Agricultural Water Use and the 1980 Groundwater Management Act:

Institutional Change and Water Conservation in South-Central Arizona, USA

by

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ABSTRACT

Present day human societies face many challenges in effectively managing resources that exhibit characteristics of "common-pool resources" (CPR), of which groundwater is a critical example. CPRs consist of natural or man-made resource systems from which it is difficult to exclude resources users, and where one person's use impacts another's. Scholars also incorporate CPRs into the broader study of social-ecological systems (SESs), placing emphasis on the role of proper and improper institutions in pushing SESs towards sustainability or collapse. Institutions are the rules-in-use that shape human action. The seminal 1980 Groundwater Management Act (GMA) in Arizona, USA is an institution designed to curb groundwater overdraft through a combination of conservation strategies, augmentation and supply development, and reduction in agricultural water use through strict prohibition of its expansion in designated areas. Today, with urbanization pressures and the halting of agricultural expansion, agriculture uses less water on the whole than in 1980. However, in spite of the conservation and efficiency regulations imposed on agriculture by the GMA, on a per-acre basis, agriculture's water consumption is stable. Employing an analytical framework used to evaluate the contribution of institutions to the maintenance of SESs, this thesis examines: a) the original institutional design and process of institutional change within the GMA, b) how institutional change affects resource users' response to signals of water scarcity, and c) how to increase water conservation on farms. Results from the institutional analysis indicate there was insufficient time to incorporate farmers' existing knowledge about water efficiency into the Act. Thus, after 1980, farmers fought against the regulations of the GMA in order to increase their water use flexibility. The thesis concludes with findings collected from primary data interviews concerning ways to increase water conservation on farms. Suggestions include: a greater understanding of the temporary nature of central Arizona agriculture in providing incentives to boost water conservation, the promotion of currently available incentives to invest in water conservation, and increased farmer education about water-saving practices.

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Chapter 1

Introduction

Present-day human societies face various challenges in effectively managing water resources given limited supplies and increasing populations. One such challenge is to design policies, regulations, and rules—collectively known as institutions (Ostrom, 2005)—in a manner compatible with the human and environmental context they seek to regulate. Examining the institutions governing groundwater in the Southwestern United States offers a glimpse into the challenge of achieving successful, long-term management of water resources in an arid environment with high population growth. “The allocation, use, and protection of water resources are among the West’s most important political and public policy issues” (Blomquist, Schlager, & Heikkila, 2004). Surface water and groundwater alike quench the West’s growing thirst. To narrow the scope of this study, I focus on groundwater.

One specific challenge arises when water resources, such as groundwater, exhibit characteristics of common-pool resources (CPRs). Common-pool resources consist of natural or man-made resource systems from which it is difficult to exclude resources users (Ostrom 1990). With CPR systems, one person’s use of a resource unit impacts another’s use by making that resource unit unavailable to others (Ostrom, 1990). Groundwater basins are an example of CPR systems, and the focus of this study. Scholars also incorporate CPRs into the broader study of social-ecological systems (SESs). “All humanly used resources are embedded in complex, social-ecological systems” (Ostrom, 2009, p. 419). Thus, SESs are ecological systems that are closely linked to and impacted by a social system (Anderies et al., 2004). Scholars emphasize the impact that proper and improper institutions, in combination with various physical and socioeconomic variables, can have in affecting the long-term performance of SESs (Ostrom, 2009; Shivakoti & Ostrom, 2002). Institutions are the formal and informal rules-in-use that guide and shape human action (Lam, 2006; Adger, Brown, & Fairbrass 2003).

One way to examine the impact of institutions on the long-term performance of an SES is through the lens of the Institutional Analysis and Development (IAD) framework (Ostrom, 2005). Employed as a way to develop structure across different case studies concerning human-environment interactions (Shivakoti & Ostrom, 2002), I use the IAD framework to highlight how a specific groundwater management policy in Arizona, USA was originally designed to reduce groundwater overdraft, a frequent dilemma in groundwater basin CPR systems. Overdraft occurs when the amount of groundwater removed from a basin exceeds the amount of water being restored; this is also referred to as exceeding safe yield or groundwater mining (Blomquist, 1992).

To stem its problem with groundwater mining, the state of Arizona passed the Groundwater Management Act (GMA) in 1980. The GMA was intended to curb groundwater overdraft through a combination of conservation strategies, augmentation and supply development, and reduction in agricultural water use through strict prohibition of its expansion in designated areas (Arizona Department of Water Resources [ADWR], 2004). Employing the IAD framework allows for a schematic representation of the variables included in the GMA that Ostrom (2009) identifies as important for achieving long-term performance of an SES. In this case study, the SES of concern encompasses two regulated groundwater basins in south-central Arizona. I use the IAD framework to draw out what variables are included and excluded from the GMA, and to discuss the implications of this institutional design for agricultural water conservation. To narrow the scope of the study, I focus on groundwater use by the agricultural sector of south-central Arizona.

Chapter 2

Research Questions

The Groundwater Management Act attempted to curb groundwater overdraft by regulating groundwater use by the municipal, industrial, and agricultural sectors (ADWR, 2004). I focus on the impacts of the GMA on agricultural water use. Thus, four main questions arise:

1. How is the 1980 GMA designed to address emerging concerns of groundwater resource scarcity in south-central Arizona?
2. How has the institutional design of the GMA affected the perceived needs of agricultural groundwater users, and how have the agricultural groundwater users impacted the institutional design of the GMA?
3. What are the implications of this process of institutional change for achieving water conservation in the agricultural sector?
4. What do farmers and experts in water and agriculture view as potential means for enhancing water conservation on farms in south-central Arizona?

Chapter 3

Methods And Overview

Theoretical Framework

To answer the research questions, I employ a state-of-the-art analytical framework. The Institutional Analysis and Development framework (Ostrom, 2005), as well as subsequent refinements (Ostrom, 2007; Ostrom, 2009), provides a theoretical framework through which to view the impacts of the GMA on agricultural water use and water users. Identifying what system characteristics lead to the successful or unsuccessful resource management of common-pool resource systems has been an important area of study for many scholars (Ostrom & Field, 1999; Lam, 1998; Ostrom, 1999; Anderies, 2006; Agrawal, 2007). A common-pool resource (CPR) is a "natural or man-made resource system that is sufficiently large so as to make it costly (but not impossible) to exclude potential beneficiaries from obtaining benefits from its use" (Ostrom, 1990, p. 30). By focusing attention on the specific attributes of the SES, specifically those relevant to the resource units, resource system, resource users, and governance system—what Ostrom (2009) calls "first-level core subsystems" (p. 421)—scholars attempt to organize findings in a systematic way so that knowledge of various SESs might accumulate (Shivakoti & Ostrom, 2002). Additionally, through accumulated knowledge of different case studies, scholars attempt to compare and contrast institutional arrangements across geographic, physical, and cultural characteristics to develop principles to guide interventions in SESs so as to improve their long-term performance (Anderies, Walker, & Kinzig, 2006).

The IAD is used to outline the variables included and excluded from the GMA as they pertain to agriculture. Like other scholarly work examining the effects of institutional change on the maintenance of SESs (Blomquist, 1992; Anderies, 2006), I focus on the 1980 Groundwater Management Act and its ensuing provisions to better understand how institutions and institutional change can impact resource unit abundance in the short and long-term, and the social and ecological consequences of these impacts.

Considering that better institutions may enhance economic performance and increase robustness to resource fluctuations for resource users, it is important to remember that in implementing new institutions or changing existing ones, new action situations result, and may generate new (often unforeseen) vulnerabilities (Anderies, 2006, p. 136). No institutional intervention will ever be perfect, so it is important to consider potential outcomes. Although in this thesis I do ultimately posit some suggestions to achieve increased per-acre water conservation on farms, I do so in awareness that there are often unintended consequences that cannot be fully predicted.

Based on the analysis of variables included in the GMA indicated by Ostrom (2009) to be important for the sustainability of SESs, I argue that by not accounting for variables specifically pertaining to the "Users" (Figure 1) in the development of the GMA, the users (farmers) regulated by the provisions of the law perceived a mismatch between costs incurred and benefits gained under the new regulations. In other words, the new regulations attempted to reduce the amount of water farmers could use over time. Because the overall benefit of reducing overdraft was not readily or quickly experienced by farmers, they lobbied for and won amendments to the GMA after its 1980 passage that achieved greater flexibility in how they could use groundwater. These amendments will be outlined and discussed in detail in a subsequent section. The amendments gained by farmers increased their water use flexibility in the short-term. This flexibility can also be viewed as increased short-term robustness to shocks such as climate extremes (e.g. high temperature, low rainfall) and market fluctuations (e.g. ability to plant a more water intensive crop if the agricultural market demands it). Nevertheless, the amendments generate a trade-off: farmers gain flexibility in their water use, but do not change the amount of water they use per-acre, even though one of the original intents of the Act was to increase water conservation by the sector (Needham & Wilson, 2005).

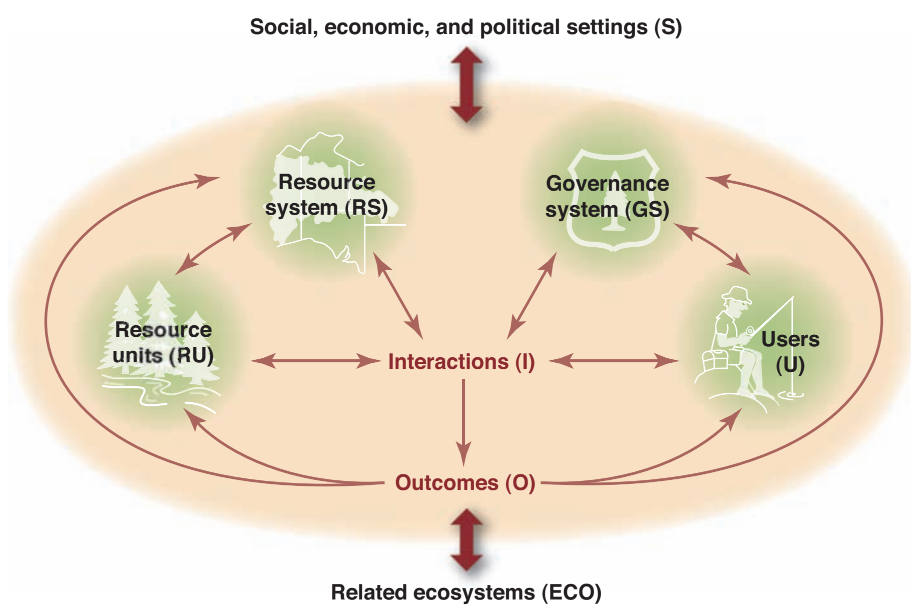

Figure 1. Core subsystems of Social-Ecological Systems (Ostrom, 2009, p. 420).

