A Comparative Assessment
of Community Water System Vulnerability to Water Scarcity
in Buckeye and Cave Creek, Arizona

by

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A Thesis Presented in Partial Fulfillment
of the Requirements for the Degree
Master of Arts

Approved November 2011 by the
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ARIZONA STATE UNIVERSITY

December 2011
ABSTRACT

With the ongoing drought surpassing a decade in Arizona, scholars, water managers and decision-makers have heightened attention to the availability of water resources, especially in rapidly growing regions where demand may outgrow supplies or outpace the capacity of the community water systems. Community water system managing entities and the biophysical and social characteristics of a place mediate communities’ vulnerability to hazards such as drought and long-term climate change. The arid southwestern Phoenix metropolitan area is illustrative of the challenges that developed urban areas in arid climates face globally as population growth and climate change stress already fragile human-environmental systems. This thesis reveals the factors abating and exacerbating differential community water system vulnerability to water scarcity in communities simultaneously facing drought and rapid peri-urban growth.

Employing a grounded, qualitative comparative case study approach, this thesis explores the interaction of social, biophysical and institutional factors as they effect the exposure, sensitivity and adaptive capacity of community water systems in Cave Creek and Buckeye, Arizona. Buckeye, once a small agricultural town in the West Valley, is wholly dependent on groundwater and currently planning for massive development to accommodate 218,591 new residents by 2020. Amid desert hills and near Tonto National Forest in the North Valley, Cave Creek is an upscale residential community suffering frequent water outages due to aging infrastructure and lack of system redundancy. Analyzing interviews, media accounts and policy documents, a narrative was composed explaining how place
based factors, nested within a regional institutional water management framework, impact short and long-term vulnerability. This research adds to the library of vulnerability assessments completed using Polsky et al.’s Vulnerability Scoping Diagram and serves a pragmatic need assisting in the development of decision making tools that better represent the drivers of placed based vulnerability in arid metropolitan regions.
DEDICATION

For my family.

With passion, perseverance, unwavering support and unconditional love, all things are possible.
ACKNOWLEDGMENTS

I would like to express my sincere gratitude to the residents, elected officials and water management professionals of Cave Creek and Buckeye, Arizona. I would also like to thank my graduate committee, Kelli Larson, Ph. D, Bob Bolin, Ph.D, and Netra Chhetri Ph.D. for their support, patience and thoughtful guidance. Lastly, I would like to thank Deidre Pfeiffer, Ph.D. and my sister, Alethea Guy.
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Chapter 1

Introduction and Purpose

Water scarcity affects more people directly than any other hazard, making it a truly global issue (Hayes et al. 2004). Despite the impossibility of precisely predicting the effects of global climate change on local precipitation rates, research overwhelming points to increased variability in precipitation patterns. The regional impacts of drought will be exacerbated by global climate change. These changes are expected to amplify the duration, severity and frequency of weather-related hazards such as drought and flood. In the Western United States, rising temperatures are expected to increase evapo-transpiration rates, decreasing the amount of water stored in mountainous snowpack—a source that accounts for up to 75% of the region’s fresh water supply (Pulwarty et al. 2005). The Western United States, especially Arizona and Nevada, are currently experiencing rapid population growth—while in the midst of a severe decadal drought—potentially increasing the impacts of arid climate conditions and limited water resources in the region.

At the nexus of growth, drought and climate change lie the local community water system (CWS). In the CWS, the human, financial, and structural resources of formal management combine with biophysical and hydrologic systems to provide for the water resource needs of a community (Dow et al. 2007). In the southwest, the CWS mediates the impacts of climate variation and drought while simultaneously coping with the suite of pressures inherent in growth (Polsky and Cash 2005). Given indications that climate change will create
a harsher environment in the West, local community water systems should evaluate and address their current vulnerability to water scarcity in order to increase their ability to adapt and mitigate losses in the face of potential extreme drought events in the future (Dow et al. 2007; Pulwarty et al. 2005).

Vulnerability to a hazard, in general, describes a potential for loss and is composed of three dimensions: exposure, sensitivity, and adaptive capacity (Polsky et al. 2007). Exposure refers to the hazard itself and is evaluated in terms of the frequency, duration and intensity of a hazardous event. Sensitivity relates to the social and biophysical attributes of a system that increase its susceptibility to loss and weaken its ability to cope with a hazard. Lastly, vulnerability is dependent on the adaptive capacity of a system, largely determined by the human and institutional characteristics that increase its ability to adapt to adverse conditions or events. In order for a system to be considered vulnerable, following this conceptualization, it must be exposed to a hazard, sensitive to exposure and the adverse effects of the hazard, and unable to cope with or adapt to disturbances to biophysical, social, or coupled human-environmental systems (HERO 2004; Polsky et al. 2007).

A review of the vulnerability literature shows an evolution from the narrow concept of biophysical vulnerability assessment to the anthropocentric conceptualization of social vulnerability, finally arriving at a comprehensive framework for assessing the vulnerability of an entire human-environmental system (Adger 2006; Turner et al. 2003). The field has reached a point in its development at which consensus has grown regarding the components and
relationships necessary to assess vulnerability to natural hazards. Accepting the notion that vulnerability embodies the exposure, sensitivity and adaptive capacity of a system, research aims to reveal the intricate interplay of biophysical, social and institutional factors in mediating vulnerability to water scarcity in particular places. Researchers now call for the development of improved, system specific assessment frameworks that can be combined to better illustrate the comprehensive vulnerability of discrete places (Cutter 2003a; Morehouse 2000; Polsky et al. 2007). Further, scholars call for the standardization of assessment tools and frameworks as a means to more readily and accurately compare vulnerability across regions and over time without ignoring or oversimplifying local context (HERO 2004; Morehouse 2000; Polsky et al. 2007).

Research in institutional capacity has a long standing within the fields of natural resource management, business administration, and community development (Ivey et al. 2006). Formal institutions include the official laws, processes, and organizational bodies of a society. Theory and methods from this rich history of research are now applied to vulnerability research to frame and assess formal institutional capacity (Hersh and Wernstedt 2002). There is ongoing debate as to the specific factors that should be operationalized to assess institutional capacity. However, scholars generally agree that capacity is influenced by institutional arrangements and institutional structure such as home rule and strong versus weak forms of local governance in addition to human and financial resources and community involvement (Biswa 1996; De Loe et al. 2002; Hersh and Wernstedt 2002; Ivey et al. 2004; Ivey et al. 2006).
Drought is a relative term that cannot be defined outside of its geographic context. Measures of duration, frequency, and intensity generally combine to create geographically specific definitions of drought. Duration refers to how long a period of drought lasts, frequency refers to how often drought events occur, and intensity refers to how dry conditions are during a drought event. Intensity is generally measured as a percent of the long-term average precipitation. However, drought can be classified as meteorological, hydrological, agricultural or socio-economic depending on how the lack of water affects precipitation patterns, water-source levels, soil moisture, or human activities. The rate at which a meteorological drought progresses to another classification depends on the levels of sensitivity and adaptive capacity held by the associated population or system under consideration. For example, a region can suffer from a meteorological drought made evident by a lack of precipitation but will only suffer a socio-economic drought if the lack of precipitation progresses to directly or indirectly negatively effect a social or economic process such as growth, migration, or food production.

Arizona’s population growth rate is second in the nation. The population of the Phoenix metropolitan area is projected to double within the next forty years. Much of this growth is occurring on the urban periphery in the form of suburban development. Currently, while the state is in the midst of a severe multi-year drought, overall water demand is expected to increase by 15% by the year 2040 (Morehouse 2000). The Towns of Buckeye and Cave Creek, along with other local municipalities undergoing rapid land-use change, are charged with
balancing the demands of growth with limited supplies of surface water or groundwater. Concurrently, federal support for water infrastructure development and improvement is declining while state mandated regulation is increasingly complex. The combination of water scarcity, growth and changing levels of state and federal involvement are heavily affecting the capacities of Buckeye and Cave Creek to manage water resources. The vulnerability of community water systems (CWS) is determined by the extent to which the structure or processes of a CWS are susceptible or unable to adapt to biophysical or social perturbations such as drought, climate change and population growth (Adger 2006; Ivey et al. 2006).

There is a conceptual and pragmatic need to assess the CWS vulnerability to water resource scarcity among fast growing peri-urban communities in Arizona and elsewhere (Dow et al. 2007; Maguire 2005). Peri-urban communities in Arizona are undergoing rapid growth and tend to rely mostly on non-renewable groundwater sources or less secure, low priority surface water sources. The combination of these factors creates the potential for increased vulnerability to water scarcity. Buckeye is groundwater dependent a peri-urban area in transition that illustrates region-wide patterns of rapid annexation and land-use change, which increases pressure on institutional capacity. The peri-urban Town of Cave Creek relies on surface water and illustrates another region-wide trend toward municipal control of community water systems. Like Buckeye, Cave Creek is also under development pressure, despite their support of open space preservation. A comparative case study of the community water systems (CWS) of Cave Creek and Buckeye will help to explore the differential effects of internal social,
institutional and biophysical characteristics on system vulnerability. The two
towns have similar municipal governance structures and are currently exposed to
similar meteorological drought conditions. However, they vary greatly in their
socio-economic characteristics, access to water resources, and biophysical
properties.

