FACTORS AFFECTING AGRICULTURAL WATER USE AND SOURCING IN IRRIGATION DISTRICTS OF CENTRAL ARIZONA

by

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STATEMENT BY AUTHOR

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LIST OF ACRONYMS AND INITIALISMS

ADWR	Arizona Department of Water Resources
AF	acre-feet
AFY	acre-feet per year
AMA	Active Management Area
AMS	Agricultural Marketing Service
APA	Arizona Power Authority
AWBA	Arizona Water Banking Authority
AWP	Adjusted World Price
AZMET	Arizona Meteorological Network
BoR	Bureau of Reclamation
CAGRD	Central Arizona Groundwater Replenishment District
CAP	Central Arizona Project
CAWCD	Central Arizona Water Conservation District
CLIMAS	Climate Assessment for the Southwest
CRB	Colorado River Basin
DSR	Desert Southwest Region
ED	Electrical District
ERS	Economic Research Service
GDP	Gross Domestic Product
GHCN-D	Global Historical Climate Network – Daily
GL	gigaliters = 1 billion liters
GMA	Groundwater Management Act
GSF	Groundwater Savings Facility
ID	Irrigation District
IDD	Irrigation and Drainage District
IGFR	Irrigation Grandfathered Right
INA	Irrigation Non-expansion Area
kWh	kilowatt-hour
LTSC	Long-Term Storage Credit
MAF	million acre-feet
ML	megaliters = 1 million liters
MSA	Metropolitan Statistical Area
M&I	Municipal & Industrial
NASS	National Agricultural Statistics Service
NCDC	National Climate Data Center
NGS	Navajo Generating Station
NIA	non-Indian agriculture
NOAA	National Oceanic and Atmospheric Administration
SPI	Standardized Precipitation Index
SRP	Salt River Project
USDA	United States Department of Agriculture
WAPA	Western Area Power Administration
WRRC	Water Resources Research Center

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ABSTRACT

The purpose of this research is to quantify how macro-scale factors such as weather, crop prices, and land conversion affect agricultural water use at the irrigation district level in central Arizona and to understand what constraints and considerations district managers face when making water-sourcing decisions. A conceptual model is developed and econometrically estimated finding that much of the annual variation in total water use for agriculture can be explained by differences in precipitation, cotton prices, and alfalfa prices. Further, results from empirical analysis support the notion that total water use for agriculture has been greatly affected by land conversion from agriculture to other uses. Irrigation district manager interviews indicate that the water sourcing process is very similar across districts in central Arizona and has varied little since 1995, due to common constraints. This research lays an important foundation for future models designed to forecast agricultural water use in central Arizona.

CHAPTER 1: INTRODUCTION

1.1 Motivation and Contribution

Two questions act as the motivation for this thesis. First, what factors influence overall water use annually for irrigated agriculture in central Arizona? Second, how do central Arizona irrigation districts make water-sourcing decisions to meet the demands of their member growers and what types of constraints do they face in making those decisions?

Understanding factors that affect water use for agriculture in central Arizona is important for a number of reasons. Since water use by the agricultural sector makes up such a large portion of overall water use in such an arid state with a growing population, policy makers are likely to create regulations encouraging agriculture to reduce its water use in the future (Frisvold, Wilson, & Needham, 2007). Policy makers need to have knowledge of factors affecting agricultural water use, including magnitude of effect, in order to design efficient policies that have the desired outcome. In addition, many parties rely on water use projections that were constructed from a historical understanding of factors affecting water use. For example, canals deliver a large quantity of water used by irrigated cropland in central Arizona. These canals, from the large Central Arizona Project (CAP) canal to the smaller farm section-scale canals, have a finite capacity. If those projecting annual water use lack an understanding of factors affecting agricultural water use, such projections are likely to be inaccurate. Under predicting water use could lead to infrastructure capacity induced shortages during crucial growing periods that reduce agricultural profits and hurt rural economies that are vital to the state (Betcher, 2013). One particular factor potentially affecting water use is water price. With water prices of some sources projected to increase dramatically in coming years, water use is likely to decline (Central Arizona Water Conservation District, 2013b). Determining the magnitude of decline is important in predicting how much water agriculture will use in the future and how much will be left for other sectors. In the longer-term, other issues surrounding water use also become important. Given climate change research, many experts believe Arizona will experience a warmer future with more variable precipitation (U.S. Bureau of Reclamation, 2012). Quantifying how increases in temperature and fluctuations in precipitation affect overall water use in agriculture is, therefore, important in understanding the future of water use as a whole. By no means is this list of reasons exhaustive, it simply provides a glimpse of how important this issue is for Arizona.

Irrigation districts play a central role in how much water the agricultural sector uses and, more importantly, where the water comes from. Having knowledge of how irrigation districts make sourcing decisions and what constraints they face in making those decisions is important for two reasons. First, the cost of water to growers is a function of where their irrigation districts are able to source water. Less expensive water sources mean less costly water for growers increasing their profit per acre, possibly inducing them to plant more acres and demand more water. Further, water use is sometimes constrained by availability. District sourcing decisions and constraints affect how much individual source price changes and quantity constraints are passed on to growers. Second, irrigation district sourcing decisions have critical long-term implications. Take groundwater for example. Arizona is keenly aware of the consequences of groundwater overdraft as in the 1970s, the state was annually pumping 2.2 million-acre feet (MAF) [2,714 gigaliters (GL)] more than nature could replenish (Glennon, 1995). These consequences, already experienced in parts of the state, include land subsidence, increasing soil salinity, and falling groundwater levels that lead to losses in plant and animal life and diversity (Arizona Department of Water Resources, 2008; Zektser, Loáiciga, & Wolf, 2005). If irrigation districts source a larger percentage of the water they provide to their member growers from the ground, these negative effects will likely be enhanced. Similar negative effects could also be the result of high irrigation district water prices that drive growers to use groundwater from their own wells instead of from any renewable surface water supplies the district might provide.

This thesis quantifies the impact of annual weather variation on water use of agricultural irrigation in central Arizona.[1] It also quantifies the relationship between agricultural land conversion and water use for agriculture in central Arizona. Finally, it formally describes the decision making process of irrigation district managers in central Arizona and what constraints they face.

In order to examine the two questions posed at the beginning of this thesis, background essentials must be established to interpret the rest of the analysis. The next section describes the nature of agriculture and associated water use in Arizona. Thereafter, a basic background in topics fundamental to water use in Arizona is provided. A summary of the methodology of analysis, findings, and how the rest of the paper proceeds completes the chapter.

1.2 Background

1.2.1 Arizona Agriculture

Agriculture in Arizona, at first glance, might seem to be an oxymoron. It is no secret that the state, proudly displaying a saguaro cactus on its license plate, has a dry climate. More specifically, Arizona receives an average of 13.09 inches [33.2 centimeters (cm)] of precipitation annually, even less in agricultural areas (U.S. Department of the Interior, 2003). That is less than half of Iowa's 33.11 inches [84.1 cm], the state many people associate with agriculture (U.S. Department of the Interior, 2003). Only Wyoming, Utah, and Nevada receive less average annual precipitation than Arizona (U.S. Department of the Interior, 2003). Still, there is a reason many Arizonan schoolchildren learned that three of the Five Cs are Cotton, Citrus, and Cattle; Copper

[1] Statistical significance is defined in Chapter 6

and Climate being the remaining two (Larson, 2002). While the Five Cs highlight the pillars of the early state economy, agriculture has been important in Arizona for far longer. The Hohokam Native American culture thrived in the Salt River Valley, where Phoenix now lies, as far back as the time of the Roman Empire, using canals, impressive even by today's standards, to divert the Salt River for agricultural irrigation (Reisner, 1986).

Today, agriculture is a much smaller component of the state's economy than it once was. A recent economic impact study done by agricultural economists at The University of Arizona found the following (Department of Agricultural and Resource Economics, 2010): Averaged between 2005 and 2007, crop and livestock production directly contributed $1.6 billion annually to the state's gross domestic product (GDP). While that might sound like a large number, it represents only 0.7 percent of the state's $232.5 billion total GDP. This relatively small percentage is not out of the norm nationwide where crop and livestock production contribute 0.85 percent of total GDP in the U.S. For comparison, the mining sector, another historic pillar, only accounted for 1.6 percent of Arizona's GDP in 2007. When accounting for value added, the agricultural sector contributed $4.0 billion to the state's economy in 2007.

With regard to population, dramatic growth since the 1970s led Arizona's march up the state population rankings from 29th in 1980 to 16th in 2010 (U.S. Census Bureau, 2011). Much of that growth occurred on farmland in the Phoenix Metropolitan Statistical Area (MSA)[2] that now contains roughly 4.3 of the state's 6.5 million people (U.S. Census Bureau, 2012). Despite a tremendous conversion of land from agricultural to urban uses, Arizona's agricultural sector still boasts some high national production rankings: 2nd in cantaloupe and honeydew melons, head and leaf lettuce, spinach, broccoli, cauliflower, and lemons; 1st in average alfalfa yield per acre, 4th in durum wheat production, 7th in upland cotton production, and 12th in milk and dairy

[2] Phoenix-Mesa-Scottsdale Metropolitan Statistical Area (MSA) includes Maricopa & Pinal County

product output (National Agricultural Statistics Service, Arizona Field Office, 2012). Table 1.1 displays the number of acres devoted to major crops and associated production values across the state in 2011 (National Agricultural Statistics Service, Arizona Field Office, 2012).

Table 1.1: Major Crops Grown in Arizona (2011)

Crop	Acres Harvested	Percent Harvested	Production Value	Percent Production Value
Alfalfa Hay	250,000	27.7%	$460,650,000	19.2%
Upland Cotton	248,000	27.5%	$362,496,000	15.1%
Durum Wheat	79,000	8.8%	$66,625,000	2.8%
Barley	64,000	7.1%	$37,600,000	1.6%
Head, Leaf, & Romaine Lettuce	63,100	7.0%	$828,690,000	34.5%
Other Hay	35,000	3.9%	$23,940,000	1.0%
Corn (Grain)	32,000	3.6%	$38,016,000	1.6%
Total Harvested Cropland[3]	901,000		$2,404,336,000	

Source: (National Agricultural Statistics Service, Arizona Field Office, 2012)

Arizona has three major growing regions. Each region specializes in crops based on climate, soils, and available water sources (Frisvold, 2004a). The three regions, their locations, number of irrigated acres, and major crops grown as of the 2007 Census of Agriculture are presented in Table 1.2 (U.S. Department of Agriculture, National Agricultural Statistics Service, 2012; U.S. Department of Agriculture, 2007).

Table 1.2: Major Regions of Agriculture in Arizona

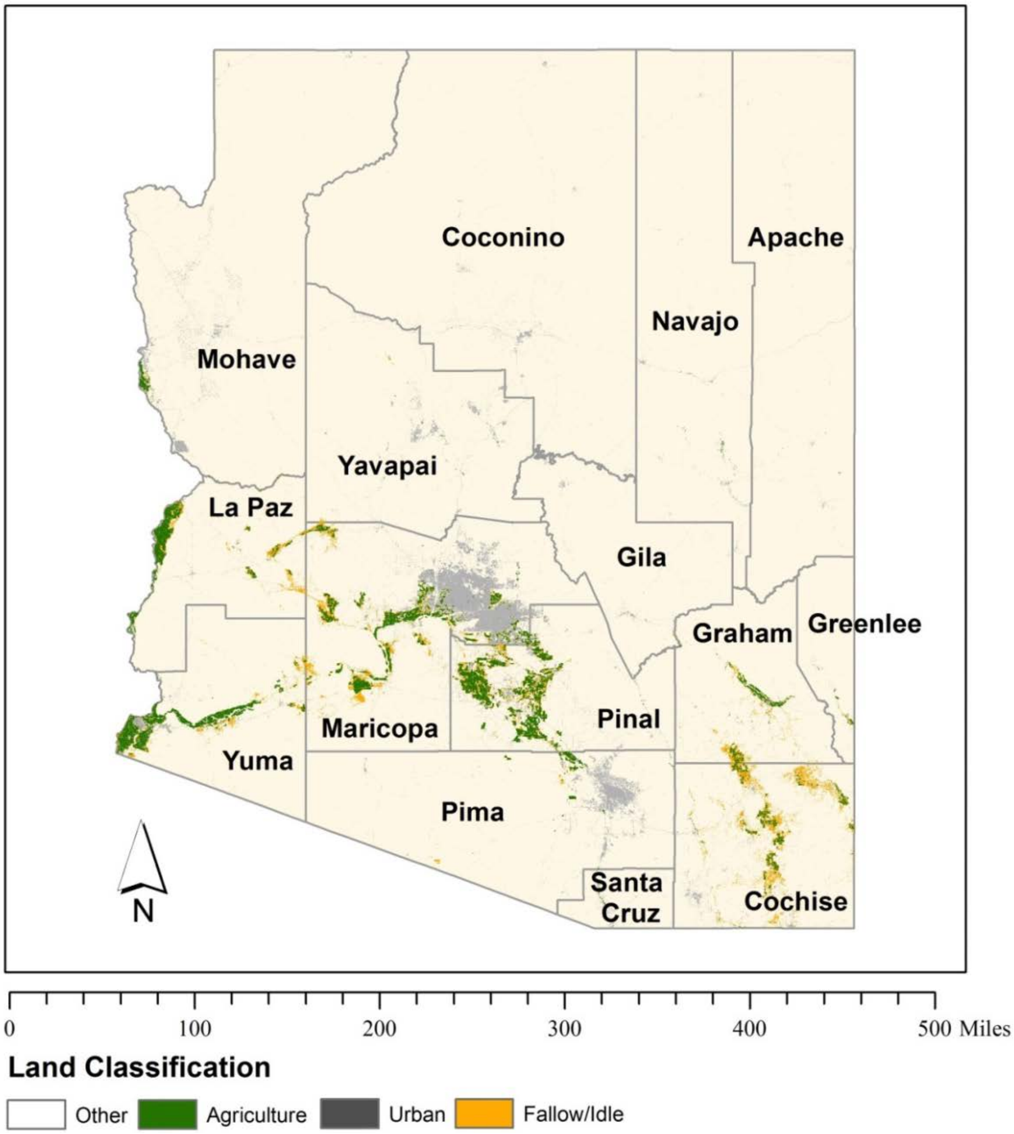
Colorado River: Colorado River and Lower Gila River valleys			
	Yuma County	174,245 acres irrigated	Vegetables (including Lettuce), Hay, Durum Wheat, & Cotton
	La Paz County	100,498 acres irrigated	
	Mojave County	17,107 acres irrigated	
Central: West of Phoenix south to Tucson			
	Pinal County	215,121 acres irrigated	Alfalfa Hay, Upland Cotton, Durum Wheat, Barley & Vegetables
	Maricopa County	199,367 acres irrigated	
	Pima County	35,684 acres irrigated	
Southeast: Wilcox Basin & Upper Gila River valley			
	Cochise County	67,598 acres irrigated	Hay, Corn (Grain), Cotton, & Pecans
	Graham County	28,300 acres irrigated	

Source: (U.S. Department of Agriculture, 2007)

[3] Data from USDA-NASS Quick Stats 2.0 website

Figure 1.1 provides a spatial display of where irrigated acres are located with respect to county boundaries based on the 2006 National Land Cover Database (U.S. Geological Survey, 2006).

Figure 1.1: Map of Irrigated Acres in Arizona



Source: (U.S. Geological Survey, 2006); map created by Brett Fleck

The focus of this research is the central Arizona region. The drivers for studying this region are twofold. First, it is the only region with access to CAP canal water from the Colorado River (Arizona Department of Water Resources, 2010). Second, it is the only major agricultural region in the state subject to groundwater regulations stemming from the 1980 Groundwater Management Act.

1.2.2 Water for Agriculture

Agriculture is the most dominant economic sector in Arizona water use. According to The University of Arizona's Water Resources Research Center (WRRC), the agricultural sector uses around 75 percent of the state's water supply annually (The University of Arizona, Water Resources Research Center, 2007).[4] Average state usage of water by all sectors is eight million-acre feet (MAF) [9,868 GL], though, estimates vary above and below this figure (The University of Arizona, Water Resources Research Center, 2007; McKinnon, 2005). The estimated 5.8 MAF [7,154 GL] the agricultural sector uses could support roughly 23 million people; keeping in mind Arizona's current population is 6.5 million.[5] Many farms in central Arizona receive all or a significant portion of their water supply from irrigation districts (Arizona Department of Water Resources, 2010).

There are 39 irrigation districts within the five Active Management Areas (AMA) of central Arizona, described later (Arizona Department of Water Resources, 2010). However, only a fraction of the districts comprise most of the water demand for agriculture (Arizona Department of Water Resources, 2010). These districts were organized throughout the 20th century for a similar purpose. Since irrigation infrastructure is so costly, it is more economical for growers to use economies of scale in constructing distribution systems. The mission statement or goal of each district in central Arizona is very similar. The districts seek to provide water efficiently, at the lowest practicable and stable cost, while working to enhance property values of their members. The previous statement is a paraphrased combination from both the

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[4] Arizona water use noted in this paragraph are consumptive use figures

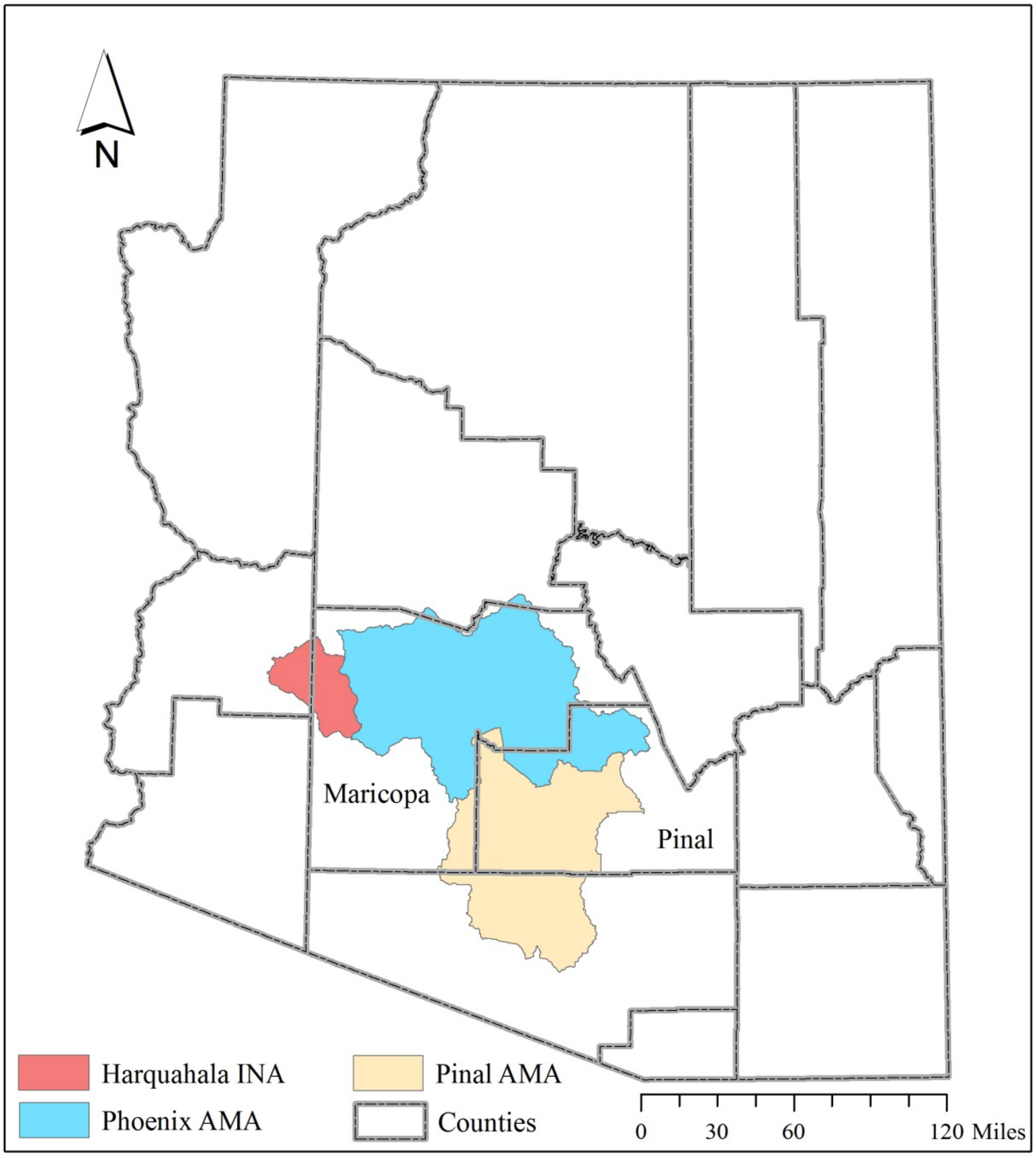
[5] Assumes one person uses 0.25 AF per year

Central Arizona Irrigation and Drainage District (IDD) and San Carlos IDD mission statement and goals. Though each irrigation district operates under a similar premise, they carry out their mission in different ways depending on many factors. Factors that influence the way districts carry out their mission include size, built infrastructure, spatial layout, soil composition, control of groundwater pumps, and most importantly, water supply availability. Water supplies and associated quantities and qualities available to irrigation districts vary considerably. For example, some districts have four sources available to them while others have only two. For most districts in central Arizona, present supply source conditions did not solidify until the completion of the CAP canal in the late 1980s. Until then, many districts had only one source to draw from, groundwater.

Before detailing the primary sources of water for irrigation in central Arizona, a spatial distinction should be made. Crop data, such as acres grown or production value, are based on county boundaries. When referencing water supply and usage data, these values are based on groundwater basins classified as AMAs. Only the Phoenix and Pinal AMAs are of interest to this thesis. Figure 1.2 shows how the Phoenix AMA roughly corresponds to Maricopa County and the Pinal AMA roughly corresponds to Pinal County. This thesis combines data at the county and AMA spatial scales. A second distinction needing to be made is a legal one. Active Management Areas were established based on the 1980 Groundwater Management Act (GMA) (Arizona Department of Water Resources, 2008). The GMA set in place groundwater monitoring and withdrawal regulations for all lands within the AMAs except those on Indian reservations. Unless otherwise noted, I present water supply and usage data for agriculture excluding Indian reservations. Following the vocabulary in common use, including by the Central Arizona Water

Conservation District (CAWCD), I refer to this water as non-Indian agriculture (NIA) water (Arizona Department of Water Resources, 2010).

Figure 1.2: Arizona AMAs and County Boundaries



Source: (Arizona Department of Water Resources, 2013c); map created by Brett Fleck

The earliest source of water to irrigation districts was surface water originating in the central highlands of Arizona and New Mexico, also known as the transition zone (Gooch, Cherrington, & Reinink, 2007; The University of Arizona, Water Resources Research Center, 2007). The transition zone separates the basin and range geography of the desert, where Phoenix is located, with the Colorado Plateau geography of the high desert, where Holbrook and Winslow are located, in Arizona and Western New Mexico (Arizona Department of Water Resources, 2010). These waters largely come from the spring snowmelt and flow down the Gila, Salt, and Agua Fria Rivers where they are diverted, in part, for agricultural irrigation (Arizona Department of Water Resources, 2010). The amount of surface water supply in any given year depends primarily on precipitation and the management of reservoirs built along the rivers. Between 2001 and 2005, a combined average of just less than 250,000 AF [308,370 ML] of surface water was used for NIA in the Phoenix and Pinal AMAs annually (Arizona Department of Water Resources, 2010). This total is roughly 15 percent of all non-Indian water used for agricultural irrigation within the two AMAs. Not all irrigation districts in central Arizona have access to surface water originating in the transition zone. An irrigation district must have a legal entitlement to use surface water supplies (Arizona Department of Water Resources, 2010). These entitlements were largely set based on historical usage under the doctrine of prior appropriation commonly referred to as, “First in time, first in right (Arizona Department of Water Resources, 2010).” Since the long-distance conveyance of water via canals did not largely exist outside of the Salt River Valley, as previously described, those first in time were those nearest to the source.

The second, and most abundant, source of water available to irrigation districts is groundwater. According to the Arizona Water Atlas, Arizona has a huge endowment of groundwater beneath much of the state, tens of millions of acre-feet (Arizona Department of Water Resources, 2010). However, the water varies considerably in depth and salinity, with much of it not currently economically recoverable (Arizona Department of Water Resources, 2010). Prior to the completion of the CAP canal and after the introduction of cheap electricity from Hoover Dam along with increased pumping efficiencies around World War II, groundwater supplied the majority of irrigation water in central Arizona (Glennon, 1995). This reliance on a slowly replenishing resource caused declining aquifer levels that ultimately led to the passage of the 1980 Groundwater Management Act. Between 2001 and 2005, the Phoenix and Pinal AMAs pumped a combined average of 733,900 AF [905,252 ML] of water representing just less than 44 percent of the total amount used for NIA within the two AMAs (Arizona Department of Water Resources, 2010).

The third source of water comes from the Colorado River via the CAP canal and is generally broken into two major categories with respect to agricultural use. The CAP canal provides water to irrigation districts both as a direct supply and as a replacement to groundwater that would have otherwise been pumped. Direct supplies for agriculture primarily come from CAP's Ag Settlement Pool. This is a 400,000 AF [493,392 ML] pool of water designated for participating irrigation districts (Central Arizona Water Conservation District Board, 2002). It is important to note explicitly that while CAP canal water is surface water from the Colorado River, the term surface water usually refers to non-Colorado River supplies in the state's water lexicon. This linguistic distinction is observed for the remainder of the thesis. The Phoenix and Pinal AMAs received a combined 664,700 AF [819,895 ML] of CAP water for NIA annually representing almost 40 percent of use for agriculture (Arizona Department of Water Resources, 2010). Central Arizona Project water used in place of groundwater pumping is known as In-lieu water. In-lieu water generates long-term storage credits (LTSC) associated with the groundwater not pumped for the original owner of the CAP water, if the groundwater is not pumped for at least one year (Arizona Department of Water Resources, 1999). In most cases, the original owner is the Arizona Water Banking Authority (AWBA), the Central Arizona Groundwater Replenishment District (CAGRD), or municipalities such as the City of Phoenix (Central Arizona Water Conservation District, 2011b). Districts where CAP In-lieu water is supplied for the purpose of 'storing' groundwater are known as Groundwater Savings Facilities (GSF). These facilities, farms really, must be permitted through the Arizona Department of Water Resources (ADWR) (Arizona Department of Water Resources, 1999). The GSF idea is straightforward. A city, such as Phoenix, contracts with a permitted irrigation district to take delivery of its unused allocation of CAP canal water in lieu of pumping groundwater. The untouched groundwater is considered saved or stored water and generates a LTSC that allows its owner, Phoenix, to pump groundwater in the same amount at a later date, as long as the pumping occurs in the same AMA that the In-lieu water was used (Arizona Department of Water Resources, 2010).

The fourth source, treated effluent, is only available to a few districts and subsequently supplies just two percent of non-Indian agricultural water use in central Arizona (Arizona Department of Water Resources, 2010). The two percent, equal to nearly 30,000 AF [37,000 ML], is subject to state regulations governing treatment standards and associated uses (Arizona Department of Water Resources, 2013d). One example of treated effluent being used for agricultural irrigation comes from Roosevelt Water Conservation District (RWCD). The San Tan Electrical Generating Plant operated by Salt River Project (SRP), provides high quality industrial wastewater to RWCD for irrigation purposes (Leonard, 2013). While treated effluent use for agriculture is likely to increase in the future as other primary sources become more scarce, dedicated infrastructure to deliver the treated wastewater is a major limiting factor.

The final source of water, tail water, shares similar characteristics with treated effluent. It makes up a very small percentage of irrigation water supplies at the irrigation district level and is not really a unique source as it originates from some other supply. Tail water is the excess irrigation water that is applied to the high end of the field from a head gate and flows to the low end, or tail end, without soaking into the ground. Only a few irrigation districts make use of tail water where their physical layout and collection infrastructure allows for the tail water at the bottom of one field to be used for irrigation at the top of the next (Leonard, 2013). Some growers have tail water collection and pump systems on individual tracts of land, but overall, the availability and use of tail water has fallen as irrigation systems have become more efficient (McEachern, 2013).

Figure 1.3 shows the percentage of irrigation water derived from each source in the Phoenix and Pinal AMAs combined. Figure 1.4 shows how total water use for irrigation in the two AMAs is split between Indian and NIA. Figures 1.5 and 1.6 provide further detail as to the makeup of Indian and NIA water supplies.

Figure 1.3: Average Water Supply Sources for Irrigation in Phoenix & Pinal AMAs from 2001 – 2005

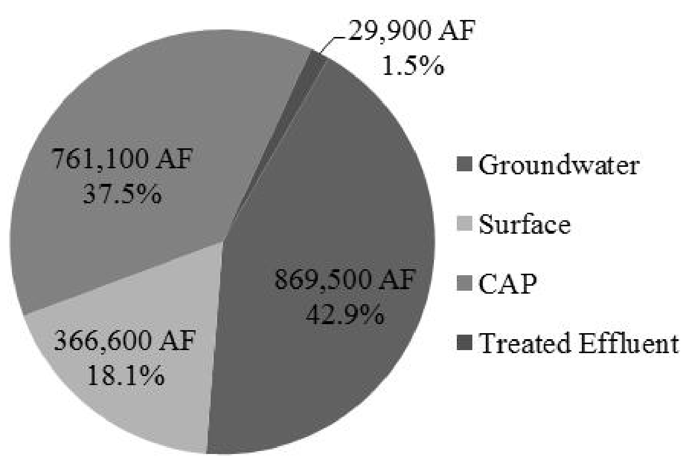


Figure 1.4: Average Split Between Indian and NIA Agricultural Water Use from 2001 – 2005

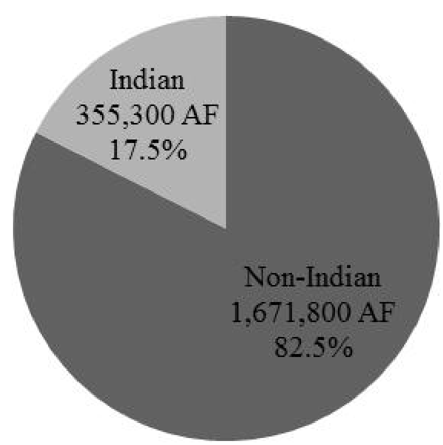


Figure 1.5: Average Indian Water Supply Sources for Irrigation in Phoenix & Pinal AMAs from 2001 – 2005

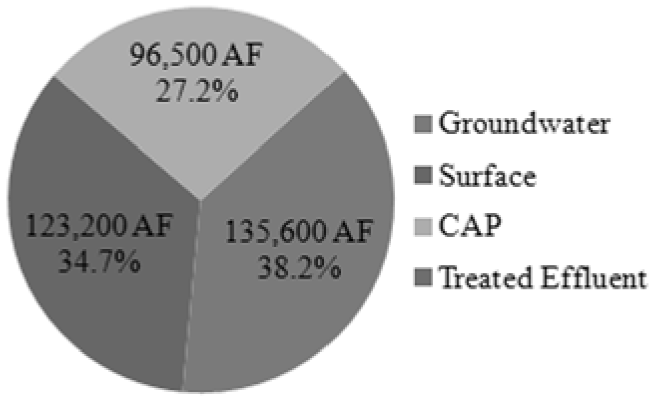
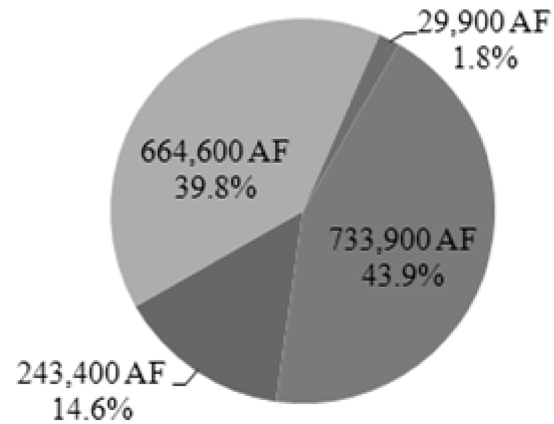


Figure 1.6: Average Non-Indian Water Supply Sources for Irrigation in Phoenix & Pinal AMAs from 2001 – 2005



Source: (Arizona Department of Water Resources, 2010)

1.2.3 Central Arizona Project

Since completion, CAP has dramatically altered the landscape of water supply in central Arizona. The U.S. Bureau of Reclamation (BoR) and Arizona representatives devised CAP as a means to help Arizona make beneficial use of its entire 2.8 MAF [3,454 GL] Colorado River water allotment (Hanemann, 2002; The University of Arizona, Water Resources Research Center, 2007). This water was intended to help reduce Arizona's nearly three MAF [3,700 GL] per year groundwater overdraft crisis in the central region of the state (Hanemann, 2002). Construction began on the canal in 1973 and was largely finished by 1993 at a cost of nearly $4 billion (Central Arizona Water Conservation District, 2010b). The concrete-lined canal carries water diverted from Lake Havasu along the California-Arizona border uphill past Phoenix to where it terminates just southwest of Tucson, 335 miles [539 km] from and nearly 2,900 feet [884 m] above where it began (Glennon, 1995). Figure 1.7 shows the path CAP takes through the state. Annually, the canal carries 1.5 MAF [1,850 GL], supplying approximately 32 percent of all water use in central Arizona's five AMAs (Arizona Department of Water Resources, 2010). Legal restrictions on the rest of Arizona's 2.8 MAF [3,454 GL] Colorado River Compact allotment keep the system from utilizing its entire 2.2 MAF [2,714 GL] per year design capacity (Central Arizona Water Conservation District, 2010b). Still, it is the largest single water conveyance project in the United States, though few Americans have heard of it (Hanemann, 2002).

Figure 1.7: Central Arizona Project System Map

Source: (Central Arizona Water Conservation District, 2013a)

1.2.4 1980 Groundwater Management Act

The 1980 Groundwater Management Act was drafted and signed in exchange for the Carter Administration providing federal support for CAP (Wilson, 2002). The aim of the legislation was to address Arizona's falling groundwater levels due to significant overdrafts. The GMA and subsequent legislation created five AMAs and five Irrigation Non-Expansion Areas

(INA) in which to monitor and regulate groundwater usage (Arizona Department of Water Resources, 2008). Both AMAs and INAs are based on groundwater basin boundaries (Arizona Department of Water Resources, 2008). The primary management goal of AMAs, except for the Pinal AMA, is to reach safe-yield, or zero groundwater overdraft, by 2025 through a series of five increasingly strict management plans issued by ADWR (Bautista, Waller, & Roanhorse, 2010).

The importance of the GMA to this research stems from three provisions. First, the GMA assigned one Irrigation Grandfathered Right (IGFR) certificate per farm for any acres that were irrigated entirely or partially with groundwater in any year from 1975 – 1980 (Megdal, Smith, & Lien, 2008). These acres are known as irrigable acres. Irrigable acres differ from water duty acres in that water duty acres are the maximum number of acres irrigated in any one year from 1975 – 1980 (Megdal, Smith, & Lien, 2008). Water duty acres are always less than or equal to irrigable acres (Bautista, Waller, & Roanhorse, 2010). The GMA specifies that no new IGFRs are to be issued, meaning no new acres can be irrigated within the AMAs or INAs. This is important because it limits the number of acres that can be irrigated in any given year acting as an upper ceiling on overall water use. Second, the GMA established an agricultural water conservation program called the Base Conservation Program (Bautista, Waller, & Roanhorse, 2010). Under the Base Conservation Program, a maximum annual water allotment was set for each IGFR (Arizona Department of Water Resources, 1999). The maximum annual water allotment is the irrigation water duty times the water duty acres as shown in equation (1.1) (Arizona Department of Water Resources, 1999).

$$\text{Maximum Annual Water Allotment} = \text{Irrigation Water Duty} \times \text{Duty Acres} \tag{1.1}$$

The irrigation water duty is calculated by dividing the total irrigation requirement per acre by the assigned irrigation efficiency[6] as shown in equation (1.2) (Arizona Department of Water Resources, 1999).

$$\text{Irrigation Water Duty} = \frac{\text{Total Irrigation Water Requirement Per Acre}}{\text{Assigned Irrigation Efficiency}} \qquad (1.2)$$

Total irrigation water requirements per acre are static and were based the crops historically grown in the farm unit between 1975 and 1980 and sometimes include leaching allowances for traditionally high saline water supplies (Arizona Department of Water Resources, 1999). Consumptive water use[7] figures for each crop are based on experimental studies carried out by the USDA in 1982 and from other previous research on the subject (Arizona Department of Water Resources, 1999). According to self-calculations based on 2011 IGFR data from ADWR, the average irrigation water duty per irrigable acre, not accounting for irrigation efficiency, was 2.78 AF in the Pinal AMA and 4.36 AF in the Phoenix AMA. Assigned irrigation efficiency, in the current Third Management Plan, is 80 percent (Arizona Department of Water Resources, 2002). However, not all IGFRs are subject to the 80 percent requirement as a number of exceptions were made in the groundwater code (Bautista, Waller, & Roanhorse, 2010). The efficiency figure was intended to be increased in each management plan thereby decreasing the amount of groundwater available to irrigate each acre (Wilson & Needham, 2006). With less water available, growers would be encouraged to adopt more efficient irrigation systems or to switch to less water intensive crops. This maximum annual water allotment could act as a constraint on how much growers use, thereby affecting overall water use.

[6] Irrigation efficiency is defined as the total amount of water required to produce a crop divided by the total amount of water applied to the crop
[7] Amount of water consumed by a crop through growth and evapotranspiration

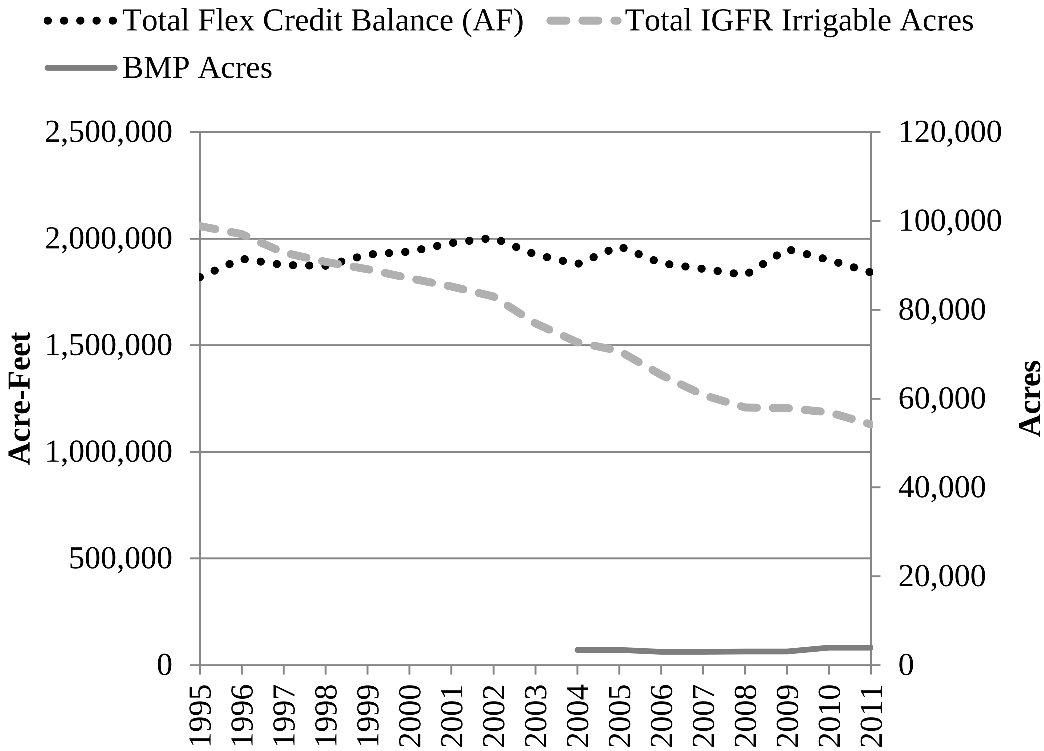
Third, the GMA established flexibility accounts for the Base Conservation Program to give growers the flexibility to address variable weather and market conditions (Arizona Department of Water Resources, 1999). For example, in a drought or year of high market prices, a grower might use more water than his or her maximum annual water allotment. In this case, the grower can debit his or her account up to 50 percent of the annual allotment (Bautista, Waller, & Roanhorse, 2010). In years with poor market conditions or excessive precipitation, a grower might not use his or her entire allotment. In this case, the grower can credit his or her account. There is no limit on how many flex credits can be accrued under the Base Conservation Program (Arizona Department of Water Resources, 1999). Since many growers make use of water from sources other than groundwater, it is important to note how flex credits and debits for groundwater withdrawal are accounted. Flex credits and debits are calculated using a 'stacking' order with groundwater at the top (Bautista, Waller, & Roanhorse, 2010). For example, if a grower has an annual water duty of 100 AF and uses 50 AF of CAP water and 60 AF of groundwater, his or her flexibility credit account is debited ten AF (Bautista, Waller, & Roanhorse, 2010). In the same way, if a grower uses 40 AF of CAP water and 40 AF of groundwater, he or she is credited 20 AF (Bautista, Waller, & Roanhorse, 2010). Note, the grower does not accumulate credits for the 40 AF of CAP water used. Finally, In-lieu water from the CAP canal is considered groundwater for flex credit and debit accounting (Bautista, Waller, & Roanhorse, 2010).

Since the passage of the original GMA, subsequent legislation has approved two additional conservation programs. The Historic Cropping Program was devised as an alternative to the Base Conservation Program. No IGFRs have been enrolled into the Historic Cropping Program as of 2010 (Bautista, Waller, & Roanhorse, 2010). The Best Management Practices

(BMP) program was introduced in 2004 as another alternative to the Base Conservation Program (Bautista, Waller, & Roanhorse, 2010). The primary difference between the two programs is how they accomplish water conservation. The Base Conservation Program uses annual water allotments to encourage efficient water use while the BMP program requires a certain standard of physical and management conservation practices with no annual water use limit (Bautista, Waller, & Roanhorse, 2010). As long as growers with IGFRs enrolled in the BMP program meet its requirements, they are legally able to apply as much water as needed to irrigate their crops effectively removing any use ceiling that might have existed (Bautista, Waller, & Roanhorse, 2010). While this may seem counterproductive, the idea behind the program is that overall water use compared to the Base Conservation Program is nearly identical as the conservation practices ensure water use per acre is similar to the irrigation water duty per acre (Bautista, Waller, & Roanhorse, 2010). As of November 2008, 36,651 acres were enrolled in the program, 80 percent of which were in the Pinal AMA (Bautista, Waller, & Roanhorse, 2010). The program is still growing, however, in 2011 just over 60,000 acres have been enrolled (Williams, 2013). Even with over 60,000 acres enrolled in the BMP program, the vast majority of acres are still under the Base Conservation Program and are still subject to annual water duty restrictions. However, there is some evidence to support the notion that the annual water duty restrictions are generally not very restrictive.

A quick survey of flexible credit balances on the ADWR website shows balances that are routinely in excess of multiple years' water allotment (Arizona Department of Water Resources, 2013b). According to Wilson and Needham, the accumulation of flex credits owes to water allotments that were based on a record number of irrigated acres, economic hardship in the 1980s that caused growers to plant fewer acres, and federal land set-aside programs that paid growers to let land lay fallow (Wilson & Needham, 2006). However, according to some growers, these balances do not necessarily reflect current annual water requirements (Rayner, 2013). Figure 1.8 and 1.9 show the flex credit balances from 1995 through 2011 for select irrigation districts in the Phoenix AMA and Pinal AMA respectively. They also show the number of acres enrolled in the BMP program within the same districts since its inception in 2004. Finally, the figures show the number of IGFR certificate acres in those irrigation districts from 1995 through 2011.

