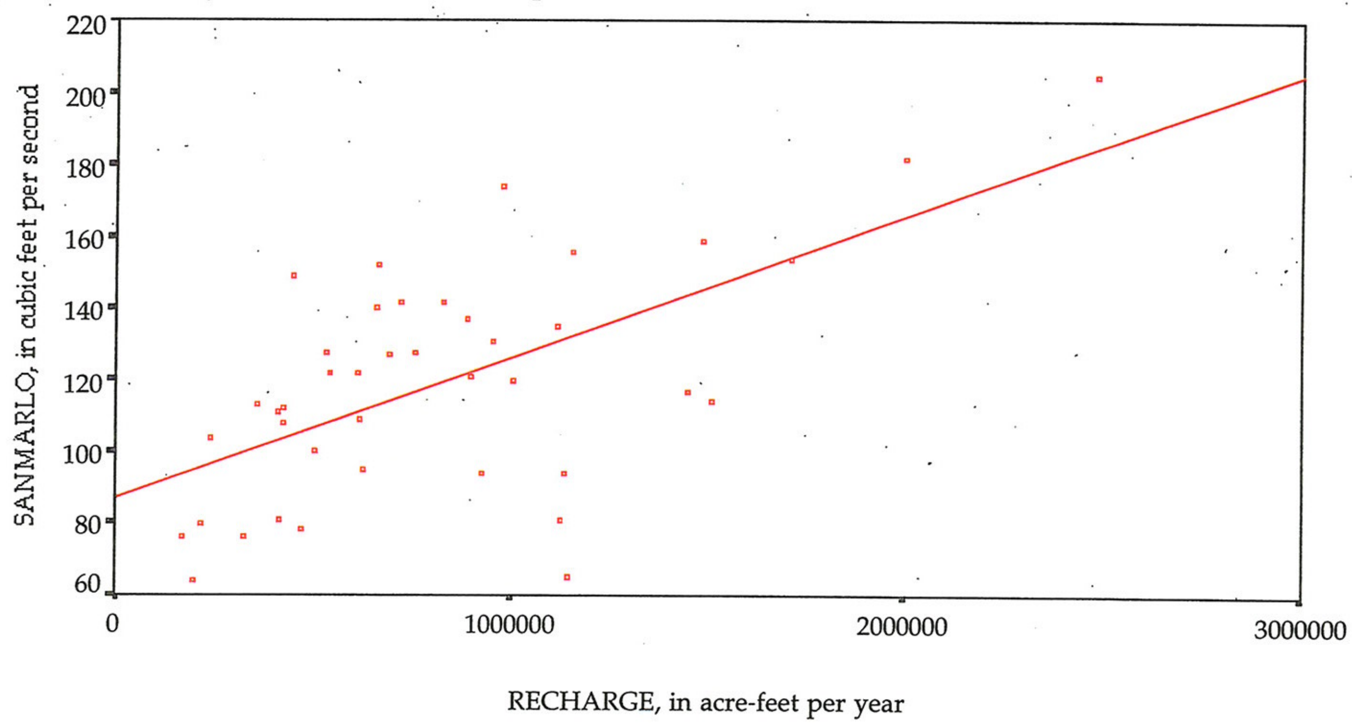


Figure 31. Scatterplot of Dependent Variable SANMARLO and Independent Variable REJANJUN

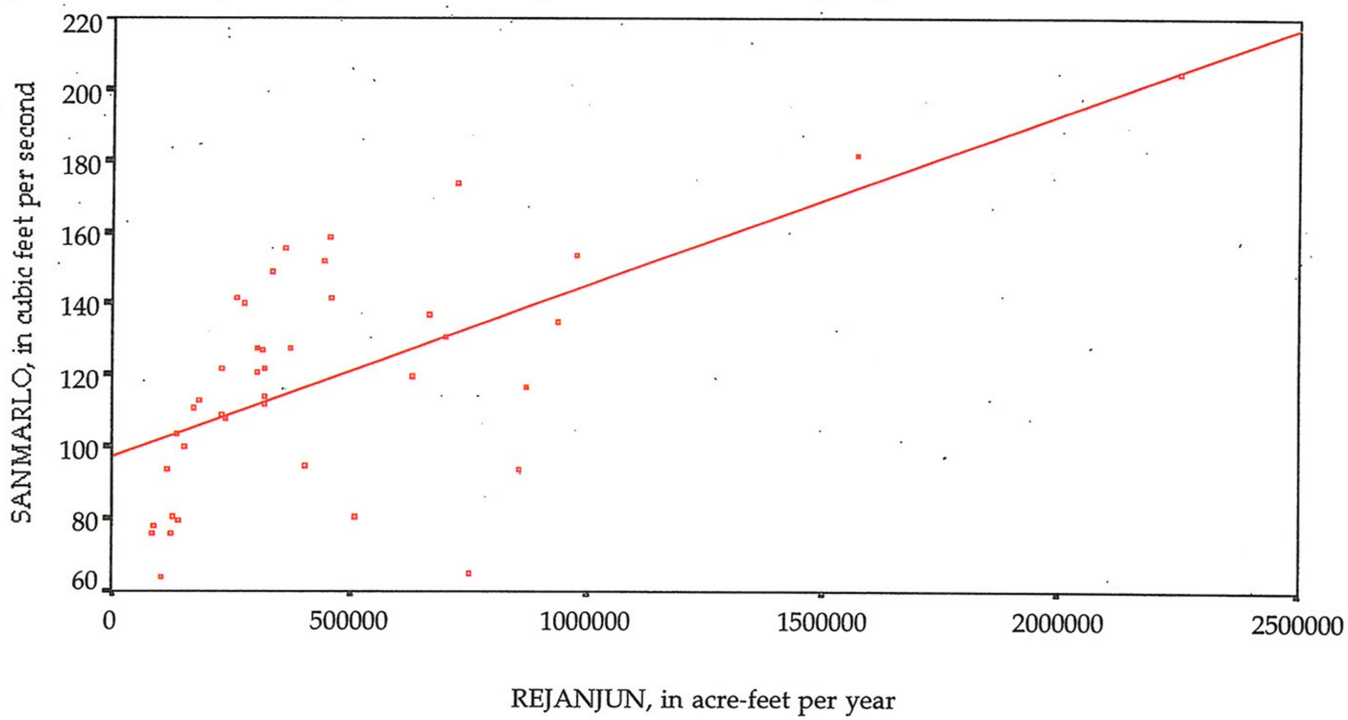


Figure 32. Scatterplot of Dependent Variable SANMARLO and Independent Variable REJULD_1

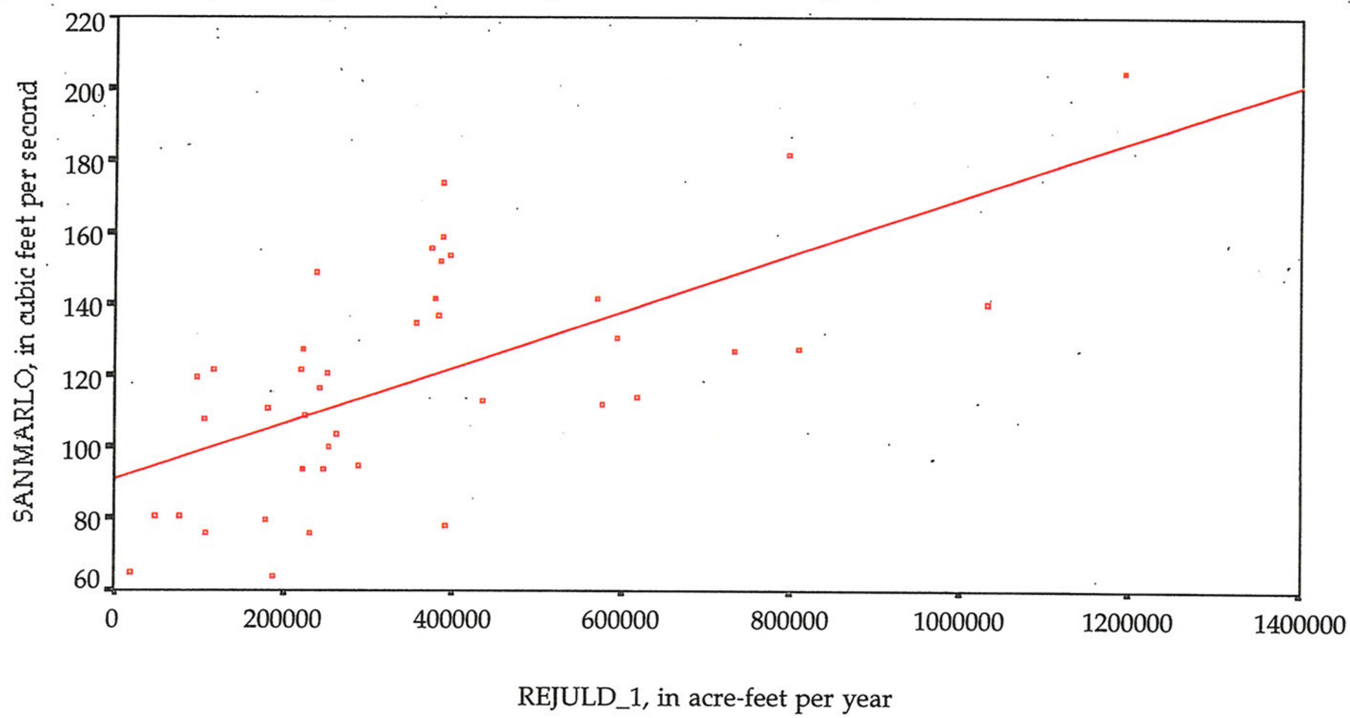
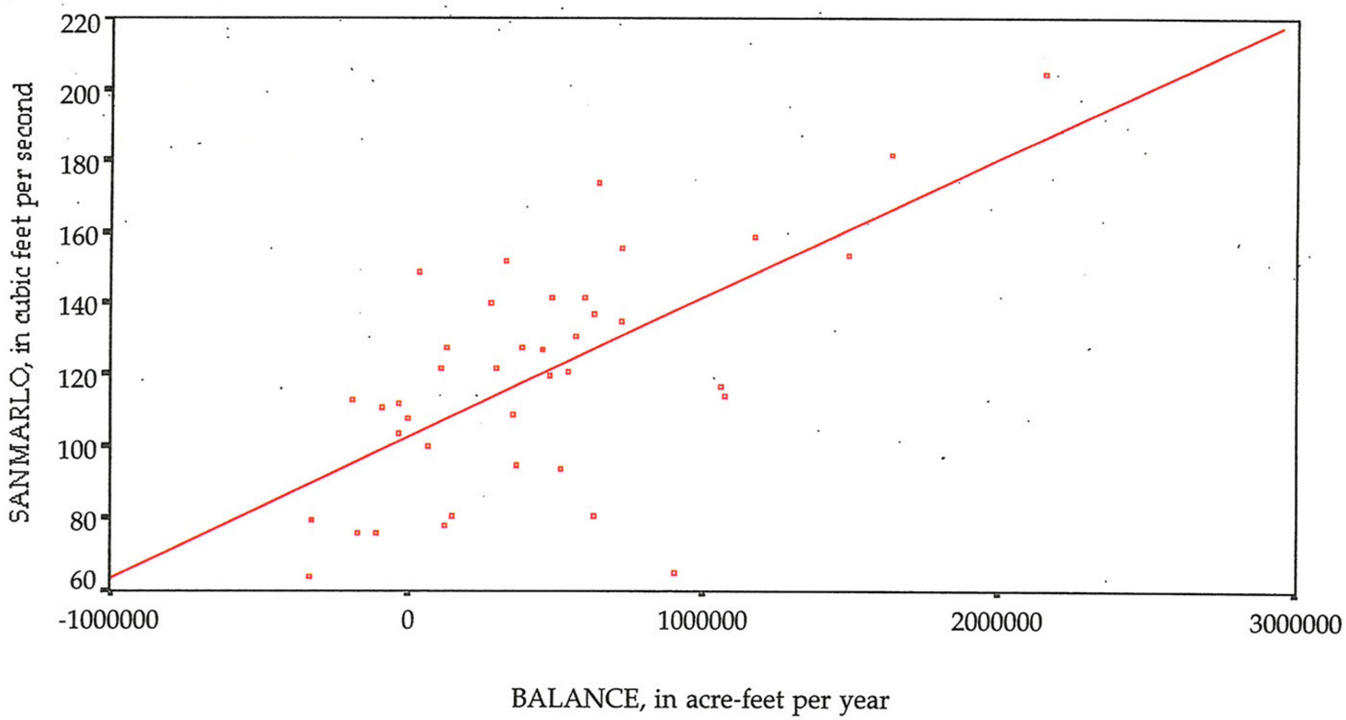


Figure 33. Scatter plot of the Dependent Variable SANMARLO and Independent Variable BALANCE



The results of the individual regressions with each independent variable for COMALLOW are found in Table 42, and for SANMARLO Table 43. Scatterplots of each dependent and independent variable were prepared to examine the potential relationships between the variables (Figure 24 through Figure 33).

The results of these analyses show that, with the exception of PUMPING, the remainder of the variables showed a stronger relationship with SANMARLO than with COMALLOW. For both dependent variables the F statistic was significant for each of the independent variables, although the F statistic for PUMPING and SANMARLO was relatively weak. PUMPING is the only independent variable that has a negative relationship with dependent variables, as was expected, since pumping decreases the volume of water in the aquifer. Some combination of these dependent variables might produce an acceptable model for predicting low spring discharge. Q-Q plots for both COMALLOW and SANMARLO show that the data for the dependent variables are normally distributed (Figure 34 and Figure 35).

Figure 34. COMALLOW Test for Normality

Normal Q-Q Plot of COMALLOW

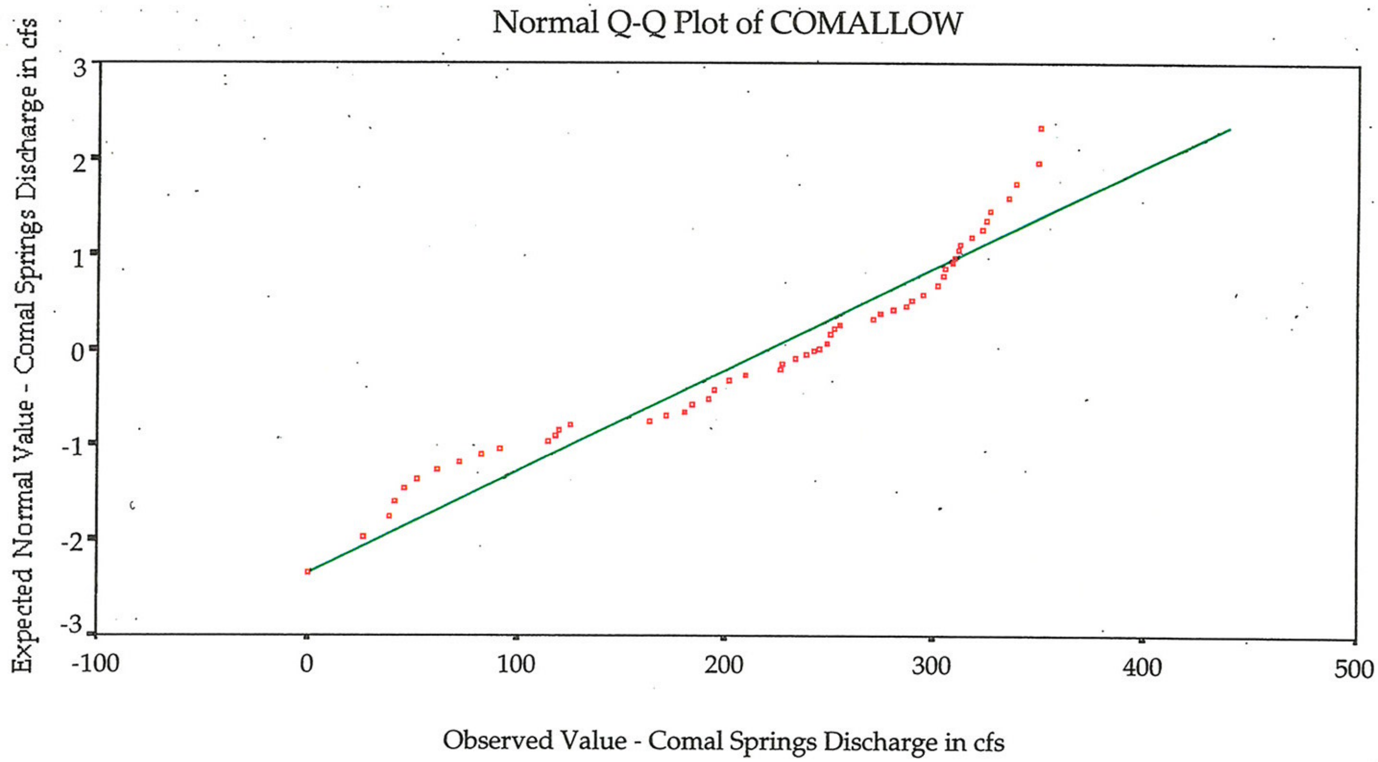
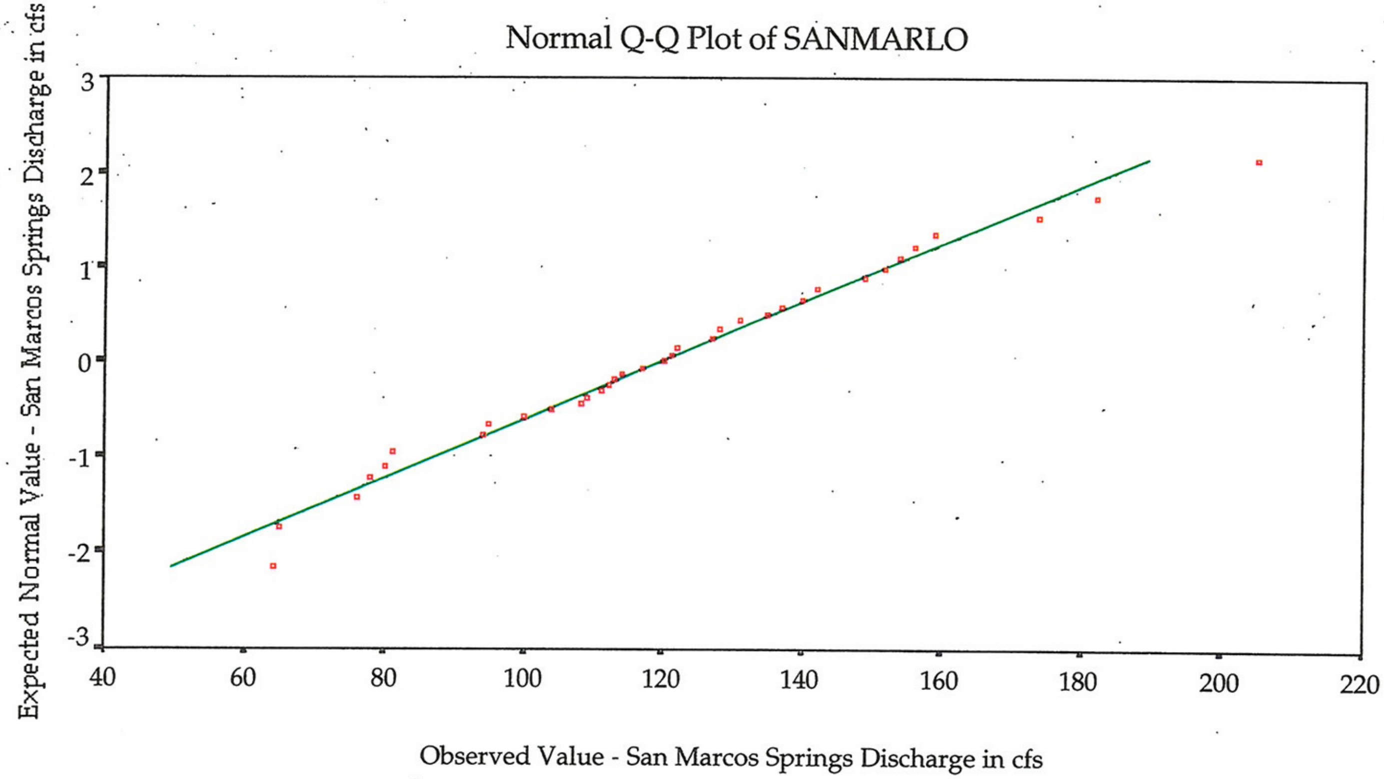


Figure 35. SANMARLO Test for Normailty



Modeling Critical Discharge Rates at Comal and San Marcos Springs

I have used multiple regression analysis in an attempt to construct a model that predicts the minimum spring discharge at Comal Springs in any following year using data for the current and preceding years. One of the requirements for regression analysis is that errors be independent of each other (Keller, Warrack, and Bartel 1990, 976). However, strong autocorrelation was found among the residuals of the dependent variable. While the existence of strong autocorrelation reduces the validity of regression analysis, it can provide a basis for producing accurate forecasts (Keller, Warrack, and Bartel 1990, 976). If the Durbin – Watson test indicates that there is correlation between consecutive residuals, then the model can be helpful in forecasting future values of the dependent variable (Keller, Warrack, and Bartel 1990, 976). Consecutive values of the time series are correlated if the residuals are correlated (Keller, Warrack, and Bartel 1990, 976). Therefore, parameters of the independent variable can be estimated by least squares, and the equation can be used to make forecasts (Keller, Warrack, and Bartel 1990, 976).

Stepwise regression of the independent variables with the dependent variable was used to produce the best predictive model for Comal Springs. The best of these models are included. In Model 1, I attempted to predict the low discharge rate at Comal Springs for the following year with the independent variables PUMPING and RECHARGE. First, I created a new variable, FLOW2, the lowest daily mean flow at Comal Springs for each year, 1934 through 1990, so that values for 1991 through 1996 could be predicted. Stepwise regression was used to determine that independent variables PUMPING and RECHARGE, should be retained in Model 1. The critical values for the Durbin – Watson test at the .05 level were 1.49 and 1.65, while the model produced a .78 result indicating the presence of autocorrelation (Keller, Warrack, and Bartel 1990, A42). The R square was low (.34), indicating that the model explained only 34% of the variability in the dependent variable, and that one or more variables were missing from the model; however the F statistic was significant (14.03). The unstandardized predicted values were retained in Model 1 to predict the values for FLOW2 from 1991 through 1996, which are compared with actual values of COMALLOW for the same period (Table 44).

Table 44 shows that Model 1 provided some relatively close approximations to the actual values recorded at Comal Springs such as 1992 and 1993, but in general, the estimates generated by this model were not close approximations.

In Model 2, I also attempted to predict the low discharge rate at Comal Springs for the following year using data for the current and preceding years. For this model, recharge was divided into two six month periods, REJANJUN (January through June) and REJUD_1 (July through December of the previous year). With FLOW2 as the dependent variable, stepwise regression showed that all of the independent variables, PUMPING, REJANJUN, and REJUD_1, should be retained in Model 2. The critical values for the Durbin – Watson test at the .05 level were 1.45 and 1.68, while the model produced a .89 result indicating the presence of autocorrelation (Keller, Warrack, and Bartel 1990, A42). The R square was low, .51, indicating that the model explained only 51% of the variability in the dependent variable, and that something was missing from the model;

Table 44. Predicted and Actual Low Comal Springs Discharge Rates: Model 1

Year	Predicted Low Comal Springs Flow in cfs	Actual Low Comal Springs Flow in cfs
1991	252	180
1992	386	349
1993	157	335
1994	160	248
1995	168	227
1996	115	83

Model Number 1: Method: Stepwise regression

Dependent Variable: FLOW2

Independent Variables: PUMPING, RECHARGE

Multiple R .58

R Square .34

Adjusted R Square .32

Standard Error 78.18

Analysis of Variance:

	Degrees of Freedom	Sum of Squares	Mean Square
Regression	2	171523.96717	85761.98358
Residual	54	330090.24336	6112.78228

F = 14.0299 Significant F = .0000

Variables in the Model:

Variable	B	SE B	Beta	T	Sig T
PUMPING	-3.42985E-04	8.3399E-05	-.459945	-4.113	.0001
RECHARGE	9.87822E-05	2.4977E-05	.442309	3.955	.0002
(Constant)	252.408344	28.175622		8.958	.0000

Residuals Statistics:

	Min	Max	Mean	Std Dev	N
*PRED	87.5524	346.2280	218.5263	55.3437	57
*RESID	-244.8867	113.9069	.0000	76.7754	57
*ZPRED	-2.3666	2.3074	.0000	1.0000	57
*ZRESID	-3.1322	1.4569	.0000	.9820	57

Total Cases = 57 Durbin-Watson Test = .78

however, the F statistic was significant (18.22). The unstandardized predicted values retained in Model 2 were used to predict the values FLOW2 from 1991 through 1996, which are compared with actual values of COMALLOW for the same period (Table 45).

Table 45 shows that, like Model 1, Model 2 provided some relatively close approximations to the actual values recorded at Comal Springs such as 1991 and 1996, but in general, the estimates generated by this model were not close approximations. In Model 3, I used a proxy for storage, J17HIGH, to improve the ability of the model to explain the variability in FLOW2. J17HIGH consists of the annual high measurement of the J-17 groundwater index well in feet above msl. With FLOW2 as the dependent variable, I used stepwise regression to determine that all of the independent variables PUMPING, RECHARGE, and J17HIGH should be retained in Model 3. The critical values for the Durbin – Watson test at the .05 level were 1.45 and 1.68, while the model produced a 2.23 result indicating that no significant autocorrelation was present (Keller, Warrack, and Bartel 1990, A42). The R square was very high, .91, indicating that the model explained 91% of the variability in the dependent variable, and the F statistic was very significant (171.98). The unstandardized predicted values retained in Model 3 were used to predict the values FLOW2 from 1991 through 1996, which are compared with actual values of COMALLOW for the same period (Table 46).

Table 46 shows that, unlike the previous models, Model 3 generated close approximations to the actual values recorded at Comal Springs for the entire period 1991 and 1996.