Interpreting the case in the context of the framework. After utilizing the IAD framework to demonstrate which variables were included and excluded from the original GMA, I proceed by discussing how the amendments won by the agricultural sector after

1980 improved farmers' short-term robustness to inter-annual shocks such as climate variability and market fluctuations. Carlson and Doyle (2002) describe robustness as "the maintenance of some desired system characteristics despite fluctuations in the behavior of its component parts or its environment" (as cited in Anderies et al., 2004). Another way to describe robustness is through robust control: "Robust control refers to the maintenance of performance (e.g. the ability to feed a population) when a system is subjected to external perturbations (e.g. highly variable rainfall in space and time)" (Anderies, 2006, p. 134). Thus, farmers increased their robustness to shocks that may have, without the amendments, reduced the water available to them if one of the aforementioned shocks (climate or market fluctuations) occurred. Thanks to the institutional amendments, instead of receiving less water in times of scarcity, farmers were able to buffer themselves against any such signals and maintain steady application of water to their crops.

Additionally, studying the process of institutional change as it pertains to agriculture and the GMA addresses the reasons and motivations farmers had to want to amend the law. Unlike previous work in the literature that discusses the "weakening" of the GMA through the amendments won by agriculture as well as the municipalities (Hirt, Gustafason, & Larson, 2008), I explore the process of institutional change to illustrate the legitimate concern held by farmers that the original provisions of the GMA did not provide sufficient year-to-year flexibility for water application in their agricultural operations. I then argue that one result of these gains in inter-annual robustness to certain shocks was that farmers were blocked from receiving signals of water scarcity that might have served to motivate them to conserve water. Thus, farmers are not induced to implement water-conserving strategies to the extent originally predicted with the establishment of the GMA. With the institutional arrangements inhibiting the flow of information to farmers signaling impending or actual scarcity, farmers have less incentive to implement water conservation strategies on the farm. And given the importance of proper incentives in determining the success of an SES (Ostrom & Shivakoti, 2002), I then ask farmers and water and agriculture experts what incentives could be employed to boost water conservation on farms in south-central Arizona.

In this thesis, I do not assert that farmers are poor stewards of water in the desert nor do I examine agriculture with the intention of negatively singling out the sector. Many farmers have implemented innovative water conservation strategies on their farms. What I explore is how institutions, and in this case, the process of institutional change, may be buffering farmers from signals of and information about water scarcity, so that the incentive to implement further water-saving strategies is not as strong as was originally predicted at the outset of the GMA.

Data Collection

To populate the Ostrom (2009) framework, discuss the amendments and their implications, and suggest implementable solutions to boost water conservation, I collected the following data:

- Case study historical data
- Secondary sources pertaining to the GMA
- Primary data collected from fieldwork interviewing farmers and water and agriculture experts

The interview data derives from semi-structured interviews conducted in the spring of 2010. The interviews are coded and categorized according to the each theme addressed in the interviews. This allows for an assessment in the range of agreement (or disagreement) across the interviewees. Major interview themes include: the background situation prior to the passage of the GMA; issues in agricultural water conservation and installation of efficiency techniques; the relationship between policymakers and farmers; conflicts between statutory water law and the feasibility of its implementation on the farm; on-the-farm impacts of the GMA; and suggestions of how to boost water conservation in a manner acceptable to farmers. I use the primary interviews to contribute original data concerning recommendations to achieve greater water conservation on farms; primary interview data also supplements the secondary data.

Study Area

The Phoenix and Pinal Active Management Areas (AMAs) are the geographic areas of focus (Figure 2). AMAs are the groundwater basins outlined in statute as those experiencing the most severe overdraft and thus the basins in which groundwater regulations from the GMA would be applied (ADWR, 2004). The Phoenix and Pinal AMAs were chosen for analysis because of the five basins designated by the GMA, they are the two with the largest agriculture sectors, and thus the AMAs with the highest agricultural water use (ADWR, 2009b; ADWR, 2009c; ADWR, 2009d; Megdal et al., 2008). Additionally, these two AMAs represent areas of agrarian landscapes in transition (Redman & Foster, 2008). Land conversion from agricultural to urban uses is a widespread global environmental change, and a worthy topic of study. The USDA suggests, “In the United States alone, 105 acres of agricultural land go out of production every hour; about half that is used for urban ... growth” (as cited in Redman & Foster, 2008, p. 4).

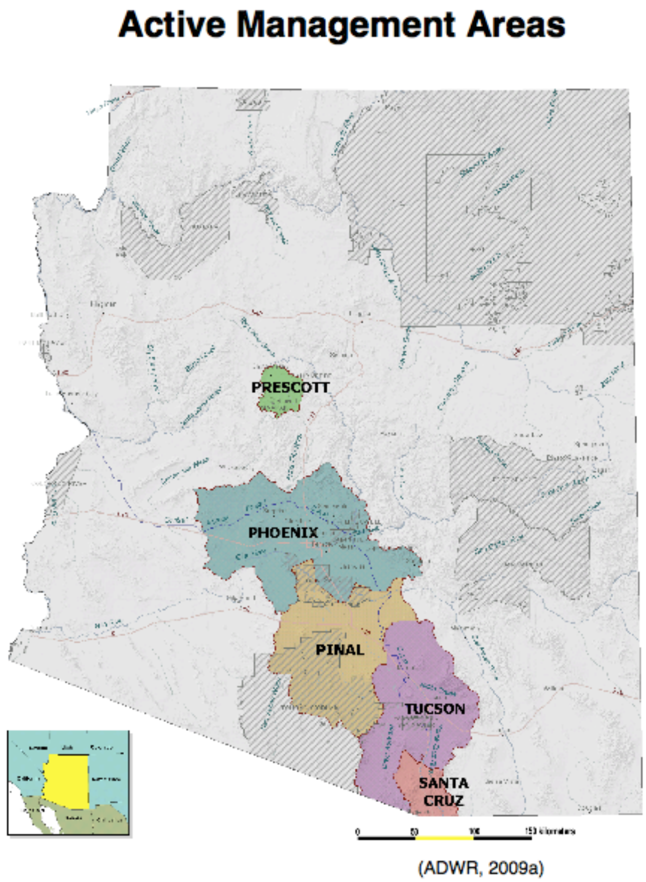

Figure 2. Active Management Areas (ADWR, 2009a).

Chapter 4

Background

Groundwater Use in Arizona

According to statute, agricultural, municipal, and industrial uses make up the three water-consuming sectors in the state of Arizona (Figure 3) (ADWR, 2010a). Together, the three sectors utilize the state's available surface and groundwater supplies. Groundwater is a particularly important type of water resource in the desert because if managed properly, it can "remain plentiful in an area for some years after a drought has taken it toll on water supplies at the surface" (Blomquist et al., 2004, p. 23). In the years prior to 1980, the south-central part of Arizona relied heavily on groundwater. Because there was no surface water supply such as the Central Arizona Project, which currently delivers 1.3 million acre feet of water a year from Colorado River water to the central part of the state (Larson, Gustafason, & Hirt, 2009), Arizona experienced rampant groundwater overdraft throughout the populous south-central part of the state during the middle part of the 20th century. In the year 1977, for example, Arizona citizens consumed roughly 2.5 million acre-feet more groundwater than was replenished (Arizona Groundwater Management Study Commission, 1980). Today, thanks to available surface water supplies being used in-lieu of groundwater, such high levels of overdraft have been reduced, although reaching the statutory goal of safe yield, where the amount of groundwater withdrawn equals the amount naturally or artificially replenished (Jacobs & Holway, 2004), has not yet been met. Properly maintaining the natural functions of groundwater aquifers and basins is important, especially in arid environments, because underground storage of water limits evaporation, as opposed to storing water in surface water reservoirs (Blomquist, 1992). Ensuring the maintenance of groundwater also provides a buffer in times of need. For instance, if surface water supplies run low during periods of drought, groundwater can be used as a backup (Governor's Drought Task Force, 2004). All of these factors lend merit to the study of the institutions governing groundwater use.

Prior to the passage of the pivotal 1980 Groundwater Management Act, groundwater was governed by the doctrine of reasonable use, whereby a landowner had the right to pump as much groundwater from underneath his or her property as could be put to use (Schlager, 1995). This institutional arrangement worked well for nearly a century, but with urban population growth and the steady consumption of groundwater by the industrial and agricultural sectors in the south-central part of the state, negative environmental and economic impacts emerged (Connall, 1982). To fix the problems associated with groundwater overdraft, such as subsidence, land fissuring, and aquifer compaction (Bouwer, 1977), as well as to maintain federal funding for the Bureau of Reclamation project called the Central Arizona Project (CAP), the state of Arizona hammered out a comprehensive overhaul of previous doctrine by developing a new groundwater code (Connall, 1982). After 1980, groundwater became a state-owned resource, with the Arizona Department of Water Resources (ADWR) allocating and monitoring groundwater use for the municipal, industrial, and agricultural sectors within Active Management Areas (AMAs), the regions where groundwater overdraft was most severe (ADWR, 2004).

The state of Arizona is no exception to the challenges posed when many users want to access limited resources. And despite the development of the 1980 Groundwater

Management Act to manage groundwater use, Arizona still faces challenges in ensuring the long-term viability of its groundwater resource base. Most scholars and practitioners agree that the AMAs are not on track to reach safe-yield (ADWR, 2003a; Megdal, Smith, & Lien, 2008). And today, groundwater still remains a vital part of Arizona's water budget. As of 2006, the state of Arizona used roughly 2.7 million acre-feet of groundwater, 2.8 million acre-feet of Colorado River water, 1.1 million acre-feet of other in-state river surface water (e.g. the Salt, Verde, and Gila Rivers), and 0.22 million acre-feet of effluent (ADWR, 2010a). Total water use by the state of Arizona equals 6.84 million acre-feet (ADWR, 2010a). Figure 3 show the statewide percentage of water used by each sector as of 2006. Even with the gains made in the utilization of surface water (mainly from the Colorado River), groundwater continues to play a critical role in meeting Arizona's total water demand.