A comparative case study of these communities will aid in the
advancement of a contextually appropriate framework for assessing local CWS
vulnerability. The resulting framework will operationalize place-specific factors
affecting vulnerability in a manner that suits the complex web of water
management in Arizona, particularly in the Phoenix metropolitan region. Further,
this framework can be inserted as a component into a comprehensive framework
for assessing overall human-environmental system vulnerability to water scarcity
in an arid metropolis.

This thesis contributes to the pragmatic and conceptual need for
comprehensive assessment of vulnerability to water resource scarcity by focusing
on the biophysical, social and institutional factors that influence community water
systems vulnerability. In doing so, I have answered the following research
question.

**RQ:** In the arid, urban periphery of the Phoenix metropolitan area what
are the factors abating and exacerbating differential community water
system vulnerability to water resource scarcity in the face of rapid peri-
urban growth?

Based on a review of the literature and preliminary research I expected to
find that the main factors affecting the vulnerability to water resource
scarcity will be institutional arrangements within the state of Arizona,
characteristics of the municipal management structure, lack of municipal
revenues, local community involvement and representation and diversity of and access to water sources.

To determine the factors abating and exacerbating CWS vulnerability, I have followed an inductive process that follows a grounded theory approach involving, qualitative, case study methodology. Data pertaining to hazard exposure, system sensitivity and adaptive capacity were organized using Polsky et al.’s Vulnerability Scoping Diagram (VSD) (Polsky et al. 2007). The VSD is a tool used to organize and represent exposure, sensitivity and adaptive capacity factors contributing to vulnerability (Figure 1). I began by creating a contextual research backdrop that combined biophysical, social and formal institutional characteristics for the study areas of Buckeye and Cave Creek, Arizona. This information revealed points of exposure to drought stress and socially derived sensitivities to biophysical stress. The contextual backdrop also began to identify potential areas of adaptive capacity derived from formal management practices and institutional agreements. Next, I used semi-structured, open-ended interviews with municipal managers and policy officials to identify institutional factors that exacerbate or mitigate vulnerability to potential water scarcity. Finally, I substantiated interview responses by reviewing official state and local policy documents that outline existing institutional arrangements, resource allocations, and management structures relating to water resource management.

I inductively analyzed the two sets of interviews from each community and combined the major themes found in each with the factors identified from policy documents. I used the combined set of findings to create an understanding
of the complex factors that affect vulnerability to water resource scarcity in Buckeye and Cave Creek, Arizona. The data from policy documents, interviews and other sources were organized into the VSD. Finally, I used the completed Vulnerability Scoping Diagrams to create an integrative descriptive narrative comparing the two communities. The comparative narrative illuminates place specific characteristics that create differential vulnerability while informing broader understanding for comprehensively assessing vulnerability to water scarcity in the arid region.

Figure 1. Vulnerability Scoping Diagram
Chapter 2

Literature Review

Among academics, international and local policy makers, the environmental and societal impacts of natural disasters are gaining attention within the field of hazards research and under the realm of vulnerability. In December of 1987, the U.N. designated the 1990’s as the Decade for Natural Disaster Reduction. This designation was given by the General Assembly in an attempt to put institutional support and funding behind research and policy geared toward reducing disaster-related losses. In order to reduce human, environmental and economic losses, vulnerability to disaster impacts must be understood and addressed (Blaikie et al. 1994).

The term vulnerability has taken many forms involving biophysical, social, institutional and economic aspects (Janssen 2006). While experts often focus their discussions of vulnerability of different elements, the majority has come to agree that vulnerability refers to the “degree to which a system is susceptible to and is unable to cope with adverse effects” (Adger 2006: 269). Varying interpretations of the concept of vulnerability have resulted in divergent schools of thought as to how to conceptualize and measure vulnerability. Literature within the field focuses on the biophysical causes, the social causes, or a combination of the two. Integrated conceptualizations of vulnerability tend to incorporate characteristics of physical exposure, system sensitivity, and individual
and institutional adaptive capacity into placed-based assessments of single or multiple hazards (Cutter et al. 2000; Polsky et al. 2007).

In order to lay out the conceptual underpinnings of this research, I will review the vulnerability literature primarily as it applies to water scarcity and resource management. First, a review of the main themes and critiques of biophysical and social vulnerability research is presented, followed by a discussion on the capacity of formal management institutions to mitigate vulnerability. Finally, the literature on comprehensive vulnerability assessment is synthesized to provide the theoretical foundation for this research.

**Biophysical Vulnerability**

The field of water management has historically been rooted in the realm of the biophysical and engineering sciences. Early assessment of vulnerability to water-related phenomena was centered specifically on units of biophysical stress (Hurd et al. 1999). Commonly referred to as hazards research, biophysical assessment tends to focus on the likelihood of human exposure to probable stressors or natural disasters (Cutter 2003a; Eakin and Luers 2006; Montz et al. 2003). As such, research has focused on predicting natural hazards. In this respect vulnerability is a function of exposure. Exposure to a natural hazard is measured in terms of “magnitude, frequency, duration, aerial extent, speed of onset, spatial dispersion and temporal spacing” (Adger 1996: 34).

Early hazards research centered on biophysically induced risk was undertaken with a positivist epistemology. Researchers placed human needs and
societal processes at the center of a one-way (environment to human) linear cause-and-effect conceptual framework in which a physical process was viewed as the cause of risk. The diverse nature of society is often oversimplified into a homogenous fabric where exposure to a hazard resulted in uniform losses across the public (Eakin and Luers 2006; Vincent 2004; White 1936). Policy informed by such projects tended to create “top-down technocratic policy prescriptions” and centralized resource management institutions led by experts. Absorbing the collective risk of individuals, institutions created in this vein were designed to collect scientific knowledge on hazards and design physical mechanisms that limit exposure to such hazards (Adger 1996). Applied to water related hazards this style of management results in heavy investment in drought and flood forecasting as well as capital intensive dam and levee projects.

Still practiced today, biophysically centered hazards inquiry often seeks to quantify and model the probability of an environmental or technologic perturbation, as a means of controlling the possible impacts on the human elements of the system (Vincent 2004). Until recently, climate change science had followed suit by basing the assessment and projection of climate change impacts mainly on biophysical attributes of a region (Adger 1996). The Water Evaluation and Planning System (WEAP) model developed by the Stockholm Environmental Institute is a computer program for water resource planning that allows the user to input biophysical and institutional factors such as supply, demand, storage, technology, use patterns and water allocations into a scenario building model in order to predict and plan for a variety of outcomes. Hurd et al.
used supply and demand figures to develop a set of measures that were used to assess the current and potential vulnerability of regional water systems to current hazards and climate change. Both are two examples of quantitative biophysically centered models used for assessing the vulnerability of human populations to water resource variability (Hurd et al. 1999; Levite et al. 2003). Both projects serve to identify at-risk water systems and areas in need of future case study research. Independently heralded as revolutionary works for their respective ability to cover water supply, human demand, and multiple environmental stressors, as well as provide needed decision making tools, these models fail to fully account for social and institutional factors that often mediate vulnerability to water resources (Adger 2006; Downing et al. 2005).

Political ecology, a field aimed at understanding the underlying political, social and economic structures affecting the human-environmental system, criticizes exposure-based research as being incomplete and detrimental to the aim of reducing vulnerability (Blaikie et al. 1994). This critique generally stems from a lack of appreciation for the technocratic engineered management solutions commonly born of exclusively biophysical hazards assessment (Brendle 2002). In poverty and livelihood research, political ecology asserts that by engineering infrastructural and technological solutions to societal problems, the underlying internal and external causes of vulnerability, which are mainly social and institutional structures are hidden and therefore erode the social-environmental fabric. Furthermore, centralized resource management institutions are often faulted for resisting change and implementing programs that exchange long-term
vulnerability reduction for short-term crises management (Adger 1996). The critique further heralds the worth of social assessment as being a means of more thoroughly understanding and advising effective vulnerability remediation policy (Blaikie et al. 1994).

**Social Vulnerability**

There has been an international call to expand the role of water management to include an understanding of the function of social and institutional forces as they pertain to water scarcity (Montz et al. 2003). This influence, exerted from both academia and policy makers, recognizes that past approaches focusing on exposure based risk management have caused an increase in overall long-term vulnerability (Downing et al. 2005; Sarewitz et al. 2003).

Social vulnerability research defines vulnerability in terms of the resistance or resilience of a social system to respond to a stressor such as drought or flood (Cutter et al. 2003b; Eakin and Luers 2006; Folke 2006; Janssen 2006). Studies in social vulnerability generally follow a constructivist approach while exploring the social and geographical characteristics of an individual, group or location that affect their differential abilities to cope with perturbations (Vincent 2004). Unlike biophysical measurements of vulnerability, social vulnerability is hard to quantify and so often goes unmeasured in disaster and hazards research (Cutter et al. 2003b; Downing et al. 2005).

Despite long-standing representation within the social sciences, different social causes of vulnerability have only recently been integrated into water related
risk mediation strategies (Downing et al. 2005). Social differentiation in this sense is created by two main factors: social inequalities that increase susceptibility to exposure; and place inequalities that are born of geographic location and characteristics (Cutter et al. 2003b). Social inequalities are often inferred from general demographics such as age, gender, income, race and occupation, as well as structural indicators such as political power, social networks, and access to public assistance. These characteristics combine with place inequalities to create overall social vulnerability.

