AN IMPACT ASSESSMENT OF WATER CONSERVATION POLICY IN AGRICULTURE: THE ARIZONA GROUNDWATER MANAGEMENT ACT OF 1980

by

Robert A. Needham

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This thesis has been approved on the date shown below:

_______________________________ _______________________________

Paul N. Wilson Date

Professor

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TABLE OF CONTENTS

1. INTRODUCTION……………………………………………………………….10
1.1 A World Perspective…………………………………………………………….10
1.2 A National Perspective…………………………………………………………14
1.3 Objectives……………………………………………………………………….16

2. WHY A WATER CONSERVATION POLICY FOR ARIZONA AGRICULTURE?……………………………………………………………….18
2.1 Over-Consumption………………………………………………………….....18
2.1.1 Social Costs…………………………………………………………..19
2.1.2 Common Property Resource…………………………………………20
2.1.3 Solutions to Over-Consumption………………………………………..21
2.1.4 Arizona's Water Challenge………………………………………………..24
2.2 Arizona's Groundwater Management Act…………………………………….25
2.2.1 GWMA History…………………………………………………………...26
2.2.2 GWMA of 1980……………………………………………………….....31
2.2.2.1 Active Management Areas……………………………………….33
2.2.2.2 Grandfathered Rights……………………………………………..35
2.2.2.2.1 Irrigation Grandfathered Rights……………………………….36
2.2.2.2.2 Non-Irrigation Grandfathered Rights………………………….37
2.2.2.3 Flexibility Accounts……………………………………………….37
2.2.3 GWMA Immediate Effects………………………………………………..40
2.2.4 Amendments to the GWMA……………………………………………42

3. EVALUATION OF THE GWMA……………………………………………….44
3.1 Impact Assessment Literature……………………………………………….....44
3.2 Impact Assessment……………………………………………………………47
3.2.1 Qualitative Assessment……………………………………………………50
3.2.2 Quantitative Assessment…………………………………………………..52
3.2.2.1 A Conceptual Model……………………………………………...52
3.2.2.2 Panel Data……………………………………………………………...53
3.2.2.2.1 Fixed Effects Model……………………………………………...54
3.2.2.2.2 Random Effects Model…………………………………………..55
3.2.2.2.3 Panel Data Tests…………………………………………………….56
3.2.2.2.3.1 F-Test…………………………………………………………56
3.2.2.2.3.2 Hausman Test…………………………………………….....57
3.2.2.3 Panel Data Model……………………………………………………...58
3.2.2.3.1 Explanation of the Data………………………………………….59

4. RESULTS……………………………………………………………………….....63
4.1 Qualitative Results…………………………………………………………….....63
4.1.1 Initial Impact of the GWMA……………………………………………...63
4.1.1.1 Agricultural Land Constraints……………………………………….64
4.1.1.2 Central Arizona Project………………………………………………..64
4.1.1.3 Awareness, Perceptions, and Measurement………………………...65

Table of Contents- *Continued*

4.1.2 Impact of the Implementation of the GWMA……………………………….66
4.1.2.1 Impact on Farmer Practices and Decisions……………………………66
4.1.2.2 Law Created with a Faulty Design…………………………………….68
4.1.2.3 Enforcement Difficulties………………………………………………73
4.1.3 Impact on Agricultural Water Use………………………………………...74
4.2 Quantitative Results……………………………………………………………..75
4.2.1 Fixed Effects Versus Random Effects……………………………………75
4.2.2 Explanatory Variable Results……………………………………………..79
4.2.3 Irrigation District Results…………………………………………………80
4.2.4 Management Plan Results…………………………………………………81
4.2.5 Integration of Qualitative and Quantitative Results………………………82

5. **SUMMARY, APPLICATIONS, LESSONS LEARNED………………………...83**

References………………………………………………………………………………..90
Appendix A-1 Timeline of Policy Events……………………………………………….96
Appendix A-2 Sources of Qualitative Data.…………………………………………….97
Appendix A-3 Irrigation District Summaries…………………………………………...98
Appendix A-4 NOAA Weather Stations for Irrigation District Data………………….120

LIST OF FIGURES

FIGURE 1.1 Potential Water Supply Crises by 2025……………………………..16
FIGURE 2.1.3 Over-Consumption……………………………………………….22
FIGURE 2.1.4 Estimated Annual Groundwater Withdrawal in Arizona…………...24
FIGURE 2.2.2.1 Current Active Management Areas (AMAs) in Arizona…………...34
FIGURE 3.2-1 Data Triangulation Design for Qualitative Impact Analysis………..49
FIGURE 3.2-2 Methodological Triangulation Design for Quantitative Impact Analysis…………………………………………………….50
FIGURE 3.2.2.4.1 Average Weather in Irrigation Districts……………………………61
FIGURE 4.1.2.2-1 Conceptual Model of the GWMA's Non-Binding Water Constraint for a Farm…………………………………………………..69
FIGURE 4.1.2.2-2 Flex Credit Balances……………………………………………..70
FIGURE 4.1.2.2-3 Irrigated Acres in the AMAs……………………………………..71
FIGURE 4.1.3-1 Water Consumption in Agriculture by AMA……………………….74
FIGURE 4.1.3-2 Efficiency in Irrigation……………………………………………...75

LIST OF TABLES

TABLE 2.1.2 Public Goods Versus Private Goods…………………………………20
TABLE 2.2.2.3 Consumptive Use Requirements by Crop……………………………39
TABLE 3.2.2.3.1 Approximated Percent of Irrigated Area Represented by the Irrigation Districts Analyzed in the Model……………………………………..60
TABLE 4.2.1-1 Estimation Results for Model 1……………………………………...77
TABLE 4.2.1-2 Estimation Results for Model 2……………………………………...78

LIST OF ACRONYMS

ADWR	Arizona Department of Water Resources
AF	acre-feet
AGMSC	Arizona Groundwater Management Study Commission
AMA	Active Management Area
ASFC	Area of Similar Farming Conditions
AWC	Arizona Water Commission
BCA	Benefit-Cost Analysis
BMP	Best Management Practices
BOR	Bureau of Reclamation
CAP	Central Arizona Project
CGA	Critical Groundwater Area
CWR	Crop Water Requirement
DOI	U.S. Department of the Interior
FICO	Farmers Investment Company
GWMA	Groundwater Management Act
IGFR	Irrigation Grandfathered Right
IWD	Irrigation Water Duty
NOAA	National Oceanic Atmospheric Administration
NRCS	Natural Resources Conservation Service
UNEP	United Nations Environmental Program
USDA-NASS	United States Department of Agriculture, National Agricultural Statistics Service
USGS	United States Geological Survey
WRRC	Water Resources Research Center

ABSTRACT

Water conflicts between urban and rural populations often center on water use in the agricultural sector. Public officials may select a water conservation policy as the primary tool for reducing agricultural water use with the goal to improve water availability to urban areas and future generations. The Groundwater Management Act of 1980 (GWMA) in Arizona was designed, in part, to induce water conservation in irrigated agriculture so that a desert state could sustain economic growth. This mixed-method evaluation design merges qualitative, interview-based information with state agency data and an estimated water demand function to assess the performance of the GWMA. The results of this study show that (1) the GWMA began with a flawed design and evolved through political pressure into a minor day-to-day water conservation tool, and (2) nearly all water use in Arizona's agricultural sector from 1984-2002 can be explained by market factors with no evidence that the GWMA's management plans directly contributed to reduced water demand. Since public water conservation efforts are rarely evaluated, this impact analysis may assist policy makers as they compare the expected costs and benefits of their current or proposed programs.

1. INTRODUCTION

In most regions of the world, agriculture uses a clear majority of the surface and groundwater resources utilized by the human community. Allocation conflicts along the water boundary between the agricultural sector and the sectors representing municipalities, industry, Native communities, and even the environment are increasingly prevalent in arid and semi-arid regions. Policy debates over water quality, water quantity, water conservation, and property rights dominate the political process on an increasingly regular basis (Anderson 1995; Donahue and Johnston 1998; Garduno 2003; Gleick 1998; Postel 1997; Wilson 2002).

1.1 A World Perspective

Water is a political and powerful resource in nature, creating conflicts between people where conflicts may not arise otherwise since water is a necessity for human survival. Secretary General of the United Nations Boutros Boutros-Ghali, King Hussein of Jordan, and President Anwar Sadat of Egypt all predict that the next war fought will be over water (Simon 1998).

The need for water is prevalent in society. In ancient times, water was considered one of the four basic elements, demonstrating the importance of water in civilization. Glancing back in history, lack of water supplies may have been the cause of several collapses of civilizations in various areas of the world. The cities of Mesopotamia, the Mayan, and the Hohokam Civilizations are all believed to have collapsed when their growth exceeded their sustainability (Learner.org 2005; Gammage 2004; Hodell et al 2004; Postel 1999). In times of drought, water supplies were not abundant enough to provide the farms the necessary water to produce food for the people in these communities. Famine struck these nations and coerced the people to move.

Water supplies, in the ancient past, have influenced the location one may choose to live (Genesis 13:1-12, NIV 1995). However, currently one-third of the world's population is located where freshwater is lacking. The communities have outgrown their sustainability and water transfers are more common. Worldwide, the need for water doubles every 21 years (Centre for Development Studies 2001). This increase in demand is largely due to the growth in agriculture as well as population growth.

Today, water transfers from the rural to the populous areas are commonplace when municipalities outgrow their water existing water sources. For example, Latin America faces a water allocation problem with its people. The majority of Mexico's population live in areas where water is the most scarce. In fact, 77% of the Mexican population live where only 28% of the available water in the country is located (Garduno 2003). Hence, transferring water from agriculture and other rural areas has become a necessity for these regions and other regions like Mexico to thrive.

Over-usage of water is a problem in Mexico City as well. Initially Mexico City was built near a lake and was self-sustained. As the city grew, over-pumping of groundwater caused the underground water flow to reverse. Instead of groundwater recharging the lake, the lake began recharging the groundwater resulting in increased groundwater pollution. The lake was depleted and now part of the city has been built where the lake used to be. In addition to the lake depletion, the groundwater has depleted, and parts of Mexico City are sinking one centimeter every 14 days causing negative externalities such as extensive damage to historic buildings (Centre for Development Studies 2001, Glennon 2002).

Asia faces allocation conflicts regarding water rights as well. In today's Mesopotamia, more commonly known as Iraq, conflicts over water rights between the agricultural, environmental, and municipal sectors accompany the other political turmoil. The marshlands of Mesopotamia, which was the Biblical Garden of Eden, are disappearing and will vanish completely in five years, according to the United Nations Environmental Program (UNEP). The UNEP states that the draining of the marshes is 'one of the world's greatest environmental disasters,' comparable with the drying up of the Aral Sea and the deforestation of large tracts of the Amazon. This "fertile crescent" only has seven percent of its marshlands remaining, endangering many species including the Sacred Ibis, African darter, an estimated 40 species of waterfowl, and numerous species of fish. Seven species have become extinct. Ninety percent of the marshlands disappeared from the early 1970s to 2000. The marshlands once covered an area of 15,000 to 20,000 square kilometers (Molavi 2003). All that remains is marshlands along the border of Iraq and Iran covering approximately 1000 square kilometers (People and the Planet 2003).

The Iraqi marshes are believed to be shrinking due to two primary reasons. Turkey and Syria dammed the upper Tigris and Euphrates rivers in the 1950s to accommodate the population growth and irrigation demands, thereby reducing the flow of water to the marshes. The other cause of this decimation is political in nature (Lamb 2004). Following the 1991 Gulf War, Saddam Hussein's regime retaliated against the Marsh Arabs, the natives living in the marshlands for the last 5000 years, because of their uprising that failed. Saddam Hussein's massive drainage schemes decimated the livelihoods of 500,000 Marsh Arabs, and many of these agricultural producers were forced to move to Iran. This action led to large negative externalities, such as the destruction of wetlands larger than the Florida Everglades (People and the Planet 2003).

Australia appears to have found a balance in water allocations among the sectors representing the environment, agriculture, and the native population in a civil and orderly way. Australia, being one of the driest continents on earth, faces numerous water conflicts among its people. The communities, farms, and the Australian natives, known as Aborigines, fight for their fair share. The courts are trying to determine the "fair" amount, but only since the early 1980s when Australia experienced a drought did the courts have to determine property rights for this water. Water allocations to individual licensees were about 10 to 20 percent of licensed water entitlements. The Government realized that these volumes were too low to grow a crop, so it allowed irrigators to trade their available water temporarily on an annual basis.

Following initial apprehension, this system today is an integral part of irrigation farm business planning. The Murray-Darling Basin Ministerial Council agreed that a balance between consumptive and instream uses of water in the Basin was needed. The Macquarie Marshes is a major wetlands system covering 1500 square kilometers near the center of the Murray-Darling Basin and is listed as international environmental significance. The Council limited the quantity consumed by setting a 'cap' in an attempt to prevent basin water extractions from increasing. Any future growth in water-based economic productivity must come from gains in water use efficiency, or from water trades. As a result of this decision, the market value of irrigation water entitlements virtually doubled overnight. The Water Management Act of 2000 gave river health the top priority, and water management and development must conform to the needs of the environment. Irrigators have realized that as a result of these policies, halting the growth in water consumption has protected their current reliability of water supply (Haisman 2003). Hence, a synergy between the sectors representing the environment, agriculture, and the Aborigines has resulted from these policies.

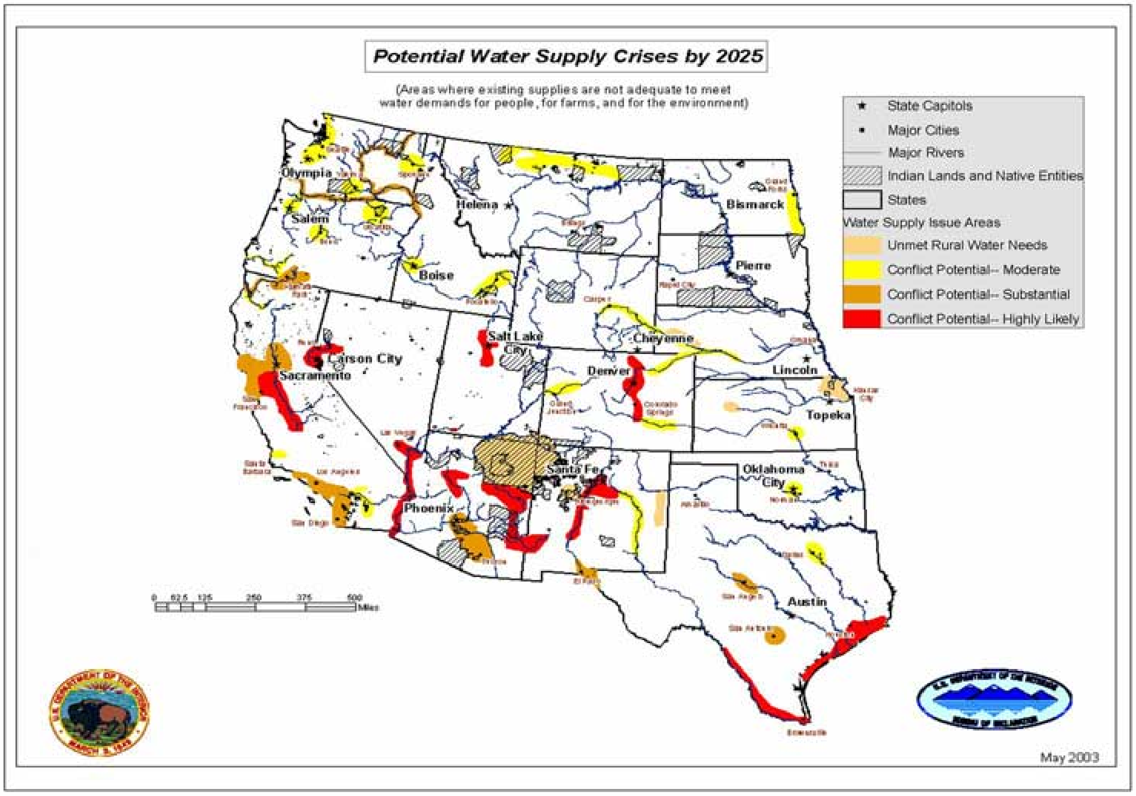
1.2 A National Perspective

On the other side of the globe, the United States also is attempting to resolve water allocation conflicts. In the last century, the U.S. population grew 200 percent while the water use per capita increased 500 to 800 percent. Today Americans use three times as much water per capita as the Japanese. Much of this difference is due to the growth in the agricultural water demands in the U.S. during the 1900s. Recently though, the number of farms have been declining, but Japanese farms are disappearing at twice the rate of U.S. farms (Blank 1998). Forty percent of the irrigation water used on U.S. farms is supplied with groundwater, with a total groundwater supply in the United States of 65 quadrillion gallons in the aquifers (Kenski 1990). With the increasing populations and higher demands for water, tensions are mounting between States and also between rural-urban populations.

For example, the lands of Nebraska recharge one of the largest aquifers in the world (the Ogallala aquifer that stretches down to Texas), and groundwater and surface water property rights are creating turmoil between the neighboring states as well as within the state itself. The line between “surface water” and “groundwater” in Nebraska is gray in some cases. In a time of drought, some growers in Nebraska cannot irrigate their fields (Crummett 2005). This creates many hardships for a state dependent on agriculture. Groundwater pumping will increase with the decline of surface water supplies, which will exacerbate the problem of groundwater depletion causing areas of the Ogallala aquifer to become dry, both in Nebraska and surrounding states. With water becoming more scarce in the Plains, water tensions continue to mount and dozens of lawsuits are pending between Nebraska, Colorado, Wyoming, and Kansas for water rights.

Other areas, generally more urbanized areas of the country, can anticipate water conflicts in the next two decades. Figure 1.1 from the U.S. Department of the Interior shows the predicted hotspots for water debates. Arizona is one of those states. Battles for water rights in Arizona's agriculture are part of the state's history. Arizona's crop-based agricultural sector relies on irrigation water. Without irrigation, crops would wither and die before the producer has a chance to harvest the crop. Due to this dependence on irrigation, growers in Arizona have been fighting for their rights to groundwater and surface water for nearly a century. Arizona farmers have organized agricultural groups more effectively than other areas of the country in order to have greater political clout in the legislative process. Growers realize the need for sustainability of water supplies, but they also want policies to reflect their "fair share." Producers do not desire to be regulated, but in the case of Arizona's groundwater, regulation may be a necessity to preserve the precious natural resource (Glennon 2002).

Figure 1.1 Potential Water Supply Crises by 2025



1.3 Objectives

In this research project, the Arizona Groundwater Management Act (GWMA) of 1980, "The Code" to manage the state's water, will be analyzed.[1] This assessment will include qualitative and quantitative analyses to measure the effectiveness of the policy on water conservation in agriculture. The hypotheses of this research are twofold: (1) though the intentions were valid, the GWMA began with a flawed design and, due to political pressure, became a minor day-to-day water conservation tool, and (2) market forces can explain almost all of the water use in Arizona's agricultural sector from 1984-2002 with

[1] The Groundwater Management Act is commonly referred as "The Code" in literature.

no evidence that the management plans of the GWMA directly contributed to reduced water demand.

Subsequent chapters will discuss aspects regarding these hypotheses. Chapter two explains why Arizona may need a policy for its groundwater, the history leading up to this Act, and the Code itself. Chapter three discusses literature-based evaluation methods, and how these evaluation techniques are applied both qualitatively and quantitatively. Chapter four contains the results of the analysis, and a summary, conclusions, and lessons learned conclude the paper in chapter five.

2. WHY A WATER CONSERVATION POLICY FOR ARIZONA AGRICULTURE?

All sectors in Arizona, including agriculture, desire a reliable water supply. This supply can come from renewable resources or from groundwater. If the reliability of groundwater for future generations is the focus, groundwater consumption in certain areas of the state needs to decrease. Over-consumption of groundwater in Arizona has been problematic for decades due to externalities not reflected in the cost of water. Government intervention can potentially redirect the demand curve to reflect the true cost of water. The social costs causing this over-consumption, and potential corrections, will be discussed in the following section.

2.1 Over-Consumption

When studying natural resources such as water, over-consumption is often problematic when demand for that resource increases and property rights are not clearly defined. The "open access" of groundwater allows the resource to be owned by everyone and no one simultaneously (Carlson et al 1993). The users may have no incentive to conserve the resource because they cannot keep what they save, unless a particular user owns enough land to have sole control of the resource. The cost of water to a grower is typically the cost to retrieve the water. Water will be consumed as long as the marginal benefit exceeds the marginal cost of that unit of water.

In a perfect market, goods are bought and sold with clear definitions of quantities and procedures. A market, by definition, is a set of institutions, rules, or informal norms that promote exchange between willing buyers and sellers (Munger 2000). Perfect markets contain four characteristics in the perfect competition model of agriculture. First, all market participants have free and immediate access to accurate information about prices, the quality of products, and the implications of present actions for future welfare. Second, no market participant is large enough to influence the price either up or down. Third, choices by individuals do not affect the welfare of others. In other words, no externalities in production and no externalities in consumption exist. Fourth, all goods are private (Munger 2000). The third and fourth conditions of perfect competition do not hold in the case of groundwater consumption in Arizona agriculture. Water generally is not traded in a “market” because generally transaction costs are too high and building an infrastructure to trade water would cost more than pumping the water locally. This lack of market leads to “market failure” for society. Hence, water is not a market good in the state of Arizona, and Arizona may need government intervention to correct for this market failure because of the cost of externalities and the “open accessibility” of the resource.

2.1.1 Social Costs

Social costs in the form of externalities may occur with the over-consumption of water. Ignoring the social costs of water consumption can be damaging and may eventually lead to harmful implications such as subsidence, inability to irrigate, cost prohibitiveness, destruction of riparian areas, and unreliable water supplies for everyday life. The economic system for water is incapable of gauging true scarcity values because of externalities (Munger 2000). Markets cannot give accurate present values for future use, and markets cannot give accurate values for amenities that may be damaged by pollution or consumption. Hence, market-based economies lead to over-consumption of groundwater pumping because these social costs are ignored.

2.1.2 Common Property Resource

The fourth condition of a perfectly competitive market does not hold in the case of water consumption in Arizona because groundwater is not a private good. Groundwater is owned by the state of Arizona rather than by individuals, though Arizona gives its people permission to consume the water. Table 2.1.2 shows that a "common property resource" has high marginal costs but exclusion is costly (Munger 2000, Tietenberg 1988). Arizona's groundwater is a common property resource except that Arizona has rules that govern its use whereas a classic common property has no governance on its use. Groundwater typically is rivalrous, meaning that any groundwater consumed by one individual is not available for others (assuming the consumption of the water is not recharged), so the marginal cost is significant. However, it is difficult to prevent that individual from consuming from the "common pool", making the exclusion of an individual costly.