Table 45. Predicted and Actual Low Comal Springs Discharge Rates: Model 2

Year	Predicted Low Comal Springs Flow in cfs	Actual Low Comal Springs Flow in cfs
1991	197	180
1992	467	349
1993	168	335
1994	164	248
1995	171	227
1996	109	83

Model Number 2 Method: Stepwise regression

Dependent Variable: FLOW 2

Independent Variables: PUMPING, REJANJU, REJULD_1

Multiple R	.72
R Square	.51
Adjusted R Square	.48
Standard Error	68.31

Analysis of Variance:

	Degrees of Freedom	Sum of Squares	Mean Square
Regression	3	255093.55968	85031.18656

Residual	52	242674.15461	4666.81067

F = 18.2204 Significant F = .0000

Variables in the Model:

Variable	B	SE B	Beta	T	Sig T
PUMPING	-3.58171E-04	7.4213E-05	-.473240	-4.826	.0000
REJANJUN	1.09477E-04	3.3390E-05	.334409	3.279	.0019
REJULD_1	1.81016E-04	4.4304E-05	.420182	4.086	.0002
(Constant)	229.590311	25.445303		9.023	.0000

Residuals Statistics:

	Min	Max	Mean	Std Dev	N
*PRED	82.5510	415.2604	217.4286	68.1033	56
*RESID	-190.9039	125.2453	.0000	66.4248	56
*ZPRED	-1.9805	2.9049	.0000	1.0000	56
*ZRESID	-2.7945	1.8334	.0000	.9723	56

Total Cases = 57 Durbin-Watson Test = .89

Table 46. Predicted and Actual Low Comal Springs Discharge Rates: Model 3

Year	Predicted Low Comal Springs Flow in cfs	Actual Low Comal Springs Flow in cfs
1991	191	180
1992	344	349
1993	300	335
1994	209	248
1995	200	227
1996	105	83

Model Number 3 Method: Stepwise regression

Dependent Variable: FLOW2

Independent Variables: PUMPING, RECHARGE, and J17HIGH

Multiple R	.95
R Square	.91
Adjusted R Square	.90
Standard Error	29.69

Analysis of Variance:

	Degrees of Freedom	Sum of Squares	Mean Square
Regression	3	454885.11920	151628.37307
Residual	53	46729.09132	881.68097

F = 171.9765 Significant F = .0000

---------------------- Variables in the Model ----------------------

Variable	B	SE B	95% C.I.	B	Beta
J17HIGH	6.205754	.346163	5.511439	6.900068	.923112
PUMPING	-2.94343E-04	3.1790E-05	-3.58105E-04	-2.30582E-04	-.394716
RECHARGE	-2.23810E-05	1.1647E-05	-4.57427E-05	9.80664E-07	-.100214
(Constant)	-3868.483593	230.116024	-4330.037890	-3406.929297	

---------------------- Variables in the Model -----------

Variable	Tolerance	VIF	T	Sig T
J17HIGH	.662921	1.508	17.927	.0000
PUMPING	.967190	1.034	-9.259	.0000
RECHARGE	.646235	1.547	-1.922	.0600
(Constant)			-16.81	.0000

Residuals Statistics:

	Min	Max	Mean Std	Dev	N
*PRED	-40.5738	329.6455	218.5263	90.1274	57
*RESID	-85.3456	73.8898	.0000	28.8868	57
*ZPRED	-2.8748	1.2329	.0000	1.0000	57
*ZRESID	-2.8743	2.4884	.0000	.9728	57

Total Cases = 57 Durbin-Watson Test = 2.23

In Model 4, I used a lead dependent variable, FLOW3, and an independent variable to represent storage in the aquifer to predict the low discharge rate at Comal Springs for the following year, J17HIGH, the high water level in feet msl for J-17 for the year. Leading a variable replaces the original value of the variable with the value of a subsequent case. In this model, the dependent variable did not contain data from the year being predicted, but instead used the value of the preceding year. The new dependent variable was called FLOW3 and contains the low flow at Comal Springs for 1934 through 1990 led by one year. Stepwise regression was used to determine that the independent variables PUMPING, and J17HIGH should be retained in the Model 4. The critical values for the Durbin – Watson test at the .05 level were 1.45 and 1.68, while the model produced a 2.16 result indicating that no autocorrelation was present, probably due to the effect of the lead dependent variable (Keller, Warrack, and Bartel 1990, A42). The R square was low, .49, indicating that the model explained only 49% of the variability in the dependent variable, and that something was missing from the model; however, the F statistic was significant (26.33). The unstandardized predicted values retained in Model 4 were used to predict the values FLOW3 from 1991 through 1996, which are compared with actual values of COMALLOW for the same period (Table 47).

Table 47. Predicted and Actual Low Comal Springs Discharge Rates: Model 4

Year	Predicted Low Comal Springs Flow in cfs	Actual Low Comal Springs Flow in cfs
1991	208	180
1992	331	349
1993	268	335
1994	205	248
1995	200	227
1996	129	83

Model Number 4   Method: Stepwise regression

Dependent Variable: FLOW3

Independent Variables: J17HIGH and PUMPING

Multiple R	.70
R Square	.49
Adjusted R Square	.47
Standard Error	68.41

Analysis of Variance:

	Degrees of Freedom	Sum of Squares	Mean Square
Regression	2	246427.29791	123213.64895

Residual	54	252716.73718	4679.93958

F = 26.3280 Significant F = .0000

--------------------- Variables in the Equation ----------------------

Variable	B	SE B	95% C.I.	B	Beta
J17HIGH	4.293586	.649525	2.991366	5.595806	.640254
PUMPING	-2.26827E-04	7.2049E-05	-3.71276E-04	-8.23789E-05	-.304929
(Constant)	-2614.233983	438.037267	-3492.445834		-1736.022131

--------------------- Variables in the Equation -----------

Variable	Tolerance	VIF	T	Sig T
J17HIGH	.999444	1.001	6.610	.0000
PUMPING	.999444	1.001	-3.148	.0027
(Constant)	-5.968	.0000		

Residuals Statistics:

	Min	Max	Mean	Std Dev	N
*PRED	27.4229	305.9275	216.7719	66.3362	57
*RESID	-147.2285	113.2142	.0000	67.1774	57
*ZPRED	-2.8544	1.3440	.0000	1.0000	57
*ZRESID	-2.1521	1.6549	.0000	.9820	57

Total Cases = 57 Durbin-Watson Test = 2.05

Table 47 shows that like Models 1, 2, and 3, Model 4 provided some relatively close approximations to the actual values recorded at Comal Springs such as 1992, 1995, and 1996. While all the estimates were not close approximations, they were closer to the actual values than those produced by Models 1 and 2.

In Model 5, I attempted to predict the low discharge rate for San Marcos Springs for the following year with the independent variables PUMPING, J17HIGH, REJANJUN, and REJULD_1. First, I created a new variable from SANMARLO, FLOWSM, as the lowest daily mean flow at San Marcos Springs for each year, 1957 through 1990 so that values for the years 1991 through 1996 could be predicted. Stepwise regression determined that the independent variables PUMPING and REJULD_1 should be dropped from the model leaving J17HIGH and REJANJUN. The critical values for the Durbin – Watson test at the .05 level were 1.33 and 1.58, while the model produced a 1.57 result indicating that autocorrelation might be present (Keller, Warrack, and Bartel 1990, A42). The R square was moderately high, .70, indicating that the model explained 70% of the variability in the dependent variable, but that something was missing from the model; however, the F statistic was significant (36.98). The unstandardized predicted values retained in Model 5 were used to predict the values for FLOWSM from 1991 through 1996, and are compared with actual values of SANMARLO for the same period (Table 48).

Table 48. Predicted and Actual Low San Marcos Springs Discharge Rates: Model 5

Year	Predicted Low San Marcos Springs Flow in cfs	Actual Low San Marcos Springs Flow in cfs
1991	121	114
1992	207	205
1993	143	149
1994	119	122
1995	114	128
1996	88	76

Model Number 5 Method: Stepwise regression

Dependent Variable: FLOWSM

Independent Variables: PUMPING, REJANJUN, REJULD_1, and J17HIGH

Multiple R .84

R Square .70

Adjusted R Square .69

Standard Error 17.09

Analysis of Variance:

	Degrees of Freedom	Sum of Squares	Mean Square
Regression	2	21606.63533	10803.31766
Residual	31	9055.24703	292.10474

F = 36.9844 Significant F = .0000

---------------------- Variables in the Model ----------------------

Variable	B	SE B	95% C.I.	B	Beta
J17HIGH	1.774887	.279540	1.204761	2.345013	.694233
REJANJUN	2.35841E-05	1.0179E-05	2.82396E-06	4.43442E-05	.253335
(Constant)	-1094.275584	187.496075		-1476.676352	-711.874815

----------- in ------------

Variable	T	Sig T
J17HIGH	6.349	.0000
REJANJUN	2.317	.0273
(Constant)	-5.836	.0000

------------- Variables not in the Model -------------

Variable	Beta In	Partial	Min Toler	T	Sig T
PUMPING	-.192510	-.348819	.772658	-2.039	.0504
REJULD_1	.175422	.260389	.558267	1.477	.1501

Residuals Statistics:

	Min	Max	Mean	Std Dev	N
*PRED	74.1854	183.8227	117.9412	25.5880	34
*RESID	-26.8272	34.1268	.0000	16.5651	34
*ZPRED	-1.7100	2.5747	.0000	1.0000	34
*ZRESID	-1.5697	1.9968	.0000	.9692	34

Total Cases = 34 Durbin-Watson Test = 1.57

Table 48 shows that Model 5 provided close approximations to the actual values recorded at San Marcos Springs in every year from 1991 through 1996. The close approximations provided by this model are most likely caused by the J17HIGH variable.

In the final model, Model 6, I attempted to predict the low discharge rate for San Marcos Springs for the following year with the independent variables PUMPING, J17HIGH, and RECHARGE. First, I created a new variable from SANMARLO, FLOWSM_1, as the lowest daily mean flow at San Marcos Springs for each year, 1957 through 1990, led by one year. Stepwise regression determined that the independent variables PUMPING and J17HIGH should be dropped from the model leaving RECHARGE. The critical values for the Durbin – Watson test at the .05 level were 1.39 and 1.51, while the model produced a 2.16 result indicating that autocorrelation was not present (Keller, Warrack, and Bartel 1990, A42). The R square was very low, .18, indicating that the model explained only 18% of the variability in the dependent variable, and that something was missing from the model; however, the F statistic was significant (7.35). The unstandardized predicted values retained in Model 6 were used to predict the values for FLOWSM_1 from 1991 through 1997, and are compared with actual values of SANMARLO for the same period (Table 49). An additional year, 1997, is included because unlike for PUMPING, a consistent value for RECHARGE was available for 1997.

Table 49 shows the predictions made using Model 6 in comparison with the actual values recorded at San Marcos Springs in every year from 1991 through 1997.

Table 49. Predicted and Actual Low San Marcos Springs Discharge Rates:

Model 6

Year	Predicted Low San Marcos Springs Flow in cfs	Actual Low San Marcos Springs Flow in cfs
1991	140	114
1992	168	205
1993	109	149
1994	112	122
1995	111	128
1996	105	76
1997	129	94

Model Number 6 Method: Stepwise Regression

Dependent Variable: FLOWSM_1 LEADS(FLOWSM,1)

Independent Variables: J17HIGH, PUMPING, and RECHARGE

Multiple R	.43
R Square	.19
Adjusted R Square	.16
Standard Error	27.91

Analysis of Variance:

	Degrees of Freedom	Sum of Squares	Mean Square
Regression	1	5728.81842	5728.81842
Residual	32	24933.06393	779.15825

F = 7.3525 Significant F = .0107

------------------------ Variables in the Model -------------------------

Variable	B	SE B	Beta	Tolerance	VIF
RECHARGE	2.92126E-05	1.0773E-05	.432248	1.000000	1.000
(Constant)	95.853479	9.448257			

------ in -------

Variable	T	Sig T
RECHARGE	2.712	.0107
(Constant)	10.145	.0000

----------------------- Variables not in the Model -----------------------

Variable	Beta In	Partial	Tolerance	VIF	Min Toler
J17HIGH	.099598	.088469	.641585	1.559	.641585
PUMPING	.079130	.085870	.957594	1.044	.957594

----------------------- Variables not in the Model -----------------------

Variable	T	Sig T
J17HIGH	.495	.6244
PUMPING	.480	.6347

Residuals Statistics:

	Min	Max	Mean	Std Dev	N
*PRED	97.1318	154.3848	117.9412	13.1758	34
*RESID	-44.1250	58.9118	.0000	27.4872	34
*ZPRED	-1.5794	2.7660	.0000	1.0000	34
*ZRESID	-1.5808	2.1105	.0000	.9847	34

Total Cases = 34 Durbin-Watson Test = 2.15

Discussion

Table 42 and Table 43 compared the relationship between the springs and various independent variables. The explanation for the higher coefficient of determination between recharge at San Marcos Springs compared with Comal Springs is most likely that a higher percentage of the recharge for San Marcos Springs is local (Rothermel and Ogden 1987, abstract). This could also explain why pumping in the San Antonio area appears to have a greater influence over Comal Springs discharge than for San Marcos Springs, in addition to the fact that Comal Springs is closer to San Antonio.

For both springs, the volume of recharge that occurs in July through December of the previous year appears to be a greater influence over low spring discharges in the current year than recharge in the immediately preceding January through June period. The aquifer may regain hydrologic equilibrium in the months following the peak pumping in August, if recharge replenishes the aquifer prior to the beginning of irrigation pumping in the west in the following spring. This result reveals the importance of low recharge in the latter half of the year as an indicator of potential low flows in the coming year, which is the basis of the Take and Jeopardy Early Warning Indicators (Table 40 and Table 41).

Because of collinearity, the best combination of independent variables required that some variables that appear to have explained a higher percentage of the variability of the dependent variable be removed from the models. For example, BALANCE was not included in the best models because the variables RECHARGE and PUMPING, from which BALANCE was created, collectively explained more of the variation in the dependent variables for Comal and San

Marcos Springs. In Model 4, the use of the lead dependent variable eliminated autocorrelation in the model, reducing its predictive value and lowered the adjusted R square to slightly under .50. The use of a lead dependent variable in Model 4 to predict the minimum spring discharge at Comal Springs for the approaching year did not produce predicted values that were as close to the actual values as had been hoped; however, predictions within 50 cfs of the actual mark were produced in 5 out of the 6 years. The ability to predict the low for Comal Springs within 50 cfs in most years would represent a significant advantage for managing the aquifer. Minimum spring discharge years with the greatest deviations from average rainfall conditions were, as expected, the most difficult to anticipate. Years such as 1993, which followed the year of record recharge, and low recharge years, such as 1994 and 1996, resulted in predictions that were the most inaccurate. Similar attempts to predict minimum discharge for San Marcos Springs using a lead dependent variable produced Model 6, which has a low R square value, .18, but the predicted values for San Marcos Springs were all within 40 cfs of the actual values. Years such as 1992 and 1993, the year of record recharge and a year of low recharge that followed, respectively, resulted in predictions that were inaccurate.

If the availability and accuracy of the recharge and pumping data could be improved, better predictive models might be created. However, there are significant complications with use of the annual pumping estimates to model future aquifer management scenarios. Historically, pumping data have been published as an annual estimate. Estimated withdrawals by approximately 1,000 pumpers from the Edwards Aquifer were prepared by the USGS and TWDB, and are available for the entire period 1934 to 1996. The annual pumping figure includes withdrawals that occur after the typically low spring discharge period in July and August. The inability to divide pumping data into shorter periods, such as six months, as recharge estimates have been divided, reduces the ability of the models to predict spring discharge accurately. Also, although total withdrawal estimates have been treated as if they were known with great accuracy, this is probably not the case, since the EAA has only recently installed meters on wells. The pumping estimates have been compiled jointly by the USGS and TWDB based in part on voluntary reporting requirements under USDA agricultural programs. It is unlikely that these estimates are as accurate as the spring discharge measurements used as the dependent variable, and with which they have been compared.

In addition, as of 1997, the Freedom to Farm Act eliminated the data collection requirements from which pumping for agricultural irrigation was determined (Ozuna 1999). For this reason, 1996 is the last year for which a comparable record of total irrigation withdrawals from the aquifer exists. In the future, the capability will exist to retrieve pumping data for shorter periods of time, since most of the wells were metered in 1998, with the remainder completed in 1999 (Ellis 1999). New pumping estimates will be prepared by the EAA using data from metered wells; however, the portion of pumping for domestic and livestock use will still be estimated, because domestic and livestock wells are exempt from metering and reporting even though they are required to be registered with the EAA. A question has arisen concerning the comparability of the USGS historical pumping estimates with the EAA's new estimates. Currently, the direction and the magnitude of any differences between the two estimates are unknown. The EAA declined to fund an effort to continue to produce the USGS estimate for an overlapping year so that the estimates could be compared (Ozuna 1999). The USGS proposed to use satellite images of crop patterns to estimate pumping, since the USDA's Natural Resource Conservation Service (NRCS) irrigation data were not available to continue the method previously used (Ellis 1999). The EAA did not fund this proposal, because as proposed by USGS it would have produced an estimate using a third technique, making comparisons difficult (Ellis 1999). The outcome is that results from existing models of the aquifer that use the pumping estimates produced from 1934 – 1996 could produce results that would be difficult to interpret for managing the aquifer after 1996 using the EAA's pumping estimates. One of the most significant problems this difference will produce is how to interpret the TWDB's GWSIM-IV model results for the Edwards Aquifer which uses the USGS historical estimates in light of the EAA's new pumping estimates (see Figure 12). The pumping limits derived from the TWDB's model have guided many of the management decisions regarding the Edwards Aquifer, and continue to do so today (see Figure 20 and Figure 21). However, the use of meters on Edwards wells could be altering the way water is used and the amount that is used. The irrigators now see how much water they are using, and since they now pay a management fee per acre-foot of water used, they use less (Ellis 1999).

The accuracy of the recharge data has also been questioned. A study has described the calculation of recharge:

> Efforts to date by various investigators have come up with substantially differing recharge rates; these results simply indicate the limits of our knowledge. One of the key goals of the EAA research studies is to determine recharge and its variability across the entire unconfined aquifer. (Todd Engineers 1999, 12)

A more comprehensive methodology for measuring recharge is currently under development by USGS (Todd Engineers 1999, 32). HDR Engineering, Inc. has produced recharge estimates, based on their own calculations, that are generally higher than those of the USGS (Bradley 1999). Despite this, recharge is the analytical and management parameter preferred to rainfall, because rainfall only correlates with spring discharge in a general way (Texas Department of Water Resources 1979, 61). The correlation between rainfall measured at the San Antonio Airport and recharge estimates over the period from 1934 to 1997 is .72. It should be noted that daily USGS spring discharge reports, which are issued as provisional reports, can occasionally contain substantial errors. For example, on July 24, 1997, the USGS revised a string of inaccurate spring discharge estimates for Comal Springs, raising the previous July 21, 1997 estimate from 216 cfs to 306 cfs (U.S. Geological Survey 1997). The revision altered the discharge estimate by 42%, which had appeared to be approaching take levels.

The timely availability of pumping and recharge data is another major impediment to the use of techniques for initiating the Withdrawal Suspension Program. For example, Watkins and McKinney (1999) have concluded that whenever annual recharge is below approximately 650,000 acre-feet, the WSP should be initiated to reduce pumping by approximately 49,000 acre-feet/year (Watkins and McKinney 1999, 22). They also concluded that pumping should be limited to approximately 324,000 acre-feet/year or less in dry years, while it could rise in wet years to approximately 487,000 acre-feet, even though approximately 401,000 acre-feet might represent the optimal value (Watkins and McKinney 1999, 22, 23). Watkins and McKinney's conclusions require that pumping and recharge data be available at the beginning of each calendar year. The current method for calculating recharge doesn't allow the estimate to be determined until April 1 of the following year; however, upon request by a court, it could be available on February 15, as was the case in 1995 (Ozuna 1999). Pumping data from the EAA will not generally be available until the spring. A real-time reporting network for recharge is needed to use any predictor based on recharge so that the recharge can be monitored throughout the year, particularly during the fall and winter months when crucial management decisions affecting irrigation water use must be made for the coming year. With the increasing regional reliance on the aquifer, a real-time precipitation and stream flow network for more timely and accurate data reporting for recharge will eventually be needed for the day-to-day management of the aquifer. The development of such a network is currently in progress (Edwards Aquifer Authority 1998, 54).

Developing a consistent record of historical pumping data, and increasing the early availability of accurate pumping and recharge data to allow additional development of predictors of future minimum spring discharges, should be a high priority for the sustainable management of the aquifer. In the future, with the timely availability of more accurate pumping and recharge data, the potential for future critical spring discharges could be better anticipated.

In the absence of the necessary recharge and pumping data, the use of spring discharges in the fall as a predictor of flows in the following summer, such as has been done in the discussion of Take and Jeopardy Early Warning Indicator Flows above becomes a primary alternative. Using spring discharge as an indicator is admittedly somewhat unsophisticated. However, the Director of the San Antonio USGS office has stated that spring discharge is the overall integrator of stress across the Aquifer and should be used as the trigger for conservation, if the goal is to save the springs (Ozuna 1999). This method is based on historical data instead of a complex mathematical model. Such predictions using historical data analyses have been criticized for their simplicity. A Colorado State University professor, William Gray, uses computer programs for his forecasts of Atlantic seasonal hurricanes, but primarily bases his predictions on what he calls the cultural method, or study of the past (Associated Press 1999a, 1). "These forecasts are based on the premise that trends in global environmental conditions which preceded comparatively active or inactive hurricane seasons in the past provide meaningful information about trends in future seasons as well" (Gray and others 1999, 26).

I believe that using Take and Jeopardy Early Warning Indicator Flows is an improvement over the current method by a vote of the EAA board for initiating the WSP, because the indicators provide some statistical basis for the decision. Because of the political nature of such decisions, using this method is also an improvement over requiring the board of the EAA to decide when to initiate pumping reductions, thus allowing the Authority's technical staff to recommend such an action. Using Comal Springs discharge is also an improvement over a recommendation made by the TWC in 1992 for triggering the WSP. The TWC suggested that when J-17 Well is at ≤ 649 feet msl at the beginning of the year, conservation measures should be initiated (Appendix 3, Item 2. Summaries of the Texas Water Commission's Emergency Conservation Proposals). As Figure 14 shows, when J-17 is at 649 feet msl, Comal Springs flow has ranged from 180 to 250 cfs. The TWC's suggestions were made prior to the establishment of the 200 cfs take level at Comal Springs. In addition, the beginning of the year, as recommended by the TWC in 1992, might be too late to begin the process necessary to organize and implement such a program since many irrigators have committed to financing for seed, fertilizers, herbicides and other costs by January. On February 11, 2000, the EAA announced plans for a WSP for the summer of 2000 (Ellis 2000). The announcement states that the WSP would be triggered for two regions, once J-17 reaches 650 feet msl and the Uvalde well reaches 845 feet msl (Ellis 2000, 1). As the previous chapter demonstrated critical spring discharge rates are likely at both Comal and San Marcos Springs prior to 650 feet msl at J-17 and 845 feet msl at Uvalde. In addition, the last year that the Uvalde well was as low as 845 feet msl was 1958, the recovery period after the drought of record.

In 1995, I selected the final day of each of the last three months of the year as the dates for the Take and Jeopardy Early Warning Indicator Flows. I believed that keying the initiation of measures to the November 30 date was preferable to October 31 because of additional opportunity for rainfall to recharge the aquifer. The last of November was the second date for which the percentages are calculated, the preferred date for initiating the process for reducing pumping in the upcoming year, because of the time required to organize such a program. The November 30 date would allow organizational activities for the WSP to commence, which could be cancelled if sufficient recharge were to occur during December. In addition, after November the likelihood of large amounts of recharge decrease as the hurricane season ends, and, as Table 4 indicates, average total rainfall from December through March is less than seven inches. The last day of December was included in Table 40 and Table 41 to provide a fail-safe measure to cancel the implementation of pumping reduction programs should the necessary recharge materialize in the interim. As already stated, if preparations are delayed until December 31, it could be too late to organize a program such as the WSP for the upcoming year.

Selecting the spring discharge level to trigger the WSP is also a risk assessment issue. Identifying precursors that minimize false positive results is crucial, because water use restrictions can have significant costs, depending on the severity of the restrictions, producing significant adverse impacts upon the economy of the entire region. Taking smaller steps to reduce pumping earlier before a potential low flow year can reduce the need for more severe measures later, if dry conditions and high pumping persist. However, if drought measures are initiated when unnecessary, public confidence in drought-related water conservation efforts will suffer. Based on Table 41, and given the vulnerability of the aquifer to short-term droughts and the lack of supplemental supplies, the WSP should be initiated in years when Comal Springs is less than 300 cfs on November 30 (or San Marcos Springs is less than 100 cfs). With Comal Springs discharging at this rate, take has historically occurred during 60% of the years that followed, and jeopardy in 30% of those years (1958 – 1999). If the flow rises above 300 cfs (for a sustained period) by December 31, the WSP preparations could be terminated. While this conservative trigger level would be likely to initiate the WSP in years when aquifer levels might recover in the spring, in the absence of available alternatives, conservation measures must be initiated earlier to avoid violations of the ESA. Once a combination of the alternatives discussed in Chapter 10 are developed conservation measures could be initiated in years when Comal Springs is less than 250 cfs on November 30 (or San Marcos Springs is less than 100 cfs). Using the 300 cfs level for predicting critical spring discharge in 2000, the measurement on December 31, 1999, of 289 cfs indicates that a discharge rate of less than 200 cfs is likely to occur at Comal Springs in the year 2000 unless measures are taken to reduce pumping from the aquifer prior to the summer.

For any precursors of low spring discharge, two provisos concerning their reliability should be noted. First, unusual random events such as periods of heavy rainfall and flooding or extreme short-term drought can make predictions of future spring discharge extremely difficult. Second, in years when conservation measures are placed in effect, predicted critical spring discharges may be successfully avoided, if pumping from the Edwards Aquifer is curtailed early and sufficiently, which will result in a positive prediction seemingly appearing to be false. What would happen in years when the WSP is triggered, but the necessary rainfall materializes and the need for the cutbacks ends? Reductions can always be eased later, if rainfall during the spring significantly improves Comal Spring discharge to a seven-day moving average of 300 cfs or more by April 1st. The investment should not be wasted. An alternative would be to allow those pumpers that fund the program, SAWS being the primary supporter, to pump the water out of the aquifer and store it in an aquifer storage and recovery (ASR) project currently under development (discussed in detail in Chapter 10). This would prevent years when the WSP was unnecessarily triggered from being a total loss. It would also help to build a reserve for droughts in critical years when municipal and industrial users bear the brunt of reductions during short-term droughts (also discussed in Chapter 10).

10. DEVELOPING A SUSTAINABLE WATER SUPPLY FOR THE EDWARDS AQUIFER REGION

Introduction

This chapter contains a discussion of water policies and projects that could provide the Edwards Aquifer region, and surface water users downstream on the Guadalupe River, with a continuous water supply adequate to support the present population and economy and provide for orderly and sustainable growth, while reducing transboundary disputes. Because drought is a constant threat, possible solutions are divided into two categories – short range (1 to 10 years) and long range (longer than 10 years). Construction required for storage or transportation facilities will determine the length of time required to implement some alternatives. Solutions are designed either to reduce demand or to increase supply.

> . . . I do think it ought to be stated, however, that there does need to be some long-range planning by the people in San Antonio. . . . Somewhere down the line there is going to have to be a plan that will allow San Antonio to gather water from some dam or river and use part of that water in lieu of pumping every drop they use from the aquifer. The citizens of San Antonio haven't been overly fond, however, of spending any money to get this done. . . . There just isn't an unlimited source of fresh water. (Bunton 1999, 311)

Table 50 provides an estimate of the potential water supply deficits between 2000 and 2050 for the area included in the EAA's jurisdiction.