Place inequalities can be measured in terms of the level and location of development, as well as the quality of housing stock and other infrastructure (Cutter et al. 2003b). Applying these characteristics to a hypothetical hazard scenario, research would generally hypothesize that a well-educated, wealthy, politically active, middle-aged Caucasian married couple that own a home in a well-established suburb are less socially vulnerable because they can afford to purchase insurance, live within a designated community and have access to community decision making bodies and services. Concurrently, an uneducated, young African American single mother living in a rental property in a single-industry rural community would be said to have a much higher level of social vulnerability. While most agree that demographic - and place - specific concepts are imperative in determining a populations’ sensitivity and ability to cope with stressors, there is much debate over the appropriate metrics for measuring and ranking of indicators as they interrelate and influence increases or decreases in vulnerability (Janssen 2006). To date, Cutter et al.’s (2003b) Social Vulnerability
Index (SoVI) and methodological framework stands out as the most widely accepted guide to quantifying social vulnerability. The SoVI index uses socio-economic and demographic data to create a comparable social vulnerability score for each county in the United States. The index reveals the interrelated nature of social vulnerability factors but does not consider the biophysical or institutional aspects of a system that often mediate the overall effect of natural hazards on a population.

A synthesis of the literature on social vulnerability applied to water management arrives at several key attributes of vulnerability formerly under-recognized within the field. Mainly, the literature reveals that the creation or continuation of differential vulnerability (Cutter et al. 2003b; Downing et al. 2005) is a dynamic process (Cutter 2003a; Folke 2006) acted upon by multiple actors within varying social and institutional networks (Mehta 2001; Morehouse 2000; Robbins 2004). Research also stresses the importance of recognizing that vulnerability to multiple simultaneous stressors (Wilhite et al. 2005) lies within nested geographic and temporal scales (Downing et al. 2005; Wescoat 2003).

Socially centered hazards research is criticized for failing to fully recognize the complex and adaptive feedback linkages in human-environmental systems. By analyzing the impacts of stressors through an anthropogenic lens, researchers claim that the vulnerability of the environmental component of a system is ignored, doing a great disservice to the entire system (Eakin and Luers 2006; Turner et al. 2003). Researchers geared toward creating a general vulnerability theory that can be applied across varying temporal and spatial scales,
often criticize social assessment for being too place- or subject- specific, thereby not allowing for generalization. In addition, social vulnerability research can be criticized for over-simplifying the human component of risk by discounting the adaptive role of personal risk perception and unique coping mechanisms, especially those that go beyond descriptive demographic and place characteristics. When applied specifically to assessment of CWS vulnerability, research focusing on social vulnerability is inadequate if it does not fully incorporate the role of formal institutions in mediating the effects of water scarcity on individuals.

**Institutional Vulnerability**

Vulnerable systems are those that do not have the capacity to cope with or adapt to perturbations. Institutions are the “rules, organizations, and social norms that facilitate coordination of human action” (World Bank 2003). Institutions are often categorized as informal and formal. Formal institutions include the official laws, decision-making processes, and organizational bodies of a society, whereas informal institutions refer to societal norms, beliefs and unwritten rules governing society (Ivey et al. 2004). Research in institutional vulnerability falls under the wider social vulnerability agenda as a subset of factors that affect a society’s collective ability to cope with hazardous perturbations. Past research has assessed vulnerability in terms of an institutional systems’ capacity to adapt to challenging or changing environmental or social conditions (Ivey et al. 2006).

Debate within the fields of natural resources, public administration, business administration, health sciences, and community development can be
illustrated by exploring two main debates that relate to how institutional capacity is operationalized in research and assessment (Lenz 1980). The first stream of debate relates to how capacity is measured. While ultimate survival of an institution may mean success for a business or market, the success of public institutions cannot be evaluated on their mere existence (Honadle 1981). The service argument attests that existence does not always translate to success and that institutions should be measured on a continuum that allows for varying degrees of success, evident by the services provided by the organization (Honadle 1981; Lenz 1980). Measuring the success of an institution on a continuum allows for celebration of nuanced success while revealing vulnerable areas of service in need of improvement.

The second stream of debate on institutional capacity relates to goals and measures of success by the organization. The mission of an organization and the measure of its success can be contingent on means or results (Honadle 1981). In the public administration of water resources management, the processes and results of management and adaptation are integral to the societal objectives and organizational success.

Applied to water scarcity and community water systems, the capacity of a managing organization should be measured on a continuum that considers the means implemented to achieve goals and the final results of coping mechanisms associated with water management and natural hazards. The success of a CWS is not measured solely on the ability to deliver drinking water. For example, the institution must also exhibit social responsibility and economic efficiency while
managing water quality and infrastructure replacement and expansion (Dow et al. 2007). In order to gauge the vulnerability of a formal organization, research is geared toward assessing the means or mechanisms that an organization has available to it for adapting and coping with perturbations and changes (Ivey et al. 2006).

Although scholars debate which discreet factors should be used to represent coping capacity of water management at a local level, there is generally agreement upon the indicators embodying institutional capacity. First, the strength and weaknesses of internal and external institutional arrangements determine whether the CWS managing entity has the authority to set water rates, charge development or impact fees, increase or curtail supplies and pass ordinances. Having this authority increases the flexibility of the management entity to employ a portfolio of coping mechanisms to mediate potential scarcity. Next, the community characteristics of a CWS such as level of public involvement, access to decision making and information, and ethics (e.g., for environmental preservation or water conservation) help to determine the level of public buy-in available for targeted programs that can be enacted to reduce demand as a means of coping with scarcity. High levels of public involvement also tend to lead to higher accountability within the associated political sphere. Third, the development pattern associated with a CWS either increases or decreases its coping capacity. Generally, rapid, uncontrolled growth, especially in biophysically sensitive areas, stresses human and financial resources while steady managed growth places less stress on the system and allows for more deliberate
planning, reflection and adaptive management. Lastly, the human and financial resources of the institution heavily weigh into the coping capacity of the CWS. High levels of institutional knowledge, expertise, capitol funds and availability of credit increase the long-term effectiveness of water and land use planning and financial flexibility- both of which can mediate the real and potential effects of climate or growth induced scarcity. (Biswa 1996; Hersh and Wernstedt 2002; Ivey et al. 2004; Ivey et al. 2006).

The CWS serves as the mediator between climatic variability and community vulnerability to water scarcity. At the local level, place-specific internal and larger scale external institutional mechanisms that facilitate adaptation attempt to compensate for institutional, physical and social sensitivities in the face of water scarcity (Adger1996; Dow et al. 2007). Often, the capacity of a CWS is stressed more by local drivers of sensitivity, such as institutional fatigue, growth, aging infrastructure and increasing state and federal regulation, rather than by actual exposure to drought or physical characteristics of scarcity. As a result research calls for grounded placed-based assessments in order to understand differential vulnerability of community water systems to climatic variation and other perturbations (Dow et al. 2007; HERO 2004; Polsky et al. 2007). Place-based assessment will advance understanding of the spectrum of internal and external drivers and relationships influencing the ability of a CWS to cope under current and future stresses.
Integrated Vulnerability

The late Gilbert F. White first introduced the concept of integrated hazard vulnerability in the mid-20th century through his work in floodplain management. After studying the effects of technocratic, structural floodplain management, White argued that flood related losses are the collective effect of social and biophysical factors. In 1978 Gilbert White elaborated on the causes of disaster and offered this warning:

“Hazard always arises from the interplay of social and biological and physical systems; disasters are generated as much or more by human actions as by physical events; the present forms of government intervention in both traditional and industrial societies often exacerbate the social disruptions from extreme events; if we go on with the present public policy emphasis in many regions upon technical and narrow adjustments, society will become still less resilient and still more susceptible to catastrophes like the Sahelian drought.” (White, 1978)

Over the last decade, critiques from all sides of the debate have led to a revival of White’s original position on integrated vulnerability. As a result, an overarching call to action has been made for the biophysical and social aspects of vulnerability to be integrated into a comprehensive framework for assessment (Cutter et al. 2000; Cutter 2003a; Downing et al. 2005; Turner et al. 2003). Tying assessment frameworks based in biophysical exposure-based hazards research and sensitivity-based social risk frameworks with the structural underpinnings found within political ecology research can be a daunting task. Integrating all three frameworks requires a deep understanding of human-environmental systems that encompasses principals and research methods found in physical, social and political science, among other disciplines.
The Pressure and Release Model (PAR) developed by Blaikie et al. (1994) has been helpful in paving the way towards a truly comprehensive conceptual framework for vulnerability assessment by incorporating both internal and external biophysical and social root causes. The PAR model proposes that the root causes of risk are created by large-scale political-economic structures that exert pressure on the local socio-economic fabric, thus increasing community vulnerability. A disaster occurs when the vulnerable population is exposed to a natural or technological hazard. Further, the model explains that to alleviate a population from unsafe conditions and reduce social sensitivity, the structural root causes of vulnerability must be dealt with it. In other words, to reduce vulnerability requires precautionary socio-political projects that address root causes as opposed to secondary post-hazard impacts. Having served as an initial step toward integration, the PAR model is now criticized for not fully incorporating nested scales of two-way influence and adaptation within the human
environmental system or the potential vulnerability of biophysical components (Adger 2006; Folke 2006; Turner et al. 2003).