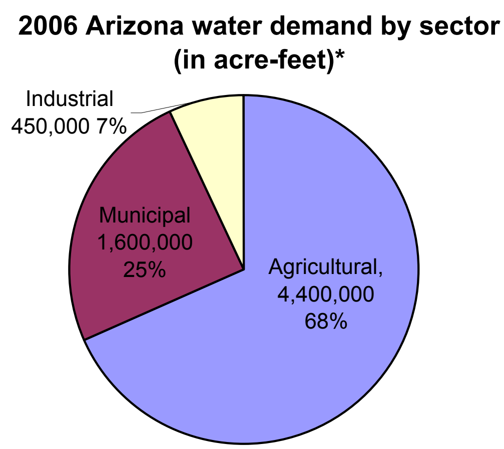

Figure 3. Statewide water use by sector (ADWR, 2010a).

A combination of urbanization pressures and a rule in the GMA prohibiting the expansion of irrigated agricultural acreage in the AMAs means that today, agriculture uses less total water in central Arizona than it did in 1980: “The agricultural sector’s contribution to meet the Phoenix AMA’s safe-yield goal is projected to come from a combination of improved on-farm water management practices, the utilization of renewable supplies, and the reduction of irrigated acreage due to urban development” (ADWR, 2003a, p. 3). As of 2006, agriculture used 36% of the water used in the Phoenix AMA (ADWR, 2009c); in the Pinal AMA, where agriculture remains a strong driver of the local economy, and where urbanization pressures are less, agriculture used 94% of the water (ADWR, 2009d). Both are decreases from 1986, when agriculture water use in the Phoenix and Pinal AMAs comprised 59% and 97%, respectively (ADWR, 2009c; ADWR, 2009d).

Common-Pool Resources

To see how Arizona landed in its dire groundwater situation prior to 1980, it is first helpful to look at the nature of the resource system from which resource units are drawn. Some of the most extensively studied social-ecological systems are those concerning CPRs, and the collective-action situations that appropriators in such resource systems face (Ostrom, 1990). One attribute of CPRs is that they tend to encompass large geographic areas, making it costly and sometimes difficult to exclude potential resource users (Carpenter, 1998). Also, the resources appropriated from CPRs are subtractable and take time to be replenished, meaning one user has the potential to inhibit another’s use of a resource in the resource system (Walker & Gardner, 1992).

To some, common-pool resource systems are equated to the "tragedy of the commons" (Hardin, 1968). In Garrett Hardin's (1968) classic piece, he describes the decimation of a pasture. In the open access regime that governs Hardin's pasture, individual herders, motivated to increase the animals grazing the pasture to maximize their individual benefits, collectively overgraze to the point where the pasture collapses. According to Hardin (1968), because the herder receives the direct benefit of his own animals and bears only some of the costs, in such situations, the pasture will always be overgrazed, thus creating an inevitable "tragedy of the commons" situation (Ostrom, 1990, p. 2).

Hardin's (1968) article has since been countered by many scholars demonstrating that not all CPR systems are doomed for tragedy, thanks to the rule arrangements, trust, and communication often present among resource users in CPR systems (Ostrom, 1990). Human societies oftentimes utilize cultural norms and rules to sustainably manage the commons (Ostrom,1990; Berkes, 1999; Ostrom, 2005). However, prior to the seminal 1980 Groundwater Management Act, groundwater basins in the south-central part of the state of Arizona were in the midst of a tragedy of the commons situation (Schlager, 1995). The reason for the dire situation was because prior to 1980, groundwater was governed by the doctrine of reasonable use (Schlager, 1995). This governance regime does not account for how one person's groundwater extraction can impact another person's available groundwater resources (e.g. an adjoining landowner), except when the issue of transportation of water away from the site of withdrawal is raised (Burton, 1990).

Case studies of groundwater systems that do not regulate how many resource units a user can extract, or the number of users who can extract resource units present similar "tragedy" situations like those described by Hardin (1968). In many parts of Asia where groundwater is under the worst threat of depletion, such as Western India, Baluchistan, and North China, scholars have suggested that the first step to resource management under stress is to establish secure property rights over groundwater (Shah, Deb Roy, Qureshi, & Wang, 2003). However, closing the open access regimes that govern much of Asia and assigning people groundwater property rights is difficult given that modern groundwater development has been chaotic and unregulated, being shaped by millions of private users whose individual resource use is relatively small (Shah, Deb Roy, Qureshi, & Wang, 2003). Enforcement and regulation of the numerous smaller users presents significant costs that monitoring, sanctioning, and enforcement is difficult, if not impossible. In cases with little institutional structure regulating resource use extraction, there is a fear that pumpers cannot capture tomorrow what they do not pump today, thus undermining the incentive to forgo current pumping for future pumping (Negri, 1989). Additionally, because of the migratory nature of water, and because groundwater is often located below numerous, independently owned plots of land where one does not begin to obtain ownership of the water until it is pumped, the more an owner pumps, the greater the economic value a pumper has at any one time (Bruggink, 1992). However, over the long run, as groundwater is a common pool resource generating scarce resource units, "users of groundwater acting independently will obtain less total net benefits than if users had coordinated their strategies in some way" (Ostrom, 1990, p. 38).

Yet when a different set of institutions accompanies the extraction of a CPR such as groundwater, the situation can be much less bleak. Because institutional design affects how many users are allowed to enter and harvest from a particular resource and the obligations of those who gain benefits from the system, if constructed properly for the context of a specific SES, institutions can help steer a system towards high levels of performance (Shivakoti & Ostrom, 2002). Always important to keep in mind is that panacea policy prescriptions do not work for every groundwater basin (Ostrom, 2007). For instance, in Southern California, where high population and a sometimes arid environment have lead to groundwater scarcity, one basin, the San Gabriel, manages its groundwater use successfully without the heavy hand of a water czar or regional master plan, which many policymakers and scholars suggested as vital for managing groundwater successfully (Blomquist, 1992). In the San Gabriel Basin, "Compliance with the management program … has been high. No party has been sanctioned for overproducing [groundwater]. … Through the first eighteen years of operation, … groundwater production from the basin has remained close to the operating safe yield" (Blomquist, 1992, p. 184). The institutional arrangements of the basin have also promoted efficient groundwater use by steering use of the precious resource towards more high value uses and taking advantage of the large underground storage space of the aquifer to engage in recharge and augmentation activities (Blomquist, 1992). Lastly, the rules governing groundwater use in the San Gabriel Basin are products of adaptation "to address the particular problems in each case" (Blomquist, 1992, p. 186). When policy is stagnant and does not adapt to the changing needs of the resource users and the resource system, non-compliance with the institutions, or a push to change the institutions can ensue.

The state of Arizona attempted to develop institutions to fix its common-pool resource problem, starting with the Groundwater Act of 1945. However, this was a weak attempt to coordinate strategy among users, only requiring that wells be registered with the State Land Commissioner, and placing no limits on how much groundwater one could pump (Schlager, 1995). With land ownership acting as the only real rule governing access and no limits placed on how much groundwater could be withdrawn, Arizona had almost pumped itself dry by the middle of the 20th century (Schlager, 1995).

Rumblings of institutional reform. To overcome the commons dilemma concerning groundwater overdraft in the state of Arizona, state lawmakers and vested water interests began to acknowledge that they needed to change the way in which groundwater was accessed, utilized, and monitored. The "decades of inaction" (Connall, 1982, p. 314) by the state of Arizona to reform its groundwater code demonstrate how rules can be difficult to develop, implement, and change. "All rules are nested in another set of rules that define how the first set of rules can be changed" (Ostrom, 2005, p. 58). Therefore, the establishment of the Groundwater Management Act affects what Ostrom calls collective-choice rules by "determining who is eligible to be a participant and the rules to be used in crafting the set of collective-choice rules that, in turn, affect the set of operational rules" (Ostrom, 2005, p. 58). Collective-choice rules determine the participants and the possible decisions those participants can make in the operational rules (Ostrom, 2005). In other words, the GMA affects farmers' day-to-day decisions by telling them how much groundwater they can use and where they can use it. Altering institutions that govern water is often difficult and contentious, because "water management institutions are resistant to change … [and] operate along established norms of conduct, …thereby tend[ing] to be conservative in maintaining the status quo" (Larson, Gustafson, & Hirt, 2009, p. 114). A few key events prefaced the development of the institutional arrangements that would lead to the development of the new groundwater code of 1980.

One such event was a ruling by the Arizona Supreme Court in 1976 in *Farmers Investment Company (FICO) vs. Betty* put reform into motion (Connall, 1982). The case dealt with transportation of groundwater away from the basin of use (Connall, 1982). Farmers worried about the quality and quantity of their groundwater wells when mines, for industrial purposes, transported water outside the land area "from which the water was taken" (Connall, 1982, p. 316). After the court case turned out a decision neither the agricultural, industrial, nor municipal sectors found favorable, the time was ripe for institutional reform. For a group of people to supply and follow a new set of institutions to deal with a collective-action problem, oftentimes a situation exists in which all users would benefit from a change in the rules (Ostrom, 1990). For the state of Arizona to reform its groundwater policy, it ultimately took an outside threat to overturn the reigning 20th century doctrine of reasonable use. This final push to overhaul the rules surrounding Arizona's groundwater came in the form of federal funding for the Central Arizona Project (CAP), a 300-mile long canal that delivers Arizona's 1.3 million acre-feet entitlement of the Colorado River to its population centers in the central part of the state (Larson et al., 2009). Groundwater reform in Arizona passed in the state legislative session of 1979-1980 thanks to then-Secretary of the Interior Cecil Andrus' ultimatum: either Arizona enacts a binding groundwater code, or it loses the federal money backing the construction of the CAP (Connall, 1982). In November 1977, the Arizona Groundwater Management Study Commission formed to study the best way to govern groundwater; in June 1980 the Groundwater Management Act became law (Connall, 1982).