Table 2.1.2 Public Goods Versus Private Goods

	No Exclusivity	*Exclusivity*
Not Rivalrous (Negligible Marginal Costs)	Pure Public Goods	Example: Toll Roads
Rivalrous (High Marginal Costs)	Common Property Resources	Pure Private Goods

Source: Munger 2002.

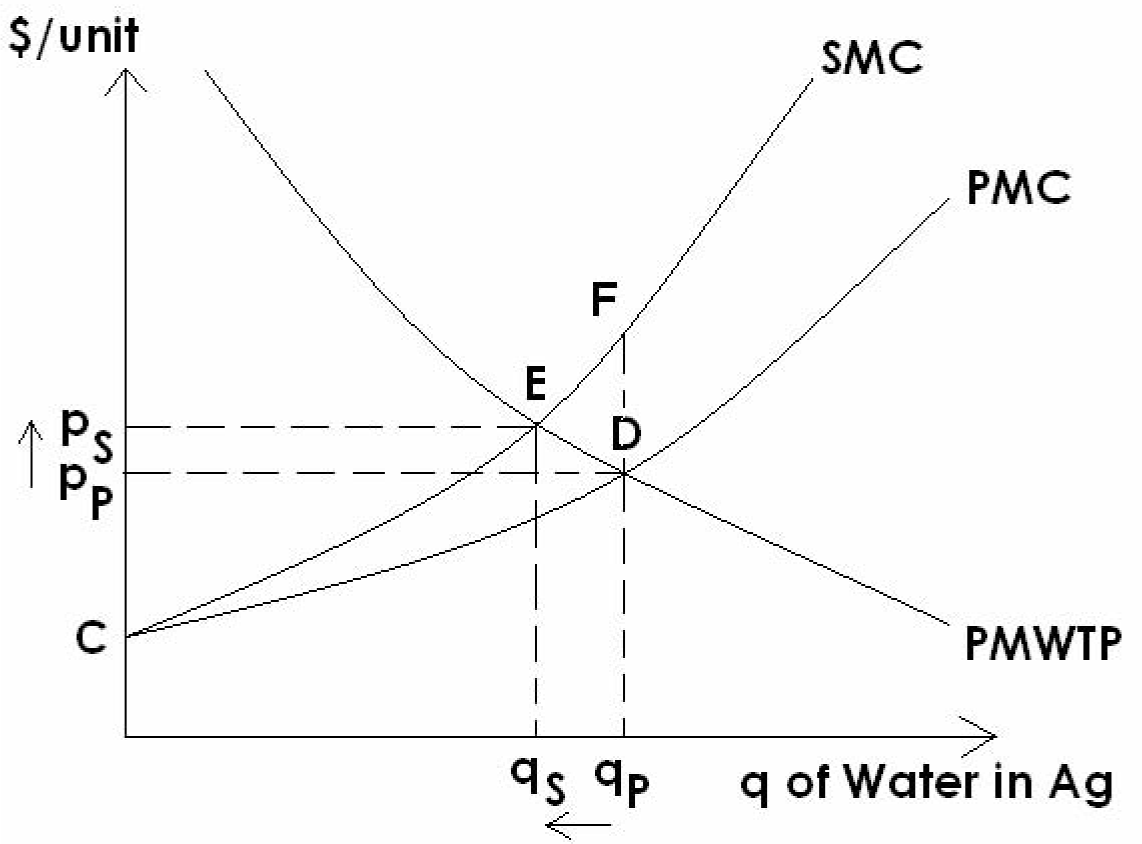
The open access of the resource creates a conundrum when the social costs of water consumption are neglected. An individual's action affects others' welfare, and the others being affected have no control of that individual's action without policy intervention. Since the groundwater is a common property-like resource, landowners may have a "use it or lose it" mentality, and over-consumption can result.

2.1.3 Solutions to Over-Consumption

Over-consumption of water may be solved with the proper regulations. The government can redirect the functioning of the sector back to the correct Pareto optimum, as shown in Figure 2.1 (Harris 2002). The downward sloping line PMWTP represents the private marginal willingness-to-pay, and the upward sloping line PMC represents the private marginal cost curve for pumping water. The equilibrium is at the point where these lines cross, at point D. In this case, the marginal cost curve represents the individual's cost to consume an additional acre-foot of water. In other words, the cost of the groundwater equals the cost to pump the water, implicitly assuming the water itself is free. These costs do not take into account the social costs (in the form of negative externalities) of consuming that water. When social costs are added, the marginal cost line shifts upwards to SMC, thereby creating a new equilibrium at point E and representing the Pareto optimum. The difference on the horizontal axis between the private and social equilibriums (qP-qS) is the amount of water that is inefficiently being over-consumed.

The Pareto optimum can be achieved by shifting the private marginal cost curve to SMC. Pareto optimality is the point where the gains compared to the losses are maximized. To measure this, consumer surplus and producer surplus may be used. Consumer surplus is the difference between the benefits from consumption and the price paid. It is shown as the area below the demand curve (PMWTP), but above the price. In the figure, the area above p_P to the PMWTP line is private consumer surplus. Consumer surplus, following the market correction, is reduced to the area above p_S to the PMWTP line. Therefore, the reduction in consumer surplus due to the shift is the area p_P-D-E-p_S.

Figure 2.1.3 Over-Consumption



Producer surplus is the difference between the production costs and the price received. Graphically, producer surplus is the area above the PMC curve up to p_P for the private market, and above the SMC curve up to p_S for the social market. Therefore, in this scenario the producer will be better off with a higher price if the area between p_P and p_S

to the left of the SMC curve is larger than the area between the SMC and PMC curves below the line p_P. Society will benefit with a higher price by the amount q_P-q_S-E-F, but the private sector will be hindered by q_P-q_S-E-D. Hence, the net benefit to society, including the future value of water, by raising the price from p_P to p_S is the area of the triangle D-E-F. In other words, when the water price in Arizona doesn't take into account the social costs, the loss in benefits to Arizona equal an amount D-E-F.

Two different methods of regulation can solve the problem of over-pumping groundwater: the government can set the price to the social optimum (p_S in Figure 2.1.3), or the government can limit the quantity of groundwater that may be legally pumped (q_S in Figure 2.1.3). Pigou's theory fixes the price while Coase's theory solves the quantity correction, both theoretically achieving the Pareto optimum but differing in the distribution of who wins and who loses.

On the one hand, Pigou suggests taking into consideration the problem of these negative externalities by imposing a tax on the good. This Pigouvian tax will cause the individual marginal cost curve to shift up to equal the social marginal cost curve, thereby achieving Pareto optimality. On Figure 2.1.3, this shift is represented by moving the line PMC to the line SMC. The Pigouvian tax equals the area between p_S and p_P, and from the vertical axis to the left of the point q_S. The government collecting the tax will yield the difference in consumer surplus.[2]

On the other hand, Coase argues that if property rights are clearly specified, if the legal system functions smoothly, and if a mechanism for reducing transactions costs can be found, the best way to solve problems of externalities may be to allow individuals to

[2] Consumer surplus is the difference between the consumer's willingness to pay and the amount that is actually paid (i.e. the upper-triangular area between the price and the demand curve).

trade permits instead of by government action to tax or regulate (Munger 2000). Efficient property rights include universality, exclusivity, transferability, and enforceability.[3] Coase's method minimizes any errors in measurement or corruption. The government simply offers a limited number of permits, equal to q_S on Figure 2.1.3, each representing a respective pumping right thereby limiting the quantity available. This constraint will encourage society to achieve Pareto optimality. Under the Coase Theorem, the individuals trading the permits will yield the difference in consumer surplus (Tietenberg 1988).[4]

2.1.4 Arizona's Water Challenge

Prior to the GWMA, Arizona was annually consuming approximately five million acre-feet of groundwater as shown in Figure 2.1.4, which was almost twice the estimated dependable supply. This over-consumption resulted in a drop in water levels of

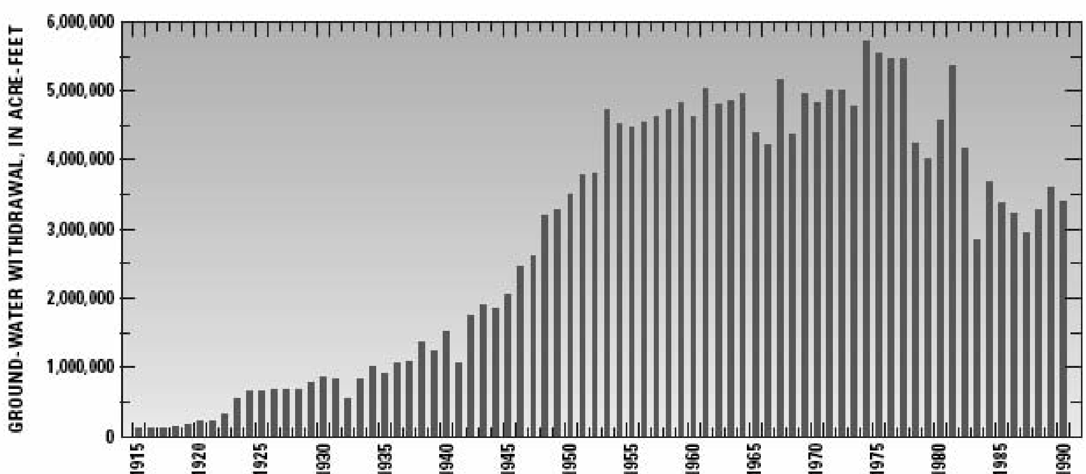


Figure 2.1.4 Estimated annual groundwater withdrawal in Arizona
Source: USGS, 2004

[3] Universality defines all resources are privately owned and all entitlements completely specified.
[4] The Murray-Darling Basin in Australia solved their problem of over-consumption by applying Coase's approach.

approximately ten feet every year in some areas of Arizona (AGMSC 1980, Connall 1982, USGS 2004). In 1975, agriculture consumed 89 percent of all water used in Arizona (AGMSC 1980). In Pima County in 1975, cities and industries used more than the total water recharged in the area (AGMSC 1980). Groundwater depletion exceeded thirty times the natural recharge rate in 1975 in Maricopa County (AGMSC 1980).[5] The Central Arizona Project (CAP) was expected to import, at least temporarily, a major portion of 1.5 million acre-feet per year to non-Indian agriculture, which would help with the groundwater consumption problem. However, Connall adds that with the completion of the Central Arizona Project canal system, there would still be an overdraft of one million acre feet per year given the levels of consumption prior to the Act. Therefore, measures in agriculture were inevitable to solve this groundwater depletion problem since the vast majority of the groundwater use was in agriculture.

2.2 Arizona's Groundwater Management Act

In response to the perceived urgent need to solve the state's groundwater over-consumption problem, the Groundwater Management Act was passed in 1980. It was one of the first pieces of legislation in the country that confronted groundwater management issues. From the publicity that this landmark legislation received, a greater awareness of the value of water spread across the nation.

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[5] The model discussed in Chapter 3 focuses strictly on agriculture since agriculture consumed 89% of the groundwater annually used. The study area includes Phoenix, Tucson, and Pinal Active Management Areas since these areas experienced the greatest groundwater depletion and have the majority of agricultural acres in Arizona.

2.2.1 GWMA History

Arizona has a long history of water conflicts and legislation attempting to resolve those conflicts. The Howell Code of 1864 was the first constitution for the Arizona territory. The Howell Code stated there was a “definite underground channel” of water where the first to pump had the first in right, known as an appropriation right. However, the Howell Code did not mention subsurface water rights. “Percolating” waters, as defined by the Howell Code, were treated as accompanying title to the land, and the landowner was permitted to withdrawal without being regulated (Burton 1990).

As an influx of people began settling in the Southwest, water conflicts became more common and organizations began to form. The League of the Southwest was an organization of the Colorado River Basin States that formed in 1919 to promote the development of the Colorado River. In 1923, the Colorado River Compact was approved by all the basin states except Arizona. The Compact evolved into the Boulder Canyon Project Act of 1928, which allocated 2.8 million acre-feet (maf) of river water to Arizona. The Hoover and Parker Dams were completed in the 1930s.

The Howell Code remained the water law in Arizona for several decades. In the “Dirty Thirties”, slight modifications were made to the code when the Arizona Supreme Court declared that the right to use groundwater was a private property right, governed by the rule of reasonable use.[6] Also, the courts declared that no landowner could transport water if it caused injury to neighboring landowners (AGMSC 1980).

With numerous court cases reinforcing the Howell Code, the Arizona legislature made unsuccessful attempts to enact a groundwater code during the early 1940s. However, the Bureau of Reclamation (BOR) claimed in 1945 and again in 1947 that Arizona needed

[6] The Dirty Thirties was a period in the 1930s of severe drought in the nation.

more responsible groundwater management that restricted agricultural development or else the BOR would find it difficult to justify Central Arizona Project (CAP) construction (AGMSC 1980, Burton 1990).[7]

These threats by the BOR prompted the passage of legislation. As a result of this first threat, a bill was passed in 1945 that required record-keeping of wells, but the law was not renewed when it expired in 1955. Out of desperation from this second threat in 1947, Arizona passed the Groundwater Code of 1948. It was assumed to be a temporary measure, but it remained Arizona's only statutory groundwater law until 1980. It was designed to limit irrigated acres in critical groundwater areas (CGAs), but it did nothing to reduce groundwater withdrawals.[8] The code allowed construction of new irrigation wells if construction was started prior to the designation of critical areas, which led to a "race-to-the-pumps". The code also did not provide adequate funds for enforcement. Therefore, many people claimed this legislation was weak and ineffective because it was not heavily enforced.

In the post WWII era, the cotton boom accelerated and additional lands were brought into production. In 1950 a severe drought began. Following the cotton boom, other industries expanded, triggering the exceptional population growth of the 1950s in the state of Arizona. All these factors produced ever-higher groundwater demands.

Also, the 1950s was a decade of litigation. The federal government declined to provide the necessary funds for the CAP until Arizona resolved its Colorado River water rights dispute with California. Litigation with California continued for twelve years, and

[7] The Central Arizona Project is a 336-mile canal system that transports Colorado River water to central Arizona.

[8] All but two of the CGAs are included in the four Active Management Areas established by the GWMA of 1980. The two CGAs not included in the GWMA AMAs are the Douglas CGA and the Joseph City CGA.

in 1964 the U.S. Supreme Court decreed that Arizona had a right to 2.8 maf of river water.[9]

In 1968, legislation was passed by Congress and signed by President L.B. Johnson for the construction of the Central Arizona Project (Burton 1990, CAP 2005). This 336-mile aqueduct would import Colorado River water into central Arizona, thereby offering an alternative to groundwater pumping. CAP would give stability to Arizona's water supply so that future generations could enjoy the quality of life in the desert.

Although the CAP was authorized, groundwater management issues continued to complicate the prospects for the federal allocation of CAP funding. Groundwater transfers became a heated topic in the late 1960s and the 1970s. In the Jarvis cases, the City of Tucson wanted to transport groundwater for urban uses from Avra Valley and Altar Valley, two CGAs. In the Jarvis I case (1969), the Arizona Supreme Court declared the cities were enjoined from making remote withdrawals (Jarvis v. State Land Department, 104 Ariz. 527, 456 P.2d 385 [1969] "Jarvis I"). In the Jarvis II case (1970), the court modified its ruling to allow non-injurious off-site municipal withdrawals (Jarvis v. State Land Department, 106 Ariz. 506 479 P.2d [10970] "Jarvis II"). Tucson could purchase and retire farmlands in the valleys and transport the amount of groundwater historically used. In 1976, the court quantified these withdrawals in the Jarvis III case, allowing that amount of water being consumptively used at the site of extraction at the time the land was retired from agriculture (Jarvis v. State Land Department, 113 Ariz. 230, 550 P.2d 227 [1976] "Jarvis III").

In 1976, the Arizona Supreme Court ruled that mines could no longer withdrawal groundwater from neighboring lands when depleting a common groundwater resource if

[9] Of the 2.8 million acre-feet, 1.5 maf is now distributed to non-Indian agriculture in Arizona

the waters were transported away from the withdrawal site for use elsewhere (Farmers Investment Company (FICO) v. Bettwy, 113 Ariz. 520, 558 P.2d 14 [1976]). FICO was a victory for farmers and a defeat for the mines (Burton 1990).

Mines require much more water resources than the water available beneath mined lands, so in a counter-complaint, mining interests convinced the court to enjoin the city from out-of-basin groundwater transfers in excess of the amounts being transferred in 1972. Though the cities won the case, they still had to buy an entire farm at market value in order to gain the water rights, rather than just purchasing the water rights or the water itself, which severely restricted the planned activities of the City of Tucson (AGMSC 1980, Burton 1990). The court relied on the fact that groundwater was being transported for use outside of a critical groundwater area, and that groundwater could not be pumped from one parcel to another just because both overlied the common source of supply if the owner's land or wells suffered injury.

In reaction to the FICO case, cities took action to ensure adequate supplies of water for its people. For instance, the City of Tucson, seeking an additional water supply, purchased and retired a total of 12,000 acres of farmland in Avra Valley by 1978. The City of Tucson also budgeted $20 million to acquire three times that much land by 1985.

In 1977, a Groundwater Study Commission was created by the Arizona Senate to study the possibility of more comprehensive groundwater law reform. This commission included representatives from agriculture, mining, municipal government, Indian communities, electric utilities, and the Arizona Legislature (AGMSC 1980). Their primary responsibilities included: developing a means to reduce withdrawals, and providing methods for an equitable and dependable allocation of groundwater resources to meet the changing water needs of the State. The 1977 Commission was to prepare a Draft Report that developed a comprehensive groundwater management code for Arizona. Progress to meet these objectives continued through 1979.

The Groundwater Study Commission of 1979 (hereafter stated as "The Commission") had several different members than the Groundwater Study Commission of 1977 (Connell 1982). The Commission had five objectives for a state groundwater law. First, they desired clarification of conflicting groundwater rights claims, including transportation rights. Second, management of critical overdraft areas was needed. Third, they wanted the water used efficiently. Fourth, they desired management of growth needs. Finally, protection for the environment needed consideration (AGMSC 1980). The Commission, with its diverse group of people, experienced difficulty agreeing on issues pertaining to the sectors they represented. Many lengthy and heated discussions occurred during the process of writing the Draft Report to be submitted to the Governor and the state legislature.

The Jarvis and FICO cases caused confusion and uncertainty within the state. Cities and mines wanted as few restrictions as possible on both the acquisition of additional water rights and the transportation of extracted groundwater from distant pumping sites (Burton 1990). Cities did not want to be required to buy entire farms to gain additional water rights. Also, cities and mines were interested in effective conservation measures by agriculture. Agriculture argued that effective conservation measures were not economically feasible on the farm in many cases. Also, farmers wanted to be compensated for the loss of their water resources by legislatively tying a property interest in groundwater to property interest in farmlands. Agricultural producers wanted cities and mines to be forced to buy the farms in order to get the groundwater rights.

Within this uncertain state-level legal environment, the federal government imposed significant political pressure on the State of Arizona in the late 1970s. President Carter announced in February 1977 that he was considering the cancellation of the Central Arizona Project funding (Connall 1982). As a result, the Arizona legislature passed an Act in 1977 that included a provision allowing the commission's proposal to become law if the legislature failed to enact groundwater legislation by September 7, 1981 (AGMSC 1980, Connall 1982). In September 1979, Cecil Andrus, the Secretary of Interior in the Carter administration, threatened to not fund the CAP unless the state passed a comprehensive groundwater management code by the summer of 1980 (AGMSC 1980).[10]

2.2.2 GWMA of 1980

In response to Secretary Andrus's threat, the Groundwater Management Act (GWMA) was passed on June 11, 1980 in one hour and fifteen minutes with minimum debate and no amendments, the shortest special session in state history (Woodard 1990). It was a product of two and one-half years of work by the Arizona Groundwater Management Study Commission, which began in 1977. The Act was the first comprehensive groundwater management code in the State's history and was unique in the United States for its ambitious approach to groundwater management. The GWMA has won numerous

[10] The cost of the entire project, in the end, was four billion dollars, paid by the Federal Government with the stipulation that Arizona taxpayers would reimburse a portion of the cost (CAP 2005).

awards, including an award from the Ford Foundation and Harvard University (Woodard 1990, Scythe 2004).

The GWMA is a program that mandates five management plans during its implementation, each plan approximately ten years in duration. The GWMA requires each management plan to be progressively more stringent in hopes of solving the groundwater overdraft problem in the Active Management Areas (AMAs).

The GWMA created the Arizona Department of Water Resources (ADWR) for the purpose of statewide administration and management of the state's water. ADWR is led by a Director who is appointed by the Governor with the consent of the Senate. The Director has many responsibilities, including the development of a management plan for each Active Management Area prior to each management period.

The implementation of the GWMA is complex. Essentially, the Act's goal is to conserve water in all sectors. Cities and private water companies must meet conservation requirements by not utilizing more than their allotted amount, and may transport water within their service areas. Under certain conditions, transports may occur outside of the cities' sub-basins. Industries are required to use the latest conservation technologies and to use modest landscaping designs that do not use an excessive amount of water. Under the GWMA, Indian tribes are exempt from state regulation. Agriculture may only irrigate land that has an Irrigation Grandfathered Right (IGFR) within an AMA, and agriculture will conserve water by facing constraints in the quantity of water supplied to the grower, thereby encouraging the producer to adopt water conservation technologies and best management practices. The Arizona Department of Water Resources will monitor agricultural CAP water, and irrigation district-owned wells must meet the same requirements as individual-owned wells.

Prior to amendments, groundwater withdrawal fees, not to exceed $5.00 per acre-foot per year, were required by the GWMA to finance the Act. A portion of the withdrawal fee, between $.50 and $1.00 per AF per year, funded the administration and enforcement. Another portion, up to $2.00 per AF per year, supported the augmentation. If the management plan required the purchase and retirement of agricultural land, the last portion, $2.00 per AF per year, would be used for that purpose after 2006 (AGMSC 1980).[11]

In the following section, three main parts of the GWMA regarding agriculture will be discussed, though the GWMA includes many more guidelines than strictly with agriculture. These three topics are: Active Management Areas, Grandfathered Rights, and Flexibility Accounts.