Short Range Actions

Critical Period Management Plan

Since drought can produce the most serious threat in the short range before additional water supplies can be developed, the CPMP is the highest priority. The CPMP should use Comal Springs discharge, or in some years San Marcos Springs discharge, to trigger adequate conservation measures for agricultural as well municipal, industrial and other water uses, to avoid take and jeopardy flows and assure minimal water for water users downstream on the Guadalupe River.

Withdrawal Suspension Program

The ability to initiate conservation measures at the beginning of potentially critical years is crucial for protecting spring discharge in the absence of alternatives to pumping Edwards Aquifer water. Because of the tendency for critical spring discharges to occur after irrigation has been completed for the year, the WSP is required to achieve water use reductions in agricultural irrigation, the second largest category of Edwards Aquifer water use.

Table 50. Projected Population, Water Demand, Available Water Supply, and Potential Deficit

Year	Population	Demand, acre-feet	Edwards Aquifer Supply, acre-feet	Other Groundwater, acre-feet	Water Reuse, acre-feet	Surface Water, supply, acre-feet	Deficit, acre-feet
2000	1,700,000	773,000	450,000	39,000		20,000	264,000
2010	2,050,000	795,000	400,000	39,000	50,000	20,000	286,000
2020	2,460,000	838,000	400,000	39,000	50,000	20,000	329,000
2030	2,890,000	903,000	400,000	39,000	50,000	20,000	394,000
2040	3,270,000	962,000	400,000	39,000	50,000	20,000	453,000
2050	3,600,000	1,009,000	400,000	39,000	50,000	20,000	500,000

Sources: Demand: HDR Engineering, 1998, Table 2-5, 2-11. Taken from original source Most Likely Case, below normal rainfall and advanced water conservation, Texas Water Development Board 1996. Edwards supply and non-Edwards groundwater supply: HDR Engineering, 1998, 2-11, Table 2-7, 2-15. Taken from original source, Texas Water Development Board 1992. The deficit figures are likely to be inflated in the initial years, but is provided here for purposes of demonstration.

Water Conservation, Reducing Demand

The EAA contracted for a study of the optimization of the aquifer with optimization defined as involving "a procedure with the end result yielding an aquifer operation that enables all of the desired benefits to be accomplished. The most water will be produced at the lowest cost simultaneously with preserving and protecting the aquifer as well as associated ecological systems" (Todd Engineers 1999, 3). As part of the Optimization Study, several management alternatives were evaluated, including:

- Water demand reduction;
- Recharge enhancement;
- Basin water recharge;
- Recirculation strategies;
- Redistribution of pumping;
- Springflow augmentation;
- Reclaimed wastewater;
- Demineralization [desalination];
- Lease/purchase of water; and
- External sources.

(Todd Engineers 1999, 7)

The draft study report contained a significant conclusion:

> It is important to keep in mind that the Edwards Aquifer, although voluminous, is not a limitless resource. The flow of groundwater from recharge to discharge areas, from one county to another, is contingent upon the aquifer remaining fully saturated and under pressure. Dewatering the aquifer, a common and destructive practice in some western states, simply is not a viable option here. What can be achieved are two significant goals – guaranteed minimum flows for the two major springs and an increase, perhaps modest, in the permitted pumpage requirements facing EAA. Providing for future water demands beyond these two achievements must come about via an interregional intrastate water resources planning effort. (Todd Engineers 1999, 38)

Conservation and reuse provide the least expensive water supplies for the region. Water conservation has been, and will continue to be, for the near future, the primary means to alleviate demands on the Edwards. There are four major reasons; (1) water conservation is the least expensive option; (2) water conservation assures immediate results; (3) water conservation requires the least vertical integration within government (i.e. many of the techniques for water conservation can be implemented by the EAA, local governments and the private sector); and (4) it is typically the option with the least opposition.

There has been cultural resistance to landscape water conservation, particularly to the adoption of xeriscaping, as people move to the region from other parts of the nation characterized by lush lawns and tropical gardens. As a result, the largest component of municipal water use in the region's cities during the summer is for business and residential landscaping. Conservation would allow the major municipal suppliers to sell conserved and reused water to new customers. The Texas Water Commission (now the Texas Natural Resource Conservation Commission) stated that conservation efforts in the Edwards Aquifer area could reduce pumpage between 88,000 and 125,000 acre-feet annually, primarily through municipal and agricultural water conservation achieved by a management entity and local governments (Texas Water Commission 1992, 7). However, given the regional demand found in Table 6 and Table 50, conservation alone will not be enough to meet regional water needs.

Irrigation Water Conservation

Withdrawals for irrigated agriculture vary according to cropping patterns and to rainfall over the region. In 1967, withdrawals for irrigated agriculture exceeded 100,000 acre-feet annually for the first time, and in 1985 peaked at 203,100 acre-feet (see Table 16). Irrigation withdrawals have stabilized over the last decade. While acreage irrigated from Edwards groundwater has declined in Bexar County over this thirty-year period and has been minimal in Comal and Hays Counties, it has dramatically increased in Medina and Uvalde Counties during the same period (Texas Water Development Board 1991a); (Texas Water Development Board 1999a).

The Texas Water Commission has estimated that irrigated agriculture could save 40,000 to 52,000 acre-feet per year from the Edwards (Texas Water Commission 1992, 8). Some irrigation farmers have already adopted more efficient irrigation practices or installed more efficient irrigation equipment. Thus, some reduction in irrigation aquifer withdrawals has already been realized. While there is some evidence that installation of efficient systems may not always be cost effective, the quantity of water that can be saved makes the effort worthwhile, if the water that is saved can be sold or leased to municipal or industrial users.

Municipal Water Conservation

The range of achievable water savings for municipal and industrial use has been estimated at 48,000 to 73,000 acre-feet per year (Texas Water

Commission 1992, 7). In 1992, the average per capita use in the Edwards Aquifer region ranged from a low of 53 gallons per capita per day (gpcd) to a high of 526 gpcd (Texas Water Commission 1992, 7-9). Municipal users below 100 gpcd cannot be expected to use much less water. Conversely, municipal water purveyors that have high usage rates could achieve substantial savings without affecting basic water needs for public health, sanitation, and safety.

SAWS water use in the late 1980's was 285 gpcd (Thuss 1999). The System plans to reduce gpcd consumption from the 1993 amount, 160 gallons, to 140 gallons by 2008 (San Antonio Water System 1993, ii). So far, a reduction to 155 gpcd has been realized (Thuss 1999). Bexar Met anticipates a saving of 1,500 acre-feet per year by the year 2000 from its municipal water conservation plans. By renovating and reducing leakage from its canal system, off-canal storage, and agricultural water use, Bexar Met, Bexar - Medina - Atascosa Water Control and Improvement District #1 (BMA), and the NRCS believe approximately 30,000 acre-feet per year can be conserved (Bexar Metropolitan Water District 1999, 54).

Another method for encouraging water conservation is inverted block water rates with higher costs per unit of water as water use increases from one block to the next. SAWS has adopted such a rate structure.

Reuse of Treated Wastewater

Treated wastewater will become an increasingly critical resource. In 1997, SAWS discharged almost 159,000 acre-feet of highly treated effluent from its wastewater treatment plants (Wilcut 1999). The current SAWS Reuse Plan identifies 35,000 acre-feet per year of reuse in place by the year 2008. Further expanded reuse of treated wastewater from the SAWS system is severely limited by lack of storage capacity (Thuss 1999). Other wastewater treating entities should maximize reuse of their discharges.

Control of Exotic Species

While not strictly water conservation, additional water could be withdrawn from the Edwards Aquifer in low rainfall years with the control of the giant rams-horn snail according to the USFWS (Shockey 1993b, 4). If an Incidental Take Permit from the USFWS were in place, approximately 65,000 acre-feet of additional water could be withdrawn annually in dry years with control of this exotic species (Moore and Votteler 1995a, 108). Additional measures such as removing plants such as elephant ears might be needed to improve species habitat.

Habitat Conservation Plan and Section 10(a) Incidental Take Permit from the U.S. Fish and Wildlife Service

A Section 10 (a) ITP would significantly reduce the exposure of the Edwards Aquifer Authority and pumpers to enforcement actions under the ESA when spring discharge at Comal is between 150 and 200 cfs as the result of the permittee's "otherwise legal" pumping from the aquifer. While this alternative allows pumpers to utilize more water from the aquifer, it does not offer a permanent solution to meet present or future water requirements. If the take levels are lowered as a result of controlling the rams-horn snail, pumpers would be protected when flow is as low as 60 cfs for short periods of time. Implementation of either of these options would, of course, substantially reduce the downstream flows in Guadalupe River during low rainfall or drought years. Only the U.S. District Court has developed a similar draft regional plan for the Edwards Aquifer, the largest HCP ever attempted for an aquifer. When development of that plan began, only 33 HCPs had been completed in the United States (Grote 1994). As of 1999, 243 habitat conservation plans had been completed and about 200 more are being developed covering approximately 6.5 million acres (Hoffman 1998, 4). The plan being developed for the court was abandoned with the termination of the *Babbitt* case.

The Bexar Met has developed a draft habitat conservation plan that is currently under review by the USFWS that represents the most advanced effort undertaken since the effort by the U.S. District Court. In 1996, the Bexar Met began the process of applying for a 10(a) permit after Judge Pennington had found the EAA unconstitutional, and before the Texas Supreme Court overruled this decision. The process is taking longer than the USFWS initially indicated to Bexar Met (Rosenberg 1999). In addition, Bexar Met has encountered an issue that could scuttle their attempt to get a 10(a) permit. The USFWS has informed Bexar Met that before 2012, the District must prepare a plan assuming total pumping from the aquifer is limited to 300,000 acre-feet annually, with further reductions anticipated (Seawell 1999b, 9). This limit on annual withdrawals is considerably less than the initial 450,000 acre-feet limit and the later 400,000 acre-feet limit beginning in 2008 (Ch. 626, 1993 Tex. Gen. Laws 2355, §1.14(b) and (c)). While Senate Bill 1477 clearly states that after 2012 pumping shall be limited to assure the continuous minimum flows necessary to protect the endangered species, it does not state any annual limit. Such a limitation on the use of the Edwards Aquifer, during high recharge years, seems unwarranted based on the TWDB model results (Figure 12).

In 1999, the Edwards Aquifer Authority began the process of developing an HCP, exploring the possibility of obtaining an Incidental Take Permit from the USFWS. Apparently modeled after the draft HCP developed for the U.S. District Court, the EAA's regional HCP would essentially be a regional water conservation and supply plan. While it took the court-sponsored effort nine months to prepare a draft HCP, the EAA's contractors anticipate it will take 3 years, with the draft HCP ready for review by the USFWS in March 2002. It is likely that review and revisions would extend completion of the task into 2003 or 2004, and possibly much later if any issue is litigated.

Future ESA litigation could influence the EAA's efforts to get a 10(a) permit. The likelihood of additional litigation hasn't changed much since the EAA began operating (Ellis 1999). However, once the HCP is underway, Mr. Ellis has stated that the chance of ESA litigation will diminish (Ellis 1999). If a new ESA case were to be filed, the EAA would stop all work on the HCP, with those resources going into defending the lawsuit (Ellis 1999). Furthermore, it is unclear whether the EAA could be sued as a taker under the ESA (Ellis 1999). Different federal court circuits have different opinions about this issue. Ellis has stated; since the EAA itself is not a pumper, it might be immune from ESA lawsuits (Ellis 1999). However, if the EAA is exempt from prosecution under the ESA, how can they have a 10(a) permit?

> The population of the Nueces, San Antonio, and Guadalupe River basins is projected to double over the next 50 years. Water demand will increase, but not double. If an ITP is secured, there is enough water in the three basins, if properly managed and developed, to supply all needs in the basin and maintain the necessary springflow. (Thuss 1999)

There is also an unresolved question concerning the protections that a 10(a) permit would provide to participants when jeopardy flows are reached at the springs. Clearly, the permit would protect a holder during take flow at Comal. But it is unclear whether a 10(a) permit will protect a holder during jeopardy (Rosenberg 1999); the ESA does not state that an ITP would protect an applicant during jeopardy. It does state in Section 10(a)(2)(B)(iv) that as a condition for approval, "the taking will not appreciably reduce the likelihood of survival and recovery of the species in the wild." The USFWS has stated that:

> A Section 10(a)(1)(B) permit authorizes incidental take of Federally listed threatened and endangered species by a non-federal entity. A mandate for the Service prior to issuing a Section 10(a)(1)(B) permit is to ensure that the proposed activity does not jeopardize the continued existence of any federally listed species. (Seawell 1999a, 1)

This language suggests that an ITP will provide a significant level of protection for a permit holder, between 200 – 150 cfs flow at Comal Springs, or possibly as low as 60 cfs, but not when flows are less than 150 cfs or 60 cfs. This decline is still significant because, as discharge decreases below 200 cfs, the lower the discharge, the less time historically that Comal Springs has been at these levels. Historically, an ITP with a take level of 60 cfs would have protected a permit holder during the majority of the time. Ellis has indicated that the HCP protects the permit holder from any incidental takes, and that if the HCP is being adhered to and the springs dry up, permit holders, including the EAA, are protected from ESA penalties (Ellis 1999).

Since all individual elements of any HCP, such as pipeline or reservoir construction, cannot be completed for years, the HCP must outline how the applicants will comply with the ESA in the immediate future. The use of ITPs by USFWS has been criticized recently as an environmental give – away, in part because of the lack of measurable goals (Hood 1998, x). The USFWS is now altering the process to counter this complaint. However, the goals for an Edwards Aquifer ITP would be easy to monitor because discharge rates measured at Comal and San Marcos Springs provide obvious, and easy to understand, measures of the success or failure of the effort. For this reason, a regional ITP should be issued as 'interim', or some other designation that clearly stipulates that the applicant cannot receive protection from penalties under the ESA if it delays fulfilling the requirements of the ITP. An 'interim' ITP should be issued by the USFWS with an expiration date. During the interim period, the ITP would provide protection for flows between the take and jeopardy levels only if the applicant is meeting established milestones incorporated into the HCP. However, the 300,000 acre-feet, or less, limit under consideration by the USFWS may be too low for the region to achieve during the foreseeable future.

Violating the take or jeopardy level is actually a violation of the Recovery Plan, not the ESA (Ellis 1999). Ellis has stated that the take and jeopardy levels will be reworked in the regional HCP being developed by the EAA. The EAA will request interim protection while working on the HCP; a reservoir project is unlikely to be part of the HCP (Ellis 1999).

Water Markets - Lease of Water Rights

The development of an efficient market for trading Edwards Aquifer water rights would likely result in significant groundwater conservation. In addition, the Legislature has shown support for free market solutions to environmental problems, in part because minimal government involvement is required. The 50% limitation on the lease of irrigation water, plus the guaranteed 2-acre-feet of water per each acre of irrigated land in Senate Bill 1477, could create a surplus of as much as 118,600 acre-feet that could be leased to municipal and industrial users, primarily in Bexar County (based on the amount of water that the EAA proposed to allocate to irrigators in 1998). While the irrigator benefits financially from the lease, some of the needs of municipal and industrial users could be met as well. This solution is viable only when there is adequate water stored in the aquifer. One of the major advantages of a water quantity lease program is that no conveyance facility is required from the property for which water is permitted to the point of use. The aquifer itself is the conveyance facility, so long as the EAA will authorize the change in point of withdrawal.

Long Range Actions

Land Treatments and Preservation

Active land management is becoming an integral component of watershed management. In areas of the contributing and recharge zones overtaken by juniper, mesquite and other high water-use vegetation, ranching and farming techniques could be altered to reverse this process. The control of vegetation which transpires large amounts of water has been under consideration by the state at least since the *1968 Texas Water Plan*. That plan focused primarily on areas where dense populations of saltcedar were found along Texas water courses (Texas Water Development Board 1968a, III-28, III-29). Juniper was listed in the 1968 plan as one of a number of species with "little or no economic value" that "transpires tremendous quantities of water, tentatively estimated to be on the order of 38% of the average annual water budget of the state" (Texas Water Development Board 1968a, III-29). More recently, the Natural Resources Conservation Service conducted a demonstration project in the Seco Creek watershed over the Edwards Aquifer in Medina County to improve water quality, test conservation measures, and increase recharge to the Edwards through land treatments (Natural Resource Conservation Service 1995). The demonstration project examined the use of water and sediment control basins installed at strategic locations to demonstrate and quantify (1) the value of small impoundments for increasing recharge to the aquifer; (2) brush management measures such as axing, prescribed burning, grubbing, and chaining; and (3) herbicide treatments. The project also examined the effect of juniper removal from pastureland to reduce evapotranspiration and thereby increase moisture, runoff and recharge in the area of the contributing and recharge zones. These actions could decrease the amount of water crossing the recharge zone during storm events, releasing the water more slowly over a longer period of time so that it can more readily enter the aquifer. Such programs are favored by agricultural interests that consider the brush a nuisance (juniper can be removed without harming the endangered golden-cheeked warbler). However, ranching practices will likely be slow to change, so this program may take decades to produce significant results. During that time, a considerable portion of the contributing and recharge zones in Bexar and some other adjacent counties may be lost to urbanization.

The NRCS has estimated that between 24,000 acre-feet (25% of the total 96,500 acre-feet estimated annual water savings) and 38,600 acre-feet (40% of the total 96,500 acre-feet estimated annual water savings) could be recharged to the Edwards Aquifer through recommended land treatments (Natural Resource Conservation Service 1995, summary table). Those watersheds within the contributing zone and portions of the recharge zone that, on a per acre basis, provide the most recharge to the aquifer, should receive the maximum protection possible. These areas should be identified and considered for purchase for use as parkland and wildlife management areas, much as Austin is purchasing portions of the recharge zone for the Barton Springs segment of the aquifer. Presumably, water purveyors, such as SAWS and the Bexar Metropolitan Water District, could pay the costs for brush removal and be credited with the conserved water by the EAA.

As for habitat for the endangered golden-cheeked warbler in areas where ashe juniper is prevalent, Secretary Babbitt wrote Governor Ann Richards on September 22, 1994:

> I agree with you that normal agricultural and ranching activities in Texas have little impact on golden-cheeked warbler habitat. Assertions that protection of the warbler in Texas would have a significant negative impact on such practices are wrong. The Department testified recently before a joint hearing of the State Legislature's Natural Resources Committees and said unequivocally that if land has been plowed or farmed for years, it is not warbler habitat. While the Act does not give us the authority to exempt specific land-use practices, as a practical matter traditional ranching and farming activities will not hinder warbler conservation. Regrowth cedar that has invaded cleared fields is also not habitat, and can be cleared without concern. Most warblers live on rocky slopes. Since most agricultural and building activity does not occur on rocky slopes, those activities should not affect warbler conservation. (Babbitt 1994)

This same viewpoint was echoed by the former Texas State Administrator of the USFWS, Sam Hamilton:

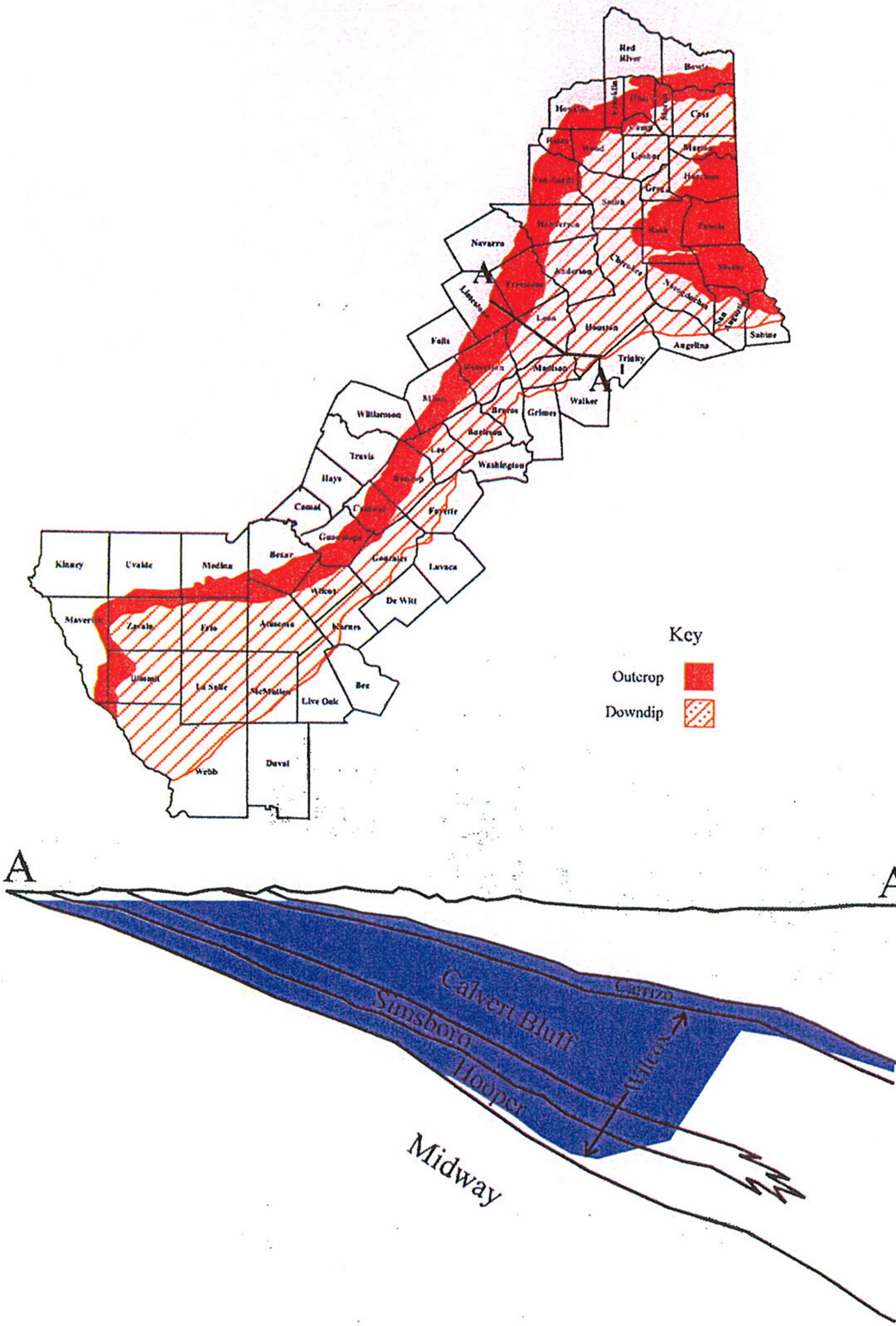
> The areas where warblers are found are typically on slopes and areas with highly erodible-type soils . . . Those areas are not that important to livestock production.
>
> Unfortunately, the impression is that any and every cedar tree is valuable for the golden-cheeked warbler, and that's just not the case . . . Pure stands and young stands of cedar are simply not habitat. (Needham 1995, 5A)

Groundwater Alternatives

<u>Carrizo-Wilcox Aquifer</u>

The Carrizo-Wilcox Aquifer, shown in Figure 36 is one of the most extensive aquifers in Texas, spanning a wide belt extending from the Arkansas

Figure 36. The Carrizo – Wilcox Aquifer



(Ashworth and Hopkins 1995, 16)

and Louisiana borders south to the Rio Grande (LBG - Guyton Associates 1994, executive summary). The average thickness of the aquifer in Atascosa, Wilson, Gonzales, and Bastrop Counties is 1,500 feet, with a maximum thickness of 2,500 feet in Atascosa County (LBG - Guyton Associates 1994, executive summary). The quality of water in these counties meets the federal and state drinking water standards, although secondary standards for iron may be exceeded in some areas (LBG - Guyton Associates 1994, executive summary). The results of many ground-water studies (Klemt and others, 1976, and Throkildsen and others, 1989, etc.) indicate that the Carrizo-Wilcox Aquifer is essentially at capacity in an area northeast of Atascosa County and is currently discharging water to the streams and rivers where they cross the outcrop (LBG - Guyton Associates 1994, executive summary). Water from the Carrizo-Wilcox Aquifer could be imported from Wilson or Gonzales County, into San Antonio. HDR Engineering, Inc. has estimated that 90,000 acre-feet could be provided for an estimated $466 per acre-foot delivered (Todd Engineers 1999, 20).

On December 30, 1998, SAWS Board of Trustees approved a plan to pipe groundwater from the Simsboro Aquifer (a formation within the Carrizo-Wilcox) at an Aluminum Company of America (Alcoa) lignite mining operation northeast of Austin near Rockdale (Needham 1998g, 1A). As much as 90,000 acre-feet produced by Alcoa as it dewaters its mining area (about 50% of SAWS current annual withdrawals from the Edwards Aquifer) could be diverted annually through a pipeline across the Colorado and Guadalupe River basins to San Antonio (Needham 1998c, 8A). Alcoa could assure 40,000 to 60,000 acre-feet of water to San Antonio in 7 years, if a maximum effort were made (Nevola 1999). A Bastrop County lignite mine could produce an additional 15,000 to 30,000 acre-feet in 15 years (Nevola 1999). The water would require settling and chlorination before it would meet drinking water standards. The estimated delivered cost of raw water would be between $500 and $700 per acre-foot and could require a 10% rate increase for SAWS customers (Nevola 1999). SAWS will spend $200,000 studying the Alcoa project for the next few years until a decision is made on whether to go forward (Thuss 1999). An analysis conducted for the TWDB by The University of Texas, Bureau of Economic Geology (BEG), reports that there is enough water in the Carrizo-Wilcox Aquifer to meet these withdrawals and current water needs, with additional water available for future use, to the year 2050 (Texas Water Development Board 1999b, 2).

There is opposition to the Carrizo-Wilcox water transfer in the area from which the water will be pumped. The BEG study found that, over 50 years, the project could cause a maximum water-level decline in the aquifer of 260 feet in the vicinity of the areas of highest groundwater withdrawal (Texas Water Development Board 1999b, 2). The fact that SAWS is a landowner in Bastrop County concerns some of the local residents; however, if SAWS does not buy the water, the LCRA might (Thuss 1999). In addition, while the water transfer could help San Antonio overcome some of the constraints placed upon it by the listed species at the springs, another endangered species, the Houston toad in the Elgin – Bastrop area could present a problem for the project if it is present in the area to be mined.