As an alternative to the widely cited PAR model, Turner et al. (2003) propose a new integrated conceptual model centered around principals of sustainability that treat the human and environmental elements as integral to the functioning of a system. Representing the emerging resilience branch of vulnerability science, the new model conceptualizes the human-environmental system as a mutually adaptive dynamic system including nested scales of human and biophysical components, which exhibit different exposure, sensitivity and resilience thresholds (Turner et al. 2003). Though complex, this model has been praised for having the potential to incorporate virtually all of the aspects of vulnerability needed to comprehensively depict the social and biophysical forces acting on a system (Adger 2006; Eakin and Luers 2006). Allowing for full representation of the human-environment system in vulnerability assessments is a massive endeavor. Doing so requires the use of both quantitative analysis of socio-economic and environmental indicators as well as processes, and contextually rich narratives of complex socio-cultural and biophysical phenomena. Considering the complexity of this task, the resilience literature backs a call by Cutter (2003a) and others for interdisciplinary collaboration to integrate institutional, social, and biophysical assessments of placed-based vulnerability (Folke 2006).

primarily for assessments related to sustainability and climate change, Polsky et al. propose a framework for Vulnerability Assessment acknowledging that components of human-environmental systems experience different levels of hazard exposure, sensitivity, and adaptive capacity. The authors’ approach recommends that discreet components of a system be assessed individually and then fit into a larger framework for assessing full system vulnerability (Polsky et al. 2007). The model calls for a grounded assessment of system components, with attention to avoiding oversimplifications and assumptions of biophysical or social homogeneity. Instead, the grounded assessment is constructed from local placed-based information sources and grounded in the contextual landscape being evaluated. Using local informants, participant observation and in-depth archival searches, grounded vulnerability assessments are not bound to predetermined avenues of explanation; instead, they have the potential to reveal dominant and nuanced factors influencing vulnerability that may not surface through the use of standardized data sources alone.

Recognizing that grounded assessment tends to result in a unique set of factors and associated measures, Polsky et al. accept that findings are not easily compared across places. In response, the researchers offer a Vulnerability Scoping Diagram (VSD) as a framework for organizing and representing the factors and measures that determine vulnerability of a specific unit of analysis. By standardizing the organization and representation of findings, the VSD allows for placed-based assessments as well as inter-assessment comparisons. Through cross-regional comparisons of discreet projects that employ the VSD,
generalizations regarding best-fit indicators and best practices can be formed (Polsky et al. 2007). These factors and best practices for assessment can then be fit into larger comprehensive projects that assess the vulnerability of entire human-environmental systems to an array of potential hazards. Comparative, grounded assessments also contribute to the broader goal of vulnerability theory building while retaining the importance of place-based specifics. In addition, targeted case studies using the VSD can be referenced by organizations charged with hazard mediation that do not have the human, financial or time resources to conduct grounded assessments.

Considering increasing agreement among researchers regarding the need for comprehensive frameworks, and the availability of conceptual frameworks allowing for inclusion of multiple, complex factors, case studies are necessary to improve upon the individual components of vulnerability feeding into comprehensive assessments in particular places. Given a gap between vulnerability concepts and pragmatic assessment, on the-ground, placed-based assessments of institutional, social, and biophysical vulnerability that incorporate local context need to be conducted in order to operationalize and validate the concepts of vulnerability research.

Water management in the United States and elsewhere has gone through several transformations resulting in a variety of resource management mechanisms. Developments in the science/policy interface, technology and engineering have been applied to the landscape, creating a patchwork of institutional designs. The capacity of institutional designs varies greatly according
to their application of supply versus demand-side mechanisms and anticipatory risk mitigation versus reactionary risk management (Polsky and Cash 2005).

Supply side management mechanisms may involve augmenting existing water supplies or increasing treatment efficiency while demand side mechanisms may include conservation incentives, or targeted building ordinances that mandate maximum efficiency indoor plumbing and outdoor irrigation systems. Applied to water scarcity, anticipatory vulnerability mitigation is generally associated with demand side mechanisms and centers on continual drought planning, education and conservation incentives while reactionary risk management occurs post-hazard and tends to involve supply augmentation or abrupt curtailments which do little to reduce future vulnerability.

Despite the benefits of anticipatory vulnerability mitigation strategies, one concern is that they can result in demand hardening. Demand hardening occurs when an institution implements mechanisms such as tiered rate structures or strict conservation codes in advance of a perturbation and as a result water use is trimmed to a point at which there is no room remaining for further non-essential reductions. In response to this argument, water managers often attest that if a stress occurs and low per-capita water use has been obtained through technological and economic mechanisms, the CWS can still rely on mandated or optional behavioral changes to at least temporarily drive demand down further.

At the regional and local level, the differential capacity of institutional mechanisms combine with social and biophysical factors, producing very different levels of water system vulnerability. In order to work toward the broad
goal of reducing vulnerability to water scarcity on the urban periphery of Phoenix, community water systems must be assessed to identify the inherent capacity and sensitivity of discreet institutional designs, mechanisms and infrastructures.

Through a comparative assessment of two different community water systems, each possessing a different institutional design and infrastructure system, a better understanding of vulnerability and risk reduction in local water resource management will be gained.

This thesis will further research currently being conducted in two National Science Foundation funded research institutes. First, I will employ the VSD, a conceptual tool developed by Polsky et al. By utilizing the framework I hope to add to the body of work being conducted by the Human-Environment Regional Observatory (HERO) to which Colin Polsky is a major contributor. As part of its greater research agenda, the HERO program seeks to develop effective tools to facilitate the assessment and comparison of local causes and consequences of global environmental change. Second, I contribute to a body of research being conducted at the Decision Center for a Desert City (DCDC), housed within Arizona State University. The case study findings and methodological research design will aid in the development of a place appropriate assessment tool that accounts for the intricacies inherent in the sensitivity and capacity of local community water systems. Conducted under the vulnerability research theme, this thesis will serve to enrich DCDC’s effort to assess overall-regional vulnerability to water scarcity.
Chapter 3

Methodology

In order to identify the factors abating and exacerbating institutional vulnerability to water resource scarcity in Buckeye and Cave Creek, I have taken a comparative case study approach (Yin 1994). A case study approach allows for a contextually rich placed-based grounded assessment capable of explaining the discrete factors and cumulative processes that create or augment differential water resource vulnerability at the local municipal level. I apply a suite of mainly inductive qualitative methods to a variety of primary and secondary sources to triangulate data and findings as well as to ground the assessment within the appropriate local and regional context. Using the municipal CWS as the unit of analysis, I employ an integrated placed-based vulnerability theoretical framework to analyze the differential vulnerability of Buckeye and Cave Creek. Following the case study approach, the findings of the project assist the development of a more comprehensive theory of slow-onset natural hazard and climate change related CWS vulnerability.

This explanatory case study focuses on the three dimensions of vulnerability presented in Polsky et al.’s framework for assessing vulnerability to climate change (Polsky et al. 2007). Exposure, sensitivity, and adaptive capacity will be considered as the main factors affecting CWS vulnerability. These dimensions have been researched as a means of identifying the specific factors and relationships that abate and exacerbate vulnerability. For example, specific factors relating to exposure are drought severity, frequency and duration while
sensitivity is composed of factors such as infrastructure age, supply source, social characteristics and local hydrology. Adaptive capacity factors are those that affect the ability of the CWS to cope with scarcity such as financial and human resources, institutional agreements, CWS ownership, and delivery and extraction system redundancy. The division of factors along the lines of exposure, sensitivity and adaptive capacity is conceptual. In practice, the presence of a factor such as household income would be considered a point of sensitivity if it was considerably low; however, if household income is high than the factor would positively contribute the adaptive capacity of the system. Thus, each factor cannot be analyzed in isolation. Instead, they must be considered in relation to each other to understand the cumulative effect that they have on overall CWS vulnerability to water scarcity.

Throughout all stages of research and analysis I have organized findings using the Vulnerability Scoping Diagram (VSD) developed by Polsky et al. (2007). The diagram resembles a bullseye that places an exposure unit in the center. In this research, the CWS is the exposure unit vulnerable to a hazard, water scarcity. From the center the diagram radiates outward in three concentric circles beginning with broad conceptual dimensions of vulnerability, continuing to more specific components and ending with discrete measures of vulnerability. The diagram is further divided into three pie shaped areas representing exposure, sensitivity and adaptive capacity (Figure 1). Following this conceptualization, sensitivity is a dimension of CWS vulnerability and growth is a component of sensitivity which can be measured in terms of growth rate or qualified in terms of
land use intensity and development style. Use of this diagram has involved an iterative process to refine the list of potential factors and relationships affecting CWS vulnerability. Further, use of this diagram has helped to achieve the goal of creating a common conceptual tool for inter-assessment comparisons of climate related vulnerability (Polsky et al. 2007).