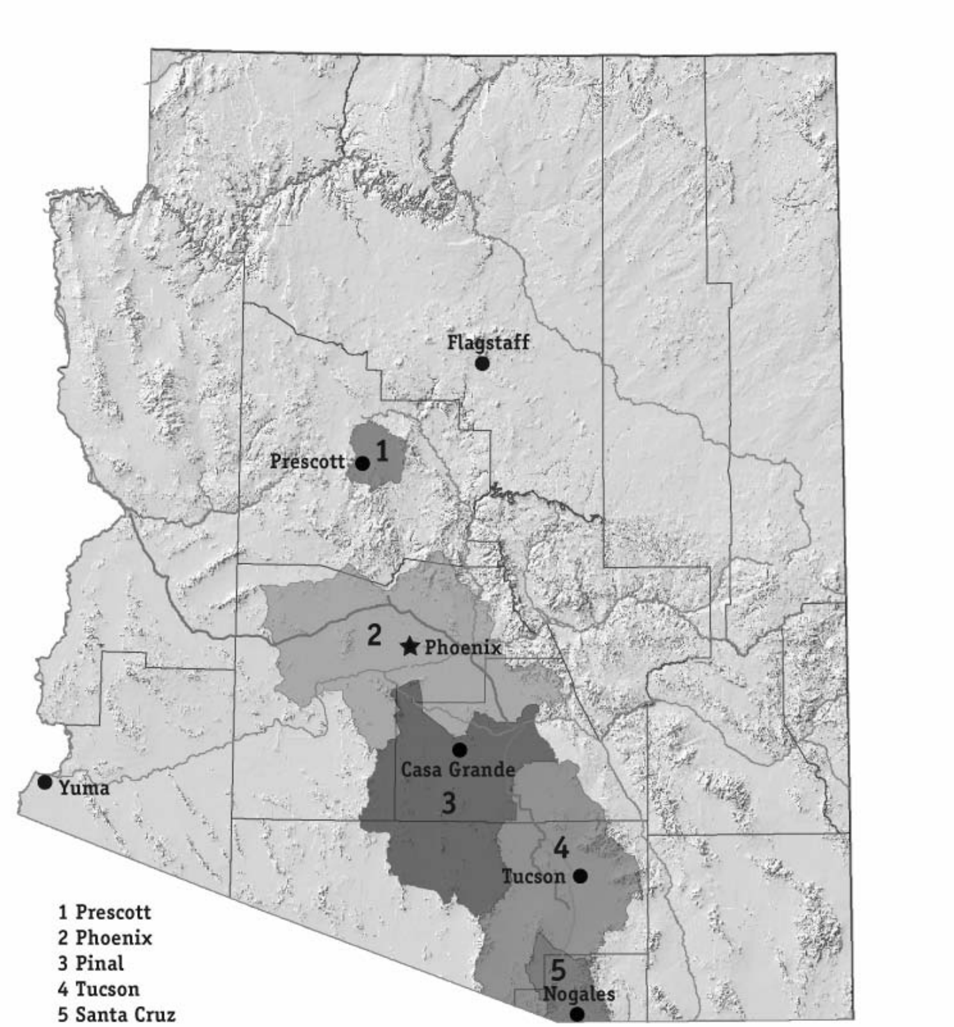
2.2.2.1 Active Management Areas

The GWMA established four initial Active Management Areas (AMAs) where the land was suffering from severe overdraft of groundwater, displayed in Figure 2.2.2.1. Three of the AMAs include Phoenix, Prescott, and Tucson where the goal is to reach safe yield by the year 2025.[12] In the Pinal AMA, the goal is to preserve the agricultural economy as long as possible, while reserving some groundwater supplies for non-irrigation uses. The Director may establish additional AMAs if it is determined that

[11] Following the amendments, the withdrawal fees currently include $2.50 per AF for water banking purposes, and $.50 per AF to support conservation assistance and water supply augmentation.
[12] The Santa Cruz AMA was split from the Tucson AMA in the mid 1990s. Safe yield is defined in the Code as groundwater withdrawn equal to water recharged.

preservation of groundwater supplies is necessary or use of groundwater has serious water quality implications.

Figure 2.2.2.1: Current Active Management Areas (AMA) in Arizona



Development of new irrigated acreage in an AMA is prohibited under the Groundwater Code. In the initial AMAs, only land that was irrigated between January 1, 1975 and January 1, 1980 may be irrigated. However, a person contracting for CAP water may apply to the Department to substitute, one for one, acres irrigated between

1975 and 1979 with acres irrigated between 1958 and 1968 in order to effectively use CAP water.

The Director is given the authority to make necessary adjustments so that water consumption in agriculture is reduced. The Code allows the Director to purchase and retire agricultural land after the year 2006 if progress toward the goal of "safe yield" is deemed insufficient (AGMSC 1980, Woodard 1990). In the third management period, 2000-2010, the Director had the jurisdiction to adjust the highest twenty-five percent of the growers' water duties within the AMAs to reflect the average water duties within that AMA (Connall 1982).[13]

More broadly, the Director is given authority to make adjustments in non-agricultural sectors as well. The ADWR Director is authorized to prohibit new residential land development in Active Management Areas (AMAs) unless the developer has an "assured water supply" for a period of 100 years. Until 1999, all cities that signed agreements for the delivery of CAP water were legislatively presumed to have an assured supply. After 1999, cities must now prove this 100-year supply.

2.2.2.2 Grandfathered Rights

The Code established three types of rights for groundwater consumption: irrigation grandfathered rights (IGFRs), non-irrigation grandfathered type I rights, and non-irrigation type II rights. The IGFRs allow the growers to irrigate their land and produce a crop, while the non-irrigation rights define quantities that may be used for non-irrigation purposes.

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[13] This provision was later amended in 1992 and again in 2002. It now provides that no water duty may be reduced to an amount less than a water duty computed using an irrigation efficiency of 80 percent (Laws 2002, Ch. 5, sec. 4, 6 and 8).

The GWMA allows grandfathered rights to be sold to new users as long as certain conditions are met.[14] The amount of the rights that can be sold depends on whether the sale is for irrigation use or non-irrigation use, and whether the farmer's irrigated land is inside or outside of the exterior boundaries of the service area of a city or private water company. Generally, a farmer may sell the right to use the maximum amount allowed by his irrigation grandfathered right to another farmer and up to three acre-feet per acre for a non-irrigation use. Since irrigation grandfathered rights are tied to irrigation acres, the farmer must sell irrigation acres in order to sell grandfathered rights (AGMSC 1980). In an AMA, a person may withdraw groundwater only in compliance with a grandfathered right or with a permit. Outside AMAs, any person may withdrawal groundwater for reasonable use (AGMSC 1980).

2.2.2.2.1 Irrigation Grandfathered Rights

An irrigation grandfathered right (IGFR) is the right to irrigate land for commercial agricultural production rather than the right to use a specific quantity of groundwater. The Code gives a formula for calculating the maximum amount of groundwater that may be used for a given grandfathered right. This set of equations is discussed in more detail in section 2.2.2.3

[14] A grandfathered right is a right to withdraw groundwater based on the fact that a person was legally withdrawing and using groundwater prior to the time an AMA is established.

2.2.2.2.2 Non-Irrigation Grandfathered Rights

The GWMA no longer requires non-agricultural users to buy whole farms in order to acquire additional groundwater rights. The law set guidelines how the groundwater is to be shared among agriculture, urban, and industrial uses based on the type of grandfathered right.

As previously noted, two types of non-irrigation grandfathered rights exist: type 1 rights and type 2 rights.[15] A type 1 right is based on retired irrigated land. If a user retires land legally, he may withdraw up to three acre-feet per acre per year. Type 2 rights are based on the user's historical withdrawals (1975-1979) of groundwater. Type 1 rights must be sold with the retired irrigated land they are based on, but type 2 rights may be sold apart from the sale of land.

Water transport may occur under the GWMA. The rules on water transportation are based on hydrological factors. Generally, groundwater may be transported between sub-basins of an AMA or away from an AMA (AGMSC 1980). Up to three acre-feet per acre of water may be transferred from a farm if the groundwater is withdrawn with grandfathered rights based on the retirement of land (type 1 rights). Transportation between sub-basins of a groundwater basin or away from a groundwater basin is allowed (type 2 right), subject to payment of damages (AGMSC 1980).

2.2.2.3 Flexibility Accounts

At the insistence of Leroy Michael, the farmer representative on The Commission, a system of flex accounts is included in the GWMA (AGMSC 1980, Connall 1982). The

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[15] A non-irrigation grandfathered right is a right to withdraw a specific quantity of groundwater for a non-irrigation use.

flex account system allows a producer to maintain the economic viability of the farm while, in theory, placing a constraint on the producer's water supply. ADWR measures annual water use by requiring flow meters on all wells and irrigation district-managed turnouts in all AMAs. If a farmer uses less water than the amount allotted in a given year, that grower can bank the difference in a flexibility account. This difference is referred to as a flex credit. A farmer may borrow from the flex account in years when the farm's water needs exceed the annual allotment in order to maintain the economic productivity of the farm. The maximum that a farmer's account may be in debt at one time is 50 percent of the current irrigation water duty, but there is no limit on the amount of credits that can be aggregately accumulated (AGMSC 1980).[16]

In the case of agriculture, the GWMA regulates water conservation by (1) not allowing the development of new agricultural land, and prohibiting the drilling of new, non-replacement wells in the AMA without the Director's approval, and (2) a series of management plans that gradually reduce the quantity of water available to the grower in a given year. The annual water allotments (A) represent the amount of water a grower can use from wells and/or surface supplies, where:

(1) $$A = W * L$$

and

(2) $$W = (I/E)$$

A grower's on-farm efficiency may be calculated by:

(3) $$E = CWR/w$$

[16] Beginning in the Historic Cropping Program (Second Management Plan), the credit balance in a flex account may not exceed 75 percent of the farm's annual allotment in a given year (ADWR 2003).

From (1) and (2) above, W is the irrigation water duty (the quantity of water determined by the Director to be reasonable to apply to an acre of land, assuming conservation practices), and L is the highest number of acres farmed during the period of January 1, 1975 to January 1, 1980 (i.e. water duty acres).

The annual irrigation requirement per acre for the crops grown on the farm during this same period is I. In the Pinal AMA, the average irrigation requirement was set at 3.15, and it varied depending on the crop grown between 1975 and 1979. The irrigation requirement was calculated by the consumptive use requirement of the crop (including transpiration and evaporation), plus other needs such as germination moisture, plus a leaching allowance which may be necessary to prevent salt accumulation in the root zone (ADWR 2003). Table 2.2.2.3 shows the consumptive use for the four most prominent crops in central Arizona.

Table 2.2.2.3 Consumptive Use Requirements by Crop for Pinal County

Crops	Consumptive Use (AF/ac)
Alfalfa	4.06
Barley	2.08
Cotton	3.43
Wheat	2.15

Source: ADWR 2003.

The assigned irrigation efficiency is symbolized by E in the equations.[17] To calculate if the grower is achieving the efficiency rate, CWR is the crop water requirement and w

[17] A farm's optimal irrigation efficiency depends primarily on the slope of the fields and the soil's characteristics, such as uniformity, intake rates, and water holding capacity (Cory 1992).

is the actual volume of water applied. ADWR does not actually measure a grower's efficiency and a grower is not required to achieve this efficiency, but an assigned efficiency rate is used to calculate the water allocation (e.g. 75%). ADWR had policy discretion over the two variables, E and I, used to establish the annual water allotment. An average irrigation efficiency of 65% was established in this first period in the Pinal AMA, with the expectation that E would increase in the second (1990-2000) and third (2000-2010) management plans, and the increase would depend partially on soils and slopes of the land ("Areas of Similar Farming Conditions" as described in ADWR 2003).[18] By increasing E, ADWR expected to induce growers to adopt water-conserving irrigation practices as their water allotment declined.

A grower is given the freedom to reach the water duty in any way he chooses, including adopting new irrigation techniques, irrigating fewer acres, or increasing overall farm efficiency. Farmers can request a variance, which is a five-year delay in the reduction of water duties due to financial hardship (AGMSC 1980). By the early 1990s, roughly one-third of the farmers in the Phoenix AMA affected by the GWMA requested an administrative review (Cory 1992).

2.2.3 GWMA Immediate Effects

Since the GWMA contains an emergency clause and was passed with greater than two-thirds majority in the State legislature, it became law immediately upon the signature of the Governor. The Act was approved by a 23 to 5 vote in the Senate and 50 to 8 in the House of Representatives (AGMSC 1980).

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[18] ADWR believes the 85 percent efficiency can be achieved by installing level basin irrigation systems and by using best water management practices (ADWR 1991). The Third Management Plan established an efficiency range of 75-80% for all AMAs, except the Phoenix AMA was set at 70-80%.

The mines and large cities benefited with the passage of the GWMA. The GWMA assured the mines additional water for their operations without having to buy farms, and the Act made it easier to transport extracted groundwater. Contrary to pre-GWMA law, large cities now can obtain additional groundwater simply by extending their service areas.

Governor Babbitt was sympathetic to mining interests for two reasons. The locations of mineral resources dictated where mining activities had to take place (Connall 1982). Also, mining showed a greater profitability per unit of water deployed than agriculture (AGMSC 1980). With the farming practices in 1987, agriculture used about 30 times more water per year than the mines in Arizona (Burton 1990).

Farmers found themselves more constrained with the GWMA. The GWMA authorizes the sale of only three acre-feet of groundwater per irrigated acre of farmland per year for non-agricultural uses (type 1 rights), rather than selling as much water as they can pump. Despite the limitations, some farmers supported the GWMA because they needed the CAP water in order to remain in business given increasingly costly groundwater pumping lifts (Burton 1990).

Due to the fear that agriculture would gradually erode the conservation requirements via the courts, the cities and mines inserted a non-severability clause to the GWMA that declared the entire act void if the courts found any portion of the GWMA unconstitutional (AGMSC 1980). Non-severability clauses are common in groundwater legislation because they ensure that the courts do not alter the compromises developed through negotiations (Connall 1982). To date, the GWMA remains constitutional, but it has been amended numerous times in its twenty-five year history as political and economic conditions warrant in Arizona.

2.2.4 Amendments to the GWMA

Several significant Amendments have been passed regarding agriculture since the passage of the GWMA. These amendments include matters concerning flex account credits, water duty calculations, and alternatives to the base management plan that requires conservation at least equivalent to the base plan.

The flex account system has been modified three times since the GWMA was passed in 1980. The amendments allowed an owner of a farm within an irrigation district to convey or sell all or part of his flex credits acquired from the previous year to the flexibility account of other farms. In the 1991 amendment, the flex credits could be conveyed or sold to another farm within the same irrigation district. The 1998 amendment allowed these credits to be conveyed or sold to a farm outside of an irrigation district if the two farms were in the same groundwater sub-basin. Finally, a third amendment was passed in 2002 that allowed the flexibility account credits to be conveyed or sold to the flexibility account of a farm located outside of the irrigation district (and vice versa) if both farms were owned or leased by the same person.

Water duty calculations were modified slightly with the passage of two amendments. In 1998, statutes were added requiring the director to include an historic cropping program in the Third, Fourth and Fifth Management Plans as an alternative to the base agricultural conservation program. Under the historic cropping program, irrigation water duties were calculated in the same manner as in the base program, but the director used an irrigation efficiency of 75 percent in areas without limiting soils and 70 percent in areas with limiting soils. Also, a grower using groundwater on a farm enrolled in the program was to comply with performance standards established by the director. Finally, a grower using groundwater on a farm enrolled in the program could not accumulate flexibility account credits in excess of 75 percent of the maximum annual groundwater allotment. The grower could not accumulate debits that exceeded 25 percent of the maximum annual groundwater allotment and could not sell or purchase flexibility account credits from other farms. The statutes also authorized, but did not require, the management plans to provide additional alternative agricultural conservation programs that would achieve conservation at least equivalent to the base program. In 2002, an amendment stated the irrigation water duty should be calculated using an irrigation efficiency of 80 percent, but an efficiency less than 80 percent could be used if the farm had limiting soils or excessive slopes.

Besides the Historic Cropping Program, another alternative to the Base Program was offered in 2002 for the third, fourth, and fifth management periods. An amendment required the third management plan to include a best management practices program that offered an alternative to the base program. The BMP Program was to achieve conservation at least equivalent to the requirement by the base program. The best management practices program required the implementation of specific agricultural conservation practices on the farm in lieu of an irrigation water duty and maximum annual groundwater allotment.

3. EVALUATION OF THE GWMA

To the knowledge of the author, no formal, non-ADWR evaluation of the agricultural water conservation program has been conducted during the GWMA's 25-year implementation period. Most reflections on the agricultural provisions of the GWMA are descriptive and fail to quantify in any way the program's success in promoting water conservation. One economic evaluation effort, using a mathematical programming model to simulate expected water use in the agricultural sector, concluded that neither improved water conservation practices or technologies, or agricultural land retirement, would assure safe yield in 2025 as hoped by the GWMA (Cory et al. 1992). Despite this study, to our knowledge no external assessment of the impact of the GWMA on agricultural water use exists today. Impact assessment, by definition, is an evaluative study that answers questions about program outcomes and impact on the social conditions it is intended to ameliorate (Rossi 2004). This chapter outlines a mixed-method framework for evaluating the impact of GWMA regulations on water use in central Arizona's agricultural sector.

3.1 Impact Assessment Literature

Program evaluation is a social science tool that systematically analyzes the effectiveness of program performance, the outcomes relative to program goals, or both. Evaluations are conducted for a myriad of reasons, among them (1) outcome assessment, (2) implementation improvement, (3) oversight, and (4) knowledge generation. Generally and ideally, the stated goal of evaluations is some form of future social improvement, either directly or indirectly. The overall scheme of evaluation tools contains many evaluation approaches, methods, and purposes (Mark et al. 2000).

Stufflebeam analyzed and ranked 22 widely-used evaluation models. He concluded that eight approaches ranked “very good” and should receive preference in 21st century evaluations. Of these eight methods, five of them will be discussed and applied, at least partially, in this impact assessment. These five methods are included in the broad categories of improvement/accountability, social agenda/advocacy, and questions/methods.

Under the improvement/accountability group, decision/accountability evaluation methods are recommended for 21st century evaluations. This method judges the merit or worth of a program, such as conservation programs. The procedure focuses the evaluation so that the most important and relevant questions are asked, and information collected by the evaluation helps to assist the decision-making. It also produces an accountability record. The program’s goals and priorities are defined, allowing the evaluator to ask if the program is working or if it needs to be revised. The purpose of this type of evaluation is to improve, rather than to prove, the effectiveness of the program. It provides a framework for both internal and external evaluation. Since the results may be biased if the program is politically charged, this method may be used in conjunction with case studies, interviews, or several other methods.

Two evaluation methods, utilization-focused and client-centered/responsive, are included in the social agenda/advocacy category. Patton’s (2001) utilization-focused method is geared to maximize program evaluation impacts. The studies are judged for the differences made to improve the program. This method builds social capital by valuing the evaluation process because it enhances shared understandings among stakeholders and strengthens the organizational capacity. This method is relevant with all other evaluation methods. The third method of the five applied in this analysis, the client-centered/responsive evaluation is primarily qualitative in nature and it triangulates qualitative data to find common themes. The evaluator continuously interacts with a client group, such as teachers, government officials, legislature, and managers in the field to understand the perspectives of the various groups to identify the program's strengths and weaknesses. Generally, the client group wants to know what the program achieved. The end goal is program improvement, but this method does not seek a final authoritative conclusion even though side effects and incidental gains are identified. In combination with the client-centered/responsive evaluation method, the case study method may be employed for consistent findings.

Questions/methods evaluations include two prominent evaluation techniques for pertinent assessments. The case study evaluation illuminates the program while outcomes monitoring/value added evaluation provides direction for future policy-making. A case study assessment triangulates multiple perspectives, methods, and information sources, similar to the client-centered/responsive method. It is highly appropriate since it offers checks and balances among both qualitative and quantitative data. This method analyzes the program in geographical, cultural, organizational, and historical contexts either as it is occurring or as it had occurred in the past. It observes central themes as well as intended and unexpected outcomes. The primary purpose of case studies is to provide authoritative, in-depth, well-documented explication of the program rather than judging the worth of the program. The final method, outcomes monitoring/value added evaluations assess trends to provide direction for policy-making and to provide feedback for future improvement. It values each entity, but the main interest is at the aggregate rather than the individual level. This method offers means to improve outcomes by reporting the results for policy, accountability, and improvement purposes. The outcomes monitoring/value added evaluations are typically politically volatile and rely heavily on quantitative data. However, when this method is used with other evaluation techniques, the impact assessment can prove to be very stable.

Published evaluations by economists of agricultural water conservation programs in the U.S. are limited in number and scope. Most of the professional literature focuses exclusively on technology adoption at the firm level utilizing standard benefit-cost analysis methods (Caswell and Zilberman 1986; Coupal and Wilson 1990; Anderson, Wilson and Thompson 1999). Adoption decisions of water conserving technology depend, according to this literature, on appropriate soil conditions, increments in yield, water savings, and the availability of investment resources. Only in rare circumstances do evaluators forecast potential water savings in the sector associated with these technologies (Ayer, Wilson and Snider 1984). Evaluations of ongoing, public-supported water conservation programs, on a program-wide basis, are strikingly absent in the public domain.

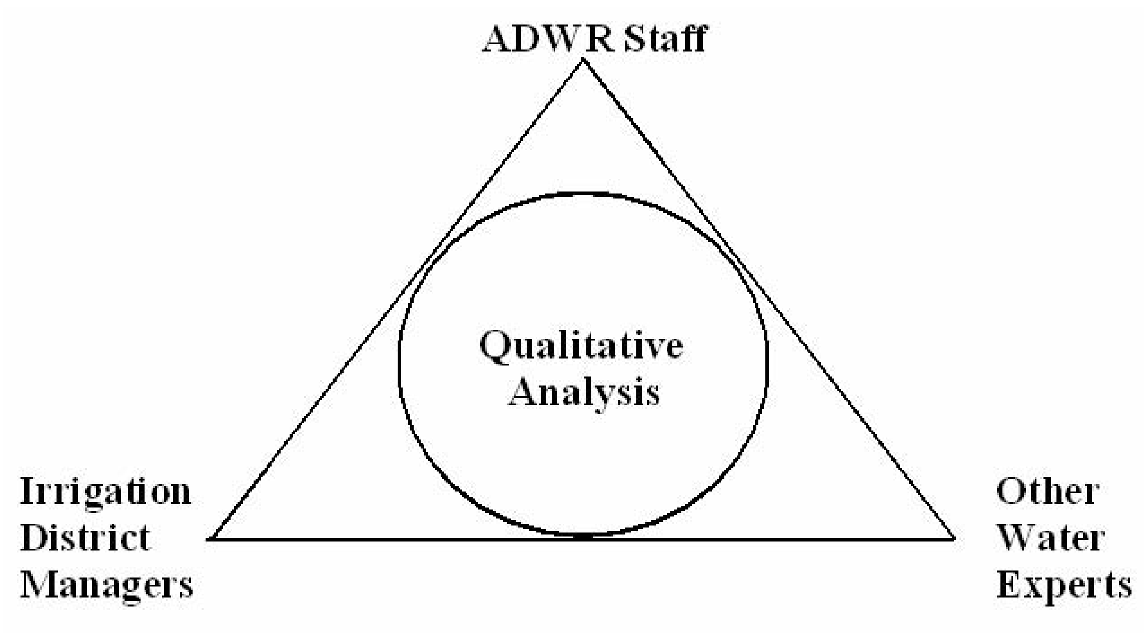
3.2 Impact Assessment

The mixed-method evaluation of the agricultural water conservation component of the GWMA combines qualitative and quantitative causal analysis to assess program outcomes. A more accurate label for the evaluation design is impact analysis or impact assessment. The analysis is limited to program impacts, largely avoiding the greater question of whether these impacts justify the agricultural provisions of the GWMA. A complete benefit-cost analysis of GWMA's agricultural programs would far exceed the financial and time resources of this assessment effort.