Many suggest that without the carrot of the CAP, the GMA would not have been established (Smith & Johnson, 2008; Water-agriculture expert #2, personal communication, February 25, 2010). The threat from the federal government also made for a hasty passage of the Groundwater Management Act. “There wound up being basically about four people in the room when the deal was finally cut” (Farmer #4, personal communication, February 15, 2010). With little time to consider the physical system and how the new institutions might combine to affect the incentives and behavior of groundwater users in a variety of cultural and economic contexts, policymakers at the Arizona capitol made sweeping changes in how farmers could use groundwater in the state. The swiftness of the development and passage of the Act would come to haunt policymakers and resource users with an ongoing, 25-year-fight for various revisions to the rules of the GMA. Scholars have found that some of the major problems regarding the governance of CPRs are related to the lack of understanding of the investment required for the design of relevant institutions that will match the ecological, cultural, political, and social systems of the users (Lam, 2006). The following analysis will use the case of groundwater management policy and farmers as groundwater users in Arizona to highlight the importance of considering the ecological, cultural, and political factors when designing an institution for long-term performance.

Chapter 5

Analysis

Institutional Design

Upon agreement that an institution is needed to regulate an unsustainable CPR regime, rules are established that severely constrain the "authorized actions available to [the resource users]" (Ostrom, 1990, p. 43). The next section outlines the institutional structure of the GMA. To minimize the conflict over and depletion of groundwater in Arizona, the ADWR restricts and monitors the possible actions of groundwater users with certain provisions (outlined below) in the GMA. Using the latest framework for analyzing sustainability of SESs (Ostrom, 2009), the following tables highlight the second-level variables within Ostrom's (2009) framework included in the GMA. Subsequent tables will outline which second-level variables are excluded from the GMA.

Table 1

Ostrom (2009) second-level variables included in original GMA

Ostrom (2009) variable	Groundwater Management Act
• RS1 Sector • RS2 Clarity of system boundaries • RS3 Size of resource system • GS6 Collective-choice rule	Designation of Active Management Areas (AMAs) determines the boundaries of the regulated system as defined in the GMA. GMA only regulates groundwater, no jurisdiction over surface water. AMAs determined according to hydrologically connected groundwater basins experiencing serious overdraft problems prior to 1980 (ADWR, 2004). Thus, AMAs both an ecological and institutional boundary. Outside the AMAs, these rules do not apply.
• RU5 Number of units • GS4 Property-rights systems • GS5 Operational rules • U3 History of use • U4 Location	The establishment of a program of groundwater rights and permits. Agricultural groundwater rights called Irrigated Grandfathered Rights (IGFRs) and confer the right to irrigate with a set amount of groundwater on specific plots of land irrigated with groundwater between 1975 and 1980 (Needham & Wilson, 2005). One must continue to farm on original land for the water allocation to be supplied and utilized, because water and land stay tied together (Megdal et al., 2008).
• RU4 Economic value	If the use of the land switches from agricultural to urban, for example, only three acre-feet of water per acre can be transferred to the new use, not the entire IGFR water allotment (Burton, 1990).

Table 1 cont.

Ostrom (2009) second-level variables included in original GMA

Ostrom (2009) variable	Groundwater Management Act
• RU2 Growth or replacement rate • RU7 Spatial and temporal distribution	Development of a program requiring urban developers to demonstrate a 100-year assured water supply for new growth (ADWR, 2004).
• RU5 Number of units • GS5 Operational rules	Farmers required to increase water efficiency every ten years, with the intention that farms would use less water in 2025 than in 1980 (ADWR, 2003a).
• RS2 Clarity of system boundaries • GS5 Operational rules	A provision prohibiting irrigation of new agricultural lands within AMAs (ADWR, 2004).
• GS8 Monitoring and sanctioning processes	A requirement to meter/measure water pumped from all large wells (ADWR, 2004).
• GS8 Monitoring and sanctioning processes	A program for annual water withdrawal and use reporting. These reports may be audited to ensure water-user compliance with the provisions of the Groundwater Code and management plans. Penalties may be assessed for non-compliance (ADWR, 2004).
• GS1 Government organizations	The establishment of the Arizona Department of Water Resources (ADWR) as the monitoring entity (Hirt et al., 2008)

Table 2

Ostrom (2009) second-level variables excluded from original GMA

Ostrom (2009) variable NOT TAKEN INTO ACCOUNT	Groundwater Management Act
• U5 Leadership / entrepreneurship	Assigned water allotments to farmers based on use from 1975-1980. Those who used more water were awarded a larger allotment than those who had been irrigating efficiently.
• U7 Knowledge of SES	Previous groundwater doctrine overturned quickly, making it difficult to incorporate the proper incentive structure to reward farmers for irrigating efficiently (as one way of coping with resource scarcity).
• U7 Knowledge of SES	Assumed reaching 85% irrigation efficiency standard in Third Management Plan was economically feasible for farmers.
• U6 Norms / social capital • U8 Importance of resource	Assumed agricultural acreage and water use would decline quickly. Significant amount remains.
• U9 Technology used	Placed emphasis on reducing agricultural acreage (scale effect) as main way to conserve groundwater. Not as much emphasis on aiding farmers with water technology effects that could reduce per-acre consumption.

Table 3

Second-level variables (bolded and underlined) included in GMA within corresponding Ostrom (2009) first-level core subsystem

RESOURCE SYSTEM (RS)	GOVERNANCE SYSTEMS (GS)
RS1 Sector (groundwater) **RS2 Clarity of system boundaries** **RS3 Size of resource system** RS4 Human-constructed facilities RS5 Productivity of system RS6 Equilibrium properties RS7 Predictability of system dynamics RS8 Storage characteristics RS9 Location	**GS1 Government organizations** GS2 Nongovernment organizations GS3 Network structure **GS4 Property-rights systems** **GS5 Operational rules** **GS6 Collective-choice rules** GS7 Constitutional rules **GS8 Monitoring and sanctioning processes**
RESOURCE UNITS (RU)	**USERS (U)**
RU1 Resource unit mobility **RU2 Growth or replacement rate** RU3 Interaction among resource units **RU4 Economic value** **RU5 Number of units** RU6 Distinctive markings **RU7 Spatial and temporal distribution**	U1 Number of users U2 Socioeconomic attributes of users **U3 History of use** **U4 Location** U5 Leadership/entrepreneurship U6 Norms/social capital U7 Knowledge of SES/mental models U8 Importance of resource U9 Technology used

From these tables it is evident that the subsystem "Users" has the fewest variables included or considered in the GMA. Scholars studying other social-ecological system cases around the world have noted that when users and other stakeholders are given a strong voice and real responsibility, users of natural resources, such as irrigation farmers, may enhance the economic and ecological performance of the SES (Shivakoti & Ostrom, 2002). When institutions are crafted without consideration of the variables Ostrom (2009) suggests as important for sustainability, conflict in resource management can arise. In the case of the GMA, farmers, excluded for the most part in the drafting of the legislation, did not find the rules favorable and thus lobbied for and won several concessions that would grant them greater flexibility in their water use. I argue that by not considering the variables outlined in Table 2, farmers did not buy in to the new regulations at the onset of the GMA and thus fought to change the rules in the years and decades following 1980. When outsiders seek to improve the performance of an SES, in this case, reduce overdraft by regulating farmers' groundwater use, acknowledging and planning for the possible (sometimes perverse) incentives generated by new institutions as they interact with the existing social norms and physical world is critical if compliance with the established institutions and long-term performance of the SES is to be reached (Shivakoti & Ostrom, 2002).

Institutional Change

When the operational, day-to-day needs and decisions of the resource users are analyzed in tandem with the groundwater resource system and the governance system of the GMA, the perceived costs incurred by farmers after the Act was established are easier to understand. Using the IAD framework to examine the interactions among the users and the governance system helps to see why a conflict between farmers and the GMA arose: users perceived a mismatch between costs and benefits (Anderies, Janssen, & Ostrom, 2004). Given how quickly Arizona overturned its barely-existent groundwater code in 1980 in order to meet the ultimatum of the federal government to receive the CAP funding, it appears there was not sufficient time to incorporate farmers' existing knowledge into the institutions regulating groundwater use that might promote groundwater conservation. Some experts interviewed for this study suggested that the lawmakers who constructed the initial GMA rules knew little of the on-the-ground nuances related to farming, especially in the desert. "[The GMA] was written by people that ... didn't really understand what was going on down on the farm" (Water-agriculture expert #5, personal communication, March 4, 2010). A farmer adds:

> There are a lot of assumptions that government people make that have low or no reality. You [can] talk hypothetically [about] the amount of water the plant need[s] but when you actually deliver that water in a production situation it is a lot different because the plant can't take up all the water you send to it. (Farmer #6, personal communication, February 26, 2010)

Without a close examination of the various factors influencing agricultural water use included in the initial development of the GMA, the result was a mismatch between costs and benefits—at least as perceived by the agricultural resource users of south-central Arizona. Farmers were no longer permitted to expand their farms' irrigated acreage. They were expected to become more efficient with their water use, and with that efficiency, experience reductions in the water allotted to their farms. The resource once extracted as a private property right was suddenly defined as the communal property of the state of Arizona to be divvied up based on a farmers' historic use. A water expert suggests the stark reality farmers suddenly faced:

> I think it was shock at first for farmers that on June 11, 1980 you could use as much water and irrigate any land that you wanted. Then June 12, 1980 comes in and its like, "I can only irrigate this much, and how much water do I have to use? Who is going to tell me what to do?" (Water-agriculture expert #8, personal communication, March 10, 2010)

This mismatch sent the Arizona Department of Water Resources and state lawmakers scrambling to adjust certain provisions in the original Act to provide farmers the necessary flexibility to respond to changes in climate and the agricultural market not long after its 1980 passage. Anderies et al. (2004) highlight that institutions associated with successful SESs often provide a "rough proportionality between the benefits a resource user obtains and his or her contributions to the public infrastructure" (p. 12). An institution that does so is considered fair in most social systems (Issac et al., 1999). When institutions are constructed and considered fair, they reduce the chance that resource users will try to challenge, avoid, or disrupt the policies of the public infrastructure providers (Anderies et al., 2004). To the agricultural sector of south-central Arizona, the GMA did not appear fair:

> [It was] an upheaval in the agriculture industry because we developed our water ourselves. The wells that we drilled we owned. We bought and paid for them, and took the risks when we drilled them. Sometimes you get dust, sometimes you get water. And here were some people ... suggesting that we were going to lose control of those wells and the water that came from them, and that the water belonged to the state of Arizona instead of to me and my peers. It was brutal. (Farmer #1, personal communication, February 3, 2010)

Thus, farmers, as water resource users, challenged the policy set forth by the Arizona public infrastructure providers to gain back some of the flexibility they felt they had lost (Megdal et al., 2008). These challenges manifested in the form of institutional amendments to the GMA for agriculture, and will be discussed in the next section.