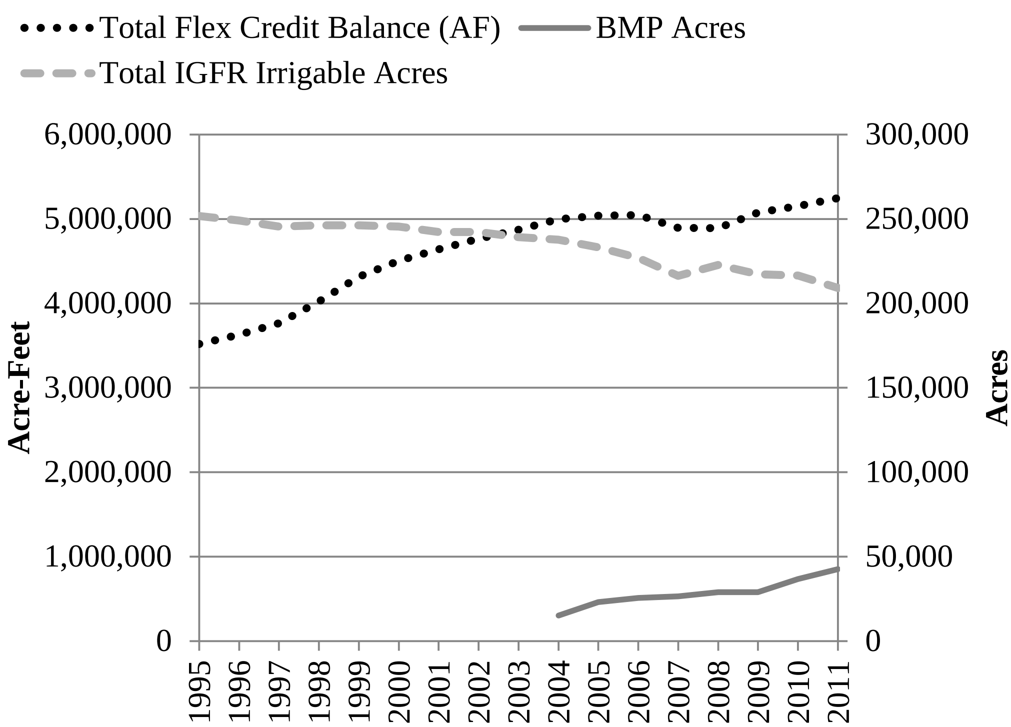
Figure 1.8: Flex Credit Balances of Select Phoenix AMA Irrigation Districts 1995 – 2011[8]



Source: (Williams, 2013)

[8] Districts include: Tonopah ID, Maricopa Water District, Roosevelt Water Conservation District, Queen Creek ID, and New Magma IDD

Figure 1.9: Flex Credit Balances of Select Pinal AMA Irrigation Districts 1995 – 2011[9]



Source: (Williams, 2013)

Looking at Figure 1.8, over 44,000 IGFR acres have been retired along with their flex credit balances and yet the overall balance has remained steady. This suggests that flex credits are still being accumulated, even under the prosperous and high agricultural water use conditions of the past few years. In Figure 1.9, it looks as though flex credit balances have largely stopped accruing. Again, the number of total acres has declined by 42,000 and an additional 42,000 acres are no longer accruing credits as they are now enrolled in the BMP program. Yet, flex credit balances have maintained their levels. This also suggests that growers in the districts examined, as a whole, are not constrained by the Base Conservation Program.

Regardless of how the balances accrued, they allow most growers to use water almost without restriction for a number of years before the balances would be drawn down to zero. Still,

[9] Districts include: Central Arizona IDD, Maricopa-Stanfield IDD, Hohokam ID, and San Carlos IDD

anecdotal evidence from individuals familiar with central Arizona farming practices noted that growers fallow some acres in order to have enough water on other acres, specifically noting the Base Conservation Program as a constraint (Husman, 2013). This evidence would suggest the Base Conservation Program acts as a water constraint for some growers but is not a constraint for others. A formal study of whether the Base Conservation Program actually constrains growers' water demand is sorely needed but difficult to undertake as reporting requirements of necessary data are lacking. Until then, a fair assessment of whether growers water use is constrained by the Base Conservation Program or not would be that some growers are constrained while most others are not.[10]

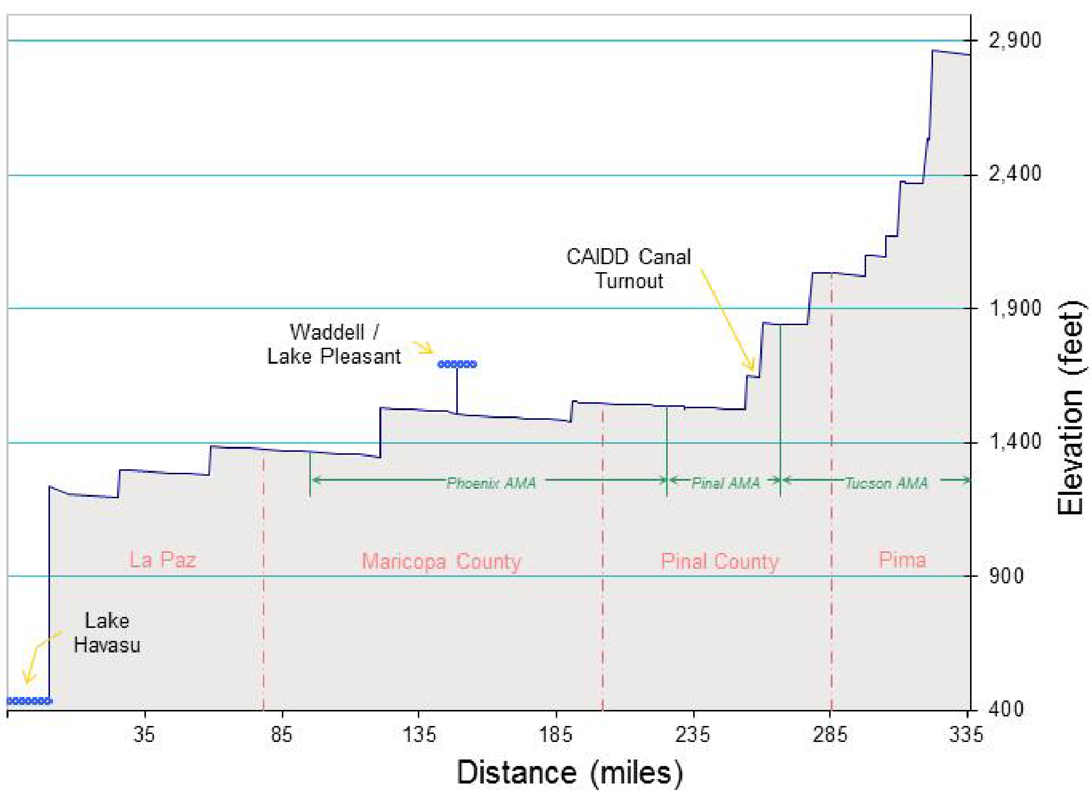
1.2.5 Price of Water

A vast amount of energy is required to supply water to farms in central Arizona. One AF of water weighs more than three fully loaded Boeing 747 Jumbo Jets (Boeing, 2010). [11] A single acre of alfalfa, accounting for irrigation system efficiency, can require six AF per year (Arizona Department of Water Resources, 1999). The weight of this water is equivalent to the combined weight of just over 20 such aircraft. This fact would not be important if irrigation water always flowed downhill from its source. However, the vast majority of water applied to fields in central Arizona comes from the Colorado River or from aquifers beneath the fields (Arizona Department of Water Resources, 2010). Therefore, CAP water has to be pumped up 1,214 feet [370 m] to reach the Central Arizona Irrigation & Drainage District (IDD) canal turnout, just under the height of the Empire State Building, excluding the broadcast antenna, in New York City

[10] There are numerous exceptions and additional provisions to each point made in the 1980 GMA section that are beyond the scope of this thesis.
[11] 1 AF of water = 2.72 million lbs.; Boeing 747-400 weighs 800,000 lbs.; (2,720,000 lbs. / 800,000 lbs. = 3.4)

(Wilson, 2002; Empire State Building Company, LLC, 2013).[12] Figure 1.10 is an elevation schematic of CAP clearly displaying canal sections and the pump stations that border them. According to interviews with irrigation district managers in central Arizona, groundwater must be pumped up between 250 and 1,000 feet depending on the depth to the aquifer in their district. Groundwater sources with lifts nearing 1,000 feet are not generally economical for crop production and would only be utilized in emergencies. By understanding that it can take lifting the equivalent of 20 Jumbo Jets to the top of the Empire State Building to water a single acre of alfalfa, the enormity of the relationship between water and energy becomes clear.

Figure 1.10: CAP Elevation Schematic



Source: Ken Seasholes, CAWCD

When the price of energy used to pump water increases, the price of water increases in almost lock-step fashion. In 2012, CAP was the largest single electricity user in Arizona

[12] CAIDD turnout: 1,664 feet; Lake Havasu: 450 feet; Empire State Building (without antenna): 1,250 feet

consuming over 2.8 million megawatt hours of electricity just to move CAP water (Central Arizona Water Conservation District, 2012). That is enough electricity to supply 250,000 average Arizona homes (Southwest Energy Efficiency Project, 2011)[13]. Over 90 percent of the energy used by CAP is supplied by the Navajo Generating Station (NGS) near Page, Arizona that is along its northern border with Utah (U.S. Environmental Protection Agency, 2013). Because NGS is a coal-fired power plant, it is subject to increasingly stringent and expensive federal emissions regulations. The most recent regulation stems from a ruling by the U.S. Environmental Protection Agency (EPA) regarding nitrous oxide emissions diminishing visibility in regional National Parks (U.S. Environmental Protection Agency, 2013). This new regulation, however, is only one source of uncertainty regarding future price increases of NGS power for CAP. As the price of electricity from NGS rises, so does the price of water from CAP to irrigation districts in central Arizona.

The other major source of energy-intensive irrigation water in central Arizona, besides CAP water, is groundwater. Electricity provides the energy source for most groundwater pumps in central Arizona, though, natural gas and diesel driven pumps exist as well (Wong, 2012). Groundwater costs remain relatively low because the cost of the energy that drives the pumps remains relatively low. Like irrigation districts, areas of Arizona have been organized into electrical districts (ED) for the purpose of receiving and supplying electricity to individual farms and irrigation districts (Ward & Orme, 2013). The boundaries of EDs do not match up exactly with irrigation districts but most irrigation districts are served by one or two EDs (Western Area Power Administration, 2012). In some cases, the manager of the irrigation district is also the manager of the ED (McEachern, 2013). The Western Area Power Administration’s (WAPA)

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[13] Average residential electricity use per Arizona household = 11,061 kWh; CAP electricity use = 2.8 million mWh; (2,800,000,000 kWh / 11,061 kWh = 253,142)

Desert Southwest Region (DSR) and Arizona Power Authority (APA) provide most of the low-cost electricity supplied by EDs for pumping groundwater (Western Area Power Administration, 2012). In addition, some more costly supplemental power is routinely purchased from the state's major electrical utility, Arizona Public Service (APS) (Western Area Power Administration, 2012). The WAPA supplies low-cost electricity generated at Hoover, Davis, and Parker Dams, as well as NGS, and the Colorado River Storage Project at Glen Canyon Dam both to EDs directly and indirectly through APA (Western Area Power Administration, 2013). The APA's primary mission is to market Arizona's allocation of Hoover Dam electricity to EDs. Arizona Power Authority, therefore, acts as an intermediary (State of Arizona, 2013a).

Just like the uncertainty that surrounds the future cost of CAP water to growers, the future cost of pumping groundwater is also uncertain. The allocation of Hoover hydroelectric power contracts by APA is currently up for review with any changes set to take effect post-2017 (State of Arizona, 2013a).[14] Since irrigated agriculture is heavily dependent on the low cost power provided by WAPA and APA, any change in its price or allocation would have a rippling effect on the agricultural sector. As one irrigation manager put it, "Hoover contracts are like gold (Hatch, 2013)."

1.3 Summary of Methodology and Findings

Quantitative and qualitative techniques are employed to formally identify and analyze those factors that influence agricultural water use and how irrigation districts make water-sourcing decisions. Quantitative analysis is used to determine what factors influence agricultural water use in aggregate and qualitative analysis to understand how irrigation districts make sourcing decisions. For the quantitative analysis, a fixed-effects panel econometric model with total water use at the irrigation district level as the dependent variable is used. By regressing total

[14] Hoover Dam is also known as the Boulder Canyon Project

water use of several irrigation districts against a host of potential explanatory factors, insight is gained on how each factor affects total water use. The analysis is focused on exogenous explanatory factors such as water price, climate, agricultural land conversion, crop prices, and other macro-level variables.[15,16] For the qualitative analysis, information gleaned from subject matter expert interviews is combined with other quantitative data. Through this combined approach, how irrigation districts make sourcing decisions and what constraints they face in making those decisions is summarized. Finally, the results of the analysis are used to make conclusions about the nature of water demand in central Arizona irrigation districts and how future developments are likely to affect both individual growers and overall water use.

This thesis is organized into seven chapters, followed by a number of appendices providing additional research notes and data. The first chapter provided a background of the main topics relating to agricultural water use throughout the state from which to interpret later chapters. In Chapter 2, I outline past research relating to this thesis and how I make use of it in the analysis. In Chapter 3, I detail factors that influence the creation of the conceptual model used to inform the econometric analysis. Chapter 4 is all about irrigation district water sourcing decisions and constraints managers face in making those decisions. In Chapter 4, I discuss the methodology used to collect the qualitative data and results obtained from its analysis. Next, Chapter 5 discusses the methodology used to empirically estimate the conceptual model of Chapter 3. The empirical model, tests used to ensure its validity, and a description of the data used in the model are presented. In Chapter 6, I show the results from the econometric analysis along with an interpretation of the results. Finally, in Chapter 7, I discuss conclusions from both the qualitative and quantitative analysis and offer a broad look at the future of central Arizona

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[15] Exogenous means determined externally. For example, an individual grower does not choose and cannot influence the weather.
[16] Assuming water price is exogenous.

irrigation water sourcing. I then note some of the drawbacks of my process and areas for future research. The paper finishes with a number of appendices providing additional detail.

The findings of this thesis complement both economic theory and other studies that have sought to understand and model changes in agricultural water use. I find that agricultural land conversion has had a significant negative impact on overall water use. Crop prices, especially those of the high water use crops, cotton and alfalfa, are significant in explaining annual water use variability. A weather variable for precipitation is also significant in explaining annual water use but one for temperature is not. As expected, precipitation has a negative effect on water use. More interestingly, in some of the econometric models, I find that a climate index for precipitation in the catchment areas of surface water supplies is positively significant in explaining overall water use. Through anecdotal evidence as well as an inspection of the data, I find the price of water from each irrigation district paid by growers not to be an explanatory factor in annual fluctuations of water use. For irrigation districts, findings were a little more surprising. Unlike my initial thoughts where irrigation district managers freely built their supply portfolios from scratch annually based on current conditions, they have relatively little flexibility in how they meet the water demand from their growers. Water supply availability and other regulatory constraints limit the quantity available from each source and even the order in which it can be acquired. For the most part, annual water supplies for each district vary little from year to year with fluctuations coming from the quantity of water contributed by each source to the total.

CHAPTER 2: LITERATURE REVIEW

Up until this point, I have been using the terms water demand and water use almost interchangeably. However, it is important to make a distinction from this point forward that use refers to the actual amount of water used, whereas, demand, an economic term, refers to the water demanded at a given price.

Since agricultural water use makes up such a large share of the total water use both nationally and globally, studies exploring factors that affect total water use are in no short supply (de Fraiture & Perry, 2002). Unfortunately, the rich body of literature that exists on agricultural water use in central Arizona is largely dated. Early pioneers in the economic study of agricultural water use of Arizona, such as Professors William E. Martin, Robert A. Young, Maurice M. Kelso, and Lawrence E. Mack, spent decades studying the demand for water by agriculture in Arizona (Young & Martin, 1967; Kelso, Mack, & Martin, 1973). Many of the publications by these authors focused on estimating the price of CAP water and its economic benefits, as the canal had yet to be constructed, along with the ability and willingness of growers to pay for CAP water (Martin, Ingram, & Laney, 1982; Bush & Martin, 1986; Martin, 1988). Unlike agricultural water demand studies, literature specific to sourcing decisions at the irrigation district level and constraints they face is quite sparse, especially for central Arizona. Three relatively recent publications are the most relevant when looking at central Arizona irrigation districts and their water sourcing options. The first publication examines the economics of agriculture in Maricopa-Stanfield Irrigation and Drainage District in particular (Wilson & Gibson, 2000). The second examines sourcing decisions of multiple districts with respect to CAP versus groundwater only (Wilson & Gibson, 2000; Wilson, 1997). Finally, the third, a report submitted to the Office of the Governor, offers a substantial introduction to the characteristics of the irrigation districts in this study (Wilson, 1992). While these publications provide a useful introduction to the topic of this thesis, they address different questions, and as noted, are somewhat dated.

For the most part, quantitative studies estimating water demand proceed using the same basic formula, and this analysis is no different. Water demand for crop irrigation is a derived demand. That is, it represents demand for water as an input in a production process rather than as a consumption good. Irrigation water demand is derived by modeling water use as a function of water price and a host of other factors that affect demand. By accounting for all of the factors that affect use, it is possible to see how changes in individual factors, particularly water price, contribute to fluctuations in overall use. The economic term for the magnitude and relationship a change in one factor exerts on another is elasticity. Elasticity studies have been used for all kinds of factors with one of the most prevalent being water price (Johansson, 2005; Scheierling, Loomis, & Young, 2004). Own-price elasticity of demand (PED) measures the percentage change in demand for a good or service in response to a one percent change in its price, other things constant. The demand for inelastic goods and services such as gasoline changes less than one percent for every percent increase in price. Goods and services with elastic demand, such as restaurant meals, have their demand change by more than one percent for every percent increase in price. In addition to being elastic or inelastic, PED can be positive or negative. For most goods and services, including water for agricultural irrigation, own-price elasticity of demand is negative, meaning as its price rises demand falls.

When it comes to water demand in irrigated agriculture, most research shows that water is negatively inelastic (Scheierling, Loomis, & Young, 2004). A meta-analysis of PED studies by Scheierling, Loomis, and Young (2004) looked at 53 PED estimates with a minimum elasticity of -0.002, maximum of -1.973, with a median of -0.216, a mean of -0.509, and standard deviation of 0.515. Despite all of these studies, just how inelastic demand for water is remains highly contested, and for good reason. As described in the introduction, water use by agriculture makes up the vast majority of water use in the already arid West. In the future, effects of climate change are expected to decrease overall water supplies while population and environmental demands continue to grow (Frisvold, 2004b). Policy makers are already looking to agriculture as part of the solution to addressing increased scarcity and enacting policies that affect prices is a potential solution (Frisvold, Wilson, & Needham, 2007). Thus, knowing how much water is likely to be 'freed up' through decreasing demand as the price of irrigation water increases is a very important topic. Price elasticity of demand is derived from a demand curve. Therefore, estimating a demand curve for agricultural irrigation water is a necessity.

According to Scheierling, Loomis, and Young (2004), three general methods have been used to estimate demand curves for agricultural irrigation water: mathematical programming, crop-water production functions, and econometrics. Mathematical programming, usually linear, optimizes farm production under various constraints, most commonly relating to a fixed water supply or land area. Crop-water production functions use field experiment data to develop a demand curve based on crop prices and a varying cost of water. Finally, econometric methods use secondary data based on historic grower behavior under varying water prices to estimate a demand curve. Relatively speaking, elasticity estimates are the most elastic for programming techniques followed by econometric and crop-water function techniques (Scheierling, Loomis, & Young, 2004). Since this thesis employs econometric techniques to explore factors affecting water use, studies using similar techniques are the focus of the next section.

According to Gardner, a rational grower will respond to higher water prices in four ways: leave land fallow, irrigate more efficiently, alter crop mix, and invest in more efficient irrigation technology (de Fraiture & Perry, 2002).[17] In their 1994 paper, Moore, Gollehon, and Carey (Moore et al.) decomposed crop-level water demand into intensive and extensive margins. Relating to Gardner's four responses to higher water prices, the intensive margin refers to short-run water application decisions throughout the growing season such as increased irrigation management. The extensive margin refers to longer-run decisions that impact water use such as acreage choices, crop mix, and irrigation technology decisions.

With cross-sectional farm level data from the Farm and Ranch Irrigation Survey for farms in the western half of the U.S., Moore et al. used a two-step regression technique that estimated land allocation decisions with a Tobit econometric model and water demand with a Heckman model. In Moore et al.'s model, they controlled for crop prices, precipitation, temperature using cooling-degree days, and input costs with the use of labor prices and gasoline prices. Doing so, they found that water price is not a significant factor in explaining water use at the intensive margin. In other words, once a crop is planted, the price of water does not affect how much a grower will apply to his or her field. This suggests that, if quantity is not constrained, growers will irrigate their crops to achieve maximum yields even if a water price increase will lower their profits through increased costs. Next, Moore et al. found that at the extensive margin, water demand was negative and moderately to significantly inelastic. This means that as water price increases, growers will adjust their crop mix and total land allocation resulting in slightly less water being demanded. The second finding of negative, highly inelastic demand for water is consistent with other research. One explanation for the inelastic demand of water in the short-run is that growers apply water to land in a fixed ratio (Moore, Gollehon, & Carey, 1994). Since the study used cross-sectional data with little variation in controlling factors, it did not provide a useful explanation of factors that affect water use other than crop price.

[17] Cited in deFraiture & Perry (2002)

Mullen, Yu, and Hogenboom (Mullen et al.) conducted an analysis nearly identical to Moore on water demand in the humid climate of Georgia rather than the arid west as Moore et al. had done (Mullen, Yu, & Hoogenboom, 2009). Like Moore et al., Mullen et al. used farm-level cross-sectional data to estimate Tobit and Heckman models. Unlike Moore et al., Mullen et al. also used a seemingly unrelated regression (SUR) approach to estimate an additional short-run water demand model. Using the SUR approach, Mullen et al. found own-price elasticities of demand for water to be -0.01 – -0.17, slightly lower than estimates from similar studies. They attribute this to the fact that irrigation plays a supplemental role in crop production. Therefore, the amount of supplemental water needed in a dry year is such that water price does not play into the irrigation decision-making process.

In a panel environment using farm section data, Schoengold, Sunding, and Moreno (Schoengold et al.) estimate water demand using a two-step regression technique similar to Moore et al.to account for endogeneity of acreage decisions (Schoengold, Sunding, & Moreno, 2006). After pooling their data, they used a linear generalized least squares (GLS) model to explain water demand with time-varying variables for average yearly temperature, marginal water price, fuel prices, farm labor wages, and time-invariant variables for land slope, soil permeability, and average section temperature. The model used a single-lag autoregressive approach and corrected for heteroscedastic errors with robust instrumental variable standard errors calculated using a bootstrap method. For their land allocation model, they use the Tobit technique to account for zero values in their dependent variable. The land allocation model explained land use with time-varying variables such as lagged crop prices, marginal water price, annual temperature, fuel prices, and farm labor wage. It also included time-invariant variables for land characteristics including land slope, soil permeability, average section temperature, and frost-free days as well as lagged land allocation values. Of note, the study period was selected because of a significant change in the price of water. Key findings relating to this thesis are that the coefficient on water price was negative and significant, annual temperature was positive and significant, and input price variables were insignificant in explaining water demand. Also, in contrast to Moore et al., Schoengold et al. found that PED at the intensive margin was negative and statistically significant meaning growers, as a group, adjust management practices during the growing season to account for water prices. Total PED was calculated to be -0.787 split roughly evenly between adjustments made at the intensive versus extensive margin.

Closest to the subject of this thesis, Wilson and Needham estimated water demand in central Arizona at the irrigation district level with a log-log fixed-effects panel model using panel-corrected standard errors (Wilson & Needham, 2006). They explained water demand using variables for water price, precipitation, temperature, and real prices of alfalfa, cotton, wheat, and barley. Water price and precipitation were both statistically significant and negative in sign with respect to water demand. Temperature was positive and significant. Unlike other water demand models, crop prices were not significant. For this quantitative analysis, Wilson and Needham's econometric model at the irrigation district level acts as my guide.

The literature review of econometric agricultural water demand models leads to a few conclusions. First, most demand analyses are done at the farm or section level because that is the scale data are available. Second, because of land fallowing, farm or section level data often contain zero values for the dependent variable. To account for the zero values, the censored-dependent variable Tobit model is frequently used. Third, nearly all studies relating to water demand find that the PED is negatively inelastic and almost completely inelastic under relatively low water prices. Fourth, weather related variables are generally statistically significant in explaining a portion of water demand.

Influences on agricultural water demand research are not limited to water price effects. In a 2004 article, Frisvold (2004b) examined how federal farm programs affect overall water use in agriculture. Since every farm program is meant to affect crop production or farm net income in some way, they typically also all affect water demand. However, it is often difficult to quantify the specific effects of individual farm programs on water demand. For example, though no programs exist for alfalfa, a water intensive crop, programs affecting the dairy industry affect alfalfa planting because it is a major feed source for dairy cows. In another example, cotton subsidies incentivize the planting of cotton. Though cotton uses a significant amount of water in its own right, it usually requires less than alfalfa. Since cotton and alfalfa are complementary crops in Arizona, programs affecting cotton also affect alfalfa and thus overall water use. Finally, irrigation technology adaptation subsidies can have an ambiguous impact on water use. Though such subsidies promote efficiency, without other quantity controls, such efficiency can actually lead to greater water use through the following mechanism (Ward & Pulido-Velazquez, 2008): If irrigation system subsidies allow growers to invest in more efficient systems, they will use less water per acre. As their water use per acre falls, so does their cost per acre, thereby increasing profit per acre, assuming water cost savings exceed irrigation system investments. The more profitable an acre of land is, the more likely it is to be planted. These incentives and subsidies potentially increases the number of acres planted and thereby increase water use.

CHAPTER 3: CONCEPTUAL MODEL

3.1 Profit Maximizing

Water use for agriculture at the irrigation district level is the sum of use from individual growers within the district. Therefore, to understand total water use at the district level, it is important to understand water use at the individual grower level. This is not an uncomplicated task, as this chapter will show. Assuming growers are profit-maximizing agents, they must balance the costs of multiple inputs such as water and fertilizer against the additional crop outputs these inputs generate in order to maximize net revenue generated by multiple outputs such as cotton and alfalfa.

3.1.1 Single Input – Single Output Example

Since this thesis is interested in factors affecting water use, I will focus attention on water as an input to production. As noted previously, understanding changes in farm water use is complicated. The mathematics associated with modeling the decisions of a multi-input, multi-output profit-maximizing grower under multiple constraints are beyond the scope of this thesis (Moore & Negri, 1992). Instead, I use a simplified single-input, single-output illustrative example to explain growers' demand for water. The following illustration is modified from Beattie, Taylor, and Watts, <u>The Economics of Production</u>, and Griffin's, <u>Water Resource Economics</u> (Beattie, Taylor, & Watts, 2009; Griffin, 2005). Profit is defined as total value product (TVP) minus total cost (TC) as in equation (3.1) where π represents profit. For example, I define the single output as tons of alfalfa and the single input as AF of water. Total value product then is the product of alfalfa price, p, and the quantity of alfalfa produced using a specific amount of water, $f(w)= Y$. I assume the production function of alfalfa to be concave in the profit-maximizing region with respect to water. In other words, alfalfa production will rise as additional water is applied but at a diminishing rate. Total cost is the sum of the variable costs of the single input (the price of water, *r*) times the amount of water, *w*, and fixed costs, *b* as in equation (3.2). Profit maximization occurs where the marginal benefit from an additional unit of alfalfa production equals the marginal cost of the additional unit of water required to produce the alfalfa. Equation (3.3) shows this by taking the first derivative of profit, π, with respect to water. By rearranging terms in equation (3.3) I get the first-order conditions for profit maximization. Profit maximization in this example occurs where the price of alfalfa times its marginal physical productivity (MPP) equals the price of water, *r*, as in equation (3.4). Equation (3.5) shows this in another way where the price of alfalfa times its MPP equals its value marginal product (VMP). Assuming second order conditions are such that profit is maximized and TVP > variable water costs, equation (3.5) yields an intuitive result. Value marginal product is the revenue gained from the last unit of alfalfa production. This means that a grower will continue to apply water to his or her crop until the cost of water equals the production value received from using it. In other words, if water costs $35 per AF, the grower will keep applying water until the revenue gained from additional alfalfa production associated with that water equals $35.

$$\pi = \mathrm{TVP} - \mathrm{TC} \qquad (3.1)$$

$$\pi = \mathrm{p}f(\mathrm{w}) - \mathrm{rw} - \mathrm{b} \qquad (3.2)$$

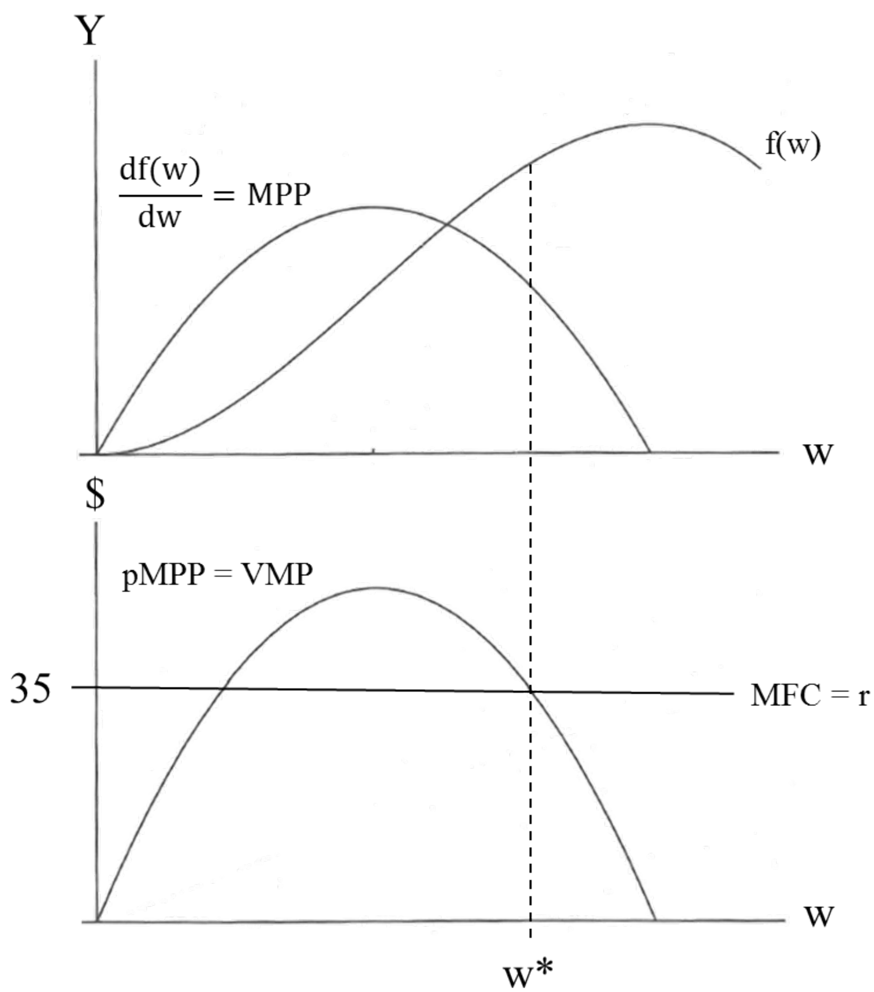
$$\max_{\mathrm{w}} \pi = \frac{d\pi}{dw} = \mathrm{p}\frac{df(w)}{dw} - \mathrm{r} = 0 \qquad (3.3)$$

$$\mathrm{pMPP} = \mathrm{r} \qquad (3.4)$$

$$\mathrm{VMP} = \mathrm{r} \qquad (3.5)$$

Figure 3.1 shows the result of equation (3.5) graphically. In the upper panel of the graphic, the production function of alfalfa with respect to water is shown along with its MPP. The lower panel takes MPP from the upper, multiplies it by the price of alfalfa and overlays the cost of water per AF on top of it. In the graphical example, much like the real world, water has a constant price invariant of quantity used. The profit maximizing level of water is where VMP = r or the marginal factor cost (MFC) at w*.

Figure 3.1: Graphical Representation of Profit-Maximizing Solution



Source: (Griffin, 2005)

3.2 Factors Affecting Water Use

In the previous section, I showed the intuitive result produced in an unconstrained single input-single output profit-maximizing scenario. Though the intuition behind the result still applies, there are many more considerations to determining where the profit-maximizing amount of water use lies. In this section, I discuss the factors and constraints that affect water demand by individual growers in the real world. According to Frisvold, Wilson, and Needham (2007), agricultural water use depends on four effects: scale effects (total acreage), crop mix effects (which crops are grown), location effects (where they are grown) and technology effects (irrigation type).

3.2.1 Scale Effects

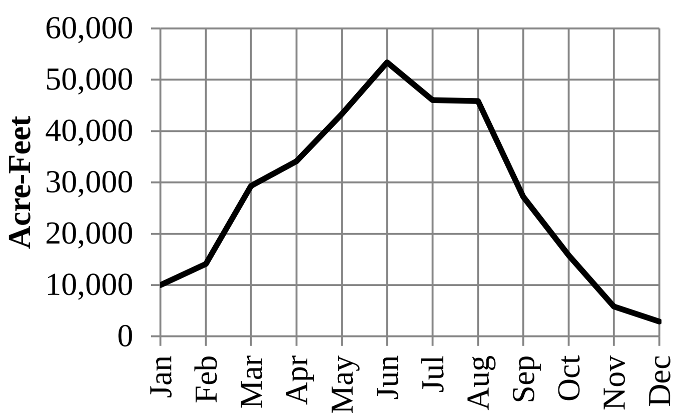
Scale effects refer to factors that influence the total number of acres planted (Frisvold, Wilson, & Needham, 2007). In central Arizona, there are three primary scale effects. The first is the GMA of 1980 as described in the first chapter. The GMA capped the number of acres legally irrigable by the number of acres irrigated in any year between 1975 and 1980 (Megdal, Smith, & Lien, 2008). This clause acts as a hard upper constraint on the number of acres available to be irrigated in the central Arizona AMAs. This upper constraint is not static, however, leading to the second scale effect.

As the population of Arizona has increased, more and more agricultural land has been converted for urban and other uses. When a developer purchases agricultural land, he or she is also purchasing the IGFR associated with that land (Arizona Department of Water Resources, 2008). If the developer chooses to change the use of the land from agricultural to some other purpose, the IGFR must be either retired or converted for another use. I will refer to these retired or converted IGFR certificates as inactive. This means that the number of active IGFRs has decreased as agricultural land has been converted for other uses. The Phoenix AMA has seen the most IGFRs become inactive primarily due to urban expansion. Because of the no new IGFR certificate clause, as agricultural land is converted for other uses, the total number of acres available to irrigate falls causing a drop in overall water use.

The third scale effect stems from farm level decisions that determine how many acres are fallowed from year to year. Depending on commodity prices, some growers will plant a large percentage of their acres to high water use crops such as alfalfa (Rayner, 2013). Under such a scenario, a grower's IGFR water duty averaged over all his or her irrigable acres might not be sufficient to allow the irrigation of a high water use crop on all acres. To accommodate this restriction, growers will fallow some acres to allow the water that would have been applied to those acres to be used for irrigating the alfalfa that was planted (Husman, 2013). While growers try to match the water requirements of acres that are planted with the total water duty, excess water duty capacity is sometimes left over (Rayner, 2013). This unused water duty allotment can generate flex credits as described in the first chapter.

Another reason to fallow land stems from the physical availability of water. Whether a grower receives water from his or her own groundwater well or from an irrigation district, there might not be enough supply to meet peak demand (Betcher, 2013). In other words, there might be enough water available averaged over the course of the year, but water use is not smooth, generally peaking in June as Figure 3.2 shows. Peak water demand in June can surpass groundwater pumping capacity and even infrastructure capacity.

Figure 3.2: Maricopa-Stanfield IDD Monthly Water Deliveries (2011)

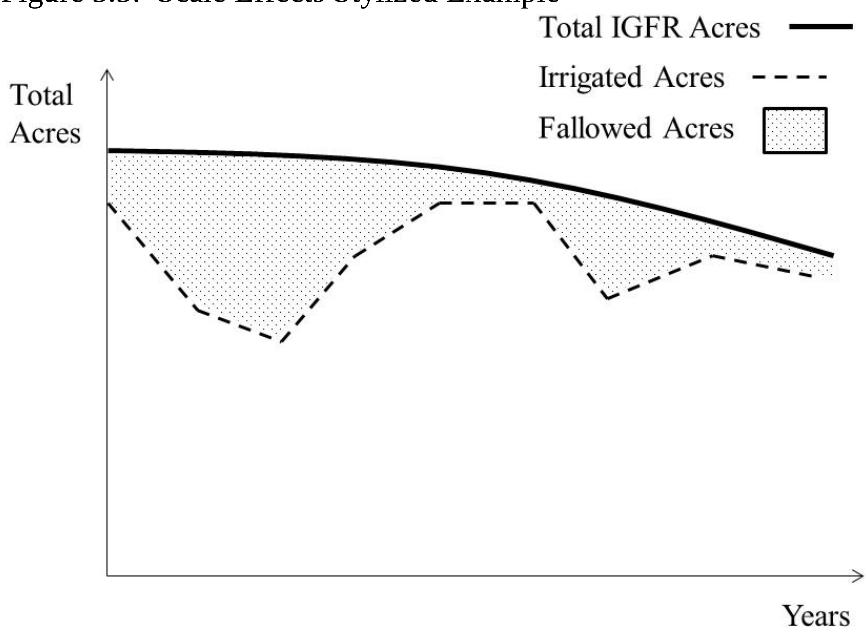


Source: (Betcher, 2013)

It is important to note, however, that this restriction varies greatly depending on irrigation district-grower water supply agreements. For example, cotton requires a substantial amount of water during the hottest period of the year. If a grower's only source of water is through the irrigation district, and he or she determines that enough water will not be available during peak demand, he or she will likely forgo planting some acres to avoid a shortfall (Rayner, 2013). A solution to this restriction would be expanding water supply capacity with more groundwater pumps or larger canal infrastructure. In most cases, however, the cost of a new groundwater well and associated regulatory compliance is such that additional revenue gained from irrigating a few more acres would not be enough to turn a profit on those additional acres (Rayner, 2013). Even if it is, the payback period on the capacity investment is very long. Many growers do not own the land they operate or, in the case of those near development, are waiting to sell to developers. Therefore, they have little to no incentive to invest in a system they might not have access to a year later (Rayner, 2013).

Perhaps the biggest reason to fallow land relates to farm profitability considerations. As Wilson and Needham (2006) point out, relatively low commodity prices coupled with a tight credit market and high water costs meant for many growers in the early 1990s that it was either not profitable to plant some or all acres, or that they could not get enough lending to support planting costs. Since 1995, lower water costs and sufficiently high commodity prices have meant farm profitability has played less of a role in fallowing land than the previously mentioned reasons, though, they still exist depending on the year. In addition to profitability considerations, until the Federal Agricultural and Improvement Reform Act of 1996, growers were often required to fallow acres in exchange for government payments (Frisvold, 2004b). Since those programs ended in 1996 and my study period begins in 1995, I chose not to take such programs into account. In aggregate, these scale effects combine to produce a situation where the total number of acres planted in any given year expands and contracts as the total number of IGFRs declines with agricultural land conversion as demonstrated in Figure 3.3. Note, the number of irrigated acres never reaches the total number of IGFRs as some acres are invariably fallowed in any given year. However, the overall trend in irrigated acres is pushed downward by the IGFR acres constraint. The expansion and contraction of number of acres fallowed directly impacts overall water use by agriculture in any given year.

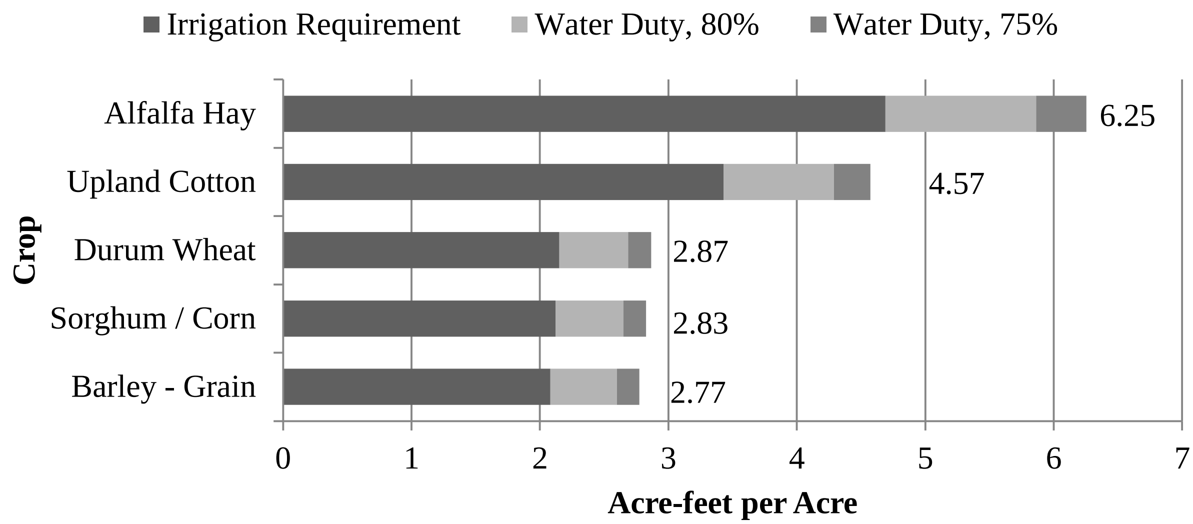
Figure 3.3: Scale Effects Stylized Example



3.2.2 Crop Mix Effects

In conjunction with the decision of how many acres to plant or fallow is the decision of what crops to plant on those acres (Marques, Lund, & Howitt, 2005). Common crops grown in central Arizona require substantially different amounts of water per acre so it is important to understand which crops are planted in any given year. Figure 3.4 shows the water requirements of major crops grown in central Arizona including their water duties associated with irrigation efficiencies of 75 and 80 percent (Arizona Department of Water Resources, 1999).

Figure 3.4: Irrigation Requirements and Water Duties for Major Central Arizona Crops

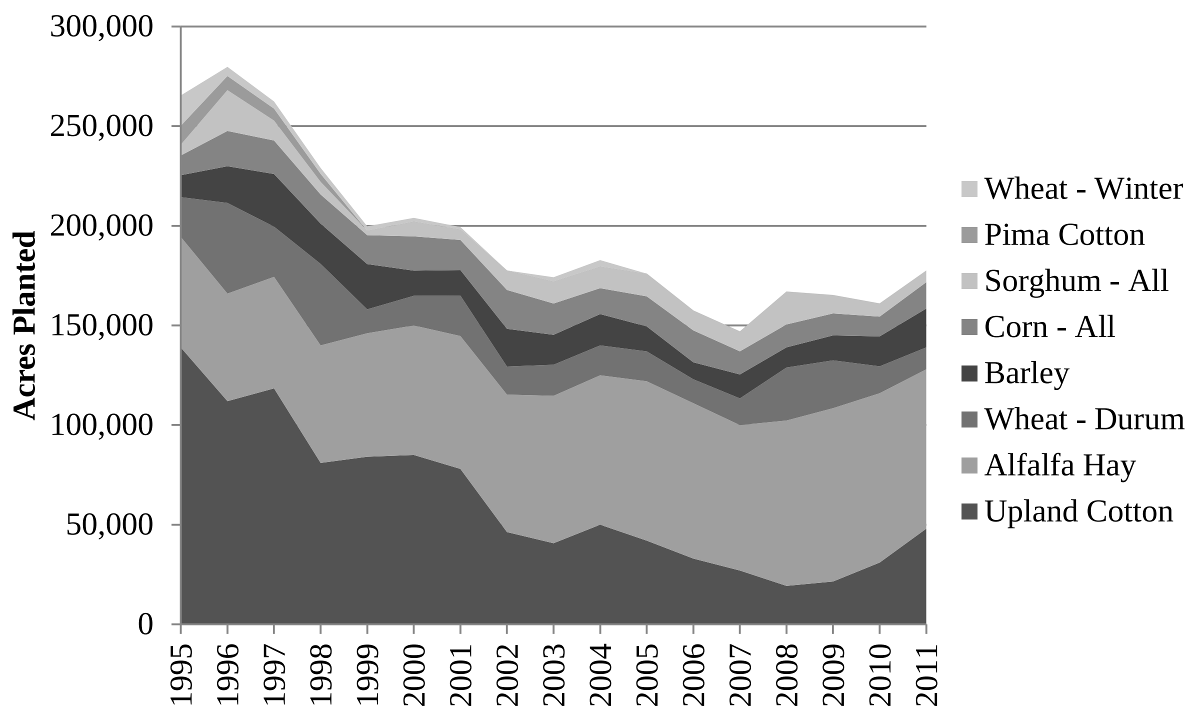


Source: (Arizona Department of Water Resources, 1999)

Crop mix effects are those decisions that affect total water use through what crops a grower decides to plant. In the beginning of this chapter, I noted that while growers are profit-maximizing agents, the profit maximizing level of water use is not as simple as the result derived in the single input-single output model. In reality, growers try to maximize profits not just in any given year but throughout an entire multi-year crop rotation schedule (Rayner, 2013). An understanding of crop rotation decisions and constraints helps to paint a clearer picture.