Denzin's (1978) triangulation approach to program evaluation characterizes the mixed-method impact analysis. Triangulation inherently contains checks and balances for the analysis giving the evaluation greater strength and rigor than single method evaluations (Patton 1987). According to Patton, four types of triangulation exist. First, data triangulation uses a variety of data sources in a study, such as interviews. Second, investigator triangulation uses several different evaluators or social scientists. Third, theory triangulation interprets a single set of data using multiple perspectives. Finally, methodological triangulation uses multiple methods to study a single problem or program (e.g. interviews, observations, questionnaires, and documents).

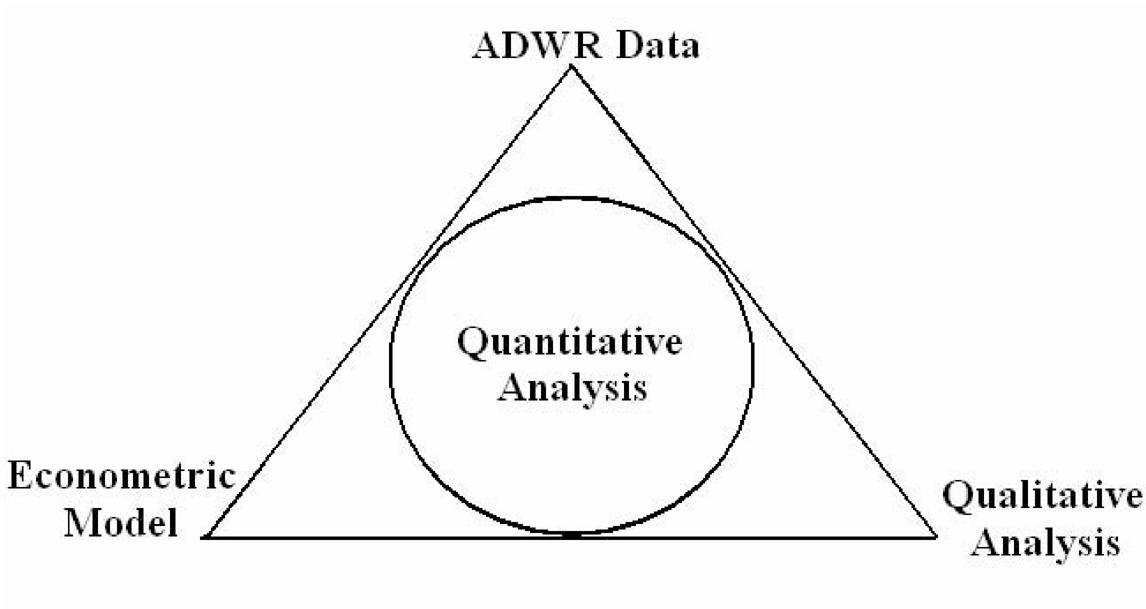
This impact analysis design utilizes Denzin's triangulation types. The qualitative analysis uses data triangulation and theory triangulation. In-depth, open-ended interviews were conducted of people from different backgrounds, affiliations, and points of view. Two analysts interpreted the results and multiple peers reviewed the findings. Theory triangulation is evident in the effort to explore alternative explanations for outcomes in the agricultural water conservation programs. Figure 3.2-1 captures the qualitative triangulation design. For the impact assessment, qualitative data flowed from Arizona Department of Water Resources staff, irrigation district managers, and other recognized water experts in the state. A list of the professionals interviewed can be found in Appendix A-2.

Figure 3.2-1: Data Triangulation Design for Qualitative Impact Analysis



These qualitative results are then used as checks and balances for the quantitative assessment, shown in Figure 3.2-2. The qualitative findings and ADWR data are compared with the econometric analysis results to strengthen the impact assessment. In the econometric analysis, ADWR water use data and irrigation district water prices are combined with other economic variables to estimate water demand by each irrigation district from 1984 to 2002. By including various methods in the quantitative analysis, greater assurance may be given from the conclusions drawn in the methodological triangulation.

Figure 3.2-2: Methodological Triangulation Design for Quantitative Impact Analysis



According to Patton, triangulation is ideal and is highly recommended. However, it requires many resources, which creates challenges since most research involves limited budgets, short time frames, and political constraints.

3.2.1 Qualitative Assessment

Fieldwork is the central activity of qualitative evaluation methods. Qualitative approaches emphasize the importance of interacting with the people and situations being studied in order to understand personally the realities of daily program implementation. Utilization-focused and case study evaluation methods allow the evaluator to gain deeper understandings of the people and situations through physical proximity as well as in the social sense through shared experience and confidentiality.

Responses to open-ended questions form the foundation of the qualitative analysis (Patton 1987). Three identical questions were directed to individuals representing the three groups in Figure 3.2-1. The questions were:

1. In your opinion, has the 1980 Groundwater Management Act been an effective policy for agricultural water conservation? Why or why not?
2. If it had been your responsibility, how would you have designed a GWMA in the year 1980 to promote agricultural water conservation?
3. In your judgment, how could the current water conservation program in agriculture be improved?

Interviews were conducted with ten irrigation district managers, eleven ADWR staff, and nine other water experts. In most cases, a two-person team conducted each interview. One team member acted as a recorder while the other maintained eye contact with the interviewee and moved the discussion along. At the end of each session the team members synthesized their findings and wrote up the results. Interviews were thirty minutes to three hours in duration.

The qualitative assessment is imperative in this particular study. Many lessons and observations can be detected through the interviews that the quantitative assessment may not reveal. For instance, as discussed in section 3.2.2.2.1, slow changing variables may appear to be statistically insignificant while the variable may be substantially significant. Urbanization could be an example. Though the model does not explicitly include an urbanization variable, urbanization is slowly changing the amount of agricultural water being consumed. Therefore, through the qualitative analysis, urbanization and other implicit variables may be recognized while quantitatively these factors may not be observed.

3.2.2 Quantitative Assessment

A quantitative assessment strengthens the qualitative assessment by statistically revealing causal relationships and removing biases from the individuals' views. Quantitative analysis is a method commonly used to quantify the amount of impact or effectiveness a policy has achieved. Quantitative analysis also can aid the evaluator in determining methods of policy improvement and future directions towards social gains if any adjustments need to be made (client-centered/responsive, outcomes monitoring/value added evaluation methods).

3.2.2.1 A Conceptual Model

Nearly all of the farms in Arizona are businesses that desire to maximize profits. The Cobb-Douglas function, a quantitative description of various technical production possibilities faced by a firm, is a good approximation for agricultural production processes (Beattie 1993). This analysis assumes that the farmers' production function is Cobb-Douglas with one factor of production, water, and that the farmers operate under perfect competition and desire to maximize profits in their farming operations. The demand for water

$$W^* = W^*(\mathbf{p}, w, P, T) \qquad (6)$$

is a function of the relative input prices of water (w), the output prices (**p**), precipitation (P), and temperature (T). One would expect from (6) that water demand would fall (increase) as water became more expensive (cheaper) relative to other inputs. These hypotheses are extended to irrigation districts that supply all or some of the water demanded from growers by gathering water use, price, and weather data for eleven irrigation districts in the three AMAs for the period 1984-2002. This pooled cross-section and time series data represent panel data for econometric analysis (Baltagi 2001).

3.2.2.2 Panel Data

Panel data has the benefit over cross-section or time-series data in that it controls for individual heterogeneity. Panel data produces more information, more variability, less collinearity, more efficiency, and more degrees of freedom than the other types of data series (Baltagi 2001). Finally, panel data allows the researcher to study the dynamics of adjustment.

A panel data regression differs from regular time-series or cross-section regression because of a double subscript on the variables. The general probability model for panel data is:

(7) $P(y_{it}) = g(\beta_i, x_{it}, \varepsilon_{it})$ where

p(.) = the probability density function of the observed random dependent variable, y_{it},

i = 1, . . . , N denotes the i^{th} group or individual,

t = 1, . . . , T denotes the t^{th} time period,

x_{it} = an observed vector of independent variables,

β_i = the parameter vector the i^{th} group or individual,

ε_{it} = the stochastic component of the model, and

g = the density of the observed random variable conditioned on the arguments.

The error term contains the effects of the unobserved variables (also referred to as unobserved components, latent variables, and unobserved heterogeneity). Fixed effects are due to omitted variables that are specific to cross-sectional units or time periods. In the equation, if a portion of the error (the time invariant error not included in the regression) is fixed, then the model becomes a fixed effects model.

3.2.2.2.1 Fixed Effects Model

Fixed effects models are used if one wants to make inferences to observed units. In other words, the fixed effects model assumes that the entire population of interest is vested in the data. The fixed effects model introduces very little heterogeneity, and consists of dummy variables for each cross-sectional and/or time-invariant variable (Beck 2001, Greene 2003).

The fixed effects model of the panel data formulation

$$(8)\quad y_{it} = \alpha_i + \beta' x_{it} + \varepsilon_{it} \qquad i = 1, \ldots, N; \; t = 1, \ldots, T$$

assumes that common slopes exist but each group has its own intercept (α_i), and the intercepts may not be correlated with the Xs. The fixed effects estimator is an ordinary least squares (OLS) regression of means-differenced variables (a.k.a. within-group estimator).

One quandary with the fixed effects model is that the model soaks up most of the explanatory power of the slowly changing variables (Beck 2001). As a result, the slowly changing variables may not appear either substantively or statistically significant. Hence, this model does not estimate the effect of any time-invariant variable, which is a key point for this analysis of the GWMA.

A one-way fixed effects model exists when the error components depend solely on the cross-section to which the observation belongs. A one-way fixed effects model specifies $\varepsilon_{it} = \upsilon_i + \mu_{it}$; where ε_{it} is the stochastic component of the model, υ_i symbolizes the unobservable individual specific effect (the time invariant error not included in the regression used to capture the heterogeneity across sections), and μ_{it} represents the remainder disturbance which is the error within the regression (Baltagi 2001). The error component υ_i can either be non-random or random. Non-random components are fixed effects whereas random components are random effects. In this research effort, the error components are random when the assumption is made that the irrigation districts in the study do not represent the entire agricultural industry in Arizona. Also, this random effects assumption concludes that the irrigation district decisions influence other irrigation districts' actions.

3.2.2.2.2 Random Effects Model

Random effects models allow an analyst to study the entire population. A sample of the total population may be drawn and can be observed with a random effects model so that conclusions can accurately be made regarding the whole population. Random effects assumes the effects are drawn from some distribution. As the sample size increases, the results of random effects tend toward becoming a "fixed effect" since a larger sample of the entire population is being represented in the model.

The random effects model features an error term with two components

(9) $y_{it} = \alpha + \beta' x_{it} + \upsilon_i + \mu_i$

where υ_i is uncorrelated with ε_{it} , and μ_i is an error term representing the degree to which the intercept of the i^{th} group differs from the overall intercept (Kennedy 1998). Intercepts are drawn from a common distribution of the random effects estimator, and the random effects estimator is approximated with generalized least squares (GLS). Since the error term is random, a particular "fixed" effect over time or group is not expected.

3.2.2.2.3 Panel Data Tests

Fixed and random effects models differ slightly, and they must be tested to determine which model is a better representation. The major difference between the random and fixed effects model is that the random effects model treats the group or individual effects as uncorrelated with the other variables in the model while the fixed effects formulation does not impose this assumption. For this research, a fixed effects assumption implies that the irrigation districts, individual years, and all the variables in the model may not be correlated with each other, while a random effects model does not impose this assumption. To determine whether a fixed or random effects model is appropriate, F- and Hausman tests can be used.

3.2.2.2.3.1 F-Test

The F-test is performed assuming a fixed effects model. The F-test is used to jointly test the significance of sectional (an irrigation district) specific effects in a one-way fixed effects model. The null hypothesis is $H_0 : \upsilon_i = 0 \ \forall \ i$, where υ_i is the specific effects of the series.

For a one-way fixed effects model, the test statistic is

$$F = ((RSS_R - RSS)/N) / (RSS/(NT - N - K))$$

Given the null hypothesis, the F-distribution has degrees of freedom equal to the deflators in the numerator and denominator. The RSS_R and RSS are the residual sum of squares from the restricted and unrestricted models respectively, and K is the number of explanatory variables.

A large F-test statistic indicates that the null hypothesis shall be rejected, and indicates individual specific effects and time effects. Therefore, if the fixed effects model is used inappropriately, conclusions drawn from these models will be misleading and incorrect due to the omitted variable bias caused by the unobserved effects since the assumption of υ_i is presumed to be fixed when in reality it is random.

3.2.2.2.3.2 Hausman Test

Hausman's specification test is commonly used to test whether a fixed or random effects model should be used. The null hypothesis, $H_0 : E(\varepsilon_{it} \mid X_{it}) = 0$, suggests no correlation between the unobserved sectional (irrigation districts) random effect variables and the regressors. Under this null hypothesis, the correlations of the random effects with the regressors are consistent and efficient. The correlations will be insignificant if no statistically significant difference occurs between the covariance matrices of the two models. The number of explanatory variables, K, is the degrees of freedom, where

$$m = (\hat{\beta}_{FE} - \hat{\beta}_{RE})'[Var(\hat{\beta}_{FE}) - Var(\hat{\beta}_{RE})]^{-1}(\hat{\beta}_{FE} - \hat{\beta}_{RE})$$

This equation result is asymptotically distributed as a chi-square (Baltagi 2001). If the null hypothesis is rejected, the fixed effects model is more appropriate.

3.2.2.3 Panel Data Model

In the assessment, the following panel data model is estimated

$$(10)\ \ln w_{it} = \alpha_i + \beta_1 \ln (wp_{it}) + \beta_2 \ln precip_{it} + \beta_3 \ln temp_{it} + \beta_4 \ln alfp_t + \beta_5 \ln barp_t + \beta_6 \ln cotp_t + \beta_7 \ln whep_t + \beta_8\, GWMA_2 + \beta_9\, GWMA_3 + \varepsilon_{it}$$

where w is the water purchased and pumped in the i^{th} irrigation district (i = 1,…,11) in year t where t is 1,…,19 (1984-2002). The price paid for irrigation water by the grower is *wp*. The expected sign is negative because water purchased decreases as the price of water increases due to the profit maximization assumption for the firms. *Precip* represents the annual rainfall in i^{th} district in year t. Precipitation is expected to have a negative sign because the more it rains, the less irrigation water is needed. *Temp*, the average temperature during the growing season March to September, will have a positive sign since plants use more water as temperature increases. Alfalfa (*alfp*) and cotton (*cotp*) prices are expected to have a positive sign since alfalfa and cotton are high water users.[19] A higher alfalfa or cotton price will yield more acres planted to alfalfa or cotton causing more water to be purchased. On the contrary, the prices of wheat (*whep*) and barley (*barp*) are expected to be negative following the same logic. $GWMA_2$ and $GWMA_3$ are dummy variables for the implementation periods of the second and third management plans, respectively, of the GWMA of 1980. If agricultural water consumption has declined in Arizona over the course of this analysis, the coefficients for both management periods will be negative and significant.

This panel data allows the ability to conduct statistical analysis of water demand across time in 11 irrigation districts. With structural, institutional and operational

[19] In Maricopa County, the amount of water applied per acre to each crop in 1998 was: alfalfa 7 ½ AF, barley 2 AF, Durum Wheat 2 1/3 AF, and Upland Cotton 5 AF (Teegerstrom 1999).

knowledge of these districts, partial explanation of the variation in water demand across districts is possible. Secondly, the modeling framework provides the opportunity to test the significance of the GWMA on agricultural water demand, controlling for other factors such as economic conditions or weather.

3.2.2.3.1 Explanation of the Data

The panel data used for this analysis of the GWMA involves non-tribal agriculture in three counties in Arizona: Maricopa, Pima, and Pinal. These three counties represent a large portion of the agricultural land in Arizona, and include the Phoenix Active Management Area (AMA), Tucson AMA, and Pinal AMA respectively. Within these AMAs are numerous irrigation districts, but eleven of the largest agriculturally concentrated irrigation districts are analyzed. As the panel data model suggests, the irrigation districts are represented by the i^{th} subscript in the model. The selected irrigation districts represent 69% of the agricultural acreage in the three Active Management Areas (AMAs).[20] These districts vary in scope, from 12,000 acres to 88,000 acres. The districts, listed by county, are shown in Table 3.2.2.3.1.

[20] Note that the respective AMAs do not include the entire county agricultural acres.

Table 3.2.2.3.1 Approximated Percent of Irrigated Area Represented by the Irrigation Districts Analyzed in the Model

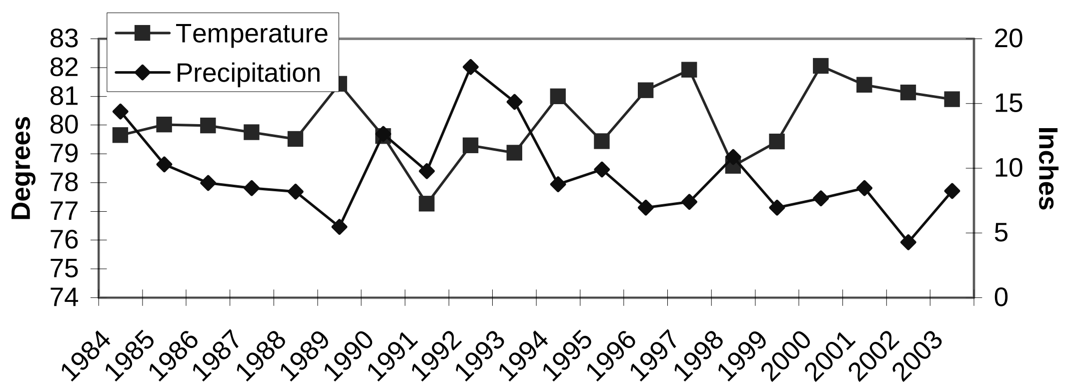
	Irrigated Area (% of County IA)
Maricopa County	
1. Buckeye Water Conservation and Drainage	6
2. New Magma Irrigation and Drainage	10
3. Queen Creek Irrigation and Drainage	5
4. Roosevelt Water Conservation	8
5. Roosevelt Irrigation	13
6. Salt River Project	20
	62
Pima County	
1. Cortaro-Marana Irrigation	32
Pinal County	
1. Central Arizona Irrigation and Drainage	31
2. Hohokam Irrigation and Drainage	8
3. Maricopa-Stanfield Irrigation and Drainage	31
4. San Carlos Irrigation and Drainage	19
	90

Source: ADWR and USDA-NASS (see Appendix A-3)

As stated in the previous section, the dependent variable in the model is water purchased and pumped in agriculture within the AMAs. The data was collected from the Arizona Department of Water Resources. Although records vary between AMAs within the department, the data used in this analysis specifically came from the Tucson office.

The independent variables capture various market factors such as input and output prices and weather. Crop prices for alfalfa, barley, durum wheat, and upland cotton were obtained from the USDA statistical service (USDA-NASS, various years). The weather variables temperature and precipitation were gathered through the National Oceanic Atmospheric Administration (NOAA 2005). The station selected for each irrigation district is listed in Appendix A-4. Temperature figures are the average temperature during the growing season, March to September. Precipitation is the total annual precipitation. As the following graph shows, average growing season temperatures and annual precipitation appear to have an inverse relationship, posing a potential problem with autocorrelation.

Figure 3.2.2.4.1 Average Weather in Irrigation Districts



Source: NOAA 2005

Weighted water prices are challenging to obtain, and the calculations vary for each irrigation district because each district has their own pricing system depending on the types of water available to the growers (see Appendix A-3 for a summary of each district). Essentially the weighted water price (W) is computed using

$$W = (\sum (\alpha_w * p_w)) / (\sum \alpha_w)$$

where α_w is the quantity of each type of water (i.e. CAP water, groundwater, effluent, on-season, off-season, etc.) and p_w is the price of the types of water respectively. The variable cost of groundwater is estimated using the following formula:

$$GW = ((\chi * \gamma) / \delta * \phi) + (\eta * \gamma) + \rho$$

χ represents the kilowatt-hour to lift one acre foot of groundwater one foot at 100 percent efficiency (Hathorn, Daugherty, various years). The feet of lift (depth of the water table) is γ. The standard efficiency rate (δ) is 54%, and the power cost per kilowatt-hour is ϕ. This gives the total energy cost to pump an acre foot of groundwater. The cost of repairs per foot of lift (η) multiplied by the feet of lift (γ) yields the total repair cost per acre foot of groundwater. Add the energy and repair costs to the pump tax (ρ) and the variable cost of groundwater (GW) per acre foot results. Power cost data is gathered from irrigation districts and power companies. The pump tax is provided by ADWR.

4. RESULTS

4.1 Qualitative Results

The results of the qualitative assessment demonstrate a number of common themes. The GWMA is a public relations policy in part. As noted in chapter 2, the legislation was passed to resolve emerging legal conflicts. The Secretary of the Interior's threat and the physical reality that Arizona was over-pumping groundwater in certain areas also prompted the passage of the GWMA. The GWMA is beneficial to Arizona in some instances, and in other cases the Code has not accomplished its objectives in the agricultural sector. The GWMA impacted water conservation the moment the policy became law according to the interviewees. However, since its passage in 1980, the impact of the Act's operational programs has been minimal due to an ineffective design.

4.1.1 Initial Impact of the GWMA

The Groundwater Management Act had a beneficial initial impact on water conservation in the agricultural sector. Some of these positive aspects were expected, and other aspects were unforeseen. The major and minor findings of these positive impacts are grouped into three main categories: Agricultural Land Constraints; the Central Arizona Project; and Awareness, Perceptions, and Measurement. The following sections discuss each category in greater detail.

4.1.1.1 Agricultural Land Constraints

The GWMA set a constraint on irrigated agricultural land in the AMAs. The amount of land that could be farmed was limited by not allowing any new raw desert land to be brought into production. Also, no new non-replacement irrigation wells could be drilled within the AMAs (AGMSC 1980). Most interviewees agree that this was the only constraint, and successful water conservation effort, that the GWMA established for the agricultural sector. A minority of respondents counter that it has been cost prohibitive to convert raw desert land to agricultural land since 1980 and claim the clause in the policy limiting agricultural land may not have made much of a difference in water conservation.

4.1.1.2 Central Arizona Project

Some of the individuals interviewed acknowledge that the GWMA is a federal-induced policy. The main motive for the passage of the GWMA was a direct response of Secretary Andrus's threat to the Arizona legislature. As indicated in chapter 2, Andrus boldly stated that Federal funding to support the Central Arizona Project canal system would end unless a policy to manage the state's waters was passed by the summer of 1980. As a result, the GWMA was passed in June of 1980.