> The Alcoa project could bring San Antonio much needed water, directly or indirectly. The water could be traded. The project would allow a wasted resource to be used. There is some opposition in San Antonio to the Alcoa project, but it is minor. The public is better informed about this project and much more involved. (Peak 1999)

Aquifer Storage and Recovery

Storage is the key to sustainable water management (Pyne 1995, preface). The difficulty is storing water when there is a surplus so that it can be used when and where it is needed later during dry years. Storage in surface water reservoirs is expensive and increasingly perceived as an unacceptable exchange for valued terrestrial ecosystems that are inundated; it has encountered significant opposition within the Edwards region. Below-ground storage has been limited for technical, political, legal and other reasons. A key element in storing water underground is the need to control well clogging due to suspended solids in the recharge water, bacterial activity, gases and other factors (Pyne 1995, preface). Dual-purpose wells, equipped for both recharge and recovery, known as aquifer storage recovery (ASR) or aquifer storage and retrieval wells, are best able to achieve recharge objectives while limiting clogging (Pyne 1995, preface). ASR is a technology that is the focus of significant interest in the Edwards Aquifer region. It provides an alternative to the expense, litigation, political rancor, and long time-frame required for constructing surface reservoirs. This alternative uses vacant underground storage space in a manner similar to a surface reservoir. Evaporation and transportation losses are negligible. Land condemnation, inundation of land, and dam construction are also avoided. The benefits of ASR in the Carrizo-Wilcox Aquifer near San Antonio include:

- Salvages surface water in excess of what is needed for inflow to bays and estuaries that otherwise would be discharged to the Gulf and lost for beneficial use;

- Increases the perennial yield of groundwater reservoirs and restores water levels to shallower depths reducing pumping costs;
- Provides for storage of cold water from streams during the winter months for use during the summer months for cooling;
- Promotes the conjunctive use of surface and groundwater resources;
- Extends the useful life of well fields and water treatment facilities;
- Allows the full-time operation of water treatment facilities at optimum rates of production;
- Allows peak water demands to be met without increasing raw water demands or adding treatment facilities;
- Eliminates some costs and environmental impact problems associated with constructing new surface water storage reservoirs or adding storage in existing reservoirs to meet peak water demands;
- Eliminates water losses due to evaporation from surface reservoirs;
- Reduces the demand on streamflow during the summer and other peak use periods; and
- Provides possible storage capacity for treated wastewater for reuse. (Kreitler 1998, 6, 7)

The technical requirements for ASR in Texas are:

- Appropriated water must be available for recharge;
- Underground reservoir space must be available for storage;
- Stored water cannot degrade native ground waters in the storage aquifer;
- The stored water can be recovered after it has been stored; and
- With adequate regulatory safeguards, the stored water cannot be withdrawn by someone else.
(Kreitler 1998, 7)

Although the first attempts to use ASR in Texas occurred in 1950 in Kingsville, ASR has only in recent years become the focus of water resources management (Kreitler 1998, 1, 5). For aquifers underlying more than one river basin there would be no problems with an interbasin transfer; losses to evaporation would be eliminated; and no lengthy property condemnation procedures and construction would be required. House Bill 1989 (1995) encourages ASR in Texas, but not within the Edwards Aquifer. However, for the Edwards excess water, when it is available, could be withdrawn and then reinjected into the depleted portions of the Carrizo-Wilcox Aquifer south of San

Antonio for underground storage until needed. The Carrizo-Wilcox lacks the hydraulic conductivity and prolific springs of the Edwards Aquifer, and could be used as an underground storage reservoir for flood flows withdrawn from rivers overlying the Edwards. Portions of the Carrizo-Wilcox Aquifer are being mined, i.e. withdrawals are continuously lowering the water table (LBG - Guyton Associates 1994, Figure 2, Figure 3). Within the Bexar County portion of the Carrizo-Wilcox Aquifer possibly 20,000 acre-feet to 40,000 acre-feet of water can be stored using ASR, but a definitive study will not be ready until mid-2000 (Thuss 1999). On September 21, 1999, the SAWS board purchased a 261 acre farm over the Carrizo-Wilcox Aquifer in southern Bexar County for use as a potential ASR site, with an option to purchase another adjacent 3,750 acres. More storage space is likely to be available in the Carrizo-Wilcox Aquifer in Atascosa County. Storage and recovery of water in the Carrizo-Wilcox Aquifer could provide an alternative to surface water importation into the San Antonio area.

Surface Water Alternatives

> An alternative would be for the state to build a reservoir for San Antonio. (Lewis 1999)

The Senate Bill 1 regional planning process is forcing the region to come to grips with regional water supply issues (Thuss 1999). Off-channel reservoirs are needed to capture flood flows in the Edwards region (Thuss 1999). However, Mike Thuss, SAWS President and Chief Executive Officer, has stated that he is not convinced that a large reservoir is needed for San Antonio (Thuss 1999). Whatever alternative is chosen, it is probable that neither SARA nor the GBRA will build any surface water reservoir in the next 25 years (Thuss 1999). Traditionally, SAWS has been described as a user of water, while a river authority such as the GBRA is a facilitator of the use of water (Specht 1999). SAWS has decided to expand its mission beyond its current role as a water purveyor to include regional water development and supply (Thuss 1999). This course of action is being undertaken because, if SAWS develops its own supplies, it could avoid passing on to its customers the costs of the profit for potential suppliers such as the LCRA and GBRA (Thuss 1999).

> The public generally wants water in the most economical way. Whatever alternative is cheapest and easiest is the most attractive. (Thuss 1999)

There are several potential surface reservoir sites within the Guadalupe and San Antonio River basins. Opposition to the construction of Cuero I and Sandies Creek Reservoirs in the Guadalupe River basin, and Goliad Reservoir in the San Antonio River basin, is still strong (Cooper 1999, 1); (Gold 1999, 1). Even if approval of one of these reservoirs were obtained, piping water from the Guadalupe River to San Antonio would require an interbasin transfer. The opposition in both of these basins frequently cites San Antonio's rejection of Applewhite Reservoir in the city's own backyard as partial justification for opposing the construction (Cooper 1999, 1); (Gold 1999, 3). Senate Bill 1 has raised additional hurdles to interbasin transfers. These may inhibit water from reaching San Antonio from the Lower Colorado River, but an event such as the repeat of the drought of record could overwhelm any objection. The residents of the Colorado River basin are leery of transferring water to the Edwards region, which they believe may eventually be needed to maintain high levels in the

Highland Lakes above Austin or for their own growth. This opinion is enhanced by a belief that the Edwards region has not done all that it could to conserve and develop its regional water resources (Highland Lakes Group 1997, 1).

Medina Lake

Medina Lake on the Medina River northwest of San Antonio is owned by the BMA. There are two reservoirs overlying the recharge zone of the Edwards Aquifer and a distribution canal. The smaller reservoir, Diversion Lake, makes the largest single contribution of recharge to the Edwards Aquifer, possibly providing almost 8 percent of the surface-water recharge (Texas Natural Resource Conservation Commission 1994, 16). The maximum storage in Medina Lake is 66,000 acre-feet (Bexar - Medina - Atascosa Water Control and Improvement District 1 1994, 1). Raising the spillway at the Main Dam could increase the firm annual yield by an estimated 50,000 acre-feet (Blackwell 1995). The TNRCC has approved a change in BMA's permit to allow municipal, industrial, or irrigation use of up to 66,000 acre-feet (Bexar - Medina - Atascosa Water Control and Improvement District 1 1992, i).

The BMA, has entered into a "take or pay" agreement to sell excess water from Medina Lake to Bexar Met on a year-to-year basis, depending on availability. Bexar Met, in turn, plans to market this surface water to the areas around San Antonio after treatment. Bexar Met has constructed a plant to treat 10,080 acre-feet per year of the Medina River water; it began operation in December 1999 (Bexar Metropolitan Water District 1999, 15). The District has been negotiating to sell 6,000 acre-feet of this output to SAWS for Kelly and

Lackland Air Force Bases in San Antonio. The plant could eventually be expanded to 20,160 acre-feet per year (Bexar Metropolitan Water District 1999, 15).

Construction of Cibolo Reservoir

Since the 1960's, the Cuero and Lindenau Reservoirs projects have been under consideration in the Guadalupe River basin, and Cibolo and Goliad Reservoirs have been under consideration in the San Antonio River basin. There appears to be less local opposition to the Cibolo Reservoir, which is closer to San Antonio than the other potential surface water projects.

The TWDB estimates that over 32,300 acre-feet/year could be developed from the Cibolo project (HDR Engineering 1998). This reservoir site provides an option for storing excess water from the Edwards Aquifer in years of high recharge through a proposed diversion discussed in the last section of this chapter. Cibolo Reservoir is a potential complement to many of the other alternatives for water delivery to San Antonio, such as temporary storage of water that could be piped to ASR storage sites in the Carrizo-Wilcox Aquifer.

Surface Water from the Guadalupe-Blanco River

San Antonio has historically looked to the Guadalupe River as a surface water source to supplement the Edwards Aquifer. On March 18, 1998, the Guadalupe-Blanco River Authority Board approved the sale of treated water to SAWS and Bexar Met (Needham 1998e, 1B, 7B). The diversion will require a 43.5-

mile pipeline from Canyon Reservoir to deliver 8,000 acre-feet. SAWS and Bexar Met initially get 3,000 acre-feet each, and GBRA uses 2,000 acre-feet for its own customers (Thuss 1999). Over time, SAWS and Bexar Met's allocations will be reduced to 2,000 acre-feet each and that of GBRA will increase by 2,000 acre-feet (Thuss 1999). The cost of each 2,000 acre-feet of water will be $1.2 million annually, $600 per acre-foot, over the 40-year term of the agreement.

The firm yield from Canyon Reservoir, and the amount of water estimated available for diversion, is 90,000 acre-feet annually with the subordination (placing electric power generation below municipal water use in priority) of senior downstream hydroelectric rights (Nevola 1997, 1). The subordinated hydroelectric water rights amount to some 35,000 acre-feet of this total (Texas Water Development Board 1997, 3-84). Because San Antonio has no water treatment plant, the treated surface water might have to be delivered to several different locations for introduction into San Antonio's water system.

More water could be made available in the GBRA system by building off-channel reservoirs near the coast to store flood flows in the Guadalupe River. The LCRA has proposed a project discussed below which could be a prototype for the GBRA.

Interbasin Transfers and Surface Water from East of the Edwards Region

More than 70 surface water interbasin transfers existed in Texas as of 1998 (Hebert 1998, 88). They are often characterized in terms of water "haves" in the wetter eastern half of Texas and "have – nots" in the drier western half of Texas; some in the east view them as "State imposed 'takings' to the areas of need" that could imperil future economic growth in East Texas (Hebert 1998, 87). A common perception in East Texas is, "don't penalize us for acting prudently while benefiting others whose lack of foresight has allowed them to be caught short" (Hebert 1998, 88). As in Aesop's Fables, some in the East believe they have created a surplus of water, much as squirrels store nuts for the winter, while those in the west have not planned ahead, as in the case of San Antonio. However, interbasin transfers often represent transboundary disputes of a different category than the sequential power disputes that result from the movement of water into, through and out of the Edwards Aquifer. Interbasin transfer falls into the category of disputes that Olen Matthews describes as exclusionary power disputes, or disputes over the movement of water across boundaries as articles of commerce (Matthews 1994, 381, 382). Within Texas, they are intrastate disputes with the fundamental issue being the restriction of the export of articles of commerce, in this case water, across political boundaries that include legislative districts and the jurisdictions of river authorities.

Provisions in Texas Senate Bill 1 passed in 1997 make interbasin transfers more difficult than in the past, but not impossible. One barrier in particular is the provision of a new Section 11.085 of the Texas Water Code that gives new interbasin transfers a 'junior' priority within the basin of origin (Hebert 1998, 89). Thus, a surface water right purchased in one basin for transfer to another does not retain its original priority date, but becomes junior to all other rights in the basin of origin, such that an interbasin transfer cannot occur until all other senior permitted needs within the basin of origin are met. This discourages interbasin transfers, since such transfers are often initiated to meet demands outside the basin during droughts, at a time when meeting needs within the basin of origin can also be difficult. According to Representative Ron Lewis of the Texas House of Representatives Natural Resources Committee, the junior water rights provision in the state law is unlikely to be changed in the near future. "The current attitude in the Legislature is, don't bother me [my district] and I won't bother you [your district]" (Lewis 1999).

But is there actually a surplus of water in the eastern half of the state? The Deputy Executive Administrator for Planning of the TWDB, Dr. Tommy Knowles, has stated that, contrary to the conventional wisdom, there is not much excess water currently available in the eastern basins. Any surplus water in those basins will be needed where it is in the near future (Knowles and Mullican 1999).

The Colorado River has been considered a future water source for the Edwards region since the *1968 Texas Water Plan*. The LCRA is currently very actively pursuing development of the basin's water resources. The Garwood Irrigation District sold 35,000 acre-feet of its Colorado River water right to Corpus Christi, which is outside the basin, several years ago (Needham 1998f, 1A).

On February 19, 1998, the LCRA announced the purchase of the remaining 101,000 acre-feet water right held by the Garwood Irrigation District (Haurwitz 1998, A1). On June 8, 1999, Austin began the process of purchasing 75,000 acre-feet of this surplus, and the sale was completed on October 8, 1999 (Lindell 1999b, A5); (Lindell 1999a, A1). Austin, which does not use all of its current allocation, will have 325,000 acre-feet reserved, but it is not projected to use any of the additional 75,000 acre-feet until 2037 (Thornhill 1999). By 2050, Austin is projected to need all of it. The LCRA has expressed interest in selling water to

San Antonio in the past. However, current LCRA policy is that no water will be sold to San Antonio (Thornhill 1999). The City has asked to buy water and has been rebuffed. These moves would appear to eliminate the possibility that any of this Colorado water might eventually reach San Antonio. However, despite LCRA's policy, LCRA water may be declared surplus under the Senate Bill 1 planning process and available for 10 – 20 years (Thornhill 1999). In 1999, 150,000 acre-feet was available for sale in the LCRA system, in addition to the 75,000 acre-feet sold to Austin (Thornhill 1999).

More water could be developed in the LCRA system under a proposal to build twelve 3,500 acre-feet off-channel ponds, 15-20 feet deep near the coast in Matagorda County (Thornhill 1999). The ponds would store flood flows from the Colorado River. The LCRA has applied for a permit for all unappropriated water in the Colorado River, estimated from the 1991 – 1992 flood at 5.5 million acre-feet (Thornhill 1999). The water stored in these ponds would be used for irrigation in the counties at the southern end of the LCRA's service area to substitute for releases from the Highland Lakes. Firm yield of the entire system could potentially be increased by 200,000 acre-feet through this project (Thornhill 1999).

Rice irrigation is a major use of water in the Lower Colorado River basin near the coast. The 1996 Freedom to Farm Act is scheduled to phase out subsidies for rice farming in 2002 (Barta 1998, T1). A consequent decline in rice growing could make additional amounts of water available in the basin. However, while rice farming in the basin has fluctuated, it has been relatively stable since the 1940s, and about 40,000 acre-feet of the water once used for irrigation is now being saved through conservation (Thornhill 1999).

The LCRA may have no plans to sell water to San Antonio, but Austin could lease the 75,000 acre-feet it is purchasing from the LCRA to the San Antonio Water System or the GBRA, until 2037, or whenever the water is needed by Austin. There is a precedent for Austin becoming involved with a project to help San Antonio get the water it needs. From October 1991 through January 1992, Austin Mayor Bruce Todd attempted to resolve the disagreements over regulation of the aquifer. The terminus of the pipeline that the LCRA is considering to Dripping Springs is close to the Blanco River. A short extension of this pipeline to the Blanco could allow water from Austin to be sold on a temporary basis to San Antonio. The GBRA's jurisdiction includes portions of Hays County near Dripping Springs. If the Dripping Springs pipeline were extended to the Blanco River, the GBRA could substitute this water for water now used in the southern end of its system. This substitution would allow water to be sold to San Antonio from the Guadalupe River at a point closer to Bexar County, possibly the pipeline that would bring the 8,000 acre-feet of Canyon Reservoir water to Bexar County or one of the other pipelines under consideration.

Senate Bill 1 limits on interbasin transfers of water may apply only if the water right is sold; a term lease of water may not be subject to the required analytical process in the statute. A permit from TNRCC for the trans-basin diversion would be required before the transfer could occur. Any major sale of Colorado River water outside the basin by LCRA, might require approval through an Act of the State Legislature. Even if none of these projects were to take surface or groundwater west to San Antonio, the crushing socioeconomic impact of a repeat of the drought of record upon a region as unprepared as the Edwards could force a sale sometime in the future.

The Conjunctive Use of Ground and Surface Water

To meet the projected long-range water supply demands for the San Antonio region, the Edwards Aquifer, the Carrizo-Wilcox Aquifer, present and future regional surface reservoirs, and water flow in several rivers should be managed together. The process of managing surface and groundwater systems to maximize their efficiency and take advantage of the best characteristics of each source is called conjunctive use. The Western Water Policy Review Advisory Commission has concluded that the conjunctive use of ground and surface water should be a prerequisite for future financial support for western water resource development:

> State law should recognize and take account of the substantial interrelation of surface water and groundwater. Rights in both sources of supply should be integrated, and uses should be administered and managed conjunctively. The Congress should require state conjunctive management of groundwater and regulation of withdrawals as a condition of federal financial assistance for construction of new water storage projects or other federally funded activities. (Western Water Policy Review Advisory Commission 1998, xxiii)

The conjunctive use of interdependent hydrologic systems of the Edwards and Carrizo-Wilcox Aquifers, and the Nueces, San Antonio, and Guadalupe River basins would take advantage of the hydrologic characteristics of each system, with the alternating seasons and fluctuating weather patterns, relying more on Edwards groundwater when recharge is high, and on alternative sources when recharge is inadequate and spring discharge is low.

The *1961 Texas Water Plan* established a goal of changing the state's haphazard local water development scheme to a coordinated effort to meet anticipated future water needs by developing and managing water within Texas' major river basins. Because of the hydrologic interconnections between these three rivers and the Edwards Aquifer, the 1961 plan "suggests treatment of these three river basins [Guadalupe, San Antonio, and Nueces] as a unit in developing total available supplies. However, any plan for meeting projected water requirements in the area must recognize the individuality of each river basin" (Texas Board of Water Engineers 1961, 26).

The *1968 Texas Water Plan* encouraged conjunctive use of ground and surface water "with the objective of developing a management program optimizing the use of water from the Edwards (Balcones Fault Zone) Aquifer for all beneficial purposes while maintaining optimum minimum flows from Comal and San Marcos Springs" (Texas Water Development Board 1968a, I-16). The plan retained the principle that, since these rivers are hydrologically interconnected with the Edwards Aquifer, it would be advantageous to treat them as a unit:

> Streamflows throughout much of the upper parts of these three river basins are strongly influenced by fluctuations in the amount of ground water in storage in the Edwards (Balcones Fault Zone) Aquifer and other limestone aquifers which underlie this area. Therefore, since these basins are essentially in hydraulic connection, there are significant advantages to planning for the development of the water resources of parts or all of these three river basins as a unit to meet projected water requirements of the area, while at the same time continuing to recognize the statutory

> individuality and needs of each basin. (Texas Water Development Board 1968a, I-14)

These basins have been treated as a unit in planning efforts such as the *Trans-Texas Water Program* and the Senate Bill 1 process, yet conflicts persist. The full potential of the basins collectively has not been realized, raising the question of whether the operational relationship between the Edwards Aquifer and the Guadalupe, San Antonio, and Nueces River basins should become more formal. To avoid transboundary disputes between the Edwards region and areas to the east and west, I believe that the regional surface and groundwater resources should be developed, before water is imported from the Colorado River or other basins. The state has encouraged voluntary cooperation in the *Texas Water Plans*; Senate Bill 1 also requires cooperation between these entities. Yet, no major reservoir project for water self-sufficiency in the region has been completed since Canyon Reservoir. In some of the interviews I conducted during my research I asked the following question:

> Given that the Nueces, San Antonio, and Guadalupe River basins are interconnected with the Edwards Aquifer, would it be an advantage or a disadvantage if the three river authorities and the EAA were to have a more formal regulatory relationship?

The following are representative responses to this question:

> The EAA and Guadalupe, San Antonio, and Nueces River Authorities should be tied in together, but the state doesn't have the will to do this. The economic growth of the state is imperiled, if the San Antonio economy doesn't have adequate water to meet its needs. - Ron Lewis, Texas House of Representatives.

A formal relationship between the EAA, GBRA, SARA, and NRA makes sense, but I am not certain how this would be accomplished.
- Howard Peak, Mayor, City of San Antonio.

Senate Bill 1 already requires the EAA to coordinate with surface water entities. - Dr. Tommy Knowles, TWDB Deputy Executive Administrator for Planning.

A super regional agency would have the advantage of being a powerful lobby, but paying for the organization would be a problem. - Mike Thuss, President and CEO of the San Antonio Water System.

Creating a super-regional water agency is an old idea. The GBRA's population does not want to be ruled by other basins or Edwards Aquifer users. Water as a public resource has always been in contention. Our system of water law is designed to keep us independent. No real progress can be made until someone decides to pay for the water. - John Specht, former General Manager of the GBRA.

Theoretically, it makes sense to manage the region's water under a regional agency that controls surface and groundwater. The problem is the political and hydrological (surface and groundwater) boundaries, and the population distributions do not converge. - Louis Rosenberg, Special Counsel for Bexar Met.

I don't believe that the EAA, NRA, SARA, and GBRA will ever be formally combined. The EAA and the authorities already have a good working relationship. - Luanna Buckner, EAA Board member representing Medina County.

Additional Alternatives

Recharge Structures in Contributing and Recharge Zone

Recharge structures increase recharge in years when rainfall produces enough water for runoff to be captured in them. There are two types. Type 1 reservoirs are catch and release reservoirs in the contributing zone that intercept storm runoff and release it at a rate that can be best absorbed by the exposed Edwards limestone outcrop in the recharge zone (Todd Engineers 1999, 9). These reservoirs may hold water for a month or more and minimize siltation at the points of recharge. Type 2 reservoirs are in the recharge zone and catch and hold water that percolates directly into the Edwards limestone (Todd Engineers 1999, 9). Type 2 reservoirs hold water for shorter periods of time than Type 1 reservoirs. The Edwards Underground Water District, and other entities, have constructed Type 2 reservoirs, flood retardation, and recharge structures over the Edwards Aquifer. The EAA currently maintains and operates four recharge dams (Ellis 1999). Type 1 and 2 projects can produce water under average conditions within a cost range of $198 to $238 per acre-foot (Todd Engineers 1999, 10). Also, flood control detaining dams located on rivers in the region act as recharge structures.

A recent study for the EAA estimates that the natural recharge to the aquifer could be enhanced up to 40% by capturing more rainfall and streamflow (Todd Engineers 1999, 9, 10). Keeping the aquifer artificially high could reduce the amount of time spring discharge is below critical levels during droughts, depending on the length of the drought. To deliver an estimated 100 cfs of flow at Comal Springs for one year requires approximately 73,000 acre-feet of recharge from numerous enhancement projects, with the important caveat that the benefit of enhancement projects for "ensuring drought springflows has yet to be documented" (Todd Engineers 1999, 11, 12).

There are disadvantages to the use of recharge structures. In years of low rainfall, little or no recharge is realized, so recharge dams are useful for increasing the amount of water in the aquifer before a drought begins. A large volume of unsaturated storage in the recharge zone probably can never be filled. Recharge enhancement should focus on capturing water for use during droughts, but such efforts can contribute only limited amounts of water during droughts (Todd Engineers 1999, 11). There are some concerns that recharge structures have a high potential to contaminate the aquifer with local runoff (Coastal Ecosystems Management 1975, 421). Also, because recharge enhancement would decrease the amount of water that would otherwise flow past the recharge zone, instream flows might be reduced to some degree in the Guadalupe, San Antonio, and Nueces River basins. While the Guadalupe River basin might gain through a smaller reduction in discharge from Comal and San Marcos Springs during droughts, flows in the San Antonio, and particularly the Nueces, River basins would decrease. This potentially could reduce inflows to Choke Canyon Reservoir and Lake Corpus Christi, which supply the City of Corpus Christi. This result has the potential to aggravate sequential power conflicts among the EAA, the NRA and Corpus Christi. Corpus Christi has already purchased water from the Lower Colorado River, and buying more water could bring that city into conflict with other users in the Colorado River basin.

Others are not convinced that recharge dams are the answer to San Antonio's water needs. Recharge dams require land acquisition, permitting, and a yet-to-be determined EAA system for allocating pumping credits for amount of water recharged. There is also the question of how much water would actually be available over time (Thuss 1999). SAWS is spending $500,000 on optimization, plus 80% of what the EAA spends on optimization, since SAWS provides 80% of the funding for the EAA through pumping fees (Thuss 1999). Recharge dams and other water supply options should be evaluated considering the likelihood of periodic multi-year droughts. They have been criticized for their relatively high costs and limited effectiveness during droughts (Watkins and McKinney 1999, 23). Recharge dams could help with short-term droughts, but would be virtually useless for long-term droughts (Thornhill 1999).

Weather Modification

The EAA, with some funding from the TWDB, has initiated a cloud seeding program to combat drought by increasing precipitation in the contributing and recharge zones. It budgeted $500,000 for the program in 1998 (Needham 1998b, 1B) and it is intended to operate from April 15th – September 15th (Buckner 1999). Cloud seeding has been practiced in Texas since 1971 (Bomar 1998, 47). Seeding with silver iodide has been found to increase the efficiency of the rain process. For example, a study of seeding with silver iodide in the Big Spring area found that rain volume increased by 230%; seeded clouds 'lived' 36% longer than unseeded clouds; seeded clouds expanded to produce rainfall over a 43% larger area; and seeded clouds merged with adjacent convective cells twice as often as unseeded clouds (Bomar 1998, 49). However, the timing and targeting of clouds is critical to the success of this procedure (Bomar 1998, 53). A previous analysis found that this type of weather modification is considered "erratic in its results and entirely unreliable during extreme drought periods when overall atmospheric moisture levels are low" (Coastal Ecosystems Management 1975, 423, 424). Other sources have questioned the usefulness of weather modification during critical droughts (Todd Engineers 1999, 13).

Desalination

Desalination has been characterized as a potential source of water that is always too expensive at the moment, but possibly affordable somewhere in the distant future. The President and CEO of SAWS has indicated that desalination might be feasible within 15 years (Thuss 1999). However, recent advances could allow water to be supplied today for as little as $1.70 per 1,000 gallons or $554 per acre-foot (Knowles and Mullican 1999). In Tampa Bay, Florida, Stone & Webster, Inc. is building a desalination plant combined with a power plant. The brine from the desalination plant is diluted in the power plant's discharge. The project uses new thin, inexpensive filters that last longer than previous filters (Knowles and Mullican 1999). Within five years the costs of filters, or membranes, may decrease by 29% from current prices (U.S. Water News 1999, 5). A similar desalination plant could be considered for Corpus Christi, to be combined with an existing power plant (Knowles and Mullican 1999). San Antonio could consider paying a portion of the costs for constructing the power plant in exchange for Corpus Christi's water in Choke Canyon Reservoir, approximately 60 miles south of San Antonio (Knowles and Mullican 1999).

Desalination has also been considered for the brackish portion of the Edwards Aquifer on the south side of the bad water line. However, concerns that withdrawals of brackish water could draw freshwater across the bad water line complicate this alternative (Todd Engineers 1999, 20).

This and previously discussed alternatives are summarized in Table 51.