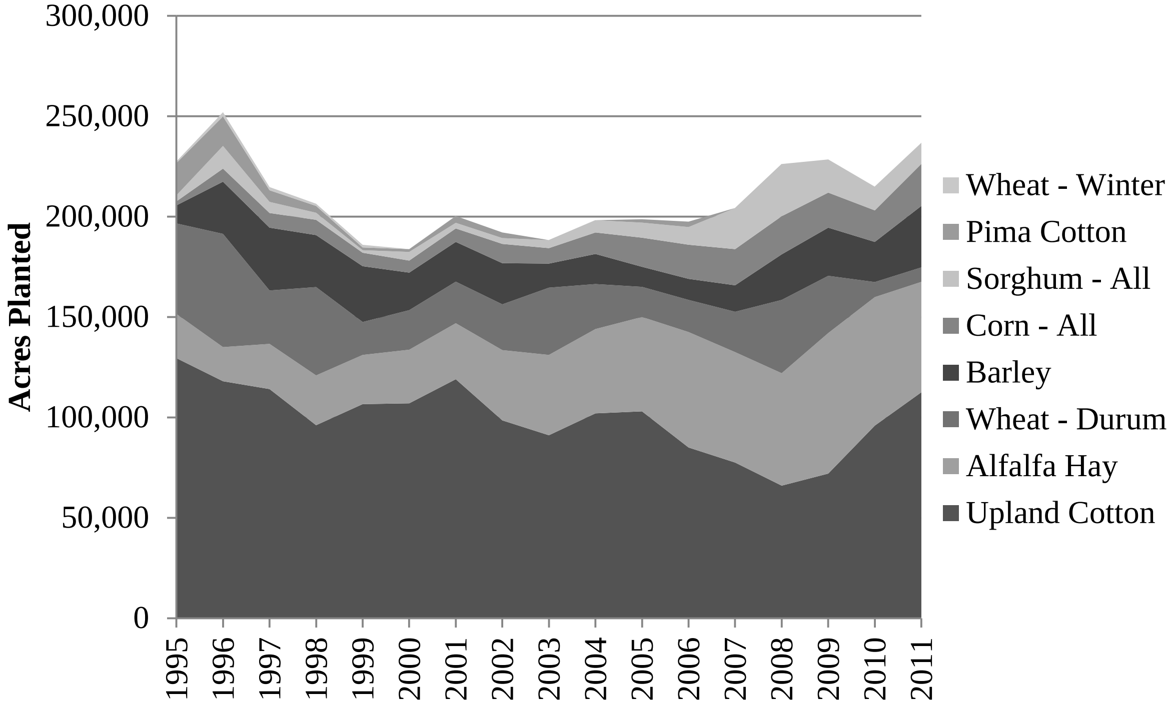
Before deciding how many acres of each crop to plant, growers are faced with the constraint of available crops from which to chThe crop choices available to central Arizona growers are largely predetermined based on climate, soils, access to markets, and availability of local processing infrastructure (Rayner, 2013). For example, alfalfa is a major crop partially because of access to local dairies and other livestock operations that use it for feed. Cotton and durum wheat are planted because of local cotton gins and wheat processing facilities. Other forage crops such as sorghum and corn also feed local livestock operations. Crop choices driven by access to markets and processing facilities then drive other fixed cost investments that further limit cropping choices. High efficiency irrigation systems for high value crops such as vegetables require a substantial investment. Once the initial investment has been made, the grower has less flexibility in growing other crops that cannot make use of that particular irrigation system. In the same way, once machinery has been purchased to plant and harvest a particular set of crops, adding other crops that require different machinery is often not financially feasible. This means that growers will tend to rotate the same set of crops once the initial set has been chosen (Husman, 2013). A look at the number of acres planted to each major crop in central Arizona over the past 15 years supports this notion with the exception of a major switch from upland cotton to alfalfa. Figures 3.5 and 3.6 show the number of acres planted to each crop annually in Maricopa County and Pinal County respectively. Over the 17-year period, alfalfa and upland cotton account for roughly 70 percent of all acres planted in both counties annually.

Figure 3.5: Acres Planted to Major Crops in Maricopa County Annually



Source: (U.S. Department of Agriculture, National Agricultural Statistics Service, 2012)

Figure 3.6: Acres Planted to Major Crops in Pinal County Annually



Source: (U.S. Department of Agriculture, National Agricultural Statistics Service, 2012)

A set of crops is also chosen based on their growing characteristics. For example, central Arizona's mild winters allow crops to be grown year-round. However, certain crops grow best during certain times of the year. In this case, cotton, wheat, and barley are good choices because wheat and barley can be grown during the winter while cotton is grown during the summer (National Agricultural Statistics Service, Arizona Field Office, 2012). This combination helps to maximize profit by spreading land costs over more acres of production. Finally, water supply quality constrains what crops can be grown. Groundwater in some parts of central Arizona is too saline to grow high value crops such as vegetables (Rayner, 2013). However, CAP water tends to have more moderate salt concentrations than many other sources in central Arizona. Therefore, districts that irrigate with mostly CAP water and have less saline groundwater are likely to grow higher value crops; Maricopa Water District just west of Phoenix is a good example of this.

All of this discussion about crop rotation assumes that crop rotation choices are intended to maximize profitability. To do so, one might think that planting the most profitable crop in any given year leads to profit maximization in the long-run. While intuitive, this hypothesis is incorrect because there are a number of other factors that drive the decision to rotate crops. Consequently, the crop planted in any given year might not be the most profitable in that year. Therefore, profit-maximizing decisions are made with respect to the entire crop rotation cycle, not any given year, as previously noted. For example, growers plant more than one crop per year in an attempt to manage risk (Patrick, Wilson, Barry, Boggess, & Young, 1985). Risks in agriculture come from many places but can generally be classified as stemming from market and yield uncertainty (Drollette, 2009). Crop price changes throughout the growing season can leave a grower on the losing end if the single crop he or she chose does not have an adequate price come harvest time. Planting more than one crop lowers the market risk associated with depending on one volatile crop price for all his or her income. Similarly, planting more than one crop decreases the yield risk a grower faces because of biological or climate induced crop failures.

Next, growers rotate crops because it reduces costs and biological-based yield uncertainty. Cotton is a nitrogen-consuming crop. If cotton were planted year after year, growers would be forced to apply increasing amounts of costly nitrogen fertilizer to make up for the nitrogen that was depleted from the soil. Alfalfa, however, is a legume, a nitrogen-fixing crop. It fixes nitrogen from the air into the soil. By rotating alfalfa and cotton, growers do not need to apply as much costly nitrogen fertilizer. Along the same lines, most of the crops commonly rotated in central Arizona have different pest problems and require different herbicides. By rotating crops, growers are less likely to experience a pest outbreak that would require additional pesticide applications. Further, using different herbicides slows the process of weed resistance to such chemicals reducing the need for additional costly applications.

Due to these constraints, many growers have a set rotational pattern that varies little year to year. For illustration purposes, one example of a rotation schedule is shown in Table 3.1. A word of caution, the rotation example of Table 3.1 is not necessarily typical of growers in central Arizona. Growers will increase or decrease acres of a certain crop if commodity prices are high enough to justify a deviation from the rotation schedule (Rayner, 2013). Costs associated with planting cotton-on-cotton are not as high in the first couple of years as they are after four or five years (Martin, 2013). For example, in recent years, cotton prices have risen substantially causing growers to plant more acres to cotton. Generally speaking, growers prefer to double crop cotton with barley over durum wheat because barley matures quicker allowing cotton a longer growing season to increase yields (Rayner, 2013). However, if durum wheat prices are high enough to offset cotton yield losses due to a shorter growing season, it is planted instead (Rayner, 2013).

Table 3.1: Crop Rotation Example: A-Tumbling-T Ranches

Year	1st Crop	2nd Crop
1	Alfalfa	n/a
2	Alfalfa	n/a
3	Alfalfa removed in Fall	Durum Wheat or Barley
4	Upland Cotton	Durum Wheat or Barley
5	Upland Cotton	Durum Wheat or Barley
6	Forage Sorghum	Newly seeded Alfalfa in Oct.
7	Start at Year 1	

Source: (Rayner, 2013)

Since cotton and alfalfa occupy the majority of acres in central Arizona and have the highest consumptive use requirements, changes in their prices would likely lead to changes in overall water use. Similarly, if barley and durum wheat prices are high enough to justify double cropping, overall water use would be expected to go up. This assumes that crop prices are a direct reflection of crop profitability, an assumption that is addressed in Chapter 5.

Though not strictly a crop mix effect, growers often have different management styles and personal experiences that lead to more or less water use. Some growers maximize profits by seeking the highest yields through high input intensities while others will try to minimize costs through lean input use while accepting lower yields. While both strategies seem to lead to the same place, their impact on water use differs. For this thesis, since I am examining water use at the irrigation district level, farm-level management style differences are unobservable; therefore, they are not taken into account. I assume that short-term deviations from traditional crop rotations due to commodity prices are what largely drive water usage variability among crop mix effects.

3.2.3 Location Effects

Location effects are those spatial characteristics that affect water use. The most obvious location effect is weather. Evapotranspiration increases along with temperature as crops try to cool their leaves (Elstein, 2004)[18]. Therefore, the higher the temperature, the more water crops use. Regarding precipitation, intuition would offer that the more rain fields get, the less irrigation water would be required. This relationship is not as clear-cut as it might seem, however. If precipitation occurs during planting time for cotton pushing back planting dates, cotton will mature during an even hotter period in the year and thus require more water (Betcher, 2013). Further, if precipitation occurs at the wrong point during early crop growth, replanting could be required along with additional irrigations (Betcher, 2013). During the growing season, precipitation has less of an effect on irrigation timing as non-agriculturalists might imagine. For instance, during the monsoon season, those driving on the interstate in Pinal County might look out their window to a field being irrigated during a rainstorm. While their instinct might be to

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[18] Four principal weather patterns affect evapotranspiration rate: Temperature, humidity, wind speed, and solar radiation. (Allen, Pereria, Raes, & Smith, 1998)

think that farmers are being negligent and wasteful, they would be wrong. Throughout the year, a one-inch rain event would be considered a good amount of precipitation. However, the minimal amount of water put down per acre during a standard irrigation is two inches and is usually closer to three to five inches (Wong, 2012). Therefore, an inch of rainfall hardly affects irrigation timing and amounts. Over the course of the entire year, though, total precipitation would be expected to influence overall water use.

Another location effect is soil characteristics. Most of central Arizona has alluvial soils ranging in texture from fine to coarse. According to interviews with irrigation district managers and growers, soil characteristics exert little influence on crop choice but do substantially affect irrigation management. For example, since coarse soils hold less water, they are irrigated more frequently but with less water per irrigation. Further, soil characteristics affect what kind of irrigation technology is adopted (Anderson, Wilson, & Thompson, 1999). Since irrigation systems have different efficiencies, soil type thereby affects water use.

A final example of location effects would be elevation differences. Different elevations allow for different planting dates that subsequently affect water use. Different elevations also have different associated average temperatures with higher elevations having lower average temperatures. Elevations in the study area range from 1,085 feet [330.7 m] above sea-level at Luke Air Force Base near the Maricopa Water District (MWD) to 1,614 feet [491.9 m] in Picacho, Arizona on the high end of the Central Arizona Irrigation and Drainage District (CAIDD) (Federal Aviation Administration, 2013; U.S. Geological Survey, 2013). For this thesis, I will assume that elevation is highly correlated with temperature and, therefore, will not be considered in the analysis. Further, since elevation and soil characteristics are not time varying, they do little to explain annual fluctuations in overall water use, though, their interaction with other variables, such as precipitation, might alter the effects of precipitation on water use. Such interactions are beyond the scope of this analysis.

3.2.4 Technology Effects

Technology effects, in this case, will refer to irrigation technology, though they can also refer to crop genetics. Up to this point, I have been discussing mostly short-run decisions that are made during the growing season or on an annual basis. Irrigation technology, however, is generally a long-term decision because of a high upfront cost. In central Arizona, there are a number of different irrigation technologies from which to choose. The two most prevalent are flood-border and flood-furrow (Betcher, 2013; McEachern, 2013). The irrigation efficiency of these two methods varies considerably depending on whether the land has been laser (precision) leveled and how much water is being applied; efficiency generally increases with larger amounts of water (Martin, 2011). Other popular methods include linear-move and center-pivot sprinklers, and drip with the latter being the most costly. Drip irrigation is the most efficient but least employed for a number of reasons. However, it is slowly being adopted on more acres because of cost incentive programs and high farm profits as of late (Betcher, 2013). According to interviews with irrigation district managers throughout central Arizona, the makeup of irrigation technology has not changed substantially since the early 1990s. Two reasons were offered for this. First, like investments in groundwater pump capacity, irrigation technology is expensive and initial investments are substantial. Since many growers do not own the land they operate or are waiting for urban development to arrive, there is little incentive to make large investments in costly irrigation technology (Bautista, Waller, & Roanhorse, 2010). Second, many irrigation system investments had already been made before the early 1990s in response to the GMA and have not changed much since (Frisvold, Wilson, & Needham, 2007). A final reason, not encountered during interviews, but noted in the literature, is that new irrigation technology can require significant additional knowledge and a change in irrigation management techniques (Anderson, Wilson, & Thompson, 1999). Many growers, especially older ones, may not be willing to change.

3.3 Conceptual Model

Having identified the major drivers of water use at the irrigation district level, I am ready to build the conceptual model. Like Moore et al., I use a two-step process to derive the conceptual model acknowledging that overall water demand is a function of water price and land allocation, which itself is a function of water price (Moore, Gollehon, & Carey, 1994). With this in mind, water demand, *w*, is modeled in equation (3.6) as a function of water price, *r*, a vector of different crop acreages, *a*, and a vector of climatic variables, *c*.

$$\mathrm{w} = \mathrm{f}(\mathrm{r}, \mathrm{a}, \mathrm{c}) \qquad (3.6)$$

The vector of crop acreages, *a*, is defined in equation (3.7) as a function of a vector of different crop prices, *p*, a vector of input prices excluding water price, *i*, and the price of water, *r*, subject to a vector of constraints, *x*, noted in the previous section including rotation schedules, irrigation systems, and IGFR water duties.

$$\mathrm{a} = \mathrm{g}(\mathrm{p}, \mathrm{i}, \mathrm{r}) \colon \mathrm{x} \qquad (3.7)$$

By substituting the crop acreage function in to the water demand function, I arrive at the conceptual model in equation (3.8).

$$\mathrm{w} = \mathrm{f}(\mathrm{r}, \mathrm{a}(\mathrm{p}, \mathrm{i}, \mathrm{r}) \colon \mathrm{x}, \mathrm{c}) \qquad (3.8)$$

Equation 3.8 will serve as the conceptual guide I use in specifying the empirical model estimated in Chapter 5.

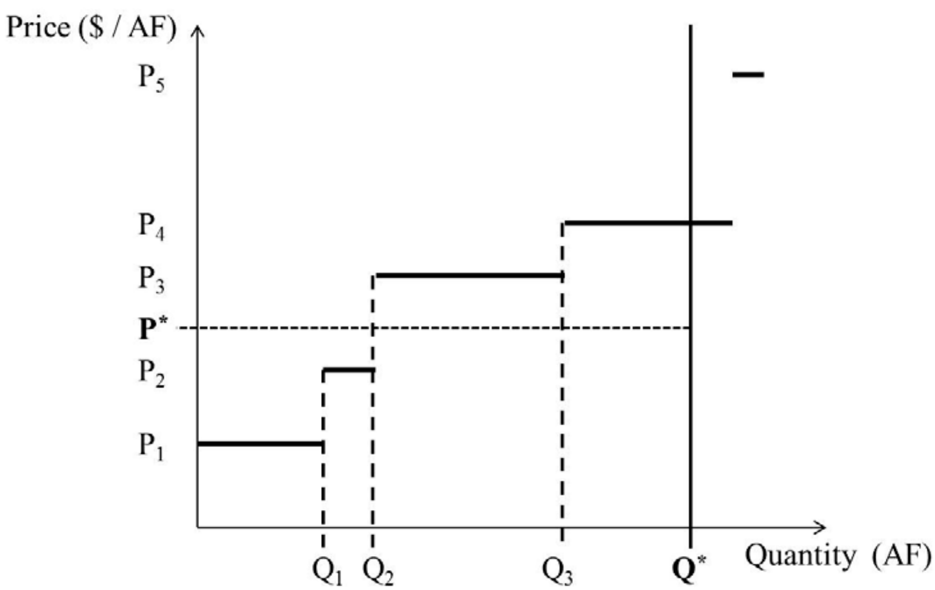
3.4 Irrigation District Water Sourcing Framework

Irrigation districts play an important role in central Arizona agriculture. Through massive canal infrastructure, they provide irrigation water to hundreds of thousands of acres of highly productive cropland. A necessary input cost in producing any crop in Arizona is water. Therefore, profitability of any given crop is dependent on the cost of water. As shown in the conceptual model, the more profitable a crop is, the more acres of it will be planted, thereby directly affecting overall water use. Therefore, overall water use is partially based on how irrigation districts source water for growers in their district. Irrigation districts also play an important role in determining the quantity of water available to growers. For some growers, irrigation district provided water is their only option. Therefore, if the district cannot provide enough water to meet their needs, less water is used overall. It is surprising then that very little current literature exists on how irrigation districts make sourcing decisions and what constraints they face.

Referencing the mission statement of many different districts, I can safely assume they are all cost minimizing agents. If an irrigation district has more than one source of water available to it, I can assume that it will purchase the least cost source first up to point where either the source is exhausted or the next source becomes the lowest cost source available. For example, sources of water to irrigation districts can become exhausted for physical or legal reasons. Irrigation districts with access to surface water are limited in supply based on what nature provides in river flows and through legal restrictions governing how much surface water can be used in a given year (Leonard, 2013). Further, irrigation districts can only make contracts for In-lieu water up to the permitted volume on their ADWR GSF permit (Van Allen, 2013). A good example of the later situation is groundwater where each pump has a different cost associated with it due to factors like water depth and pump efficiency (Betcher, 2013). Such differences mean that a first block of groundwater might be the lowest cost source but a second block of groundwater is more costly than some intermediate source.

Figure 3.7 helps to visualize the sourcing process. In the figure, a hypothetical manager purchases the quantity Q_1 of the first source at a price P_1. Then, the next least costly source is purchased at a price of P_2 and so on until enough water has been purchased to meet the water orders of growers in his or her district at Q*. Most districts, however, do not charge the individual cost of each source to their growers because water from different sources at different costs is blended in their delivery systems. Instead, irrigation districts often charge a single price for water per AF that is roughly the weighted average price of all sources plus some fixed cost rate. This blended cost to the grower, generally established prior to the growing season, is shown as a dotted line at price P*.

Figure 3.7: Irrigation District Sourcing Graph



Like the simplified profit-maximizing example at the beginning of this chapter, Figure 3.7 is only conceptual. In actuality, district managers face a number of constraints that affect the order in which they make sourcing decisions both annually and during the year. These factors and constraints are important to understand for policy makers to project how different rules and regulations will affect the cost of water available to growers and thus overall water use.

CHAPTER 4: IRRIGATION DISTRICT WATER SOURCING DECISIONS AND CONSTRAINTS

Chapter 4 begins with a definition of and the rationale for the study area and period that applies both to this and the next chapter. Then, I describe the process for how qualitative data was gathered. Following that, I discuss the results of the analysis of the qualitative data in detail. This discussion of results is organized into two sections. The first section provides a timeline of irrigation district sourcing decisions and a framework for how water is sourced by district managers. The second section describes common constraints and considerations that accompany each sourcing decision. Appendix A contains notes from interviews with irrigation district managers, organized by irrigation district.

4.1 Study Area and Period

The agricultural water use of ten irrigation districts in central Arizona from 1995 – 2011 is the focus of this thesis. A number of reasons drove the selection of the study area and time period. First, because the thesis is concerned with how irrigation districts make water sourcing decisions, irrigation districts of interest must have multiple sources available to them. To ensure this, only those districts receiving water from the CAP canal were chosen. This condition automatically restricts the study area to districts in CAP's central Arizona service area. Another advantage of having the study area restricted to central Arizona is that districts in this area are subject to many of the same macro-level influences such as climate, soils, water availability, crop mix choices, and regulations. Next, for a number of reasons beyond the scope of this thesis, a number of large districts receiving CAP water experienced financial distress, with some declaring bankruptcy, in the early 90s (Hanemann, 2002; Baker, 1995). Wilson provides a thorough history and analysis of the events surrounding this time period (Wilson, 1997; 2007). To get a better sense of overall water use under more stable operating conditions, I excluded these turbulent years, largely ending in 1994. The period of interest then, beginning in 1995, extends to 2011 for data completeness reasons. Some of the data used in this analysis are not yet available for 2012. Since CAP deliveries are unevenly distributed among irrigation districts, I targeted the largest districts making up 95 percent of all CAP canal deliveries during the study period from 1995 – 2011. In Table 4.1 all twelve districts are ranked according to total CAP deliveries from 1995 – 2011, represented by the column labeled, "Total." The total delivery amounts are split between direct deliveries and In-lieu deliveries, previously defined in Chapter 1. The percentage and cumulative shares of CAP deliveries for agriculture are provided, along with 2011 total deliveries and the share of total 2011water deliveries for agriculture for each district.

Table 4.1: CAP Deliveries by Irrigation District (Acre-Feet)[19]

Rank	District	Direct	In-Lieu	Total	Share	Cumulative	2011 Total	2011 Share
1	Maricopa-Stanfield IDD	2,231,754	778,338	3,010,092	22.9%	22.9%	212,790	28.4%
2	Central Arizona IDD	2,191,131	452,395	2,643,526	20.1%	43.1%	181,699	24.3%
3	New Magma IDD	675,640	772,849	1,448,489	11.0%	54.1%	80,577	10.8%
4	Harquahala Valley ID	1,192,755	0	1,192,755	9.1%	63.2%	44,733	6.0%
5	Hohokam ID	504,604	687,733	1,192,337	9.1%	72.3%	93,679	12.5%
6	Salt River Project	252,230	540,617	792,847	6.0%	78.3%	0	0.0%
7	Roosevelt WCD	109,834	637,125	746,959	5.7%	84.0%	39,999	5.3%
8	Queen Creek ID	393,012	224,824	617,836	4.7%	88.7%	22,751	3.0%
9	Gila River Indian IDD	215,231	110,937	326,168	2.5%	91.2%	0	0.0%
10	Maricopa Water District	98,573	149,646	248,219	1.9%	93.1%	15,307	2.0%
11	Tonopah ID	76,466	149,265	225,731	1.7%	94.8%	16,501	2.2%
12	San Carlos IDD	136,547	0	136,547	1.0%	95.9%	24,083	3.2%

Source: (Central Arizona Water Conservation District, 2011b)

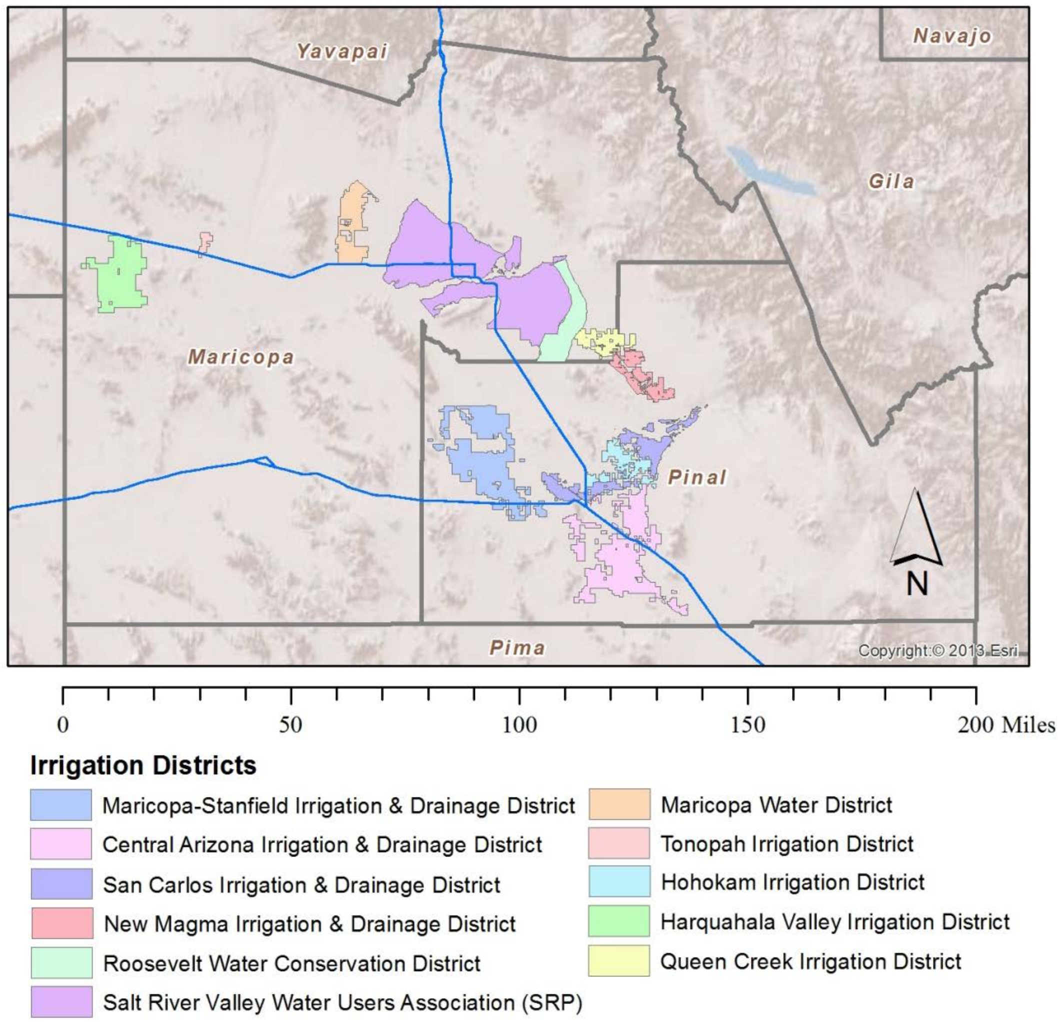
Of these twelve districts, two were excluded from the study. The two districts are the Salt River Project Agricultural Improvement and Power District (SRPAIPD) and the Gila River Indian Irrigation & Drainage District (GRIIDD). The SRPAIPD currently comprises just less than 25,000 irrigated acres located almost completely within the suburban limits of the built up

[19] Delivery totals for CAP will not exactly match those used in the econometric analysis because the data used in the econometric analysis came from ADWR under different recording schemes.

area surrounding the City of Phoenix (Gooch, Cherrington, & Reinink, 2007). Water deliveries to SRPAIPD from CAP have been highly irregular and based on water exchanges and other agreements that do not reflect annual water demand from agriculture served by it. The GRIIDD is operated by the federally recognized Gila River Indian Community (GRIC) on its 585 square mile reservation immediately south of the Phoenix Valley urban area (Arizona Rural Policy Institute, 2010). Since GRIIDD is operated on and by an Indian reservation, it is exempt from state reporting requirements (Arizona Department of Water Resources, 1999). Therefore, data used in this thesis from ADWR does not include values for GRIIDD.

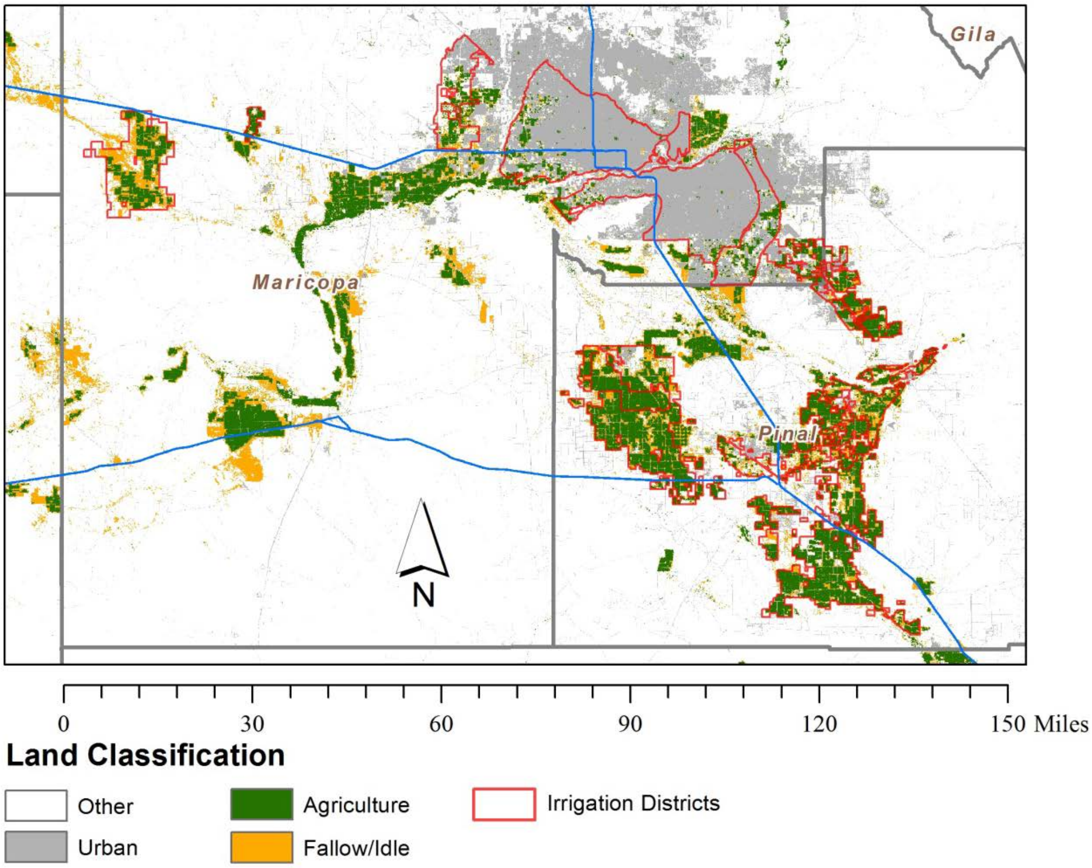
The remaining irrigation districts were not selected to be a representative sample of agricultural water users in central Arizona. Rather, they were selected because they have access to more than one source of water ensuring a basis from which to analysis sourcing decisions. To visualize the location of each district, Figure 4.1 shows the areas encompassed by district boundaries with respect to the interstate highways and county lines. Figure 4.2 shows the extent of irrigable land within the irrigation districts of interest. Since many of the irrigation districts of interest to this thesis have long names and are referenced frequently, I use initialisms to refer to them going forward. Table 4.2 contains a list of the initialism used for each irrigation district.

Figure 4.1: Irrigation District Identification



Source: (Arizona Department of Water Resources, 2013c); map created by Brett Fleck
Note: Salt River Valley Water Users Association (SRP) = SRPAIPD

Figure 4.2: Irrigated Land and Irrigation District Boundaries



Source: (Arizona Department of Water Resources, 2013c; U.S. Geological Survey, 2006); map created by Brett Fleck

Table 4.2: Irrigation District Identifying Initialisms

Irrigation District Name	Initialism
Maricopa-Stanfield Irrigation and Drainage District	MSIDD
Central Arizona Irrigation and Drainage District	CAIDD
Hohokam Irrigation District	HID
San Carlos Irrigation and Drainage District	SCIDD
New Magma Irrigation and Drainage District	NMIDD
Queen Creek Irrigation District	QCID
Roosevelt Water Conservation District	RWCD
Maricopa Water District	MWD
Tonopah Irrigation District	TID
Harquahala Valley Irrigation District	HVID

4.2 Qualitative Data Gathering Process

Qualitative data for this thesis were collected through both formal interviews and other informal communication. This data collection occurred in-person, over-the-phone, and through e-mail exchanges with subject matter experts between October 2012 and May 2013. These experts were irrigation district managers, University of Arizona extension agents and faculty, employees from organizations such as ADWR, CAWCD, USDA-NASS, and local growers. Qualitative data collected spanned a vast range of topics related to this research. Extension agents were asked about major crops in the area, common irrigation techniques, and production decisions facing growers. Irrigation district managers were asked summary information about their districts, what sources of water were available to them, how they made sourcing decisions, and what constraints they faced in making those decisions. Information gleaned from interviews with irrigation district managers is the focus of this chapter. Staff members at CAWCD were asked questions about CAP operations, agricultural water deliveries, and the recent history of Arizona water policy and regulation. Local growers were asked about production decisions and local growing conditions. A copy of the question template used during formal irrigation district manager interviews can be found in Appendix A. Notes taken during those formal interviews are also in Appendix A.

4.3 Irrigation District Water Sourcing Decisions and Constraints

Over the course of interviewing central Arizona irrigation district managers and other subject-matter experts, a common theme emerged; irrigation districts of central Arizona are heterogeneous. Irrigation districts are unique in a number of ways including size, location, available water supplies, major crops grown, and who controls groundwater pumping. The message behind this theme is clear, be cautious about making any generalizing statements. Given this warning, I proceed with care. Still, despite the message about irrigation districts being unique, the process they use to source water for their members and the constraints they face are surprisingly similar. In the next section, I describe the process most irrigation districts follow when making water sourcing decisions for their member growers, with exceptions noted where possible. An important note is that the following sections relate to irrigation districts and their member growers only, not non-member growers whose operations are located within the boundaries of the district. While the vast majority of growers and acres within district boundaries receive water from the district, a small percentage, which varies depending on the district, pump their own groundwater and receive none from the district.

4.3.1 Water Sourcing Decisions

The timeline for making water-sourcing decisions begins months before the start of the next calendar year. Irrigation district managers begin making water use projections for the following calendar year as early as June and as late as September (Van Allen, 2013; Leonard, 2013). Such projections are usually based on running averages of past district water use taking into account current crop prices, urban development, and projected climate conditions (Leonard, 2013; McEachern, 2013). Managers also consult with member growers to get an idea for how much water they are likely to use with respect to previous years (Betcher, 2013). In September, managers sign or renew In-lieu water contracts with partner organizations (Van Allen, 2013). All of these actions are done to meet the October 1st deadline for CAP Ag Settlement Pool orders (McEachern, 2013; Van Allen, 2013). However, the job of irrigation district managers does not end with the submission of their CAP orders. As would be expected, conditions surrounding initial water use projections often change requiring managers to either find additional water or willing buyers when too much has been purchased. Available options in water shortage and surplus years are noted later. As with the timeline for water sourcing decisions, most managers follow a similar framework for acquiring water. The framework is largely driven by constraints common to all districts, detailed in the next section, but also by individual district situations.

During the interviews, I characterized water use projections as a bucket to be filled and asked managers how they go about filling their respective bucket. With exception to MSIDD, all managers said they begin filling their bucket with CAP Ag Settlement Pool water (Betcher, 2013). Even though CAP Ag Settlement Pool water is not the lowest cost source, taking their initial allocation is a requirement in order to enter into In-lieu water supply contracts (Central Arizona Water Conservation District Board, 2002). Since In-lieu water supplies are generally significantly less costly, sometimes even the lowest cost source, purchasing CAP water to get at In-lieu water makes economic sense when the costs are averaged together. It is this weighted average cost that district managers use when making water sourcing decisions (Story, 2013). This is significant because it differs from the conceptual sourcing framework of Chapter 3 in that the lowest cost source, strictly speaking, is not the first source purchased. In the case of HVID, CAP water is purchased first because it alone is cost competitive with groundwater supplies (Warren, 2013). The exception to this pattern is MSIDD. It considers groundwater from its lowest cost pumps the first source, followed by CAP Ag Settlement Pool water (Betcher, 2013). In addition to purchasing their CAP allocation, most districts put in a request for any remarketed water (Warren, 2013; Van Allen, 2013). During the course of the year, as conditions influencing water usage change for each district, some end up requiring less CAP water than they initially ordered. The CAWCD takes this unused water and remarkets it to districts that request additional water. According to CAWCD, all water turned back thus far has been able to be remarketed. Remarketed CAP water is one way for districts to address surpluses and shortages. An exception to this is RWCD, because all of its remaining supplies are less expensive than CAP water (Leonard, 2013).

Once their CAP allocation has been purchased, most irrigation districts turn to In-lieu partners who want to earn LTSC by storing excess CAP water at their GSF. The availability of In-lieu water is not distributed evenly, however. Long-term storage credits can only be exercised within the same AMA they were generated in (Arizona Department of Water Resources, 2010). Therefore, In-lieu partners prefer storing water in the Phoenix AMA where future demand for LTSC is likely to be highest (Leonard, 2013). This is not to say that other entities are not interested in storing water in the Pinal AMA. The decision to store water with a particular GSF is highly situational. Using In-lieu water also requires a GSF permit through ADWR (Arizona Department of Water Resources, 2010). Some districts, like SCIDD, do not have a permit to use In-lieu water, while others like HVID are not able to attract any In-lieu partners due to its remote location in the Harquahala Valley INA (Warren, 2013). As exceptions are the rule when discussing irrigation district behavior, two irrigation districts do not consider In-lieu their second source. The RWCD considers surface water from SRP, through an agreement signed in 1924, its second source while NMIDD considers treated effluent from Rosemont Copper its second source (Van Allen, 2013; Leonard, 2013). Both sources are essentially free to the two districts (Van Allen, 2013; Leonard, 2013).

The third and final source of water for many districts is groundwater. During the study period, groundwater has often been the highest cost source, after accounting for CAP/In-lieu cost averaging, though not by much. It is also the most flexible. Owing to its flexibility, groundwater is a crucial source to all irrigation districts, whether supplied by the district or not, because it helps cover shortages and can be relatively easily turned off in surplus situations. The role groundwater plays in each district’s supply mix largely depends on who owns and operates the wells. Table 4.3 provides a summary of the groundwater well ownership situation for districts interviewed. Districts that either own or operate the wells tend to use groundwater as a pillar of their annual supply mix. For those districts that do not own or operate groundwater wells, individual growers are seen mostly as using groundwater to fill in any gaps between their own use and what the district can supply. A major exception to this characterization is HVID, where growers use groundwater from their own pumps as a pillar of annual supply in conjunction with deliveries from the district. These districts are known as conjunctive use districts (Wilson, 1992). Groundwater is not the third supply for all districts, however. Maricopa Water District considers surface water inflows into Lake Pleasant from the Agua Fria River to be its third source of water, with groundwater being its fourth (Flowers Jr., 2013).

Table 4.3: District Groundwater Well Ownership Situation

District	Groundwater Well Ownership Situation
MSIDD	District operates all member grower wells based on a 40-year lease ending in 2030
CAIDD	District operates all member grower wells based on a 40-year lease ending in 2030
NMIDD	Member growers own and individually operate all groundwater wells
QCID	Member growers own and individually operate all groundwater wells
RWCD	District owns and operates all groundwater wells
MWD	Both District and individual member growers own and operate wells
TID	Member growers own and individually operate all groundwater wells
HVID	Member growers own and individually operate all groundwater wells

Source: Irrigation district manager interviews
Note: For each district, non-member growers own and individually operate their own groundwater wells.

During the study period, especially the last ten years, the relative mix of water supplies has remained mostly constant. Table 4.4 shows the percentage contribution of available water sources to irrigation district supply mixes based on a two-year, 2010-2011, average. One of the reasons supply mixes have remained relatively constant is because of all the constraints that district managers must accommodate when making sourcing decisions. The next section attempts to organize those constraints by source while noting exceptions to the rules.

Table 4.4: Percentage Contribution of Available Water Sources by Irrigation District (2010 – 2011 Average)

District	Groundwater	CAP	In-Lieu	Surface	Other*	Total (AF)
CAIDD	44.7%	38.0%	17.1%	.	.	306,554
MSIDD	34.5%	41.2%	24.2%	.	.	297,825
HID	35.0%	24.3%	39.2%	0.6%	1.0%	118,994
HVID	56.3%	43.7%	0.0%	.	.	112,288
SCIDD	34.3%	12.2%	7.2%	46.2%	0.0%	102,300
NMIDD	1.3%	32.7%	65.9%	.	0.0%	84,273
RWCD	11.0%	7.5%	64.8%	12.4%	4.4%	38,047
MWD	29.8%	7.6%	22.1%	39.7%	0.8%	36,583
QCID	6.1%	31.9%	62.0%	.	.	29,542
TID	25.8%	16.7%	56.5%	.	.	20,560

*Other includes: Effluent and Other as categorized by ADWR
Source: ADWR Annual Water Withdrawal and Use Reports (Muse, 2013; Arizona Department of Water Resources, 2013a)

4.3.2 Water Sourcing Constraints and Considerations

The decision surrounding how much water to purchase from CAP through the Ag Settlement Pool is a non-decision of sorts, because of both constraints and incentives. Once a district manager decides to purchase CAP water, the amount they purchase is almost predetermined. Each district has been assigned a number of CAP eligible acres and a water allotment per acre ranging from 0.5 - 1.0 AF per acre (Leonard, 2013; Central Arizona Water Conservation District, 2010a). The number of acres times the water allotment per acre is known as the initial allocation. As long as Ag Settlement Pool water is available, irrigation districts can purchase either all or part of their initial allocation.[20] Most irrigation districts purchase their entire initial allocation because they are required to do so in order to have access to In-lieu water and because they receive a water price discount for doing so (Central Arizona Water

[20] Water available through the Ag Settlement Pool would be one of the first to be cut back in the event of a drought situation declared on the Colorado River (Central Arizona Water Conservation District, 2011a).

Conservation District, 2013b). Therefore, the initial allocation amount acts as a quantity constraint for CAP water, except for any remarketed water purchased. Historically, districts have also had access to relatively expensive 'full-cost excess' water from CAP above and beyond the initial allocation (Central Arizona Water Conservation District, 2011b). However, since 2000, purchases of full-cost excess water have not exceeded 3,500 AF for any irrigation district in the study and are usually less than 1,000 AF (Central Arizona Water Conservation District, 2011b).

Once an irrigation district's entire initial CAP allocation has been purchased, along with any other reasonably available alternative supplies to groundwater, they are able to enter into In-lieu water supply agreements with willing partners, assuming they are an ADWR permitted GSF (State of Arizona, 2013b). The reason for requiring districts to purchase all non-groundwater sources prior to having access to In-lieu water is because In-lieu water amounts to pumping groundwater at a later date (Central Arizona Water Conservation District Board, 2002). In the case of MWD, it is not able to enter into In-lieu contracts if its supply of Lake Pleasant water reaches a certain level (Flowers Jr., 2013). Though prices vary by individual supply arrangement, In-lieu water has been significantly less expensive than Ag Settlement Pool water. In-Lieu supplying partners are willing to accept a lower price than they paid CAWCD for their water because the water generates LTSC that will likely be very valuable in the future. Since In-lieu water is usually one of the lowest cost sources of water, I assume district managers want to acquire as much as they can. However, for two reasons, as with Ag Settlement Pool water, most district managers have very little leeway in deciding how much In-lieu water they can purchase.

First, district managers must be able to find willing In-lieu partners. For reasons described earlier, this is easier for some districts than for others. If managers are not constrained by the availability of In-lieu partner supplied water, they run into a permitted volume limit pursuant to their GSF permit. Irrigation districts accepting In-lieu water are subject to two different volume constraints defined in their GSF permits. The first is the total amount of In-lieu water that can be accepted and the second is the combined amount of In-lieu and groundwater that can be accepted and pumped (Van Allen, 2013). Some districts are constrained by the first quantity while others are constrained by the second (Betcher, 2013; Van Allen, 2013). Though the permitted volumes change little, they are not completely static. Permits are adjusted downward where land conversion is significant as is the case of RWCD (Leonard, 2013). They can also be adjusted upward in certain cases as has happened to MSIDD and CAIDD recently due to demand for water that was greater than anticipated (Betcher, 2013; Arizona Department of Water Resources, 2012).

Irrigation district managers are not completely at the mercy of outside factors when making In-lieu sourcing decisions, however. If multiple partners are available or when the price of water is up for negotiation, factors like the priority of the water being provided and any strings attached to the contract, such as which party pays for recovering the water, are important in deciding who to partner with and how much to pay (Van Allen, 2013; McEachern, 2013). Another constraint in sourcing In-lieu water, noted by TID, is infrastructure capacity. According to the former district manager, TID would like to source more In-lieu water in high demand years but its canal system is capacity constrained during peak mid-summer use (Story, 2013).

Those districts with access to surface water via non-Colorado River sources are subject to both natural and legal constraints. In the study area, MWD, RWCD, HID, and SCIDD have legal and physical access to annual surface water supplies. Since managers in HID and SCIDD were not available to be interviewed, only MWD and RWCD are discussed here. For MWD, the amount of surface water available annually is constrained by how much mother nature provides and the capacity of Lake Pleasant. The amount of surface water available annually equals the amount of water that flowed into the lake in that year from the Agua Fria River up to when the lake holds 150,000 AF (Flowers Jr., 2013).[21] In addition to the quantity constraint MWD faces, its manager noted that water quality can sometimes become a problem when water is supplied directly from Lake Pleasant (Flowers Jr., 2013). Currently, CAWCD exchanges canal water for Lake Pleasant water with MWD but sometimes cannot, such as when the canal is under maintenance (Flowers Jr., 2013). The reason for the exchange is that CAWCD pumps canal water up into the lake to use it as a storage reservoir.[22] By directly supplying canal water to MWD in exchange for Lake Pleasant water, they can avoid the cost of pumping that water into the lake. The RWCD has an entirely different set of constraints. Per its 1924 agreement with SRP, RWCD receives 5.6 percent of annual diversions at Granite Reef Dam minus a fixed amount of that water deeded to Indian Tribes annually (Leonard, 2013).