Although construction for CAP began in 1973 and was a 20 year project, the passage of the bill in 1980 prompted the federal government to continue funding the CAP allowing the Colorado River water to be channeled to central Arizona to help alleviate the overuse of groundwater. Beginning in the early 1990s, low-cost CAP water offered a substitute to growers pumping groundwater (Wilson 2002). With the utilization of CAP water, groundwater has been conserved and possibly even recharged in part by the deep percolation of CAP irrigation water. All respondents note that CAP has conserved a significant amount of groundwater in the irrigation districts.

The Central Arizona Project has had other positive effects for producers. Some growers would not have been able to stay in business without CAP water because their dropping water tables in the 1980s created high-cost pump groundwater. Most notably, this occurred in eastern Maricopa County when groundwater tables dropped below 600 feet. The CAP allowed the growers to continue farming while simultaneously conserving the groundwater.[21]

4.1.1.3 Awareness, Perceptions, and Measurement

Most individuals consulted agree that the passage of the GWMA has changed society's perspectives toward water, and has increased their awareness of the quantity of water being consumed in agriculture. Farmers and other individuals routinely attend water forums and meetings to educate themselves on water issues in the local communities, which has been a beneficial result of the GWMA. The GWMA has sparked more community involvement and discussions pertaining to water in agriculture.

According to the panelists, the policy developed a perception to some growers of an impending water constraint. This perception led producers to make investments to improve the efficiency of the irrigation water. Physical improvements, such as alternative water application systems, ditch lining, and land leveling became more common (Anderson et al. 1999). Although individual farmers adopted water

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[21] Indirect recharge programs implemented in the 1990s further encouraged the use of CAP water in agriculture. The analysis of this program is beyond the scope of this thesis.

conservation technologies, most experts agree that these actions had very little, if anything, to do with the First and Second Management Plans.

The increased awareness encouraged better measuring and monitoring of water purchases, yielding more precise data. Prior to 1980, water data was inaccurate or non-existent. Since 1980, water data on water purchased and pumped is kept much more accurately, and this more precise data can aid in more accurate future policies. The increased awareness, the efficiency improvements, and the improved measurement of water purchased have contributed to the recognition of the value of water.

4.1.2 Impact of the Implementation of the GWMA

The panel of interviewees almost unanimously agree that the year-to-year implementation of the GWMA, via its management plans, has not been an effective water conservation tool. Several reasons explain this observation. First, the plans have had little influence on farmers' practices and decisions because the plans ignore price incentives. Second, the GWMA was created with a faulty design that allotted a significant amount of water to most growers. Third, ADWR experienced difficulty enforcing some of the efficiency rules set in place by the management plans. As a result of these three reasons, the agricultural water purchased has not declined in most districts. The following sections detail each of these points to a greater extent.

4.1.2.1 Impact on Farmer Practices and Decisions

Farmer irrigation management decisions and practices have not changed due to the GWMA according to most of the panelists. The primary reason is that market forces have driven grower decisions, not a non-binding water conservation regulation. For example, a greater amount of alfalfa is produced today than twenty years ago, primarily due to the growing size of dairies in the state. Farms operate as a business with the goal of making a profit. Therefore, if a grower can make more money by changing the operation, such as changing the cropping pattern, he/she will adapt to changing economic incentives.

Urbanization in central Arizona has dominated agricultural land markets, especially within the last five years. Developers and investors have purchased nearly all the farmground in the irrigation districts included in this analysis. This urbanization creates a disincentive to adopt water-conserving technologies. The grower leases from the developer/investor, generally on year-to-year cash leases. But neither the growers nor the developer have an economic incentive to adopt water conservation technologies, such as land leveling, with short-term planning horizons.

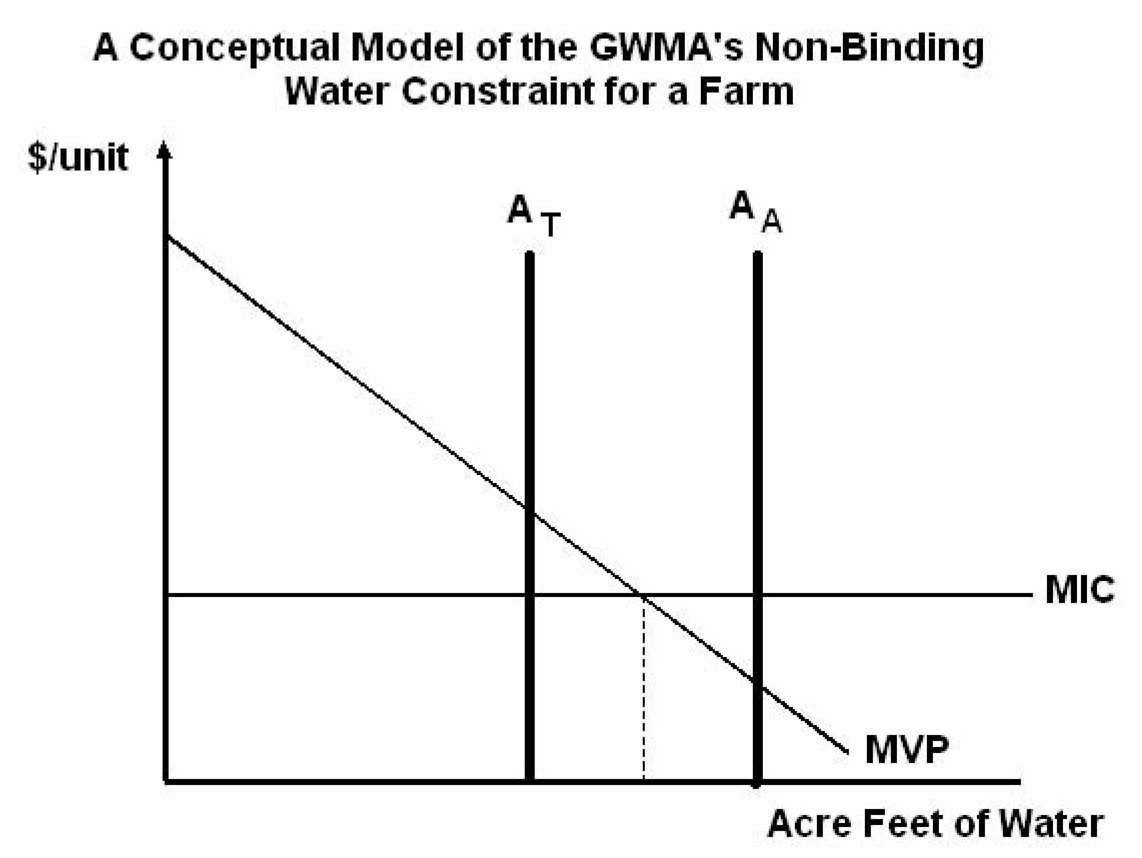
According to some individuals interviewed, many growers have received mixed water use messages from policymakers. Farmers are told to conserve water due to the over-consumption of water in the state or because of drought conditions. Meanwhile, growers are encouraged to use additional CAP water, at reduced prices, so that Arizona will use its full CAP allotment each year. The grower faces a confusing water environment: on the one hand programmatic efforts to reduce water use, and on the other hand favorably priced CAP water to encourage CAP water purchases by the irrigation districts.

4.1.2.2 Law Created With a Faulty Design

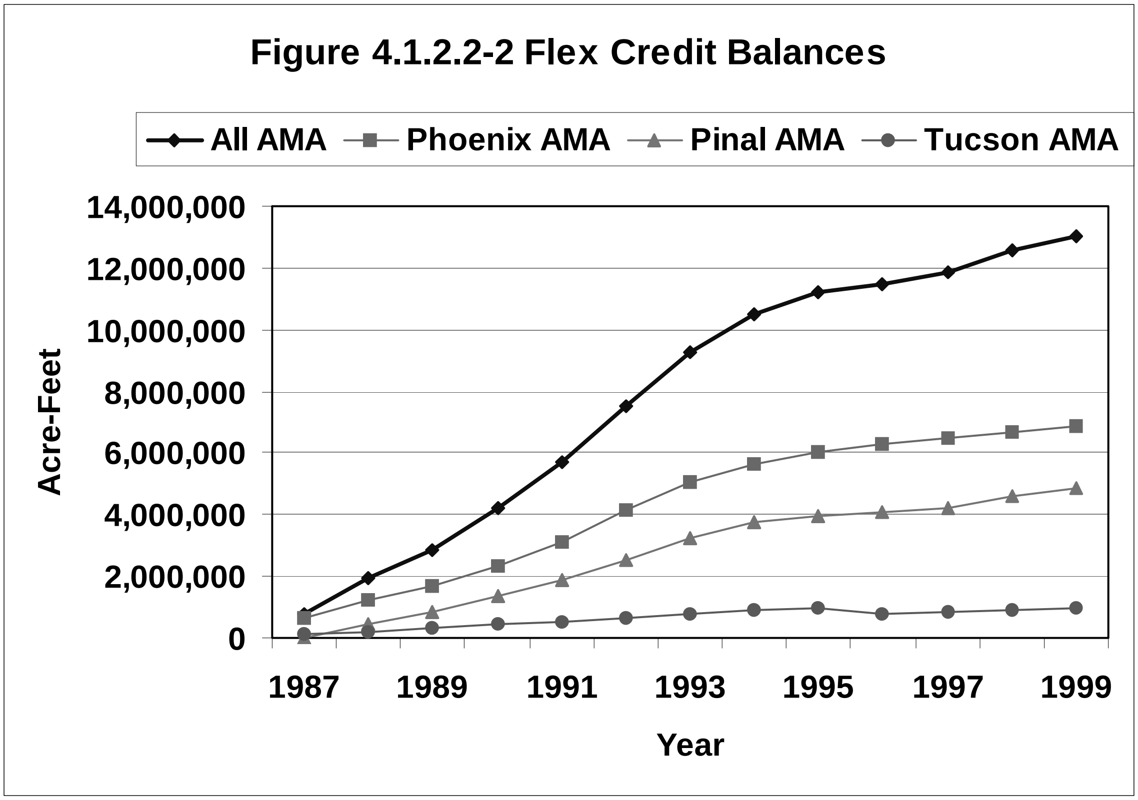
As described in Chapter 2, turmoil between local, state, and federal entities prompted the Arizona State legislature to pass a water policy. Also, prior to 1980, accurate data on the water purchased in agriculture was nonexistent. With the lack of data, and growing political pressure, the GWMA was created with a faulty initial design, according to most interviewees.

The water allotments are too generous for most growers if the goal of the allotment is to set a constraint to encourage the adoption of water conservation technologies. Figure 4.1.2.2-1 illustrates a theoretical framework of the faulty design of the GWMA in agriculture regarding the allotments. The horizontal line MIC indicates the private marginal cost of water per acre-foot for the grower. The line MVP reflects the marginal value product of water. They intersect at the dotted line, which is the point of equilibrium for profit maximization (MVP=MIC). Given no constraints, water consumption will equal this quantity. The GWMA attempts to set a constraint at A_T via water allotments. This line A_T was supposed to represent the maximum amount of water that could be purchased by a grower. However, due to generous water allocations, the actual "constraint" is A_A, thereby not serving as a binding constraint for the grower. Therefore, market factors decide how much water the grower purchases since the allocated amount of water is beyond (to the right of) the profit-maximizing point. Since a constraint in water allocations is lacking, the econometric model estimates this input demand function for irrigation districts by using market factors. With market factors, the model can evaluate the impact of the First and Second Management Plans.

Figure 4.1.2.2-1



Over the study period, most growers have accumulated large amounts of excess flex credits due to the lack of constraints. As shown in Figure 4.1.2.2-2, the cumulative flex credit balance has grown during 1986-2000 to twelve million acre-feet of water. This cumulative balance is more than six times the annual consumptive use in agriculture. In other words, the average grower can irrigate for six years using strictly the flex credits. In essence, for most growers there is no binding constraint in agricultural water use.



Source: ADWR

The flex credit accounts have increased for various reasons. Federal programs, imperfect data leading to flawed allotments, and the heterogeneity of farms all have contributed to the growth of these flex credits. Even the drought at the turn of the century has not caused the aggregate credits to decrease. Many growers will never have a binding constraint on their agricultural water use.

Federal programs also play a significant role in the flex account credits. The Food Security Act of 1985 allowed farmers to be paid for set-aside acres.[22] Growers were paid to not produce a commodity on the land. Tens of thousands of acres in Arizona sat idle, not requiring water. Yet, under the GWMA, the growers were entitled to the water

[22] Set-aside acres is idle land without a commodity being produced on it. The intent of the set-aside program was to control for the production not to exceed the nationally desired amount of a commodity.

whether or not a commodity was being produced on that land. Hence, many growers had excess water allotments, which led to the buildup of flex credits.

Imperfect data prior to 1980 led to a buildup of flex credits as well. Recall from section 2.2.2.3 that the allotments were calculated as follows:

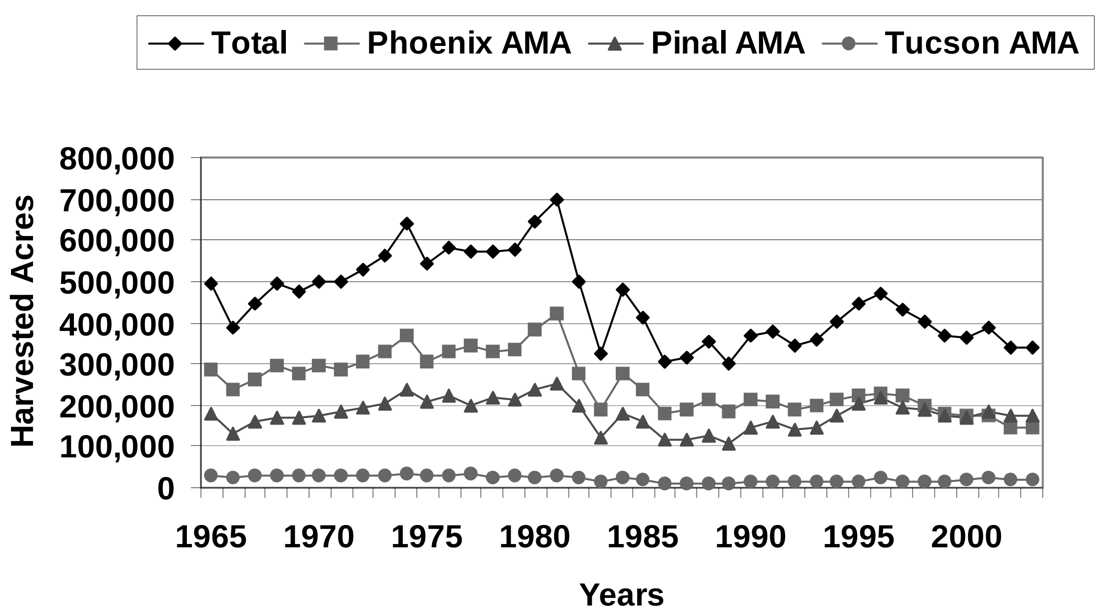
(14) $A = W * L$

and

(15) $W = (I/E)$

where (A) is the Allotments, (W) is the water duty, (L) is the water duty acres, (I) is the irrigation requirement, and (E) is the efficiency rate. Under the GWMA, the base acres used for calculations are the highest number of acres farmed between the years 1975 and 1979. During those years, the number of acres farmed in the AMAs struck historical highs, as Figure 4.1.2.2-3 indicates. By using a high (L), allotments (A) are overstated.

Figure 4.1.2.2-3 Irrigated Acres in the AMAs



Source: ADWR

Another flaw in determining water allotments is the water duty (W). Agriculture bargained with ADWR to get the annual irrigation requirement for crops (I) as high as possible. For example, in the first three management plans the average requirement in the Pinal AMA has been 3.15 AF/acre. This average requirement is a generous number for some growers, depending on their cropping patterns and set-aside acres during the years 1975 to 1979. The water duty (W) is inflated since the generous average irrigation requirement is used in the water duty calculation. Hence, allotments increase due to the overstating of the water duty (W) and water duty acres (L), allowing the buildup of flex credits.

The cropping patterns of the growers and idle land during the late 1970s greatly influence the growers' allotments. If the producer grew alfalfa during those years, a high water-intensive crop, the irrigation requirement is set higher for that individual than a farmer who produced barley during the 1975 to 1979 period. As a result, the growers that rotated their crop to alfalfa during those years are given a significantly higher water duty than the individuals that did not, regardless of the crop currently grown. Also, those farmers that had fewer set-aside acres are given a more generous water duty acre amount than a farmer that had a larger amount of set-aside acres during 1975-1979.

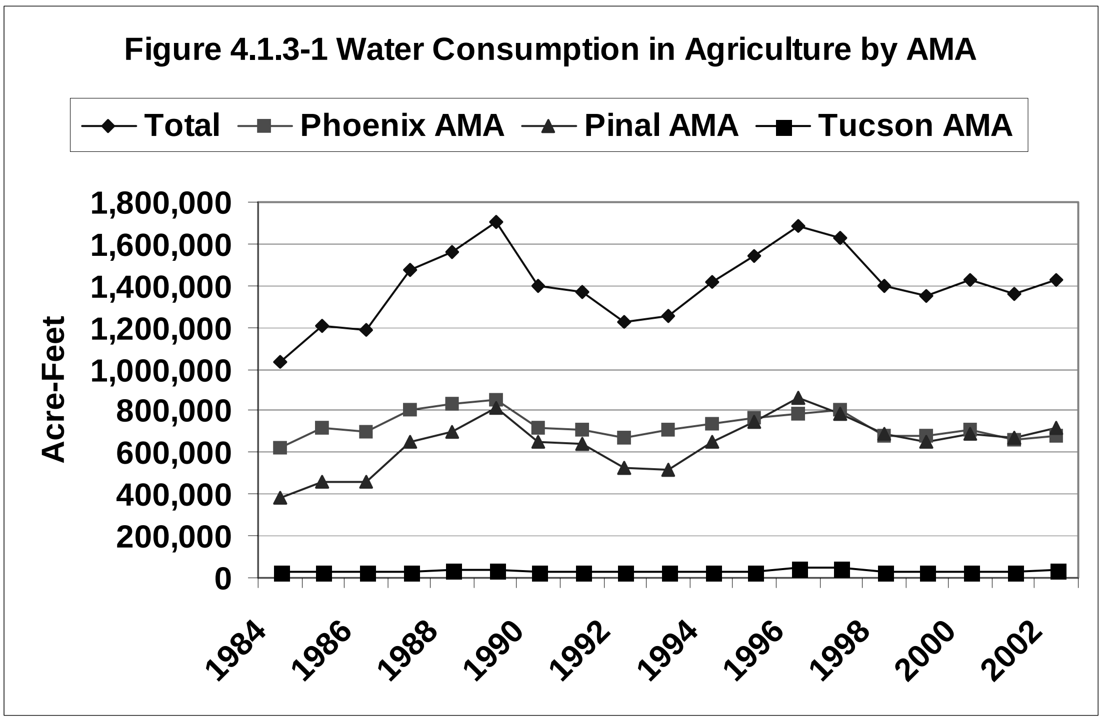
The heterogeneity of farms also is a factor in water usage. The GWMA acts as though most every farm is identical. In reality, every farm varies in soils, slope, elevation, microclimates, fertility, water conservation technology, and in numerous other ways. All these factors influence the commodity grown, the yields of the commodity, and the water usage. Yet, the policy does not recognize most of these farm-level differences. Therefore, a small number of farmers have been greatly constrained by their allotments while other farmers have been untroubled by their water allocation. The heterogeneity of farms led to the large number of variances submitted by growers, particularly in the Phoenix AMA.

4.1.2.3 Enforcement Difficulties

Any policy is ineffective if it is not enforced. Some of the individuals interviewed argue that the GWMA is not enforced because enforcement is difficult. The way the Code is designed, the agency can only control how much water the grower is allocated, not the utilization of the water. Due to threatened lawsuits by agriculture, ADWR has had difficulty increasing the efficiency to 85 percent for the purpose of determining water allotments. The Best Management Practices (BMP) Program, introduced in the Third Management Plan to provide an alternative to the flex accounts system, hopes to ensure that the water is used in the most efficient manner. To date, few growers have volunteered for the BMP program. Threatened lawsuits have also encouraged several exceptions or amendments to the GWMA regarding efficiencies and water duties, thereby reducing the constraints of the allotments if any exist. Some argue that economic incentives should be encouraged rather than regulations to promote the adoption of water conserving technologies. With the difficulty to enforce the policy, numerous lawsuits have arisen, and most economic behavior in the agricultural sector has not changed, according to some interviewees.

4.1.3 Impact on Agricultural Water Use

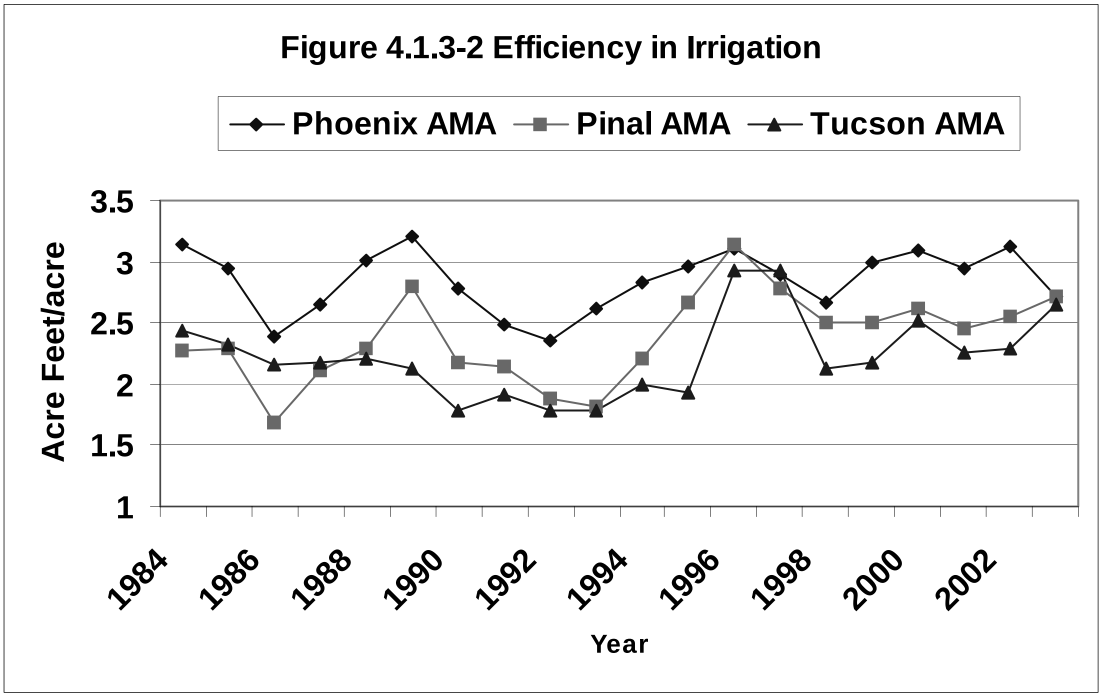
The goal of the GWMA is to conserve water in three important agricultural AMAs in central Arizona. ADWR data shows that agricultural water use has not declined during the study period (Figure 4.1.3-1).[23] The trend line is slightly upward sloping over time but the slope is not significantly different from zero. The Phoenix AMA has reduced water consumption in agriculture in recent years, probably due to urbanization in some districts, while growers in the Pinal AMA have increased water usage.