Table 51. Representative Alternatives for Reducing Withdrawals from the Edwards Aquifer

CONSERVATION ALTERNATIVES	ACRE-FEET/YEAR	ESTIMATED COST/ACRE-FOOT
Water conservation by municipalities, industries, irrigators and others	90,000	$276
Reallocation of Edwards groundwater from agricultural to municipal users	118,600	Annual Lease $50 Sale $700
SAWS reuse of treated wastewater for nonpotable uses	35,000	$380
Land treatments, such as brush control	24,000 – 38,500	$150
Recharge structures	9,250 (droughts)	$343 - $ 1,022
STORAGE ALTERNATIVES	**ACRE-FEET/YEAR**	**ESTIMATED COST/ACRE-FOOT**
Aquifer storage and recovery in the Carrizo-Wilcox Aquifer	50,000 +	$464 - $717
Construction of Cibolo Creek Reservoir	32,300	$1,145
IMPORTATION ALTERNATIVES	**ACRE-FEET/YEAR**	**ESTIMATED COST/ACRE-FOOT**
Importation of surface water from the Guadalupe-Blanco River	71,300	$828

Importation of groundwater from the Carrizo-Wilcox Aquifer near Gonzales	90,000	$419
Importation of Alcoa groundwater from the Carrizo-Wilcox Aquifer	40,000 – 60,000	$800 - $900
Use of Medina Lake water	66,000	< $451
Importation of surface or groundwater from the Colorado River Basin	50,000	$793
ASSORTED ALTERNATIVES	**ACRE-FEET/YEAR**	**ESTIMATED COST/ACRE-FOOT**
Control of the giant rams-horn snail at the springs (additional withdrawals)	65,000	undetermined
Weather Modification	Undetermined	Undetermined
Regional HCP and 10(A) Permit	Undetermined	Undetermined
TOTAL	741,450 – 775,950	

Sources: (HDR Engineering 1998, Option L-10 and L-13A, 3-2, Option S-15C and S-13C, 3-3, Option G-28, 3-4, Option C-17B, 3-6, Option CZ-10C, 3-7), (CH2M Hill and Lee Wilson and Associates 1991, 4 - 22), (Natural Resource Conservation Service 1995, table, unnamed, unnumbered), (Nevola 1999), and (Moore and Votteler 1995, 273).

The San Antonio Drought Reserve Project (SA-DROP)

Managing water in the Edwards region should be designed to take maximum advantage of the typical weather patterns and to capture as much water as possible during years of plenty to be stored for use during the periodic droughts. An active management scheme should be adopted that addresses potential future shortfalls, as opposed to the current passive system that reacts to imminent shortfalls. Such a management scheme is superior to relying upon crisis solutions or the penalties of the ESA, triggered retroactively by harm to the listed species.

Any successful management plan for the Edwards Aquifer must meet the requirements of the ESA. It must also provide the maximum flexibility for meeting requirements of the human needs of the region. It must operate within the boundaries of state regulation; however, Senate Bill 1477 has already been modified by the Legislature and is likely to be modified again in the future, so long as any modification does not allow outright violations of the ESA and are considered to be beneficial -- or at least not detrimental -- to the major interests in the region.

The centerpiece of Senate Bill 1477 is the pumping limits that decrease over time. The staged caps on withdrawals do not take full advantage of the hydrologic characteristics of the aquifer. Restricting withdrawals to 450,000, 400,000, or less, eventually, is too restrictive in years of high recharge. Likewise, withdrawing 450,000 and 400,000 acre-feet following years of low recharge could be too generous, resulting in take or jeopardy conditions subsequently at the springs and limited downstream surface water to meet essential needs. A system using a flexible cap would provide more long-term benefits. In years of high recharge, additional amounts of water (beyond what is needed to maintain minimal spring discharge, provide water to downstream users, and fulfill freshwater inflows to bays and estuaries) could be withdrawn to be stored for use in years of low recharge. The goal should be to supply the region with water while assuring that a water reserve is accumulated to maintain minimum springs and downstream flows in the Guadalupe River during droughts, thus avoiding violations of the ESA and surface water shortages with low spring discharge rates.

As stated earlier, the minimum 200 cfs flow rate below which takes occur at Comal Springs equals 144,800 acre-feet for one year. The minimum 100 cfs flow rate below which take and jeopardy occur at San Marcos Springs equals 72,400 acre-feet for one year. The total combined minimum discharge of 300 cfs from both springs for one year equals 217,200 acre-feet, which ultimately flows into the Guadalupe River. If 217,200 acre-feet is deducted from the total annual combined discharge from Comal and San Marcos Springs, the remainder could be available for diversion or use without violating the ESA. In addition to this discharge amount, there would be flow in the Guadalupe River system from Canyon Reservoir and other tributary sources. When Comal Springs is discharging at greater than 200 cfs and San Marcos Springs is discharging at greater than 100 cfs, conditions are usually such that the 258,100 acre-feet of downstream rights are met and the excess spring discharge could be diverted (Nevola 1999). In addition to the minimum flow from the springs, the Guadalupe River would continue to receive surface storm water runoff, contributions from other tributaries, and releases from Canyon Reservoir; these contributions would not be available for diversion to storage under this plan. A diversion for use or storage could take place only under the following conditions:

- Discharge from Comal Springs must be above 200 cfs and discharge from San Marcos Springs must be above 100 cfs;
- Inflow to the Guadalupe Estuary must be adequate to sustain the necessary freshwater – saline water balance as determined by the appropriate state agency;
- Surface water permits in the Guadalupe must be satisfied; and
- Candidate species in the Guadalupe River ecosystem, such as Cagle's map turtle, must not be adversely impacted.

The instream flow requirements for Cagle's map turtle are unknown, but an ongoing joint study between the TNRCC and GBRA might determine the necessary flows (Todd Engineers 1999, 29).

The water stored through this plan would be stored primarily for use by municipal and industrial users in San Antonio/Bexar County, there are four reasons for this. First, most critical spring discharge periods occur from June through September, by which time most irrigation for crop use is concluding, and restricting irrigation could result in significant crop losses. Second, discretionary municipal landscape watering increases significantly during the critical June through September period. Third, New Braunfels and San Marcos are now using surface water to substitute for withdrawals from the aquifer. And finally, developing the infrastructure necessary to deliver the stored water is most feasible for a large population center, such as that found in Bexar County.

Total combined discharge from Comal and San Marcos Springs from 1957 to 1997 totaled 13,472,400 acre-feet (Table 52). Any year when flows declined below the 100 cfs and 200 cfs minimum levels were not used in calculating the totals. Over the last 24 out of 41 years, or in 58% of the years, it appears that water could have been diverted throughout the entire year. Under the constraints given above, the total available for use or diversions over these 24 years would have been 3,962,400 acre-feet, or 29% of the total discharged from both springs. The average available annually for the 24 years would have been 165,100 acre-feet, while the annual average available over the entire period from 1957 to 1997 was approximately 96,650 acre-feet. The maximum amount available for use or diversions in any one year was 353,100 acre-feet in 1992, the year of record recharge to the Edwards Aquifer. In 10 additional years when spring discharge was below the minimum necessary to protect the listed species for at least one day (denoted with ∴ in Table 52), but total discharge exceeded 217,200 acre-feet, use or diversion could have occurred during a portion of those years, but these years were omitted from the calculations to provide a conservative estimate of the amount of water that might potentially be available. There were 7 out of the 41 years when it appears no use or diversions of excess flows could have occurred during any portion of the year, because total annual discharge from both springs was less than 217,200 acre-feet.

Table 52. Historical Estimate of the Total Amount of Comal and San Marcos Springs Discharge Potentially Available for Diversion, 1957 through 1997

Year	Total Annual Comal Springs Discharge, acre-feet	Total Annual San Marcos Springs Discharge, acre-feet	Total Annual Comal and San Marcos Springs Discharge, acre-feet	Minimum Annual Required Discharge from the Springs, acre-feet#	Maximum Annual Amount Available for Diversion or Use, acre-feetΔ
1957	105,500	110,300	215,800	217,200	(1,400)*
1958	227,000	153,400	380,400	217,200	163,200
1959	227,000	116,000	343,000	217,200	125,800
1960	230,300	141,400	371,700	217,200	154,500
1961	241,800	138,300	380,100	217,200	162,900
1962	192,200	95,860	288,060	217,200	70,860∴
1963	150,300	78,710	229,010	217,200	11,810∴
1964	137,200	70,170	207,370	217,200	(9,830)*∴
1965	188,900	123,000	311,900	217,200	94,700∴
1966	193,000	111,400	304,400	217,200	87,200∴
1967	131,000	77,650	208,650	217,200	(8,550)*∴
1968	231,200	143,100	374,300	217,200	157,100
1969	210,600	117,800	328,400	217,200	111,200
1970	221,600	144,600	366,200	217,200	149,000
1971	158,600	91,830	250,430	217,200	33,230∴
1972	224,700	116,700	341,400	217,200	124,200

1973	278,400	158,200	436,600	217,200	219,400
1974	275,200	133,800	409,000	217,200	191,800
1975	285,100	170,100	455,200	217,200	238,000
1976	266,800	153,200	420,000	217,200	202,800
1977	281,400	161,700	443,100	217,200	225,900
1978	232,000	87,420	319,420	217,200	102,220
1979	285,700	144,900	430,600	217,200	213,400
1980	204,900	95,960	300,860	217,200	83,660∴
1981	226,100	131,000	357,100	217,200	139,900
1982	197,200	93,470	290,670	217,200	73,470
1983	169,400	106,300	275,700	217,200	58,500∴
1984	89,780	72,340	162,120	217,200	(55,080)*∴
1985	181,000	132,000	313,000	217,200	95,800∴
1986	208,000	145,500	353,500	217,200	136,300
1987	261,000	183,500	444,500	217,200	227,300
1988	200,100	102,000	302,100	217,200	84,900
1989	116,800	72,530	189,330	217,200	(27,870)*∴
1990	127,400	82,570	209,970	217,200	(7,230)*∴
1991	170,100	137,900	308,000	217,200	90,800∴
1992	320,700	249,600	570,300	217,200	353,100
1993	278,900	138,100	417,000	217,200	199,800
1994	226,200	98,610	324,810	217,200	107,610
1995	200,800	115,000	315,800	217,200	98,600
1996	125,300	72,060	197,360	217,200	(19,840)*∴

1997	189,000	136,200	325,200	217,200	108,000∴
Total	8,468,180	5,004,180	13,472,360	8,905,200	

#Figure rounded and based on take at Comal Springs with a daily mean of 200 cfs, and take and jeopardy at San Marcos Springs with a daily mean of 100 cfs.
*Years in which minimum required discharge exceeded total discharge. No water would be available when spring discharge is below the minimum necessary to protect the listed species.
∴Years in which, on at least one day, flow when either Comal Springs fell below a mean of 200 cfs, and/or San Marcos Springs fell below a mean of 100 cfs.
ΔDoes not include losses due to evaporation, recharge, and withdrawals at water intakes between both springs and the Guadalupe and Comal River confluence.

Source: Calculations by author based in part upon Total Comal and San Marcos Springs Discharge data provided by Ozuna 1999a.

While 200 cfs at Comal and 100 cfs at San Marcos Springs were used to demonstrate the maximum amounts of water that could have been available, higher or lower rates of spring discharge could be chosen to determine when to cease additional pumping or diversions. When spring discharge exceeded these discharge rates for both springs, the excess could be calculated and pumped or diverted downstream. If a regional Incidental Take Permit were in place, more water might potentially be made available for use or diversion with lowered required spring discharge rates; however, additional use or diversions should not be allowed if either would violate any of the limitations listed above.

How and When to Divert the Available Water or Water in Storage

Diversion of the available water or use of the stored water could be linked to the USGS gauging stations at Comal and San Marcos Springs that measure spring discharge every 15 minutes to determine when the diversions could occur.

The storage sites for the drought reserve could include (1) a series of small off-channel reservoirs on the Guadalupe, San Antonio, or Nueces River basins similar to those the LCRA is considering for the Colorado River, (2) Cibolo Reservoir or another large regional reservoir, (3) ASR in Bexar, Wilson, or Atascosa Counties, or (4) a combination of the three. There are two primary methods for diverting and storing the additional water; (1) direct pumping from the Edwards Aquifer, or (2) diversion from the Guadalupe River basin.

Option 1: Direct Pumping from the Edwards Aquifer

Temporary permits to authorize pumping water in excess of required minimum flows could be issued under § 1.19 of Senate Bill 1477 instead of allowing the water to flow into in the Guadalupe River:

ARTICLE 1, SECTION 1.19
TERM PERMITS

(a) The authority may issue interruptible term permits for withdrawal for any period the authority considers feasible, but may not issue a term permit for a period of more than 10 years.

(b) A holder of a term permit may not withdraw water from the San Antonio pool of the aquifer unless the level of the aquifer is higher than 665 feet above sea level, as measured at Well J-17.

(c) A holder of a term permit may not withdraw water from the Uvalde pool of the aquifer unless the level of the aquifer is higher than 865 feet above sea level, as measured at Well J-27.
(Act of May 30, 1993 73rd Leg., R.S., ch. 626, 1993 Tex. Gen. Laws 2355, *as amended by* Act of May 29, 1995, 74th Le., R.S., ch. 261, 1995 Tex. Gen. Laws, §1.19(a)(b)(c)).

Because of variations between well levels and spring discharge rates §1.19(b) and (c) might need to be modified. Pumping the water from the aquifer directly using existing wells, would be less expensive than diverting the water from the Guadalupe River basin. After it is withdrawn, the water could be piped to storage sites and from there to the Edwards region.

The potential pitfall of this option is that, without adequate safeguards, this approach could simply result in additional pumping from the aquifer without assuring adequate minimum spring discharge or long-term solutions. Pumping to meet current water needs to the detriment of a drought reserve must be avoided. Without adequate safeguards for the users in the Guadalupe River basin or for the threatened or endangered species at the springs, this option would do little to reduce the transboundary disputes between Edwards Aquifer pumpers and the interests in the Guadalupe River basin. Reducing such disputes is the key to a lasting regional solution.

Option 2: Diverting Water from the Guadalupe River Basin

To reduce costs, the diversion could be part of another project requiring a pipeline going west toward San Antonio, instead of a stand-alone project. There are several options for transporting the water to several potential storage sites:

- Diversion only of the excess Comal Springs discharge above Seguin with a pipeline along the I-10 right-of-way, with San Marcos Springs component not diverted;
- Diversion near Gonzales to any pipeline under consideration that might take Guadalupe River or Carrizo-Wilcox Aquifer water to San Antonio, with the amount equal to the excess spring discharge diversion, minus evaporation and conveyance losses, redirected where a pipeline crosses Cibolo Creek, above the proposed reservoir site, for eventual storage in Cibolo Reservoir, redirected for ASR in the Carrizo-Wilcox Aquifer in Bexar, Wilson, or Atascosa Counties, or a combination of these;
- Diversion near Victoria to off – channel reservoirs for transfer via a pipeline to San Antonio, with the amount equal to the excess spring discharge diversion, minus evaporation and conveyance losses, redirected where the

pipeline crosses Cibolo Creek, above the proposed reservoir site, for eventual storage in Cibolo Reservoir, redirected for ASR in the Carrizo-Wilcox Aquifer in Bexar, Wilson, or Atascosa Counties, or a combination of these;

- Diversion through a pipeline coming from the east with Colorado River surface water, so long as the pipeline crosses the Guadalupe River below the San Marcos River and Guadalupe River confluence, with the amount equal to the excess spring discharge diversion, minus evaporation and conveyance losses, redirected where the pipeline crosses Cibolo Creek, above the proposed reservoir site, for eventual storage in Cibolo Reservoir, redirected for ASR in the Carrizo-Wilcox Aquifer in Bexar, Wilson, and Atascosa Counties, or a combination of these;
- Diversion through a pipeline coming from the east with groundwater pumped from the Carrizo-Wilcox (Simsboro) Aquifer by Alcoa, so long as the pipeline crosses the Guadalupe River below the San Marcos River and Guadalupe River confluence, with the amount equal to the excess spring discharge diversion, minus evaporation and conveyance losses, redirected where the pipeline crosses Cibolo Creek, above the proposed reservoir site, for eventual storage in Cibolo Reservoir, redirected for ASR in the Carrizo-Wilcox Aquifer in Bexar, Wilson, and Atascosa Counties, or a combination of these;
- Instead of building a pipeline directly to San Antonio, Alcoa's groundwater could be diverted to a tributary of the Colorado River and then stored in the LCRA's planned off-channel reservoirs near the coast. At this point, the distance between the Colorado and Guadalupe Rivers is minimal and a pipeline could be built from the LCRA's off-channel reservoirs to off –

channel reservoirs built by the GBRA from which water would then go to the Edwards region, with the amount equal to the excess spring discharge diversion, minus evaporation and conveyance losses, redirected where the pipeline crosses Cibolo Creek, above the proposed reservoir site, for eventual storage in Cibolo Reservoir, redirected for ASR in the Carrizo-Wilcox Aquifer in Bexar, Wilson, or Atascosa Counties, or a combination of these; and

- The Alcoa Carrizo-Wilcox Aquifer water could be traded to the LCRA to substitute for an equal amount of Colorado River water provided to GBRA to replace an equal quantity of water transferred from the Guadalupe River basin to San Antonio.

Diversion downstream of the confluence of the San Marcos River and Guadalupe River near Gonzales, Texas, would avoid much of the recreational area on the Guadalupe River. If a pipeline for a transbasin diversion of surface or groundwater from the east to San Antonio is to be built, it should cross the Guadalupe River downstream of the confluence of the Comal River so that a pump station can be placed there to divert the excess water. The pipeline should cross Cibolo Creek above the proposed reservoir site, where it could be diverted into the creek for storage in Cibolo Reservoir when storage in the Carrizo-Wilcox is not available. This diversion could also be linked to a project to harvest flood flows in the Guadalupe, San Antonio, and Nueces River basins. Because of the greater potential for Option 2 to reduce transboundary disputes, I believe that diversion after water has entered the Guadalupe River is the superior choice.

SAWS, Bexar Met, or a private concern could be the purchasers of this water. If the water is piped to the recharge zone for reinjection into the Edwards

Aquifer, it would defeat the objective of creating a drought reserve. In general, direct diversion for use in San Antonio, instead of storage, should be avoided because this would defeat the purpose of developing a drought reserve for the San Antonio area to be used to reduce pumping and protect discharge rates at the springs to avoid violations of the ESA and inadequate downstream surface water flows. However, the direct diversion option could be permitted if staged storage goals are exceeded. For example, if feasible;

- Within five years of the initial diversion, if more than 50,000 acre-feet are in storage, the excess could be diverted directly to San Antonio;
- Within ten years of the initial diversion, if more than 100,000 acre-feet are in storage, the excess could be diverted directly to San Antonio;
- Within fifteen years of the initial diversion, if more than 150,000 acre-feet are in storage, the excess could be diverted directly to San Antonio; and
- Within twenty years of the initial diversion, if more than 200,000 acre-feet are in storage, the excess could be diverted directly to San Antonio.

When Should the Drought Reserve be Accessed?

Once the drought reserve accumulates, the use of the stored water should be linked to declines in the flow of Comal and San Marcos Springs. For example, when Comal Springs reaches 250 cfs or San Marcos Springs reaches 125 cfs, the drought reserve could be tapped at the same time pumping from the aquifer is restricted by a CPMP triggered by spring discharge rates on a schedule similar to that recommended by the USFWS (see Appendix 3, Item 8. A Summary of the

USFWS Recommendations to the Edwards Aquifer Authority for Trigger Levels). Another option would allow the water to be released for any use when the amount stored in the drought reserve rises above a certain amount such as 200,000 acre-feet. This figure should be high, since this water is needed to assure the region's supply during a significant portion of a repeat of the drought of record, in conjunction with the alternatives identified in Table 51, in exchange for pumping reductions that maintain discharge at the springs above the jeopardy level.

While this project would likely be opposed in the Guadalupe River basin, it should be remembered that the population over the Edwards Aquifer is projected to double to nearly 4 million by 2050. The economic health of the Edwards region directly affects the health of the economies of the cities in the Guadalupe River basin. Also, while there are disincentives for not complying with Senate Bill 1477 and the ESA, at present there are few incentives to comply. This project would be worthwhile for the inhabitants of the Guadalupe River basin only if pumpers from the Edwards Aquifer could provide additional guarantees beyond those found in Senate Bill 1477 that pumping would be restricted to the amount necessary to maintain critical flows from Comal and San Marcos Springs during a repeat of the drought of record. These guarantees would include triggering the EAA's CPMP based on Comal Springs and San Marcos Springs discharges rates instead of levels in groundwater index wells and using the discharge rates suggested by the USFWS. It is possible that the diversions could be controlled by the GBRA. Also, in exchange, the minimum discharge rates from the springs to protect endangered and threatened species might not be lowered. An agreement to divert this water could be linked to measures that ultimately would provide greater water security for the Guadalupe River basin and move the region toward sustainable management of the Edwards Aquifer with groundwater from the Carrizo-Wilcox Aquifer surface waters of the Guadalupe, San Antonio, and Nueces River basins. The Legislature could add voting board members to the EAA from districts established in the area along the Guadalupe downstream of the springs, and San Antonio River below Bexar County, and possibly the Nueces River south of the confined zone of the aquifer. There is already a nonvoting representative on the board chosen from the downstream interests represented in the South Central Texas Water Advisory Committee.

Another possibility is that the Texas Legislature could grant the GBRA a senior surface water right in spring discharge. This water right would be senior to any pumping right in Edwards Aquifer since spring discharge has been providing for the needs of the inhabitants of the Guadalupe River basin long before the first well was drilled into the aquifer in 1884. The permit could consist of a legal right to a minimum discharge from each spring or an annual volume of water. For example, the GBRA could be given a right for a minimum discharge from the springs equal to the 200 cfs take rate at Comal and the 100 cfs jeopardy rate at San Marcos Springs, or their annual volume of 217,200 acre-feet. Such a right could allow the Guadalupe River basin to protect and manage its future water interests through established state legal and administrative institutions, instead of through the Endangered Species Act. This option should reduce transboundary disputes by eliminating some of the uncertainties with regard to property rights, allowing water supply and conservation planning in the region to proceed with fewer unknowns.

11. OBSERVATIONS AND CONCLUSIONS

The following circumstances make the Edwards Aquifer ESA issue unique:

- The inability to manage the aquifer on a sustainable basis created an intractable regional water resources and environmental dispute. The key parties historically have considered additional litigation as their best alternative to a negotiated settlement;
- The Edwards has unique physical characteristics;
- The aquifer until regulated, was a common pool resource;
- The presence of invasive terrestrial and aquatic species complicates the issue;
- This is a water (a mobile resource) based property rights dispute, not a land based dispute;
- The rule of capture prevailed as state groundwater law for years, eliminating tort litigation (except for land subsidence) as a way for individuals to recover damages for diminished groundwater availability and thereby limit pumping;
- No viable alternative to federal litigation was available in state law until *Sierra Club et al. v. Babbitt et al.* resulted in the passage of Senate Bill 1477; and
- No entity had comprehensive authority over pumping from the aquifer until the EAA was created.

The fight that continues today over the Edwards Aquifer began in the 1950s during the Texas drought of record, years before the Endangered Species Act became law in 1973. The debate pits urban culture and economics v. rural culture and economics, between agricultural interests in Bexar, Medina, and Uvalde Counties and municipal, recreational, and industrial interests in San Antonio, and similar interests in the spring communities and downstream in the Guadalupe River basin. There is also a minority in San Antonio who oppose any regulation, and believe the aquifer should be mined as has the Ogallala on the Texas High Plains. Agricultural interests fear that withdrawal limits will ruin their economies. Residents of rural areas argue that water and water rights might be transferred from rural areas to the expanding urban areas, restricting the development of rural areas and resulting in the loss of lifestyle and local governmental revenue.

Water is the key element determining both the sustainability of the area's environment, and the sustainability of the Edwards Aquifer region's economy as well as that in the Guadalupe River basin. The Edwards Aquifer may be the first instance where the survival of an endangered aquatic species has defined a limit to the sustainable development of a water resource of the magnitude of the Edwards Aquifer. Land use is also affected because alteration of the recharge and contributing zones of the aquifer can alter the amount of water that refills the aquifer, influencing the rate of discharge from the springs. Land uses and human activities over the recharge zone also can affect adversely the quality of the groundwater in the aquifer.

Agricultural interests contended that the regulation of Edwards water is a taking of private property in *Barshop, et al. v. Medina County Underground Water Conservation District, et al.;* however, under Senate Bill 1477 the regulation and allocation of Edwards water through annual withdrawal permits is actually creating quantifiable property rights as they are recognized by free market economics that can be protected under the law. Once final permits to withdraw specific amounts of water from the Edwards Aquifer are issued by the EAA, defined or quantified property rights from a free-market perspective will exist because the fundamental characteristics of property rights are present.

When the interests of the local community diverges significantly from those that control the productive assets -- in this case, water -- the community may not be able to manage the productive assets effectively (Todd 1992, 233). This finding has been applicable to the Edwards. Here, in the short-term, the interest of pumpers is unrestricted access to inexpensive water. In the long-term, sustainable development is in the local communities' interests. The EAA has been created to define rights and settle disputes, through quantifying property rights through issued permits. For those who pump from the aquifer, the price of a secured, quantified right were restrictions that occur in three primary forms (1) an annual limit on total withdrawals, (2) annual pumping fees, and (3) additional restrictions on withdrawals during critical periods. If the *Critical Period Management Plan* and the Withdrawal Suspension Program do not effectively reduce water use during anticipated critical periods, then pumpers have gained the security of going from a judicial system, in this case the federal and state courts, to a regulatory system without most of the costs of doing so. Unlike what Emel and Brooks found in the High Plains, some historical users of the Edwards

Aquifer have received increased security at little or no cost. Security is being provided to agricultural aquifer pumpers, who do not bear the full costs of regulation, since withdrawals are currently authorized at limits substantially greater than has ever been withdrawn in any single year, and no regional drought management plan is in place. The trigger level for the 2000 Withdrawal Suspension Program is 645 feet msl at the Uvalde Well, a level last reached in 1958 during the recovery period from the drought of record. Also, by Senate Bill 1477, irrigators cannot be required to pay to the EAA per acre-foot pumping fees in excess of 20% of those charged municipal and industrial pumpers. Currently, in the absence of EAA rules, pumping is limited to the historical maximum for each aquifer pumper, a staggering 792,000 acre-feet, although it is very unlikely that this amount could be pumped in one year under current demand (Needham 1999a, 8A). Irrigators in Medina and Uvalde Counties are now secure from the threat posed under the rule of capture that land could be purchased in Medina or Uvalde County, wells drilled, and water pumped in massive quantities and then piped east to San Antonio. Municipal and industrial users pay fees five times greater than irrigators to support the EAA, for less than half of the allocated water. Under Senate Bill 1477, irrigators are likely to receive rights to almost 50% of the available water, more water than they have ever used in any one year and almost twice what they are currently using, while municipal and industrial users are likely to receive less than they pumped during the historical period. This result is occurring during a period when irrigation water use is declining. Eventually, the likely result will be that at least half of the water allocated to irrigators, the statutory maximum, will be leased or sold for export to municipal and industrial users in the east. During droughts using the May 1999 CPMP, restrictions, although inadequate to prevent flows from reaching take or jeopardy at the springs, will fall disproportionately upon municipal and industrial water users east of Medina County, particularly San Antonio's burgeoning population. Irrigators in Uvalde County are likely to escape any water use restrictions during droughts, with the exception of one similar to the drought of record.