Effluent supplies are mostly constrained by availability from the entities that provide them (Leonard, 2013; Van Allen, 2013). Water quality is generally not a consideration as the effluent is of very high quality, though, salt loads can be an issue (Leonard, 2013; Van Allen, 2013).

Groundwater, because of the heterogeneity of situations it is used under, has a varied set of constraints accompanying its use. One constraint, however, was mentioned in all district interviews, pump capacity. In particular, pump capacity was noted as the limiting constraint in providing enough water during peak, mid-summer water use. With the arrival of CAP water, many districts no longer used and maintained all of their groundwater pumps, therefore, pumping capacity declined. As commodity prices have risen along with the cost of CAP water, demand

[21] Any annual flows into Lake Pleasant past when the lake contains 150,000 AF are credited to CAWCD.
[22] CAWCD uses Lake Pleasant as a storage reservoir to bank water during low flow periods on the Colorado and Agua Fria Rivers so constant delivery volumes can be maintained.

for groundwater has increased recently (Story, 2013). Further, many district managers are anticipating the availability of CAP water to decrease as the Ag Settlement Pool allotment is scheduled to drop from 400,000 AF to 300,000 AF in 2017 (McEachern, 2013). Districts are addressing their capacity constraints by investing in new groundwater wells and rehabilitating those that have been inactive for some time. Still, rehabilitation of a single well can cost $70-100,000 and a new well can cost between a half-million and a million dollars, depending on a host of factors (Betcher, 2013; McEachern, 2013; Van Allen, 2013). Such substantial investments mean groundwater supply capacity is increasing slowly but they also mean districts are moving closer to another constraint, electricity, currently affecting only one district interviewed.

Electricity supplies the power for all groundwater pumps owned or operated by irrigation districts interviewed. As described in the introduction, irrigation districts in central Arizona have access to relatively low cost hydroelectric power from dams along the Colorado River. The quantity of this low cost power is not unlimited, however, which brings rise to a second groundwater constraint. Districts with an allotment of low-cost federal hydroelectric power have just that, an allotment. Once the allotment is exceeded, secondary, more expensive sources of electricity are used. Since the cost of groundwater is almost entirely based on the cost of electricity, an increase of a few cents per kilowatt-hour (kWh) results in a substantial increase in groundwater costs. Power allotments are reviewed rarely and largely reflect the original amounts deeded many years ago prior to the introduction of CAP water that offset a significant portion of groundwater pumping (Hatch, 2013; Arizona Power Authority, 2013). Therefore, most districts do not currently approach exceeding their allotment. Many managers noted that they could exceed their allotment if all demand was met with groundwater pumping. Maricopa-Stanfield

IDD does sometimes exceed its allotment, however. For MSIDD, the jump in electricity price is substantial once the initial allotment is used. In order to keep water prices to growers as low and constant as possible, the district makes every effort to avoid exceeding its allotment of federal power (Betcher, 2013). Thus, the electricity allotment acts as a soft constraint when deciding how much groundwater to source.

All of the discussion thus far regarding sourcing constraints has been about maximums. However, two managers noted minimum use constraints for groundwater (Flowers Jr., 2013; McEachern, 2013). First, the manager of MWD noted that groundwater wells need to be operated every so often for maintenance purposes (Flowers Jr., 2013). Further, once the pumps are turned on, it is in the best interest of the operator to use the pump the entire month to spread out the one-time, monthly electrical usage fee (Flowers Jr., 2013). Therefore, a certain amount of groundwater will be pumped regardless of its relative cost. Another manager, in a unique situation, noted having to pump certain quantities of groundwater for the sake of another organization. In this case, the manager is responsible for both the irrigation district and the electrical district that supplies power to the district-operated groundwater pumps (McEachern, 2013). If the pumps are not turned on, the electrical district will not have sufficient revenue to remain solvent, therefore, the pumps need to be run a certain amount of the time (McEachern, 2013). Water quality constraints regarding groundwater were only mentioned by one district, HVID, in that some wells produced water too saline for crops and, therefore, could not be used (Warren, 2013).

Despite all of these sourcing constraints and considerations, nearly all managers reported being able to meet all grower orders through the end of the study period. An important caveat to these statements is that grower demand is based on an irrigation district water price set prior to the growing season. This ability to meet all grower demands is fast becoming a challenge for some districts as water use has increased with crop prices. Without marginal cost pricing, irrigation district managers can be constrained by the price of additional supplies if their costs of providing water to growers are not covered by the irrigation water price set prior to the growing season. It is important to note that the chronological order in which water is sourced is not necessarily the order in which it is used. For example, many districts pump more costly groundwater early in the year to 'bank' their CAP deliveries for peak, mid-summer use (Betcher, 2013; McEachern, 2013).

CHAPTER 5: QUANTITATIVE DATA AND METHODOLOGY

In this chapter, I begin by defining the empirical model to be estimated. Next, a detailed examination of the empirical model variables is provided followed by alternate variables that were also considered. After that, econometric issues relevant to estimating the empirical model are presented, including a description of panel data and, specification and assumption tests. Finally, a description and explanation of the econometric techniques chosen to estimate the empirical model, along with alternative functional forms employed and considered, is given.

5.1 Empirical Model Specification

To better understand total water use for agriculture within the ten irrigation districts described at the beginning of the previous chapter, I estimate the following linear econometric model based on the conceptual model outlined in Chapter 3 with variable descriptions provided in Table 5.1:

$$\begin{aligned}\mathrm{Total}_{it} = {} & \beta_1 \mathrm{InactiveIGFR}_{it} + \beta_2 \mathrm{MaxTemp}_{it} + \beta_3 \mathrm{Precip}_{it} + \beta_4 \mathrm{D}_{\mathrm{Surface}} \mathrm{6mSPIApr}_{it} \\ & + \beta_5 \mathrm{CottonPrice}_{it} + \beta_6 \mathrm{AlfalfaPrice}_{it} + \mathrm{D}\beta + \varepsilon_{it}\end{aligned}$$

Table 5.1: Variable Descriptions, Units of Measure, and Expected Signs

Variable Name	Description	Unit of Measure	Expected Sign
Total	Total water used for irrigation within irrigation district boundaries	AF	Dependent
InactiveIGFR	Annual cumulative IGFR certificate acres inactive based on 1995 total IGFR certificate acres	Percent	-
MaxTemp	Average maximum daily temperature March – September	°F	+
Precip	Total annual precipitation	Inches	-
$D_{surface}$6mSPIApr	Six month SPI measured in April for climate divisions with ‘surface’ headwaters multiplied by a dummy variable equal to 1 for those districts using surface water supplies	SPI	+
CottonPrice	Average upland cotton price August – July ($2011)	$ / lbs.	+

AlfalfaPrice	Average alfalfa-hay price August – July ($2011)	$ / ton	+
Dβ	Dummy variables for each irrigation district	Binary	+/-
DistWaterCost	Annual irrigation district water price charged to growers ($2011)	$ / AF	-

The model I estimate is a reflection of the conceptual model in that crop prices represent the crop acreage function, climate variables represent themselves, and the *InactiveIGFR* variable represents an acreage constraint.

5.2 Variable Descriptions and Data Sources

5.2.1 Dependent Variable

Total The dependent variable, *Total*, represents the total amount of water used annually for agricultural irrigation within the boundaries of ten central Arizona irrigation districts measured in AF. Since the study period spans 17 years, the dependent variable has 170 total observations. The variable is the annual summation of water from all sources including groundwater, direct CAP, In-lieu, surface, and, effluent. An important distinction to note is that *Total* does not represent only water provided by the irrigation districts. It also encompasses any groundwater pumped by individual growers either in conjunction with district water or as their sole source, described previously in Chapter 4. The data for the dependent variable comes from the Annual Water Withdrawal and Use Reports filed by providers of water to IGFR certificate holders i.e., irrigation districts, and individual IGFR certificate holders to ADWR.[23,24] The dependent variable for each irrigation district exhibits different temporal patterns. For those districts in or adjacent to the Phoenix urban area, *Total* shows a downward trend with only slight annual deviations from the trend. Figure 5.1 demonstrates this temporal pattern. For the two largest

[23] *Total* for HVID was constructed from ADWR groundwater pumping data and CAP delivery data, as IGFRs are not required to report water use in INAs.
[24] IGFR certificates less than or equal to ten acres and not part of a larger farming operation are not required to report annual water use (Bautista, Waller, & Roanhorse, 2010).

districts in this analysis, MSIDD and CAIDD, *Total* has a U-shape during the study period as shown in Figure 5.2. Further, some districts exhibit relatively constant water use while others have high annual variability such as HVID. Figure 5.3 shows *Total* aggregated over all ten irrigation districts in the analysis annually. Table 5.5 displays the mean, coefficient of variation, maximum, and minimum values for each irrigation district’s dependent variable along with the aggregated total over all irrigation districts; I refer to these as summary statistics.

Figure 5.1: Annual Agricultural Water Use in Roosevelt Water Conservation District

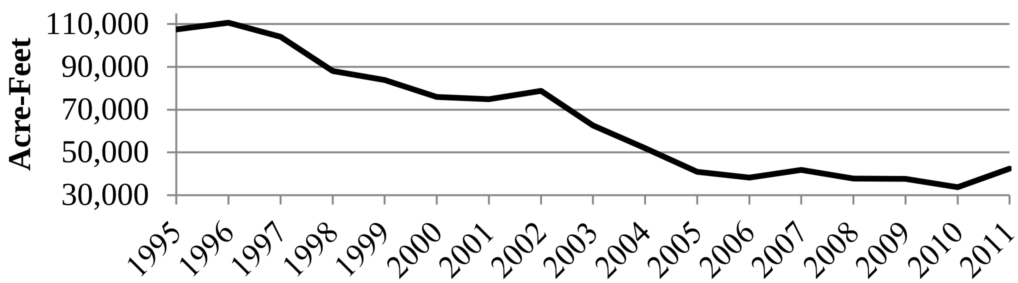


Figure 5.2: Annual Agricultural Water Use in Maricopa-Stanfield Irrigation and Drainage District

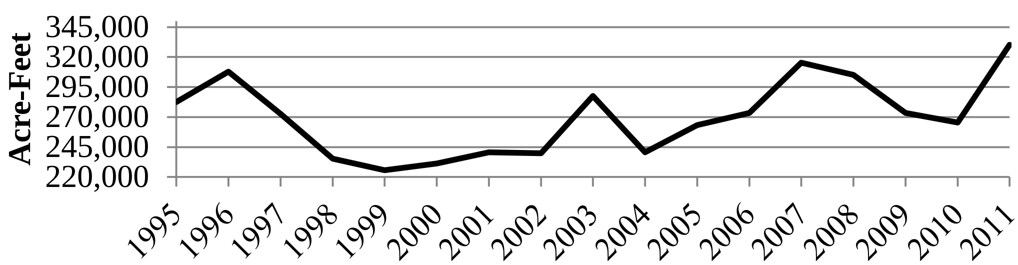
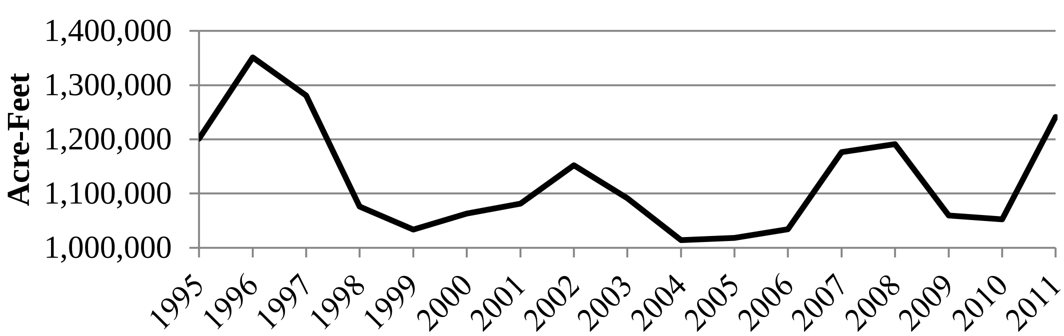


Figure 5.3: Total Annual Agricultural Water Use



5.2.2 Independent Variables

InactiveIGFR The independent variable, *InactiveIGFR*, represents the number of IGFR certificate acres made inactive annually cumulated over time as a percentage based on the actual number of IGFR certificate acres in 1995. This variable is used to account for the decreasing number of total acres available to irrigate because of land conversion, similar to the bold downward sloping line of Figure 3.3. Econometrically, the variable acts to detrend the downward sloping nature of total water use for irrigation districts significantly impacted by land conversion allowing annual fluctuations of the remaining independent variables to be modeled more accurately. The variable should also provide an estimate for land conversions impact on total agricultural water use. The expected sign of *InactiveIGFR* is negative with respect to total water use as total water use should fall as fewer acres are available to be irrigated. A word of caution, the number of IGFR certificate acres made inactive annually is an imprecise figure. Due to accounting complexities of IGFR transactions, the actual number of acres made inactive annually is difficult to calculate and unknown for this analysis.[25] Instead, the data for this variable are drawn from ADWR's IGFR certificate database using a query run by Ms. Pam Muse that collected the total number of IGFR certificate acres associated with a transaction involving the certificate, even if all acres were not made inactive (Muse, 2013). For example, if 75 acres of an IGFR certificate of 100 total acres were made inactive, the entire 100 acres associated with the certificate becomes the number made inactive for the variable, not 75. Table 5.2 attempts to clarify this distinction. The first two numerical columns report the total number of IGFR certificate acres within each irrigation district boundary whether receiving water from the district

[25] The actual number of IGFR acres made inactive for TID is known with precision due to additional information provided by former district manager, Ms. Elisabeth Story.

or not in 1995 and 2011 respectively.[26] The Actual Difference column reports the difference between the two annual figures. The InactiveIGFR Estimate is the cumulative number of IGFR certificate acres made inactive during the study period as used in the analysis. The last two columns show the percentage change in acres based on the 1995 total. Data for this variable comes courtesy of ADWR. As with the dependent variable, summary statistics for the *InactiveIGFR* variable are shown in Table 5.5.

Table 5.2: IGFR Total and Inactive Certificate Acres

District	1995	2011	Actual Difference	InactiveIGFR Estimate	Actual Percent Δ	InactiveIGFR Percent Δ
RWCD	29,632	12,929	-16,704	-14,865	-56.4%	-50.2%
MWD	24,493	14,306	-10,186	-11,536	-41.6%	-47.1%
QCID	17,819	9,820	-7,999	-6,973	-44.9%	-39.1%
NMIDD	28,608	23,174	-5,434	-3,175	-19.0%	-11.1%
MSIDD	86,630	76,547	-10,083	-7,328	-11.6%	-8.5%
TID	3,599	3,298	-301	-294	-8.4%	-8.2%
SCIDD	53,068	45,947	-7,121	-2,502	-13.4%	-4.7%
HID	27,124	27,803	679	-522	2.5%	-1.9%
CAIDD	87,566	85,056	-2,510	-1,236	-2.9%	-1.4%
HVID[27]	47,956	50,108	2,151	0	4.5%	0.0%

Source: Query of ADWR IGFR database (Muse, 2013)

MaxTemp The independent variable, *MaxTemp*, represents the maximum daily temperature averaged from March through September annually measured in degrees Fahrenheit. March through September were chosen because they are the months were most irrigation water is used and because higher temperatures have a larger impact on evapotranspiration (Wilson & Needham, 2006). While the literature suggests cooling-degree days as the best indicator of evapotranspiration-driven crop water use, data collection expeditiousness necessitated maximum

[26] Increases in IGFR certificate acres are possible under the ‘no new IGFR certificate’ clause of the 1980 GMA, if the IGFR applicant can prove the acres were irrigated at some point from 1975-1980 and were simply never recorded (Seasholes, 2012-2013).
[27] IGFR certificate acres for HVID are acres for the entire Harquahala Valley INA as acres for HVID alone were not available

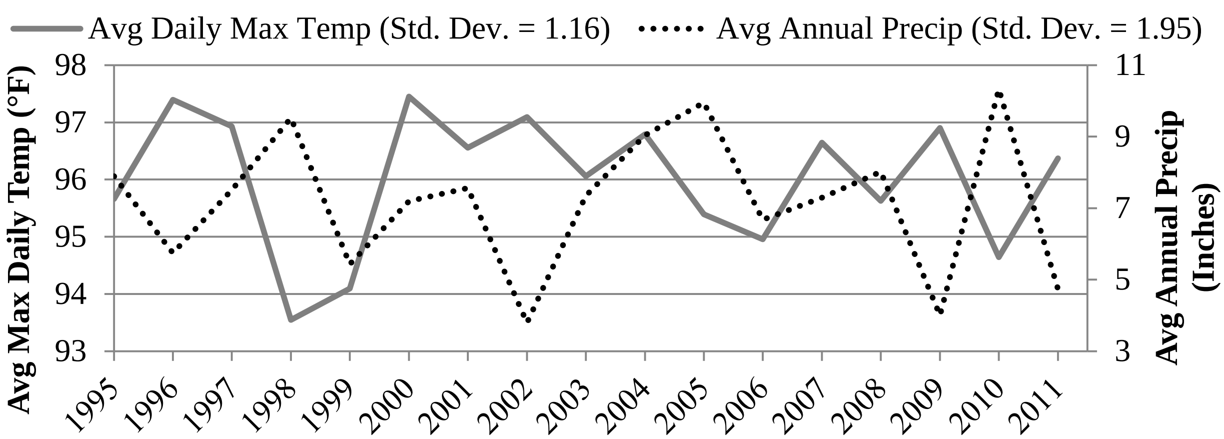
temperature as a substitute (Schlenker, Hanemann, & Fisher, 2007). I think this is acceptable because maximum temperature is likely to be highly correlated with cooling-degree days. The *MaxTemp* variable attempts to capture water use changes driven by increases in crop evapotranspiration, a location effect noted in the conceptual model. The higher the temperature, the more water crops use, therefore, I expect *MaxTemp* to have a positive sign with respect to total water use. Data for the *MaxTemp* variable for each irrigation district are a combination of weather station data from The University of Arizona's Arizona Meteorological Network (AZMET) and NOAA's Global Historical Climate Network-Daily (GHCN-D) database (The University of Arizona, 2013; National Oceanic and Atmospheric Administration, 2013b). Every effort was made to use data from weather stations nearest to or within irrigation district boundaries. In some cases, as with SCIDD and HID, the districts are so near each other that the same data was used for both.[28] Summary statistics for the *MaxTemp* variable are shown in Table 5.5.

Precip The independent variable, *Precip*, represents the total annual precipitation received by each irrigation district measured in inches. The *Precip* variable is used to capture climate related location effects. Total annual precipitation was chosen instead of the March – September period used in the *MaxTemp* variable because a significant portion of precipitation falls during winter months when barley and durum wheat are growing (Arizona Department of Water Resources, 2010). The expected sign for *Precip* is negative, as more precipitation should offset some need for irrigation lowering total water use. However, it is important to note that, as described in Chapter 3, precipitation can actually increase total water use depending on its timing and amount. In addition, unlike temperature, precipitation is highly spatially variable meaning rain

[28] See Appendix B for details on which weather stations provided each temperature observation.

measured at the weather station does not mean rain fell over all, or even some, of the irrigation district. Therefore, results from the precipitation variable should be read with caution. As with *MaxTemp*, data for each irrigation district was a combination of AZMET and NOAA weather station observations. Summary statistics for the *Precip* variable are shown in Table 5.5. A potential problem with using both maximum temperature and precipitation in the same model would be that they could be highly correlated causing problems with parameter estimates. However, as Figure 5.4 shows, maximum temperature and precipitation are not highly correlated ($\rho = -0.1627$) with precipitation varying considerably over time.

Figure 5.4: Average Annual Maximum Temperature and Precipitation[29]



Sources: (The University of Arizona, 2013; National Oceanic and Atmospheric Administration, 2013b)

6mSPIApr The Standardized Precipitation Index (SPI) is a probability index that gives the probability of recording the precipitation of the period of interest based on climate norms (National Oceanic and Atmospheric Administration, 2013c). The probabilities are standardized so that a value of zero means the historically average amount of precipitation was recorded. The more severe the drought, the more negative values get and the reverse is true for wet periods. For

[29] Average Annual Maximum Temperature is the average daily maximum temperature from March - September

the *6mSPIApr* independent variable, the April SPI value for the previous six months, including April, is observed for the climate division where the headwaters of the river providing the surface water originates. The *6mSPIApr* variable measures whether precipitation for November through April is above or below normal, in this case, reflecting winter snowpack. For example, the annual *6mSPIApr* value for SCIDD is based on New Mexico's fourth climatological division where much of the snowpack that fills the Gila River originates. Table 5.3 shows the climatological divisions chosen for the *6mSPIApr* variable.

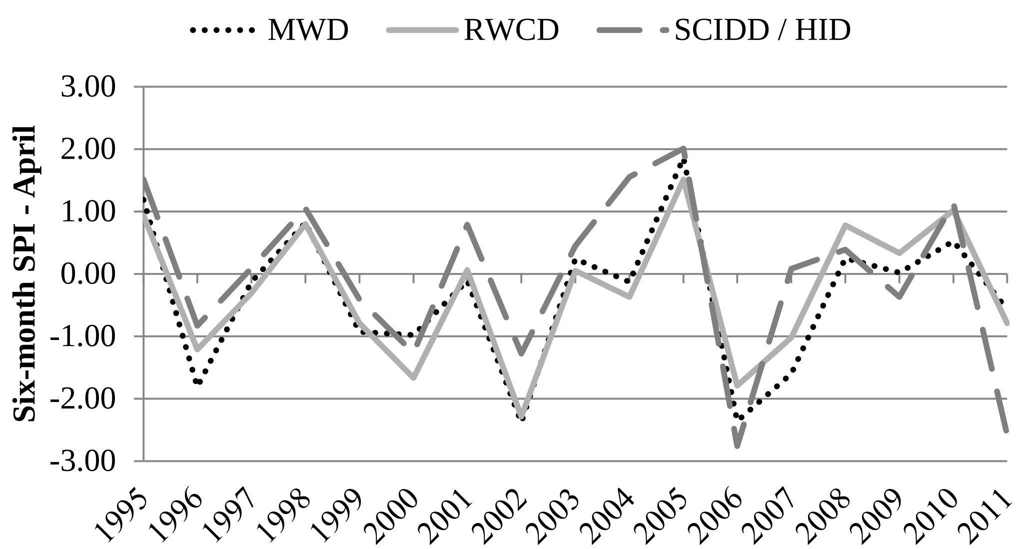
Table 5.3: SPI Values for Irrigation District Surface Water Supplies

Irrigation District	River	Climatological Division	
		State	Number
Maricopa Water District	Agua Fria	Arizona	3
Roosevelt WCD	Salt	Arizona	4
San Carlos IDD	Gila	New Mexico	4
Hohokam ID	Gila	New Mexico	4

Source: (National Oceanic and Atmospheric Administration, 2013a)

Since only four irrigation districts in the analysis use surface water from non-CAP sources, I interact a dummy variable, $D_{surface}$, with the *6mSPIApr* variable. The interaction between $D_{surface}$ and *6mSPIApr* creates a variable where those districts using surface water have their respective SPI values while those that do not use surface water, have a value of zero, equivalent to normal precipitation in all years. The idea behind including the *6mSPIApr* variable as follows: I assume some districts, in an effort to maintain a stable, affordable water price to their growers, are price constrained by the next highest cost source of water. Therefore, any additional surface water available, often costing less to provide than the price paid by growers, will be supplied (Leonard, 2013). The logic is that if there is an above normal snowpack, additional surface water supplies will be used, increasing overall water use for agriculture. One issue with this theory is that logic would also suggest districts would acquire less water from other sources as orders are filled with additional surface water. However, I believe some growers are quantity, rather than price constrained and, therefore, will make use of available supplies at the districts posted price for water until their needs are met. Figure 5.5 shows the *6mSPIApr* values for the four irrigation districts using surface water. Of note, since both *6mSPIApr* and *Precip* measure the same thing, there could be an issue with the variable explaining the same phenomenon, thereby skewing the coefficient estimates. However, for all 170 observations, *6mSPIApr* and *Precip* have a correlation coefficient of 0.3499, therefore, I do not think there is excessive collinearity. Of note, when the two variables are compared using only those districts with surface water supplies, the correlation coefficient increases to 0.5726 (n = 68).

Figure 5.5: *6mSPIApr* Values for Irrigation Districts Using Surface Water



Source: (National Oceanic and Atmospheric Administration, 2013a)

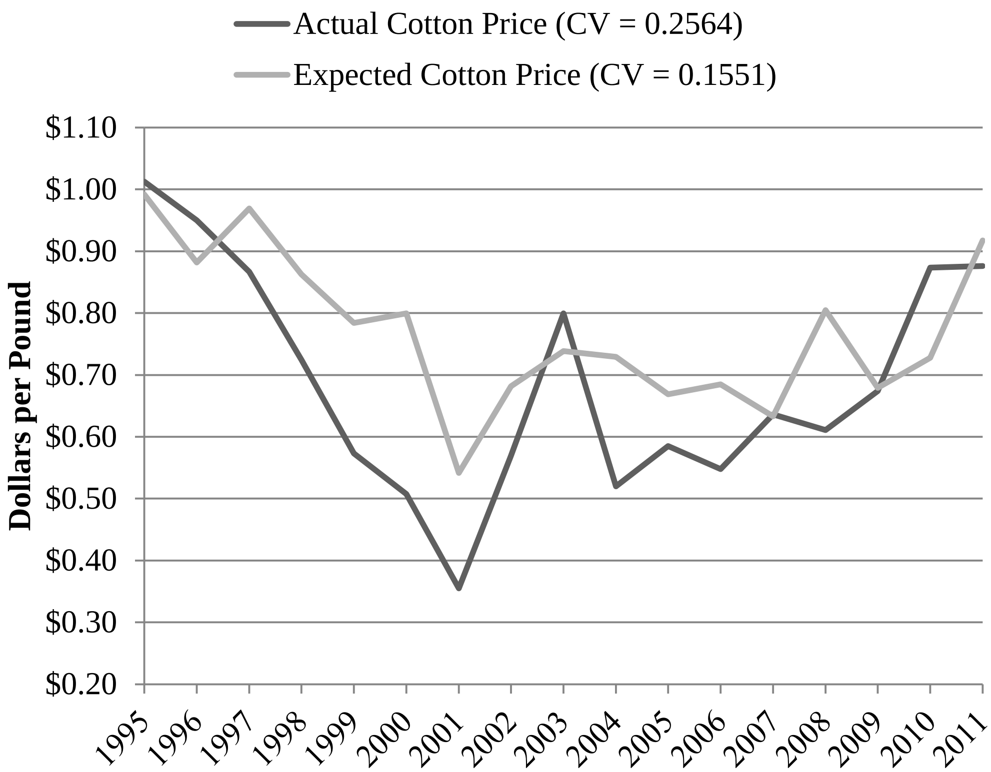
Data for *6mSPIApr* comes from NOAA through the National Climate Data Center's (NCDC) Climate Data Online database (National Oceanic and Atmospheric Administration, 2013a). Summary statistics for the *6mSPIApr* variable are shown in Table 5.5.

CottonPrice The independent variable *CottonPrice* is the state level marketing year average price of upland cotton for the current year measured in dollars per pound. The variable is in 2011 dollars and is adjusted to real terms using the seasonally adjusted GDP Implicit Price Deflator provided by the Bureau of Economic Analysis (Federal Reserve Bank of St. Louis, 2013a). The price for upland cotton was chosen as it constitutes nearly 100 percent of all cotton acres (U.S. Department of Agriculture, National Agricultural Statistics Service, 2012). I assume *CottonPrice* to directly reflect the profitability of planting cotton. This profitability assumption is based on the idea that average cotton yield improvements over the study period, along with input-factor productivity increases, have perfectly offset real increases in input prices (U.S. Department of Agriculture, Economic Research Service, 2013; National Agricultural Statistics Service, Arizona Field Office, 2012; U.S. Department of Agriculture, National Agricultural Statistics Service, 2012). Referring to the conceptual model, *CottonPrice* is both a scale effect and a crop-mix effect. The higher the expected price of cotton, the more acres growers will likely plant to it both in total and relative to other crop options, assuming other crop prices remain constant. Since cotton generally displaces alfalfa plantings, I expect the parameter of *CottonPrice* to reflect scale effects more so than crop-mix effects, as cotton generally uses less water per acre than alfalfa (Rayner, 2013). I also expect *CottonPrice* to have a positive sign with respect to total water use as higher expected prices lead to more irrigated acres.

Cotton is the most heavily subsidized crop in Arizona with respect to support programs through the federal government (Environmental Working Group, 2013). Between 1995 and 2012, cotton growers in Maricopa County and Pinal County received $412.8 million and $412.9 million respectively in subsidies from the federal government (Environmental Working Group, 2013). The second most highly federally subsidized crop in Arizona over the same period was wheat with growers receiving $35.0 million and $34.4 million in the respective counties (Environmental Working Group, 2013). Since the *CottonPrice* variable is measured in price, federal program subsidies relating to price such as counter-cycle payments and loan deficiency payments need to be taken into account (U.S. Department of Agriculture, Farm Service Agency, 2012; U.S. Department of Agriculture, Farm Service Agency, 2011).[30] In order to have a cotton price variable that reflects the expected price growers use to make planting decisions, I created an expected cotton price variable based on a method used by Tronstad and Bool (2010). Appendix B details the process for creating this variable. While the method used to construct the expected cotton price variable is sound, I chose to use the unadjusted-actual price instead. The reason is that the calculated variable smoothed much of the variability of actual cotton prices. Since econometric models require variability to have any explanatory power, I chose to use the more straightforward actual marketing year average price even though it could not be used in a forecasting model. This is reasonable because the actual cotton price variable likely reflected present and future price information that growers were more attuned to than the calculated variable shows. The two price measures have a correlation coefficient of 0.7576. I also chose to use the current price rather than a one-year lag, as much of the literature does, because a one-year lag in prices would be too far removed from pricing conditions considered for planting (Wilson & Needham, 2006). Further, the marketing year price is an average of actual prices from August of the previous year through July of the current year. Therefore, the price reasonably captures the relative range of prices growers could expect to receive. Figure 5.6 shows the difference between the actual and calculated expected cotton price variables.

[30] This thesis makes no attempt to account for all subsidies available to growers for planting cotton.

Figure 5.6: Actual versus Calculated Expected Cotton Price ($2011)



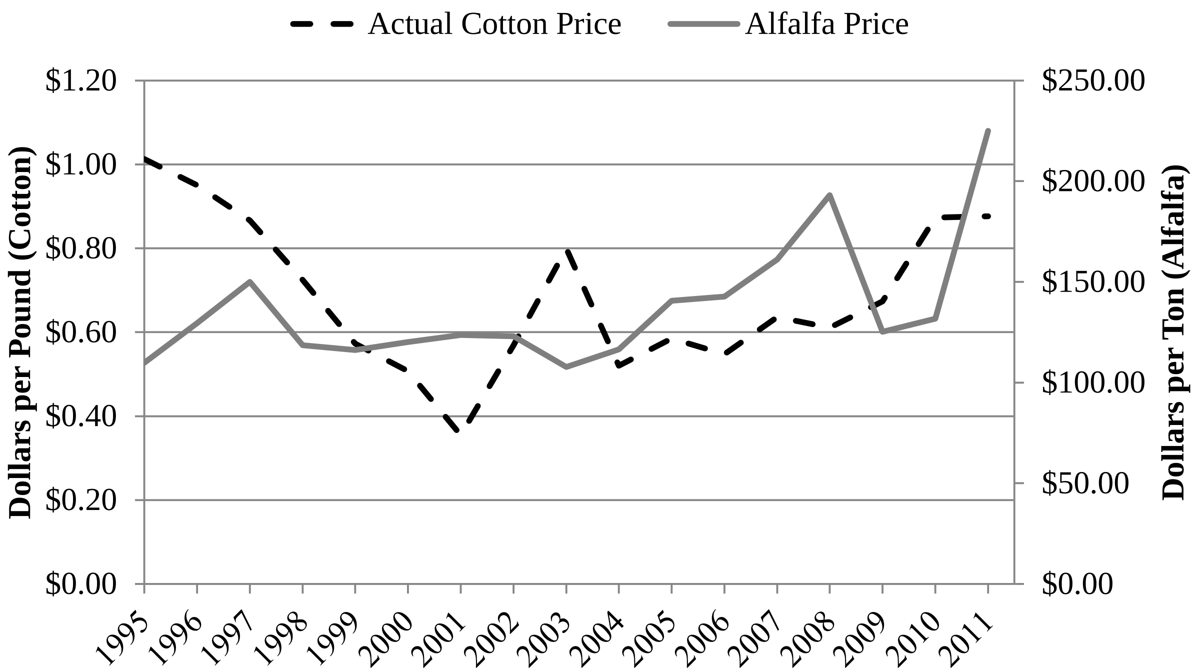
Note: CV = Coefficient of Variation = (standard deviation / mean)
Source: (U.S. Department of Agriculture, National Agricultural Statistics Service, 2012)

State cotton price data comes from the Quick Stats 2.0 database hosted by USDA's National Agricultural Statistics Service (NASS) with assistance from Mr. David DeWalt, Deputy Director of the Arizona Field Office (U.S. Department of Agriculture, National Agricultural Statistics Service, 2012). Summary statistics for the *CottonPrice* variable are shown in Table 5.5.

AlfalfaPrice The independent variable *AlfalfaPrice* is the state marketing year price reported for Arizona in 2011 dollars converted to real terms like *CottonPrice*. Since the data for this variable is at the state level, it is the same for all irrigation districts. *AlfalfaPrice* is measured in dollars per ton and is assumed to reflect the profitability of planting alfalfa, using the same logic as outlined for *CottonPrice*. I also assume that the marketing year price for alfalfa captured by the *AlfalfaPrice* variable is the best representation of expected price available for two reasons.

First, a one-year lag in prices, commonly used in the literature, would be too far removed from pricing conditions considered for planting (Wilson & Needham, 2006). Second, there is no futures market for alfalfa. Like *CottonPrice*, *AlfalfaPrice* includes both scale and crop-mix effects. Unlike *CottonPrice*, less can be said about the parameter to be estimated as higher expected alfalfa prices relative to expected cotton prices would likely result in more total acres being planted as well as more water use per acre, noting alfalfa's relatively high irrigation water requirement. I expect the sign of *AlfalfaPrice* to be positive with respect to total water use because of the scale and crop-mix effects noted above. *AlfalfaPrice* and *CottonPrice* are the same for all districts as they are state-level prices, due to lack of data on prices at a smaller spatial scale. Data for *AlfalfaPrice* comes from the Quick Stats 2.0 database hosted by USDA's National Agricultural Statistics Service (NASS) with assistance from Mr. David DeWalt, Deputy Director of the Arizona Field Office (U.S. Department of Agriculture, National Agricultural Statistics Service, 2012). Summary statistics for the *AlfalfaPrice* variable are shown in Table 5.5. Figure 5.7 shows how the *CottonPrice* and *AlfalfaPrice* variables have varied during the study period.

Figure 5.7: Annual Cotton and Alfalfa Price in Arizona ($2011)

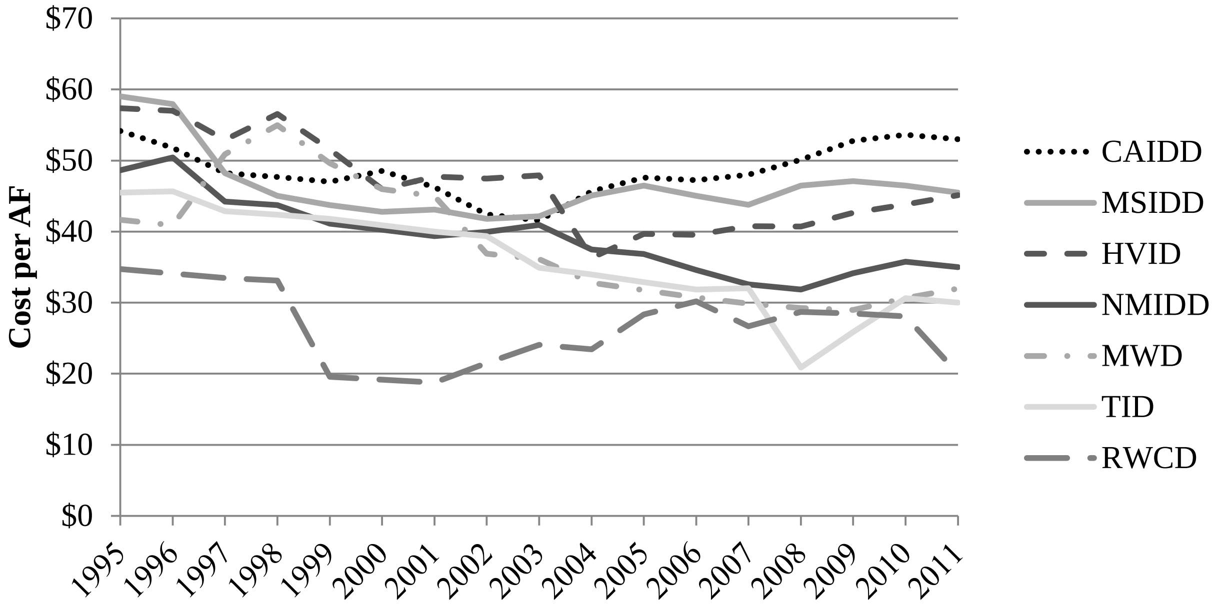


Source: (U.S. Department of Agriculture, National Agricultural Statistics Service, 2012)

DistWaterCost The independent variable *DistWaterCost* is the actual price of water per AF irrigation districts charged their member growers. The variable is measured in 2011 dollars adjusted using the GDP Implicit Price Deflator. Each irrigation district uses a different methodology for determining what price to charge its member growers in any given year. Some districts use the weighted average cost of all sources per acre-foot and then add an additional percentage of the total for fixed costs (Warren, 2013). Other districts, set water prices at the actual weighted average cost their water sources plus some percentage for fixed costs per acre-foot and use a non-volumetric assessment per acre to recoup any remaining fixed costs (Betcher, 2013). Data for the variable was gathered during interviews with district managers described in the previous chapter. *DistWaterCost* is not included in the empirical model outlined in Section 5.1 because data for it could only be gathered from seven of the ten irrigation districts. Recent retirements of long-time district managers prior to the interviews combined with the busy schedules of other managers limited quantitative data collection from districts. I was also not able to collect enough information to estimate annual groundwater costs of growers pumping water as their sole source or in conjunction with district delivered water as Wilson and Needham did (Wilson & Needham, 2006). Since *Total* records all water used within irrigation district boundaries, not having groundwater pumping costs or complete irrigation districts costs means any parameter estimates from *DistWaterCost* would not be robust.

To remediate this lack of data, using the average price of direct CAP water delivered was considered. However, CAP water makes up a vastly different percentage of total use for each district. Further, water cost spreading activities to non-agricultural entities mean CAP water costs do not accurately reflect the prices paid by growers. Examples of cost spreading are how MWD subsidizes the price growers pay using revenues from its marina on Lake Pleasant or how RWCD uses a relatively large assessment fee on its urban customers to offer a lower cost of water to its growers (Flowers Jr., 2013; Leonard, 2013). Therefore, using CAP price as a substitute was ruled out. Still, as is reflected in the conceptual model, the cost of water is central to any water use model. Recognizing this, I estimate additional models including *DistWaterCost* with the limited data to see how its inclusion affects the other independent variables. Since water is an input cost and growers are assumed to be profit-maximizing agents, I expect demand for water to be downward sloping and thus negative in sign with respect to total water use. Figure 5.8 shows how real district water prices for the seven districts have changed over time. The Figure shows that prices in each district have remained steady or fallen during the study period adjusted for inflation. Summary statistics for *DistWaterCost* can be found in Table 5.5.

Figure 5.8: Irrigation District Annual Water Cost ($2011)



Source: Irrigation District Managers

5.2.3 Alternative Independent Variables Considered

A number of variables capturing the same effects as those noted in Table 5.1 were considered prior to settling on the model to be estimated. To capture the effect of agricultural land conversion, I created a population variable. The population variable consisted of the annual populations of cities geographically located in or adjacent to each irrigation district; see Appendix B for details. Issues with this variable are that it is difficult to scale according to the size of the irrigation district and population growth in each city does not always take place on agricultural land, among others. For example, Maricopa City, near MSIDD, added over 40,000 people during the study period while Queen Creek added nearly 25,000, yet MSIDD experienced a growth in water use while QCIDs fell steadily. County population was also considered but had similar problems because of districts such as HVID and TID that are both in fast-growing Maricopa County but experienced no impact from population growth. Finally, cumulative single-family housing starts for the Phoenix MSA was considered but, not surprisingly, ended up being highly correlated with Maricopa County population growth. All three alternate land conversion measures were tried using an interaction dummy with only those irrigation districts directly touching the Phoenix metropolitan area taking a value of one. However, they all performed similarly and not as well as the more precise *InactiveIGFR* variable. Agricultural land conversion data for these variables came from three different sources. Annual population estimates for Arizona cities were provided by the Arizona State Demographer, Mr. Jim Chang (Arizona Department of Administration, 2013). Annual county population estimates come from the U.S. Census Bureau (U.S. Census Bureau, 2013). Annual housing starts for the Phoenix-Mesa-Scottsdale Metropolitan Statistical Area (MSA) come from the Federal Reserve Bank of St. Louis' FRED® Economic Data site (Federal Reserve Bank of St. Louis, 2013b).

For the weather variables, mean temperature and the nine-month October SPI (9mSPIOct) were also considered to capture local conditions. Maximum temperature was chosen over mean temperature as I thought its higher variance would better capture crop water use due to evapotranspiration. The 9mSPIOct was not chosen because all irrigation districts are in the same climate division. If I had used it, all of the precipitation related water use variation at the irrigation district level would be effectively thrown out. The six-month April SPI (*6mSPIApr*) was chosen over the 12 and 24 month SPIs for April as it better reflects the amount of water available to irrigation districts receiving surface water. For example, as described in the previous chapter, MWD's surface water supply is based on current year flows of the Agua Fria River into Lake Pleasant. Therefore, the supply smoothing effect of New Waddell Dam, that creates Lake Pleasant, in wet or dry years does not significantly influence annual deliveries to MWD. Longer indices might have performed better, if reservoir storage played a larger role in regulating the amount of surface water available annually in the districts of interest such as with SRPAIPD.

In addition to using cotton and alfalfa prices to model scale and crop-mix effects, other major crop prices were considered. These include barley, corn for grain, and durum wheat. Two reasons drove the inclusion of only cotton and alfalfa prices. First, cotton and alfalfa use the most water per acre and constitute a large majority of acres in the study area. Therefore, I assume any changes in their profitability will drive most total water use changes. Second, alfalfa price is highly correlated with barley, corn for grain, and durum wheat prices as shown in Table 5.4. Therefore, including all or even more than one of them in the model would distort their parameter estimates. Table 5.4 also shows the crop prices correlation with total water use. The number of dairy cows, by county, was also considered as an alternative to alfalfa prices. Dairy operation expansion in Arizona is a primary driver behind the increase in alfalfa plantings (Fertizona, 2007). However, like county population, I thought the variable did not show enough annual variation to explain fluctuations in alfalfa plantings. Data for dairy cow populations comes from USDA, NASS' QuickStats 2.0 database.