Source: ADWR

Figure 4.1.3-2 illustrates the efficiency of irrigation water during the study period. The regression line of water use per acre is not significantly different than zero, indicating that the water efficiency has not improved overall. The Pinal and Tucson AMAs appear to have slightly declined in efficiency while the efficiency of the Phoenix AMA has remained flat.

[23] It is important to note that Figure 4.1.2.2-2 includes irrigation districts not included in Figure 4.1.3-1.



Source: ADWR

4.2 Quantitative Results

Denzin's triangulation, as discussed in chapter 3, represents a mixed-method evaluation approach. The qualitative data discussed earlier in the current chapter produces common themes. These results are used as checks and balances with the quantitative outcomes. In short, quantitative results from the ADWR data and the econometric model are consistent with the qualitative findings.

4.2.1 Fixed Effects versus Random Effects

This chapter has explained the results of the qualitative findings and the ADWR data in the quantitative triangulation. Now the focus will be the econometric model. As discussed in Chapter 3, the log-log econometric model estimates water demand using market factors. The dependent variable is water purchased and pumped, and the independent variables include water price, annual precipitation, average temperature during the growing season, price of alfalfa, price of barley, price of upland cotton, and price of durum wheat across eleven irrigation districts over a period of nineteen years. This data is panel data so a question arises whether a fixed effects or random effects model is more appropriate for the analysis.

In review from section 3.2.2.2, several distinctions differentiate fixed effects models from random effects models. Fixed effects assumes the data is the entire population while random effects assumes the data is a sample of the population. Fixed effects models use dummy variables for cross-sectional and/or time-invariant variables. When using dummy variables, fixed effects assumes common slopes and individual intercepts. Random effects assumes common intercepts but different slopes. Fixed effects is estimated by OLS while random effects is estimated by GLS.

The Hausman test determines whether a fixed or random effects model is more appropriate. It tests the correlation between the error terms and the regressors. The χ^2 value is 16.25 for model 2 with a P-value of 0.0010. The null hypothesis, $H_0 : E(\varepsilon_{it} \mid X_{it}) = 0$, is rejected and a fixed effects model is more appropriate. The results of the fixed effects and random effects models using the statistical software SHAZAM are shown in Table 4.2.1-1 and 4.2.1-2.

Table 4.2.1-1 Estimation Results for Model 1

Variable	Uncorrected Fixed Effects Coefficient	Uncorrected Fixed Effects Std. Error	Corrected Fixed Effects Coefficient	Corrected Fixed Effects Std. Error
Ln (WaterPrice)	-.182*	.074	-.116*	.057
Ln (Annual Precipitation)	-.019**	.005	-.015**	.004
Ln (Average Temperature)	.036*	.014	.024*	.011
Ln (Alfalfa Price)	-.074	.130	.009	.119
Ln (Barley Price)	-.482*	.203	-.097	.199
Ln (Cotton Price)	.315**	.095	.113	.010
Ln (Wheat Price)	.031	.231	-.089	.210
Buckeye WC	10.373**	1.261	10.335**	1.154
Central Arizona IDD	11.419**	1.259	11.243**	1.150
Cortaro-Marana IDD	9.590**	1.253	9.448**	1.145
Hohokam IDD	10.410**	1.255	10.230**	1.148
Maricopa-Stanfield IDD	11.433**	1.267	11.238**	1.155
New Magma IDD	10.349**	1.260	10.152**	1.155
Queen Creek IDD	9.712**	1.260	9.517**	1.151
Roosevelt IDD	11.059**	1.258	10.948**	1.148
Roosevelt WC	10.548**	1.283	10.391**	1.162
Salt River Project	11.330**	1.262	11.244**	1.157
San Carlos IDD	11.038**	1.253	10.840**	1.147
Degrees of Freedom	194		204	
R^2	.9081		.9826	
LM Test for Heteroskedasticity	26.602**		---	
Breusch-Pagan LM Test	254.160**		---	

*Significant at 5% level **Significant at 1% level

Table 4.2.1-2 Estimation Results for Model 2

Variable	Corrected Fixed Effects Coefficient	Corrected Fixed Effects Std. Error	Corrected Random Effects Coefficient	Corrected Random Effects Std. Error
Intercept	---	---	9.624**	1.196
Ln (WaterPrice)	-.111*	.056	-.101*	.050
Ln (Annual Precipitation)	-.134**	.004	-.013**	.004
Ln (Average Temperature)	.249*	.011	.022*	.010
Ln (Alfalfa Price)	.069	.135	.543	.116
Ln (Barley Price)	-.076	.205	.020	.183
Ln (Cotton Price)	.138	.221	.134	.107
Ln (Wheat Price)	-.088	.121	-.082	.190
Second Management Plan	.085	.081	.034	.082
Third Management Plan	.085	.123	.053	.121
Buckeye WC	9.704**	.548		
Central Arizona IDD	10.607**	.644		
Cortaro-Marana IDD	8.808**	.483		
Hohokam IDD	9.598**	.561		
Maricopa-Stanfield IDD	10.606**	.645		
New Magma IDD	9.518**	.571		
Queen Creek IDD	8.886**	.537		
Roosevelt IDD	10.315**	.568		
Roosevelt WC	9.758**	.595		
Salt River Project	10.617**	.628		
San Carlos IDD	10.210**	.612		
Degrees of Freedom	192		202	
R^2	.9824		.9580	

*Significant at 5% level **Significant at 1% level

Table 4.2.1-1 displays the uncorrected and the corrected fixed effects model. The uncorrected model does not adjust for heteroskedasticity and autocorrelation while the corrected model does make these adjustments. The LM Test shows a significantly high statistic indicating that heteroskedasticity is present in the model. Breusch-Pagan’s LM Test results also show cross-sectional correlation or serial correlation exists in the model.

With the statistical corrections in SHAZAM, the signs, magnitudes, and significance of the coefficients remain relatively the same.

Table 4.2.1-2 presents the econometric results for fixed and random effects. As expected, the coefficients between the two models are very similar in magnitude. The signs are consistent, with the exception of barley price. The magnitudes and the significance are consistent for both scenarios. The coefficients in the tables show the effects of each variable on agricultural water purchases. The R^2 values are higher in the fixed effects model because the dummy variables for the districts absorb ten degrees of freedom while picking up the heterogeneity in the model across irrigation districts.

4.2.2 Explanatory Variable Results

The fixed effects model results provide valuable insights on the nature of water demand at the district level. The signs of the coefficients for all the variables are consistent with the hypothesized signs. As explained in section 3.2.2.4, water price is expected to yield a negative sign. The water consumed decreases as the price of water increases, ceteris paribus. Water demand is expected to be downward sloping. Hence, as the price of water increases, water purchased is expected to decrease.

Precipitation is a key factor in agricultural water consumption. Precipitation is highly significant in all four scenarios and is negatively correlated to water purchased. Common sense explains that the more it rains, the less farmers irrigate, and the models reflect this logic.

Temperature influences water demand in agriculture. In the models above, temperature is significant at the 5% level in all cases and has a positive sign. The hotter the temperature, the greater volume of water the plant consumes and the more evaporation occurs, thereby increasing water use.

The alfalfa and cotton price coefficients yield positive signs because a grower plants more alfalfa or cotton as the crop becomes more profitable due to a higher price. Since alfalfa and cotton uses a relatively high amount of water compared with other crops, more water is consumed. However, all crop prices are not statistically different from zero, so they are insignificant in the models and do not influence water demand in agriculture.

Several additional models were analyzed prior to the settling on these two models. Lagged crop prices were used in earlier models. However, these earlier lagged models produce similar results to the non-lagged crop prices. The USDA-NASS crop prices are already lagged to a degree because the prices reflect marketing years, harvest-to-harvest, rather than nominal years January to December. Similar outcomes result using a linear model as with linear-log models, and signs and significance do not change. Water purchased is highly correlated with all independent variables except crop prices. The cotton and alfalfa acres are also highly correlated, as well as alfalfa acres with precipitation, but the other exogenous variables are not highly correlated in the model.

4.2.3 Irrigation District Results

The econometric models find irrigation districts do possess heterogeneity. The results, using the one-way fixed effects model with each irrigation district as a dummy variable, clearly show that every irrigation district should be treated individually due to its heterogeneity. As Table 4.2.1-1 and Table 4.2.1-2 show, every district is highly significant at the 1% level with a positive sign and must be treated differently than the other districts when analyzing agricultural water demand. These differences can be explained by the varied water pricing systems, types of water available, cropping patterns, size and scope, location, urbanization pressure, soils, slopes, elevations, weather, management, and many other factors that make each irrigation district unique.

4.2.4 Management Plan Results

The two models show slight differences when dummy variables are added for the management plans. The addition of the management plan dummy variables test whether a structural change in water demand occurred with the Second and Third Management Plans from the First Management Plan. The first econometric model includes the exogenous variables and dummy variables for each irrigation district. The second econometric model includes all of the variables of the first model as well as dummy variables for the Second and Third Management Plans of the GWMA. If the management plans were effective towards their objective of water conservation in agriculture, the coefficients of these management plan dummy variables in the second model will be negative and statistically significant.

The results of the second model show that the Second and Third Management Plans, in a statistical sense, did not contribute to our understanding of water demand in the irrigation districts. The signs of the coefficients for the Management Plan dummy variables are positive, but these coefficients are not statistically different from zero. In short, from this econometric analysis, water purchased and pumped in the Second and Third Management Plans of the GWMA were not significantly different from the First Management Plan. Market factors have driven water demand in Arizona agriculture during the study period 1984 to 2002 and explain over 90% of the variability in water purchased.

4.2.5 Integration of Qualitative and Quantitative Results

The mixed-method of this impact assessment uses the qualitative findings as checks and balances for the quantitative results. Qualitative findings, ADWR data, and the econometric results are triangulated for the quantitative analysis of this impact assessment. All sources produce consistent results. As explained in section 4.1, the qualitative results have found that the initial passage of the GWMA produced more water conservation in agriculture than the implementation of the First, Second, and Third Management Plans. Market factors determine the quantity of water purchased. ADWR data show generous water allotments fail to constrain growers' water use, thereby allowing the market to determine water demand in agriculture. Per acre water purchased in agriculture did not change over the study period. The econometric results in section 4.2 support the findings of the qualitative analysis and ADWR data. The management plan dummy variables are statistically insignificant, indicating no apparent shift in agricultural water demand due to the management plans during the study period. Relative prices, weather, and irrigation district identification explain nearly 100% of the water purchases in the studied districts.

5. SUMMARY, APPLICATIONS, LESSONS LEARNED

For 25 years, the Groundwater Management Act of 1980 (GWMA) has been regarded as the dominant water management policy tool for central Arizona agriculture. The GWMA emerged from an era of tensions between agriculture, municipalities, industries, mines, and Indian communities. For decades, groundwater in Arizona was depleting at a greater rate than it was being recharged, causing concern among the municipalities for a stable water supply to meet the growing needs of the people, and among agriculture to continue its prosperity.

Increasing tensions between the sectors resulted in a series of policies and lawsuits. The Howell Code of 1864 defined water rights, and it was the first water policy for the territory. It remained the water law well into the 1900s. In 1945, a bill was passed in the Arizona legislature that required record-keeping of wells. The Groundwater Code of 1948 limited agricultural acreage in critical groundwater areas. In the 1950s, a drought, a cotton boom, and exceptional population growth increased water demands in Arizona. With these growing water demands, Arizona and California fought over Colorado River water for twelve years during the 1950s and 1960s.

Another series of lawsuits and threats occurred shortly after the resolution of the dispute with California. The Jarvis cases (Jarvis v. State Land Department, 1969, 1970, 1976) eventually established the right and quantified the amount of water cities could extract from off-site municipal locations and transport to municipal consumers. The Farmers Investment Company case (FICO v. Bettwy, 1976) no longer allowed mines to withdraw groundwater from neighboring lands and transport the water away from those lands for use in the mining operations because of the damage done to neighboring wells.

The FICO court ruling threatened the ability of mines and cities to meet their long-term water needs without buying large acreages of farmland. Also, during the late 1970s, the federal government threatened to discontinue funding the Central Arizona Project (CAP) unless the state passed a comprehensive groundwater management code.

In 1980, the Groundwater Management Act was passed with minimum debate. It established the Arizona Department of Water Resources (ADWR) to implement and enforce the water code. Four Active Management Areas (AMAs) were established in three important agricultural and urban areas where a long history of groundwater overdraft threatened the long-term viability of farming and urban expansion. The legislative goal of the Phoenix and Tucson AMAs was safe yield by 2025, while the goal of the Pinal AMA was to maintain agricultural production as long as possible without jeopardizing municipal water supplies.

The GWMA hoped to conserve water by placing constraints on agriculture within the AMAs. First, the policy did not allow new agricultural land to be developed. Second, no new non-replacement wells could be drilled without the consent of the Director. Third, a series of five management plans gradually reduced the quantity of water available to the grower. These water allotments represented the maximum amount of water a farmer could use in a given year. Any water allotment not used could be carried to the following years through a flex account system.

With these constraints, the question arises: “Has the GWMA promoted water conservation in agriculture?” This analysis contained two parts. The qualitative analysis triangulated common themes found in 30 interviews from current and former ADWR staff, irrigation district managers, and other water experts. The qualitative results were then triangulated with ADWR data and an econometric model to formulate the quantitative analysis.

The interviews revealed some positive and negative aspects of the GWMA. The initial impacts of the Act were primarily positive in terms of promoting groundwater conservation in agriculture. The GWMA set a constraint on the development of new agricultural land, and the passage of the act enabled the CAP to be built which has conserved a significant amount of groundwater in the central part of the state. Perceptions and awareness in the communities broadened as water issues became more transparent. A perception of an impending water constraint induced some growers to adopt water conservation technologies in the 1980s. However, water experts agree that this adoption had very little to do with the First, Second, and Third Management Plans. The greater awareness from the GWMA has provided a legal, regulatory, and organizational platform to discuss water issues throughout the state.

Implementation of the GWMA had little impact on water conservation decisions. The management plans failed to establish an effective water constraint for most farms. The "constraint" was non-binding on the decision-making of most growers. Due to the lack of a constraint, growers responded to market pressures when evaluating the adoption of water conserving irrigation technologies and practices. Declining crop prices and low, stable water prices over most of the study period served as disincentives for the adoption of costly technology or a significant change in water management practices.

Water allotments were too generous for most growers if the goal of the GWMA was to set a constraint on agriculture to encourage the adoption of technology. The GWMA established 1975-1979 as the period used to determine water duty acres in the calculation of water allotments. USDA-NASS data show this period represented the peak of irrigated acreage in central Arizona over the last 40 years. By using a high level of water duty acres, water allotments were not a limitation to most farmers.

The implementation of the flex account program also diminished the water constraint in agriculture. ADWR data show flex credit accounts grew tremendously since its implementation in 1986-87. A number of reasons contribute to this phenomenon. First, low profitability in farming in the 1980s reduced acreage planted and water use, but increased flex credits. Second, federal programs allowed payments on set-aside acres while these acres earned flex credits. Third, flaws in the equations gave generous water allotments to growers. Finally, urbanization contributed to the growth of flex credit balances because some farmground was converted to housing but still acquired water allotments in Maricopa County.

Data from ADWR supported the qualitative findings. Aggregate water use in the agricultural sector declined slightly due to urbanization in the Phoenix AMA. However, the trend in per acre water use in the agricultural sector remained relatively constant over the life of the GWMA. Fluctuations in water use over this period were explained largely by changing crop prices, input costs, weather, and macroeconomic conditions.

The econometric model analyzed water demand from 1984-2002 in 11 irrigation districts. With structural, institutional, and operational knowledge of these districts, the variation in water demand across districts could be partially explained. A change in agricultural water demand due to the impact of the First, Second, and Third Management Plans of the GWMA could be tested, controlling for other factors such as economic conditions and weather.

The econometric results were consistent with the overall finding. Water prices and crop prices explain nearly all the variation in water purchased and pumped over the study period. Water use in the Second and Third Management Plans were not significantly different from the First Management Plan.

Applications of this research are numerous. First, if a water conservation policy relies on a quantity constraint for its effectiveness, it is imperative that a scientific foundation be established to set the appropriate quantity. Otherwise, the non-binding constraint will lead to program ineffectiveness. Second, the form of impact assessment used in this study can be used to forecast water purchased and pumped in agriculture. Forecasts of water price, commodity prices, precipitation, and crop acreage allow the researcher to explain well over 90% of the variability in water demand and enables state agencies and irrigation districts to predict with great accuracy the quantity of water that will be used in agriculture.

Many lessons have been learned through the process of this research effort. First, water prices and electrical prices are very complex and extremely difficult to obtain. Water and electricity are priced in many creative ways within the irrigation districts, and several types of water and electricity exist. Some organizations are unwilling to share this pricing information with a researcher. Second, groundwater management policies contain vast complexities and are very intricate. It takes years to fully learn and understand the many details of the GWMA. The agricultural portion of the policy alone represents a significant challenge to the young researcher. Collective minds are invaluable when creating a policy, and collective minds are also invaluable when analyzing a policy. This impact assessment could not have been completed without the help of many individuals.

Other valuable lessons were learned while performing this research. Data gathering may seem like a chore at the time, but accurate data is imperative for effective policies. Without precise data, vague regulations lead to numerous lawsuits and constant exceptions to the guidelines established. Therefore, policies established without a firm scientific foundation have a greater likelihood of being ineffective. Finally, in the case of the GWMA, the promotion of water conservation in agriculture continues to be a struggle. Lowering the assigned efficiency rate from 85 percent in the Third Management Plan reduced the constraints in agriculture. New wells can be drilled in the AMAs with the Director's consent, again, reducing the constraints. The lack of constraints does not coerce a change in behavior and alternative methods may need to be considered. Besides the lack of constraints, agriculture receives mixed messages toward water conservation. Agriculture is encouraged to improve their irrigation efficiency, yet are given CAP water at reduced prices so that Arizona will utilize its full allotment and not lose their rights to the CAP water to California and Nevada. In some districts using 100% CAP water, the water used in these districts is not counted against the farmers' allotments.

Policies are in an endless cycle, constantly improving, constantly adapting to the changing environment. This is certainly true in Arizona. Policies and lawsuits regarding water rights are a part of the state's history, and these lawsuits demonstrate the value of water to the people since water is a necessity for survival in the Sonoran Desert. As the GWMA attempts to promote water conservation in Arizona, education (e.g. irrigation management) and economic incentives are probably alternative, lower cost tools for achieving desired water conservation goals in the agricultural sector.

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APPENDIX

Table A-1 Timeline of Policy Events

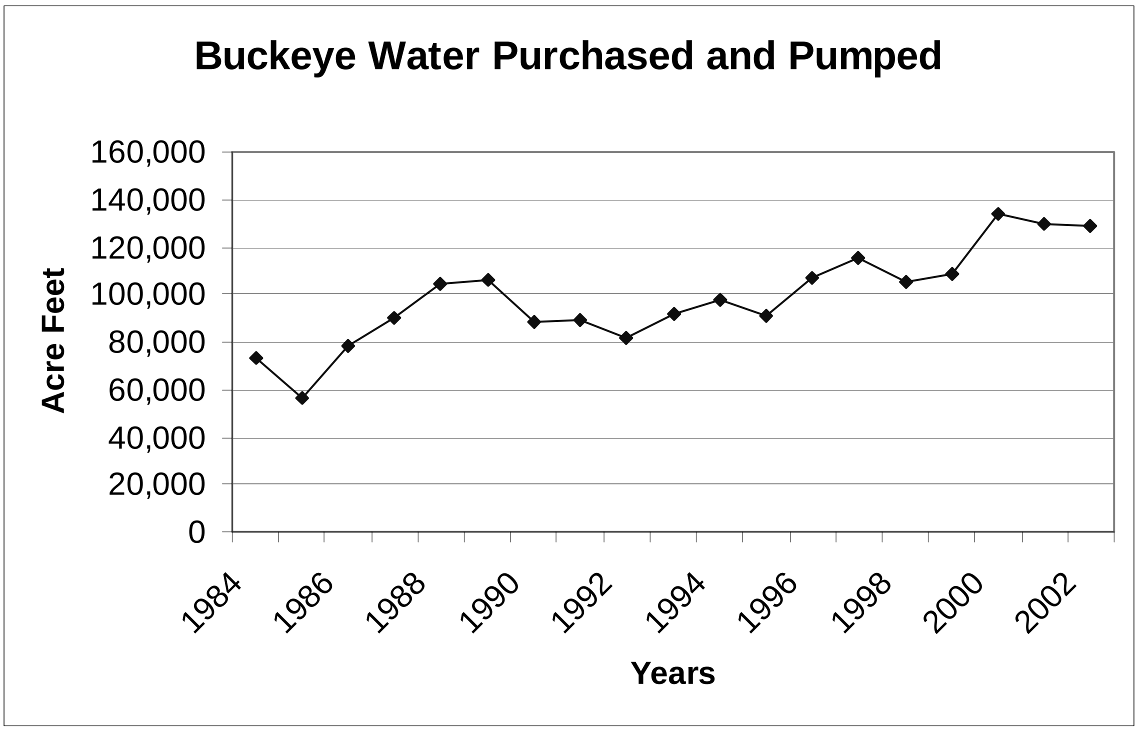
1980	GWMA passed
1982	Pinal AMA Agricultural Study (SCS, ERS, DWR) began
1983	Well measurements began
1984	**First Management Plan for Phoenix AMA, Tucson AMA adopted**; Well data accumulated
1985	**First Management Plan for Pinal AMA adopted**
1986	Environmental Quality Act passed
1987	Flex Accounts System began CAP water deliveries to Phoenix AMA began
1989	**Second Management Plan adopted** (phased in)
1990	Indirect Recharge (Amendment of GWMA)
1991	Groundwater Transportation Act (restricted Municipal provider to transport groundwater from rural sub-basins)
1993	Pool Pricing of CAP; Central Arizona Groundwater Replenishment District (CAGRD) established
1994	CH2M Hill Study began; Water Protection Fund; Underground Water Storage, Savings and Replenishment Act (rewrote recharge laws)
1995	Some reduced allotment took place; Assured Water Supply rule; Groundwater Replenishment District
1996	CH2M Hill Study ended; Arizona Water Banking Authority established
1997	Debate on CH2M Hill Study
1999	Letter Agreement with Agriculture
2000	Final allotment at 80% began for Second Management Plan; Governor’s Water Management Commission
2002	**Third Management Plan adopted** (phased in); Liberalized Flex Credit provisions
2003	Best Management Practices began (Modification of Third Management Plan)

Table A-2 Sources of Qualitative Data

ADWR Staff	**Irrigation District Managers**	**Experts / Growers / Analysts**
Tom Carr (*Assistant Director*)	Stan Ashby (*Roosevelt ID Superintendent*)	Bonnie Colby (*Professor, Agricultural and Resource Economics, University of Arizona*)
Herb Dishlip (*Former Deputy Director*)	Brian Betcher (*Maricopa-Stanfield IDD Assistant General Manager*)	Dennis Cory (*Professor, Agricultural and Resource Economics, University of Arizona*)
Randy Edmond (*Director, Pinal AMA*)	Robert Condit (*Former Cortaro-Marana District Manager*)	Rick Gibson (*Director, Pinal County Cooperative Extension, University of Arizona*)
Sandy Fabritz-Whitney (*Drought Coordinator Statewide Planning and Special Projects*)	Dean Griffith (*Queen Creek IDD General Manager*)	Steve Husman (*Agriculture Agent, Cooperative Extension, Pima and Pinal Counties, University of Arizona*)
Mark Frank (*Director Phoenix AMA*)	Michael Leonard (*Roosevelt WC General Manager*)	Dave Iwanski (*Water Resources Manager, City of Goodyear*)
Mike Hanrahan (*Manager, BMP Agricultural Water Conservation Program*)	Jack Long (*Hohokam District Manager*)	Sharon Megdal (*Director, Water Resources Research Center, University of Arizona*)
Jim Holway (*Former Assistant Director*)	Douglas Mason (*San Carlos IDD General Manager*)	Wiley Murphy (*Grower ,Tucson AMA*)
Kathy Jacobs (*Former Director, Tucson AMA*)	Ron McEachern (*Central Arizona IDD District Manager*)	Bob Roth (*Director, Maricopa Agricultural Center, University of Arizona*)
Dennis Kimberlin (*Former Director, Pinal AMA*)	Jackie Meck (*Buckeye General Manager*)	Gary Woodard (*Assistant Director, SAHRA, University of Arizona*)
Ken Seasholes (*Director, Tucson AMA*)	William Van Allen (*New Magma IDD District Manager*)	---
Ken Slowinski (*Deputy Counsel*)	---	---

A-3.1 Buckeye Water Conservation and Drainage District

Manager: Jackie Meck, General Manager
Location: Buckeye, Arizona
Irrigable Acres: 19,000
Active Management Area (AMA): Phoenix
Water Sources: Groundwater, Effluent, Gila River Surface Water



Source: ADWR

<u>Explanation of Data</u>

Water Purchased: Data is from ADWR Tucson office.