**Contextual Data**

To begin the process of constructing a comparative case study, I have created a contextual local backdrop by assembling socio-economic data and biophysical data for each community. Socio-economic data was gathered from the 2000 U.S. Census Bureau at the municipal scale. Biophysical data relating to topography, hydrologic subbasin structure, groundwater quality and current drought conditions was obtained from the U.S. Geological Survey, the Arizona Department of Water Quality, Arizona Department of Water Resources and the Arizona Department of Environmental Quality. This data was compiled and presented using maps and tables. This information allowed for a better grasp on the social and physical characteristics of the Towns of Buckeye and Cave Creek. This data was added to the VSD and began to characterize the exposure and sensitivity of the associated CWS to water scarcity. The contextual data was also used to develop an interview protocol to elicit information from municipal water managers and land use decision makers.
**Primary Data**

**Interview Data**

To obtain primary data regarding place-specific sensitivities, institutional characteristics and perspectives, adaptive capacity mechanisms and nuanced factor relationships I conducted several interviews in each study area over a seven-month period in 2006 and 2007. I conducted ten interviews in total, five in Buckeye and five in Cave Creek. All interviews were semi-structured, recorded upon consent and ran less than one hour. Semi-structured interviews encourage respondents to communicate their perspectives through a non-binding yet guided conversation. Unlike surveys, this method allows interviewees to construct a personal account of their experiences that can reveal unexpected and complex themes and relationships.

I purposely selected initial interviewees based on their position within the government or CWS management structure. As the project progressed I employed a snowball referral based sampling approach. The interviewees include members of the Town councils, the Director of Public Works, the Director of Community Development, a hydrologic professional—either agency staff or a consultant, and a representative from the agricultural sector (Buckeye) and conservation sector (Cave Creek). Consistent with the literature, this method is not representative of the population, nor is it meant to be. The interviews are meant to illustrate the range of issues and perspectives held within and across each municipality and CWS.
Consistent with the literature, the municipal interviews and transcripts have been used to identify potential factors influencing institutional vulnerability to water scarcity. The interviews where transcribed and deductively reviewed to identify the presence of predetermined themes from the vulnerability literature concerning adaptive capacity and sensitivity, such as management structure characteristics, institutional knowledge and arrangements, community values, financial resources, supply sensitivity, water system technology, and water quality. I allowed new place, or issue specific themes to emerge inductively when appropriate. Potential factors identified in the interviews relating to the adaptive capacity and sensitivity dimensions of vulnerability were catalogued in the VSD. Upon completion of the initial analysis process, I followed-up with each interviewee to clarify interview responses as needed. Themes and associated vulnerability factors were organized according to exposure, sensitivity and adaptive capacity and cataloged in a running document. This document was updated throughout the iterative research process and used to inform the Vulnerability Scoping Diagram.

**Document Data**

After assembling a contextual backdrop for the project and conducting the interviews, I attempted to substantiate and supplement the themes and factors catalogued from interview and secondary data sources. The running document and developing VSDs guided a targeted review of pertinent policy documents. The Arizona Groundwater Management Act, Third Management Plan was
reviewed for key institutional agreements, hydrologic and climatic conditions, and regional trends in supply and demand management. The general plans for each town were reviewed to substantiate interview responses regarding pertinent local institutional arrangements, development plans, water portfolios, public involvement and institutional characteristics. Lastly, the municipal budgets for Cave Creek and Buckeye were reviewed to determine financial resources and flexibility.

I began with a targeted review of the Arizona Groundwater Management Act, of 1980, Third Management Plan. From this document I identified key institutional agreements relating to extraction, regulation and reporting for groundwater-in the study communities. I paid particular attention to regulations that bound municipal governance powers. In addition, the Third Management plan supplied sub-basin specific climatic and hydrologic data and information on regional trends in development and water budget portfolios. A similar process was done using Title 9 of the State of Arizona Revised Statue, in which Chapter Five (relating to municipal utilities) was examined for rate regulations and service area guidelines. This document details the state rules and regulations that apply to water rate changes, municipal service area expansion and the private provider condemnation process. Buckeye and Cave Creek have undergone or are undergoing condemnation processes as a means of municipal service expansion and/or forced de-privatization of services. Applicable textual data from these sources were catalogued in the running document and VSD. Through this search, I substantiated key biophysical, social and institutional factors that directly affect
the sensitivity of the CWS and the capacity of its management and decision-making bodies to cope with water scarcity.

Next, I examined the Town of Buckeye and Town of Cave Creek development plans and associated development codes in order to better understand how water and land use are addressed locally. The current plan and code for the Town of Buckeye was under a year-long process of revision with a March 2008 deadline. Under this circumstance, I used the most recent draft of the new plan and current general plan and development code adopted in September, 2001 and December, 2005, respectively. For Cave Creek, I reviewed the current general plan and development code adopted in December of 2004, and 2005, respectively. I examined the sections pertaining to local water resource management, development guidelines and ordinances, development fees, community development processes, distribution of powers and responsibility, and community participation since these are the most relevant to the CWS and vulnerability to water scarcity. These documents served to substantiate interviewee responses as well as identify previously unidentified factors relating to the adaptive capacity and sensitivity of the CWS. Again, key regulations, stipulations or processes where situated within the VSD.

Next, I analyzed the Town of Buckeye and Town of Cave Creek recommended budgets for fiscal year 2007-2008. This document contributed to the municipal government structure and resources components of the adaptive capacity dimension of institutional vulnerability. The budget document serves as a financial and policy document in that it outlines expenditures, revenues and
recommendations for redistribution of resources and policy making. I acquired financial resource data from the general fund, community development, and public works sections. This data was added to the VSD and used to evaluate the availability of resources for coping with water scarcity.

Finally, I have continually monitored the West Valley View weekly newspaper (Buckeye) and Sonoran News (Cave Creek) for water and land use management issues. I have reviewed the sources for any online and print articles relating to water or growth in the planning areas. These articles were cataloged according to the three dimensions of vulnerability laid out above. This has served to keep me apprised of recent developments within the study areas.

**Analysis**

I began analysis of the wealth of data collected through the interview process by intensively reviewing each of the municipal interviews. Drawing from the literature on vulnerability and institutional capacity I developed an informal deductive reviewing scheme that allows for the identification of issues and perspectives that relate specifically to vulnerability of CWSs to water scarcity. In addition to considering predetermined factors found within the literature, I used analytic induction to identify new factors as they emerged from the interview data and planning documents. First, the themes that resulted from this process were used to characterize and contextualize adaptive coping mechanisms available to the local CWS in dealing with water scarcity. Second, these themes revealed areas of internal sensitivity within the CWS relating to issues such as water quantity,
quality and growth pressures. Finally, the themes supplemented existing data on exposure to water scarcity and drought.

After identifying the main factors affecting institutional capacity to reduce vulnerability, I assigned, when possible, a direction to each factor to indicate whether it mitigates or exacerbates vulnerability. Incorporating a factor into its place-specific context has given indications as to its positive or negative effect on local institutional coping ability. The factors where situated into Polsky et al’s Vulnerability Scoping Diagram for presentation purposes. An integrated narrative was crafted to highlight the complex interaction of factors that feed the overall vulnerability of each CWS to water scarcity.

The budget documents were analyzed separate from the interviews. The data mined from these documents included quantitative data to gauge the available financial municipal resources and financial flexibility of each CWS. This involved simple accounting and identification of appropriation trends. I looked specifically for information that indicates the availability of capital improvement infrastructure funds and development fee revenue streams. Both of which can be considered a source of adaptive capacity used to increase efficiency, and build and upgrade infrastructure.

In the final step of this process I tied together the findings from each of the preceding steps into a final qualitative comparative case study analysis. Completed individual VSDs for each town have aided in the identification of the major factors affecting CWS vulnerability to water resource scarcity. These factors have been pulled from basic research on biophysical exposure and socio-
economic sensitivity as well as from the themes identified in the municipal interviews relating to sensitivity and adaptive capacity mechanisms. Factors identified through the interview process have been substantiated through a targeted policy review. The availability of fiscal resources for growth and water management were pulled from the budget documents. I have combined the findings of the contextual research and interviews with the budget and policy documents to maximize the worth of each analysis. Triangulation of the data has substantiated my findings and revealed interrelationships existing between factors and processes within all three components of the framework (Yin 1994). Factors identified throughout the individual analyses of the diverse data sources have been listed in the VSD. The following descriptive narrative has placed the elements found to affect institutional CWS vulnerability in Buckeye and Cave Creek into a local placed-based comparative context.
Chapter 4

Study Area

Regional Overview

The Phoenix metropolitan area is located in Maricopa County of central Arizona. The region, commonly referred to as the Valley of the Sun, is composed of over 35 municipalities and unincorporated areas (MAG 2007). The semi-arid region receives on average less than eight inches of rain annually and is currently in the throes of a decadal drought (Gober 2006). As drought conditions worsen, water reservoir levels decline and the frequency and severity of related fire hazards increase. Tree-ring analyses have revealed that historic drought conditions in the region were far worse in duration and severity, indicating that current conditions have the potential to become drastically worse (Meko et al. 1995). Research in Paleoclimatic history has revealed a duration of extremely intense drought spanning the mid 1200’s to the 1400’s. These historic droughts are said to have caused massive impacts that led to the “abandonment of settlements across the southwest” (State of Arizona 2004:9).
The Valley typically has mild winters, extremely hot summers and annual late summer monsoons that bring strong winds and precipitation eastward from the Pacific coast (Gober 2006). Located within the lower Colorado sub-basin and bounded by mountain ranges on all sides, the Phoenix metro area lies south of the Colorado Plateau on the northern periphery of the Sonoran Desert (Pulwarty et al. 2005). The city is situated at the nexus of the Agua Fria, Salt, Verde, and Gila rivers, which no longer flow at least most of the time, due to human interference damming the rivers upstream. The presence of these rivers throughout history has created an alluvial subbasin system that exhibits great variability in the depth and quality of water across underground aquifers. The rivers are also responsible for the large alluvial fans that wind through the Valley’s system of bedrock outcroppings and buttes (Gober 2006). Striking views, unique microclimates and prestigious reputations make the alluvial areas or washes around the outcroppings
popular development sites for mid-to-high-income homes, despite the increased flood hazards to which such areas are prone.