Table 5.4: Correlation Coefficients and p-Values of Major Crop Prices in Arizona

	Total	Upland Cotton	Alfalfa	Durum Wheat	Barley	Corn for Grain
Total	1.0000	0.0725	0.0487	0.0589	0.0858	0.0591
		0.3478	*0.5281*	*0.4459*	*0.2658*	*0.4437*
Upland Cotton	0.0725	1.0000	0.1281	0.4025	0.5972	0.5433
	0.3478		*0.0959*	*<.0001*	*<.0001*	*<.0001*
Alfalfa	0.0487	0.1281	1.0000	0.6329	0.6905	0.7554
	0.5281	*0.0959*		*<.0001*	*<.0001*	*<.0001*
Durum Wheat	0.0589	0.4025	0.6329	1.0000	0.8244	0.7028
	0.4459	*<.0001*	*<.0001*		*<.0001*	*<.0001*
Barley	0.0858	0.5972	0.6905	0.8244	1.0000	0.8748
	0.2658	*<.0001*	*<.0001*	*<.0001*		*<.0001*
Corn for Grain	0.0591	0.5433	0.7554	0.7028	0.8748	1.0000
	0.4437	*<.0001*	*<.0001*	*<.0001*	*<.0001*	

Note: p-Values in *italics* based on 95 percent confidence level
T = 17

Table 5.5: Summary Statistics for All Model Variables by Irrigation District between 1995 and 2011

		ALL IDs	MSIDD	CAIDD	HID	SCIDD	NMIDD	HVID	TID	MWD	RWCD	QCID
Total	Mean	112,456	270,014	260,843	110,455	110,994	84,939	107,643	20,274	53,727	65,330	40,336
	CV	0.753	0.118	0.141	0.102	0.210	0.097	0.184	0.111	0.301	0.414	0.285
	Min	16,275	225,726	205,397	96,007	81,879	72,079	76,253	16,275	31,019	33,705	25,562
	Max	348,525	330,326	348,525	127,898	160,380	98,198	138,574	23,170	88,427	110,651	62,539
InactiveIGFR	Mean	7.7%	3.0%	0.7%	0.5%	1.4%	3.1%	0.0%	3.7%	22.2%	25.6%	16.5%
	CV	1.655	1.240	0.662	1.609	1.430	1.236	.	0.972	0.736	0.659	0.825
	Min	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	1.2%	0.0%
	Max	50.2%	8.5%	1.4%	1.9%	4.7%	11.1%	0.0%	8.2%	47.1%	50.2%	39.1%
MaxTemp	Mean	96.01	98.1	97.3	97.3	97.3	94.3	94.9	95.9	95.3	95.4	94.3
	CV	0.020	0.012	0.019	0.016	0.016	0.015	0.014	0.017	0.014	0.015	0.015
	Min	91.86	95.5	94.0	95.3	95.3	92.3	91.9	91.9	92.7	92.0	92.3
	Max	100.89	99.5	100.9	100.1	100.1	96.3	96.4	98.4	97.8	97.8	96.3
Precip	Mean	7.18	6.28	7.66	7.60	7.60	7.27	6.06	6.06	7.06	8.94	7.27
	CV	0.368	0.270	0.423	0.282	0.282	0.270	0.482	0.450	0.443	0.356	0.270
	Min	1.24	3.03	2.67	3.47	3.47	3.84	1.24	2.36	2.44	4.67	3.84
	Max	15.55	8.08	13.28	10.26	10.26	10.42	11.02	11.02	12.05	15.55	10.42
6mSPIApr	Mean	-0.17	0.00	0.00	-0.03	-0.03	0.00	0.00	0.00	-0.36	-0.28	0.00
	Std Dev	1.25	0.00	0.00	1.38	1.38	0.00	0.00	0.00	1.20	1.10	0.00
	Min	-2.76	0.00	0.00	-2.76	-2.76	0.00	0.00	0.00	-2.38	-2.29	0.00
	Max	2.01	0.00	0.00	2.01	2.01	0.00	0.00	0.00	1.86	1.51	0.00
CottonPrice	Mean	$0.69										
	CV	0.261										
	Min	$0.35										
	Max	$1.01										
AlfalfaPrice	Mean	$137.33										
	CV	0.220										
	Min	$107.78										
	Max	$225.00										
DistWaterCost	Mean	$40.23	$46.45	$48.57	.	.	$39.22	$46.65	$35.97	$38.12	$26.61	.
	CV	0.232	0.105	0.075	.	.	0.136	0.141	0.197	0.223	0.208	.
	Min	$18.74	$41.80	$41.55	.	.	$31.84	$36.31	$20.88	$28.98	$18.74	.
	Max	$59.04	$59.04	$54.18	.	.	$50.44	$57.37	$45.67	$54.97	$34.73	.

Note: *CottonPrice* and *AlfalfaPrice* are not listed for each district because they are the same for all districts.
N = 170 for ALL IDs column except *6mSPIApr* (N = 68) and *DistWaterCost* (N = 119)
Coefficient of Variation not used for *6mSPIApr* because mean value is negative.

5.3 Econometric Analysis

Pooled datasets combine aspects from both time-series and cross-sectional data (Gujarati & Porter, 2009). Panel data is a specific case of pooled data in that it follows the same cross-sectional units (units) over time (Gujarati & Porter, 2009). In some literature, this data is known as time-series cross-section (TSCS) data (Wilson & Butler, 2007). Since I am interested in water use for agriculture within the same ten irrigation districts (N = 10) over a period of 17 years (T = 17), the data structure is panel in nature. The dataset is also balanced, meaning that each unit or irrigation district is observed the same number of times (Greene, 2012). According to Baltagi, panel data have a number of advantages over purely time-series or cross-sectional analysis (Baltagi, 1995). Two such advantages noted are that panel data allows the use of more data when there are a small number of units and that it allows better study of the dynamics of adjustment, in this case, how water use changes over time as explanatory variables change. The basic modeling framework for panel data is shown in equation (5.1). The transposed *x* matrix contains all K time-varying variables for each unit as denoted by the *i* and *t* subscripts. The variable matrix is multiplied by the parameter vector β. The group specific or unit effects, both observed and unobserved, are contained in the transposed *z* matrix and multiplied by a parameter vector α. Finally, an error term, ε, specific to each unit and time period is added to capture modeling error.

$$y_{it} = x'_{it}\beta + z'_{i}\alpha + \varepsilon_{it} \qquad (5.1)$$

5.3.1 Modeling Considerations

There are three primary econometric model types to choose from when using panel data for analysis (Gujarati & Porter, 2009). The choice of model depends on how unobserved heterogeneity is accounted for. Heterogeneity, in this case, refers to the differences between each irrigation district. The goal of an econometric model is to account for as many differences as possible using explanatory variables. Unfortunately, there are unobserved differences that do not change or change very little over time such as grower management styles or soil characteristics that cannot or are not accounted for by other explanatory variables. Therefore, the decision concerning how to model the unobserved heterogeneity is the first decision when choosing a modeling technique. The three primary model types are pooled, fixed effects (FE), and random effects (RE) (Ajmani, 2009). The pooled model assumes that there are no unobserved differences across units. Therefore, data from each unit can be 'pooled' together and the standard ordinary-least squares (OLS) estimator can be applied to estimate explanatory variable parameters. The FE model assumes that there are unit-specific differences expressed through intercept terms differing across units but that the estimated parameters are the same across units.[31] One of the drawbacks of the FE model is that time-invariant parameters are impossible to estimate because they get included in the unit-specific intercept terms (Greene, 2012). This drawback is not an issue for the analysis, as I am not interested in estimating time-invariant parameters. An alternative to the FE model with dummy variables for each unit, known as the least-squares dummy variable (LSDV) model, is the Within-Group (WG) estimator. The WG estimator gives the same parameter and standard error values as the LSDV model, but does so in a different way. The WG estimator first subtracts dependent and independent variable means for each unit, then pools the data together and runs an OLS regression (Johnston & DiNardo, 1997). This difference is noted because the WG estimator is employed in some of the commands in the statistical software used to estimate the models (McCaffrey, Lockwood, Mihaly, & Sass, 2012). The RE model assumes that differences among units are distributed along a normal curve and that the

[31] Time-specific effects are not considered for this analysis, therefore, only one-way model specifications are of interest.

units used in analysis are a sample of an overall population sharing the same mean (Greene, 2012). An advantage of the RE model over the FE model is that it leaves more degrees of freedom because unit-specific dummy variables are not required (Greene, 2012).[32] However, a major assumption of the RE model, that can lead researchers to the FE model, is that unobserved heterogeneity accounted for in the error term is not correlated with any of the explanatory variables (Greene, 2012). This assumption may not be appropriate in some settings.

To aid the decision of how to treat unit heterogeneity, I use a process suggested by Park (Park, 2011). First, I test for FE using an F-test. The null hypothesis for the F-test is that unit-specific intercept parameters are not different from zero. If they are not different from zero, then no significant heterogeneity across units exits and the data can be pooled. An F-test for the data indicates that unit-specific intercept parameters are significantly different from zero at a 95 percent confidence interval. Complete results from this and all following econometric tests from this chapter can be found in Appendix C. Another method of examining poolability is that if explanatory variable parameters from a pooled model are not significantly different to those from a FE model, the unit-specific effects are not very influential and, therefore, it can be assumed that the data can be pooled. Since the F-test shows that unit-specific effects are significantly different from zero, I proceed to see if RE model is appropriate. The Breusch-Pagan Lagrange Multiplier (BP-LM) test can be used to test for the existence of RE (Torres-Reyna, 2011). The BP-LM test for RE does not directly reveal whether an RE or FE model should be used. Rather, since FEs are indicated, it can add support to the claim that panel effects exist and pooling the data is, therefore, inappropriate. The null hypothesis for the BP-LM test is that there are no RE and, therefore, the data can be pooled (Torres-Reyna, 2011). A BP-LM test on the data agrees

[32] Generally speaking, more degrees of freedom can lead to more robust results

with the previous test results that the data should not be pooled and that panel, or unit specific effects are present.

Since both an F-test and BP-LM test indicate that the data should not be pooled, I move on to the Hausman test to see if FE or RE are more appropriate. A cautionary note, the Hausman test is meant to be a guide but not the rule in deciding what model type to use. The null hypothesis of the Hausman test is that there is no substantial difference between the two models and, therefore, the RE model would be preferred because it is more efficient (Kristensen & Wawro, 2003). The idea behind the Hausman test is that it determines whether the error term, of which the unobserved effects are a part of, is correlated with any of the explanatory variables (Torres-Reyna, 2011). A Hausman test on the data returned inconclusive results. According to Stata, the data does not meet certain asymptotic assumptions used by the test. Instead, a test of over-identifying restrictions can be applied to see if an FE or RE model is better suited to the data (Schaffer & Stillman, 2011). Results from this test indicate at a 95 percent confidence level that a FE model should be used

5.3.2 Testing for Model Assumptions

The three model types outlined in the previous section rely on a number of mathematical assumptions to be consistent and efficient parameter estimators when using the method of OLS (Greene, 2012). If these assumptions are not met, corrective techniques need to be used to ensure the estimators are consistent and efficient. Three key assumptions are considered here: no contemporaneous correlation (cross-sectional dependence), no serial correlation (autocorrelation), and homoscedasticity (as opposed to heteroscedasticity).

A major assumption of classical regression is that error terms have the same size variance, known as homoscedasticity (Greene, 2012). Heteroscedasticity is where the variance of error terms is not the same. Heteroscedasticity is most commonly found in cross-sectional data (group-wise), as opposed to error variances changing across time, so only group-wise heteroscedasticity is considered in the analysis (Johnston & DiNardo, 1997; Beck & Katz, 1995). For this thesis, each irrigation district is considered a group. Torres-Reyna suggests using a modified Wald test to determine if group-wise heteroscedasticity is present in a FE regression model (Torres-Reyna, 2011). The modified Wald test statistic, outlined by Baum, has a null hypothesis of group-wise homoscedasticity (Baum, 2001). A note of caution is that the modified Wald test statistic used here relies on asymptotic properties (Baum, 2001). That is, confidence in the test is higher when the number of cross-sectional units or time periods is very large. In this case, the number of units is ten while the number of time periods is 17, suggesting that results from this test should be viewed cautiously. Using this approach, I find the data contains group-wise heteroscedasticity at a 95 percent confidence level, that needs to be accommodated [chi^2 (10) = 222.77, p-value = 0.0000].

Another issue that affects the robustness of OLS parameter estimates is serial correlation. Serial correlation is when errors in one time period can be explained by errors of the same unit in previous periods, sometimes referred to as temporal dependence (Johnston & DiNardo, 1997); (Beck & Katz, 1995). In the literature, the most common serial correlation specification is the AR(1) or first-order autoregressive process (Johnston & DiNardo, 1997). In this case, only the error from the proceeding period helps explain the current error. Serial correlation can be caused by inadequate model specification (Johnston & DiNardo, 1997). In other words, crucial explanatory variables are missing in each time period leading to serial correlation. To test for first-order autocorrelation, I use the test statistic outlined by Wooldridge as explained by Drukker where the null hypothesis is that no serial correlation of the first-order exists (Drukker, 2003). A cautionary note is that the Wooldridge test, based on a first-difference model, is not as powerful in small data samples such as the one under consideration, and when errors are heteroscedastic as have been shown to exist in the data (Drukker, 2003). Still, I run the test on the FE model and find that at a 95 percent confidence interval, I can safely reject the null hypothesis and assume the data contains first-order autocorrelation [$F(1,9) = 12.34$, p-value = 0.0066].

Contemporaneous correlation (cross-sectional dependence) is when the residuals or errors of two or more units of the same time period are correlated (Torres-Reyna, 2011). Since the study area is relatively small and relatively homogenous, it is not unrealistic to assume that shocks to one unit resulting in either a positive or negative error would occur in all with a similar response. An example of such a shock would be a pest outbreak or a response to a particular crop pricing situation. One of the assumptions of classical regression, OLS, is that observations need be independent. In the example above, the observations are certainly not independent as they all respond to a single shock similarly. A number of tests are available to check for cross-sectional dependence, though, none are completely appropriate for this dataset. The Pesaran CD (cross-sectional dependence) test excels when the number of observations is large compared to the number of time periods (Pesaran, 2004). However, the data is relatively small and has the number of time periods exceeding the number of observations making the Pesaran CD test inappropriate. Baum proposes using a Lagrange Multiplier (LM) test conceived by Breusch and Pagan (BP/LM) to see if cross-sectional dependence could be a problem (Baum, 2001; Breusch & Pagan, 1980). The BP/LM test works by comparing the error correlations across units (Torres-

Reyna, 2011). The null hypothesis for the BP/LM test is cross-sectional independence. Note, the BP/LM test is most appropriate when the number of observations is fixed as the number of time periods becomes increasingly large relatively speaking (Pesaran, Ullah, & Yamagata, 2006). However, while the dataset has more time periods than observations, it has only 17 time periods so the results of the BP/LM test should be read with caution. Running the BP/LM test reveals that the data contains cross-sectional dependence at a 95 percent confidence level [chi^2 (45) = 97.871, p-value = 0.0000].

5.3.3 Choice of Econometric Models

The previous tests to ensure some key classical regression assumptions were met revealed that such assumptions are not satisfied. Therefore, certain modeling techniques need to be used to ensure parameter estimates are consistent and efficient. Fortunately, the choice of corrective modeling techniques is abundant; unfortunately, none of the techniques fit the characteristics of the data perfectly. Recognizing choice of corrective technique issue, two approaches are considered.

First, since the errors exhibit serial correlation, heteroscedasticity, and contemporaneous correlation as well as individual effects I need a model specification that addresses each of these issues. To do so, I use the panel-corrected standard errors (PCSE) approach advocated for by Beck and Katz with LSDV FE to account for individual effects as noted by Kristensen and Wawro (Beck & Katz, 1995; Kristensen & Wawro, 2003). A central assumption of the PCSE method is that errors are not serially correlated (Kristensen & Wawro, 2003). Since the tests in the previous section show the existence of serial correlation, it needs to be dealt with prior to employing PCSE. Beck & Katz suggest using a lag of the dependent variable as the best way to address serial correlation (Kristensen & Wawro, 2003). However, rerunning the serial correlation test from the previous section on the model with the addition of a single-period lagged dependent variable did not change the outcome of the test. Further, by including a lag in the PCSE model, I would also have to include a lag in the model described below in order to have the same independent variables, something I was unwilling to do.[33] Instead, the Stata software command *xtpcse, correlation(ar1)* pools the data, uses an FGLS estimator with a Prais-Winsten transformation to account for serial correlation, and then applies the PCSE method (StataCorp LP, 2012). Using LSDV FE ensures that unit effects are estimated. I assume that the same AR(1) process is common to all units, as Beck and Katz suggest (Beck & Katz, 1995).

The second approach takes a different attitude toward the violation of classical regression assumptions of the dataset used in the analysis. As noted in the assumptions testing section, most of the tests and corrections rely on asymptotic properties, something that the small panel data set cannot come close to achieving. Similarly, Torres-Reyna make similar assertions regarding ‘micro’ panels noting such corrections are not appropriate (Torres-Reyna, 2011). Sophisticated modeling techniques can cause more harm than good through the liberal application of the assumptions they stand on (Kristensen & Wawro, 2003). Therefore, the detected contemporaneous correlation and serial correlation are consciously ignored. Heteroscedasticity and unit effects are, however, two things not to be neglected. Therefore, I use a simple FE model with robust standard errors recommended by Kristensen and Wawro

[33] A single-period lagged dependent variable was tried in the pooled OLS model with PCSE and LSDV FE. The lag coefficient was 0.380 (S.E. = 0.097). The lag variable absorbed a significant portion of the *InactiveIGFR* coefficient but did not significantly affect the coefficients of the other variables.

(Kristensen & Wawro, 2003)[34]. Two different model specifications allow more confidence in any results that occur in both specifications and cautious of those that appear in only one.

5.3.4 Model Functional Forms

In addition to estimating the strictly linear models described thus far, I also consider a log-log or double-log transformation. The log-log transformation takes the natural log of both the dependent variable and all independent variables, except the dummy variables for each irrigation district. The reasons for estimating the log-log transformation are threefold. First, the log-log transformation provides easier to interpret parameter coefficients as the coefficients are simply elasticities (Johnston & DiNardo, 1997). Second, the log-log model transforms variables such that the effect of outliers in the dataset are smoothed out. One disadvantage of this transformation is that the smoothing of outliers reduces some of the variance within variables transformed. As previously noted, such variance is needed for accurate parameter estimation. Third, estimating both the linear and log-log models allows a sort of sensitivity analysis of the results to functional form using their respective elasticities and marginal effects.

Alternative functional form considerations extended to individual variables as well. In particular, the effect of climate variables on agricultural water use have been shown to be non-linear at certain levels (Schlenker, Hanemann, & Fisher, 2007). Therefore, quadratic relationships between both *MaxTemp* and *Precip* with respect to overall water use were tried. Unfortunately, both performed poorly with results inconsistent with accepted theory. This is not surprising, however, as a visual inspection of their relationships with *Total* yielded no discernible patterns.

[34] In Stata, the command for heteroscedasticity-robust (HR) standard errors now includes an adjustment for autocorrelation among clusters as HR standard errors were shown to be inconsistent with the FE estimator (Stock & Watson, 2008; Baum, Nichols, & Schaffer, 2010).

Many empirical models have been discussed in this chapter. Table 5.6, below, provides a summary of the eight models that are to be estimated, with an analysis of results presented in the next chapter.

Table 5.6: Estimated Empirical Models

	FE with Cluster-Robust S.E.		PCSE with LSDV	
	linear	log-log	linear	log-log
without DistWaterCost	1	2	3	4
with DistWaterCost	5	6	7	8

CHAPTER 6: EMPIRICAL MODEL RESULTS AND ANALYSIS

Chapter 6 begins with a presentation of the empirical results from estimating the econometric models detailed in the previous chapter. Then, I offer an analysis of the results including comments about the significance, sign, and magnitude of each explanatory variable. While the discussion considers all of the models, comments are primarily based on the fixed effects model with cluster-robust standard errors, exclusive of the *DistWaterCost* variable. As noted in the previous chapter, inclusion of *DistWaterCost* in the models is for exploratory purposes only. The variable is not complete enough for use in the analysis from which I draw conclusions. Finally, I discuss marginal effects and elasticities before summary comments pertaining to the quantitative analysis.

6.1 Empirical Model Results

Table 6.1, on the following page, contains a summary of the empirical results from the eight econometric models estimated. Refer to Appendix D for complete results from each model estimated. An important reminder is that for all models, total water use is the dependent variable.

Table 6.1: Empirical Model Results

	Level-Level				Log-Log			
	Without DistWaterCost		With DistWaterCost		Without DistWaterCost		With DistWaterCost	
	Cluster-Robust S.E.	PCSE with Prais-Winsten Transform.	Cluster-Robust S.E.	PCSE with Prais-Winsten Transform.	Cluster-Robust S.E.	PCSE with Prais-Winsten Transform.	Cluster-Robust S.E.	PCSE with Prais-Winsten Transform.
RetireIGFR	-135,107 ***	-133,390 ***	-137,671 ***	-138,250 ***	-2.618 ***	-2.530 ***	-2.782 ***	-2.643 ***
	(23,250)	(14,595)	(28,238)	(15,799)	(0.270)	(0.192)	(0.324)	(0.229)
Precip	-1,851 **	-1,612 ***	-2,410 **	-2,037 ***	-0.086 **	-0.076 ***	-0.108 **	-0.089 ***
	(823)	(470)	(826)	(569)	(0.037)	(0.021)	(0.034)	(0.022)
MaxTemp	1,571	1,502 *	926	1,020	1.632 **	1.469 ***	0.737	0.794
	(1,042)	(831)	(990)	(1,071)	(0.735)	(0.526)	(0.563)	(0.599)
6mSPIApr	4,470	4,125 ***	3,156 *	2,054	0.091	0.083 ***	0.044	-0.005
	(2,620)	(1,325)	(1,461)	(1,910)	(0.060)	(0.028)	(0.041)	(0.057)
CottonPrice	24,763 **	24,497 ***	17,965 *	20,628 **	0.230	0.217 ***	0.185	0.161 *
	(8,956)	(6,848)	(8,678)	(9,432)	(0.150)	(0.075)	(0.151)	(0.095)
AlfalfaPrice	276 **	252 ***	328 *	299 ***	0.368 ***	0.331 ***	0.350 ***	0.321 ***
	(110)	(41)	(154)	(53)	(0.053)	(0.043)	(0.082)	(0.048)
DistWaterCost	.	.	314	263	.	.	-0.190	-0.122
	.	.	(465)	(347)	.	.	(0.134)	(0.098)
Constant	-69,382	.	-6,756	.	2.192	.	7.248	.
	(106,929)	.	(118,403)	.	(3.563)	.	(2.933)	.
N*T	170	170	119	119	170	170	119	119
R^2	0.9641	0.9801	0.9699	0.9832	0.9753	0.9998	0.9807	0.9998
Adj-R^2	0.9606		0.9661		0.9729		0.9783	
RMSE	16,822.94		17,671.05		0.1305		0.129	

Significance Levels: *0.10, **0.05, ***0.01

Standard Error: (####)

Note: Marginal effects for all level-level model results interpreted at the overall mean for each variable in the data set.

6.1.1 Parameter Significance

One reason for estimating multiple models with differing functional forms and econometric techniques is that more confidence can be placed in variables that are consistently significant across all models. Referring to Table 6.1, *RetireIGFR*, *Precip*, and *AlfalfaPrice* are significant at a 90 percent confidence interval for all models and at 95 percent for most models. The confidence interval refers to the percentage of time that the effect of the independent variable on the dependent variable could be expected to be different from zero i.e., statistically significant. The higher the confidence interval, the more confidence can be placed in the result. Standard errors also provide information on the confidence that can be placed in a parameter estimate. It is clear that the relative size of the standard error for *RetireIGFR,* in parenthesis in Table 6.1, is considerably smaller than those of the other variables. This suggests that the parameter estimate for *RetireIGFR* is more precise than the others meaning more confidence can be placed in it. *CottonPrice* is significant in all but two models, both of them log-log models. *MaxTemp* and *6mSPIApr* are only significant in a few models. Therefore, interpretations made from their parameters should be viewed with caution. *DistWaterCost* is not significant in any model estimated, something not entirely surprising. More than a few econometric papers, some of which are noted in Chapter 2, suggest water demand is highly price inelastic meaning that price has a very small impact on water use. Further, nearly every subject matter expert interviewed for this thesis noted that water price is not a significant factor in growers' decision-making process, at least in current water price ranges. Such comments could stem from the fact that water does not constitute a significant portion of variable production costs and because its price has remained relatively stable in real terms (Teegerstrom & Husman, 1999). Therefore, crop mix and scale decisions are not likely to be made based on it. Collinearity could also be an issue as *DistWaterCost* and *RetireIGFR* have a correlation coefficient of -0.639 (p-value < 0.0001) over 119 observations. When two explanatory variables exhibit similar patterns and both are used to explain changes in the dependent variable, it is difficult for the model to accurately assign cause between the two variables. This situation could lead to too little significance being placed on the relationship between *DistWaterCost* and *Total*. Finally, and perhaps most importantly, *DistWaterCost* could be insignificant for the very reason it was not included in the primary empirical model. As noted in the previous chapter, the variable does not include information on groundwater pumping costs and was not available at all for three of ten irrigation districts in the study area.

6.1.2 Parameter Signs

With respect to parameter signs, the models performed as expected, agreeing on all signs with the exception of *DistWaterCost*. *RetireIGFR* has a negative sign indicating a decrease in water use associated with fewer available acres. The negative sign for *RetireIGFR* is almost definitional. Total water use should fall by the average amount of water applied to each acre as each additional IGFR acre is made inactive. To test this idea, I substitute the *InactiveIGFR* variable for one that records the number of IGFR acres made inactive, measured in acres, cumulated annually, using the FE with cluster-robust standard errors method. The parameter coefficient using this new variable is -3.796 (1.668) with Prob > |t| = 0.049. The interpretation of this result is that for every acre made inactive, irrigation districts use 3.796 AF less water. Comparing this figure to the average IGFR water duty suggests that the IGFR variable is definitional. The definitional nature of *InactiveIGFR* suits its purpose to detrend *Total* for land conversion effects, as described in the previous chapter. I examine the parameter coefficient for *InactiveIGFR* in more detail shortly.

Precip has a negative sign meaning that more rain offsets some need for irrigation water lowering total water use. *MaxTemp* has a positive sign showing that total water use increases as temperature increases due to increased evapotranspiration. The *6mSPIApr* variable has a positive sign. While the sign does not necessarily mean the four districts with surface water are price constrained as was offered earlier, I can conclude that they use more water when surface water supplies are abundant, all else equal. *CottonPrice* and *AlfalfaPrice* have positive signs most likely attributed to a rise in acres planted when prices are high resulting in higher total water use. Finally, *DistWaterCost* has a positive sign for the level-level models but a negative sign for the log-log models. In all cases, *DistWaterCost* is not significant at a 90 percent confidence interval meaning any interpretation of the disagreement of signs would not be informative. No attempt is made to interpret the sign of the constant terms.

6.1.3 Parameter Coefficient Interpretation

The interpretation of variable parameters differs between the level-level and log-log models. In level-level models, the variable parameter is the marginal effect of the independent variable on the dependent variable (Thornton, 2012). The parameter is read as being the increase or decrease per unit of the dependent variable given a one-unit increase in the independent variable. For log-log models, variable parameters are elasticities (Thornton, 2012). Parameters for log-log models are read as the percentage change in the dependent variable given a one-percent increase in the independent variable. Though the parameters report only marginal effects or elasticities, the other can be calculated easily (Thornton, 2012). Log-log models are convenient because they allow for a relatively easy comparison of how independent variables affect the dependent variable. However, one disadvantage of the log-log model is that elasticities are constant, something not entirely realistic.

The following bullets are an interpretation of the parameter coefficients of only the model results of the level-level FE model, excluding *DistWaterCost*, with cluster-robust standard errors in Table 6.1. I discuss only those parameter coefficients which are significant at the 90% (or more) confidence level. Parameter coefficients are based on a hypothetical irrigation district that has characteristics equal to the mean for each variable calculated across all districts and all time periods. For example, the precipitation variable's marginal effect described below is a one-unit change from the overall mean of precipitation across districts and time periods holding all other variable values constant at their overall mean. See Table 5.5 for the overall means of each variable.

- A one-percent increase in the percentage of 1995 IGFR certificate acres made inactive leads to a 1,351.07 AF decrease in total water use; a 1.2 percent decrease in total water use evaluated from an overall mean of 112,456 AF. Note the movement of the decimal to the left two digits due to how the independent variable is measured.
- A one-inch increase in annual precipitation leads to a 1,851 AF decrease in total water use; a 1.6 percent decrease in total water use evaluated from the overall mean of 112,456 AF.
- A ten-cent increase in the price of cotton per pound leads to a 2,476.3 AF increase in total water use; a 2.2 percent increase in total water use evaluated from the overall mean of 112,456 AF. Note the movement of the decimal to the left one digit due to how the independent variable is measured.
- A ten-dollar increase in the price of alfalfa per ton leads to a 2,760 AF increase in total water use; a 2.5 percent increase in the total water use evaluated from the overall mean of

112,456 AF. Note the movement of the decimal one digit to the right due to how the independent variable is measured.

An example interpretation for the log-log cluster-robust standard errors without *DistWaterCost* model would be that a one-percent increase in *Precip* leads to a 0.086 percent decrease in total water use. The same interpretation can be extended to all results of the log-log models. However, the log-log parameters for the *RetireIGFR* variable, and the *MaxTemp* variable in the with *DistWaterCost* model are unusually high; high enough, in fact, to be unrealistic. These poor estimates could be explained by the log-log transformation itself. Taking the natural log of a variable reduces its variability greatly. With such little variation, parameter estimates can be off by considerable margins, as looks to be the case with *RetireIGFR* and *MaxTemp*.

Looking across all models in Table 6.1, generally, more variables seem to be significant in the PCSE models than in the FE models with cluster-robust standard errors. However, the magnitude of parameter estimates are relatively close which is expected as the method used to estimate the parameters is similar between the two models. Also, the addition of *DistWaterCost* seems to absorb some explanatory power of variables that are otherwise significant without it.

6.1.4 Marginal Effects versus Elasticities

As previously mentioned, marginal effects from the level-level model can easily be converted into elasticities and vice-versa for the log-log model. This allows for a better comparison of the two functional forms and for a more in-depth analysis of elasticities. Since the log-log model produces a single estimate of variable elasticity and the conversion of marginal effects to elasticities requires dividing the independent variable of interest by the dependent variable then multiplying by the parameter value, a single value for each variable is needed.

Convention for this conversion is to use the mean values of the independent and dependent variable. Table 6.2 uses the mean value approach to calculate elasticities for the level-level models. To convert elasticities of the log-log model to marginal effects, the dependent variable is divided by the independent variable of interest and multiplied by each respective parameter value or elasticity. Mean values are also used for this conversion with results show in Table 6.3 for comparison.

In Table 6.2, elasticity estimates from the two models are similar in all variables except *RetireIGFR* and *6mSPIApr*. This suggests that the empirical model is reasonably robust to changes in functional form. In Table 6.3, the same observation prevails. One major drawback of the natural log transformation, possibly manifesting itself in the unusual parameter estimates for the variables noted, is because of adjustments needing to be made to prepare the variable for transformation. Values less than or equal to zero are not defined for the natural log function. Further, values below one can be transformed into large negative numbers. Since SPI can take negative values, a constant is added to make the lowest value of the variable greater than one. A similar adjustment was used to make *RetireIGFR* greater than one. Such adjustments are not based in theory and are only made out of necessity.[35] These adjustments reduce my confidence in results from the log-log model. Therefore, elasticity and marginal effect results from the level-level model are taken to be closer to the actual value than those from the log-log model.

[35] Variable adjustments to prepare for natural log transformation: ln(*RetireIGFR*) = ln(*RetireIGFR* + 1); ln(*CottonPrice*) = ln(*CottonPrice* + 1); ln(*6mSPIApr*) = ln(*6mSPIApr* + min(*6mSPIApr*)+ 1)

Table 6.2: Elasticities Comparison across Model Functional Forms

	Level-Level				Log-Log			
	Without DistWaterCost		With DistWaterCost		Without DistWaterCost		With DistWaterCost	
	Cluster-Robust S.E.	PCSE with Prais-Winsten Transform.	Cluster-Robust S.E.	PCSE with Prais-Winsten Transform.	Cluster-Robust S.E.	PCSE with Prais-Winsten Transform.	Cluster-Robust S.E.	PCSE with Prais-Winsten Transform.
RetireIGFR	-0.092 ***	-0.091 ***	-0.094 ***	-0.094 ***	-2.618 ***	-2.530 ***	-2.782 ***	-2.643 ***
Precip	-0.118 **	-0.103 ***	-0.154 **	-0.130 ***	-0.086 **	-0.076 ***	-0.108 **	-0.089 ***
MaxTemp	1.341	1.282 *	0.790	0.871	1.632 **	1.469 ***	0.737	0.794
6mSPIApr	-0.003	-0.003 ***	-0.002 *	-0.001	0.091	0.083 ***	0.044	-0.005
CottonPrice	0.170 **	0.168 ***	0.123 *	0.141 **	0.230	0.217 ***	0.185	0.161 *
AlfalfaPrice	0.337 **	0.308 ***	0.400 *	0.366 ***	0.368 ***	0.331 ***	0.350 ***	0.321 ***
DistWaterCost	.	.	0.112	0.094	.	.	-0.190	-0.122

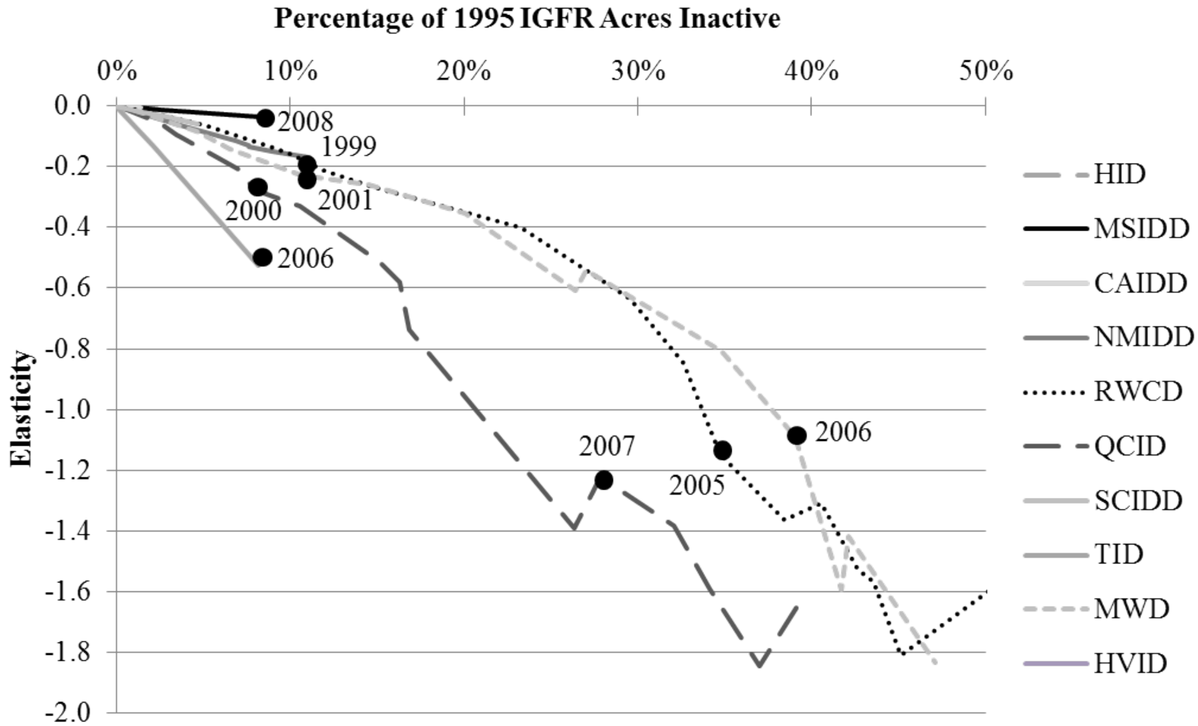
Table 6.3: Marginal Effects Comparison across Model Functional Forms

	Level-Level				Log-Log			
	Without DistWaterCost		With DistWaterCost		Without DistWaterCost		With DistWaterCost	
	Cluster-Robust S.E.	PCSE with Prais-Winsten Transform.	Cluster-Robust S.E.	PCSE with Prais-Winsten Transform.	Cluster-Robust S.E.	PCSE with Prais-Winsten Transform.	Cluster-Robust S.E.	PCSE with Prais-Winsten Transform.
RetireIGFR	-135,107 ***	-133,390 ***	-137,671 ***	-138,250 ***	-3,838,913 ***	-3,710,113 ***	-4,079,629 ***	-3,875,612 ***
Precip	-1,851 **	-1,612 ***	-2,410 **	-2,037 ***	-1,344 **	-1,195 ***	-1,698 **	-1,391 ***
MaxTemp	1,571	1,502 *	926	1,020	1,912 **	1,721 ***	863	930
6mSPIApr	4,470	4,125 ***	3,156 *	2,054	-147,680	-134,958 ***	-72,008	8,722
CottonPrice	24,763 **	24,497 ***	17,965 *	20,628 **	33,512	31,718 ***	27,034	23,462 *
AlfalfaPrice	276 **	252 ***	328 *	299 ***	302 ***	271 ***	287 ***	263 ***
DistWaterCost	.	.	314	263	.	.	-532	-342

Significance Levels: *0.10, **0.05, ***0.01

Using the variable means does not always tell the entire story, however. In the case of *RetireIGFR*, closer analysis reveals that water use with respect to the percentage of 1995 IGFR acres made inactive becomes more negatively elastic as a higher percentage of total acres are made inactive. Figure 6.1, on the next page, shows this result for each irrigation district. The three districts nearest the Phoenix metro area, QCID, RWCD, and MWD extend down to the lower right corner of the figure as they have had the largest percentage of acres converted from agriculture to another use. It is important to note that time period is not easily interpreted in the figure because an increase in the number of acres made inactive did not occur in each year for each district. Therefore, a number of years might be represented by a single point. For the three districts that have had a high percentage of IGFR acres made inactive, each step roughly represents a year. Year markers have been added to show when an irrigation district reached a certain elasticity or percentage of IGFR acres made inactive. An interpretation of this result is best explained with the aid of an example. If an irrigation district starts out with 100 percent of IGFR certificate acres or irrigable acres, it is likely to have a certain percentage of those acres fallowed, 10 percent perhaps. As the percentage of total irrigable acres is made inactive, the percentage of fallowed acres is likely to fall as growers try to maintain the size of their operations. This means that water use on the first acres made inactive would be used instead on fallowed acres so total water use does not fall significantly. However, as additional acres are made inactive, fewer fallowed acres are available to bring into production resulting in less total water use.

Figure 6.1: Elasticity of Total Water Use at Percentages of 1995 IGFR Acres Made Inactive



6.2 Empirical Model Performance Evaluation

Overall, the empirical models performed well. All statistically significant variable parameters signs are as expected. Each variable is significant in at least one model and four variables, *RetireIGFR*, *Precip*, *CottonPrice*, and *AlfalfaPrice* are quite robust. Further, all results, except for the parameters associated with *RetireIGFR* and *6mSPIApr* in the log-log models are reasonable and explainable. The unexpected result of the analysis is that *MaxTemp* is not highly significant. Information from subject-matter expert interviews suggested that *MaxTemp* would be significant and *Precip* would not. Perhaps this is because increased water use due to evapotranspiration should have been measured in cooling-degree days. Also, the lack of significance could be due to the relatively low number of observations in the data set. Finally, most alfalfa acres are flood-basin irrigated with irrigation occurring only once or twice per cutting (Tronstad, 2013). Because of this, irrigation cannot take place as a cutting approaches or the ground will be too soft for harvesting machinery to operate. In addition, a limited number of irrigations means growers have little leeway in applying additional water to address higher temperatures. Therefore, since alfalfa is a major component of total water use, limited ability to react to higher temperatures by the grower could result in the temperature variable being statistically insignificant (Tronstad, 2013). Further, temporal trends in the error terms of some districts in the model suggest either a missing explanatory variable or the model is not properly weighting explanatory variables. The latter of these issues could be due to using a single slope parameter across all districts for each variable. Still, the fact that the model performed so well and provided results in line with economic theory suggest it is more robust than the number of observations would give it credit.

With regard to explanatory power, all of the models yielded coefficients of determination, R^2, in the 0.96 to 0.98 range. This means that 96 to 98 percent of annual variation in total water use was explained by the empirical model, suggesting a nearly perfect model. However, the R^2s from the models largely reflect the explanatory power of the constant intercept shifters, or fixed effects, used for each irrigation district. Explanatory power of intercept shifters can hardly be considered explanatory power. For example, take an irrigation district that has total water use fluctuating between 75,000 and 125,000 AF annually averaging 100,000 AF. The intercept shifter's value is equal to the mean value, 100,000 AF. If the model predicts a usage of 110,000 AF when actual total usage was 120,000 AF, 100,000 AF of the predicted value was simply due to the intercept shifter, not to the explanatory power of the model. Only the 10,000 AF deviation from the mean was predicted by independent variables in the model. Therefore, instead of having an R^2 of 0.92 (110,000 AF / 120,000 AF), the more accurate R^2 is closer to 0.5 (10,000 AF / 20,000 AF). When the explanatory power of the fixed effects from the empirical models in this analysis are removed, R^2s for each model decrease into the 0.3 – 0.4 range. This means that the models are actually explaining 30 – 40 percent of annual variation or deviation from the means; a significant drop from the original value but still a useful and reasonable amount of explanatory power.

CHAPTER 7: DISCUSSION AND CONCLUSIONS

This thesis began by posing two questions:

1. What factors influence overall annual water use for irrigated agriculture in central Arizona?
2. How do central Arizona irrigation districts make water-sourcing decisions to meet the demands of their growers and what types of constraints do they face in making those decisions?

To address the first question, I used published research and subject-matter expert interviews to develop a conceptual model that explains annual overall water use for irrigated agriculture. From this conceptual model, I collected data on many potential variables that acted as proxies for factors affecting water use. Then, I developed an empirical model to explain annual fluctuations in water use and used econometric modeling techniques to estimate parameters for the explanatory variables. Quantitative results from my econometric analysis indicate the number of acres available to irrigate annually, annual precipitation, cotton price, and alfalfa price, along with an intercept shifter for each irrigation district, can explain a large portion of annual fluctuations in overall water use for agriculture in the study area. Temperature, another climatic indicator, and water cost charged by the irrigation district to its growers were not significant in explaining annual fluctuations.

For the second question, I conducted interviews with irrigation district managers to understand how they make water sourcing decisions and what factors constrain their decision making process. Then, I synthesized notes from the interviews into a decision-making framework that noted constraints accompanying water sourcing and use decisions. I found that, though facing a unique set of circumstances, irrigation districts in the study area follow a similar process when acquiring water for their member growers. More importantly, I found that district managers are highly constrained by numerous policies and incentives and that there is very little variation from year to year in what types of factors affect their decisions. This is not to say that the total amount of water acquired and the relative mix of supplies remains constant, rather that the decision-making framework does not greatly fluctuate due to similar types of considerations and constraints across irrigations districts and over the study period.

The findings of this thesis are important to a number of different entities for a variety of reasons. For example, understanding that the decision to use CAP water by irrigation districts is largely based on a comparison of the weighted average cost of Ag Settlement Pool and In-lieu water versus the cost of groundwater is important to CAWCD. Since a goal of CAWCD is to make full use of Arizona's Colorado River entitlement, CAWCD needs to understand the price comparison being made by irrigation district managers in order to price CAP water so that managers do not entirely switch back to groundwater (Central Arizona Water Conservation District Board, 2001). Conversely, knowing that the current capacity of groundwater systems is a constraining factor for districts and that the cost of removing this constraint is high, district managers are likely to continue purchasing water from CAP even when a simple price comparison would suggest a switch to groundwater. In addition to the groundwater capacity constraint, assuming prices are comparable, some growers prefer CAP water to groundwater from their own wells. The reason for this preference is that CAP water quality is more consistent and because they do not have to contend with groundwater pump operation and maintenance issues (Wong, 2012).

In the future, all those interviewed projected that irrigation districts will replace their CAP water supplies with groundwater supplies as the Ag Settlement Pool is stepped down and

In-lieu availability diminishes with cities and tribes making use of their entire CAP allocation. Understanding how irrigation district managers make sourcing decisions is the first step in trying to determine when and how quickly the switch from CAP water back to groundwater is likely to occur. After interviewing the irrigation district managers, two important ideas surrounding the switch emerged. First, irrigation districts are not likely to switch all at the same time when CAP prices reach a certain point because the price and availability of alternative water supplies for each district differs considerably. Second, once a district has committed to making the switch, it is unlikely to go back to CAP water should it still be available. The reason for this is because of the tremendous amount of capital required to prepare and deliver groundwater sources that offset CAP deliveries, along with the substantial cost of maintaining the additional pump capacity. Once groundwater sources have been prepared, it is not economical to maintain the groundwater pumping infrastructure in addition to purchasing CAP water. Further, those who have made the investment in groundwater supplies are not likely to abandon their investment unless the cost of CAP water is dramatically less than their new groundwater supplies. To avoid a wholesale switch from CAP to groundwater, CAWCD could work with ADWR to alter the policy requiring Ag Settlement Pool water to be taken prior to In-lieu water. Both parties could also raise the GSF permitted storage volumes thereby encouraging districts to continue contracting for In-lieu water as it is available. This would lower the weighted average cost of CAP water in relation to groundwater as previously discussed. While increasing GSF permitted storage volumes could reduce immediate reliance on groundwater supplies, the In-lieu credits generated ultimately allow pumping of the saved groundwater. However, this policy has the advantage of allowing for In-lieu credits to be purchased and retired in the future should groundwater issues relating to excessive pumping escalate. When the switch from CAP water back to groundwater takes place, however, it will not come without consequences.