Water Price: Data is the variable cost per acre-foot. Data is from Buckeye Water Conservation and Drainage District. The district controls nearly all the wells and charges the same rate for all types of water. Figures for 1984-1994 are based on the price charged during the summer months, and 1995-2002 figures are based on a weighted average price by monthly purchases.

Annual Precipitation: Data is recorded in inches and was gathered from NOAA stations deemed closest to the irrigation district. If data is missing from the primary station, data from the secondary and tertiary stations were collected respectively (see Table A-4 in the Appendix).

Average Temperature: Data was gathered from NOAA stations deemed closest to the irrigation district. If data is missing from the primary station, data from the secondary and tertiary stations were collected respectively (see Table A-4 in the Appendix). If data is missing from all three stations, monthly data was collected from the primary, secondary, and tertiary stations respectively to estimate an average (see Table A-4 in the Appendix). If data is missing to estimate average, data from the quaternary station was collected.

Alfalfa Price: Data was acquired from USDA-NASS. The price is a weighted average from April through March and is in dollars per ton. The price is constant for all districts.

Barley Price: Data was acquired from USDA-NASS. The price is a weighted average from May through April and is in dollars per ton. The price is constant for all districts.

Cotton Price: Data was acquired from USDA-NASS. The price is a weighted average from August through July and is in cents per pound. The price is constant for all districts.

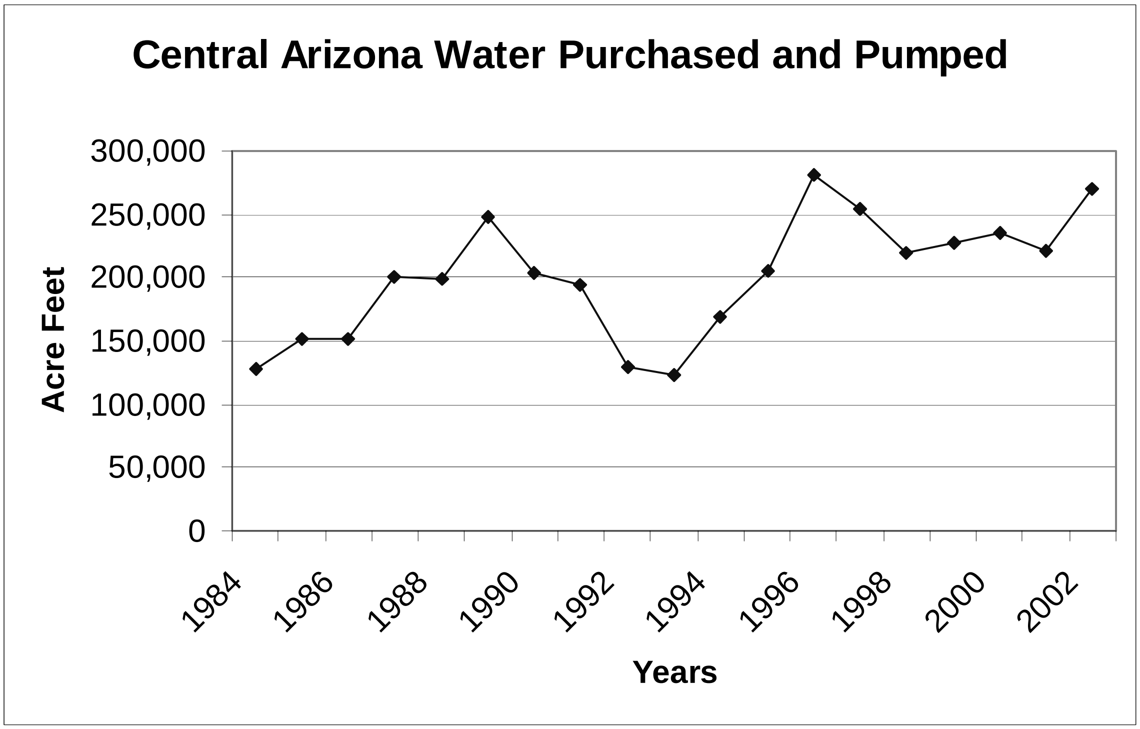
Durum Wheat Price: Data was acquired from USDA-NASS. The price is a weighted average from May through April and is in dollars per ton. The price is constant for all districts.

Alfalfa Acres: Alfalfa acres are not recorded at the district level. The percent marketshare of the district in the county was calculated. Data for irrigation acres by district are from ADWR for 1984-1999. The figures for 2000-2002 are from Scythe (2004) and are assumed to be constant during those years. County acre data is from USDA-NASS. The marketshare percentage is then multiplied by the number of alfalfa acres in the county (USDA-NASS) to determine the approximate number of alfalfa acres in the irrigation district.

Cotton Acres: Cotton acres are not recorded at the district level. Cotton acres were calculated the same way as alfalfa acres, using county cotton acres (USDA-NASS) instead of alfalfa county acres.

A-3.2 Central Arizona Irrigation and Drainage District

Manager: Ron McEachern, District Manager
Location: Eloy, Arizona
Irrigable Acres: 87,500
Active Management Area (AMA): Pinal
Water Sources: Groundwater, CAP water



Source: ADWR

<u>Explanation of Data</u>

Water Purchased: Data is from ADWR Tucson office.

Water Price: Data is the variable cost per acre-foot. Data is from Daugherty (1996) and Central Arizona Irrigation and Drainage District. The cost of pumping the groundwater was derived for 1984-1989. The data for 1990-2002 is from CAIDD since the district has controlled nearly all the wells since 1990.

Annual Precipitation: Data is recorded in inches and was gathered from NOAA stations deemed closest to the irrigation district. If data is missing from the primary station, data from the secondary and tertiary stations were collected respectively. In 1995, data was missing from all three stations, and monthly data was collected from the primary, secondary, and tertiary stations respectively to estimate an annual total (see Table A-4 in the Appendix).

Average Temperature: see Buckeye, A-3.1

Alfalfa Price: see Buckeye, A-3.1

Barley Price: see Buckeye, A-3.1

Cotton Price: see Buckeye, A-3.1

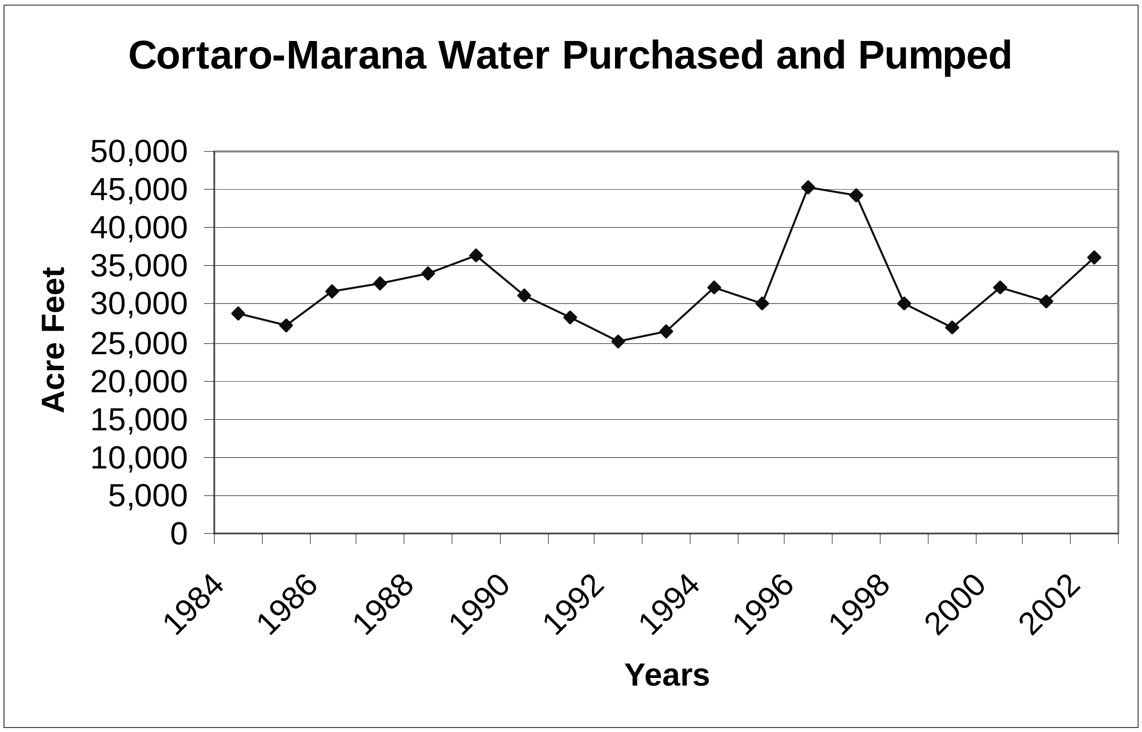
Durum Wheat Price: see Buckeye, A-3.1

Alfalfa Acres: see Buckeye, A-3.1

Cotton Acres: see Buckeye, A-3.1

A-3.3 Cortaro-Marana Irrigation District

Manager: Sidney Smith, Manager
Location: Marana, Arizona
Irrigable Acres: 11,810
Active Management Area (AMA): Tucson
Water Sources: Groundwater, CAP water, Effluent



Source: ADWR

Explanation of Data

Water Purchased: Data is from ADWR Tucson office.

Water Price: Data is the variable cost per acre-foot. Data is from Cortaro-Marana Irrigation District.

Annual Precipitation: Data is recorded in inches and was gathered from NOAA stations deemed closest to the irrigation district. If data is missing from the primary station, data from the secondary and tertiary stations were collected respectively (see Table A-4 in the Appendix).

Average Temperature: see Buckeye, A-3.1

Alfalfa Price: see Buckeye, A-3.1

Barley Price: see Buckeye, A-3.1

Cotton Price: see Buckeye, A-3.1

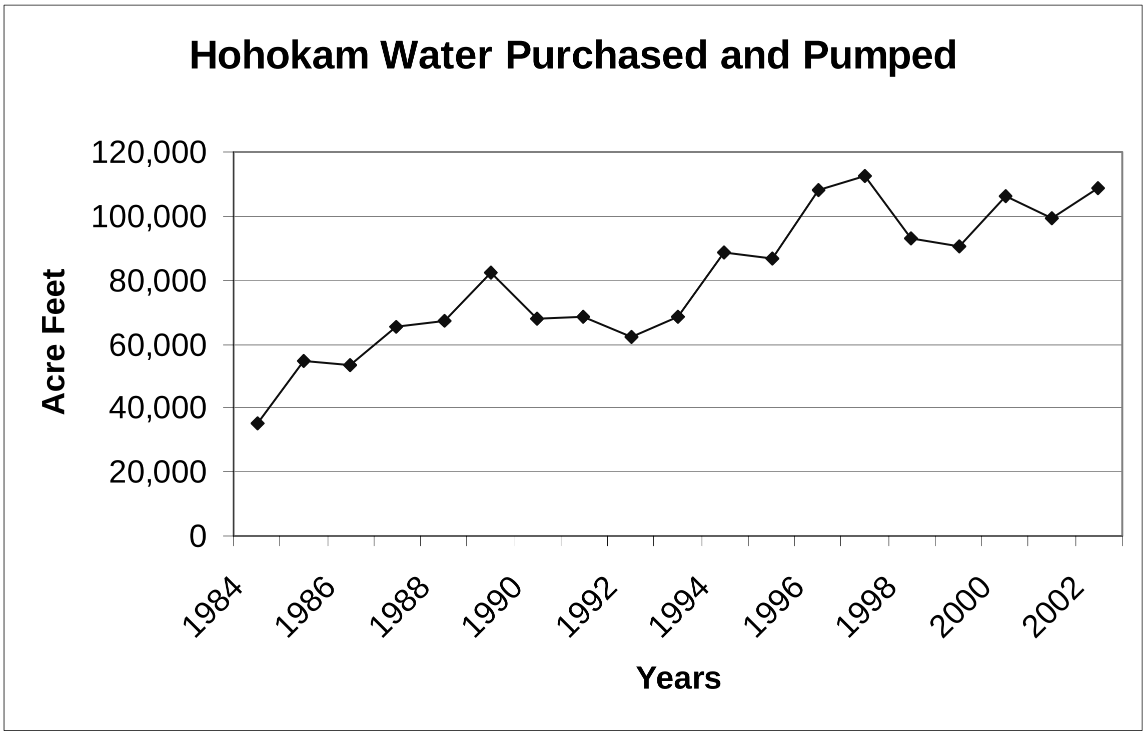
Durum Wheat Price: see Buckeye, A-3.1

Alfalfa Acres: see Buckeye, A-3.1

Cotton Acres: see Buckeye, A-3.1

A-3.4 Hohokam Irrigation and Drainage District

Manager: Jack Long, District Manager
Location: Coolidge, Arizona
Irrigable Acres: 28,200
Active Management Area (AMA): Pinal
Water Sources: Groundwater from private wells, CAP water



Source: ADWR

<u>Explanation of Data</u>

Water Purchased: Data is from ADWR Tucson office.

Water Price: Data is the variable cost per acre-foot. Data is from Hohokam Irrigation and Drainage District, Daugherty (1996), and ADWR in Tucson. Weighted CAP water prices were calculated based on seasonal prices and quantities from the arrival of CAP water in 1988 to 2002. The cost of pumping the groundwater was derived from Daugherty. The quantity of groundwater pumped was calculated by subtracting the district's CAP water figures from ADWR's total consumption figures. A weighted average price of water was then computed.

Annual Precipitation: Data is recorded in inches and was gathered from NOAA stations deemed closest to the irrigation district. If data is missing from the primary station, data from the secondary and tertiary stations were collected respectively (see Table A-4 in the Appendix).

Average Temperature: see Buckeye, A-3.1

Alfalfa Price: see Buckeye, A-3.1

Barley Price: see Buckeye, A-3.1

Cotton Price: see Buckeye, A-3.1

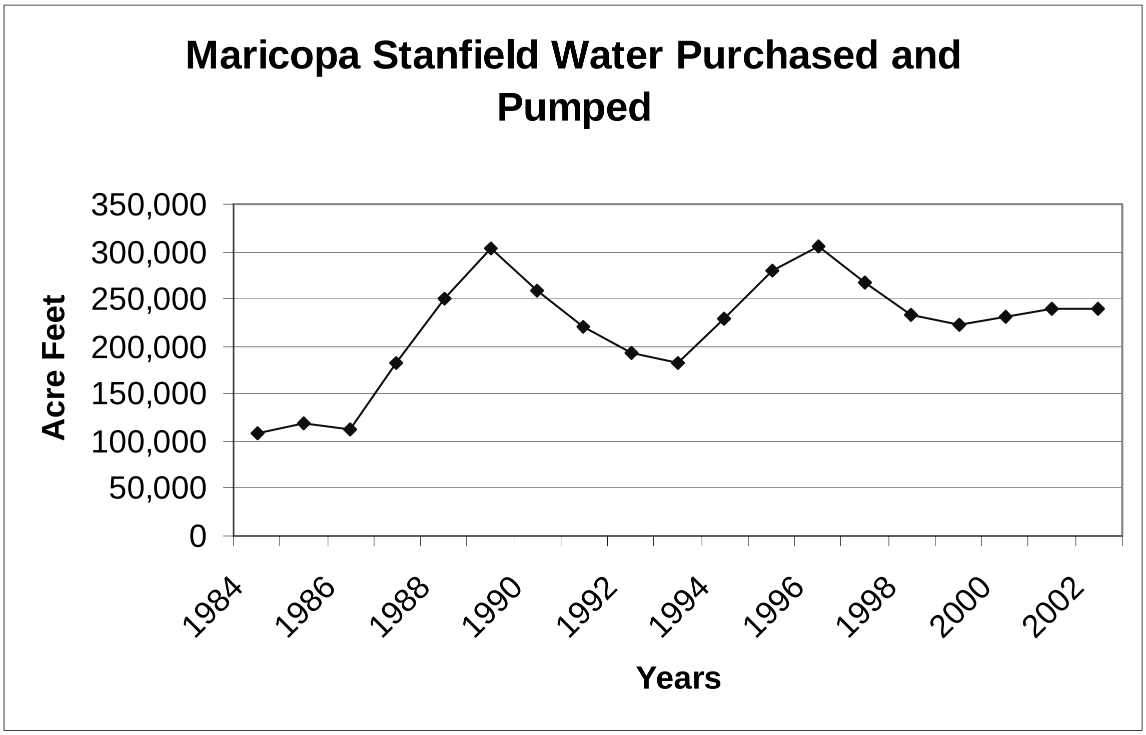
Durum Wheat Price: see Buckeye, A-3.1

Alfalfa Acres: see Buckeye, A-3.1

Cotton Acres: see Buckeye, A-3.1

A-3.5 Maricopa-Stanfield Irrigation and Drainage District

Manager:	Grant Ward, General Manager
Location:	Maricopa & Stanfield, Arizona
Irrigable Acres:	83,000
Active Management Area (AMA):	Pinal
Water Sources:	Groundwater, CAP water



Source: ADWR

<u>Explanation of Data</u>

Water Purchased: Data is from ADWR Tucson office.

Water Price: Data is the variable cost per acre-foot. Data is from Daugherty (1996) and Maricopa-Stanfield Irrigation and Drainage District. The cost of pumping the groundwater was derived for 1984-1988. The data for 1989-2002 is from MSIDD since the district has controlled nearly all the wells since 1989. A weighted price was calculated accounting for seasonal prices and quantities.

Annual Precipitation: Data is recorded in inches and was gathered from NOAA stations deemed closest to the irrigation district (see Table A-4 in the Appendix).

Average Temperature: see Buckeye, A-3.1

Alfalfa Price: see Buckeye, A-3.1

Barley Price: see Buckeye, A-3.1

Cotton Price: see Buckeye, A-3.1

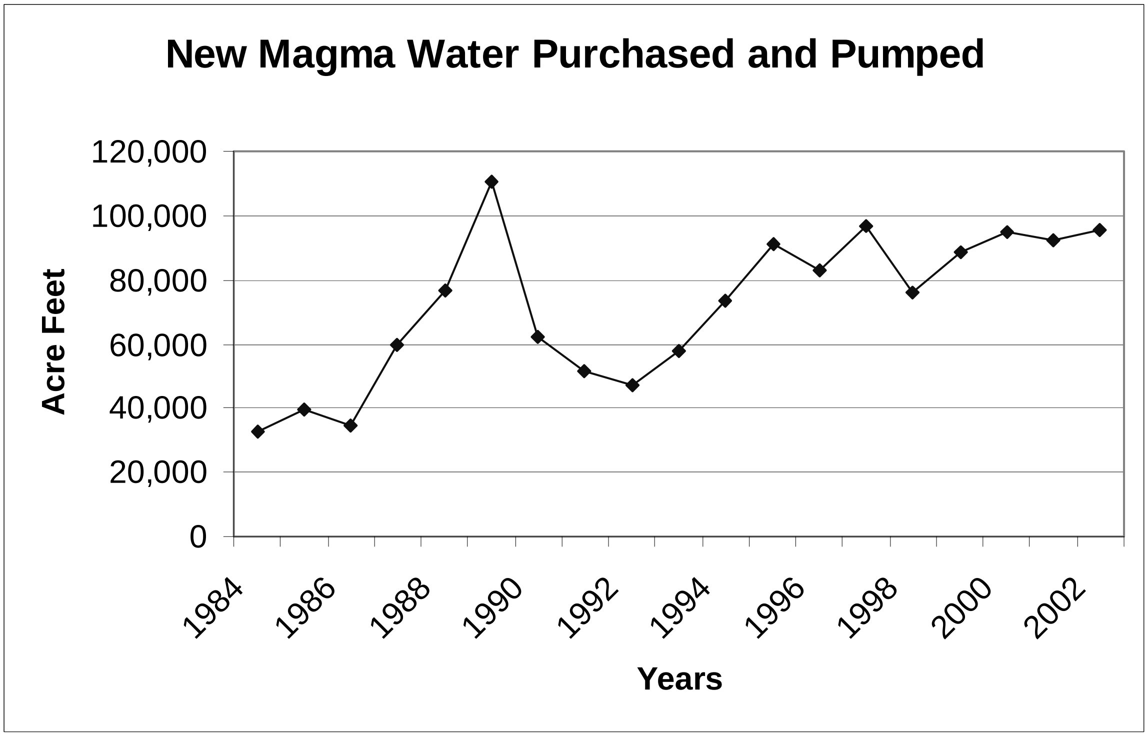
Durum Wheat Price: see Buckeye, A-3.1

Alfalfa Acres: see Buckeye, A-3.1

Cotton Acres: see Buckeye, A-3.1

A-3.6 New Magma Irrigation and Drainage District

Manager: William Van Allen, Manager
Location: Queen Creek, Arizona
Irrigable Acres: 26,900
Active Management Area (AMA): Maricopa
Water Sources: Groundwater from private wells, CAP water



Source: ADWR

<u>Explanation of Data</u>

Water Purchased: Data is from ADWR Tucson office.