Originally settled by the ancient Hohokam Indians, the region has seen waves of settlement throughout the last two hundred years, each wave adding its mark to the rugged landscape (Gober 2006). Today the region stands as a testament to human ingenuity and engineering. Previously viewed as an inhospitable desert, the region is now known for its growth-oriented economy, desirable climate, and recreational opportunities. Mainly attributed to massive water reclamation efforts, the desert has been transformed into a blooming oasis, complete with grassy lawns, imperial palms and ornamental water features. Intense transformation of the desert landscape began in the post-World War Two era, when Arizona aimed to be the "development prototype for post-industrial society" (Sheridan 1995:41).

In 2006, the region had an estimated population of 3,768,123 persons – a 22.6% increase from 2000. In 2000, the average housing price was $129,200 and in 2004 the average income was $48,304 – which is significantly higher than the state average (U.S. Census Bureau 2007). This figure has been pushed upward through a series of rapid booms and busts in the housing market. The region is characterized by a feverish growth economy where it has been said that one of every three dollars is tied directly to the housing industry and that 20% of jobs are linked to land development (Burrough and Creno 2005; Gober 2006). Rapid growth is occurring along the urban periphery of the region in the form of massive planned communities, as agricultural land and open desert is transformed into an
automobile-dependent landscape characterized by high-density single-family stucco homes and middle to upper class amenities and services (Gober 2006).

**Legal Framework for Water Management**

The metropolitan area is fueled by three main sources of water: groundwater, Colorado River water and Salt and Verde River water. At this time, the use of effluent as a water source is generally limited to agricultural and open space irrigation. Dependent on a municipality’s location within the region and the time at which they began extracting surface water, the municipality may draw from one, two or all three sources. Commonly, older core cities have senior water rights to Salt and Verde surface water while newer fringe communities generally draw from groundwater and the Colorado River (Gober 2005). While non-renewable groundwater is insulated from climatic variation and climate change, renewable surface water sources are not. General circulation models are not able to predict the direct effects that climate change will have on precipitation in the lower Colorado subbasin or the local Salt and Verde watershed (Ellis et al. 2007). However, climate change research does predict that temperatures in the arid Southwest and Phoenix will rise thus increasing evapotranspiration rates and likely decreasing overall runoff and surface flows (Ellis et al. 2007). Higher temperatures will also increase annual water demand throughout the region. Further, increased demand due to rapid growth and decreased surface water availability due to climate change create a challenging scenario for local and
regional water management now and into the future (Ellis et al. 2007; Morehouse 2000).

To continue developing the Phoenix metropolitan oasis, the region relies on groundwater and surface water. The management of these sources follow a complex web of regulatory institutions that span temporal and spatial scales. Originally heralded as a progressive step in the right direction for water management in the West, the legal framework composing Arizona water policy is extremely complex (ADWR 1999). Below is an introduction to two main cornerstones of Arizona water policy; the doctrine of prior appropriations applies to surface water rights and the Groundwater Management Act of 1980 governs the use of underground water in the study region. A synopsis of each is given below along with a summary of their relevance for infrastructure investment, institutional management, and development trends in the Phoenix metro area.

*The Doctrine of Prior Appropriations*

To allocate scarce surface water resources in the arid west, most states utilize the doctrine of prior appropriation. Unlike riparian water rights that allocate water based on its physical connection with land, prior appropriation water rights are not tied directly to physical adjacency or proximity to water. Instead, the system of prior appropriations grants water rights based on the time of initial diversion and use. In other words, the first person to put the diverted surface water toward a beneficial use is allowed to keep doing so as long as they wish. Often referred to as first in time, first in right, as a whole the doctrine
honors historically dominant uses such as agriculture and long established communities over modern water uses and the needs of newer communities. Only after the water allocations of senior rights holders are met is the surface water diverted to the junior water rights holders. In times of shortages, the supplies of the most junior users are reduced first (Carter and Morehouse 2001).

Applied most infamously to the Colorado River, the doctrine of prior appropriations is the backbone of what is informally referred to as the “Law of the River”. Running 1400 miles from the high mountains of Colorado to the Mexican Sea of Cortez, the Colorado River supplies water to seven U.S. states, two Mexican states and 34 tribes for a total of approximately 25 million people. By the year 2020 this number is projected to be 38 million (Pulwarty et al. 2005). The Law of the River began in 1922 with the signing of the Colorado River Compact. The compact divided the Colorado River basin in two, thus naming the upper and lower basins (Carter and Morehouse 2001; Pulwarty et al. 2005). Through the compact and a series of successive court rulings the upper basin, containing the states of Colorado, Utah, Wyoming and New Mexico is granted 7.5 maf of water annually, the lower basin, containing the states of Arizona, California and Nevada is also granted 7.5 maf, and lastly, Mexico is granted 1.5 maf of water annually. Original allocations were based on an exceptionally wet period of years that averaged a flow of 16.4 maf. In actuality, the average flow on the Colorado River tends to hover around 14 maf each year (Pulwarty et al. 2005). The deficit between actual river flow and total allocations stands to create potential conflict if the upper basin grows to use its full allocation or if long-term drought or climate
change continues to drive up demand and lower channel flows. As the allocations
are set up, the lower basin has senior rights over the upper basin so in times of
stress the lower basin is said to have a higher level of security, despite the lower
basins unprecedented growth rate and arid climate (Pulwarty et al. 2005).

The Lower Colorado basin supplies water to over 17 million people and
over a million acres of agriculture (Carter and Morehouse 2001). Water
allocations in the lower basin have been highly contested throughout the last fifty
years. The 1964 Supreme Court Decree, Arizona v. California, legally allocated
the waters of the lower Colorado. Under this decree Arizona was granted senior
rights totaling 2.8 maf, followed by California (4.4 maf), Nevada (.3 maf) and
Mexico (1.5 maf) (Carter and Morehouse 2001; Pulwarty et al. 2005).

The Colorado River runs thought the northwestern portion of Arizona, a
region with scarce populations of mostly native peoples. Given the location of the
river in relation to Arizona’s population nodes, much of the state’s allocation was
allowed to flow downstream, without diversion, into California and Mexico. In
response to mounting frustration over California’s unlawful overuse of Colorado
water, as well as rapid increases in metropolitan development in the state, and
non-renewable groundwater withdrawals, Arizona sought federal funding for the
Central Arizona Project (CAP), which would eventually bring more Colorado
River water to centrally located urban areas.
The Central Arizona Project was conceived as the ultimate solution to potential water scarcity throughout the Valley of the Sun (Sheridan 1995). Bringing Colorado River water to the thirsty desert, the CAP canal carries 1.5 million acre feet of water annually through a system of concrete aqueducts, pumps and reservoirs. The CAP canal runs 336 miles from Lake Havasu City, Arizona, through Phoenix, before terminating in Tucson, Arizona (CAP 2007; Carter and Morehouse 2001). It took over twenty-five years and four billion dollars to complete. Administered through the Central Arizona Water
Conservation District, the CAP pulls half of Arizona’s total allocation from the Colorado River and delivers it to municipal, agricultural and tribal users (CAP 2007). In exchange for federal approval and funding for the CAP, Arizona traded its senior rights to the Colorado for junior rights (Gober 2006). Effectively, this arrangement leaves CAP last in line for Colorado River water in the lower basin (Carter and Morehouse 2001). Given this position, if climatic stress leads to lower flows, Arizona’s allocation through CAP will be the first cut. The CAP is a major water source for metropolitan Phoenix. Despite the availability of water, Arizona is not able to use its full allotment of Colorado River water mainly due to the lack of infrastructure necessary to treat and move it around the metropolitan areas. Water in the west is generally ruled by a use it or lose philosophy. To protect Arizona’s allocation, slow California’s illegal and excessive extraction of Colorado River Water and meet tightening state requirements for the development of renewable water sources, in 1996 the state started the Arizona Water Banking Authority (AWBA) (ADWR 1999; Carter and Morehouse 2001).

The AWBA banks excess CAP and surplus Colorado River water underground through artificial recharge. The stored supply of surface water is held for later use by municipal and tribal users (ADWR 1999). Despite serving as a needed buffer during times of potential stress in the future, the AWBA is highly criticized. The banking authority provides many services, one of which allows for municipal users to pump groundwater in return for buying credits from the bank. In return, the bank stores water on their behalf. Critics question the legitimacy of the system, stating that it manages paper water without thorough consideration of
the quantity and security of wet water being stored (Carter and Morehouse 2001). Questions also exist as to how the water will be extracted and transported to the locations that need it if a major shortage does occur.

*Groundwater Management Act*

In return for $3.6 billion in federal funding for the CAP project, the State of Arizona was required to curb its rampant extraction of groundwater, which led to the passage of the Groundwater Management Act (GMA) of 1980 (Gober 2006). During the two-year period that the Act was being negotiated and drafted, the state was using approximately 4.8 maf annually, 40% from renewable surface water sources and 60% from non-renewable groundwater sources. Groundwater extraction was occurring at twice the rate needed to naturally recharge the aquifers (Pulwarty et al. 2005). The resulting condition was a state of massive overdraft made visible on the landscape through land subsidence (Gober 2006).