Other than the obvious consequences stemming from increased groundwater use, a switch back to groundwater could also decrease irrigation efficiency and, therefore, increase total water use per acre, all else equal. High efficiency irrigation systems rely on large 'heads' of water, or high flow rates, to deliver peak performance (Anderson, Wilson, & Thompson, 1999). The current canal system in many irrigation districts was designed to make use of CAP and groundwater, with CAWCD being able to supply a large head of water. When districts stop using CAP water, the smaller head provided by groundwater pumping systems could decrease irrigation system efficiencies.

Issues relating to irrigation district canal infrastructure are not limited to flow rates, however. Irrigation district delivery systems were not designed for the present crop mix. A pivot in acreage from almost exclusively cotton to more acres of water intensive alfalfa mean that some districts have recently become quantity constrained in their ability to meet peak, mid-summer demand (Betcher, 2013). This new infrastructure driven quantity constraint could be a major component in projecting annual water use, if crop prices continue to be relatively high and real water prices are held constant.

This research is also important to water planners. Overall water use was found to decline more rapidly at the margins when a high percentage of district irrigable acres are no longer available due to land conversion. This result is especially important when projecting the long-term water use of irrigation districts near urbanizing areas. The assumption that total water use at the irrigation district level declines in a linear fashion as land is converted appears to be false according to this analysis. Water planners should also be aware of the fact that despite a significant conversion of land in the irrigation districts near the Phoenix metro area, agricultural water use in central Arizona is not declining as fast as was once projected. Some growers in districts near urbanizing areas have capitalized on the value of their land and have used proceeds from selling to developers to purchase and cultivate new acres near Gila Bend, just outside the Phoenix AMA, where watering limits of the Base Conservation Program do not exist (Teegerstrom, 2013). New acres near Gila Bend are unlikely to have water supply constraints going forward as they have access to groundwater that flows beneath the Gila River bed (U.S. Bureau of Reclamation, 2003). Some of this groundwater comes from discharged effluent from the Phoenix metro area, supplied by CAP, and districts that still make use of CAP water. In effect, CAP will still be supplying farms long into the future, only in an indirect way in the Gila Bend area.

With regard to climate change, I noted in Chapter 1 that climate projections suggest a warmer climate with more variable precipitation. Results from my analysis suggest that an increase in precipitation variability will drive annual fluctuations in overall water use much more than increases in average maximum daily temperature. This conclusion should be tested, however, using cooling-degree days rather than average maximum temperature as was used in my analysis.

Making projections about the future becomes increasingly difficult as all factors such projections are based on become variable. Still, I posed the question to district managers of what they expect to see happen in the next ten years. Each manager had a different opinion based largely on access to water supplies and acres left to irrigate. For those managers in the path of Phoenix urban expansion, the future is the status quo until few acres, if any, are left to farm (Leonard, 2013; Hatch, 2013; Flowers Jr., 2013). These districts have sufficient water supplies and are able to keep water prices to growers relatively low and constant by spreading increasing costs over the encroaching urban population (Flowers Jr., 2013; Leonard, 2013). Districts outside the influence of urban expansion face two broad scenarios. For those with limited supply options, increasing investment in conservation technology, a return to agricultural practices of the past, such as letting alfalfa go to seed, and an increase in fallowed acres were offered as adaptation strategies (Van Allen, 2013; Warren, 2013). For those with sufficient supplies, a shift in reliance on CAP and In-lieu water back to groundwater is already underway. If electricity prices, and thus groundwater pumping costs, continue to increase more slowly than inflation and crop prices remain in profitable ranges, then districts and growers should have sufficient income to invest in additional groundwater capacity to offset reduced use of CAP water. Further, a reliance on CAP and In-lieu water for the last 20 years has actually lowered the lift, and thus cost, required to pump groundwater for most districts. Aquifer levels have stabilized or risen in most places. However, the 2017 reallocation of WAPA and APA power could upset this projection should significant changes be made in the quantities and costs of power available to central Arizona irrigation districts. Another example of why projections are so difficult to make comes from developments in crop genetics. The development of heat tolerant crops results in them using less water per acre (Elstein, 2004). Water savings from these developments could partially or completely offset water price increases, slowing or eliminating a shift from high water use crops to low water use crops.

As noted in Chapter 1, this thesis contributes to the literature by providing what I believe to be the first framework and summary of central Arizona irrigation district managers' decision-making and water sourcing process, along with constraints they face. This thesis has also quantified the effect of annual precipitation variation in explaining total annual water use for the irrigation districts of interest. Further, I have quantified the impact of two major crop prices and land conversion on overall water use. I found that water use elasticity, or responsiveness, increases as a larger percentage of district acres are no longer irrigable. It is important to note that the findings of this analysis only relate to the extensive margin of decision making, as described in Chapter 2 and Chapter 3. Since data for the analysis is at an annual time step, only those decisions about water use across years such as crop mix and scale were considered. Intensive use decisions, such as altering water application rates during the growing season, were beyond the scope of this thesis.

To enhance the robustness of the results, collecting more observations through including more years or more irrigation districts would be helpful. Due to the limited availability of data on crop mix and acres fallowed annually at the irrigation district level, I was unable to estimate an acreage model and instead used crop prices as a proxy for acres planted. While remotely sensed data became available for crop acreage in some locations in 1997 through USDA's Cropland Data Layer Program, the data layer is not available for Arizona until 2008 (U.S. Department of Agriculture, National Agricultural Statistics Service, 2013). Therefore, future analysis might have adequate data to estimate a crop acreage model.

To increase the explanatory power of the model, different variables could be exchanged or added to the empirical model. Rather than assuming crop profitability to be reflected entirely by crop price, a mechanism for tracking the costs of production by crop would be useful. Cooperative Extension county-level crop budgets are not updated annually (Teegerstrom, 2013). For example, cotton is said to be profitable when prices are in the range of \$0.80 – \$0.85 per pound (Van Allen, 2013; Johnson, 2010). Adjusting the empirical model to incorporate information like this would likely add explanatory power.

For future research, an overall shift in orienting the empirical model so that it can be used for forecasting water use by source would be a significant contribution, particularly with respect to agricultural land conversion. As was shown in previous chapters, a variable capturing land conversion is very important in explaining total water use at the irrigation district level. In fact, removing the variable from the models estimated in Chapter 5 significantly alters the estimated parameters and their significance. In the FE model with cluster-robust standard errors, the explanatory power of *AlfalfaPrice* is completely erased. When *DistWaterCost* is added, the variable shows a positive sign and is significant, contradicting economic theory, and *CottonPrice* loses its explanatory power as well. These changes point to the conclusion that accounting for land conversion is crucial in any study estimating agricultural water use in the presence of large amounts of land conversion. Full results from these additional models is found in Appendix D. Research making use of GIS remotely sensed data is available that attempts to predict urban expansion (Carrion-Flores & Irwin, 2004). Such models might be able to predict the retirement of IGFR certificate acres rather than looking backward as I do in this thesis. However, any accurate land conversion model will have to contend with the widespread practice of developers buying land and then leasing it back to growers to farm until actual urban development begins. Also, noting the number of acres made inactive for dairy operations in non-urban areas, it would be useful to investigate whether different types of land conversion affects water use at the irrigation district level differently.

With respect to irrigation district interviews, I would advise any future researcher to begin contacting and speaking with district managers as soon as possible. Managers and staff are very busy and the data they possess is not often in an easy to gather format. Therefore, the amount of time from first contact to data acquisition can be longer than anticipated, an issue that this thesis had to accommodate.

Over the past 15 years, irrigation district managers have been very successful in holding irrigation district water prices charged to their growers low and stable. In all seven cases where district prices were known, the cost of water to growers actually fell, adjusted for inflation, measured from 1995 to 2011; in some cases, quite considerably. In only one case, using a five-year moving average of the inflation-adjusted prices over the same period, prices rose, and by less than $2 per AF. With so many changes occurring in and around irrigation districts of central Arizona, stable or decreasing real water costs might not be observed in the next 15 years. Therefore, as it has been since Martin, Young, Mack, and Kelso examined the economics of water use in central Arizona irrigation districts in the 1950s and 60s, the topic remains as dynamic, interesting, and relevant as ever.

APPENDIX A: IRRIGATION DISTRICT INTERVIEW TEMPLATE AND NOTES

Irrigation District Interview Template:

Background:

The essence of my thesis is understanding how irrigation districts make water sourcing decisions each year to supply water at the lowest, most stable cost to their growers. In answering this question, I need to know how much of each type of water (groundwater, CAP, effluent, surface, etc.) was sourced by the district each year, how much each source cost annually, and how much was demanded in total by growers each year. I also need to develop an understanding of any other factors that enter into the decision making process such as risk management, water quality, source switching costs, etc. Finally, I need to understand what constraints district managers face in making sourcing decisions. For example, is there a limit to how much In-lieu water can be purchased and what controls the limit? If, say, CAP water was the cheapest source, does the district have the infrastructure reach and capacity available to deliver CAP water to all members or does some groundwater still need to be pumped? Ideally, I would like to understand the timeline of decisions that are made from the beginning to the end of the year. I do not expect you to have precise answers for each question so many of them will require a best guess. The following questions attempt to address what I have briefly described above.

A. When was your district originally founded?
B. Are all grower water requests satisfied each year or are there years where growers order more water than can be delivered?
C. How many growers are in your district? What is the average size of a farm?
D. What method of irrigation do most growers use (e.g., furrow, level basin, border, drip, center-pivot, etc.)? What percentage of acres are irrigated by each method? Has the percentage makeup changed significantly since 1993? What is the overall average efficiency of irrigation methods in the district? 80% perhaps?
E. What sources of water are available for purchase to the district each year? Do they vary by year?
F. How does the irrigation district usually fill its ‘bucket’ of total water requests by growers? In other words, is surface water always purchased first, then CAP water, and so on?
G. If surface water is available, how much does it cost? Is it the first source used? What is the maximum amount that can be made use of by the district in a single year?
H. Are there different lead times for the different sources? For instance, CAP water orders need to be in by October of the previous year; do similar situations exist with In-Lieu water or surface water?
I. How is groundwater managed in your district? Who controls the wells? Has it always been this way?
J. What is the capacity of wells currently in operation; how much groundwater could realistically be supplied if all other sources were cut off during peak water demand?
K. Could all district demand be physically and legally supplied by groundwater? If legally but not physically, would more wells need to be drilled or brought into operation?

L. Does the district have suitable infrastructure to deliver all available sources of water to all acres demanding it?
M. What is the primary energy source used to pump groundwater (e.g., electricity, natural gas, diesel, etc.)? What percentage of pumps use that source? Has it changed since 1993?
N. For whatever primary energy source is used, does the district have long-term contracts to stabilize the price? Who are those contracts with?
O. For energy prices, are there different rates for different amounts used or different amounts for different times of the year such as summer vs. winter, etc.?
P. Is groundwater depth at main pumps reasonably consistent across the district or do some areas have very deep wells and some very shallow? How has it changed since 1993?
Q. How often do wells collapse or go out of commission? Is well viability a consideration when choosing water sources for the district?
R. Does water source quality play into the decision making process? In other words, if groundwater has lower TDS but CAP water is a little less costly, does the district prefer groundwater?
S. Does the district reuse tail water? If not, is reuse possible or is infrastructure not set-up accordingly?
T. What is a good corn silage price per ton to quote from 1993-2011?
U. What is the structure of water costs charged to growers? For example, does the price rise after a certain amount of water per acre or total amount?
V. What type of fees are growers assessed each year for receiving water from the district?
W. How are water prices set for growers each year?
X. In your opinion, in the future, where is the district's water most likely going to come from? The same source mix as today? Will the same types of crops be planted or will the crop mix change?

Data Needs [In a perfect world, I would be able to get all the data described below. If not, we can discuss what data the district has on hand and what of that can be disclosed. The most important data needs are the cost of groundwater and other sources of water]:

- Acres planted to each major crop in the district from 1993-2011
- Total number of acres irrigated within the district from 1993-2011
- Total number of acres available to irrigate within the district from 1993-2011 i.e., how many acres were fallowed in each year?
- Acres converted to urban or other non-ag. uses annually from 1993-2011
- Per unit or variable cost of water charged growers within the district excluding assessment fees, etc. from 1993-2011
- Historical electrical rates paid by the district from 1993-2011
- Average groundwater depth at main pumps in the district from 1993-2011
- Average variable cost of groundwater per acre-foot to the district from 1993-2011
- Averaged total cost of groundwater per AF annually, including maintenance, depreciation, etc. in the district from 1993-2011 (note: Not what the district charged growers but what it cost the district to provide the groundwater to them)
- Annual cost of other water supplies such as surface or effluent from 1993-2011

New Magma Irrigation & Drainage District:

Interviewee: Mr. Bill Van Allen, General Manager, New Magma Irrigation & Drainage District
Interviewer: Mr. Brett Fleck
Location: New Magma Irrigation & Drainage District Headquarters
Date and Time: 04/04/2013, 9:45 a.m.

Method to fill grower orders:
1st – Order entire CAP Ag Settlement Pool initial allocation of 27,325 AF (limited to 1 AF per CAP eligible acre via 2004 AWSA)
2nd – Purchase all available effluent from Resolution Copper; water is free (limited by amount available from Resolution)
3rd – Enter into and renew In-lieu water agreements with offering partners (limited by 54,000 AF ADWR GSF storage permit maximum volume)
4th – Purchase any CAP Ag Settlement Pool remarket water available throughout year
5th – All grower water orders, or demand not satisfied by district, is met with groundwater pumping by individual grower-owned pumps

Calendar of operations:
Jan, Feb, and Mar – Annual reporting and audits
Apr, May, and Jun – Managing deliveries and multi-party disputes e.g., disagreements about the amount of water delivered or used between growers or the grower and district manager
Mid-summer – Crop acreage reporting
Aug/Sept – Request for grower orders and renew In-lieu contracts if no changes
Oct 1 – Place CAP order
Nov – Growers make official orders
Jan – Growers make a final order decision signing for water ordered
June – Growers must pay up-front for rest of water. Any water not used is remarketed internally. If water cannot be remarketed, grower pays for water regardless of actual use.

Notes:
- Cotton acres are on the decline because it has gotten too expensive relative to other crops to grow. Costs like tillage and fertilizer are high in growing cotton. It would take roughly 85 cents per pound for a grower to make a decent profit and consider planting a significant quantity of cotton
- Growers in the district are applying 5.5-6 AF per acre for cotton and 6-7 AF per are for alfalfa
- Alfalfa is harvested for 3-years then rotated with wheat or barley for a year then back to alfalfa
- Corn silage price in NMIDD for 2013 is $45 per ton at 72% moisture
- Major shift in acres from cotton to alfalfa over last few years as alfalfa prices have risen

District Water Supplies and Constraints:
- District formed in 1965 for receiving CAP water.
- NMIDD has a limited supply of water because of the 2004 GRIC settlement that restricts NMIDD to 1 AF of CAP Ag Pool water per acre
- In all but the most recent 2-3 years, all grower water orders have been met

- NMIDD purchases all CAP (Ag Settlement Pool & In-lieu) it can, then divides the total by the number of CAP eligible acres. The water amount available from NMIDD was about 3.6 AF per acre in 2012
- Depending on cropping decisions, some growers have plenty of water and some growers are short every year with respect to what the district can provide
- Some growers supplement district supplies with individually operated groundwater wells
- There are 39 growers averaging 650 acres, though, most acres are grown by only a few with many other hobby farms making up the rest
- Irrigation is 60% border, 30% furrow, & 10% center pivot averaging roughly 85% efficiency
- Larger growers are enrolled in the BMP program
- District purchases CAP water first, then In-Lieu water and requests any CAP remarket water. Any unmet order is fulfilled by grower owned pumps
- In-lieu partners are municipal and Indian, they include: Tohono, GRIC, City of Gilbert, CAGRD, though, contracts are year-to-year and switch with every so often
- In-lieu partners approach the district about selling water, not the other way around
- District requires one month notification if In-lieu partner intends to discontinue contract
- In-Lieu contracts are $23 - $35 per AF and average near $25
- District can contract up to 54,000 AF of In-lieu water subject to its ADWR GSF permit volume. It can provide up to 95,000 AF of groundwater and In-lieu water combined subject to the same permit
- If a grower takes receipt of district supplied water that has even 1 AF of In-lieu water in it, the entire delivered amount goes toward the annual IGFR water duty limit
- The priority of In-lieu water is a large consideration when negotiating contracts
- All orders from growers must be in by October 1st. Growers sign for all their water in November
- Growers control all wells in the district
- 27,325 CAP eligible acres have not been adjusted as lands have been developed. Means more CAP water is available per acre to growers whose land remains in production
- District has suitable infrastructure to deliver water to every acre within it
- NMIDD charges a flat rate for water to growers, no volumetric cost increases
- Growers pay the actual cost of water plus roughly $10 per AF for O&M costs
- Growers currently pay assessment of $17 per acre plus a $2.39 county surcharge totaling $19.39 per acre; assessment was $25 per acre prior to 2004 AWSA
- Wells in district could pump 35,000 AF per year based on 300 days of pumping
- Very few wells are currently used, but more are brought back online every year as CAP water availability diminishes
- All water demand could be met with groundwater, but many wells would have to be brought back into operation at significant cost
- Growers reuse tail water when possible. Usually around development to prevent water damage
- Cost is the driving factor in water sourcing, quality is a secondary consideration and is usually only relevant with respect to the salt load from Resolution Coppers effluent
- Recent estimate placed cost of a new well just below $1 million
- District wells are as reliable as maintenance schedules, but overall do not break down or collapse

- Depth of water varies greatly within district. Water is shallower on north side and deeper on south side. Levels have recovered as much as 300 feet since 1993. North side currently at 250 feet and south side between 380 – 390. South side was at 600 – 700 feet in 1993. North side has always been shallower due to surface water
- Variable groundwater pumping costs are between $35 per AF and $43 per AF including maintenance
- All pumps are electric and have been since at least 1993. A flat rate for electricity is charged per kWh. Power is Hoover B with a little Hoover A. Currently 0.041 per kWh not including a 0.01 rebate
- A second tier electricity rate exists but will not be approached under current pumping amounts. Could enter second tier if all demand was met with groundwater
- Electricity provided by Electrical District #6
- In the last two years, district was short in meeting grower demands because Indians chose to take full allocation of water rather than contract for In-lieu
- Water costs to growers are increasing quickly as CAP Ag Settlement Pool prices rise and In-lieu partners have more storage options i.e., more negotiating power
- In the future Ag Settlement Pool declines will mean more groundwater pumping. Increased costs will lead to differing crop mixes and a return to more rotational fallowing. Hope for most is to hold out until a buy-out from development

Queen Creek Irrigation District:

Interviewee: Mr. Burt Hatch, General Manager, Queen Creek Irrigation District
Interviewer: Mr. Brett Fleck
Location: Queen Creek Irrigation & Drainage District Headquarters
Date and Time: 04/04/2013, 12:30 p.m.

Method to fill grower orders:
1st – Purchase entire CAP Ag Settlement Pool water initial allocation; no need for CAP excess or remarket water
2nd – Purchase available In-lieu water to meet the rest of demand (In-lieu water averages $25 per AF)

Notes:

- Queen Creek effectively founded in 1987 with organizational operations beginning in 1985 for the receipt of CAP water
- Before CAP water introduction, all crop production supported by groundwater
- District can match all grower demands, accounting for ADWR restrictions
- Averaged 4 AF per acre in 2012 across the district
- IGFRs and flex credit accounts are individually managed by growers
- 75 growers ranging from 10 – 3,000 acres within the district; 8 growers run most of the land
- Nearly all irrigation is furrow and border amounting to 80 percent efficiency system wide
- In-lieu contracts are year-to-year but require a 6-month advanced notice to not renew; July 1 cut-off

- Excess purchased water is internally remarketed among growers and then is turned back through In-lieu partners
- Orders are turned in from growers in September for the following year
- Generally try to acquire a total of 34,000 AF of water for the year give or take a few thousand AF
- Water sourcing has been fairly consistent throughout the study period
- Dean Griffith had the foresight to set up a GSF early and to favor In-lieu water over CAP Ag Pool water developing relationships with In-lieu contractors that persist
- In-lieu contract decisions are made in September and are either rolled over or ended
- Growers own all groundwater wells. Only a couple of wells are currently being operated. Has been that way since 1993 at least
- Growers could satisfy roughly half of peak demand with all wells on or 15,000 AF per year
- Infrastructure in the district can reach every single acre
- All wells are electric driven but most were diesel way back in the '40s
- Electricity is same as New Magma under same electric district. Mostly Hoover B under long-term contracts (allocations)
- The district does not experience a marginal jump in electric prices under current groundwater pumping amounts
- Lift heights are currently 450 feet but were 600 in 1993. Water levels recovered thanks to less pumping
- Groundwater wells are very reliable if maintenance is kept up. Reliability is not a source consideration for the district
- Water quality is not a decision factor for the district
- The district does not reuse tail water within its infrastructure, but some growers do within their own systems
- No assessment fee since 2000; was $25 per AF before that
- Calculate water rates to growers by passing CAP prices straight through. Difference between CAP price and In-Lieu water contracts is banked for infrastructure maintenance
- In the future, will likely return to pumping groundwater as the CAP Ag Settlement Pool dissolves
- Likely more corn for silage plantings and wheat in the future
- Conservation investments will be made along with returning to older farming practices such as letting alfalfa go to seed
- Most growers are waiting to retire on land already sold to developers or waiting to cash out from new development
- Farming will likely continue in the area with whatever water is leftover from development i.e., those developers who planned for too much water demand and need to sell some back to farmers
- Hoover contracts are considered 'gold' and even though the district is not using their entire Hoover allotment, they are holding on to them for a future with more groundwater pumping
- QCID was once where Frito Lay contracted for much of its potato supplies in the '80s and '90s
- Land has not generally been fallowed for economic reasons since dramatic commodity price increases as of 2010

- The district has roughly half or slightly less of total acres since 1993 due to urban land conversion

Roosevelt Water Conservation District:

Interviewee: Mr. Shane Leonard, General Manager, Roosevelt Water Conservation District
Interviewer: Mr. Brett Fleck
Location: Roosevelt Water Conservation District Headquarters
Date and Time: 04/04/2013, 3:00 p.m.

Method to fill grower orders:
1st – Purchase 5,000 AF of CAP Ag Settlement Pool water to qualify for In-lieu water
2nd – Surface water from Salt River contract (– 11,000 AF for Fort McDowell Tribe – 4,500 AF for Gila River Settlement – 3,500 AF for delivery to Chandler and Gilbert) leaves 11,000 – 21,000 AF per year of surface water
3rd – In-lieu contacts/partners to satisfy any remaining demand
4th – Any unforeseen or peak demand is covered by groundwater pumps

Calendar of operations:
June/July talk with growers, look at historical deliveries over 10-15 year averages accounting for development and climate projects

General Cropping Information:
- RWCD currently has between 10,000 – 11,000 irrigated acres

District Water Supplies and Constraints:
- RWCD founded in 1920 with operations as early as 1916 under a private water provider
- Surface was first water available through Salt River Project agreement in 1924. RWCD agreed to line canals for SRP and gets ‘saved’ water at rate of 5.6% of annual diversions at Granite Reef Dam (Averages 30-40 kAF per year). This water is free but costs $5 per AF to pump into canal system
- District owns all groundwater wells and has 55 maintained wells sites with 45 active in any given year. Groundwater wells can deliver 110,000 AF per year as needed
- Groundwater costs between $30-35 per AF in electricity costs
- CAP water is subject to 0.5 AF per acre limitation per the 2004 AWSA
- Effluent is industrial wastewater from the San Tan Electrical Generating Plant run by SRP. The water is free.
- RWCD helped create the In-lieu recharge program in the early 90s
- In-lieu averages $15 per AF. Where to store water for later recovery is a bargaining chip along with exchange possibilities with SRP
- In-lieu water also comes from Tribal and federal (BoR) contracts
- 900,000 – 1,000,000 AF have been stored since 1998 in RWCD
- “Produced” water is the amount needed to meet deliveries accounting for a system loss factor
- Gave up CAP contracts in exchange for cancelling BoR loans

- Ag Settlement Pool allocations are ‘supposedly’ based on acres in each district in 2003-2004
- Note: Groundwater law in Arizona is a “right to use it,” while surface water is a “right to own it”
- GSF permit for 85,000 AF in 2013; has fallen with development
- RWCD keeps a large operating reserve to partly cover ‘relining’ of SRP canals should they fail; a key requirement in the initial 1924 agreement
- $100 per acre assessment on all lands in the district (40,000 acres) provides roughly 80 percent of revenue the other 20 percent comes from water revenue
- RWCD delivers 5-7 AF per acre on average
- The district keeps up groundwater wells as a backup in case In-lieu partners discontinue contracts
- Keeps 3, 5, & 10 year In-lieu contracts with a September 1st renewal
- Roughly 400 growers running from 10 – 1,600 acres
- Irrigation at 80-85% efficiency
- All groundwater pumps are electric and get electricity from Hoover A, and CRSP
- Currently does not reach the second tier of electricity prices but would if all demand was satisfied with groundwater
- 150 feet of lift currently with 400 feet of lift in 1993
- Very rarely do wells go out as long as maintenance is kept up
- Water quality is not a huge factor and the effluent from SRP is A+ rated
- The district does reuse tail water within the system; particularly in the lower, southern reach
- RWCD does not charge block rates for water; only one single price of $23.75 per AF in 2013
- RWCD projects being developed out by 2030-2040 and will still be around because the area will need water for development
- Will likely see CAP take Ag Settlement Pool water from those that do not need it to reduce the cut to the Ag Settlement Pool

Maricopa-Stanfield Irrigation & Drainage District:

Interviewee: Mr. Brian Betcher, General Manager, Maricopa-Stanfield Irrigation & Drainage District
Interviewer: Mr. Brett Fleck
Location: Maricopa-Stanfield Irrigation & Drainage District Headquarters
Date and Time: 04/09/2013, 10:00 a.m.

Method to fill grower orders:
1st – Groundwater is the cheapest and first source; managers asks ‘how much can we physically pump with best wells online,’ ‘what’s the power rate,’ and ‘how much is groundwater going to cost’
2nd – Secure Ag Settlement Pool water and request remarketed water if available
3rd – Purchase In-lieu water through the AWBA and exercise contracts with GRIC
4th – Use groundwater to fulfill any remaining orders. More costly than first groundwater source because of deeper and less efficient wells

Calendar of operations:
Sep/Oct – Create water budgets with the help of the Board of Directors who are active growers
Late Oct/Early Nov – Pass water cost and availability information on to growers

District Water Supplies and Constraints:

- District founded in 1962 under Arizona Title 48 for the intent of accepting delivery of Colorado River water via CAP
- All grower orders have been satisfied through 2011, though, it was a challenge because of high demand driven by high cotton prices, hot weather, and replanting because of too much heat early in the growing season; CAP capacity was maxed out system-wide
- Peak daily demand occurs in June when corn silage is in its final irrigation and young cotton is thirsty
- Engineering challenges in getting water to growers that matches irrigation system needs; flood irrigation takes a certain rate of cfs to be most efficient
- MSIDD has 80-100 growers with 10 guys running most of the land; growers run between 300 – 10,000 acres
- Irrigation is center-pivot on 3,000 acres, drip on 5,000-7,000 acres, linear-sprinkler on 1,000 acres, and level basin on 50,000-55,000 acres equally split between border and furrow; on total of 65,000 net farmable acres
- 75-80 percent irrigation efficiency system-wide
- Over time there is more center-pivot and drip irrigation which is driven by loan-programs and high commodity prices
- Key with groundwater pumping is to keep from going into second tier of electrical rates that are roughly double the price
- GSF storage permit at 240,000 AF per year which is the limiting factor in accepting more In-lieu water
- Average $32 per AF for In-lieu contracts
- Rain can increase or decrease usage because of crusting that requires replanting and more water
- Rain can also delay planting times and cropping decisions meaning crops hit peak water use during a hotter period of the year requiring more water
- MSIDD defers to groundwater pumping earlier in the year to 'save' CAP water for later in the year to ensure peak demand can be met
- District has 40-year leases from 1990-2030 on district wells
- Can currently pump between 140-150,000 AF per year if demand is strong
- Areas in the SE of the district are hard to get groundwater to because most efficient pumps are in the lower, north end of the district
- Capital Improvement Plan is set to ramp up groundwater capacity to offset higher demand now and to get ready for Ag Settlement Pool reductions in 2017
- For some contracts, notification periods for In-lieu is less than 1 month
- 4.5 AF per acre on average in 2012, used to be higher; strategy to deal with lower water availability is to plant fewer acres and put more water on planted acres
- From 1997 – 2008, more acres were fallowed because of farm economics in addition to water per acre constraints
- All groundwater pumps are electrically driven

- There are no long-term contracts for electricity but rates are fairly consistent
- Power comes from Hoover, Parker-Davis, CRSP, APS, and open market supplement
- Lift depths are currently 550 feet overall and were 450 feet in 1993
- Increase in groundwater depth not due to aquifer declines but changes in the location of pumps used from shallow north end to deeper south end driven by Maricopa City development
- Dairies relocating to Pinal county have driven the move to alfalfa and much of the increase in water demand
- Electricity rates are volumetric and the manager tries to budget usage monthly to avoid the second "step"
- MSIDD can pump 95-100,000 AF before reaching the second tier of electricity prices.
- Step 1 electricity costs for groundwater are between \$36-\$39 per AF while Step 2 costs range from \$64-\$70 per AF
- Wells are aging and are being used more; it takes a long-time to bring a well back into production with rehab costing \$70-100,000 per well with entirely new wells costing \$500-600,000 per well
- MSIDD has 330 wells in its control with roughly 140 that are operable and active
- Groundwater quality is similar to CAP water and hasn't diminished yet; some pumps might have salinity problems as more marginal ones are brought online in the future
- Growers use tail water in select situations but there is very little to reuse as irrigation systems are very efficient
- MSIDD is a not-for-profit utility with 25% of the total budget going for overhead (payroll, ADWR fee, maintenance, capital improvement) and 75% going for the cost of water. Of the 25%, half comes from the district assessment and half comes from water charges
- In the future cropping pattern changes since 2000 or so will persist
- There will still be 50,000 acres farmed in 10 years using a higher percentage of groundwater as CAP supplies for agriculture diminish
- In recent years, have gone to tiered rate structure for water to growers to charge growers for water that comes from the more costly, second tier of electricity rates

Harquahala Valley Irrigation & Drainage District:

Interviewee: Mr. Rick Warren, General Manager, Harquahala Valley Irrigation & Drainage District
Interviewer: Mr. Brett Fleck
Location: Phone
Date and Time: 04/15/2013, 9:00 a.m.

Method to fill grower orders:
1st – Order all available CAP Ag Settlement Pool water subject to 1 AF per acre constraint set by 2004 AWSA; request any additional remarketed water from CAP
2nd – Individual growers pump groundwater to satisfy additional demand subject to salinity and lift constraints

District Water Supplies and Constraints:

- Formed in 1963 in anticipation of CAP water delivery, operations began in 1985
- HVID has only two sources of water, CAP Ag Settlement Pool water and groundwater. No In-lieu partners are available in the Harquahala INA
- Requests any additional CAP water including full-cost excess if available
- All groundwater pumps are electric
- Growers own all groundwater pumps
- Electricity supplied by the Harquahala Valley Power District; Jeff Woner
- Most power from Hoover, some NGS power, supplemental from APS purchased by growers annually as needed; general rule: NGS = 2 cents, Hoover = 4 cents, APS = 8 cents per kWh
- Water rate paid is $50 per AF in 2013 plus a $12 per acre assessment that covers 100 percent of maintenance and delivery costs; water is charged at a flat rate, no volumetric increases
- District contains 32,537 irrigable acres (CAP eligible acres) with roughly 26,000 farmed in each year. The remaining 6,000 or so acres are rotationally fallowed due to high salinity groundwater that constrains overall supply
- Lift depths are 1,000 ft. +/- 100 ft.
- Growers prefer CAP water over groundwater because of salinity issues
- District does not allow tail water in its infrastructure but individual growers use individual pumping systems to reuse tail water in specific instances
- 30-35 wells in operation within district boundaries but has been ramping up in recent years in anticipation of Ag Settlement Pool stepping down to 300 kAF in 2017
- District infrastructure can reach every acre within it
- 2004 AWSA allows 1 AF per acre of CAP water each year but District requests any remarketed water within the Ag Settlement Pool
- Main crops are upland cotton, alfalfa, barley, 1,800 acres of cantaloupe, 800 acres of watermelon
- HVID has 12-15 growers running between 80-5,000 acres each
- Irrigation techniques consist of 3,000 acres of drip with the rest spread between furrow and border

Maricopa Water District:

Interviewee: Mr. Ron Flowers Jr., General Manager, Maricopa Water District
Interviewer: Mr. Brett Fleck
Location: Phone
Date and Time: 04/18/2013, 10:50 a.m.

Method to fill grower orders:
1st – Order CAP Ag Settlement Pool water available to MWD (4,000 AF)
2nd – Fill out available In-lieu contracts (10-15,000 AF)
3rd – Make use of all available surface water from Lake Pleasant (25-30,000 AF)
4th – Pump groundwater to meet remaining orders (varies)

District Water Supplies and Constraints:

- MWD founded in 1925

- District operates 47 groundwater wells with individuals running their own for convenience sake (i.e., to better time deliveries)
- Note: Once pump is turned on once, it makes more sense financially to run the pump the entire month to spread out the one-time monthly meter fee
- Groundwater pumps need to be ran every so often to keep them maintained so they are sometimes considered a 'necessary evil'
- Average lift height of wells is around 650 feet and has dropped less than 10 feet over past decade
- There are 20-25,000 acres of agriculturally irrigable land in the district with 4-5 farmers running most of it. Farms range in size from 2-5 acre hobby farms up to 4,500 acres
- Roughly 1/3 of district land has been converted to urban use since 1986. Roughly 1/3 gets converted with each housing boom with the next one to follow once the 303 loop opens around 2014-2016
- In recent years, no land is fallowed as water is cheap and there is an ever decreasing amount to run. In 90s some land was fallowed but not much
- Almost all acres are devoted to vegetables with some for alfalfa. In early 90s, most acres were cotton and citrus with nearly all of that gone now
- Three-fourths of all lands are irrigated by drip or water canon with the remaining one-fourth irrigated by furrow
- MWD is entitled to Agua Fria watershed water at Lake Pleasant up to 150,000 AF of annual inflows minus what is already in the lake at the beginning of the year. Levels over 150,000 AF are deeded to CAP
- Agua Fria inflows average roughly 25-30 kAF per year and are essentially free
- 4,000 AF per year of CAP water is usually available and must be purchased before In-lieu contracts
- In-lieu contracts are also not available when Lake Pleasant levels reach a certain height; fuller reservoir = no In-lieu availability
- In-lieu contracts are very similar in price to AWBA cost-share agreement running $30-$35 per AF recently
- Groundwater is pumped as a third resource to fill in the gaps. Roughly 30,000 AF in total water are supplied by MWD in any given year
- Budgets for water are done in September of prior year, any fluctuation is met with groundwater pumping
- Half of what is sold in any given year (18-20 kAF) could be currently supplied by the active groundwater pumps owned by the district
- MWD infrastructure was designed to deliver water to the high corner of each section (660 acres) but development has fragmented sections and made it difficult for some growers to get MWD water to their land; thus need for groundwater pumps
- All pumps owned by the district are electric. All but a few diesel pumps owned by growers are electric
- Lake Pleasant water is exchanged with CAP so that canal water is what is delivered to the district except in a few odd years when the canal cannot supply the district water, then lake water is supplied
- Water quality is not an issue except when relatively dirty lake water is supplied
- The district prices water to growers at a loss, as it is subsidized by the operation of the Lake Pleasant Marina and other district sales

- MWD does not use tail water but some growers have tail water system
- In the future, 20 years or so from now most of the district will be developed out except undevelopable areas around Luke AFB where ag. will still exist

Central Arizona Irrigation & Drainage District:

Interviewee: Mr. Ron McEachern, General Manager, Central Arizona Irrigation & Drainage District
Interviewer: Mr. Brett Fleck
Location: Central Arizona Irrigation & Drainage District Headquarters
Date and Time: 04/19/2013, 10:00 a.m.

Method to fill grower orders:
1st – Place order for allotment of CAP Ag Settlement Pool water and request any remarketed water
2nd – Renew In-lieu contracts
3rd – Pump groundwater for remaining amount not met

Calendar of operations:
- Determine water demand for coming year based on running average of previous years and commodity market conditions. Decisions are made in September before CAP orders are due on October 1st.

District Water Supplies and Constraints:
- In-lieu contracts have one month lead time to notify that they will not be renewed
- In-lieu contract considerations are made according to 'strings attached.' For example, GRIC will recover their own In-lieu water by drilling their own wells while others require CAIDD to pay for the recovery of the In-lieu water from its own wells
- Groundwater pumping by the district must take place even if cheaper water is available elsewhere as Electrical District (ED) 4 and 5 are run by the same organization.
- ED4 does not require groundwater pumping to maintain solvency because it has other sources of revenue i.e., Eloy
- ED5 relies on electric sales from agricultural groundwater pumping to stay afloat
- Price paid by growers for water from irrigation districts is not really a constraint or even a decision factor
- Recent investments into 32,000 AFY of new groundwater well capacity is increasing as In-lieu availability is shifting to the Phoenix AMA and the district prepares for the 2017 Ag Settlement Pool step-down
- New groundwater capacity comes from refurbishing inactive wells that the district has the right to operate through the well lease agreement. At the end of the 30-year well lease, the district is required to return the wells in the condition they were received in; for the most part, that means active.
- Lift depths are currently around 350 feet in the north part of the district and 700 feet in the south. Since 1995, lift depths have gotten shallower by around 100 feet due to less pumping
- CAIDD can currently meet all grower demands; in the near future, pumping capacity will limit some deliveries in June/July during peak water use

- CAIDD has around 200 growers with 6 running most of the land; farm size ranges from 10 – 4,500
- Most large dairies (2,000 – 10,000 head) moved to the area from 2002 – 2005 as their operations in the Valley were bought out.
- Irrigation is 90% furrow, 7% border, 2% drip, and 1% pivot/linear
- District meets demand by pumping early in the year to stack CAP deliveries during peak demand in the summer
- Water is priced by AF with no tier increases
- Currently has 190,000 AF of groundwater capacity
- Some small areas within the district are not within reach of CAP water and rely solely on groundwater
- Well reliability is not really a consideration or problem
- Cost of new wells are about $400k; costs are lower for CAIDD as they source all their own materials; well costs are heavily dependent on depth
- Water source quality is not really a consideration
- There is no use of tail water at the district level and little individual use by growers with independent systems
- O&M costs run about $10-$13 per AF per year and are recovered partially by an assessment and partially through water sales
- In the future, the district will probably not see much change in operation other than a switch from CAP to groundwater providing most of the water
- The capacity of wells during peak demand will be the limiting factor
- 70-75,000 acres are planted in the district; 26% are enrolled in the BMP program
- From 1995 – 2011, less land is laid fallow as commodity prices have generally risen. More double-cropping with cotton and small grains is done depending on the small grain price.
- Expects to see 45-50,000 acres still planted in 2030

Tonopah Irrigation District:

Interviewee: Mr. Elisabeth Story, Former General Manager, Tonopah Irrigation District
Interviewer: Mr. Brett Fleck
Location: E-mail directly and via Mr. Jeffrey J. Woner, K.R. Saline & Associates PLC
Date and Time: Multiple

Direct e-mail communication: 02/26/2013

- CAP districts have many similarities, but are all different
- Only physical source of water for TID comes from the CAP system
- Growers have access to groundwater from their individually owned and operated wells
- Grower makes decisions on whether to pump or use the water TID delivers
- Cost of CAP Ag Settlement Pool water is substantially higher than cost of In-lieu water, and in the absence of the availability of In-lieu, might deliver no water due to the relative cost of CAP Ag Settlement Pool water versus groundwater pumping.
- Neither the District nor individual growers have any access to other sources such as other surface water or effluent.

E-mail communication via Mr. Jeffrey Woner: 05/01/2013

- There is not enough data to determine any trends or relationships between pricing and water use for TID.
- Growers, for the most part, prefer CAP/In-lieu due to a variety of factors, including not having to worry about well repairs.
- Growers would use more CAP/In-lieu and less groundwater if TID had greater infrastructure system capacity; in the summer TID frequently delivers at capacity and the growers must use some wells to supplement
- The slight drop in composite rate in recent years is related more to increased winter planting when we charge a lower rate than to the actual costs to the District. Also, it corresponds roughly to the time service was added to two large dairies and thus had more load over which to spread our overhead.
- No easy way to assign electricity cost of the District to particular accounts, but in general, think of our Hoover (only preference resource) as going to the District's irrigation wells first with very little, if any, left to go to other customers.
- Since 1997 the District has charged the same price to growers for both In-lieu and CAP water. Before 1997, there was a differential price.
- The basic Ag Settlement Pool water available to the District has been consistent from year to year except for the drop in amount in 2004. Before 2004, District was offered water from two separate Ag Pools, one much cheaper than the other.
- The small variations in the Pool amounts reported delivered from year to year are due to differences in District's losses.
- Significantly higher number of Ag Pool water in 2001 (and the smaller one in 2000) was because the District was able to get some extra Pool 1 water at a similar or lower price than In-lieu
- District has not collected information on the number of acres planted or what crops have been planted on paper for something like 10 years.
- No discernible relationship between price and water use.
- Total delivery is influenced much more by weather and crop prices than the price of water, so long as the price of water stays in the ranges it has been over the study years.
- Because it is in the District's best interest to preserve groundwater and because growers prefer water from CAP at similar prices, the District has tried to keep the prices similar over the study years, even when the District's cost for the water was greater than for electricity to pump groundwater.
- TID believes in need to keep costs of irrigation in this range in order to preserve farming.
- The only price/use relationship is out of the date range requested, but in the very early 90's, TID CAP water use dropped to nearly zero when the price to the District dramatically increased. Water prices went from the mid 30's to something over 50 dollars per acre foot

E-mail communication via Mr. Jeffrey Woner: 05/06/2013

- For original IGFR number 58-113070, landowner had 667.3 acres in 1998

- When the first dairy was built in 2000, 78.6 acres were removed from the original Grandfatherd Right leaving 588.7 irrigation acres.
- When the second one was built in 2006, an additional 215.0 acres were removed leaving the current 373.7 irrigation acres for that owner.
  Total reduction in the District's Irrigation Grandfathered Rights for the dairies was 293.6. This represents approximately an 8% reduction in the total irrigation acres.
- Water use can easily vary by more than 8% from year to year based on weather alone.
- Amount of water used is based more on weather and the types/timing of crops than any other factors. Decisions on types/timing (i.e., winter crops or not) are highly influenced by the prices of the crop which sometimes vary dramatically from year to year. Winter cropping has increased in recent years.

APPENDIX B: VARIABLE CONSTRUCTION NOTES

Expected Cotton Price

The expected price variable takes into account both February future's prices of cotton for harvest along with projected price support payments, called loan deficiency payments (LDP), based on the Adjusted World Price (AWP) (Tronstad & Bool, 2010). The variable is calculated as follows where Exp(Price) or expected price in equation 4.5 is *ExpCottonPrice*:

$$\mathrm{Exp(BasisLDP)_t = DecFutures(LastQtr)_{t-1} - AWP(LastQtr)_{t-1}} \quad (4.1)$$

$$\mathrm{Exp(AWP) = DecFutures(Feb) + Exp(BasisLDP)} \quad (4.2)$$

$$\mathrm{Exp(LDP)} = \mathrm{Max}\begin{cases} \$0.52 - \mathrm{Exp(AWP)} & \text{if} \quad \mathrm{Exp(AWP)} < \$0.52 \\ 0 & \text{Otherwise} \end{cases} \quad (4.3)$$

$$\mathrm{StateBasis_t = StatePrice_{t-1} - DecFutures(LastQtr)_{t-1}} \quad (4.4)$$

$$\mathrm{Exp(Price) = DecFutures(Feb) + StateBasis + Exp(LDP)} \quad (4.5)$$

Where:

a. *DecFutures(LastQtr)* = weekly December futures prices reported on Fridays from the beginning of September through the last report in December of the same year
b. *AWP(LastQtr)* = weekly AWP reported by the Agricultural Marketing Service (AMS)
c. *DecFutures(Feb)* is the average December futures price for each Friday in February
d. *Exp(LDP)* = difference between the AWP and $0.52 per pound, the price support, when the AWP falls below $0.52 per pound
e. *StatePrice* = state marketing year price for Arizona[36]

Sources: Historical cotton futures prices and the Adjusted World Price (AWP) for cotton comes from Turtle Trader and Moore Research Center, Inc., and USDA's Agricultural Marketing Service (AMS), respectively (Turtle Trader, 2013); (Moore Research Center, Inc., 2013); (U.S. Department of Agriculture, Agricultural Marketing Service, 2011).