Water Price: Data is the variable cost per acre-foot. Data is from Daugherty (1996), Queen Creek Irrigation and Drainage District, and New Magma Irrigation and Drainage District. Weighted CAP water prices were calculated based on seasonal prices and quantities from the arrival of CAP water in 1986. The cost of pumping the groundwater was derived from Daugherty and QCIDD. Electrical prices came from Queen Creek's gross power price. The missing observations in electrical prices were found by fitting a regression line in OLS. The quantity of groundwater pumped was calculated by subtracting the district's CAP water figures from ADWR's total consumption figures. A weighted average price of water was then computed.

Annual Precipitation: Data is recorded in inches and was gathered from NOAA stations deemed closest to the irrigation district. If data is missing from the primary station, data from the secondary and tertiary stations were collected respectively. In 2000, data was missing from all three stations, and monthly data was collected from the primary, secondary, and tertiary stations respectively to estimate an annual total (see Table A-4 in the Appendix).

Average Temperature: see Buckeye, A-3.1

Alfalfa Price: see Buckeye, A-3.1

Barley Price: see Buckeye, A-3.1

Cotton Price: see Buckeye, A-3.1

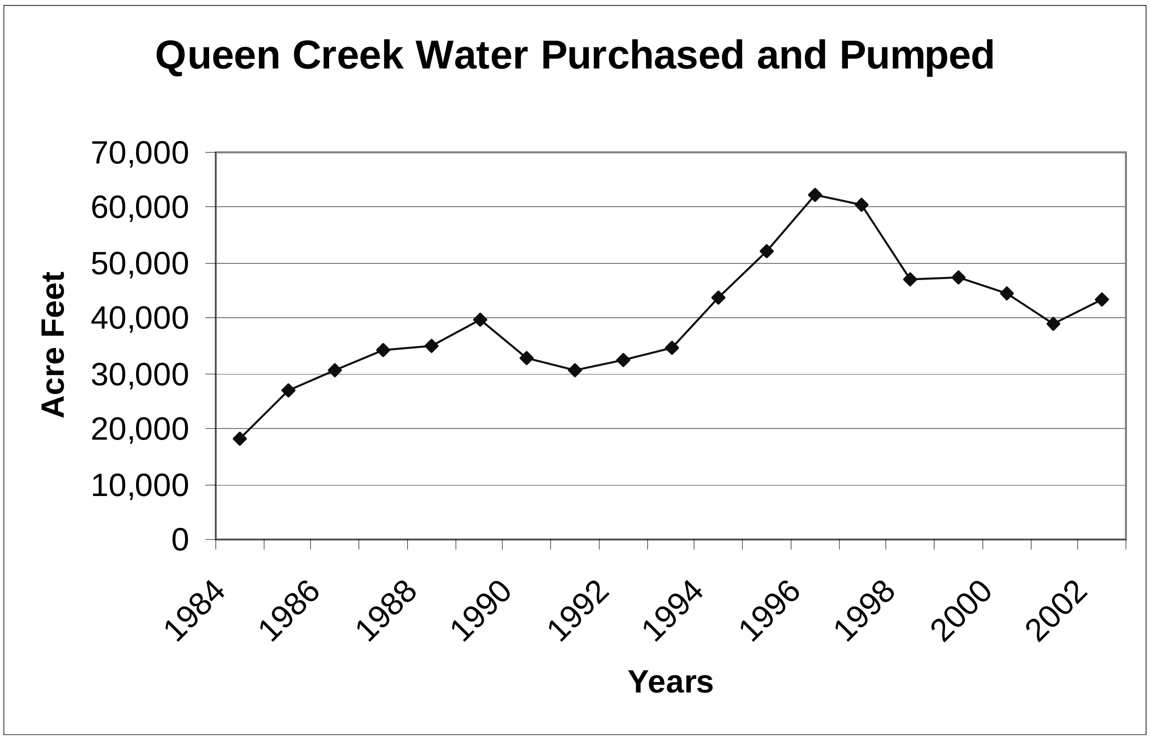
Durum Wheat Price: see Buckeye, A-3.1

Alfalfa Acres: see Buckeye, A-3.1

Cotton Acres: see Buckeye, A-3.1

A-3.7 Queen Creek Irrigation and Drainage District

Manager: Dean Griffith, Manager
Location: Queen Creek, Arizona
Irrigable Acres: 16,000
Active Management Area (AMA): Maricopa
Water Sources: Groundwater from private wells, CAP water



Source: ADWR

<u>Explanation of Data</u>

Water Purchased: Data is from ADWR Tucson office.

Water Price: Data is the variable cost per acre-foot. Data is from Daugherty (1996) and New Magma Irrigation and Drainage District. Weighted CAP water prices were calculated based on seasonal prices and quantities from the arrival of CAP water in 1987. The cost of pumping the groundwater was derived from Daugherty and QCIDD. Electrical prices came from Queen Creek's gross power price minus rebates to the growers. The missing observations in electrical prices were found by fitting a regression line in OLS. The quantity of groundwater pumped was calculated by subtracting the district's CAP water figures from ADWR's total consumption figures. A weighted average price of water was then computed.

Annual Precipitation: Data is recorded in inches and was gathered from NOAA stations deemed closest to the irrigation district. If data is missing from the primary station, data from the secondary and tertiary stations were collected respectively. In 1995, data was missing from all three stations, and monthly data was collected from the primary, secondary, and tertiary stations respectively to estimate an annual total (see Table A-4 in the Appendix).

Average Temperature: see Buckeye, A-3.1

Alfalfa Price: see Buckeye, A-3.1

Barley Price: see Buckeye, A-3.1

Cotton Price: see Buckeye, A-3.1

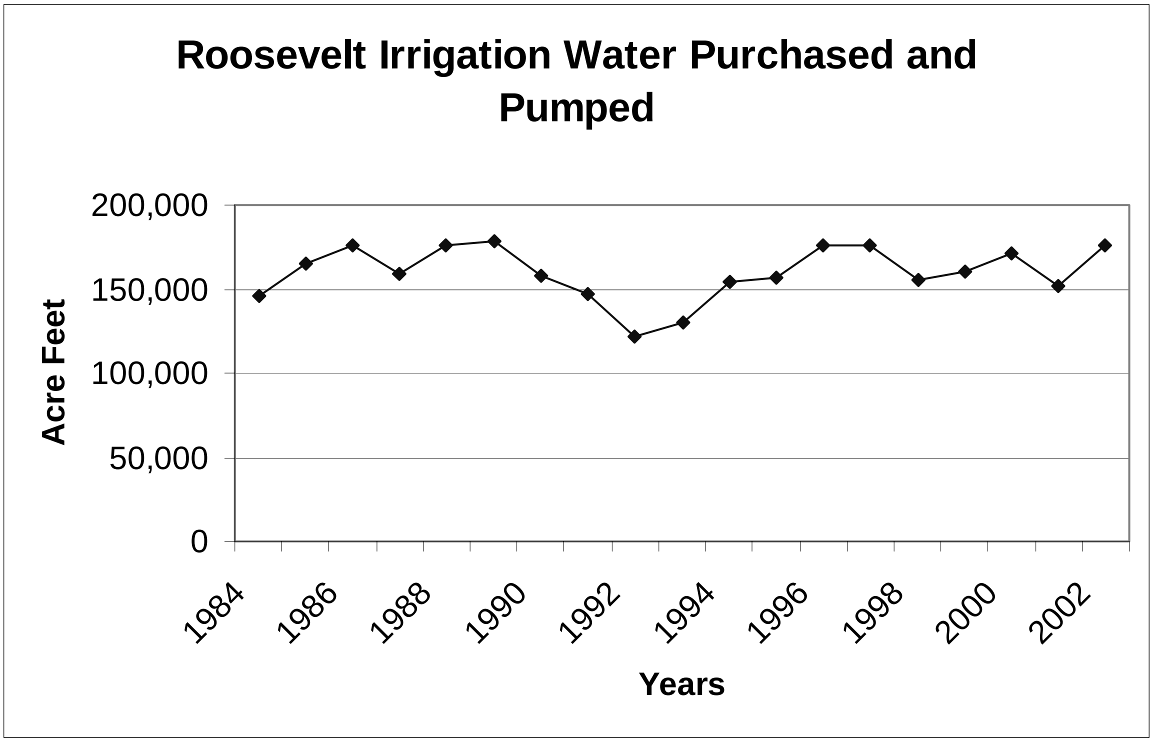
Durum Wheat Price: see Buckeye, A-3.1

Alfalfa Acres: see Buckeye, A-3.1

Cotton Acres: see Buckeye, A-3.1

A-3.8 Roosevelt Irrigation District

Manager: Stan Ashby, Superintendent
Location: Buckeye, Arizona
Irrigable Acres: 34,800
Active Management Area (AMA): Maricopa
Water Sources: Groundwater



Source: ADWR

<u>Explanation of Data</u>

Water Purchased: Data is from ADWR Tucson office.

Water Price: Data is the variable cost per acre-foot. Data is from Roosevelt Irrigation District.

Annual Precipitation: Data is recorded in inches and was gathered from NOAA stations deemed closest to the irrigation district. If data is missing from the primary station, data from the secondary station was collected (see Table A-4 in the Appendix).

Average Temperature: see Buckeye, A-3.1

Alfalfa Price: see Buckeye, A-3.1

Barley Price: see Buckeye, A-3.1

Cotton Price: see Buckeye, A-3.1

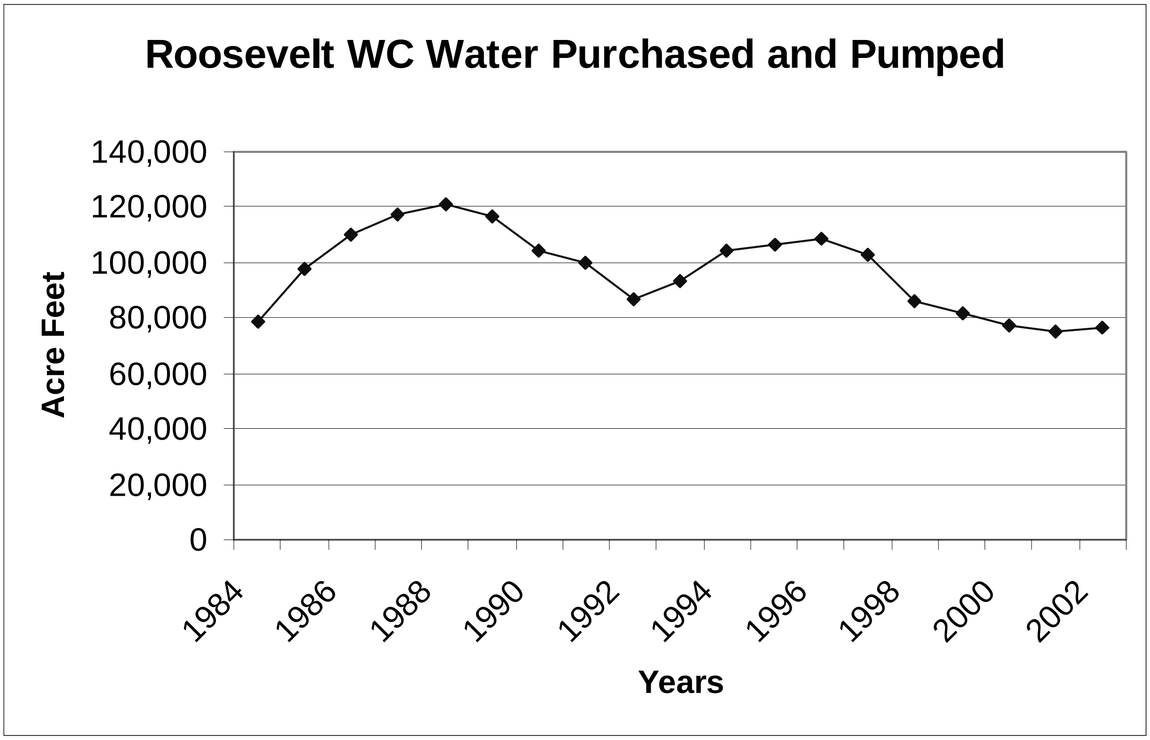
Durum Wheat Price: see Buckeye, A-3.1

Alfalfa Acres: see Buckeye, A-3.1

Cotton Acres: see Buckeye, A-3.1

A-3.9 Roosevelt Water Conservation District

Manager: Michael Leonard, Manager
Location: Mesa, Arizona
Irrigable Acres: 31,000
Active Management Area (AMA): Maricopa
Water Sources: Groundwater, Salt-Verde River System



Source: ADWR

Explanation of Data

Water Purchased: Data is from ADWR Tucson office.

Water Price: Data is the variable cost per acre-foot. Data is from Roosevelt Water Conservation District.

Annual Precipitation: Data is recorded in inches and was gathered from NOAA stations deemed closest to the irrigation district. If data is missing from the primary station, data from the secondary and tertiary stations were collected respectively (see Table A-4 in the Appendix).

Average Temperature: see Buckeye, A-3.1

Alfalfa Price: see Buckeye, A-3.1

Barley Price: see Buckeye, A-3.1

Cotton Price: see Buckeye, A-3.1

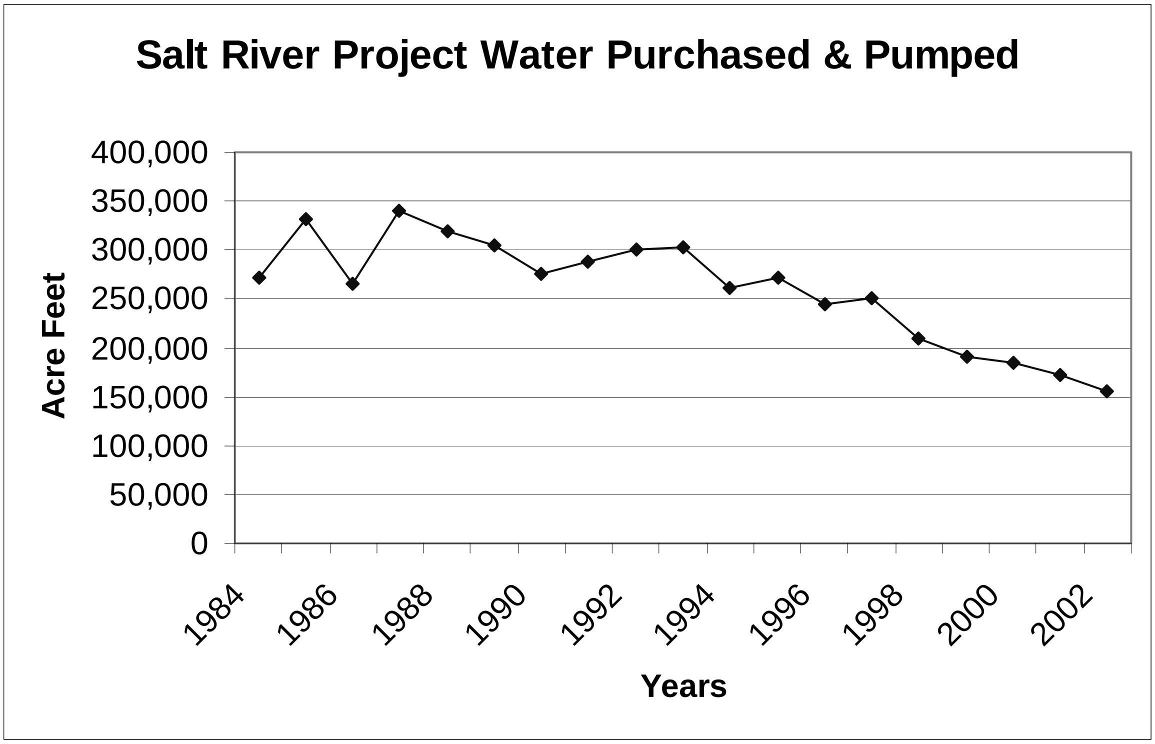
Durum Wheat Price: see Buckeye, A-3.1

Alfalfa Acres: see Buckeye, A-3.1

Cotton Acres: see Buckeye, A-3.1

A-3.10 Salt River Project

Manager:	Mike Ference, Principal Analyst
Location:	Phoenix, Arizona
Irrigable Acres:	36,328
Active Management Area (AMA):	Maricopa
Water Sources:	Groundwater, Salt-Verde River System



Source: ADWR

<u>Explanation of Data</u>

Water Purchased: Data is from ADWR Tucson office.

Water Price: Data is the variable cost per acre-foot. Data is from SRP.

Annual Precipitation: Data is recorded in inches and was gathered from NOAA stations deemed closest to the irrigation district (see Table A-4 in the Appendix).

Average Temperature: see Buckeye, A-3.1

Alfalfa Price: see Buckeye, A-3.1

Barley Price: see Buckeye, A-3.1

Cotton Price: see Buckeye, A-3.1

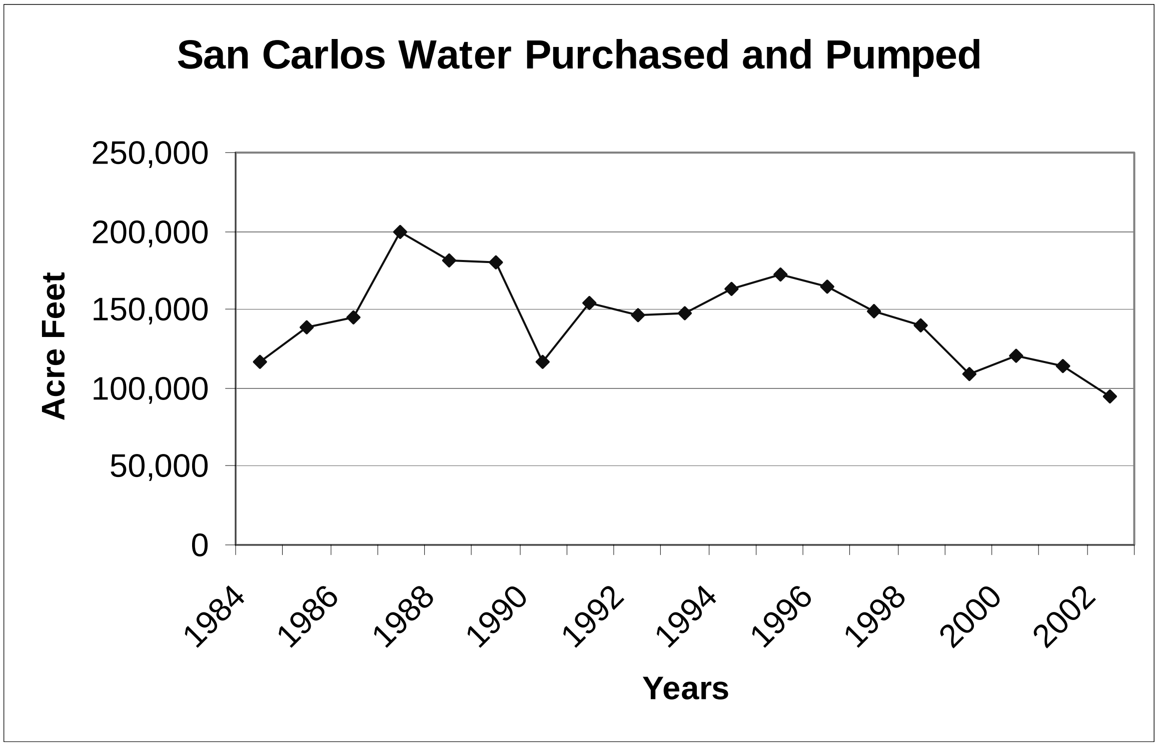
Durum Wheat Price: see Buckeye, A-3.1

Alfalfa Acres: see Buckeye, A-3.1

Cotton Acres: see Buckeye, A-3.1

A-3.11 San Carlos Irrigation and Drainage District

Manager: Douglas Mason, General Manager
Location: Coolidge, Arizona
Irrigable Acres: 45,000
Active Management Area (AMA): Pinal
Water Sources: Groundwater, Gila River surface and stored water, CAP water



Source: ADWR

<u>Explanation of Data</u>

Water Purchased: Data is from ADWR Tucson office.

Water Price: Data is the variable cost per acre-foot. Data is from Daugherty (1996), DWR, and San Carlos Irrigation and Drainage District. The cost of pumping the groundwater was derived for 1984-2002. The district began receiving CAP water in 1990. The district also has groundwater and surface water owned wells. This water is charged an assessment fee for the first two acre-feet of water apportioned, and $20 per additional acre-foot of the apportionment. A weighted price was calculated for the district pumped and surface water. Quantities of grower owned wells were calculated by subtracting CAP quantities, district pumped water, and district surface water from DWR figures. Groundwater prices were calculated from Daugherty (1996), and electrical prices were obtained from ED-2 for 1993-2002. Pump tax was gathered by DWR for 1990-2002. A weighted water price was calculated based on the various types of water.

Annual Precipitation: Data is recorded in inches and was gathered from NOAA stations deemed closest to the irrigation district. If data is missing from the primary station, data from the secondary station was collected (see Table A-4 in the Appendix).

Average Temperature: see Buckeye, A-3.1

Alfalfa Price: see Buckeye, A-3.1

Barley Price: see Buckeye, A-3.1

Cotton Price: see Buckeye, A-3.1

Durum Wheat Price: see Buckeye, A-3.1

Alfalfa Acres: see Buckeye, A-3.1

Cotton Acres: see Buckeye, A-3.1

Table A-4 NOAA Weather Stations for Irrigation District Data				
	Primary	Secondary	Tertiary	Quaternary
Buckeye	21026	28598	29634	---
Central Arizona	22807	21306	21314	---
Cortaro-Marana	28795	26513	28817	---
Hohokam	21314	22807	23027	---
Maricopa-Stanfield	25270	27370	21306	---
New Magma	23027	21514	20498	21314
Queen Creek	21514	22782	21314	---
Roosevelt Irrigation	28598	29634	24829	---
Roosevelt WC	25467	22782	21514	28499
Salt River Project	28499	26481	25467	---
San Carlos	23027	21314	22807	---