In a paradoxical twist, irrigators will reap the greatest benefits from future water leases or sales with the strictest enforcement of Senate Bill 1477 and the ESA, despite the fact that the agricultural interests sued in state court in 1995 to have Senate Bill 1477 declared unconstitutional. Limiting pumping to guarantee spring discharge above critical minimums, given the anticipated regional economic and population growth that will spur the demand for water, combined with cyclical droughts, will eventually increase the price of Edwards groundwater. Agriculture is an important contributor to a diversified regional economy. However, less water could probably provide an equivalent crop yield using more efficient irrigation technologies. If the cropland in Medina and Uvalde Counties were not cultivated, eventually it could be infested with ashe juniper and mesquite, reducing the flow in the Nueces and San Antonio Rivers, thereby creating an additional water management problem for those downstream. More time will be lost in political and legal conflict if the 2 acre-foot minimum for irrigators is altered. At this point, it is important to make do with what is available now. At the same time, the provisions in Senate Bill 1477 that guarantee that the springs continue to flow and the ESA is not violated, must also be honored, requiring that a sufficient number of the measures for alternative water supplies be undertaken.

In the Edwards Aquifer, none of the conditions establishing a true property right described in Chapter 2 were met prior to regulation. There was no universality, because entitlements could not be quantified under a system where a pumper's reserve of water was vulnerable to extraction by a neighbor. Exclusivity did not exist, because during periods when withdrawals were not needed, well owners did not have the option of leasing or selling the water to which they had access, since there was no established value or price nor a guarantee to assure a fixed available quantity. Similarly, transferability did not exist. Even if one well owner were paid not to pump water, nothing prevented another landowner from drilling a new well into the aquifer to begin or increase withdrawals; thus a transfer was rendered valueless, since the purchaser was not protected from excessive withdrawals by other users. Finally, there could be no enforceability of a property right for all of the stated reasons. By the very nature of the rule of capture, there was no effective way to prevent one pumper from encroaching on another individual's property right.

Should the springs decline to the point where they could potentially cease to flow, thus far the results of *Sierra Club v. San Antonio et al.*, which is still pending, indicate that the ESA cannot be relied upon to impose a court-ordered CPMP to save endangered species dependent on the springs. For the EAA to take the necessary steps to make sure that the springs do not go dry, at least eight of the fifteen board members would have to vote to restrict their constituents' access to water from the aquifer. Two of the current board members actively opposed Senate Bill 1477 and the creation of the EAA. The four votes representing interests in the Guadalupe River basin in the districts east of San Antonio appear willing to accept restrictions on water use in their counties. The four votes representing irrigation interests in the western counties appear unlikely to accept significant restrictions on their counties' water use. The seven remaining San Antonio board members are the key. It is likely that the majority of this voting block will determine whether the EAA fulfills the expectations of those who created it. An alliance between representatives east of San Antonio and those west of San Antonio did not exist in the Legislature during consideration of Senate Bill 1477, but some EAA board members from these areas regularly vote together now (Buckner 1999). However, if the board members representing the western districts decide that their constituents would benefit from higher prices for their water as a result of the strict enforcement of the provisions of Senate Bill 1477 requiring flows at the springs to be maintained above critical levels, a shift in the balance of power may occur. This coalition could eventually require San Antonio, finally, to build a surface water reservoir and complete some of the other options found in Table 51.

Eventually, Senate Bill 1 might generate a proactive approach to address these shortages, as opposed to the reactive approach embodied in Senate Bill 1477. While the latter provides for conserving water, it does not provide for developing new sources of water. The result is policy driven by growth for which reliable water is not yet available, by droughts, and inevitably, by costly litigation. Ironically, this reactive approach is similar to the "emergency room" approach embodied in the Endangered Species Act, a formula that awaits the decline of a species to critical populations where salvation often requires severe measures, imposes the highest costs, and creates the greatest conflicts with private property rights.

Assuring Spring Discharge above Critical Levels

Some combination of the following elements will be required to ensure that Comal and San Marcos Springs continue to flow on a permanent basis and that downstream flows in the Guadalupe River are able to meet future needs:

- The adoption of an effective regional drought management plan triggered by spring discharge that will require all users to restrict pumping prior to critical periods;
- Perfection of the Withdrawal Suspension Program;
- Development and refinement of techniques for anticipating years in which low spring discharge will be encountered to activate the Withdrawal Suspension Program and drought management plan(s), and to take other measures as far in advance as is practical so as to avoid critical low flows;
- Development of significant amounts of additional surface and groundwater supplies;
- The conjunctive management of all the region's surface and groundwater;
- Creation of an efficient free market for leasing, selling or trading Edwards Aquifer withdrawal rights;
- Conservation of Edwards water to the maximum extent possible;
- Control of invasive species;
- Storage of aquifer water when excess recharge and high spring discharges occur; and

- Development of a regional habitat conservation plan to obtain an ESA § 10(a) Incidental Take Permit that protects aquifer pumpers from ESA violations under take conditions.

Sustainable development of the Edwards region depends on minimizing sequential power conflicts between the LCRA, GBRA, SARA, NRA, Bexar Met, SAWS, and the EAA, and between Austin, San Antonio, and Corpus Christi. However, opposition within the Edwards region exists for almost every substantial water development alternative, and the rush to secure control over any surpluses of surface and groundwater has already commenced. Growth in central Texas has been rapid despite the potential shortage of water during a repeat of the drought of record and for future growth. To avoid sequential power conflicts, the EAA must reduce withdrawals during critical periods to sustain minimum human and economic activity, as well as dependent aquatic ecosystems.

> Senate Bill 1477 has opened Pandora's Box. The need to relieve the demand on the Edwards Aquifer has cascaded across the state (Lewis 1999).

As San Antonio looks east for new water supplies, a cascade of transboundary disputes has already begun to erupt over regional competition for diminishing surface and groundwater supplies that will eventually be needed in those basins. A sequential power dispute is growing between the Edwards region and the Colorado River basin, which has a temporary surplus of available surface and groundwater. Corpus Christi continues to look east for water.

In an era when regional cooperation is rare, when other readily available water supply alternatives are few, and when the construction of large water supply projects takes longer to complete, cost more, and often lack public support, this challenge is made even greater. How do you get people to think of their water needs 50 years in the future? Lieutenant Governor Bob Bullock, who was first elected to the Texas Legislature in the final year of the drought in 1957, tried to do this through Senate Bill 1 (Lewis 1999). The drought of record ended 42 years ago, yet its effects continue to shape the Edwards region and the rest of the state.

Whether the decade of ESA litigation during the 1990's will assure continued flow during a drought similar to the drought of record remains undetermined. The existence of the EAA does not guarantee that Comal and San Marcos Springs will continue to flow indefinitely. If the region's population does double, the water demand will make the preservation of environmental amenities, such as the springs, an increasing challenge for decisionmakers, resource managers, and the public. The will to implement and enforce the statute is essential. However, as difficult as Senate Bill 1477 is to implement, it is workable (Ellis 1999). The EAA is the progeny of *Sierra Club et al. v. Babbitt et al.* It is in the region's, as well as the court's, interest that the Authority successfully implements Senate Bill 1477.

What might happen with a repeat of the recharge the Edwards experienced from 1942 to 1957 with current levels of withdrawals? No one knows when a drought such as the drought of record will begin. We could even be in the early years of the repeat of such a drought today. What would happen during a drought that lasted even longer and was more severe, as has apparently happened regularly over the last 2000 years (Woodhouse and Overpeck 1998)?

Invoking the Endangered Species Committee

The fate of the Edwards Aquifer species should not be decided by the Endangered Species Committee. Pumping groundwater at a rate that is unsustainable, intuitively would not seem to qualify as an Act of God. Unlike the more famous snail darter and the Tellico Dam in Tennessee, and the vast majority of species listed under the ESA, the human-induced threats to the flow of Comal and San Marcos Springs have been well understood and predicted for some 40 years -- more than a decade before the ESA became law. In a future crisis, the fountain darter's existence and plight would have been widely known for decades before the crisis that would generate a petition to convene the Committee. Since the drought of record, the region, and the City of San Antonio in particular, has been repeatedly warned that without one or more surface water reservoirs, the withdrawal of groundwater from the aquifer would eventually eliminate flow from both springs. How much advance warning is reasonable?

Delaying the development of a supplemental water supply should not be a deliberate strategy. However, with delay, the probability of a conflict that results in an appeal to the Committee grows. The decision would be couched as a choice between people and the endangered species, probably made during a severe drought as the discharge of Comal Springs nears zero. It is also possible, given the potential for rapid declines in spring discharge, that Comal Springs might cease to flow before the Committee could reach a decision.

The intervention of the Endangered Species Committee would seem to be inappropriate for the Edwards Aquifer. The recalcitrance of the region's leaders to resolve their differences and prepare for a future crisis should not be rewarded by a favorable ruling from the Endangered Species Committee. To do so would punish interests downstream in the Guadalupe River basin for a fact of basic geography, their location. It would also establish the unfortunate precedent that the goals of the ESA can be circumvented by ignoring the Act until a crisis prevails. As the limits of the sustainable development of water resources are pressed across the United States where there are endangered aquatic species, such an argument could become an expedient solution with increasing regularity.

Conclusion

> Nature within the past decade has inscribed upon the wide-spreading Texas landscape grim warnings of greater disasters to come if development of the State's water resources is neglected. (Texas Board of Water Engineers 1961, 5)

These are the opening words in Texas' first official water plan in 1961. They are applicable today and just as appropriate as they were 39 years ago.

Predicting Years of Low Spring Discharge

Developing a consistent record of historical pumping data, and increasing the early availability of accurate pumping and recharge data to allow additional development of predictors of future minimum spring discharges, should be a high priority for the sustainable management of the aquifer. In the future, with the timely availability of more accurate pumping and recharge data, the potential for future critical spring discharges could be better anticipated. However, in the absence of the necessary recharge and pumping data, the use of spring discharges in the fall as a predictor of flows in the following summer, such as has been done in the discussion of Take and Jeopardy Early Warning Indicator Flows above becomes the primary alternative.

Until more accurate predictors can be developed, given the vulnerability of the aquifer to short-term droughts, and the lack of supplemental supplies, the WSP should be initiated in years following those when Comal Springs flow is less than 300 cfs on November 30, or San Marcos Springs is less than 100 cfs. At this level, take has historically occurred during 60% of the years that followed, and jeopardy in 30% of those years. If the flow rises above 300 cfs (for a sustained period) by December 31, the WSP preparations could be terminated. While this conservative method of prediction would be likely to initiate the WSP in years when aquifer levels might recover in the spring, in the absence of available alternatives, conservation measures must be initiated earlier to avoid violations of the ESA. Once a combination of the alternatives discussed in Chapter 10 are developed conservation measures could be initiated in years when Comal Springs is less than 250 cfs on November 30, or San Marcos Springs is less than 100 cfs.

Trigger Levels for Drought Management

Assuming a repeat of the historical record of Edwards Aquifer conditions, trigger levels for conservation measures proposed by the Edwards Aquifer Authority in its May 1999 CPMP to protect minimum Comal and San Marcos Springs and downstream flows will likely fail to achieve the desired results in most drought years. These analyses for Comal and San Marcos Springs demonstrate that the EAA's May 1999 CPMP will rarely trigger conservation measures across the aquifer in advance of violations of the ESA at either of the springs. This places the burden for pumping reductions upon Bexar, Comal, and Hays Counties where conservation measures are triggered by the J-17 indicator well, and to a lesser extent on Medina and parts of Atascosa County, triggered by the Hondo indicator well. This will result in reductions of municipal water use, primarily in San Antonio, rather than crop irrigation in Medina County, and to a lessor extent, Uvalde County, during droughts. Springflows are better measures of Edwards Aquifer sustainability than groundwater well levels. The focus for management plans should be flow at Comal and San Marcos Springs as direct measures of aquifer conditions as opposed to using less effective indirect indicators because using the index well levels will not trigger reductions early enough before critical spring discharges are reached.

Alternative Sources of Water

Some 660,250 – 730,750 acre-feet of water that could be made available through conservation or alternative sources are identified in Chapter 10, other alternatives are available which were not discussed in this research. However, among the alternatives in Chapter 10, the most feasible are: water conservation by municipalities, industries, irrigators and others; reallocation of Edwards groundwater from agricultural to municipal and industrial users; reuse of treated wastewater for nonpotable uses; land treatment, such as brush control; aquifer storage and recovery in the Carrizo-Wilcox Aquifer; importation of groundwater from the Carrizo-Wilcox Aquifer near Gonzales; use of Medina Lake water; control of the giant rams-horn snail at Comal and San Marcos Springs (allowing additional withdrawals); and regional HCP and 10(A) permit.

Planning for Conjunctive Use of Surface and Groundwater

This study has shown that the wise conjunctive management of the surface water from, and groundwater in, the Edwards and Carrizo - Wilcox Aquifers can assure the sustainable development and growth for the region, protect endangered species and provide critical downstream flows in the Guadalupe River. Only by conjunctively managing the two aquifers, the surface water within the 8,100 square mile area of the contributing, recharge, and confined zones, and the water in the Upper Nueces, San Antonio, and Guadalupe River basins, can the region's future water needs be developed on a sustainable basis. To meet the projected water supply demands for this region, the Edwards Aquifer, regional reservoirs, and several rivers must be managed together. Such management is economically feasible prior to looking outside this region for permanent additional supplies. The water supply from the Edwards Aquifer can be managed so as to achieve its optimum annual utilization for the benefit of those interests who depend upon it. A focus solely upon fixed annual pumping limits plus management during drought years, embodied in the EAA's present implementation of Senate Bill 1477, ignores benefits which might be realized during years when water supply is average or above average. A management system is needed that maximizes utilization of all available groundwater from the Edwards, the Carrizo – Wilcox Aquifer, and surface water in the region's rivers, while protecting endangered species.

Flexible Pumping Limits are Preferable

The staged pumping limits in Senate Bill 1477 do not take full advantage of the hydrologic characteristics of the aquifer. Restricting withdrawals to 450,000 acre-feet or less every year is too restrictive in years of high recharge, while withdrawing 400,000 acre-feet or more following years of low recharge could be too generous, resulting in take or jeopardy conditions subsequently at the springs and limited downstream surface water to meet essential needs. A system using a flexible cap would provide more long term benefits. In years of high recharge, additional amounts of water (beyond what is needed to maintain minimal spring discharge, provide water to downstream users, and fulfill freshwater inflows to bays and estuaries) should be withdrawn for use or stored for use in years of low recharge. The goal should be to supply the region with water while assuring that a water reserve is accumulated to maintain minimum springs and downstream flows in the Guadalupe River during droughts to avoid violations of the ESA and surface water shortages.

Creating a Drought Reserve

Managing water in the Edwards region should be designed to take maximum advantage of the typical weather patterns and capturing as much water as possible during years of plenty to be stored for use during the periodic droughts. An active management scheme should be adopted that addresses potential future shortfalls, as opposed to the current passive system that reacts to imminent shortfalls. Such a management scheme is superior to relying upon the penalties of the ESA, triggered retroactively by harm to the listed species.

Under the proposed San Antonio Drought Reserve Project the total available for use or diversions would have been more water than could currently be stored in the region. If a regional Incidental Take Permit were in place, more water might potentially be made available for use or diversion than is indicated in Chapter 10; however, additional use or diversions should not be allowed if either would violate any of the limitations provided in Chapter 10. This project could be accomplished by diverting water from the Guadalupe River basin. To reduce costs, the diversion could be part of another project requiring a pipeline going west toward San Antonio, instead of a stand-alone project. There are several options for transporting the water to several potential storage sites, which must also be developed.

Sustainable Development

All of the measures summarized above are designed to provide for the sustainable development of the water resources in the Edwards Aquifer region. As communities in Texas become more vulnerable to drought as economic and population growth increase the demand for water, the value of water increases, and growth without conflict becomes more difficult. Sustainable development will reduce transboundary conflicts within the Edwards region and between regions to the east with current water surpluses. Geographers have made sustainable development issues a priority, and as a cross-cutting discipline geography is uniquely qualified to address these issues.

Emel and Brooks (1988) found that administrative organizations eventually replaced judges and courtrooms as the primary forum for defining rights and settling disputes. These changes resulted from a conscious preference for increased security at the price of reduced freedom in the exercise of property rights over groundwater. On the surface, this consequence would appear to be precisely what is happening with the regulation of the Edwards Aquifer, even though regulation was imposed by the state and a federal court rather than through local choice. Since the advent of the Edwards Aquifer Authority, some of the most vocal opponents of government intervention have now become ardent supporters of regulation, because of the certainty that regulation may eventually provide through the creation of a firm water right (Haurwitz 1997a, 15A). With regard to Texas, the key difference is the rule of capture, which means that state courts have not been the forum for settling similar groundwater disputes. Unlike Nebraska, Kansas, and Oklahoma, the Texas Supreme Court decision in *Sipriano et al. v. Ozarka* appears to ensure that the rule of capture will prevail until acts of the Legislature create enough special districts to blanket the state.

The Edwards Aquifer controversy demonstrates that, in some areas in Texas, the management of water resources has reached a critical stage. The state is being divided into water fiefdoms, the so-called 'balkanization' of water. The different legal systems governing ground and surface water in the Edwards Aquifer region have complicated water resource planning and made a solution to periodic shortages elusive. Water demand in Texas continues to grow, while potential new supplies diminish. Water resource development has shifted from new reservoirs and withdrawing more groundwater to conserving and reallocating existing supplies. *Water for Texas* (1997) states that conserved water could meet 12% of state water needs by 2050 (Texas Water Development Board 1997, 3-29). Even with these conservation savings and recognizing the difficulty of constructing new surface water reservoirs, new demands for water cannot be met without reallocating some water, either through canceling unused surface water rights or by the voluntary transfer of water rights between willing buyers and willing sellers (Kaiser 1994, Executive summary). Water marketing is well suited to meet new water demands because it encourages voluntary transfers rather than forced reallocations and because it moves water from lower valued agricultural uses to higher valued urban uses (Kaiser 1994, Executive summary). Transferring water through marketing will alter water use by agriculture since agriculture consumes approximately 70 percent of the total water in the state (Kaiser 1994, Executive summary). Currently, an unfettered free market in

Edwards Aquifer water rights permits does not exist. A modified market that allows permit holders to sell or lease water is evolving. If a true free market in water rights were established for the Edwards Aquifer, municipal shortfalls would be less likely as the greater demand for municipal water, reflected by the price that municipal users can pay for water, would eventually result in the wholesale conversion of permits for irrigation to permits for municipal use.

The piecemeal elimination of the rule of capture in Texas began in Harris and Galveston Counties with the creation of the Harris – Galveston Coastal Subsidence District to protect the Gulf Coast Aquifer, because over-pumping was causing land subsidence. Unlike the Subsidence District, the EAA was created because of the unsustainable use of Edwards groundwater, most notably demonstrated by the catfish farm. The state's approach has been to modify the rule as each groundwater crisis reaches its critical stage. For this reason, the EAA is in the unique position to serve as a model for managing Texas groundwater resources. If the EAA fails to manage the aquifer on a sustainable basis, it will discredit the state's chosen alternative to the elimination of the rule of capture, local groundwater districts.

While the urban versus rural balance is shifting in Texas, the strong west versus east division remains, a division that is largely the result of the geographic distribution of water within the state. Generally, the west has a deficit of water, while the east has a surplus. If the Texas crisis model is taken to the extreme, there is a disturbing prospect that it will result in a pattern where those who employ inefficient technology and harvest water for the lowest value uses will later reap windfall profits from established historical claims to groundwater that can be sold or leased to the thirsty municipalities and industries in the future. As the population increases, the demand for water rises as well. San Antonio's sole reliance on the Edwards has made it vulnerable to economic dislocation resulting from drought and changes in public policy, as well as litigation concerning the aquifer. Like San Antonio, El Paso faces an urban water shortage due to limited access to regional water resources, in this instance the Rio Grande. El Paso's difficulties can be traced to rapid population growth and legal and political barriers to alternative water supplies (Earl and Czerniak 1996).

Final Thoughts

How will we know if four decades of effort to manage water in the Edwards Aquifer has failed? This may be the simplest question of all to answer. We will know that we have failed if Comal Springs goes dry again. Despite six *Texas Water Plans* spanning thirty years recommending limits on Edwards Aquifer withdrawals and supplemental water for San Antonio and the Edwards Aquifer region, only 10,500 acre-feet of Medina River surface water has reached the city. In 41 years of combined operation, the first 37 as the Edwards Underground Water District and the last four as the Edwards Aquifer Authority, not enough has been accomplished to ensure that Comal Springs will not cease to flow again during a return of the drought of record. Thus far, the EAA has been hampered by litigation. However, four years of working together on a regular basis through the EAA board has diminished some of the animosity between the regional interest groups, perhaps reducing the intensity of transboundary disputes.

In the introduction I suggested that when Comal Springs ceased to flow in 1956 it could be looked upon as a gift, a valuable insight into a future without limits upon the reliance on the Edwards Aquifer. However, an insight such as this is only a gift if the knowledge results in avoiding the anticipated future consequences. The three-decade cycle of generous replenishment to the Edwards Aquifer is bound to end. When it does, we will quickly discover whether the events of 1956 were a gift, or mere foreshadowing.

12. APPENDIXES

Appendix 1. Population, Water Use, and Water Demand Tables

Item 1. *1961 Texas Water Plan* Population Estimates and Projections for Selected River Basins

River Basin	Population Estimate, 1960	Population Projection, 1980
Guadalupe	191,702	254,563
San Antonio	765,767	1,153,930
Nueces	495,208*	701,060*
Total	1,452,677	2,109,553

*Includes the City of Corpus Christi in the Nueces - Rio Grande Coastal Basin.
Source: (Texas Board of Water Engineers 1961, 18).

Item 2. *1968 Texas Water Plan* Population Estimates and Projections for the San Antonio Standard Metropolitan Statistical Area

City	Population Estimate, 1960	Population Projection, 1990	Population Projection, 2020
San Antonio	716,168	1,322,918	1,937,895

Source: (Texas Water Development Board 1968a, III-1).

Item 3. *1984 Water for Texas* Population Estimates and Projections for Selected River Basins

River Basin	1980	1990	2000	2010	2020	2030
Guadalupe	243,400	313,200	379,400	450,200	523,100	599,700

San Antonio	1,054,400	1,311,500	1,591,000	1,863,500	2,262,900	2,888,000
Nueces	153,500	186,400	216,400	248,100	279,500	309,300
Total	1,451,300	1,811,100	2,186,800	2,561,800	3,065,500	3,797,000

Source: (Texas Department of Water Resources 1984, III-18-8, III-19-7, and III-21-7).

Item 4. *1990 Water for Texas* Population Estimates and Projections for Selected River Basins

River System	Population Estimate, 1980	Population Estimate, 1990	Population Projection, 2040
Guadalupe	243,300	303,200	564,100 –692,800
San Antonio	1,100,000	1,300,000	2,600,000-3,400,000
Nueces*	153,500	166,800	279,600-308,900
Total	1,496,800	1,770,000	3,443,700-4,401,700

*Excludes the majority of the population of Corpus Christi.
Source: (Texas Water Development Board 1990, 3-43, 3-45, 3-47).

Item 5. *1997 Water for Texas* Population Estimates and Projections for Selected River Basins

River System	Population Estimate, 1980	Population Estimate, 1990	Population Projection, 2050
Guadalupe	243,400*	302,400	823,000
San Antonio	1,054,500*	1,271,000	3,331,000
Nueces*	152,300*	165,500	298,000

Total	1,450,200	1,738,900	4,452,000

*Calculated from Stated Data.

Source: (Texas Water Development Board 1997, 3-167, 3-172, 3-177).

Item 6. *1961 Texas Water Plan* Water Demand and Projections for Selected River Basins, acre-feet per year

River System	1959, Surface Water	1959, Ground-water	1959, Total	1980, Surface Water	1980, Ground-water	1980, Total
Guadalupe	24,100	21,700	45,800	100,900	32,800	133,700
San Antonio	30,150	168,800	199,000	192,200	106,300	298,500
Nueces*	78,800	292,600	371,400	NA	34,900	NA

*NA = Not available.

Source: (Texas Board of Water Engineers 1961, 147, 148, 153, 165).

Item 7. *1968 Texas Water Plan* Water Municipal and Industrial Demand and Projection for Selected River Basins, acre-feet per year

River Basin	1960, Surface Water	1960, Ground-water	1960, Total	Projected 1990, Surface Water	Projected 1990, Ground-water	Projected 1990, Total	Projected 2020, Surface Water	Projected 2020, Ground-water	Projected 2020, Total
Guada-lupe	3,200	40,500	43,700	43,800	46,300	90,100	110,600	80,500	191,100
San Antonio	--	120,600	120,600	60,800	219,200	280,000	220,000	226,500	446,500
Nueces	3,500	16,400	19,900	12,500	27,200	39,700	26,700	40,500	67,200

Note: Municipal and Industrial Water Use Only.

Source: (Texas Water Development Board 1968a; Texas Water Development Board 1968b, Table IV-41, IV-54, Table IV-43, IV-58, Table IV-46).

Item 8. *1984 Texas Water Plan* Current Water Use and Demand and Projected Water Demand for Selected River Basins, acre-feet per year

River Basin	1980, Surface Water	1980, Ground-water	1980, Total	1990, Surface Water	1990, Ground-water	1990, Total
Guadalupe	75,600	51,600	127,200	131,000	53,200	184,200
San Antonio	57,700	285,800	343,500	128,100	303,400	431,500
Nueces	89,700	437,000	526,700	145,000	213,200	358,200

River Basin	2000, Surface Water	2000, Ground-water	2000, Total	2010, Surface Water	2010, Ground-water	2010, Total
Guadalupe	171,900	63,200	235,100	222,500	62,100	284,600
San Antonio	210,500	311,800	522,300	283,900	323,800	607,700
Nueces	155,800	220,100	375,900	180,700	236,900	417,600

River Basin	2020, Surface Water	2020, Ground-water	2020, Total	2030, Surface Water	2030, Ground-water	2030, Total
Guadalupe	275,500	65,600	341,100	337,200	69,700	406,900
San Antonio	411,600	313,900	725,500	587,500	316,800	904,300

Nueces	184,900	249,400	434,300	252,500	198,000	450,500

Source: Based on [Texas Department of Water Resources, 1984 #238, Table II-18-3, II-18-8; Table III-19-3, III-19-7; Table III-21-3, III-21-7].