The Groundwater Management Act of 1980 is celebrated for its potential to positively influence statewide changes in water management (ADWR 1999; Gober 2006). The act created the Arizona Department of Water Resources (ADWR) and put into place a comprehensive five-step water management plan that spans fifty years (ADWR 1999). In addition, the GMA spurred the creation of many statewide and regional institutions charged with administering a number of supplemental management mechanisms and programs, all geared towards the sustainable use of groundwater and development of renewable surface water resources in Arizona (Carter and Morehouse 2001).
As the administrative body of the GMA, the department was designed with the overall mission to “ensure an adequate quantity of water of adequate quality for Arizona’s future” (ADWR 1999). In addition to implementing the GMA, ADWR is charged with several tasks such as registering all water rights in the state of Arizona, administering Indian water rights, protecting Arizona’s Colorado river allocation, monitoring groundwater withdrawals and levels, and aiding water users with technical and bureaucratic duties necessitated by state regulations (ADWR 1999). Despite national praise, critics take issue with the limited enforcement powers granted to ADWR by the GMA. While ADWR has the responsibility to register all groundwater extraction, they do not have the authority to limit groundwater extraction by private residents and do not have the legal power to concurrently manage groundwater and surface water, despite the obvious hydrologic relationship between the two (Morehouse 2000).

The Groundwater Management Act outlines a progressive plan geared towards reducing groundwater extraction and improving the overall sustainability of water supplies in the state of Arizona. The primary goal of the GMA is to reach “safe yield” by 2025. Safe yield is defined as the point at which annual groundwater recharge equals or surpasses annual groundwater extraction (ADWR 1999). The Act defined five Active Management Areas (AMAs), Prescott, Phoenix, Pinal, Tucson and Santa Cruz, in which 80% of the state’s population lives and 70% of the water is used in the state (Sheridan 1995). Each AMA has a series of temporally progressive tailored management plans that includes enforceable requirements for conservation (never actually enforced), detailed
water budgets and area-specific mechanisms designed to assist user groups in achieving the legal mandates. Referred to as management plans, each AMA is required to provide a publicly approved plan every ten years. Currently, the AMA’s are implementing their third management plans (2000-2010) and planning is underway for their fourth (Carter and Morehouse 2001).

In addition to creating ADWR and the AMA management planning process, the GMA spawned the creation of the Assured Water Supply (AWS) program. Based on the 1973 water adequacy law, the AWS program requires municipalities and subdivision developers within an AMA to provide proof that the developed property will have at least a 100 year secure supply of water of adequate quality. The program also requires that development plans be consistent with GMA goals and that the water provider servicing the developed lands has the fiscal resources to provide appropriate storage, delivery and treatment infrastructure. (ADWR 1999; Carter and Morehouse 2001; Pulwarty et al. 1995). To obtain a certificate of assured water supply, a developer may apply as a private water provider or provide written proof that the development will be served by an existing certified water provider. In 1995 the program was updated to include a clause that requires assured water to come from renewable sources (Carter and Morehouse 2001). Considering the lack of physical access to renewable surface water sources in large portions of the Phoenix metropolitan region, the Central Arizona Groundwater Replenishment District (CAGRD) was created (Pulwarty et al. 2005).
In 1993 the CAGRD was created through the Groundwater Replenishment District Act. Overseen by the administrative branch of the CAP, the CAGRD offers groundwater recharge services to its members. Areas in the Phoenix AMA that do not hold the sufficient surface water rights needed to prove 100 years of assured water may voluntarily enroll in the CAGRD program. Once enrolled in the program, member lands are permitted to pump groundwater with the understanding that an equal amount of surface water is being purchased and recharged into the ground by the CAGRD on their behalf. Fees for the service are assessed according to how much groundwater is being used at the individual household level. Individual homeowners are automatically enrolled into the program if they purchase a home on member lands and annual fees are included in their property tax bill (CAGRD 2007).

**Case Study Approach**

To understand the factors abating and exasperating CWS vulnerability to water scarcity on the periphery of an arid metropolis, I choose to more closely examine the community water systems of Cave Creek and Buckeye, Arizona. Efforts underway to collectively assess regional vulnerability to water scarcity can be made more robust by gaining a comprehensive understanding of how biophysical, social and institutional factors intermix at the local level to create differential vulnerabilities within the region.

The towns of Cave Creek and Buckeye serve as two exemplary cases to evaluate differential CWS vulnerability to water scarcity in the fringe of the metro
area. Both towns demonstrate region-wide growth trends but vary greatly as to their water sources, planning ethics and managerial frameworks. Applying an integrative conceptualization of natural hazards vulnerability, both towns suffer similar exposure to water scarcity but exhibit very different points of sensitivity and potential for adaptive capacity. Pointed reasons for focusing on these two communities include extraordinary growth trends in Buckeye and recent water outages in the Cave Creek area. By understanding how these differences affect CWS vulnerability at the local level, regional assessments can be made more accurate, thereby helping to move toward the goal of regional vulnerability reduction.

**Case Study Area 1: Cave Creek**

The Town of Cave Creek is located in Maricopa County, directly northeast of the City of Phoenix. The planning area encompasses approximately 29 square miles and is bordered by Phoenix to the south, by Carefree to the east, by the Tonto National Forest to the north and by an unincorporated area of Maricopa County to the west (Cave Creek, Arizona 2007). The town hosts several ephemeral washes and the town’s name sake, Cave Creek, which generally flows only in the winter months. The average elevation of the town is 2,200 feet above sea level; a dry and ridged landscape characteristic of the upper Sonoran Desert. Cave Creek sits atop the southwestern portion of the Carefree groundwater subbasin. The Carefree subbasin is relatively shallow, measuring approximately 2000 feet in depth. Groundwater moves west-southwest and can be reached
anywhere between 30 feet below the surface along the creek bed to 390 feet below the surface (ADWR 1999). The Carefree aquifer has been deemed a critical aquifer by ADWR due to heavy groundwater pumping, which has led to large cones of depression and rapid decreases in the water table.

Figure 5. The Town of Cave Creek

Cave Creek has a rich history of settlement beginning with the ancient Hohokam Indians. After the Hohokam Indians abandon central Arizona in roughly 1400 AD, Apache Indians settled the area. In the 1860’s gold was discovered throughout central Arizona. Soon after, the area containing present day Cave Creek was settled by miners and ranchers, drawn by the lush desert landscape with the inviting waters of Cave Creek. In the early to mid-20th century, Cave Creek became a well-liked destination for those with respiratory problems as well as a popular stop for laborers building nearby Bartlett dam (Cave Creek, Arizona 2007). Since then, Cave Creek has continued to attract people of all types. Known for its wild west sense of independence and adventure, Cave Creek
now hosts an eclectic blend of independent commercial interests ranging from
dude ranches to bohemian style coffee houses, catering to both the wealthy
residents and visiting tourists.

Incorporated in 1986, Cave Creek is currently under pressure from nearby
Phoenix and private interests to develop many of its natural desert areas. The
town has a longtime stance on open space conservation and private property rights
that creates a unique and often conflicting setting for policy debates about land
annexation. As of 2006 nearly half of the land area of Cave Creek has been
officially designated as land preserves. The jewel of their efforts is the Spur Cross
recreation area, encompassing over 2000 acres of upper Sonoran desert and
purchased with funds levied by the voters of Cave Creek (Cave Creek, Arizona
2007).

The U.S. Census reported the population of Cave Creek was 3,728 people
in 2000. In 2005 official estimates approximated the population to be 4,615 (U.S.
Census Bureau 2007). In comparison to the Town of Buckeye and the broader
region, the growth rate of Cave Creek is low and mostly characterized by
increased commercial use and custom residential development on large lots of an
acre or more. Average household income and average single family housing costs
for the town are significantly above the county (U.S. Census Bureau 2007).

Case Study Area 2: Buckeye

The Town of Buckeye is located in Maricopa County thirty-five miles
west of Phoenix, Arizona (Buckeye, Arizona 2007). The town planning area
encompasses just over 600 square miles and is bordered on the north by Wickenburg, on the south by Gila Bend, Goodyear, Surprise and Glendale on the east and the unincorporated area of Tonopah on the west. It is situated on the confluence of the Gila and Hassayampa Rivers, both of which run underground as subflows. The elevation of the town is 869 feet above sea level, a flat expanse punctuated by the White Tank Mountain range in the northeast (Buckeye, Arizona 2007).

Figure 6. The Town of Buckeye

Buckeye is located largely atop the Hassayampa groundwater subbasin, with eastern sections atop the West Salt River groundwater subbasin. In the Hassayampa subbasin groundwater has historically been reached at a depth of 800-1300 feet and in the West Salt River groundwater has been reached between 700-1,350 feet. In some areas where the Gila River runs through the southern
portion of the town, groundwater from the West Salt River subbasin can be reached just four feet below the surface. This hydrologic condition, partly due to water from irrigation run-off, has resulted in water-logged land that is pumped and drained to desalinate the soil and prevent spoiling or souring of the soil (ADWR 1999). Despite water logging in some areas, both subbasins are experiencing dropping water tables and large cones of depression from groundwater pumping.