[36] Marketing Year price is the average price from August of the first year to July of the second year. The price for 2011 then is the average price from August 2010 through July 2011.

MaxTemp and *Precip*

District	NOAA ID	AZMET	From Month	From Year	To Month	To Year	Notes
CAIDD	22807		1	1993	9	2005	AZMET "Eloy" station used to fill 03/95, 08/97, 08/99, & 10/99; NOAA station 20404 used to fill 11/02 & 06/05
	20404		10	2005	12	2011	
MSIDD	25270		1	1993	12	2011	
HVID	27462		1	1993	3	1996	
		Harquahala	4	1996	12	2011	NOAA station 27462 used to fill 12/96
SCIDD	21314		1	1993	12	2011	
HID	21314		1	1993	12	2011	
MWD		Waddell	1	1993	12	2009	NOAA station 24977 used to fill 07/96 - 12/96
	24977		1	2010	12	2011	
QCID	21514		1	1993	3	1995	NOAA station 23027 used to fill 04/94 & 03/95
		Queen Creek	4	1995	12	2011	NOAA station 21514 used to fill 07/96, 04/97, 07/97, 07/99, 09/99, 10/99, & 06/00; NOAA station 23027 used to fill 02/97
NMIDD	21514		1	1993	3	1995	NOAA station 23027 used to fill 04/94 & 03/95
		Queen Creek	4	1995	12	2011	NOAA station 21514 used to fill 07/96, 04/97, 07/97, 07/99, 09/99, 10/99, & 06/00; NOAA station 23027 used to fill 02/97
TID	21026		1	1993	3	1996	NOAA station 28641 used to fill 01/93 - 07/93, 10/93 & 01/94
		Harquahala	4	1996	3	2004	NOAA station 27462 used to fill 12/96
	28641		4	2004	12	2011	AZMET "Harquahala" station used to fill 08/04 - 09/04, 12/05, & 08/10 - 12/11
RWCD	21514		1	1993	7	2005	NOAA station 27370 used to fill 04/94 & 03/95; NOAA station 28499 used to fill 02/97; NOAA station 22782 used to fill 09/03; AZMET "Queen Creek" station used to fill 10/00
	22782		8	2005	12	2011	NOAA station 21514 used to fill 05/06 - 06/06 & 04/07

Sources: (The University of Arizona, 2013; National Oceanic and Atmospheric Administration, 2013b)

Population

District	City or Census Designated Place (CDP)	Notes
MSIDD	Maricopa City	(1)
CAIDD	Eloy	
HID	Coolidge	
SCIDD	Florence	
NMIDD	San Tan Valley CDP	(2)
QCID	Queen Creek	
RWCD	Gilbert	
MWD	Surprise	
TID	.	(3)
HVID	.	(4)

Population Data Source: Jim Chang, Arizona State Demographer (Arizona Department of Administration, 2013)

(1)	Census values starting in 2000; 1990 arbitrarily filled with value of 500; 1990-2000 interpolated using Pinal County growth rate
(2)	Census values for 2000 and 2010 only; 1990 arbitrarily filled with value of 500; 1990-2000 interpolated using Pinal County growth rate; 2000-2010 interpolated using Queen Creek growth rate
(3)	Assume no growth; constant value arbitrarily set at 60 for all years
(4)	Assume no growth; constant value arbitrarily set at 60 for all years

APPENDIX C: EMPIRICAL MODEL ASSUMPTION AND SPECIFICATION TESTING RESULTS

Contemporaneous Correlation

Breusch-Pagan Lagrange Multiplier test of independence:

Stata 12 Code –

- xtreg TOTAL RETIGFRPER PRECIP MAXTEMP _6mSPIApr realActCTNPrice realALFPrice, fe
- xttest2

Correlation Matrix of Residuals:

	__e1	__e2	__e3	__e4	__e5	__e6	__e7	__e8	__e9	__e10
__e1	1.0000									
__e2	0.3055	1.0000								
__e3	-0.2309	0.4315	1.0000							
__e4	0.6273	-0.0412	-0.1698	1.0000						
__e5	0.0222	0.0681	-0.0926	-0.1694	1.0000					
__e6	-0.6961	0.1211	0.2038	-0.6912	0.1220	1.0000				
__e7	0.0686	-0.0298	-0.2000	-0.0188	0.6724	0.2651	1.0000			
__e8	-0.6207	0.2237	0.5765	-0.6382	0.1635	0.5062	-0.0922	1.0000		
__e9	-0.5147	-0.1865	0.2456	0.0284	-0.1934	0.1411	-0.1333	0.2496	1.0000	
__e10	-0.2956	0.1332	-0.0182	-0.5267	0.5203	0.4843	0.5901	0.2609	-0.2952	1.0000

H_0: corr(ε_i,ε_j) = 0 for all $i \neq j$; i.e., residuals across entities are not correlated
Results: chi^2 (45) = 97.871, Prob > chi^2 = 0.0000
Based on 17 complete observations over 10 panel units
Interpretation: Reject the null-hypothesis, contemporaneous correlation is present at 95 percent confidence interval

Groupwise Heteroscedasticity

Modified Wald test for groupwise heteroscedasticity in a fixed effects regression model:

Stata 12 Code –

- xtreg TOTAL RETIGFRPER PRECIP MAXTEMP _6mSPIApr realActCTNPrice realALFPrice, fe
- xttest3

H$_0$: $\sigma_{\varepsilon}{}^{2}{}_{i} = \sigma_{\varepsilon}{}^{2}$ for all i; i.e., variance of residuals is the same for all units
Results: chi^2 (10) = 222.77, Prob > chi^2 = 0.0000
Interpretation: Reject null-hypothesis, heteroscedasticity is present at 95 percent confidence interval

Serial Correlation

Wooldridge test for autocorrelation in panel data:

Stata 12 Code –

- xtserial TOTAL RETIGFRPER PRECIP MAXTEMP _6mSPIApr realActCTNPrice realALFPrice

H$_0$: $E(\varepsilon_{it},\varepsilon_{is}) = 0$ for all $t \neq s$; i.e., no first-order autocorrelation [AR(1)]
Results: F(1,9) = 12.34, Prob > F = 0.0066
Interpretation: Reject null-hypothesis, AR(1) present at 95 percent confidence interval

Fixed vs. Random Effects

F-test for fixed effects:

Stata 12 Code –

- quietly tab DISTRICT, gen(dum)
- regress TOTAL RETIGFRPER PRECIP MAXTEMP _6mSPIApr realActCTNPrice realALFPrice dum1-dum10, noconstant
- test dum1 dum2 dum3 dum4 dum5 dum6 dum7 dum8 dum9 dum10

H$_0$: Dummy parameters = 0; no unit / fixed effects
Results: F(10,154) = 326.6
Prob > F = 0.0000
Interpretation: Reject the null-hypothesis; unit effects are present at 95 percent confidence interval

Breusch-Pagan Lagrange Multiplier test for random effects:

Stata 12 Code –

- xtreg TOTAL RETIGFRPER PRECIP MAXTEMP _6mSPIApr realActCTNPrice realALFPrice, re
- xttest0

TOTAL[DISTRICT,YEAR] = $X\beta + \mu$[DISTRICT] + ε[DISTRICT,YEAR]

Estimated Results:

	Variance	Std. Dev.
TOTAL	7.18E+09	84726.56
ε	2.83E+08	16822.94
μ	6.06E+09	77819.11

H_0: Var(μ) = 0; i.e., no panel effects
Results: $chibar^2(01) = 875.5$, Prob > $chibar^2 = 0.0000$
Interpretation: Reject null-hypothesis, panel effects present at 95 percent confidence interval

Hausman test for fixed versus random effects:

Stata 12 Code –

- xtreg TOTAL RETIGFRPER PRECIP MAXTEMP _6mSPIApr realActCTNPrice realALFPrice, fe
- estimates store fixed
- xtreg TOTAL RETIGFRPER PRECIP MAXTEMP _6mSPIApr realActCTNPrice realALFPrice, re
- estimates store random
- hausman fixed random

	Coefficients			
	(b) fixed	(B) random	(b-B) Difference	sqrt(diag(V_b-V_B)) S.E.
RETIGFRPER	-135106.600	-136377.400	1270.839	858.420
PRECIP	-1850.870	-1837.572	-13.298	.
MAXTEMP	1571.170	1676.343	-105.173	30.034
_6mSPIApr	4470.424	4505.727	-35.303	.
realActCTNPrice	24763.370	24716.310	47.053	.
realALFPrice	276.236	277.756	-1.519	.

b = consistent under H_0 and H_a; obtained from xtreg
B = inconsistent under H_a, efficient under H_0; obtained from xtreg

H_0: difference in coefficients not systematic; i.e., unique unit errors are not correlated with the regressors
Results: $chi^2(6)$ = (b-B)'[(V_b-V_B)^(-1)](b-B) = -6.76 ==>
==> Model fitted on these data fails to meet the asymptotic assumptions of the Hausman test, see Seemingly Unrelated Estimation [suest] for a generalized test
Interpretation: Test inconclusive, try test of over-identifying restrictions

Test of over-identifying restrictions: fixed versus random effects

Stata 12 Code –

- xtreg TOTAL RETIGFRPER PRECIP MAXTEMP _6mSPIApr realActCTNPrice realALFPrice, re
- xtoverid

Cross-section time-series model: xtreg re robust
H_0: Random effects model is more appropriate
Results: Sargan-Hansen statistic = 14.979, Prob > Sargan-Hansen = 0.0105
Interpretation: Reject null-hypothesis, fixed effects model preferred at 95 percent confidence interval

APPENDIX D: EMPIRICAL MODEL RESULTS

Fixed-Effects with Cluster-Robust Standard Errors (level-level without *DistWaterCost*):

Stata 12 Code –

- areg TOTAL RETIGFRPER PRECIP MAXTEMP _6mSPIApr CTNrealnolag ALFrealnolag, absorb(DISTRICT1) vce(cluster DISTRICT1)

Number of observations =	170
F(6,9) =	8.93
Prob > F =	0.0023
R^2 =	0.9641
Adj-R^2 =	0.9606
Root MSE =	16,822.94

Parameter	Coefficient	Cluster-Robust Standard Error	t-value	Prob > |t|	95% confidence interval	
InactiveIGFR	-135,106.6	23,250.1	-5.81	0.0000	-187,701.9	-82,511.2
Precip	-1,850.9	823.4	-2.25	0.0510	-3,713.6	11.9
MaxTemp	1,571.2	1,041.5	1.51	0.1660	-784.9	3,927.2
6mSPIApr	4,470.4	2,620.0	1.71	0.1220	-1,456.5	10,397.3
CottonPrice	24,763.4	8,956.0	2.77	0.0220	4,503.5	45,023.3
AlfalfaPrice	276.2	109.9	2.51	0.0330	27.7	524.7
Constant	-69,382.1	106,929.1	-0.65	0.5330	-311,272.5	172,508.3

Linear regression, absorbing indicators

District absorbed (10 categories)

Standard Errors adjusted for 10 clusters in District

Fixed-Effects with Cluster-Robust Standard Errors (level-level with *DistWaterCost*):

Stata 12 Code –

- areg TOTAL RETIGFRPER PRECIP MAXTEMP _6mSPIApr CTNrealnolag ALFrealnolag realDistWaterCost, absorb(DISTRICT1) vce(cluster DISTRICT1)

Number of observations =	119
F(6,6) =	.
Prob > F =	.
R^2 =	0.9699
Adj-R^2 =	0.9661
Root MSE =	17,671.01

Parameter	Coefficient	Cluster-Robust Standard Error	t-value	Prob > |t|	95% confidence interval	
InactiveIGFR	-137,671.0	28,238.3	-4.88	0.0030	-206,767.6	-68,574.4
Precip	-2,409.7	826.4	-2.92	0.0270	-4,432.0	-387.5
MaxTemp	925.6	989.7	0.94	0.3860	-1,496.1	3,347.3
6mSPIApr	3,155.8	1,460.6	2.16	0.0740	-418.1	6,729.8
CottonPrice	17,964.6	8,678.0	2.07	0.0840	-3,269.8	39,198.9
AlfalfaPrice	327.7	153.9	2.13	0.0770	-49.0	704.4
DistWaterCost	314.4	464.9	0.68	0.5240	-823.3	1,452.0
Constant	-6,755.7	118,402.6	-0.06	0.9560	-296,476.4	282,965.0

Linear regression, absorbing indicators

District absorbed (7 categories)

Standard Errors adjusted for 7 clusters in District

FGLS with Panel-Corrected Standard Errors and LSDV Fixed-Effects (level-level without *DistWaterCost*):

Stata 12 Code –

- xtpcse TOTAL RETIGFRPER PRECIP MAXTEMP _6mSPIApr CTNrealnolag ALFrealnolag dCAIDD dHID dHVID dMSIDD dMWD dNMIDD dQCID dRWCD dSCIDD dTID, correlation(ar1) noconstant

Group variable =	District	Number of observations =	170
Time variable =	Year	Number of groups =	10
Panels =	correlated (balanced)	Observations per group =	17
Autocorrelation =	common AR(1)	R^2 =	0.9801
Estimated covariances =	55	Wald chi^2(16) =	42,012.54
Estimated autocorrelations =	1	Prob > chi^2 =	0.0000
Estimated coefficients =	16		

Parameter	Coefficient	Panel-Corrected Standard Error	t-value	Prob > |t|	95% confidence interval	
InactiveIGFR	-133,390.3	14,594.6	-9.14	0.0000	-161,995.1	-104,785.5
Precip	-1,612.2	469.9	-3.43	0.0010	-2,533.3	-691.2
MaxTemp	1,502.0	831.4	1.81	0.0710	-127.4	3,131.4
6mSPIApr	4,125.0	1,325.3	3.11	0.0020	1,527.5	6,722.5
CottonPrice	24,496.9	6,848.1	3.58	0.0000	11,075.0	37,918.8
AlfalfaPrice	252.1	40.5	6.22	0.0000	172.6	331.5
dCAIDD	76,660.7	81,882.3	0.94	0.3490	-83,825.7	237,147.0
dHID	-74,679.3	81,612.3	-0.92	0.3600	-234,636.5	85,277.9
dHVID	-76,929.2	79,425.0	-0.97	0.3330	-232,599.3	78,741.0
dMSIDD	86,260.7	82,284.2	1.05	0.2940	-75,013.4	247,534.8
dMWD	-98,832.1	79,240.6	-1.25	0.2120	-254,140.9	56,476.7
dNMIDD	-92,473.4	78,961.1	-1.17	0.2420	-247,234.3	62,287.4
dQCID	-119,239.6	78,579.4	-1.52	0.1290	-273,252.3	34,773.2
dRWCD	-79,998.0	79,545.2	-1.01	0.3150	-235,903.8	75,907.8
dSCIDD	-72,300.8	81,723.1	-0.88	0.3760	-232,475.2	87,873.6
dTID	-161,266.0	80,108.9	-2.01	0.0440	-318,276.7	-4,255.4

Prais-Winsten regression, correlated panels, corrected standard errors (PCSE)

$\rho = 0.263695$

FGLS with Panel-Corrected Standard Errors and LSDV Fixed-Effects (level-level with *DistWaterCost*):

Stata 12 Code –

- xtpcse TOTAL RETIGFRPER PRECIP MAXTEMP _6mSPIApr CTNrealnolag ALFrealnolag realDistWaterCost dCAIDD dHID dHVID dMSIDD dMWD dNMIDD dQCID dRWCD dSCIDD dTID, correlation(ar1) noconstant

Group variable =	District	Number of observations =	119
Time variable =	Year	Number of groups =	7
Panels =	correlated (balanced)	Observations per group =	17
Autocorrelation =	common AR(1)	R^2 =	0.9832
Estimated covariances =	28	Wald chi^2(14) =	13,000.35
Estimated autocorrelations =	1	Prob > chi^2 =	0.0000
Estimated coefficients =	14		

Parameter	Coefficient	Panel-Corrected Standard Error	t-value	Prob > |t|	95% confidence interval	
InactiveIGFR	-138,250.3	15,799.0	-8.750	0.000	-169,215.9	-107,284.8
Precip	-2,037.0	568.8	-3.580	0.000	-3,151.7	-922.2
MaxTemp	1,020.4	1,070.7	0.950	0.341	-1,078.1	3,118.8
6mSPIApr	2,054.1	1,910.4	1.080	0.282	-1,690.2	5,798.4
CottonPrice	20,628.2	9,432.0	2.190	0.029	2,141.8	39,114.6
AlfalfaPrice	299.4	52.6	5.690	0.000	196.3	402.4
DistWaterCost	263.0	347.4	0.760	0.449	-417.8	943.8
dCAIDD	110,064.1	104,875.2	1.050	0.294	-95,487.5	315,615.6
dHID	.	.	.	.	.	.
dHVID	-44,823.1	101,923.8	-0.440	0.660	-244,590.1	154,943.9
dMSIDD	120,086.3	105,419.6	1.140	0.255	-86,532.3	326,704.9
dMWD	-63,388.0	101,226.6	-0.630	0.531	-261,788.5	135,012.5
dNMIDD	-57,985.6	101,108.1	-0.570	0.566	-256,154.0	140,182.7
dQCID	.	.	.	.	.	.
dRWCD	-40,385.0	101,319.0	-0.400	0.690	-238,966.6	158,196.6
dSCIDD	.	.	.	.	.	.
dTID	-125,599.6	102,562.2	-1.220	0.221	-326,617.9	75,418.7

Prais-Winsten regression, correlated panels, corrected standard errors (PCSE)

$\rho = 0.236613$

Fixed-Effects with Cluster-Robust Standard Errors (log-log without *DistWaterCost*):

Stata 12 Code –

- areg lnTOTAL lnRETIGFRPER lnPRECIP lnMAXTEMP ln6mSPIApr lnCTNrealnolag lnALFrealnolag, absorb(DISTRICT1) vce(cluster DISTRICT1)

Number of observations =	170
F(6,9) =	110.64
Prob > F =	0.0000
R^2 =	0.9753
Adj-R^2 =	0.9729
Root MSE =	0.1305

Parameter	Coefficient	Cluster-Robust Standard Error	t-value	Prob > |t|	95% confidence interval	
InactiveIGFR	-2.6177	0.2700	-9.69	0.0000	-3.2286	-2.0069
Precip	-0.0858	0.0369	-2.32	0.0450	-0.1693	-0.0023
MaxTemp	1.6323	0.7347	2.22	0.0530	-0.0297	3.2944
6mSPIApr	0.0908	0.0603	1.51	0.1660	-0.0455	0.2271
CottonPrice	0.2296	0.1502	1.53	0.1610	-0.1103	0.5694
AlfalfaPrice	0.3682	0.0527	6.99	0.0000	0.2490	0.4874
Constant	2.1916	3.5633	0.62	0.5540	-5.8692	10.2524

Linear regression, absorbing indicators

District absorbed (10 categories)

Standard Errors adjusted for 10 clusters in District

Fixed-Effects with Cluster-Robust Standard Errors (log-log with *DistWaterCost*):

Stata 12 Code –

- areg lnTOTAL lnRETIGFRPER lnPRECIP lnMAXTEMP ln6mSPIApr lnCTNrealnolag lnALFrealnolag lnrealdistwatercost, absorb(DISTRICT1) vce(cluster DISTRICT1)

Number of observations =	119
F(6,6) =	.
Prob > F =	.
R^2 =	0.9807
Adj-R^2 =	0.9783
Root MSE =	0.1290

Parameter	Coefficient	Cluster-Robust Standard Error	t-value	Prob > |t|	95% confidence interval	
InactiveIGFR	-2.7819	0.3240	-8.59	0.0000	-3.5747	-1.9890
Precip	-0.1084	0.0344	-3.15	0.0200	-0.1927	-0.0241
MaxTemp	0.7372	0.5634	1.31	0.2390	-0.6415	2.1158
6mSPIApr	0.0443	0.0409	1.08	0.3210	-0.0559	0.1445
CottonPrice	0.1852	0.1508	1.23	0.2650	-0.1839	0.5542
AlfalfaPrice	0.3502	0.0816	4.29	0.0050	0.1506	0.5498
DistWaterCost	-0.1904	0.1337	-1.42	0.2040	-0.5175	0.1367
Constant	7.2476	2.9333	2.47	0.0480	0.0700	14.4251

Linear regression, absorbing indicators

District absorbed (7 categories)

Standard Errors adjusted for 7 clusters in District

FGLS with Panel-Corrected Standard Errors and LSDV Fixed-Effects (log-log without *DistWaterCost*):

Stata 12 Code –

- xtpcse lnTOTAL lnRETIGFRPER lnPRECIP lnMAXTEMP ln6mSPIApr lnCTNrealnolag lnALFrealnolag dCAIDD dHID dHVID dMSIDD dMWD dNMIDD dQCID dRWCD dSCIDD dTID, correlation(ar1) noconstant

Group variable =	District	Number of observations =	170
Time variable =	Year	Number of groups =	10
Panels =	correlated (balanced)	Observations per group =	17
Autocorrelation =	common AR(1)	R^2 =	0.9998
Estimated covariances =	55	Wald chi^2(16) =	3,110,000.00
Estimated autocorrelations =	1	Prob > chi^2 =	0.0000
Estimated coefficients =	16		

Parameter	Coefficient	Panel-Corrected Standard Error	t-value	Prob > |t|	95% confidence interval	
InactiveIGFR	-2.5299	0.1920	-13.18	0.0000	-2.9062	-2.1536
Precip	-0.0763	0.0208	-3.67	0.0000	-0.1170	-0.0356
MaxTemp	1.4695	0.5260	2.79	0.0050	0.4386	2.5003
6mSPIApr	0.0830	0.0279	2.97	0.0030	0.0282	0.1378
CottonPrice	0.2173	0.0746	2.91	0.0040	0.0711	0.3634
AlfalfaPrice	0.3313	0.0432	7.67	0.0000	0.2466	0.4159
dCAIDD	4.0537	2.4043	1.69	0.0920	-0.6586	8.7660
dHID	3.2031	2.4055	1.33	0.1830	-1.5116	7.9177
dHVID	3.1602	2.3898	1.32	0.1860	-1.5237	7.8442
dMSIDD	4.1285	2.4086	1.71	0.0870	-0.5921	8.8492
dMWD	2.9470	2.3940	1.23	0.2180	-1.7451	7.6391
dNMIDD	3.0445	2.3886	1.27	0.2020	-1.6371	7.7260
dQCID	2.5616	2.3888	1.07	0.2840	-2.1204	7.2437
dRWCD	3.1877	2.3969	1.33	0.1840	-1.5102	7.8855
dSCIDD	3.2214	2.4059	1.34	0.1810	-1.4941	7.9369
dTID	1.5727	2.3958	0.66	0.5120	-3.1230	6.2685

Prais-Winsten regression, correlated panels, corrected standard errors (PCSE)

$\rho = 0.322818$

FGLS with Panel-Corrected Standard Errors and LSDV Fixed-Effects (log-log with *DistWaterCost*):

Stata 12 Code –

- xtpcse lnTOTAL lnRETIGFRPER lnPRECIP lnMAXTEMP ln6mSPIApr lnCTNrealnolag lnALFrealnolag lnrealdistwatercost dCAIDD dHID dHVID dMSIDD dMWD dNMIDD dQCID dRWCD dSCIDD dTID, correlation(ar1) noconstant

Group variable =	District	Number of observations =	119
Time variable =	Year	Number of groups =	7
Panels =	correlated (balanced)	Observations per group =	17
Autocorrelation =	common AR(1)	R^2 =	0.9998
Estimated covariances =	28	Wald chi^2(14) =	1,530,000.00
Estimated autocorrelations =	1	Prob > chi^2 =	0.0000
Estimated coefficients =	14		

Parameter	Coefficient	Panel-Corrected Standard Error	t-value	Prob > |t|	95% confidence interval	
InactiveIGFR	-2.6428	0.2286	-11.56	0.0000	-3.0907	-2.1948
Precip	-0.0888	0.0223	-3.99	0.0000	-0.1324	-0.0452
MaxTemp	0.7939	0.5990	1.33	0.1850	-0.3801	1.9679
6mSPIApr	-0.0054	0.0566	-0.09	0.9250	-0.1163	0.1056
CottonPrice	0.1607	0.0949	1.69	0.0900	-0.0253	0.3467
AlfalfaPrice	0.3215	0.0477	6.75	0.0000	0.2281	0.4149
DistWaterCost	-0.1222	0.0977	-1.25	0.2110	-0.3137	0.0692
dCAIDD	7.8399	2.7861	2.81	0.0050	2.3792	13.3006
dHID	.	.	.	.	.	.
dHVID	6.9200	2.7698	2.5	0.0120	1.4913	12.3486
dMSIDD	7.9172	2.7899	2.84	0.0050	2.4491	13.3853
dMWD	6.6929	2.7646	2.42	0.0150	1.2744	12.1113
dNMIDD	6.7866	2.7647	2.45	0.0140	1.3679	12.2052
dQCID	.	.	.	.	.	.
dRWCD	6.9007	2.7619	2.5	0.0120	1.4874	12.3140
dSCIDD	.	.	.	.	.	.
dTID	5.3105	2.7717	1.92	0.0550	-0.1220	10.7429

Prais-Winsten regression, correlated panels, corrected standard errors (PCSE)

ρ = 0.346203

Fixed-Effects with Cluster-Robust Standard Errors (level-level without *RetireIGFR* and *DistWaterCost*):

Stata 12 Code –

- areg TOTAL PRECIP MAXTEMP _6mSPIApr CTNrealnolag ALFrealnolag, absorb(DISTRICT1) vce(cluster DISTRICT1)

Number of observations =	170
F(5,9) =	3.89
Prob > F =	0.0373
R^2 =	0.9493
Adj-R^2 =	0.9447
Root MSE =	19,927

Parameter	Coefficient	Cluster-Robust Standard Error	t-value	Prob > |t|	95% confidence interval	
Precip	-2,130.96	1,057.28	-2.02	0.0750	-4,522.69	260.76
MaxTemp	537.66	1,882.05	0.29	0.7820	-3,719.83	4,795.15
6mSPIApr	3,126.19	2,839.27	1.10	0.2990	-3,296.69	9,549.06
CottonPrice	31,771.44	9,333.16	3.40	0.0080	10,658.37	52,884.52
AlfalfaPrice	103.21	132.53	0.78	0.4560	-196.60	403.02
Constant	40,346.24	191,971.20	0.21	0.8380	-393,922.80	474,615.30

Linear regression, absorbing indicators

District absorbed (10 categories)

Standard Errors adjusted for 10 clusters in District

Fixed-Effects with Cluster-Robust Standard Errors (level-level without *RetireIGFR*):

Stata 12 Code –

- areg TOTAL PRECIP MAXTEMP _6mSPIApr CTNrealnolag ALFrealnolag realDistWaterCost, absorb(DISTRICT1) vce(cluster DISTRICT1)

Number of observations =	119
F(6,6) =	5.93
Prob > F =	0.0239
R^2 =	0.9589
Adj-R^2 =	0.9542
Root MSE =	20,641

Parameter	Coefficient	Cluster-Robust Standard Error	t-value	Prob > |t|	95% confidence interval	
Precip	-2,680.14	1,263.85	-2.12	0.0780	-5,772.66	412.39
MaxTemp	-235.08	2,626.06	-0.09	0.9320	-6,660.82	6,190.65
6mSPIApr	1,272.76	1,923.05	0.66	0.5330	-3,432.77	5,978.28
CottonPrice	14,642.56	10,229.70	1.43	0.2020	-10,388.61	39,673.73
AlfalfaPrice	202.13	177.32	1.14	0.2980	-231.76	636.02
DistWaterCost	1,073.46	431.65	2.49	0.0470	17.27	2,129.66
Constant	83,791.12	278,373.70	0.30	0.7740	-597,364.80	764,947.00

Linear regression, absorbing indicators

District absorbed (7 categories)

Standard Errors adjusted for 7 clusters in District

APPENDIX E: DATA FOR ANALYSIS AND LEGEND

Variable	Unit of Measure	Description
District	n/a	District identifier; cross-sectional unit
Year	Year	Year; time-series unit
Total	AF	Total annual water used for agriculture within boundaries of each irrigation district
GW	AF	Annual groundwater pumped for agriculture within irrigation district boundaries
CAP	AF	Annual CAP water used for agriculture within irrigation district boundaries
In_Lieu	AF	Annual In-lieu water used for agriculture within irrigation district boundaries
Other	AF	Annual other water used for agriculture within irrigation district boundaries; other includes ADWR categories, “effluent,” and “other.”
Surface	AF	Annual surface water diverted for agriculture within irrigation district boundaries
Precip	Inches	Annual precipitation measured at weather stations noted in Appendix B
MaxTemp	°F	Average maximum daily temperature from March – September at weather stations noted in Appendix B
MeanTemp	°F	Average mean daily temperature from March – September at weather stations noted in Appendix B
6mSPIApr	SPI	Six month SPI index measured in April
12mSPIApr	SPI	Twelve month SPI index measured in April
24mSPIApr	SPI	Twenty-four month SPI index measured in April
3mSPIAug	SPI	Three month SPI index measured in August
6mSPIAug	SPI	Six month SPI index measured in August
9mSPIOct	SPI	Nine month SPI index measured in October
12mSPIDec	SPI	Twelve month SPI index measured in December
DistWaterCost	$/AF	Nominal water cost for agriculture reported by irrigation districts
ExpCTNPrice	$/lbs.	Calculated expected price of upland cotton based on methodology detailed in Appendix B
ActCTNPrice	$/lbs.	Nominal Arizona state price of upland cotton
ALFPrice	$/ton	Nominal Arizona state price of alfalfa-hay
WHTPrice	$/bu.	Nominal Arizona state price of durum wheat
BARPrice	$/bu.	Nominal Arizona state price of barley for grain
CRNPrice	$/bu.	Nominal Arizona state price of corn for grain
GDP_IPD	Index	Gross Domestic Product, Implicit Price Deflator index where 2005=100
CityPop	Pop.	Population of city in or near each irrigation district as noted in Appendix B
CountyPop	Pop.	Annual county population
PHXHStarts	Starts	Phoenix MSA single-family housing starts cumulated over time
DairyCows	Head	Number of dairy cows by county
InactiveIGFR	Acres	Actual number of IGFR certificate acres made inactive annually cumulated over time
InactIGFRper	Percent	Percent of 1995 IGFR certificate acres by irrigation district made inactive annually cumulated over time
AcresPlant	Acres	Total of upland cotton, pima cotton, alfalfa-hay, durum wheat, winter wheat, barley, corn-all, and sorghum-all annual acres planted (harvested for alfalfa) by county

District	Year	Total	GW	CAP	In_Lieu	Other	Surface	Precip	MaxTemp	MeanTemp	6mSPIApr
CAIDD	1994	169,285	57,273	106,812	0	4,100	1,100	10.00	97.85	79.98	0
CAIDD	1995	205,397	71,616	132,301	0	880	600	7.34	95.90	77.95	0
CAIDD	1996	280,557	135,004	145,553	0	0	0	6.15	97.47	78.36	0
CAIDD	1997	253,417	129,536	123,654	0	228	0	8.60	97.91	80.11	0
CAIDD	1998	222,117	89,392	124,647	8,078	0	0	13.28	94.95	77.00	0
CAIDD	1999	230,980	100,481	124,506	5,993	0	0	3.56	95.41	77.62	0
CAIDD	2000	235,182	94,148	125,167	15,867	0	0	9.57	98.83	81.27	0
CAIDD	2001	220,866	76,216	133,537	11,113	0	0	12.07	98.57	80.03	0
CAIDD	2002	272,784	96,327	131,188	45,270	0	0	2.84	100.89	81.94	0
CAIDD	2003	279,661	127,703	146,146	5,612	100	100	5.56	98.01	80.29	0
CAIDD	2004	254,689	118,079	118,390	18,180	0	40	7.35	100.32	81.27	0
CAIDD	2005	233,180	85,901	115,962	31,227	90	0	10.27	97.91	79.93	0
CAIDD	2006	245,529	99,017	117,678	28,672	0	162	9.53	95.95	79.83	0
CAIDD	2007	292,867	118,664	109,044	63,968	0	1,190	7.46	97.67	80.93	0
CAIDD	2008	316,065	146,526	121,502	48,038	0	0	7.46	96.90	79.85	0
CAIDD	2009	277,932	119,494	129,161	29,277	0	0	2.67	98.37	81.27	0
CAIDD	2010	264,584	115,318	120,570	28,696	0	0	12.07	94.02	78.03	0
CAIDD	2011	348,525	158,558	112,231	76,137	0	1,600	4.39	95.00	78.62	0
MSIDD	1994	231,575	90,092	141,482	0	0	0	8.37	98.55	81.45	0
MSIDD	1995	282,382	135,099	147,283	0	0	0	6.31	97.08	79.83	0
MSIDD	1996	307,884	158,164	149,719	0	0	0	3.03	98.75	81.35	0
MSIDD	1997	272,706	147,761	124,945	0	0	0	6.41	98.93	81.73	0
MSIDD	1998	235,285	79,674	123,133	32,478	0	0	8.08	95.46	79.03	0
MSIDD	1999	225,726	83,845	121,562	20,303	16	0	6.82	96.16	79.52	0
MSIDD	2000	231,256	80,279	122,688	28,289	0	0	8.02	99.37	82.53	0
MSIDD	2001	240,564	71,758	119,983	48,823	0	0	7.39	98.86	81.78	0
MSIDD	2002	239,878	83,088	109,926	46,864	0	0	3.07	98.83	81.04	0
MSIDD	2003	287,437	127,471	145,286	14,641	38	0	5.11	97.80	81.06	0
MSIDD	2004	240,710	118,779	101,671	20,260	0	0	8.06	98.60	81.29	0
MSIDD	2005	263,268	97,193	110,941	55,135	0	0	8.07	97.70	80.34	0
MSIDD	2006	273,420	95,449	103,366	74,606	0	0	6.22	97.31	80.93	0
MSIDD	2007	315,307	118,230	115,589	81,487	0	0	7.25	98.99	82.07	0
MSIDD	2008	305,241	121,955	129,141	54,145	0	0	7.03	97.91	80.86	0
MSIDD	2009	273,530	100,426	126,849	46,255	0	0	4.33	99.35	82.04	0
MSIDD	2010	265,325	80,653	125,187	59,485	0	0	7.17	97.65	80.29	0
MSIDD	2011	330,326	124,995	120,478	84,852	0	0	4.44	99.50	81.78	0
HID	1994	99,918	52,245	43,108	0	0	4,566	10.38	100.12	81.24	-0.28
HID	1995	97,361	77,304	16,092	0	0	3,965	8.19	98.99	78.80	1.51
HID	1996	117,113	98,862	13,974	0	0	4,276	10.13	100.07	80.37	-0.83
HID	1997	124,742	102,765	19,357	0	0	2,619	7.43	99.63	80.83	0.09
HID	1998	101,484	51,032	14,710	32,835	21	2,886	9.72	95.87	77.21	1.05
HID	1999	97,790	42,395	15,744	38,430	0	1,220	7.48	96.52	78.29	-0.41
HID	2000	113,306	48,524	19,602	44,742	0	438	6.09	99.78	80.86	-1.27
HID	2001	108,039	41,741	16,818	47,268	143	2,069	9.72	97.55	80.60	0.79
HID	2002	118,230	44,581	28,595	44,224	0	831	4.81	98.14	80.57	-1.28
HID	2003	111,549	58,908	29,907	21,755	0	979	5.29	96.70	80.21	0.45
HID	2004	99,444	54,547	32,782	12,115	0	0	8.89	97.21	80.65	1.55
HID	2005	96,007	43,314	30,270	21,379	246	797	10.26	95.69	79.11	2.01
HID	2006	104,711	43,659	29,900	30,315	0	837	7.14	95.28	79.96	-2.76
HID	2007	125,659	46,261	40,645	38,352	65	336	9.31	96.95	81.04	0.08
HID	2008	127,898	49,911	40,455	36,456	260	815	7.09	95.93	79.67	0.39
HID	2009	96,422	39,949	27,532	28,009	529	404	3.47	97.19	81.04	-0.37
HID	2010	114,000	39,200	29,504	42,784	1,456	1,057	9.56	95.26	79.08	1.13
HID	2011	123,988	44,124	28,345	50,415	811	294	4.57	97.55	80.73	-2.58
NMIDD	1994	73,237	8,854	64,384	0	36	-36	8.11	94.23	79.98	0
NMIDD	1995	91,267	33,199	58,068	0	0	0	10.07	93.22	77.32	0
NMIDD	1996	84,273	38,663	44,139	0	-154	1,625	6.17	96.31	80.95	0
NMIDD	1997	98,198	48,471	49,028	647	53	0	6.79	95.41	79.54	0
NMIDD	1998	76,285	2,792	37,486	36,008	0	0	7.63	92.43	75.86	0
NMIDD	1999	93,313	5,427	40,240	47,646	0	0	5.43	92.41	78.03	0
NMIDD	2000	94,965	3,144	44,212	47,609	0	0	6.82	95.85	80.43	0
NMIDD	2001	92,083	1,818	42,546	47,719	0	0	6.84	95.43	80.29	0

District	Year	Total	GW	CAP	In_Lieu	Other	Surface	Precip	MaxTemp	MeanTemp	6mSPIApr
NMIDD	2002	97,500	2,269	45,744	49,488	0	0	4.17	95.43	80.29	0
NMIDD	2003	72,079	4,260	43,055	24,764	0	0	5.68	95.14	79.86	0
NMIDD	2004	77,424	5,762	23,563	48,100	0	0	10.42	95.14	79.71	0
NMIDD	2005	80,417	4,823	30,626	44,968	0	0	9.46	92.86	77.00	0
NMIDD	2006	79,500	2,383	30,382	46,736	0	0	7.87	92.29	77.71	0
NMIDD	2007	81,984	1,071	27,240	53,672	0	0	7.95	94.29	79.00	0
NMIDD	2008	79,305	1,590	27,892	49,823	0	0	8.32	93.43	78.14	0
NMIDD	2009	76,830	2,332	28,429	46,069	0	0	3.84	95.43	80.57	0
NMIDD	2010	80,525	619	29,488	50,281	0	137	9.89	92.86	77.86	0
NMIDD	2011	88,020	1,624	25,674	60,722	0	0	6.20	95.00	79.14	0
RWCD	1994	106,932	53,130	17,994	10,185	110	25,512	8.46	95.08	80.11	0.09
RWCD	1995	107,556	34,449	13,974	17,715	138	41,279	11.24	94.07	78.70	0.93
RWCD	1996	110,651	59,471	13,251	17,940	162	19,826	5.20	95.05	80.99	-1.21
RWCD	1997	104,013	18,534	12,986	55,277	33	17,184	10.13	95.23	81.01	-0.31
RWCD	1998	88,024	32,194	12,804	19,885	0	23,141	9.17	92.04	77.90	0.8
RWCD	1999	83,929	14,072	117	56,546	4	13,189	6.28	92.97	79.01	-0.79
RWCD	2000	75,961	809	0	65,811	0	9,341	6.91	95.75	81.42	-1.67
RWCD	2001	74,814	1,146	17	67,616	0	6,035	7.68	94.61	80.52	0.06
RWCD	2002	78,729	21,372	0	52,793	17	4,547	4.67	95.95	80.75	-2.29
RWCD	2003	62,664	16,235	0	45,689	0	739	8.07	95.51	80.19	0.05
RWCD	2004	51,940	527	7,292	36,405	0	7,716	7.83	95.59	81.32	-0.37
RWCD	2005	40,931	1,140	5,646	32,612	258	1,274	11.90	95.77	80.19	1.51
RWCD	2006	38,125	2,404	3,859	15,207	1,845	14,809	11.28	95.90	81.22	-1.79
RWCD	2007	41,799	14,158	4,071	16,521	1,863	5,186	7.93	97.65	83.04	-1.02
RWCD	2008	37,769	2,797	3,899	29,814	379	880	15.09	95.87	80.47	0.78
RWCD	2009	37,614	3,852	3,611	25,598	1,028	3,524	6.56	96.88	81.45	0.33
RWCD	2010	33,705	6,059	2,731	18,958	1,397	4,560	15.55	95.26	80.03	1.02
RWCD	2011	42,389	2,285	2,952	30,317	1,941	4,892	6.46	97.75	81.89	-0.79
HVID	1994	60,632	8,099	52,533	0	0	0	6.31	95.49	80.55	0
HVID	1995	110,158	10,139	100,019	0	0	0	5.01	93.84	78.95	0
HVID	1996	135,501	22,102	113,399	0	0	0	1.24	95.79	79.70	0
HVID	1997	135,715	21,211	114,504	0	0	0	7.15	95.43	78.71	0
HVID	1998	93,193	17,149	76,044	0	0	0	8.95	91.86	75.00	0
HVID	1999	76,253	22,903	53,350	0	0	0	4.71	92.71	76.57	0
HVID	2000	87,474	27,368	60,106	0	0	0	5.90	96.43	79.71	0
HVID	2001	126,166	23,186	102,980	0	0	0	4.32	95.86	79.29	0
HVID	2002	138,574	42,551	96,023	0	0	0	3.08	96.00	78.86	0
HVID	2003	91,947	27,614	64,333	0	0	0	11.02	95.43	79.00	0
HVID	2004	78,250	46,788	31,462	0	0	0	10.39	96.43	79.86	0
HVID	2005	87,506	43,268	44,238	0	0	0	9.71	95.29	77.14	0
HVID	2006	119,059	13,927	105,132	0	0	0	2.95	94.57	78.29	0
HVID	2007	115,220	53,718	61,502	0	0	0	6.10	95.29	79.00	0
HVID	2008	105,408	70,924	34,484	0	0	0	6.92	95.00	78.57	0
HVID	2009	104,925	67,798	37,127	0	0	0	3.50	95.43	78.71	0
HVID	2010	107,115	53,796	53,319	0	0	0	8.71	92.43	76.29	0
HVID	2011	117,461	72,728	44,733	0	0	0	3.28	94.86	78.57	0
QCID	1994	44,620	11,841	32,341	1,037	-599	0	8.11	94.23	79.98	0
QCID	1995	52,493	22,611	29,882	0	0	0	10.07	93.22	77.32	0
QCID	1996	62,539	33,724	26,979	1,608	33	195	6.17	96.31	80.95	0
QCID	1997	61,147	34,326	26,820	0	0	0	6.79	95.41	79.54	0
QCID	1998	49,187	9,833	25,290	14,064	0	0	7.63	92.43	75.86	0
QCID	1999	48,948	9,457	27,064	12,428	0	0	5.43	92.41	78.03	0
QCID	2000	45,132	9,187	25,585	10,360	0	0	6.82	95.85	80.43	0
QCID	2001	38,687	6,846	22,903	8,938	0	0	6.84	95.43	80.29	0
QCID	2002	43,164	6,952	27,620	8,592	0	0	4.17	95.43	80.29	0
QCID	2003	39,914	6,328	23,529	10,057	0	0	5.68	95.14	79.86	0
QCID	2004	37,828	5,061	17,712	15,054	0	0	10.42	95.14	79.71	0
QCID	2005	30,908	3,312	15,907	11,688	0	0	9.46	92.86	77.00	0
QCID	2006	25,562	3,427	15,844	6,291	0	0	7.87	92.29	77.71	0
QCID	2007	30,785	3,632	17,555	9,597	0	0	7.95	94.29	79.00	0
QCID	2008	31,349	2,989	13,381	14,979	0	0	8.32	93.43	78.14	0