Item 9. *1990 Texas Water Plan* Projected Water Use from the Edwards Aquifer for 2000 and 2040, acre-feet per year

River Basin	Year 2000	Year 2040
Guadalupe	32,700	33,200
San Antonio	269,000	294,300
Nueces	115,200	120,400
Total	416,900	447,900

Source: Based on (Texas Water Development Board 1990, 3-42, 3-44, and 3-46).

Appendix 2. Senate Bill 1477 Provisions on Initial Groundwater Allocation

Section 1.16 of Senate Bill 1477 provides the guidelines for allocating Edwards water through permits issued by the EAA:

ARTICLE 1, SECTION 1.16
DECLARATIONS OF HISTORICAL USE; INITIAL REGULAR PERMITS

(a) An existing user may apply for an initial regular permit by filing a declaration of historical use of underground water withdrawn from the aquifer during the historical period from June 1, 1972 through May 31, 1993.

(b) An existing user's declaration of historical use must be filed on or before March 1, 1994, on a form prescribed by the board. An applicant for a permit must timely pay all application fees required by the board. An owner of a well used for irrigation must include additional documentation of the number of acres irrigated during the historical period provided by Subsection (a) of this section.

(c) An owner of a well from which the water will be used exclusively for domestic use or watering livestock and that is exempt under Section 1.33 of this article is not required to file a declaration of historical use.

(d) The board shall grant an initial regular permit to an existing user who:

(1) files a declaration and pays fees as required by this section; and

(2) establishes by convincing evidence beneficial use of underground water from the aquifer.

(e) To the extent water is available for permitting, the board shall issue the existing user a permit for withdrawal of an amount of water equal to the user's maximum beneficial use of water without waste during any one calendar year of the historical period. If a water user does not have historical use for a full year, then the authority shall issue a permit for withdrawal based on an amount of water that would normally be beneficially used without waste for the intended purpose for a calendar year. If the total amount of water determined to have been beneficially used without waste under this subsection exceeds the amount of water available for permitting, the authority shall adjust the amount of water authorized for withdrawal under the permits proportionately to meet the amount available for permitting. An existing irrigation user shall receive a permit for not less than two acre-feet a year for each acre of land the user actually irrigated in any one calendar year during the historical period. An existing user who has operated a well for three or more years during the historical period shall receive a permit for at lest the average amount of water withdrawn annually during the historical period.

(f) The board by rule shall consider the equitable treatment of a person whose historic use has been affected by a requirement of or participation in a federal program.

(g) The authority shall issue an initial regular permit without a term, and an initial regular permit remains in effect until the permit is abandoned, canceled, or retired.

(h) The board shall notify each permit holder that the permit is subject to limitations as provided by this article.

(Act of May 30, 1993 73rd Leg., R.S., ch. 626, 1993 Tex. Gen. Laws 2355, *as amended by* Act of May 29, 1995, 74th Le., R.S., ch. 261, 1995 Tex. Gen. Laws, §1.16).

Appendix 3. Regional Drought Management Plans Developed for the Edwards Aquifer

Item 1. A Summary of the Trigger Levels and Withdrawal Reductions in the 1988 and 1989 Edwards Underground Water District, Drought Management Plan

Eastern Zone: Hays, Comal, and Bexar Counties.

Stage	Trigger Level	Withdrawal Reduction
I - Awareness	<80% of average rainfall, or Well J-17 level <640 ft (corresponding to 160 cfs at Comal Springs or 110 cfs at San Marcos Springs)	10% municipal goal. Military, commercial, and industrial users encouraged to voluntarily reduce by 10%. No irrigation reductions.
II - Watch	Well J-17 level <628 ft (corresponding to 70 cfs at Comal Springs or 80 cfs at San Marcos Springs)	15% municipal goal. Military, commercial, and industrial users encouraged to voluntarily reduce by 15%. No irrigation reductions.
III - Alert	Well J-17 level <612 ft (corresponding to 0 cfs at Comal Springs or 50 cfs at San Marcos Springs)	25% municipal goal. Military, commercial, and industrial users encouraged to voluntarily reduce by 25%. No irrigation reductions.
IV - Risk	Well J-17 level <612 ft (corresponding to 0 cfs at Comal Springs or 50 cfs at San Marcos Springs).	30% municipal goal. Military, commercial, and industrial users encouraged to voluntarily reduce by 30%. Irrigation limited to 2 acre-feet/year.
V - Emergency	Unacceptable deterioration of water quality.	To be decided by EUWD.

Note: The EUWD reserved the right to exercise discretion in determining stages when conditions did not correspond to trigger levels. Correlated springflow rates with J-17 levels are supplied by EUWD as a reference and not as triggers for various stages. The trigger level for stage III is the same as stage IV. This plan was adopted before the judgment in *Sierra Club et al. v. Babbitt et al.*

Western Zone: Medina and Uvalde Counties.

Stage	Trigger Level	Withdrawal Reduction
I - Awareness	Uvalde Well <870 ft.	10% municipal goal. Military, commercial, and industrial users encouraged to voluntarily reduce by 10%. No irrigation reductions.
II - Watch	Uvalde Well <840 ft.	15% municipal goal. Military, commercial, and industrial users encouraged to voluntarily reduce by 15%. No irrigation reductions.
III - Alert	Uvalde Well <829 ft.	25% municipal goal. Military, commercial, and industrial users encouraged to voluntarily reduce by 25%. No irrigation reductions.
IV - Risk	Uvalde Well <811 ft.	30% municipal goal. Military, commercial, and industrial users encouraged to voluntarily reduce by 30%. Irrigation limited to 2 acre-feet/year.
V - Emergency	Unacceptable deterioration of water quality.	To be decided by EUWD.

Note: The EUWD reserved the right to exercise discretion in determining stages when conditions did not correspond to trigger levels. Agricultural irrigation is normally less than 2 acre-feet/year.

Sources: (Edwards Underground Water District 1988, 2-1, 2-2), (Edwards Underground Water District 1989, Table 2-1).

Item 2. Summaries of the Texas Water Commission's Emergency Conservation Proposals

Option 1

Stage	Trigger Level	Withdrawal Reduction
I	Well J-17 ≤ 666 ft.	All users must reduce pumping by 10%.
II	Well J-17 ≤ 649 ft.	All users must reduce pumping by 20%.
III	Well J-17 ≤ 632 ft.	All users must reduce pumping by 40%.

Option 2: Dry - Year Option

Stage	Trigger Level	Withdrawal Reduction
I	Well J-17 ≤ 649 ft. at beginning of year.	Irrigated acres reduced 25% in Bexar, Medina, and Uvalde Counties. Irrigators paid $75 per acre for acreage not irrigated. Municipal, industrial, and aquacultural use reduced 20%.
II	Well J-17 ≤ 632 ft. at beginning of year.	Irrigated acres reduced 75% in Bexar, Medina, and Uvalde Counties. Irrigators paid $75 per acre for acreage not irrigated. Municipal, industrial, and aquacultural use reduced 30%.

Source: (Texas Water Commission 1992, iii, iv).

Item 3. A Summary of the Edwards Underground Water District's 1992 Demand Management Plan

Stage	Trigger Level	Withdrawal Reduction
I	Well J-17 ≤ 649 ft., for a	15% goal
II	10-day moving average Well J-17 ≤ 640 ft., for a 10-day moving average	20% goal
III	Well J-17 ≤ 632 ft., for a 10-day moving average	30% goal
Extreme Water Emergency	Discretion of EUWD	Discretion of EUWD

Source: (Edwards Underground Water District 1992).

Item 4. A Summary of the Monitor's Proposed 1994 Emergency Withdrawal Reduction Plan for the Edwards Aquifer

Stage	Trigger Level	Withdrawal Reduction
Preliminary	Comal Springs At all flows	Implement Water Conservation Reuse Plan provisions to minimize withdrawals from the Aquifer.
I	250 cfs at Comal Springs	Voluntary reductions in discretionary uses with a 10% reduction goal from the volume of withdrawals on July 1, 1994.
II	225 cfs at Comal Springs	Mandatory reductions in discretionary uses with inspection and aggressive enforcement to achieve 15% reduction from the volume of withdrawals on July 1, 1994.
III	200 cfs at Comal Springs	Mandatory reductions in discretionary uses with inspection and aggressive enforcement to achieve 25% reduction from the volume of withdrawals on July 1, 1994; activation of the Incidental Take Permit.
IV	175 cfs at Comal Springs	Mandatory reductions in nondiscretionary [sic, should be discretionary] uses except those essential for the protection of public health and safety with inspection and aggressive enforcement to achieve 40% reduction from the volume of withdrawals on July 1, 1994; Incidental Take Permit continues in effect.
V	160 cfs at Comal Springs	Such additional mandatory reductions as may be possible as determined by water purveyors, military installations, irrigation farmers and ranchers, industries, and underground water districts or the Court; Incidental Take Permit remains in effect.

Source: (Moore 1994, 79, 80).

Item 5. A Summary of the Monitor's Proposed Court's 1995 Revised Emergency Withdrawal Reduction Plan for the Edwards Aquifer

For military, municipal and industrial use only:

Stage	Trigger Level	Withdrawal Reduction
Preliminary	Comal Springs At all flows	Implement Water Conservation and Reuse Plan provisions to minimize withdrawals from the Aquifer.
I	250 cfs and below	Voluntary reductions in discretionary uses with a goal of 10% reduction from the volume of withdrawals in the base period monthly water use.
II	225 cfs and below	Mandatory reductions in discretionary uses with inspection and aggressive enforcement to achieve 20% reduction from the volume of withdrawals in the base period monthly water use.
III	200 cfs and below	Mandatory reductions in discretionary uses with inspection and aggressive enforcement to achieve 30% reduction in the base period monthly water use.
IV	175 cfs and below	Mandatory reductions to zero for discretionary uses and reductions in nondiscretionary uses except those essential for the protection of public health and safety with inspection and aggressive enforcement to achieve 40% reduction in the base period monthly water use.
V	160 cfs and below	Such additional mandatory reductions as may be possible as determined by water purveyors, military installations, industries, underground water districts and the regulatory authority or the Court.

Base period monthly water use (for military, municipal and industrial water users); Total water use in millions of gallons in the immediate preceding calendar year, minus three times the winter average water use, divided by nine.

Source: (Moore and Votteler 1995b, 23, 24).

Item 6: A Summary of the Edwards Underground Water District's 1995 Demand Management Plan

Stage	Trigger Level	Withdrawal Reduction
I	250 cfs at Comal Springs	Voluntary 10% goal
II	225 cfs at Comal Springs	15% goal
III	175 cfs at Comal Springs	20% goal
IV	150 cfs at Comal Springs	30% goal
Extreme Water Emergency	Discretion of EUWD	Discretion of EUWD

Source: (Edwards Underground Water District 1995, 5).

Item 7. A Summary of the U.S. District Court's 1996 Emergency Withdrawal Reduction Plan for the Edwards Aquifer

These staged reductions and withdrawal requirements are also found in the Compromise Emergency Withdrawal Reduction Plan (CEWRP) otherwise known as the *Lawyer's Panel Plan*.

Stage	Trigger Level	Withdrawal Reduction
None	Comal Springs >260 cfs or Well J-17 >655 ft msl	None. Maximum allowable peak-to-base period pumping ratio: full
I	Comal Springs ≤260 cfs or Well J-17 ≤655 ft msl	10%. Maximum allowable peak-to-base period pumping ratio: 1.8 x base
II	Comal Springs ≤200 cfs or Well J-17 ≤648 ft msl	20%. Maximum allowable peak-to-base period pumping ratio: 1.6 x base
III	Comal Springs ≤175 cfs or Well J-17 ≤642 ft msl	40%. Maximum allowable peak-to-base period pumping ratio: 1.2 x base

NOTES:

(1) Reduction stages will terminate when J-17 levels have been above the trigger level by five feet or more for seven consecutive days.

(2) Base period usage is indexed to the monthly winter usage, i.e., average of the three lowest months of November, December, January, and February 1995. Total elimination of discretionary use would drop the Peak-To-Base Pumping Ratio to 1.0.

(3) Reductions will cease when J-17 levels have been above the trigger level by five feet or more for seven consecutive days.

Source: (Votteler 1996, 16).

Item 8. A Summary of the USFWS Recommendations to the Edwards Aquifer Authority

"Below are the components that the Service believes are needed for EAA's drought plan to provide the needed withdrawal reductions to protect springflows (Frederick 1998)."

Stage	Trigger Level	Withdrawal Reduction
I	Comal Springs 250 cfs	Mandatory 10% use reduction.
II	Comal Springs 225 cfs	Mandatory 15% use reduction.
III	Comal Springs 200 cfs	Mandatory 25% use reduction.
IV	Comal Springs 175 cfs	Mandatory 40% use reduction.
V	Comal Springs 160 cfs	Mandatory additional reductions as may be determined by the applicant to achieve reductions greater than 40%.

Note: No indication of base usage volume to which reduction percentage is to be applied. It is assumed these reductions apply to all water uses.

Sources: (Frederick 1998, 1, 2).

Item 9. A Summary of the Edwards Aquifer Authority's 1998 Critical Period Management Plan

Bexar, Caldwell, Comal, Hays and Guadalupe Counties

Stage	Trigger Level	Withdrawal Reduction
I	Well J-17 ≤ 650 ft. and > 642 ft.	1.7 x base withdrawals*
II	Well J-17 ≤ 642 ft. and > 636 ft.	1.6 x base withdrawals
III	Well J-17 ≤ 636 ft. and > 632 ft.	1.4 x base withdrawals
IV	Well J-17 ≤ 632 ft. and > 628 ft.	1.3 x base withdrawals
V	Well J-17 < 628 ft.	To be determined by the EAA board.

Medina and Atascosa Counties

Stage	Trigger Level	Withdrawal Reduction
I	Medina Well ≤ 670 ft. and > 660 ft.	1.7 x base withdrawals
II	Medina Well ≤ 660 ft. and > 655 ft.	1.6 x base withdrawals
III	Medina Well ≤ 655 ft.	1.4 x base withdrawals

Uvalde County

Stage	Trigger Level	Withdrawal Reduction
I	Uvalde Well ≤ 845 ft. and > 840 ft.	1.7 x base withdrawals
II	Uvalde Well ≤ 840 ft.	1.6 x base withdrawals

*The base withdrawal for each applicant was to be determined by the general manager, based on water withdrawals for the three lowest of the months of November, 1995 through February, 1996.

Source: (Edwards Aquifer Authority 1998a).

Item 10. A Summary of the Edwards Aquifer Authority Proposed May 1999 Critical Period Management Plan

Bexar, Caldwell, Comal, Hays and Guadalupe Counties.

Stage	Trigger Level	Withdrawal Reduction
I	Well J-17 ≤ 650 ft. and > 640 ft.	1.7 x base withdrawals or 95% of permitted ground-water withdrawals.
II	Well J-17 ≤ 640 ft. and > 630 ft.	1.5 or 1.6 x base withdrawals or 90% of permitted groundwater withdrawals.
III - Emergency Springflow Protection Measures	Well J-17 ≤ 630 ft.	1.3 or 1.4 x base withdrawals or 85% of permitted groundwater withdrawals.

Medina and Atascosa Counties.

Stage	Trigger Level	Withdrawal Reduction
I	Medina Well ≤ 670 ft. and > 660 ft.	1.7 x base withdrawals or 95% of permitted groundwater withdrawals.
II	Medina Well ≤ 660 ft. and > 655 ft.	1.5 or 1.6 x base withdrawals or 90% of permitted groundwater withdrawals.
III - Emergency	Medina Well ≤ 655 ft.	1.3 or 1.4 x base withdrawals or Springflow 85% of permitted groundwater Protection Measures withdrawals.

Uvalde County.

Stage	Trigger Level	Withdrawal Reduction
I	Uvalde Well ≤ 845 ft. and > 840 ft.	1.7 x base withdrawals or 95% of permitted groundwater withdrawals.
II	Uvalde Well ≤ 840 ft. and > 835 ft.	1.5 or 1.6 x base withdrawals or 90% of permitted groundwater withdrawals.
III - Emergency Springflow Protection Measures	Uvalde Well ≤ 835 ft.	1.3 or 1.4 x base withdrawals or 85% of permitted groundwater withdrawals.

Source: (Edwards Aquifer Authority 1999b, 2 - 5).

Item 11. A Summary of the 1999 Department of Defense *Drought Management Plan* approved by US. Fish and Wildlife Service

Stage	Triggers*	Triggers*	Triggers*	Multi-plier	Installation's Total Maximum Monthly Withdrawal
		Comal	San Marcos		
I	5 days where the level is ≤ 657.5 feet	5 days at or below 250 cfs	3 days at or below 80 cfs	1.7	1,436 acre-feet
II	5 days where the level is ≤ 647.0 feet	5 days at or below 200 cfs	Any Stage I trigger, plus 3 days at or below 80 cfs	1.6	1,352 acre-feet
III	5 days where the level is ≤ 642.0 feet	5 days at or below 180 cfs	Any Stage II trigger, plus 3 days at or below 80 cfs	1.4	1,183 acre-feet
IV	5 days where the level is ≤ 640.5 feet	5 days at or below 160 cfs	Any Stage III trigger, plus 3 days at or below 80 cfs	1.3	1,098 acre-feet
V	3 days where the level is ≤ 637.0 feet	3 days at or below 100 cfs	Any Stage IV trigger, plus 3 days at or below 80 cfs	1.185	1,001 acre-feet

*Whichever comes first.

Note: Each stage will be in effect for 10 consecutive days unless a more restrictive stage is implemented and will not be rescinded until the 10 day rolling (moving) average of the J-17 index well and spring discharge levels trigger a less restrictive stage.

Source: (Frederick 1999, 17 - 20).

Appendix 4. Chronology of Events Concerning the Edwards Aquifer Issue

Prior to Pumping	Comal and San Marcos Springs, the largest springs in the Southwest United States, have strong, continuous spring discharge at all times, even during major droughts. A unique assemblage of species dependent on spring discharge flourish.
1884	The first irrigation well is completed in Bexar County.
1900	Aquifer withdrawals reach approximately 30,000 acre-feet per year.
1949	The state authorizes voluntary creation of underground water conservation districts.
1950 - 1957	The drought of record in Texas. For the Edwards Aquifer the drought probably began in 1942 and continued until 1957. Comal Springs dries up for 144 days in 1956, and San Marcos Springs drops to a low of 46 cfs. Portions of the aquifer are possibly contaminated by intrusion of adjacent bad-quality water containing very high concentrations of dissolved solids and hydrogen sulfide. In 1956 annual recharge is a record low 43,700 acre-feet while withdrawals reach 321,000 acre-feet. The Beverly Lodges index well (later replaced by J-17) in San Antonio hit its record low of 612 ft. msl.
1952	San Antonio City Master Plan recommends that San Antonio join with the Corps of Engineers and Guadalupe - Blanco River Authority (GBRA) to construct Canyon Reservoir.
March 2, 1953	San Antonio files a "presentation" to the Texas Board of Water Engineers (TBWE) to participate in the Canyon Reservoir project. When their request is denied on April 2, an appeal is made to the TBWE.
1955	The Texas Supreme Court recognizes that San Antonio has a serious water supply problem and that it needs to obtain alternative supplies from other sources. *Board of Water Engineers v. City of San Antonio*, 283 S.W.2d 722, 723 (Tex. 1955). Some of the early determinations of boundaries and recharge of Edwards Aquifer are made. First attempt to form the Edwards Underground Water District (EUWD).

July 5, 1957	TBWE, in 2-1 split vote, sides with GBRA against San Antonio on the Canyon Reservoir project. The matter eventually goes to the Texas Supreme Court, with GBRA prevailing. A second attempt to establish the EUWD is made but unsuccessful.
1957	Texas Water Development Board (TWDB) created as a consequence of the drought of record.
1959	56th Legislature creates the Edwards Underground Water District to protect and preserve the Edwards Aquifer.
1961	TBWE publishes first Texas Water Plan.
1962	TBWE reorganized as Texas Water Commission (TWC).
1964	Governor John Connally directs the TWC to design a comprehensive state water plan.
1966	The Endangered Species Preservation Act becomes law. The Secretary of the Interior is charged with charged with conserving, protecting, and restoring species determined to be threatened with extinction, primarily through the acquisition of habitat.
Oct. 26, 1966	Texas Supreme Court in *City of San Antonio, et al. v. The Texas Water Commission, et al.* finds that San Antonio is authorized to purchase Canyon Reservoir water.
1967	U.S. Fish and Wildlife Service (USFWS) lists Texas blind salamander as endangered.
1968	TWDB publishes update of Texas Water Plan.
1969	The Endangered Species Conservation Act becomes law.
1970	Texas Water Quality Board (TWQB) issues first Edwards "Board Order" for aquifer protection. USFWS lists Fountain darter as endangered.
1972-1984	EUWD builds four small recharge dams over the Edwards Aquifer.
1973	The modern Endangered Species Act (ESA) becomes law. Penalties for 'taking' listed species are in place. Actions of private parties and public entities effected.

1974	TWQB issues an amended "Board Order" for aquifer protection. Environmental groups form an Aquifer Protection Association (APA) with the single purpose of raising funds to purchase land on the recharge zone of the aquifer. Congress passes Public Law 93-943 authorizing construction of Cibolo Reservoir in the San Antonio River basin.
1975	The GBRA and San Antonio's City Water Board (CWB) begin negotiations for Canyon Reservoir water. The Edwards Aquifer is designated the first Sole Source Aquifer under the Safe Drinking Water Act.
1976	The San Antonio City Council led by Mayor Pro Tem Glen Hartman (and joined by councilman Henry Cisneros) rejects by a 5 to 4 margin a contract to purchase up to 50,000 acre-feet of water per year from Canyon Reservoir and other, future projects in the Guadalupe basin. The contract had already been approved by the GBRA Board of Directors and the CWB staff.
1978	USFWS lists Texas wild-rice as endangered and San Marcos salamander listed as threatened. ESA amendments require the preparation of recovery plans.
July, 1979	San Antonio City Council passes resolution #79-35-74 requesting the CWB to proceed with construction of the Applewhite Reservoir located on the Medina River in Southern Bexar County.
1980	USFWS lists San Marcos gambusia as endangered. Critical habitat designated for four of the species in the San Marcos Springs ecosystem.
1980 - 1990	Withdrawals have increase significantly after the drought of record and now average nearly 500,000 acre-feet per year, exceeding 500,000 in some years.
June, 1981	The San Antonio City Council passes resolution #81-34-64 reaffirming its support for Applewhite Reservoir.
1982	ESA amendments allow for incidental takings.

1984	Flow at Comal and San Marcos Springs nearly ceases during a brief drought. Texas Department of Water Resources publishes update of Texas Water Plan.
1985	The San Marcos Recovery Plan is adopted by USFWS.
1986	The TWC issues rules (called the Edwards Rules) regulating development over the aquifer recharge zone.
1987	San Antonio and EUWD endorse legislation, House Bill (H.B.) 1942. The 70th Legislature authorizes the EUWD to develop and enforce a regional drought management plan, prior to September 1988, "to minimize drawdown of the water table or the reduction of artesian pressure and spring discharge . . ." H.B. 1942 also provides for an elective board and allows counties in the district to de-annex themselves.
July, 1988	A Joint Committee on Water Resources completes the *Regional Water Resources Plan* and submits it to respected entities.
August, 1988	EUWD approves a drought management plan in accordance with H.B. 1942.
January, 1989	Uvalde and Medina Counties vote to secede from the EUWD over disagreement about withdrawal limits and tries to establish single-county underground water districts.
May, 1989	Legislative attempt at groundwater allocation fails. A committee of legislative members, the Special Committee on the Edwards Aquifer, is established to study the aquifer.
June 15, 1989	The GBRA issues a notice of intent to sue for violations of the ESA. GBRA also files suit in the Hays County State District Court to have the aquifer declared an underground river owned by the State of Texas. That case is still pending.
1989	A long-range regional water plan, adopted by the EUWD and San Antonio after prolonged negotiation, fails enactment by the 71st Legislature. During the summer the aquifer drops rapidly in another brief drought. Annual withdrawals peak at 542,400 acre-feet.
1989 - June, 1990	TWC Commissioner John Birdwell initiates discussions to try to resolve the controversy. No consensus emerges and the Birdwell negotiations end.

1989 - 1990	Spring discharge plunges at Comal and San Marcos Springs; however summer rains raise spring discharge. The USFWS warns of the need to respond and threatens federal withdrawal limits. The EUWD adopts an emergency action plan, but the plan expires in December 1990 after rainfall increases spring discharge.
1990	Upon recommendation of the Special Committee on the Edwards Aquifer, a professional mediator, John Folk – Williams, is appointed to attempt to form a consensus among various aquifer interests. TWDB publishes update of State Water Plan.
April 12, 1990	The Sierra Club issues a notice of intent to sue for violation of the ESA.
December, 1990	The CWB begins construction of the Applewhite Reservoir.
1991	The Living Waters Artesian Springs catfish farm opens 15 miles southwest of San Antonio, using as much as 40 million gallons of water a day, by some estimates. The actual drilling of wells started in late 1988 and continued into early 1989. In October 1991, the EUWD and the San Antonio River Authority file suit in state district court, claiming the catfish farm is wasting water and polluting the Medina River. By consent decree the farm's wells are shut down pending approval of a wastewater discharge permit from the TWC.
March, 1991	A consensus is reached that mediation attempts have failed.
May, 1991	The voters of San Antonio vote to abandon the Applewhite Reservoir Project. The City Council affirms the election results in a subsequent vote and directs the CWB to begin measures to abandon the project. The CWB in turn sues the city, questioning the legality of the election.
May 16, 1991	The Sierra Club files a lawsuit in U.S. District Court for the Western District of Texas, Midland (*Sierra Club, et al. v. Manual Lujan, et al.;* later *Sierra Club, et al. v. Babbitt, et al.*). The GBRA and San Antonio, along with numerous other parties quickly intervene on both sides. The suit alleges that the Secretary of the Interior and the USFWS failed to protect endangered species dependent on the aquifer in violation of the ESA. Plaintiffs ask the court to order USFWS to determine the minimum spring discharge required at the Comal and San Marcos Springs to avoid 'takes' of and' jeopardy' to the listed species.