Others see the situation differently. Hirt et al. (2008) state that, "Arizonans took the water supply bull by the horns over a quarter century ago in a landmark water conservation law ... but subsequent loopholes and evasions have gutted its original intent and taken the state off the path toward sustainability" (p. 483). Once hailed as innovative and a model for other states, the GMA's effectiveness at reducing overdraft is questionable, especially considering that most scholars and practitioners agree the AMAs are not on track to reach safe yield (ADWR, 2003a; Megdal et al., 2008). Designing institutions that offer the proper incentives to reach an end goal (e.g. safe yield) is critically important to the long-term maintenance of an SES (Shivakoti & Ostrom, 2002).

In this case, the proper incentives must align with the socioeconomic attributes of farmers to achieve the end goal of reducing overdraft and eventually reaching safe yield. As will be demonstrated, the institutional concessions won by agriculture boosted farmer robustness to shocks such as climate extremes and market fluctuations. In exchange for this robustness to short-term shocks, these institutional amendments appear to block farmers from signals of groundwater scarcity and contribute to Needham & Wilson's (2005) finding that water use by agriculture in the AMAs has been stable since 1980. Based on the previous analysis concerning the lack of Ostrom (2009) variables in the "Users" subsystem, the following discussion examines three specific institutional amendments that arose after 1980, outlining what they entail, why they surfaced, and their implications for water conservation in the agricultural sector.

According to Ostrom (1990), "Participants prefer a set of rules that will give them the most advantageous outcome. Although all will prefer a new institution that [enables] them to coordinate ... activities, ... a fundamental disagreement [may] arise among participants regarding which institution to choose" (p. 42). To receive a more advantageous institutional outcome, the agricultural sector fought for and won three significant institutional concessions from the ADWR: flex credits, the Best Management Practices conservation program, and a reduced irrigation efficiency standard. These changes to the GMA are now discussed.

Flex credits. Flex credits, also called flexibility accounts, were instituted in the Phoenix and Pinal AMAs in 1987 and 1988, respectively, after concerns raised by farmers about the need for flexibility in water use (ADWR, 1999a; ADWR 1999b). Flex credits work as follows:

> If a grower uses less water than his allotment in a given year, then he can bank the difference in a flexibility account. In another year, if the grower has a greater demand for water than his annual allotment entails, the grower could use his accumulated flex credits to use more water. (Frisvold et al., 2007, p.146)

Farmers fought for such a provision because they felt the original conservation programs in the GMA did not provide the flexibility needed to respond to changes in the agricultural economy (Megdal et al., 2008). Furthermore, because the water allotments for the base conservation program are based on historic irrigation acres and crop mix, it is difficult for some farmers to adjust the crops grown in order to meet the demands of the market (Megdal et al., 2008). The ADWR acknowledged these constraints by granting the use of flexibility accounts to the agricultural sector:

> The Department recognizes that water use varies by year and locality. Therefore, the Department has provided maximum flexibility when administering the regulatory provisions of the management plan. ... [T]he establishment of

> "flexibility accounts" ... generally allow[s] water users to borrow or bank water from one year to the next in order to overcome the variation in use caused by weather or other unforeseen circumstances. ... Flex credits also allow farmers to take advantage of changing agricultural market conditions. (ADWR, 1999a, p.7)

Today, accumulated credits represent significant flexibility in water use for farmers. "In essence [growers] could farm forever" (Water Policy Professional #5, personal communication, March 4, 2010). Initially created to help farmers deal with weather and agricultural market uncertainties, they have turned into a huge windfall that "no one predicted or contemplated, even the farmers themselves" (ADWR, 2000, p. 7). As of the year 2000, 6.6 million acre-feet of banked flex credits existed in the Phoenix AMA (Maguire, 2007). Additionally, farmers can sell accumulated flex credits to other farmers within the same AMA (Maguire, 2007). However, due to the large amounts of credits already banked by most farmers, there has not been the marketplace exchange originally envisioned: "The sector has contracted so much and prices have not been good, so there really is very little market for flex credits" (Water Policy Professional #5, personal communication, March 4, 2010). Despite the lack of a market, farmers, when asked if they could ever envision a situation in which they would need to access their banked flex credits, replied in the affirmative (Farmer #4, personal communication, February 15, 2010; Farmer #5, personal communication, February 16, 2010). The desire to hold on to their flex credits appears to be form of insurance against future water supply uncertainty, and thus, a way to boost robustness to possible shocks where more water would be needed to grow crops in a given year or series of years.

As with all costs and benefits, what is beneficial to one group may not be beneficial for the system as a whole. Thus, flex credits have ignited significant controversy in the management of Arizona's groundwater resources. Some argue that the initiation of the flexibility account institution was problematic because it allowed farmers to accumulate a large amounts of flex credits on fallowed land during the slumped agricultural economy of the late 1980s and early 1990s (Needham & Wilson, 2005). To others, the flex credit account program provides a significant cushion for compliance, minimizing the participation in water conservation efforts by some farmers (Megdal et al., 2008). Additionally, others argue that flex credits "create a future liability for the aquifer and undermine the achievement of safe yield" (Maguire, 2007, p. 372). This liability could manifest if the agricultural market signaled more farmers to grow water-intensive crops (such as vegetables, or alfalfa for the local dairies), or extreme temperatures demanded more water be applied to fields to maintain production. In both circumstances, farmers have every legal right to access more water than their prescribed 1980 allotment, as long as they have stored or purchased flex credits.

Others, however, disagree that flex credits are lingering problem: "[Farmers] aren't saying, 'Oh, I have this huge bank of flex credits, I am going to grow rice.' They're growing what they need to grow, and in most years, they're still meeting their conservation requirements" (Water-agriculture expert #3, personal communication, February 26, 2010). Additionally, the decline in total agricultural acreage in the Phoenix and Pinal AMAs, as well as the GMA prohibition of the development of new irrigated acres, makes the liability of flex credits somewhat less daunting. However, if, for instance, the dairy sector of Arizona recovers from its recent slump, and the housing market remains quiet due to The Great Recession, farmers could ramp up alfalfa production, one of the more water-intensive crops commonly grown in Arizona, leading some farmers to steadily dip into their flex credits for a number of years.

There is little doubt that flex credits boost farmer robustness to shifts in the agricultural economy and to local climate perturbations. And given the importance they hold with farmers as security against potential future water supply uncertainty, attempting to eliminate flex credits appears politically unfeasible. However, serious problems concerning the sustainability of the groundwater basins could arise if enough farmers wanted to access their flex credits during the same time period.

With flex credits, farmers received a deal they found agreeable, the trade-off being that flex credits have not induced a binding water constraint for most farmers, thus contributing to the stable water use per-acre over the life of the GMA (Needham & Wilson, 2005). The establishment and ensuing results of flexibility accounts demonstrates the difficulty in designing institutions that manage the trade-off between the short-term interests of particular actors in the SES and the long-term concerns of the resource base (in this case, groundwater) in the SES.

Best Management Practices water conservation program. Not all farmers could accumulate flex credits, however, because “flex credits were only available to those who were big water users” (Farmer #1, personal communication, February 3, 2010). A dichotomy emerged after the establishment of the GMA in 1980: the haves and have-nots of Irrigated Grandfathered Right (IGFR) holders. IGFRs represent the right to pump groundwater and were established based on the consumptive use of water on a specific plot of land from 1975-1980 (Needham & Wilson, 2005). Some farmers received large water allotments and therefore had greater flexibility in their water use. Others received smaller allotments, thus affecting their operation's ability to respond to changes in the agricultural economy and biophysical climate. Part of the reason certain farmers received a smaller water allotment had to do with the efficient irrigation practices of those farms between 1975 and 1980, the years when the water allocations for farms were determined (Megdal et al., 2008). Thus, those who irrigated conservatively were effectively punished with a smaller water allotment. A farmer remembers a story about his relative's farm:

> At a time when all of the [allotment] numbers were being identified, his usage was lower, and so his history of [water] use was much lower than the guys who had been using water less efficiently. ... He was upset that someone who is actually trying to be efficient got penalized. That just seemed so negative to him. Why wouldn't you create an enhanced version of [the law] so that if you were efficient, there was some way to benefit. You know, create an incentive to be more efficient. (Farmer #5, personal communication, February 16, 2010)

The ADWR eventually realized that the fixed water allotments based on historical water use and cropping patterns made it difficult for certain farmers to respond to fluctuating market conditions from year to year (Governor's Water Management Commission, 2001). As a result of such concerns, the ADWR worked with farmers to develop and implement the Best Management Practices (BMP) in a modification to the Third Management Plan (Megdal et al., 2008). The Management Plans are developed every ten years and were often the time when institutional change to the GMA occurred

(ADWR, 2004). One proponent, a farmer, suggests why the BMP program was a necessity for certain growers:

> You've got to have the ability to change cropping patterns. You have to have the ability to be flexible so you can plant a crop that hopefully brings you a profit. People like myself who had a very small water duty were pretty much relegated to historic cropping patterns, ... so we worked out this program where we can farm all of our farm, [and have] the flexibility that's needed to be a farmer. (Farmer #1, personal communication, February 3, 2010)

Implemented in 2002, the agricultural BMP program is an alternative to the base conservation program of the original GMA. Farmers who hold IGFRs in the AMAs must be enrolled in a conservation program with the ADWR; thus, until the inclusion of the BMP program in 2002, all farmers were enrolled in the base conservation program. The base program uses the water allotments and increasing irrigation efficiency standards (established every ten years with a new Management Plan) to force water conservation (Megdal et al., 2008). A complete departure from the base program, the BMP program is voluntary, and includes a menu of water-saving strategies from which farmers can choose. Unlike those enrolled in the base program, farmers in the BMP program do not have to comply with a set water allotment, nor must they reach a certain irrigation efficiency standard (ADWR, 2009f). The logic: the ADWR-approved on-farm water saving practices negate the need for compliance with specific water allotments because the approved irrigation strategies increase water efficiency. The BMP program focuses on four categories of on-farm irrigation efficiency improvements (Megdal et al., 2008):

- Water conveyance system improvements

- Farm irrigation systems
- Irrigation water management
- Agronomic management

Each category lists specific best practices to irrigate efficiently, and a farmer earns points depending on which strategies are implemented. For example, under the "farm irrigation systems" category, the ADWR (2009f) lists the practice and associated points of uniform slopes with tailwater reuse (two points), high-pressure sprinkler systems (two points), level systems (three points), and trickle irrigation systems (three points) as four possible ways to earn points in the category. No more than three points can be counted in any one category, and a total of 10 points are necessary to be enrolled in the BMP program (ADWR, 2009f). One farmer interviewed responded positively to the more menu-like approach of the BMP program, as opposed to the regulatory approach of the base conservation program (Farmer #5, personal communication, February 16, 2010). The BMP program "get[s] guys to start thinking on their own about everything that is available out there to save water" (Farmer #5, personal communication, February 16, 2010).