District	Year	Total	GW	CAP	In_Lieu	Other	Surface	Precip	MaxTemp	MeanTemp	6mSPIApr
QCID	2009	28,977	1,859	8,730	18,388	0	0	3.84	95.43	80.57	0
QCID	2010	27,095	1,688	9,632	15,776	0	0	9.89	92.86	77.86	0
QCID	2011	31,989	1,946	9,198	20,846	0	0	6.20	95.00	79.14	0
SCIDD	1994	151,086	44,217	4,204	0	1,288	101,377	10.38	100.12	81.24	-0.28
SCIDD	1995	160,380	45,084	1,156	0	938	113,201	8.19	98.99	78.80	1.51
SCIDD	1996	148,218	50,621	1,776	0	1,021	94,801	10.13	100.07	80.37	-0.83
SCIDD	1997	137,363	62,389	3,722	16	637	70,598	7.43	99.63	80.83	0.09
SCIDD	1998	130,274	43,387	2,095	3,368	72	81,353	9.72	95.87	77.21	1.05
SCIDD	1999	98,223	51,966	7,742	4,773	276	33,466	7.48	96.52	78.29	-0.41
SCIDD	2000	102,691	64,320	8,509	7,312	275	22,274	6.09	99.78	80.86	-1.27
SCIDD	2001	103,171	47,537	2,001	3,971	135	49,526	9.72	97.55	80.60	0.79
SCIDD	2002	84,794	55,194	2,088	5,848	0	21,664	4.81	98.14	80.57	-1.28
SCIDD	2003	81,879	60,057	2,254	3,198	310	16,060	5.29	96.70	80.21	0.45
SCIDD	2004	86,118	57,272	10,992	2,787	1	15,065	8.89	97.21	80.65	1.55
SCIDD	2005	118,428	37,384	8,666	4,508	65	67,805	10.26	95.69	79.11	2.01
SCIDD	2006	83,782	37,464	4,728	3,402	21	38,168	7.14	95.28	79.96	-2.76
SCIDD	2007	116,839	39,680	9,170	5,299	0	62,689	9.31	96.95	81.04	0.08
SCIDD	2008	125,559	39,957	7,506	5,208	0	72,888	7.09	95.93	79.67	0.39
SCIDD	2009	104,574	39,000	8,372	5,821	33	51,348	3.47	97.19	81.04	-0.37
SCIDD	2010	110,960	31,112	6,757	6,447	0	66,644	9.56	95.26	79.08	1.13
SCIDD	2011	93,640	39,160	18,266	8,330	0	27,884	4.57	97.55	80.73	-2.58
TID	1994	15,957	10,246	6,549	-838	0	0	4.41	98.99	81.27	0
TID	1995	17,173	11,923	5,250	0	0	0	4.34	97.31	80.37	0
TID	1996	16,275	12,217	4,058	0	0	0	2.36	96.31	80.03	0
TID	1997	18,336	13,080	5,256	0	0	0	7.15	95.43	78.71	0
TID	1998	17,740	8,401	5,245	4,094	0	0	8.95	91.86	75.00	0
TID	1999	18,335	5,626	5,256	7,453	0	0	4.71	92.71	76.57	0
TID	2000	22,007	7,493	5,314	9,200	0	0	5.90	96.43	79.71	0
TID	2001	21,465	7,409	6,413	7,643	0	0	4.32	95.86	79.29	0
TID	2002	23,097	8,884	5,243	8,970	0	0	3.08	96.00	78.86	0
TID	2003	19,491	5,706	5,233	8,552	0	0	11.02	95.43	79.00	0
TID	2004	21,520	7,362	3,672	10,486	0	0	8.77	96.52	80.52	0
TID	2005	22,506	9,763	3,449	9,294	0	0	9.46	95.46	79.57	0
TID	2006	21,355	6,606	3,455	11,294	0	0	4.26	96.26	80.63	0
TID	2007	22,736	7,915	3,450	11,371	0	0	4.69	98.21	82.01	0
TID	2008	20,829	6,302	3,439	11,088	0	0	6.22	96.90	80.81	0
TID	2009	20,676	5,542	3,452	11,682	0	0	4.11	98.37	82.27	0
TID	2010	17,949	4,183	3,431	10,335	0	0	10.42	96.29	78.99	0
TID	2011	23,170	6,424	3,422	12,898	0	426	3.28	94.86	78.57	0
MWD	1994	63,667	23,347	5	0	247	40,068	7.42	95.71	81.86	-0.09
MWD	1995	76,787	27,008	47	0	436	49,295	8.16	94.00	80.29	1.19
MWD	1996	88,427	43,701	9,168	780	869	33,909	6.85	97.83	83.02	-1.81
MWD	1997	75,067	36,549	35,112	2,153	-185	1,438	7.22	96.29	82.43	-0.13
MWD	1998	62,227	22,362	9,957	11,582	-5	18,332	12.05	92.71	78.57	0.82
MWD	1999	59,983	21,584	0	12,652	1,303	24,444	2.44	93.14	79.29	-0.93
MWD	2000	55,140	17,262	321	17,106	400	20,050	9.81	96.43	82.71	-0.98
MWD	2001	55,404	18,288	0	17,705	731	18,679	6.69	95.86	81.71	-0.11
MWD	2002	55,213	23,247	4,017	12,365	784	14,799	3.28	96.14	81.71	-2.38
MWD	2003	44,766	16,761	9,304	10,545	162	7,995	10.78	94.71	80.57	0.24
MWD	2004	66,035	23,299	3,407	13,977	2,034	23,318	9.32	95.71	81.57	-0.13
MWD	2005	45,282	18,178	0	7,195	373	19,536	10.68	94.71	80.00	1.86
MWD	2006	43,117	19,310	0	6,629	10	17,168	2.51	94.43	80.86	-2.36
MWD	2007	33,073	11,745	0	4,168	11	17,148	4.94	96.14	81.71	-1.6
MWD	2008	41,530	16,364	0	9,392	10	15,764	6.66	95.00	79.71	0.25
MWD	2009	38,139	13,848	0	11,178	10	13,103	4.19	95.43	80.86	0.02
MWD	2010	31,019	8,797	2,661	9,237	92	10,232	10.47	94.54	81.24	0.52
MWD	2011	42,146	12,979	2,929	6,905	489	18,844	3.94	96.67	82.81	-0.57

District	Year	12mSPIApr	24mSPIApr	3mSPIAug	6mSPIAug	9mSPIOct	12mSPIDec	DistWaterCost
CAIDD	1994	0	0	-1.92	-0.41	0.05	0.36	38.00
CAIDD	1995	0	0	-0.35	0.03	0.01	0.31	39.00
CAIDD	1996	0	0	0.06	-0.56	-0.03	-0.87	38.00
CAIDD	1997	0	0	-0.36	-0.8	-0.73	-0.16	36.00
CAIDD	1998	0	0	-0.01	0.56	1.86	1.08	36.00
CAIDD	1999	0	0	1.24	0.94	0.53	-0.46	36.00
CAIDD	2000	0	0	-0.18	0.34	1.01	0.21	38.00
CAIDD	2001	0	0	-0.03	0.5	-0.07	0.14	37.00
CAIDD	2002	0	0	-1.73	-2.48	-2.05	-2.35	34.50
CAIDD	2003	0	0	-0.52	-0.49	0.36	-0.06	34.50
CAIDD	2004	0	0	-0.83	0.1	0.42	0.62	39.00
CAIDD	2005	0	0	0.57	0.14	0.99	0.7	42.00
CAIDD	2006	0	0	0.95	0.86	0.57	-0.32	43.00
CAIDD	2007	0	0	-0.11	-0.25	-0.87	-0.01	45.00
CAIDD	2008	0	0	0.96	0.26	-0.41	0.41	48.00
CAIDD	2009	0	0	-1.44	-1.64	-1.48	-1.91	51.00
CAIDD	2010	0	0	-0.18	-0.3	-0.13	0.6	52.50
CAIDD	2011	0	0	-0.79	-1.08	-1.27	-0.99	53.00
MSIDD	1994	0	0	-1.92	-0.41	0.05	0.36	40.00
MSIDD	1995	0	0	-0.35	0.03	0.01	0.31	42.50
MSIDD	1996	0	0	0.06	-0.56	-0.03	-0.87	42.50
MSIDD	1997	0	0	-0.36	-0.8	-0.73	-0.16	36.00
MSIDD	1998	0	0	-0.01	0.56	1.86	1.08	34.00
MSIDD	1999	0	0	1.24	0.94	0.53	-0.46	33.50
MSIDD	2000	0	0	-0.18	0.34	1.01	0.21	33.50
MSIDD	2001	0	0	-0.03	0.5	-0.07	0.14	34.50
MSIDD	2002	0	0	-1.73	-2.48	-2.05	-2.35	34.00
MSIDD	2003	0	0	-0.52	-0.49	0.36	-0.06	35.00
MSIDD	2004	0	0	-0.83	0.1	0.42	0.62	38.50
MSIDD	2005	0	0	0.57	0.14	0.99	0.7	41.00
MSIDD	2006	0	0	0.95	0.86	0.57	-0.32	41.00
MSIDD	2007	0	0	-0.11	-0.25	-0.87	-0.01	41.00
MSIDD	2008	0	0	0.96	0.26	-0.41	0.41	44.50
MSIDD	2009	0	0	-1.44	-1.64	-1.48	-1.91	45.50
MSIDD	2010	0	0	-0.18	-0.3	-0.13	0.6	45.50
MSIDD	2011	0	0	-0.79	-1.08	-1.27	-0.99	45.50
HID	1994	0.2	1.34	-1.92	-0.41	0.05	0.36	.
HID	1995	1	0.75	-0.35	0.03	0.01	0.31	.
HID	1996	-1.26	-0.09	0.06	-0.56	-0.03	-0.87	.
HID	1997	1.13	0.01	-0.36	-0.8	-0.73	-0.16	.
HID	1998	1.52	1.75	-0.01	0.56	1.86	1.08	.
HID	1999	0.01	1.03	1.24	0.94	0.53	-0.46	.
HID	2000	0.38	0.18	-0.18	0.34	1.01	0.21	.
HID	2001	0.6	0.57	-0.03	0.5	-0.07	0.14	.
HID	2002	-0.43	0.06	-1.73	-2.48	-2.05	-2.35	.
HID	2003	0.45	-0.04	-0.52	-0.49	0.36	-0.06	.
HID	2004	0.07	0.27	-0.83	0.1	0.42	0.62	.
HID	2005	0.92	0.61	0.57	0.14	0.99	0.7	.
HID	2006	-1.73	-0.39	0.95	0.86	0.57	-0.32	.
HID	2007	1.52	0.11	-0.11	-0.25	-0.87	-0.01	.
HID	2008	-0.03	1	0.96	0.26	-0.41	0.41	.
HID	2009	0.06	-0.06	-1.44	-1.64	-1.48	-1.91	.
HID	2010	0.73	0.47	-0.18	-0.3	-0.13	0.6	.
HID	2011	-1.15	-0.25	-0.79	-1.08	-1.27	-0.99	.
NMIDD	1994	0	0	-1.92	-0.41	0.05	0.36	35.00
NMIDD	1995	0	0	-0.35	0.03	0.01	0.31	35.00
NMIDD	1996	0	0	0.06	-0.56	-0.03	-0.87	37.00
NMIDD	1997	0	0	-0.36	-0.8	-0.73	-0.16	33.00
NMIDD	1998	0	0	-0.01	0.56	1.86	1.08	33.00
NMIDD	1999	0	0	1.24	0.94	0.53	-0.46	31.50
NMIDD	2000	0	0	-0.18	0.34	1.01	0.21	31.50
NMIDD	2001	0	0	-0.03	0.5	-0.07	0.14	31.50

District	Year	12mSPIApr	24mSPIApr	3mSPIAug	6mSPIAug	9mSPIOct	12mSPIDec	DistWaterCost
NMIDD	2002	0	0	-1.73	-2.48	-2.05	-2.35	32.50
NMIDD	2003	0	0	-0.52	-0.49	0.36	-0.06	34.00
NMIDD	2004	0	0	-0.83	0.1	0.42	0.62	32.00
NMIDD	2005	0	0	0.57	0.14	0.99	0.7	32.50
NMIDD	2006	0	0	0.95	0.86	0.57	-0.32	31.50
NMIDD	2007	0	0	-0.11	-0.25	-0.87	-0.01	30.50
NMIDD	2008	0	0	0.96	0.26	-0.41	0.41	30.50
NMIDD	2009	0	0	-1.44	-1.64	-1.48	-1.91	33.00
NMIDD	2010	0	0	-0.18	-0.3	-0.13	0.6	35.00
NMIDD	2011	0	0	-0.79	-1.08	-1.27	-0.99	35.00
RWCD	1994	-0.16	1.67	-1.92	-0.41	0.05	0.36	25.00
RWCD	1995	0.87	0.39	-0.35	0.03	0.01	0.31	25.00
RWCD	1996	-2.15	-0.43	0.06	-0.56	-0.03	-0.87	25.00
RWCD	1997	-0.22	-1.37	-0.36	-0.8	-0.73	-0.16	25.00
RWCD	1998	0.21	-0.16	-0.01	0.56	1.86	1.08	25.00
RWCD	1999	-1.05	-0.61	1.24	0.94	0.53	-0.46	15.00
RWCD	2000	-0.74	-1.27	-0.18	0.34	1.01	0.21	15.00
RWCD	2001	0.58	-0.16	-0.03	0.5	-0.07	0.14	15.00
RWCD	2002	-1.94	-0.64	-1.73	-2.48	-2.05	-2.35	17.50
RWCD	2003	-0.86	-1.76	-0.52	-0.49	0.36	-0.06	20.00
RWCD	2004	-0.83	-1.22	-0.83	0.1	0.42	0.62	20.00
RWCD	2005	1.27	0.4	0.57	0.14	0.99	0.7	25.00
RWCD	2006	-2.9	-0.18	0.95	0.86	0.57	-0.32	27.50
RWCD	2007	-0.7	-1.92	-0.11	-0.25	-0.87	-0.01	25.00
RWCD	2008	0.48	-0.22	0.96	0.26	-0.41	0.41	27.50
RWCD	2009	0.72	0.68	-1.44	-1.64	-1.48	-1.91	27.50
RWCD	2010	0.46	0.67	-0.18	-0.3	-0.13	0.6	27.50
RWCD	2011	-0.43	-0.09	-0.79	-1.08	-1.27	-0.99	20.00
HVID	1994	0	0	-1.92	-0.41	0.05	0.36	37.30
HVID	1995	0	0	-0.35	0.03	0.01	0.31	41.30
HVID	1996	0	0	0.06	-0.56	-0.03	-0.87	41.80
HVID	1997	0	0	-0.36	-0.8	-0.73	-0.16	39.50
HVID	1998	0	0	-0.01	0.56	1.86	1.08	42.70
HVID	1999	0	0	1.24	0.94	0.53	-0.46	39.50
HVID	2000	0	0	-0.18	0.34	1.01	0.21	36.00
HVID	2001	0	0	-0.03	0.5	-0.07	0.14	38.20
HVID	2002	0	0	-1.73	-2.48	-2.05	-2.35	38.60
HVID	2003	0	0	-0.52	-0.49	0.36	-0.06	39.80
HVID	2004	0	0	-0.83	0.1	0.42	0.62	31.00
HVID	2005	0	0	0.57	0.14	0.99	0.7	35.00
HVID	2006	0	0	0.95	0.86	0.57	-0.32	36.00
HVID	2007	0	0	-0.11	-0.25	-0.87	-0.01	38.20
HVID	2008	0	0	0.96	0.26	-0.41	0.41	39.00
HVID	2009	0	0	-1.44	-1.64	-1.48	-1.91	41.20
HVID	2010	0	0	-0.18	-0.3	-0.13	0.6	42.90
HVID	2011	0	0	-0.79	-1.08	-1.27	-0.99	45.10
QCID	1994	0	0	-1.92	-0.41	0.05	0.36	.
QCID	1995	0	0	-0.35	0.03	0.01	0.31	.
QCID	1996	0	0	0.06	-0.56	-0.03	-0.87	.
QCID	1997	0	0	-0.36	-0.8	-0.73	-0.16	.
QCID	1998	0	0	-0.01	0.56	1.86	1.08	.
QCID	1999	0	0	1.24	0.94	0.53	-0.46	.
QCID	2000	0	0	-0.18	0.34	1.01	0.21	.
QCID	2001	0	0	-0.03	0.5	-0.07	0.14	.
QCID	2002	0	0	-1.73	-2.48	-2.05	-2.35	.
QCID	2003	0	0	-0.52	-0.49	0.36	-0.06	.
QCID	2004	0	0	-0.83	0.1	0.42	0.62	.
QCID	2005	0	0	0.57	0.14	0.99	0.7	.
QCID	2006	0	0	0.95	0.86	0.57	-0.32	.
QCID	2007	0	0	-0.11	-0.25	-0.87	-0.01	.
QCID	2008	0	0	0.96	0.26	-0.41	0.41	.

District	Year	12mSPIApr	24mSPIApr	3mSPIAug	6mSPIAug	9mSPIOct	12mSPIDec	DistWaterCost
QCID	2009	0	0	-1.44	-1.64	-1.48	-1.91	.
QCID	2010	0	0	-0.18	-0.3	-0.13	0.6	.
QCID	2011	0	0	-0.79	-1.08	-1.27	-0.99	.
SCIDD	1994	0.2	1.34	-1.92	-0.41	0.05	0.36	.
SCIDD	1995	1	0.75	-0.35	0.03	0.01	0.31	.
SCIDD	1996	-1.26	-0.09	0.06	-0.56	-0.03	-0.87	.
SCIDD	1997	1.13	0.01	-0.36	-0.8	-0.73	-0.16	.
SCIDD	1998	1.52	1.75	-0.01	0.56	1.86	1.08	.
SCIDD	1999	0.01	1.03	1.24	0.94	0.53	-0.46	.
SCIDD	2000	0.38	0.18	-0.18	0.34	1.01	0.21	.
SCIDD	2001	0.6	0.57	-0.03	0.5	-0.07	0.14	.
SCIDD	2002	-0.43	0.06	-1.73	-2.48	-2.05	-2.35	.
SCIDD	2003	0.45	-0.04	-0.52	-0.49	0.36	-0.06	.
SCIDD	2004	0.07	0.27	-0.83	0.1	0.42	0.62	.
SCIDD	2005	0.92	0.61	0.57	0.14	0.99	0.7	.
SCIDD	2006	-1.73	-0.39	0.95	0.86	0.57	-0.32	.
SCIDD	2007	1.52	0.11	-0.11	-0.25	-0.87	-0.01	.
SCIDD	2008	-0.03	1	0.96	0.26	-0.41	0.41	.
SCIDD	2009	0.06	-0.06	-1.44	-1.64	-1.48	-1.91	.
SCIDD	2010	0.73	0.47	-0.18	-0.3	-0.13	0.6	.
SCIDD	2011	-1.15	-0.25	-0.79	-1.08	-1.27	-0.99	.
TID	1994	0	0	-1.92	-0.41	0.05	0.36	0.00
TID	1995	0	0	-0.35	0.03	0.01	0.31	32.75
TID	1996	0	0	0.06	-0.56	-0.03	-0.87	33.50
TID	1997	0	0	-0.36	-0.8	-0.73	-0.16	32.00
TID	1998	0	0	-0.01	0.56	1.86	1.08	32.00
TID	1999	0	0	1.24	0.94	0.53	-0.46	32.00
TID	2000	0	0	-0.18	0.34	1.01	0.21	32.00
TID	2001	0	0	-0.03	0.5	-0.07	0.14	32.00
TID	2002	0	0	-1.73	-2.48	-2.05	-2.35	32.00
TID	2003	0	0	-0.52	-0.49	0.36	-0.06	29.00
TID	2004	0	0	-0.83	0.1	0.42	0.62	29.00
TID	2005	0	0	0.57	0.14	0.99	0.7	29.00
TID	2006	0	0	0.95	0.86	0.57	-0.32	29.00
TID	2007	0	0	-0.11	-0.25	-0.87	-0.01	30.00
TID	2008	0	0	0.96	0.26	-0.41	0.41	20.00
TID	2009	0	0	-1.44	-1.64	-1.48	-1.91	25.00
TID	2010	0	0	-0.18	-0.3	-0.13	0.6	30.00
TID	2011	0	0	-0.79	-1.08	-1.27	-0.99	30.00
MWD	1994	-0.45	1.45	-1.92	-0.41	0.05	0.36	40
MWD	1995	0.83	0.18	-0.35	0.03	0.01	0.31	30
MWD	1996	-1.81	-0.34	0.06	-0.56	-0.03	-0.87	30
MWD	1997	-0.33	-1.34	-0.36	-0.8	-0.73	-0.16	38
MWD	1998	0.78	0.2	-0.01	0.56	1.86	1.08	41.5
MWD	1999	-0.11	0.32	1.24	0.94	0.53	-0.46	38
MWD	2000	0.05	-0.22	-0.18	0.34	1.01	0.21	36
MWD	2001	0.42	0.15	-0.03	0.5	-0.07	0.14	36
MWD	2002	-2.68	-0.91	-1.73	-2.48	-2.05	-2.35	30
MWD	2003	-0.19	-1.44	-0.52	-0.49	0.36	-0.06	30
MWD	2004	-0.55	-0.66	-0.83	0.1	0.42	0.62	28
MWD	2005	1.7	0.94	0.57	0.14	0.99	0.7	28
MWD	2006	-2.36	0.43	0.95	0.86	0.57	-0.32	28
MWD	2007	-0.91	-1.91	-0.11	-0.25	-0.87	-0.01	28
MWD	2008	-0.07	-0.77	0.96	0.26	-0.41	0.41	28
MWD	2009	-0.18	-0.35	-1.44	-1.64	-1.48	-1.91	28
MWD	2010	-0.28	-0.49	-0.18	-0.3	-0.13	0.6	30
MWD	2011	-0.46	-0.67	-0.79	-1.08	-1.27	-0.99	32

District	Year	ExpCTNPrice	ActCTNPrice	ALFPrice	WHTPrice	BARPrice	CRNPrice	GDP_IPD
CAIDD	1994	0.670	0.706	103.000	4.340	2.850	3.250	79.935
CAIDD	1995	0.714	0.729	79.000	4.710	2.950	3.700	81.603
CAIDD	1996	0.647	0.697	95.000	5.000	3.550	3.650	83.154
CAIDD	1997	0.723	0.647	112.000	4.700	2.900	3.200	84.624
CAIDD	1998	0.651	0.547	89.500	4.500	2.450	2.750	85.579
CAIDD	1999	0.601	0.439	89.000	4.000	2.400	2.720	86.837
CAIDD	2000	0.626	0.397	94.000	3.500	2.420	2.780	88.718
CAIDD	2001	0.433	0.284	99.000	3.950	2.400	2.790	90.726
CAIDD	2002	0.555	0.463	100.000	4.400	2.550	3.140	92.194
CAIDD	2003	0.613	0.664	89.500	4.650	2.840	3.280	94.128
CAIDD	2004	0.623	0.444	99.500	4.250	2.800	3.030	96.779
CAIDD	2005	0.590	0.516	124.000	4.200	2.750	3.180	99.993
CAIDD	2006	0.624	0.499	130.000	4.850	3.200	4.370	103.228
CAIDD	2007	0.593	0.596	151.000	7.110	4.000	5.030	106.222
CAIDD	2008	0.771	0.585	185.000	8.340	4.800	5.800	108.589
CAIDD	2009	0.656	0.651	121.000	8.640	3.740	4.140	109.529
CAIDD	2010	0.713	0.855	129.000	5.610	3.820	5.800	110.989
CAIDD	2011	0.917	0.876	225.000	8.500	4.860	6.780	113.355
MSIDD	1994	0.670	0.706	103.000	4.340	2.850	3.250	79.935
MSIDD	1995	0.714	0.729	79.000	4.710	2.950	3.700	81.603
MSIDD	1996	0.647	0.697	95.000	5.000	3.550	3.650	83.154
MSIDD	1997	0.723	0.647	112.000	4.700	2.900	3.200	84.624
MSIDD	1998	0.651	0.547	89.500	4.500	2.450	2.750	85.579
MSIDD	1999	0.601	0.439	89.000	4.000	2.400	2.720	86.837
MSIDD	2000	0.626	0.397	94.000	3.500	2.420	2.780	88.718
MSIDD	2001	0.433	0.284	99.000	3.950	2.400	2.790	90.726
MSIDD	2002	0.555	0.463	100.000	4.400	2.550	3.140	92.194
MSIDD	2003	0.613	0.664	89.500	4.650	2.840	3.280	94.128
MSIDD	2004	0.623	0.444	99.500	4.250	2.800	3.030	96.779
MSIDD	2005	0.590	0.516	124.000	4.200	2.750	3.180	99.993
MSIDD	2006	0.624	0.499	130.000	4.850	3.200	4.370	103.228
MSIDD	2007	0.593	0.596	151.000	7.110	4.000	5.030	106.222
MSIDD	2008	0.771	0.585	185.000	8.340	4.800	5.800	108.589
MSIDD	2009	0.656	0.651	121.000	8.640	3.740	4.140	109.529
MSIDD	2010	0.713	0.855	129.000	5.610	3.820	5.800	110.989
MSIDD	2011	0.917	0.876	225.000	8.500	4.860	6.780	113.355
HID	1994	0.670	0.706	103.000	4.340	2.850	3.250	79.935
HID	1995	0.714	0.729	79.000	4.710	2.950	3.700	81.603
HID	1996	0.647	0.697	95.000	5.000	3.550	3.650	83.154
HID	1997	0.723	0.647	112.000	4.700	2.900	3.200	84.624
HID	1998	0.651	0.547	89.500	4.500	2.450	2.750	85.579
HID	1999	0.601	0.439	89.000	4.000	2.400	2.720	86.837
HID	2000	0.626	0.397	94.000	3.500	2.420	2.780	88.718
HID	2001	0.433	0.284	99.000	3.950	2.400	2.790	90.726
HID	2002	0.555	0.463	100.000	4.400	2.550	3.140	92.194
HID	2003	0.613	0.664	89.500	4.650	2.840	3.280	94.128
HID	2004	0.623	0.444	99.500	4.250	2.800	3.030	96.779
HID	2005	0.590	0.516	124.000	4.200	2.750	3.180	99.993
HID	2006	0.624	0.499	130.000	4.850	3.200	4.370	103.228
HID	2007	0.593	0.596	151.000	7.110	4.000	5.030	106.222
HID	2008	0.771	0.585	185.000	8.340	4.800	5.800	108.589
HID	2009	0.656	0.651	121.000	8.640	3.740	4.140	109.529
HID	2010	0.713	0.855	129.000	5.610	3.820	5.800	110.989
HID	2011	0.917	0.876	225.000	8.500	4.860	6.780	113.355
NMIDD	1994	0.670	0.706	103.000	4.340	2.850	3.250	79.935
NMIDD	1995	0.714	0.729	79.000	4.710	2.950	3.700	81.603
NMIDD	1996	0.647	0.697	95.000	5.000	3.550	3.650	83.154
NMIDD	1997	0.723	0.647	112.000	4.700	2.900	3.200	84.624
NMIDD	1998	0.651	0.547	89.500	4.500	2.450	2.750	85.579
NMIDD	1999	0.601	0.439	89.000	4.000	2.400	2.720	86.837
NMIDD	2000	0.626	0.397	94.000	3.500	2.420	2.780	88.718
NMIDD	2001	0.433	0.284	99.000	3.950	2.400	2.790	90.726

District	Year	ExpCTNPrice	ActCTNPrice	ALFPrice	WHTPrice	BARPrice	CRNPrice	GDP_IPD
NMIDD	2002	0.555	0.463	100.000	4.400	2.550	3.140	92.194
NMIDD	2003	0.613	0.664	89.500	4.650	2.840	3.280	94.128
NMIDD	2004	0.623	0.444	99.500	4.250	2.800	3.030	96.779
NMIDD	2005	0.590	0.516	124.000	4.200	2.750	3.180	99.993
NMIDD	2006	0.624	0.499	130.000	4.850	3.200	4.370	103.228
NMIDD	2007	0.593	0.596	151.000	7.110	4.000	5.030	106.222
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NMIDD	2010	0.713	0.855	129.000	5.610	3.820	5.800	110.989
NMIDD	2011	0.917	0.876	225.000	8.500	4.860	6.780	113.355
RWCD	1994	0.670	0.706	103.000	4.340	2.850	3.250	79.935
RWCD	1995	0.714	0.729	79.000	4.710	2.950	3.700	81.603
RWCD	1996	0.647	0.697	95.000	5.000	3.550	3.650	83.154
RWCD	1997	0.723	0.647	112.000	4.700	2.900	3.200	84.624
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RWCD	2000	0.626	0.397	94.000	3.500	2.420	2.780	88.718
RWCD	2001	0.433	0.284	99.000	3.950	2.400	2.790	90.726
RWCD	2002	0.555	0.463	100.000	4.400	2.550	3.140	92.194
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HVID	2011	0.917	0.876	225.000	8.500	4.860	6.780	113.355
QCID	1994	0.670	0.706	103.000	4.340	2.850	3.250	79.935
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QCID	2009	0.656	0.651	121.000	8.640	3.740	4.140	109.529
QCID	2010	0.713	0.855	129.000	5.610	3.820	5.800	110.989
QCID	2011	0.917	0.876	225.000	8.500	4.860	6.780	113.355
SCIDD	1994	0.670	0.706	103.000	4.340	2.850	3.250	79.935
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TID	1994	0.670	0.706	103.000	4.340	2.850	3.250	79.935
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MWD	2009	0.656	0.651	121.000	8.640	3.740	4.140	109.529
MWD	2010	0.713	0.855	129.000	5.610	3.820	5.800	110.989
MWD	2011	0.917	0.876	225.000	8.500	4.860	6.780	113.355

District	Year	CityPop	CountyPop	PHXHStarts	DairyCows	InactiveIGFR	InactIGFRper	AcresPlant
CAIDD	1994	7,582	135,979	0	9,000	0	0.0000	0
CAIDD	1995	8,767	143,933	0	9,000	0	0.0000	227,513
CAIDD	1996	8,854	150,167	0	9,000	0	0.0000	251,997
CAIDD	1997	9,033	157,651	0	8,000	459	0.0052	214,723
CAIDD	1998	9,936	166,381	0	11,000	459	0.0052	206,415
CAIDD	1999	10,244	175,626	0	12,000	459	0.0052	185,955
CAIDD	2000	10,421	182,435	0	14,000	459	0.0052	183,800
CAIDD	2001	10,526	186,844	0	13,000	459	0.0052	200,300
CAIDD	2002	10,533	190,881	0	14,000	459	0.0052	192,100
CAIDD	2003	10,407	204,075	0	21,000	459	0.0052	188,300
CAIDD	2004	10,216	219,048	0	17,000	459	0.0052	198,200
CAIDD	2005	10,480	250,195	0	48,000	459	0.0052	198,700
CAIDD	2006	10,701	304,889	0	48,000	610	0.0070	197,500
CAIDD	2007	12,781	333,977	0	59,000	1236	0.0141	204,300
CAIDD	2008	14,620	358,190	0	65,000	1236	0.0141	226,200
CAIDD	2009	17,003	364,995	0	70,000	1236	0.0141	228,479
CAIDD	2010	16,657	376,369	0	60,000	1236	0.0141	214,912
CAIDD	2011	17,151	384,231	0	65,000	1236	0.0141	236,662
MSIDD	1994	1,118	135,979	0	9,000	0	0.0000	0
MSIDD	1995	1,376	143,933	0	9,000	0	0.0000	227,513
MSIDD	1996	1,579	150,167	0	9,000	0	0.0000	251,997
MSIDD	1997	1,823	157,651	0	8,000	0	0.0000	214,723
MSIDD	1998	2,107	166,381	0	11,000	0	0.0000	206,415
MSIDD	1999	2,407	175,626	0	12,000	300.07	0.0035	185,955
MSIDD	2000	2,629	182,435	0	14,000	300.07	0.0035	183,800
MSIDD	2001	3,130	186,844	0	13,000	300.07	0.0035	200,300
MSIDD	2002	3,589	190,881	0	14,000	300.07	0.0035	192,100
MSIDD	2003	5,088	204,075	0	21,000	300.07	0.0035	188,300
MSIDD	2004	5,814	219,048	0	17,000	519.47	0.0060	198,200
MSIDD	2005	10,087	250,195	0	48,000	2245.17	0.0259	198,700
MSIDD	2006	26,661	304,889	0	48,000	3952.17	0.0456	197,500
MSIDD	2007	33,336	333,977	0	59,000	7247.78	0.0837	204,300
MSIDD	2008	38,794	358,190	0	65,000	7327.78	0.0846	226,200
MSIDD	2009	41,309	364,995	0	70,000	7327.78	0.0846	228,479
MSIDD	2010	43,598	376,369	0	60,000	7327.78	0.0846	214,912
MSIDD	2011	44,450	384,231	0	65,000	7327.78	0.0846	236,662
HID	1994	7,204	135,979	0	9,000	0	0.0000	0
HID	1995	7,259	143,933	0	9,000	0	0.0000	227,513
HID	1996	7,376	150,167	0	9,000	0	0.0000	251,997
HID	1997	7,426	157,651	0	8,000	0	0.0000	214,723
HID	1998	7,542	166,381	0	11,000	0	0.0000	206,415
HID	1999	7,742	175,626	0	12,000	0	0.0000	185,955
HID	2000	7,921	182,435	0	14,000	0	0.0000	183,800
HID	2001	8,002	186,844	0	13,000	0	0.0000	200,300
HID	2002	8,253	190,881	0	14,000	0	0.0000	192,100
HID	2003	8,263	204,075	0	21,000	0	0.0000	188,300
HID	2004	8,260	219,048	0	17,000	0	0.0000	198,200
HID	2005	8,182	250,195	0	48,000	0	0.0000	198,700
HID	2006	9,914	304,889	0	48,000	0	0.0000	197,500
HID	2007	11,662	333,977	0	59,000	421.91	0.0156	204,300
HID	2008	12,236	358,190	0	65,000	421.91	0.0156	226,200
HID	2009	12,089	364,995	0	70,000	521.91	0.0192	228,479
HID	2010	11,855	376,369	0	60,000	521.91	0.0192	214,912
HID	2011	12,014	384,231	0	65,000	521.91	0.0192	236,662
NMIDD	1994	1,131	135,979	0	9,000	30.13	0.0011	0
NMIDD	1995	1,395	143,933	0	9,000	30.13	0.0011	227,513
NMIDD	1996	1,602	150,167	0	9,000	30.13	0.0011	251,997
NMIDD	1997	1,851	157,651	0	8,000	30.13	0.0011	214,723
NMIDD	1998	2,141	166,381	0	11,000	41.94	0.0015	206,415
NMIDD	1999	2,448	175,626	0	12,000	41.94	0.0015	185,955
NMIDD	2000	2,674	182,435	0	14,000	41.94	0.0015	183,800
NMIDD	2001	4,526	186,844	0	13,000	43.94	0.0015	200,300

District	Year	CityPop	CountyPop	PHXHStarts	DairyCows	InactiveIGFR	InactIGFRper	AcresPlant
NMIDD	2002	6,712	190,881	0	14,000	43.94	0.0015	192,100
NMIDD	2003	13,724	204,075	0	21,000	420.64	0.0147	188,300
NMIDD	2004	27,516	219,048	0	17,000	480.77	0.0168	198,200
NMIDD	2005	43,651	250,195	0	48,000	548	0.0192	198,700
NMIDD	2006	54,568	304,889	0	48,000	1125.22	0.0393	197,500
NMIDD	2007	65,755	333,977	0	59,000	1966.86	0.0688	204,300
NMIDD	2008	73,493	358,190	0	65,000	2179	0.0762	226,200
NMIDD	2009	79,505	364,995	0	70,000	2189	0.0765	228,479
NMIDD	2010	81,321	376,369	0	60,000	2581.9	0.0903	214,912
NMIDD	2011	83,689	384,231	0	65,000	3175.23	0.1110	236,662
RWCD	1994	49,039	2,390,508	4,324	91,000	305.76	0.0103	0
RWCD	1995	55,721	2,498,964	6,729	100,000	359.58	0.0121	227,513
RWCD	1996	68,561	2,690,974	9,195	103,000	558.72	0.0189	251,997
RWCD	1997	80,838	2,787,690	11,845	108,000	1505.02	0.0508	214,723
RWCD	1998	93,313	2,884,939	14,869	112,000	2634.63	0.0889	206,415
RWCD	1999	103,368	3,004,604	18,030	112,000	3003.64	0.1014	185,955
RWCD	2000	111,250	3,092,927	20,827	115,000	3529.96	0.1191	183,800
RWCD	2001	120,447	3,173,219	23,630	116,000	4395.05	0.1483	200,300
RWCD	2002	129,864	3,261,203	26,979	119,000	6894.98	0.2327	192,100
RWCD	2003	145,758	3,353,875	30,839	125,000	8757.93	0.2956	188,300
RWCD	2004	156,412	3,466,592	35,488	130,000	9668.57	0.3263	198,200
RWCD	2005	166,919	3,577,074	39,791	105,000	10293.67	0.3474	198,700
RWCD	2006	179,602	3,663,915	42,668	105,000	11398.27	0.3847	197,500
RWCD	2007	196,602	3,753,413	44,736	100,000	12012.24	0.4054	204,300
RWCD	2008	206,264	3,808,829	45,655	100,000	12646.02	0.4268	226,200
RWCD	2009	207,783	3,821,136	46,391	100,000	12912.56	0.4358	228,479
RWCD	2010	208,453	3,824,058	47,006	90,000	13374.8	0.4514	214,912
RWCD	2011	213,519	3,843,370	47,637	98,000	14865.33	0.5017	236,662
HVID	1994	60	2,390,508	0	91,000	0	0.0000	0
HVID	1995	60	2,498,964	0	100,000	0	0.0000	227,513
HVID	1996	60	2,690,974	0	103,000	0	0.0000	251,997
HVID	1997	60	2,787,690	0	108,000	0	0.0000	214,723
HVID	1998	60	2,884,939	0	112,000	0	0.0000	206,415
HVID	1999	60	3,004,604	0	112,000	0	0.0000	185,955
HVID	2000	60	3,092,927	0	115,000	0	0.0000	183,800
HVID	2001	60	3,173,219	0	116,000	0	0.0000	200,300
HVID	2002	60	3,261,203	0	119,000	0	0.0000	192,100
HVID	2003	60	3,353,875	0	125,000	0	0.0000	188,300
HVID	2004	60	3,466,592	0	130,000	0	0.0000	198,200
HVID	2005	60	3,577,074	0	105,000	0	0.0000	198,700
HVID	2006	60	3,663,915	0	105,000	0	0.0000	197,500
HVID	2007	60	3,753,413	0	100,000	0	0.0000	204,300
HVID	2008	60	3,808,829	0	100,000	0	0.0000	226,200
HVID	2009	60	3,821,136	0	100,000	0	0.0000	228,479
HVID	2010	60	3,824,058	0	90,000	0	0.0000	214,912
HVID	2011	60	3,843,370	0	98,000	0	0.0000	236,662
QCID	1994	3,046	2,390,508	4,324	91,000	0	0.0000	0
QCID	1995	3,207	2,498,964	6,729	100,000	0	0.0000	227,513
QCID	1996	3,380	2,690,974	9,195	103,000	79	0.0044	251,997
QCID	1997	3,550	2,787,690	11,845	108,000	448.88	0.0252	214,723
QCID	1998	3,777	2,884,939	14,869	112,000	624.59	0.0351	206,415
QCID	1999	4,023	3,004,604	18,030	112,000	647.42	0.0363	185,955
QCID	2000	4,420	3,092,927	20,827	115,000	1273.8	0.0715	183,800
QCID	2001	4,939	3,173,219	23,630	116,000	1415.38	0.0794	200,300
QCID	2002	5,551	3,261,203	26,979	119,000	1888.18	0.1060	192,100
QCID	2003	7,515	3,353,875	30,839	125,000	2701.44	0.1516	188,300
QCID	2004	11,378	3,466,592	35,488	130,000	2906.05	0.1631	198,200
QCID	2005	15,897	3,577,074	39,791	105,000	3003.1	0.1685	198,700
QCID	2006	18,955	3,663,915	42,668	105,000	4694.81	0.2635	197,500
QCID	2007	22,088	3,753,413	44,736	100,000	4966.13	0.2787	204,300
QCID	2008	24,255	3,808,829	45,655	100,000	5722.61	0.3212	226,200

District	Year	CityPop	CountyPop	PHXHStarts	DairyCows	InactiveIGFR	InactIGFRper	AcresPlant
QCID	2009	25,939	3,821,136	46,391	100,000	6082.18	0.3413	228,479
QCID	2010	26,448	3,824,058	47,006	90,000	6598.89	0.3703	214,912
QCID	2011	27,218	3,843,370	47,637	98,000	6972.95	0.3913	236,662
SCIDD	1994	9,517	135,979	0	9,000	0	0.0000	0
SCIDD	1995	12,547	143,933	0	9,000	0	0.0000	227,513
SCIDD	1996	12,863	150,167	0	9,000	0	0.0000	251,997
SCIDD	1997	14,664	157,651	0	8,000	0	0.0000	214,723
SCIDD	1998	15,945	166,381	0	11,000	0	0.0000	206,415
SCIDD	1999	16,929	175,626	0	12,000	21	0.0004	185,955
SCIDD	2000	17,050	182,435	0	14,000	21	0.0004	183,800
SCIDD	2001	17,075	186,844	0	13,000	21	0.0004	200,300
SCIDD	2002	14,318	190,881	0	14,000	21	0.0004	192,100
SCIDD	2003	16,731	204,075	0	21,000	170.83	0.0032	188,300
SCIDD	2004	16,686	219,048	0	17,000	170.83	0.0032	198,200
SCIDD	2005	19,776	250,195	0	48,000	177.83	0.0034	198,700
SCIDD	2006	20,288	304,889	0	48,000	611.33	0.0115	197,500
SCIDD	2007	20,700	333,977	0	59,000	1429.79	0.0269	204,300
SCIDD	2008	22,574	358,190	0	65,000	2502.21	0.0472	226,200
SCIDD	2009	24,001	364,995	0	70,000	2502.21	0.0472	228,479
SCIDD	2010	25,537	376,369	0	60,000	2502.21	0.0472	214,912
SCIDD	2011	25,971	384,231	0	65,000	2502.21	0.0472	236,662
TID	1994	60	2,390,508	0	91,000	0	0.0000	0
TID	1995	60	2,498,964	0	100,000	0	0.0000	265,463
TID	1996	60	2,690,974	0	103,000	0	0.0000	279,784
TID	1997	60	2,787,690	0	108,000	0	0.0000	262,415
TID	1998	60	2,884,939	0	112,000	0	0.0000	229,073
TID	1999	60	3,004,604	0	112,000	0	0.0000	199,776
TID	2000	60	3,092,927	0	115,000	78.6	0.0218	204,000
TID	2001	60	3,173,219	0	116,000	78.6	0.0218	199,400
TID	2002	60	3,261,203	0	119,000	78.6	0.0218	177,600
TID	2003	60	3,353,875	0	125,000	78.6	0.0218	174,200
TID	2004	60	3,466,592	0	130,000	78.6	0.0218	182,800
TID	2005	60	3,577,074	0	105,000	78.6	0.0218	176,000
TID	2006	60	3,663,915	0	105,000	293.6	0.0816	157,500
TID	2007	60	3,753,413	0	100,000	293.6	0.0816	147,000
TID	2008	60	3,808,829	0	100,000	293.6	0.0816	167,000
TID	2009	60	3,821,136	0	100,000	293.6	0.0816	165,255
TID	2010	60	3,824,058	0	90,000	293.6	0.0816	161,015
TID	2011	60	3,843,370	0	98,000	293.6	0.0816	177,496
MWD	1994	9,431	2,390,508	4,324	91,000	0	0.0000	0
MWD	1995	10,457	2,498,964	6,729	100,000	0	0.0000	265,463
MWD	1996	11,262	2,690,974	9,195	103,000	283.04	0.0116	279,784
MWD	1997	14,168	2,787,690	11,845	108,000	1131.34	0.0462	262,415
MWD	1998	18,673	2,884,939	14,869	112,000	1600.81	0.0654	229,073
MWD	1999	25,903	3,004,604	18,030	112,000	2336.94	0.0954	199,776
MWD	2000	32,667	3,092,927	20,827	115,000	2434.67	0.0994	204,000
MWD	2001	39,628	3,173,219	23,630	116,000	2605.53	0.1064	199,400
MWD	2002	47,739	3,261,203	26,979	119,000	3553.04	0.1451	177,600
MWD	2003	56,259	3,353,875	30,839	125,000	4922.76	0.2010	174,200
MWD	2004	71,328	3,466,592	35,488	130,000	6465.36	0.2640	182,800
MWD	2005	89,488	3,577,074	39,791	105,000	6618.84	0.2702	176,000
MWD	2006	102,901	3,663,915	42,668	105,000	8521.86	0.3479	157,500
MWD	2007	110,741	3,753,413	44,736	100,000	9570.15	0.3907	147,000
MWD	2008	115,626	3,808,829	45,655	100,000	10210.58	0.4169	167,000
MWD	2009	117,230	3,821,136	46,391	100,000	10210.58	0.4169	165,255
MWD	2010	117,688	3,824,058	47,006	90,000	10311.42	0.4210	161,015
MWD	2011	118,349	3,843,370	47,637	98,000	11536.49	0.4710	177,496

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