1991	Legislation is approved establishing an underground water district for Medina County.
November, 1991	Texas Attorney General Dan Morales decides it is constitutional for the TWC to regulate groundwater.
October, 1991 January, 1992	Austin Mayor Bruce Todd attempts to resolve the dispute over aquifer regulation. No resolution was reached. TWC attempts negotiation.
1992	TWDB publishes update of Texas Water Plan.
February, 1992	John Hall, chairman of the TWC, circulates a 1992 proposed management plan (based on previous discussions with all interested parties) describing a voluntary regional management plan for the Edwards Aquifer as an alternative to state regulation.
March, 1992	Attorney General Morales reverses his opinion that the TWC has sufficient authority to regulate the use of groundwater.
May 14, 1992	The Edwards Aquifer hits a record high of 703.2 at the J-17 well. Annual recharge for 1992 is a record 2,485,700 acre-feet.
April, 1992	The TWC releases its interim plan for management of the Edwards Aquifer. Sets date of April 14 as the deadline for approval by City of San Antonio, EUWD, Medina County, City of Uvalde, Uvalde County, and Industrial Water Users Association. City of San Antonio and the EUWD reject TWC's interim management plan.
April 15, 1992	The TWC declares the Edwards to be an underground stream and, therefore, state water. It adopts emergency rules and initiates rulemaking proceedings.
August, 1992	A Travis County District Court invalidates the commission's declaration that the aquifer is an underground river and voids the commission's new rules for the aquifer (*Texas Farm Bureau, Cattleranchers Association, et al. v. the Texas Water Commission*). State District Judge Pete Lowry, citing legislative treatment of the aquifer and the enactment of legislation creating underground water districts in the Edwards region, rules that the TWC has no legal power to impose withdrawal limits.
September 9, 1992	Rules designating the Edwards as an underground river are approved by the TWC.
September, 1992	Judge Bunton sets a special court date for November 16, 1992 to hear *Sierra Club, et al. v. Babbitt, et al.*

September 11, 1992	A Travis County District Court grants irrigators' motion, striking down TWC Edwards Rules and voids TWC declaration that the Edwards Aquifer is an Underground River on grounds that the TWC did not have statutory authority to assert jurisdiction. (On appeal, that Judgment is set aside after the TWC withdrew its rules).
September 14, 1992	Texas Attorney General Morales files suit against USFWS saying the federal agency is illegally trying to take control of the Edwards Aquifer and thereby "usurp the States sovereignty."
November 16-19, 1992	Trial in *Sierra Club, et al. v. Babbitt, et al.* before Judge Bunton in Midland.
February 1, 1993	Judge Bunton enters Judgment and separate Findings of Fact and Conclusions of Law in favor of the Sierra Club, GBRA and other plaintiffs. Among other-things, Bunton finds that the "firm yield" of the Edwards (the amount of water that can be safely withdrawn each year during a major drought) is approximately 200,000 acre-feet per year – far below the 500,000+ acre-feet per year being withdrawn in dry years. He determines that if withdrawals from the aquifer continue without reduction, spring discharge will be diminished, and endangered and threatened species will be "taken" in violation of the ESA. The Texas Natural Resources Conservation Commission (TNRCC, which replaced TWC) is directed to devise a plan to limit withdrawals and preserve spring discharge (even in a repeat of a drought of record) by March 1, 1993. If the Legislature does not enact a regulatory plan by May 31, 1993, the judge will allow the plaintiffs to seek additional relief, and the aquifer may become subject to federal judicial control. The USFWS is ordered to determine endangered and threatened species "take" and "jeopardy" spring discharge levels for Comal and San Marcos Springs.
April 15, 1993	Pursuant to Judge Bunton's Order, USFWS determines that takes begin when Comal spring discharge declines to 200 cfs, and when San Marcos spring discharge declines to 100 cfs.
March, 1993	The TNRCC submits its plan to the court.
May 26, 1993	Judge Bunton enters Amended Judgment and Amended Findings of Fact and Conclusions of Law pursuant to an agreement between USFWS and plaintiffs. USFWS drops its appeal.

May 30, 1993	73rd Legislature enacts Senate Bill 1477, creating the Edwards Aquifer Authority (EAA), to regulate groundwater use, abolishing the EUWD. Governor Ann Richards signs the bill on June 11, 1993. Senate Bill 1477 establishes that the EAA will become operational on September 1, 1993.
June 15, 1993	Pursuant to Judge Bunton's Order, USFWS determines that under normal conditions jeopardy occurs when flow at Comal Springs declines to 150 cfs, and when San Marcos spring discharge declines below 100 cfs (same as take at San Marcos Springs).
August, 11, 1993	The Mexican American Legal Defense and Education Fund question the legality of equal representation by minorities on the new Edwards Aquifer Authority appointed board, and files for a U.S. Department of Justice (USDOJ) review.
September 1, 1993	Senate Bill 1477 is to take effect, but implementation is delayed while the USDOJ decides if the abolition of the EUWD elected board and substitution of an appointed board violates the Voting Rights Act.
September 3, 1993	TNRCC's Underground River Rules invalidated by Judge Pete Lowry of the Travis County District Court.
September 22, 1993	The catfish farm is issued a water quality permit from the TNRCC.
November 19, 1993	USDOJ rules that Senate Bill 1477 does not meet the requirements of the Voting Rights Act because it would abolish an elected board (the EUWD) and replace it with an appointed one (the EAA).
December, 1993	The State of Texas asks USDOJ to clarify its ruling. The state proposes that the EAA and the EUWD be allowed to coexist and implement Senate Bill 1477.
1994	New Braunfels Utilities switched from a sole dependence upon Edwards groundwater to surface water from the Guadalupe River
January, 1994	Eight of the nine appointees for the EAA board are named and informally meet with the Governor Richards and representatives of the TNRCC.
January, 1994	The EUWD board agrees to accept that all its 12 board members be elected from single-member districts by January 1998 settling a two-year old Voting Rights Act lawsuit (*Williams v. Edwards Underground Water District*. C.A. No. SA-92-CA-144, (W.D. Texas) (1992) which had challenged the EUWD's election system on one-person, one-vote grounds.

February 25, 1994	Judge Bunton appoints Joe G. Moore, Jr. as Court Monitor to gather data for the court.
March 9, 1994	Attorney General Morales files suit (*State of Texas v. United States of America*) in the U.S. District Court for the District of Columbia seeking to reverse the Justice Department's decision that Senate Bill 1477 does not meet the requirements of the federal Voting Rights Act. The court grants the state's request to appoint a three-judge panel to consider the issue.
March, 1994	The USDOJ decides that the EUWD and the EAA cannot exist concurrently because the appointed board of the new authority (created by Senate Bill 1477) would effectively replace the elected board of the EUWD, thus violating the Voting Rights Act.
May, 1994	The City of San Antonio announces adoption of a water-resource plan that includes an election on whether to complete construction of the Applewhite Reservoir project on August 13, 1994. Judge Bunton denies a motion to declare a water emergency.
June 6, 1994	Judge Bunton orders the Court Monitor to prepare a plan by August 1, 1994 to limit withdrawals, and also orders the USFWS to publish a proposed recovery plan for the species by August 1, 1994.
August 1, 1994	The Court Monitor delivers *Emergency Withdrawal Reduction Plan for the Edwards Aquifer* to the federal district court.
August 13, 1994	City referendum in San Antonio rejects the 2050 Plan and the Applewhite Reservoir. San Antonio Water System (SAWS) staff is directed to start disposal of the property in the Applewhite Reservoir site.
September 25, 1994	Judge Bunton orders the formation of a panel, chaired by the Court Monitor, to draft a regional water management plan/habitat conservation plan to obtain an ESA §10(a) Incidental Take Permit.
March 31, 1995	The Court Monitor delivers *Revised Emergency Withdrawal Reduction Plan for the Edwards Aquifer* to the federal district court.
April 19, 1995	A Letter of Intent is executed to assure the transport of 15,000 acre-feet of Guadalupe River water to the military bases in San Antonio in an attempt to remove the water supply issue as a factor in the deliberations of the Base Realignment and Closure Commission over the fate of five San Antonio military bases.

April 28, 1995	The Sierra Club files an ESA suit in Judge Bunton's court against the U.S. Department of Agriculture (USDA). *Sierra Club v. Glickman, et al.* alleges that USDA is allowing agricultural activities, primarily irrigation, to harm listed species at Comal and San Marcos Springs without consulting with the USFWS.
May 31, 1995	Governor George Bush approves changes to Senate Bill 1477 adopted by the 74th Legislature in H.B. 3839 to give the EAA an elected board to satisfy the concerns of USDOJ.
June 23, 1995	The Court Monitor distributes for comment *Draft Habitat Conservation Plan for the Edwards Aquifer (Balcones Fault Zone - San Antonio Region)* developed over 9 months through a panel.
August 22, 1995	A group led by the Medina and Uvalde Counties Underground Water Conservation Districts challenge the constitutionality of Senate Bill 1477 in State District Court in Medina County only 8 days before the EAA is to begin operating (*Barshop, et al. v. Medina County Underground Water Conservation District, et al.*, No. 95-0881 (Tex. Aug. 22, 1996)).
October 18, 1995	The Court Monitor's activities are stayed by the U.S. 5th Circuit Court of Appeals.
October 27, 1995	The Medina County State District Court Judge Mickey Pennington rules that Senate Bill 1477 is unconstitutional in *Barshop, et al. v. MCUWCD, et al.*
1996	Drought returns to the region. Spring discharge declines rapidly.
February 14, 1996	The USFWS finishes the Comal and San Marcos Springs recovery plan bringing *Sierra Club, et al. v. Babbitt, et al.* to an end by satisfying a ruling by the U.S. Fifth Circuit Court of Appeals.
March 20, 1996	Oral arguments in an expedited appeal of Pennington's decision in *Barshop, et al. v. MCUWCD, et al.* before the Texas Supreme Court.
May 1, 1996	Comal Springs drops below take and San Marcos Springs drops below take and jeopardy.
June 10, 1996	The Sierra Club files another ESA suit in Judge Bunton's court against all Edwards Aquifer pumpers. *Sierra Club v. San Antonio, et al.* alleges that pumpers are causing takes by lowering the aquifer, thereby reducing spring discharge.
June 28, 1996	A unanimous Texas Supreme Court reverses the Medina County State District Court, and finds Senate Bill 1477 constitutional.

July, 1996	EAA convenes first organizational meeting.
July 2, 1996	Judge Bunton orders the USDA to develop a species conservation plan in *Sierra Club v. Glickman, et al.*
July 31, 1996	The EAA board abstains from voting on a declaration of a water emergency during the drought.
August 1, 1996	Judge Bunton appoints the author as Special Master in *Sierra Club v. San Antonio, et al.* The Special Master is ordered to develop a regional water conservation plan within ten days.
August 17, 1996	EAA issues first draft *Critical Period Management Plan* rules.
August 23, 1996	The Special Master delivers the *1996 Emergency Withdrawal Reduction Plan* to the Court, which has been revised and adopted after a public comment period. Judge Bunton declares a water emergency and sets a date for the plan's activation.
September 11, 1996	Judge Bunton's August 23, 1996, Order is stayed by the U.S. 5th Circuit Court of Appeals.
October 22, 1996	SAWS approves routing for water reuse project to provide 35,000 acre-feet of recycled water. Later the project is expanded to 55,000 acre-feet.
October 23, 1996	The U.S. 5th Circuit grants USDA's motion for stay in *Sierra Club v. Glickman, et al.* pending an appeal.
October 29, 1996	EAA passes rules for filing applications for permits for historical Edwards Aquifer use.
November 21, 1996	Judge Bunton denies Sierra Club request to have case proceed as a class action against all well owners.
December 19, 1996	EAA adopts *Interim Critical Period Management Plan* and processing rules for Edwards Aquifer claims.
December 30, 1996	Deadline for historic claims for all Edwards well owners due to EAA.
1997	TWDB publishes update of Texas Water Plan. The Legislature develops a new state water planning statute, Senate Bill 1.

January 9, 1997	Spring discharge still at diminished levels. The EAA receives price per acre-foot offers from irrigators to participate in the Irrigation Suspension program.
April 30, 1997	The U.S. 5th Circuit Court of Appeals vacates Judge Bunton's August 23, 1996 Order, finding that the Court should have abstained from acting on a matter that the EAA could potentially resolve.
December 18, 1997	The USFWS lists Comal Springs riffle beetle, Comal Springs dryopid beetle, and Peck's cave amphipod as endangered.
1998	After significant rains in 1997 drought returns to the region. Comal Springs drops below take for 39 days.
August 5, 1998	Travis County District Court Judge Joseph Hart issues a temporary injunction on behalf of the catfish farm in *Living Waters Artesian Springs, LTD. v. Edwards Aquifer Authority*, enjoining the EAA from implementing or enforcing its rules for processing permit applications to allocate aquifer water.
August 14, 1998	The Sierra Club notifies the EAA and USFWS of its intent to sue for violations of the ESA.
September 11, 1998	In a second case challenging EAA rules, *Glenn and JoLynn Bragg v. Edwards Aquifer Authority and Gregg Ellis,* the Medina County District Court Judge Mickey Pennington also enjoins the EAA from enforcing its rules for issuing permits as the result of violations of the Texas Private Real Property Rights Preservation Act.
September 14, 1998	The Environmental Defense Fund notifies the EAA of its intent to sue for violations of the ESA.
September 24, 1998	Ruling on an appeal of *Sierra Club v. Glickman, et al.* the U.S. 5th Circuit Court of Appeals finds that the ESA requires the USDA to develop programs to conserve endangered species.
December 1, 1998	Judge Joseph Hart finds in *Living Waters Artesian Springs, LTD. v. Edwards Aquifer Authority* that the rules of the EAA are invalid because their adoption violated the Administrative Procedures Act. The rules of the EAA limiting withdrawals are invalidated, as well as the EAA's *Critical Period Management Plan* rules.
December 30, 1998	The SAWS board of trustees gives preliminary approval for the purchase of as much as 90,000 acre-feet (about 50% of SAWS current withdrawals from the Edwards Aquifer) from the Aluminum Company of America (Alcoa) lignite operation northeast of Austin in the Carrizo – Wilcox Aquifer.

1999	The EAA holds public meetings and begins the process of developing a habitat conservation plan to obtain an ESA §10(a) Incidental Take Permit from USFWS.
2000	San Marcos begins using surface water as its primary source.
January 1, 2000	The Texas Court of Appeals in San Antonio vacates Judge Pennington's ruling in *Glenn and JoLynn Bragg v. Edwards Aquifer Authority and Gregg Ellis* and rules in favor of the EAA.

Appendix 5. A Data Dictionary of Selected Edwards Aquifer Metadata

Metadata are descriptive information about data. They consist of a common set of terms and definitions for use when documenting a database. Metadata can help data users find the data they need and determine the best way to use it. The organizations producing metadata benefit as well. For example, as personnel changes occur within the organization, undocumented data may lose their value, because institutional knowledge within the organization is lost, new employees may have little understanding of an existing database. In addition, knowledge about the data available at another organization may reduce duplication. The major uses of metadata include:

- Organizing and maintaining an organization's internal investment in spatial data;
- Providing information about an organization's data holdings to data catalogues, clearinghouses, and brokerages; and
- Providing information to process and interpret data received through a transfer from an external source (Grant 1998, 1).

The information included in metadata is typically selected on the basis of four characteristics:

- Availability - data needed to locate the sets of data that exist for a geographic location;
- Fitness for use - data needed to determine if a set of data meets a specified need;
- Access - data needed to acquire an identified set of data; and
- Transfer - data needed to process and use a set of data (Grant 1998, 1).

The Federal Geographic Data Committee (FGDC) has adopted standards for metadata. Executive Order 12906 signed by President Clinton on April 11, 1994, required all federal agencies to begin using the FGDC metadata standards as of January, 1995 for all newly created geospatial data (National Spatial Data Infrastructure 1996, 2). During my review, it became apparent that the adoption of any standards developed by the FGDC is still in progress.

This attached data dictionary includes metadata for Edwards Aquifer water resource databases. I have incorporated the databases that I used in my research. This data dictionary is useful for individuals studying the relationship between withdrawals of aquifer water and the effects upon spring discharge at Comal and San Marcos Springs and downstream flow in the Guadalupe River System. This information is necessary for the Edwards Aquifer Authority and aquifer pumpers, such as the San Antonio Water System, to reduce the effects of withdrawals on the flow of Comal and San Marcos Springs, which are home to threatened and endangered species dependent on adequate spring discharge for their habitat.

The format for this data dictionary was developed after reviewing examples of other data dictionaries, Texas Metadata Lite, and the databases described here. Texas Metadata Lite (which is only accessible using a Windows format) was developed as a small subset of the FGDC metadata standard (Texas General Land Office in cooperation with the U.S. Environmental Protection Agency 1996, Appendix F). This data dictionary includes a subset of the contents of Texas Metadata Lite most relevant to hydrologic databases. Metadata for the databases included in this data dictionary have not been developed previously (Decker 1998), (Lambert 1998), and (Walthour 1998).

Name: Comal Spring Discharge.

Source: U.S. Geological Survey (USGS).

Contact person: Raymond Slade, USGS (512) 873-3000. Station maintained by San Antonio Field Unit in cooperation with GBRA.

How are the data collected? Data are collected at USGS station 08168710 by a surface water - stage recorder and then transmitted by a satellite telemeter to the USGS. Older references for Comal Springs data refer to station 08169000. Station 08168710 and 08169000 are one in the same. The difference is that spring discharge data is separated out and given a unique designation 08168710.

Where are the data collected? New Braunfels, Comal County, Texas, latitude 29°42'21", longitude 098°07'20". The station is located on the west bank of the Comal River 200 feet upstream from the San Antonio Street viaduct in New Braunfels, and 1.1 mile upstream from the confluence of the Comal and Guadalupe Rivers. Gage datum 582.80 ft msl. Drainage area 130.0 square miles.

Period of record: December 19, 1927 to present.

Data are currently available for: December 19, 1927 to June 3, 1998.

Count: 25735 as of September 30, 1998.

Missing data: 48. Missing data result from flood events overwhelming the water - stage recorder.

Access: Data are available from standard graph or ASCII file of tab separated data. Files available for downloading from the USGS FTP site <http://tx.usgs.gov/cgi-bin/dvinv/?station=08168710>.

Are the data parametric or nonparametric? Parametric.

Variable:	Date
Definition:	Date including month, day, year.
Measurement scale:	Ordinal.
Format example:	12 31 1973 (MMtabDDtabYYYY)
Measurement units:	Integer.
Frequency:	Once per day.
Missing value:	Blank.
Variable:	Discharge, in cfs
Definition:	Mean discharge of water from the Edwards Aquifer at Comal Springs in cubic feet per second (cfs) of spring discharge.
Measurement scale:	Continuous.
Format example:	429.
Measurement units:	Integer. 2 decimal places.
Frequency:	Mean of 15 daily measurements.
Missing value:	Blank.

Name: San Marcos Springs flow.

Source: USGS.

Contact person: Raymond Slade, USGS (512) 873-3000. Station maintained by San Antonio Field Unit in cooperation with EAA.

How are the data collected? Data are collected at USGS station 08170000 by a surface water - stage recorder and then transmitted by a satellite telemeter to the USGS. A new reference for the San Marcos River data may be encountered, station 08170500. Station 08170000 and 08170500 are one in the same, with a Pearson correlation coefficient of 1.0000.

Where are the data collected? San Marcos, Hays County, Texas, latitude 29°53'20", longitude 097°56'02". The station is currently located on the west bank at downstream side of bridge on Aquarena Springs Drive, 500 feet downstream from Spring Lake, and 4.2 miles upstream from the Blanco River. Gage datum 557.67 ft msl. From May 1956 to September 1988, measurements were taken at a site 0.7 miles downstream from the bridge on Interstate 35 and 2.1 miles upstream from the Blanco River. From October 1988 to September 1994, measurements were taken at well LR-67-09-110, 0.2 miles southwest of the intersection of FM 2439 and McCarty Lane and 3.7 miles south of San Marcos. Drainage area 93 square miles.

Period of record: May 1, 1956 to present.

Data are currently available for: May 26, 1956 to September 29, 1998.

Count: 15467 as of September 29, 1998.

Missing data: 0.

Access: Data are available from standard graph or ASCII file of tab separated data. Files available for downloading from the USGS FTP site <http://tx.usgs.gov/cgi-bin/txnwis>.

Are the data parametric or nonparametric? Parametric.

Variables:	Date
Definition:	Date including month, day, year.
Measurement scale:	Ordinal.
Format example:	11 30 1974 (MMtabDDtabYYYY)
Measurement units:	Integer.
Frequency:	Once per day.
Missing value:	Blank.
Variable:	Discharge, in cfs
Definition:	Discharge of water from the Edwards Aquifer at San Marcos Springs in cfs of spring discharge.
Measurement scale:	Continuous.
Format example:	225.
Measurement units:	Integer. 2 decimal places.
Frequency:	Mean of 15 daily measurements.
Missing value:	Blank.

Name: State index well AY-68-37-203.

Source: Edwards Aquifer Authority (EAA), San Antonio, Texas.

Contact person: Steve Walthour, EAA, (800) 292-1047.

How are the data collected? By water - level recorders at the observation well.

Where are the data collected? San Antonio, Bexar County, Texas, longitude 098°25′54″, latitude 29°28′45″. AY-68-37-203 (Texas Water Development Board designation) is also known by an older local designation as well J-17, and colloquially as the Dodd Field well, or Bexar County well. The well is located at Fort Sam Houston. The USGS designation is 292884509825540l. AY-68-37-203 is an unused artesian well in the Edwards Aquifer. A data disk from the EAA states that the land surface datum is 722.56' msl (other sources indicate 730.81 feet above msl (Brown, Petri, and Nalley 1992, 35)). From November 12, 1932 to March 2, 1962 this data was collected at the Beverly Lodges Well (also known as Ed Stevens and Sons Well) approximately 1.5 miles southeast of J-17's location. Data, which was not available, was collected from 1911 to approximately 1946 at the Brackenridge Park Well. The exact location of the Brackenridge Park Well and Beverly Lodges Well is not known (Brown 1999).

Period of record: November 12, 1932 to present.

Data are currently available for: November 12, 1932 to December 31, 1997

Count: 23,791.

Missing data: 798. Missing data result from malfunctioning water - level recorders at the observation well and lost data.

Access: Compressed files available for downloading from the EAA FTP site <http://www.e-aquifer.com/field/sdw134.htm>. Systems using Netscape

Navigator lack the capability to download files from this site. Water level data will be available over the Internet from the TWDB in the near future.

Are the data parametric or nonparametric? Parametric.

Variables:	Date
Definition:	Date including month, day, year.
Measurement scale:	Ordinal.
Format example:	10/13/86 (MM/DD/YY).
Measurement units:	Integer.
Frequency:	Once per day.
Missing value:	Blank.
Variable:	Well level
Definition:	Groundwater level in feet above msl.
Measurement scale:	Continuous.
Format example:	862.12.
Measurement units:	2 decimal places.
Frequency:	Once per day.
Missing value:	Blank.

Name: State well YP-69-50-302.

Source: EAA, San Antonio, Texas.

Contact person: Steve Walthour, EAA, (800) 292-1047.

How are the data collected? By water - level recorders at the observation well.

Where are the data collected? Uvalde, Uvalde County, Texas, longitude, 099°47′12″, latitude: 29°12′37″. YP-69-50-302 (TWDB designation) is also known by an older local designation as well H-5-1 and colloquially as Uvalde County index well. The USGS designation is 291237099471201. YP-69-50-302 is an unused artesian well in the Edwards Aquifer. Land surface datum 904.85' msl.

Period of record: January 23, 1941 to present.

Data are currently available for: October 24, 1940 to December 31, 1997.

Count: 20,888.

Missing data: 1009. Missing data result from malfunctioning water - level recorders at the observation well and lost data.

Access: Compressed files available for downloading from the EAA FTP site <http://www.e-aquifer.com/field/sdw134.htm>. Systems using Netscape Navigator lack the capability to download files from this site. Water level data will be available over the Internet from the TWDB in the near future.

Are the data parametric or nonparametric? Parametric.

Variable: Date

Definition: Date including month, day, year.

Measurement scale: Ordinal.

Format example: 10/13/86 (MM/DD/YY).

Measurement units: Integer.

Frequency:	Once per day
Missing value:	Blank.
Variable:	Well level
Definition:	Groundwater level in feet above msl.
Measurement scale:	Continuous.
Format example:	994.45.
Measurement units:	2 decimal places.
Frequency:	Once per day
Missing value:	Blank.

Name: State well TD-69-47-306.

Source: EAA, San Antonio, Texas.

Contact person: Steve Walthour, EAA, (800) 292-1047.

How are the data collected? By water - level recorders at the observation well.

Where are the data collected? Hondo, Medina County, Texas, longitude: 098°20'45", latitude 29°08'18". TD-69-47-306 (TWDB designation) is also known by an older local designation as well I-3-134, and colloquially as the Hondo index well. The USGS designation is 292045099081801. TD-69-47-306 is an unused artesian well in the Edwards Aquifer. Land surface datum 887.5'.

Period of record: September 8, 1986 to present.

Data are currently available for: September 8, 1986 to December 31, 1997.

Count: 4133.

Missing data: 294.

Access: Compressed files available for downloading from the EAA FTP site <http://www.e-aquifer.com/field/sdw134.htm>. Systems using Netscape Navigator lack the capability to download files from this site. Water level data will be available over the Internet from the TWDB in the near future.

Are the data parametric or nonparametric? Parametric.

Variable: Date

Definition: Date including month, day, year.

Measurement scale: Ordinal.

Format example: 10/13/86 (MM/DD/YY).

Measurement units: Integer.

Frequency: Once per day.

Missing value:	Blank.
Variable:	Well level
Definition:	Groundwater level in feet above msl.
Measurement scale:	Continuous.
Format example:	773.23.
Measurement units:	2 decimal places.
Frequency:	Once per day.
Missing value:	Blank.

Appendix 6. Interviews Requested and Completed

Interviews Completed:

- Beldon, Mike, EAA Chairman
- Buckner, Luana, EAA board member
- Bunton, Judge Lucius, Senior U.S. District Court Judge
- Ellis, Greg, EAA General Manager
- Knowles, Tommy, Deputy Executive Administrator for Planning of TWDB
- Lewis, Ron, Texas House of Representatives, co-sponsor of Senate Bill 1477
- Moore, Billy, Mayor of San Marcos
- Nevola, Roger, lawyer for GBRA and Alcoa
- Ozuna, George, Director USGS San Antonio Field Office
- Peak, Howard, Mayor of San Antonio
- Rosenberg, Lou, lawyer for the Bexar Metropolitan Water District
- Specht, John, former General Manager of the GBRA
- Thornhill, Paul, LCRA, expert witness in Sierra Club et al. v. Babbitt et al.
- Thuss, Mike, CEO of SAWS

Interviews Requested, but not Granted:

- Armbrister, Ken, Texas Senate, co-sponsor of Senate Bill 1477
- Briscoe, Dolph, former Governor of Texas
- Brown, Buster, Texas Senate
- Counts, David, Texas House of Representatives
- Hubbs, Clark, Emeritus Zoology Professor, The University of Texas at Austin

- King, Tracy, Texas House of Representatives
- Miller, Doug, EAA board member
- Morton, Cliff, former SAWS board member
- Pucek, Ronnie, Living Waters Artesian Springs (the Catfish Farm)
- Richards, Ann, former Governor of Texas
- Rimkus, Maurice, former board member of the MCUWCD
- Rothe, Greg, General Manager of SARA
- Shull, Alisa, USFWS
- West, Bill, GBRA General Manager

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