In the Phoenix AMA, 6,919 out of 308,681 acres are registered in the BMP program (Megdal et al., 2008). In the Pinal AMA, 30,559 of 281,200 acres are enrolled (Megdal et al., 2008). For most farmers in the AMAs, especially those allocated sufficient water at the outset of the GMA, the base program is satisfactory (Farmer #4, personal communication, February 15, 2010; Farmer #6, personal communication, February 26, 2010). Thus, many farms choose not to enroll in the BMP program because they have an excess of flexibility credits and have "no trouble complying with the current regulations" (Megdal et al., 2008, p. 47). The BMP program, however, appeals to the farmers with smaller allotments, or those who need more water use flexibility given the diversity of their cropping patterns (Farmer #1, personal communication, February 3, 2010; Farmer #5, personal communication, February 16, 2010).

At first glance, the BMP program seems to alleviate some of the regulatory problems that emerged at the onset of the GMA in 1980: the ADWR developed the BMP program with farmers, thus incorporating into policy farmers' knowledge concerning water conservation practices; the BMP program allows farmers to choose the technology that is right for their operation; and the BMP potentially even increases their responsiveness and adaptability to climate and market perturbations, because enrolled farmers are meeting the required points with a slew of different technologies and practices to irrigate efficiently. However, some farmers and water and agriculture experts question whether the BMP program has led to increased water conservation (Water-agriculture expert #2, personal communication, February 25, 2010; Farmer #1, personal communication, February 3, 2010). Critics and proponents alike suggested that the BMP program simply allows farmers to continue irrigating as they had previously, except without the restraint of an irrigation efficiency standard or a prescribed not-to-exceed water allotment (Water-agriculture expert #2, personal communication, February 25, 2010; Farmer #1, personal communication, February 3, 2010). The program was developed in conjunction with farmers. Naturally, farmers lobbied for the BMP program to encompass practices already in use out in the fields. Therefore, the water savings achieved by the BMP are questionable (Water-agriculture expert #2, personal communication, February 25, 2010; Water-agriculture expert #8, personal communication, March 10, 2010; Farmer #1, personal communication, February 3, 2010).

Others suggest that the water savings of the BMP program are “at least equivalent” to the water savings resulting from the base program (Kilb, 2010, p. 8). But as Needham and Wilson (2005) demonstrate, the conservation results in the base program are minimal, given that water consumption per-acre remains stable since 1980. The BMP program was originally intended to be temporary, the plan being that a study would be conducted by the ADWR to assess its effectiveness, and a determination on whether or not to make the program permanent based on that study (Megdal et al., 2008). The BMP program was made permanent before a study could be completed (ADWR, 2009e). Unfortunately, given Arizona’s current budget woes and the drastic reductions of staff in the ADWR, conducting a proper assessment of the BMP program’s impact on enrollee’s water use appears unlikely at this time.

By examining why the BMP institution was created in the first place, the cost/benefit trade-off becomes clear: farmers, particularly those who could not accumulate the aforementioned flex credits to boost their robustness to market and climate shocks, needed to gain robustness another way. The BMP program provides typically lower-water allotment farmers increased flexibility to adjust to the aforementioned perturbations by eliminating the irrigation efficiency standard and water allotments. However, in granting this institutional concession to farmers, it is yet to be seen if the BMP program will significantly contribute to reducing water consumption per-acre.

Irrigation efficiency standard reduction. The final institutional concession examined in this analysis is the adjusted maximum irrigation efficiency standard required of farmers by the Third Management Period (2000-2010). The irrigation efficiency standard is used to calculate the water allocation a farmer receives in each ten-year management plan under the base conservation program (note: farmers enrolled in the BMP program do not need to comply with water duties/allotments) (ADWR, 1999a). One way the GMA planned to reduce agricultural water consumption was by gradually increasing irrigation efficiency standards. Irrigation efficiency measures how effectively irrigation water is applied to crops; for example, a 50% irrigation efficiency means that 50% of the water applied to a field is taken up by the crop in its growth (Megdal et al., 2008). Therefore, the higher the efficiency, the more water taken up by the crop, and the less water that is lost to evaporation or seepage (although this does indirectly recharge groundwater basins). By meeting increased efficiencies, ADWR then planned to lower the annual water allotments to farmers over time after efficiencies were shown (Needham & Wilson, 2005). Structuring the institution such that once farmers became more efficient, their water was then taken away appears to be a perverse incentive to farmers—why conserve if you will receive less water for doing so? However, this was the plan in the GMA for reducing agriculture's groundwater consumption.

In the first management plan (1980-1990), the minimum irrigation efficiency in the Phoenix AMA was 55-60%, depending on the farm (Megdal et al., 2008). For the Pinal AMA, the minimum irrigation efficiency was 60% (Megdal et al., 2008). The intermediate number that most farmers were assumed to achieve, however, was 70% efficiency (Megdal et al., 2008). These numbers were determined to be achievable "without imposing a significant economic burden on irrigators in the AMA" (Megdal et at., 2008, p. 71). The second management plan (1990-2000) set the maximum irrigation efficiency for the Phoenix and Pinal AMAs at 75% (ADWR, 2003a; ADWR 2003b). In the third management plan, the original statute called for a maximum 85% irrigation efficiency that would be used to calculate farmers' water allotment (Megdal et al., 2008), but farmers, among others, argued that this was not economically feasible and would fight to obtain a compromise. Eventually, agriculturalists received an 80% maximum irrigation efficiency standard, which is not set to change in any future management plans (Megdal et al., 2008; Water-agriculture expert #7, personal communication, March 9, 2010).

By calculating a farmers' water allotment with a higher irrigation efficiency standard, the intent is to reduce the amount of water farmers can receive in a given year, thus reducing the agricultural water demand over time (ADWR, 1999a). The ADWR assumed that reaching 85% efficiency could be achieved through a combination of "on-farm physical improvements, irrigation water management practices, improved crop varieties, deficit irrigation, effective precipitation, and land fallowing," then changed its stance to say that efficiency would be achieved through conversions of farms to level irrigation systems (as cited in Salt River Project [SRP], 1999, p. 5-6). The Salt River Project (SRP) (a power and water delivery organization) and farmers argued that the assumptions of the ADWR in how farmers would reach the 85% irrigation efficiency were not practical nor economically feasible for farmers (SRP, 1999).

SRP and farmers also argued that the 85% irrigation efficiency standard went against the original intent of the GMA, which was to allow existing grandfathered groundwater users to continue farming with the water allotment necessary to produce crops historically grown (Water-agriculture expert #7, personal communication, March 9, 2010; SRP, 1999). They argued that if water allotments were less, as they would be if calculated by the 85% irrigation efficiency standard, farmers would not be able to farm in an economically feasible way (Water-agriculture expert #7, personal communication, March 9, 2010). In a letter before the Director of the ADWR, SRP argued for an irrigation efficiency standard of 75% (SRP, 1999). In 2002, the 85% standard was determined to be unachievable by the ADWR, and farmers in the base program received an 80% irrigation efficiency that was not to change in future management plans (Megdal et al., 2008). The two sides reached a compromise.

The institutional concession of the 80% irrigation efficiency standard for agriculture was one of the most contentious battles of the GMA post-1980 (Water-agriculture expert #7, personal communication, March 9, 2010). Tensions have since cooled, but the awareness on the part of farmers that their water is an ever-important and desired resource for the state of Arizona remains. Holding on to as much of it as they can for as long as they can is a pervasive attitude among farmers, at least until they decide to sell their land, most likely for urban development (Farmer #4, personal communication, February 15, 2010). With the 80% irrigation efficiency compromise, farmers and regulators reached a number tolerable to both sides, and alleviated the previous imbalance of costs and benefits (as perceived by farmers).

Effectiveness of the GMA

The institutional amendments described above appear to limit the achievements of the GMA in terms of increased agricultural water conservation. This is not to suggest that farmers' fight for greater flexibility to respond to fluctuations from year to year is without merit. Describing the changes to the GMA demonstrates the delicate balance between short-term concerns of resource users and long-term concerns over the resource base. Certain provisions in the GMA do contribute to a reduction of agricultural groundwater consumption since 1980; however, this is mainly the result of the halting of the expansion of irrigated acres and the retirement of thousands of acres of agricultural land. According to Hirt et al. (2008), "analysts agree that farm [water] use will continue on a steady downward trend ... [with the] irreversible transfer of water from farms to cities" (p. 487). The reduced overall water consumption by agriculture is also a result of low-cost surface water (delivered via the aforementioned CAP canal) being made available to some farmers and irrigation districts to use in-lieu of pumping groundwater (Needham & Wilson, 2005).

Despite the establishment of the GMA, and reductions in total agricultural water use, overdraft still threatens central Arizona (Megdal et al., 2008). Researchers in the study of institutions find "when exclusion is difficult and consumption is subtractive, resource users face incentives to over harvest [...] unless institutions are crafted, monitored, and enforced that counteract these incentives" (Anderies et al., 2004, p. 9). The GMA attempts to curb overharvesting of groundwater in Arizona with its statutory goal, at least in the Phoenix AMA, of reaching safe yield. For the Pinal AMA, the statutory goal is to "preserve existing agricultural economies for as long as feasible, while preserving future water supplies for non-irrigation uses" (ADWR, 2003b). In the law, safe yield is defined as achieving a long-term balance between the annual amount of groundwater withdrawn and the annual amount of natural as well as artificial recharge (Jacobs & Holway, 2004).

Safe yield is a worthy goal, but as of yet, has not been reached. The statutory deadline for reaching safe yield is 2025; most conclude this goal will not be reached by that time (Larson et al., 2009; Maguire, 2007; ADWR, 2003a). As such, the AMAs face a "statutory dilemma" (Maguire, 2007, p. 366). Since the AMAs are not on track to reach safe yield, having the goal of safe yield on the books and not reaching it can be problematic. If there is "no penalty for not getting there, then people might say, 'Well, let's just not worry about the goal at all'" (Water-agriculture expert #2, personal communication, February 25, 2010). Reaching safe yield is a broad issue dealing with retirement of lands, groundwater augmentation and recharge, and other large-scale, AMA-wide actions.

Yet despite the restrictions placed on agricultural water use through the establishment of the GMA, per-acre water consumption by agriculture has not decreased (Needham & Wilson, 2005). According to the study, agricultural water consumption remained relatively constant from 1980-2002, with crop prices, water prices, weather, total acreage, and crops grown explaining most of the variation in water purchased and withdrawn from the AMAs, not the GMA's conservation requirements (Needham & Wilson, 2005). Additionally, they argue that the Act is ineffective at inducing farmers to reduce water consumption on their farms because it did not establish a binding water constraint since water allotments were calculated based on historic water use between the years 1975-1980 (Needham & Wilson, 2005). These five years represent the peak of irrigated acreage in Central Arizona over the last 40 years; according to Needham and Wilson (2005), water was, for most growers, generously allocated.

To further understand why the GMA has not increased per-acre water conservation, Frisvold, Wilson, and Needham (2007) suggest four effects upon which agricultural water use depends: 1) crop mix effects (which crops are grown), 2) scale effects (total acreage), 3) water technology effects (types of irrigation systems used), and 4) location effects (where crops are grown) (p. 137). As it stands, the GMA's only binding regulation actually reducing agricultural water use is the prohibition of the expansion of irrigated agricultural acreage, a type of scale effect. What a farmer chooses to grow is a way to cope with changes in the agricultural market, and current institutions in Arizona have no say in regulating what a farmer can and cannot grow (crop mix effect).

Water technology effects hold more promise to reducing water demand, and have been employed and installed on many farms in the Phoenix and Pinal AMAs. Yet efficiency can mean that the same amount of water simply goes further. For instance, higher irrigation efficiency—through the implementation of laser-leveled fields or drip irrigation, for example—might allow a farmer to double crop his or her acres because the same amount of water is used over two crops without exceeding the ADWR-assigned irrigation water allotment for those acres. Additionally, farmers can plant more water-intensive crops if the irrigation efficiency technologies they have implemented on their farm reduce the amount of water lost to seepage or evaporation, thus allowing more water to be taken up by the plant (Water-agriculture expert #5, March 4, 2010).

On the other hand, irrigation efficiency technologies (water technology effects) can contribute to a significant decrease in the amount of water applied to fields, and thus make an impact on per-acre water conservation. As Frisvold et al. (2007) found, the aforementioned water technology effects can make a large impact in the water applied to a field to grow crops. Farms relying solely on flood and gravity systems—systems associated with low water efficiency, where water is distributed by gravity (United States Geological Survey, 2000)—applied about 4.3 acre-feet of water per acre. Farms employing drip or sprinkler irrigation (systems associated with high water efficiency) applied significantly less, 3.4 acre-feet of water per acre (Frisvold et al., 2007).

Lastly, some suggest that per-acre agricultural water conservation has thus far not been achieved in part because conservation was not the most influential mechanism by which the GMA planned on reaching reach safe yield:

> The conservation programs were not really intended to be the direct linkage to getting to the goal [of safe yield], so you see things like purchasing and retiring [agriculture water rights], as well as [groundwater] augmentation as the main ways to reach that goal" (Water-agriculture expert #7, personal communication, March 9, 2010).

Signals of Scarcity

What are the implications of this stable water consumption by agriculture in the Phoenix and Pinal AMAs? In addition to helping reveal how rules affect resource users and vice versa, analyzing the Groundwater Management Act with a focus on agriculture provides greater insight into the role that institutions play in mediating trade-offs between effective management of inter-annual variability (e.g. farmers' responses to extreme temperatures or fluctuations in the agricultural market) and adaptation to longer-term impacts such as climate change and groundwater overdraft. By approaching the conservation discussion from the lens of adaptation, I demonstrate that the various institutional amendments won by agriculture may be serving as an impediment to adaptation to potential risks, such as long-term drought. Upon investigation, the GMA's amendments for agriculture appear to block farmers from signals of scarcity because a farmer can call upon his or her flex credits, or take advantage of not having an irrigation efficiency standard or assigned water allotments (as in the BMP program) to adjust to perturbations such as climate or market demand. Thus, instead of using less groundwater in times of water scarcity, the amendments to the GMA helped buffer farmers from experiencing the full brunt of such a reality.

Scholars have long demonstrated that institutions can impede or promote the flow of information such that resource users are able to respond to looming or current scarcity (Hanna, 1999; Costanza & Perrings, 1990). In the case of agricultural water use and the GMA, the institution has been modified with flex credits, the BMP program, and the reduced irrigation efficiency standard, giving farmers various tools to ensure their water use is flexible, particularly in times of need (often the times of the highest scarcity). Through these modifications, the GMA effectively buffers farmers from signals of longer-term environmental trends (such as extended or more frequent drought periods) and reduces the incentive to address per-acre water conservation with specific management practices as a method of preparing for possible future shortages. Instead, farmers can respond to inter-annual variability by cashing in on flex credits if they need to. However, by doing this, farmers do little to reduce their exposure to the possibility of increasing competition for scarce water resources now and into future. Of the three GMA amendments, flex credits are especially interesting because they convey idea that water is constantly available, although replenishment of aquifers and distribution from surface flows vary year-to-year. Thus, the use of flex credits now is independent of the availability of water in the future. Lastly, flex credits perpetuate the idea that an individual farmer's water consumption has no effect on the collective availability of the groundwater CPR. This relates back to the CPR discussion in that the flex credit amendment to the GMA negates the fact that groundwater is subtractable, meaning one's use affects another's ability to use that resource.

In this sense, the GMA has served as an impediment to effective adaptation, since the pressure to adapt and change was lessened with the addition of the institutional amendments. While in the short term such policies appear to enhance farmers' robustness to inter-annual climatic and economic variability in the face of stress, the implications for the broader social-ecological system are questionable.

One plausible scenario could involve the curtailment of in-lieu (of groundwater) surface water deliveries of Central Arizona Project (CAP) water to farmers due to low flows on the Colorado River. Farmers could then legally demand and use their stored flex credits to irrigate their crops. Such a high demand on the groundwater basins could have drastic impacts on the sustainability of the resource base. Additionally, farmers could significantly increase their water use during prolonged drought conditions or extreme temperatures with the BMP program, which places no limits on how much water can be used by farmers, as long as they use certain irrigation efficiency practices on the farm. Scholars note that despite predictions that reductions in agricultural water use would free up the supplies needed for the West's burgeoning population, it does not appear that irrigation will be giving way soon (Blomquist et al., 2004). Although cities and suburbs displace thousands of acres of farmland per year, agricultural production is intensifying on remaining land, meaning that reduced agricultural acreage does not necessarily translate into reduced agricultural water demand (Blomquist et al., 2004, p. 5). Both of these scenarios have the potential to compromise the sustainability of the resource base. In other words, the short-term gains for farmers could have an impact on the long-term availability of groundwater in the AMAs.

However, if farmers implemented greater water conservation techniques, they may be better prepared in times of scarcity, because they need less water to achieve the same satisfactory outcome on their farm. Thus, their adaptive capacity to scarcity shocks increases. Water-conserving technologies allow farmers to save money when water is not scarce by using whatever water is available as efficiently as possible. However, if water does become scarce, on-farm efficiency technologies enable farmers to adapt to the scarcity conditions, when they might not have been able to do so otherwise.

Improving On-Farm Water Conservation

Instead of focusing on eliminating more agricultural land as a way to conserve groundwater, only to have it pumped later by a new suburban development, thus doing little to eliminate long-term overdraft issues, I will now emphasize the important role agriculture can play in conserving a substantial amount of water. As demonstrated above, agricultural water conservation not only benefits the groundwater basins, it can also boost the capacity a farmer has to adapt in scarcity situations. To develop recommendations and suggestions for boosting per-acre water conservation, I interviewed experts in water and agriculture, as well as central Arizona farmers.

Increasing per-acre water conservation in agriculture remains an elusive yet important component in managing Arizona's groundwater resources sustainably, and one that can be implemented at the farm-level. Defined as the reduction of water use through enhanced efficiency (Gleick, 2002), conservation is critical to the future of Arizona as both groundwater and surface water supplies are predicted to become scarcer through long-term drought and increased urbanization (McKinnon, 2009a; McKinnon, 2009b). Conservation is critical to the performance of the Phoenix and Pinal AMAs because obtaining new supplies, through augmentation or importation for example, is expensive and "increasingly problematic" (Larson et al., 2009, p. 108). Conservation is important to the ADWR as well, and according to the Department, to reduce groundwater consumption by agriculture, improvements of on-farm irrigation systems and increased farm management will continue to be necessary (ADWR, 2003a). Agriculture contributed 46% of the total overdraft in the Phoenix AMA in the year 1995 (ADWR, 1999a). By reducing the amount of water consumed per-acre, agriculture's contribution to overdraft can be mitigated, and the performance of the groundwater basins improved.

General, repeating themes from the primary data interviews included the sentiment that more state-level statutory negotiations and amendments to curb agricultural water use are not going to be effective at achieving conservation, mainly because the previously discussed institutional battles have left both the ADWR and farmers politically exhausted. Similarly, both experts and farmers suggested that achieving greater agricultural water conservation is likely to come from economic incentives that farmers choose to implement on their farms, not increased regulation. Lastly, it was often expressed that farmers want to be as efficient with their water use as economically possible because water is an input cost and anything that reduces costs is appealing to farmers as business operators. To develop strategies to conserve water, efforts to tap into this social (agriculturalist/farmer) norm should be increased.

Specific recommendations. Specific recommendations from those interviewed will now be highlighted. By interviewing central Arizona farmers, I attempt to understand how the people immersed in the day-to-day nuances of growing crops interpret water conservation and its importance (if any). Additionally, through the interviews, I elicit any suggestions for increasing conservation farmers might offer. Supplementing the farmer interactions, I interviewed experts in water and agriculture to understand the broader picture of historical and present groundwater policy. Obtaining experts' views on potential methods for increasing per-acre conservation provides a balanced picture with what farmers suggested. Many of the suggestions from farmers and experts are compatible, and some even compliment each other.

With this original contribution of primary interview data, some implementable suggestions surfaced, and will be further reported to regional and national agricultural organizations. Please note that some suggestions tend to reflect farmers' experiences and with various local, state, and national agricultural organizations, and thus are very specific.

The recommendations for increasing water conservation on farms in central Arizona include:

1. Recognition by the Natural Resources Conservation Service (NRCS)—a USDA-sponsored organization that "works with landowners through conservation planning and assistance designed to benefit the soil, water, air, plants, and animals that result in productive lands and healthy ecosystems" (Natural Resources Conservation Service [NRCS], 2010a)—of the temporary nature of farming in central Arizona, a rapidly urbanizing area. By recognizing that farmers move around the area and farm different plots of land depending on their specific situation, the NRCS could adjust their requirement necessitating proof of land tenure to receive funding for water conservation improvements. This would allow more farmers who are leasing land the opportunity to participate in NRCS grants and other opportunities (Farmer #5, personal communication, February, 16, 2010).
2. Many farmers now lease the land they farm from developers who are not yet ready to develop. Leases tend to be temporary in nature, with some only season-to-season. With such short time horizons and uncertainty about the duration that one will be farming, investment in water savings technologies decreases. With greater access to incentives—state tax credits or federal matching funds, for example—to install efficient irrigation systems (such as sprinkler, drip, level basin), a farmer could recoup his or her investment faster and be more likely to invest in water savings technologies on the farm (Farmer #2, personal communication, February 10, 2010; Farmer #5, personal communication, February, 16, 2010; Water-agriculture expert #1, personal communication, January 28, 2010).

3. An increased presence of the USDA's Environmental Quality Incentives Program (EQIP) in Arizona. EQIP provides a "voluntary conservation program for farmers and ranchers that promotes agricultural production and environmental quality as compatible national goals. EQIP offers financial and technical help eligible participants install or implement structural and management practices on eligible agricultural land" (NRCS, 2010b) (Water-agriculture expert #1, personal communication, January 28, 2010).
4. Promote the leasing (instead of the ownership) of portable irrigation systems, such as sprinklers and drip. By leasing portable water-savings technologies, farmers who do not want to purchase a permanent physical structure, because they are unsure of the duration that they will be farming on a specific plot of land have another way of accessing efficient irrigation technologies (Farmer #5, personal communication, February, 16, 2010).
5. The ADWR sponsors a Water Management Assistance Program and has other funds to help the agricultural sector implement on-farm water efficiency technologies (ADWR, 1999b). Continue to promote and make farmers aware of the assistance that is available to them. "[It is] funded every year and only a handful of people take advantage of it" (Water-agriculture expert #8, personal communication, March 10, 2010).
6. Increased farmer education. Farmers who have been irrigating a certain way their whole life may just continue to operate in that manner because they are accustomed to certain methods of irrigating. Through the practices associated with the BMP program, for example, farmers can see how efficient practices are

implemented on the farm and how they save water (Water-agriculture expert #8, personal communication, March 10, 2010).

7. Although there would be implications on the economics of farming, raising the price of water would induce significant water savings on farms because if something is more expensive, people tend to use less (Water-agriculture expert #4, personal communication, March 4, 2010; Water-agriculture expert #5, personal communication, March 4, 2010; Water-agriculture expert #6, personal communication, March 5, 2010).

From these suggestions, it is evident that many farmers are concerned with the temporary nature of their operations, and the impact that land tenure has on implementing great water conservation measures. However, these recommendations represent tangible actions farmers and policymakers at the state and federal level can take to boost water conservation relatively quickly. These suggestions are promulgated in hopes of maintaining a certain level of farmer robustness, while also contributing to per-acre water conservation, which can help maintain the viability of the groundwater basins in south-central Arizona.

Chapter 6

Conclusion

The GMA achieved two things crucial for meaningful groundwater reform in its attempt to reduce overdraft: it quantified transferable (and therefore valuable) water rights of existing users, and it broke free of the groundwater overdraft cycle by placing restrictions on what were previously individual property owner rights (Glennon, 2002). Additionally, the GMA "actually required the measurement and reporting of water use. ... Before you can actually really get a handle on anything, you have to measure [use] and figure out who is using how much water, and where" (Water-agriculture expert #7, personal communication, March 9, 2010). Prior to the GMA, there were no such measuring requirements.

The rules of the GMA also greatly altered farmers' permissible actions concerning the groundwater they could pump and apply to their fields. With institutions that "close" open access regimes, or in the case of the GMA, a partially open access regime (due to the private property rights previously associated with pumping groundwater), if everyone follows the new rules, then "resource units will be allocated more predictably and efficiently, conflict levels will be reduced, and the resource system itself will be sustained over time" (Ostrom, 1990, p. 43). However, in the case of the GMA, not everyone followed the new rules. As demonstrated in the analysis, farmers not only refused to follow some of the new rules, they fought to change them altogether.

Given that resource users have livelihoods to maintain, it is not surprising that farmers fought to maintain their water use flexibility. Nor should farmers be singled out as different from other resource users in wanting to amend the GMA. Industrial and municipal users have lobbied for similar amendments to the GMA since 1980 as well. A promising area of further research lies in conducting a similar analysis of the institutional design and change of the GMA for the industrial and municipal sectors. Highlighting all three sectors would provide a more balanced picture to how groundwater users in the Phoenix and Pinal AMAs have approached and adapted the institution of the GMA. Further study of all three sectors could contribute an enhanced understanding of how to best mediate the trade-off between short-term robustness of the resource users and long-term sustainability of the Social-Ecological System encompassing the Active Management Areas of south-central Arizona.

An additional area of future research includes conducting a comparative assessment of farmers' risk perceptions to future water scarcity. By performing another institutional analysis, this time pertaining to the rules governing agricultural water use outside the jurisdiction of the GMA, I could explore the specific implications of water management institutions on the process of adaptation to experienced and anticipated water scarcity. Evaluating the use of water by agriculture within and outside the physical and institutional boundary of the AMAs allows researchers to identify the drivers of farmers' actions and lessons learned to enhance the institutional context of adaptation and the adoption of conservation technologies.

Furthermore, discussing per-acre water conservation as a method of adaptation to future shocks such as prolonged drought demonstrates that conserving water can have benefits to agriculture. By installing efficiency techniques such as those recommended by farmers and experts, the remaining irrigated acreage in the AMAs might be better prepared in times of scarcity. Instead of buffering themselves from information flow indicating a looming shortage, for example, farmers could be better prepared to weather the impacts of prolonged drought without having to draw down the aquifer by accessing flex credits or irrigating without a limited allotment.

To some, the GMA has been quite successful in reducing Arizona's reliance on groundwater (Jacobs & Holway, 2004). Others assert that the Act has been greatly weakened over the years since 1980 and that it is not doing enough to curb groundwater overdraft (Hirt et al., 2008). Instead of seeing the rule adjustments made for agriculture since 1980 as less strict water management, this examination of the institutional design and alterations of the 1980 Groundwater Management Act provides a fuller picture of the various factors to consider when constructing institutions to manage scarce resources. In the case of the GMA, without proper considerations of farmers' needs, the Act's originally strict provisions meant little over time after farmers won amendments.

The plight of Arizona to sustainably manage its natural resources while at the same time meet the needs of those who rely on the resources is not unique. Many communities, regions, and nations continue to experience the difficult task of providing sufficient resources for growing populations while meeting the obligation to future generations. What is useful about this case study of agriculture and groundwater use in south-central Arizona is the acknowledgment of resource user needs (perceived or otherwise) and socio-economic norms. When the concerns of those regulated by a new institution are not considered, trouble often lies ahead. In this case, the trouble manifested with three main institutional changes for agriculture that boosted farmer robustness to certain shocks, but which appear to have implications for the overall sustainability of the resource base. Of course, acknowledging and understanding the concerns of the resource users is not a cure-all for effective governance, however, it is one way to approach the design of institutions governing common-pool resources.

Ostrom's (2009) framework allows researchers to gather information systematically and compare cases more effectively. Further work on this topic includes condensing this thesis into a quickly readable case study format for inclusion into an electronic library of other CPR cases to ensure the continued analysis of how institutions interact to impact the sustainability of Social-Ecological Systems around the world.

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APPENDIX A

IRB APPROVAL FORM

ARIZONA STATE UNIVERSITY
RESEARCH AND ECONOMIC AFFAIRS

Office of Research Integrity and Assurance

To:	John Anderies ASU School
From:	For ~~ab~~ Mark Roosa, Chair Soc Beh IRB
Date:	11/02/2009
Committee Action:	**Exemption Granted**
IRB Action Date:	11/02/2009
IRB Protocol #:	0910004497
Study Title:	Agriculture, Water, and Institutions: An Investigation of Water Management Policy and Its Effects on Water Use by Agriculture in Arizona

The above-referenced protocol is considered exempt after review by the Institutional Review Board pursuant to Federal regulations, 45 CFR Part 46.101(b)(2) .

This part of the federal regulations requires that the information be recorded by investigators in such a manner that subjects cannot be identified, directly or through identifiers linked to the subjects. It is necessary that the information obtained not be such that if disclosed outside the research, it could reasonably place the subjects at risk of criminal or civil liability, or be damaging to the subjects' financial standing, employability, or reputation.

You should retain a copy of this letter for your records.

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