The Town of Buckeye was founded in 1888 under the original name of Sidney. In 1910, the town was renamed after the Buckeye canal, which supplied the area with ample water for agriculture. Incorporated in 1926, the Town of Buckeye rose to the top of regional agricultural production, creating a community identity that remains to this day. Currently, Buckeye is undergoing rapid land use change. Mid-priced single-family houses and shopping plazas now stand where pima cotton once grew. Thirty proposed master planned community plats have been recently been proposed to the municipal planning department. Once completed, six of these communities alone will add an estimated quarter million homes to the housing stock of Buckeye (Buckeye, Arizona 2007).

The 2000 U.S. Census put the population of Buckeye at 6,573 people. In 2005, official estimates approximated the population to be 30,000 (U.S. Census Bureau 2007). Further, the population of the Town of Buckeye is projected to reach 250,000 by the year 2020 (Buckeye, Arizona 2007). Average household income and average single family housing costs for the town are slightly below the county average (U.S. Census Bureau 2007).
Figure 7. Total population

Figure 8. Percent change in population
Chapter 5

Data Analysis and Results

This chapter summarizes my research findings to explain and compare the factors abating and exacerbating the vulnerability of community water systems to water scarcity across two peri-urban communities in metropolitan Phoenix, Arizona: Buckeye to the west and Cave Creek to the north. Water scarcity is defined as the complete or partial inability to provide quality water to users within the community water system. Water scarcity can be: biophysically determined by conditions, such as meteorological drought or naturally occurring groundwater contamination; socially constructed, as with the case of failing infrastructure or institutions; or, mutually constituted through the combination of the two, which is often the case. I therefore explain how interacting factors – characterizing exposure, sensitivity, and adaptive capacity – affect the vulnerability of the two community water systems to water scarcity. Following from a holistic understanding of vulnerability from the scholarly literature, I identify the water supply and quality, institutional, social and other factors determining vulnerability. Factors found to increase or decrease the vulnerability of the Buckeye and Cave Creek CWSs are summarized in a comparative table (Table 1) and in the Vulnerability Scoping Diagram. Triangulation of the diverse information sources employed in this study revealed a process whereby varying degrees of vulnerability are created and perpetuated by the interactions among factors representing the exposure, sensitivity and adaptive capacity of each CWS.
In the sections that follow, I explain how the community water systems of the two municipalities are comparatively vulnerable to water scarcity. The findings are largely organized according to the biophysical, social, and institutional, components defining vulnerability in terms of their influence on exposure, sensitivity, and adaptive capacity. First, exposure relates to the biophysical characteristics of drought hazards and the CWSs exposure unit. Next, the sensitivity of a system is determined by social and biophysical factors that render the system more or less susceptible to damage or losses due to water scarcity and biophysical exposures. Lastly, the adaptive capacity of a system is determined by the availability of mitigation mechanisms and resources that a CWS can employ in anticipation of, or in reaction to, exposure to water scarcity. The division of these factors is organizational, since in reality exposure, sensitivity, and adaptive capacity interact to determine the degree to which community water systems are vulnerable to scarcity. Where relevant, the interactions among biophysical, social and institutional factors are interwoven throughout the narrative analysis. For example, artificial recharge and water quality regulations are generally considered to be institutional dimensions of CWS vulnerability. However, because recharge and quality regulations are so intimately tied to the biophysical availability of water, I incorporate their role into the discussion on biophysically determined vulnerability. Each section builds upon the last in explaining the complex web of intersecting factors that define relative vulnerability across the two case study communities.
### Table 1. Comparison of factors contributing to vulnerability

<table>
<thead>
<tr>
<th>Factor</th>
<th>Buckeye</th>
<th>Effect</th>
<th>Care Creek</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Biophysical</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drought status</td>
<td>Moderate and severe</td>
<td>+B</td>
<td>Abnormally dry</td>
<td>+B</td>
</tr>
<tr>
<td>Aquifer characteristics</td>
<td>Two deep, contiguous aquifers flowing toward Buckeye</td>
<td>-E, -S</td>
<td>Shallow confined aquifers that depend on precipitation for recharge</td>
<td>+B, +S</td>
</tr>
<tr>
<td>Water quality</td>
<td>Hassayampa Aquifer — good</td>
<td>+S</td>
<td>Care Creek / Carefree Aquifer — poor. Quality in both aquifers is declining</td>
<td>+S</td>
</tr>
<tr>
<td></td>
<td>West Salt River Aquifer — poor. Quality in both aquifers is declining</td>
<td>+S</td>
<td>Care Creek / Carefree Aquifer — Poor</td>
<td>+S</td>
</tr>
<tr>
<td><strong>Social</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Growth rate</td>
<td>Rapid growth rate</td>
<td>+B, +S</td>
<td>Steady relatively low growth rate</td>
<td>+B, +S</td>
</tr>
<tr>
<td>Development style</td>
<td>Fragmented yet high density master planned development over a rapidly expanding service area</td>
<td>+S</td>
<td>Low density large lot development over a relatively small service area *</td>
<td>-S</td>
</tr>
<tr>
<td>Demographics</td>
<td>Lower median income, housing values, hom ownership rate, and level of educational attainment</td>
<td>+S, -AC</td>
<td>Higher median income, higher housing values, hom ownership rate, and level of educational attainment</td>
<td>-S, +AC</td>
</tr>
<tr>
<td>Community involvement</td>
<td>Lower level of Community involvement</td>
<td>+S, -AC</td>
<td>Higher level of community involvement</td>
<td>-S, +AC</td>
</tr>
<tr>
<td>Institutional</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CWS ownership</td>
<td>Long-term municipal ownership</td>
<td>+AC</td>
<td>Recently purchased by municipality</td>
<td>+AC</td>
</tr>
<tr>
<td>Number of sources</td>
<td>One</td>
<td>-AC</td>
<td>One</td>
<td>-AC</td>
</tr>
<tr>
<td>Water source — groundwater or CAP</td>
<td>100% groundwater with limited access to surface water rights</td>
<td>-E, -S, -AC</td>
<td>100% CAP water. Quality issues severely limit the use of groundwater</td>
<td>+S, +AC</td>
</tr>
<tr>
<td>Infrastructure</td>
<td>New with sufficient storage, backup power and redundancy</td>
<td>-S, +AC</td>
<td>Old with insufficient backup power and lack of redundancy. Recently increased storage capacity</td>
<td>+S, -AC</td>
</tr>
<tr>
<td>Aquifer recharge efforts</td>
<td>Mandated CAP and recharge</td>
<td>-S, +AC</td>
<td>Extremely limited local recharge</td>
<td>-S, +AC</td>
</tr>
<tr>
<td>Financial resources</td>
<td>Nearly debt free</td>
<td>+AC</td>
<td>Highly indebted due to purchase and upgrades of CWS</td>
<td>-AC</td>
</tr>
<tr>
<td>Water rate structure</td>
<td>Block rate structure higher than AAMA average</td>
<td>+AC</td>
<td>Flat rate structure that had not been raised since 1980</td>
<td>-AC</td>
</tr>
<tr>
<td>Institutional knowledge</td>
<td>High</td>
<td>+AC</td>
<td>Extremely low</td>
<td>+S, -AC</td>
</tr>
<tr>
<td>Local institutional agreements</td>
<td>Strong recharge ordinances and few conservation ordinances</td>
<td>+S, -AC</td>
<td>Strong conservation ordinances and preservation zoning rules</td>
<td>+S, +AC</td>
</tr>
<tr>
<td>Drought planning</td>
<td>Comprehensive staged drought plan</td>
<td>+AC</td>
<td>Staged drought plan</td>
<td>+AC</td>
</tr>
<tr>
<td>Information and Communication</td>
<td>Limited education efforts and no functional rapid information dispersion network</td>
<td>+E, +S, +AC</td>
<td>Many education programs, public drought severity signs and rapid information dispersion program</td>
<td>+E, +S, +AC</td>
</tr>
</tbody>
</table>
Biophysical Factors

The exposure component of vulnerability “characterizes the stressors and the entities under stress” of water scarcity (Polsky et al. 2007, 478). In this case study, drought is the primary hazard under consideration, while the CWS is the exposure unit or entity under stress. Drought is defined within a specific geographic context and is commonly characterized by measures of duration, frequency, and intensity.

As of 2008, the semi-arid state of Arizona was entering into its second decade of meteorological drought. While inter-annual and decadal climate variability is common in the southwest United States, conditions over the last ten years have remained dry, progressively impacting water storage, soil moisture, wildfire, and vegetation throughout the state. The current drought exists at varying levels of intensity across the state. These variations are generally caused by differential topography and resulting microclimates. Despite variation, as of December 2008, all Arizona watersheds were given a long-term drought status of abnormally dry to severe drought based on the SPI or Standard Precipitation Index. According to ADWR, long term for the SPI index is a period greater than 12 months. Although drought conditions generally persist over broad geographic regions, available drought indicators for the three watersheds in the two study areas suggest more severe drought conditions in portions of Buckeye than in Cave Creek. In the Town of Cave Creek, located in the northern section of the Salt River watershed, the Salt-Verde system was given the drought status of abnormally dry in 2008. The Town of Buckeye, located partially in the Aqua Fria
watershed, had a moderate drought status. In other areas of the Lower Gila watershed, which contains the majority of the planning area, the drought status was abnormally dry (ADWR 2008). In 2008 the drought status of Buckeye was more intense than that of Cave Creek, therefore Buckeye had a higher degree of exposure to climatic drought conditions. Yet the impacts of drought are dependent upon the water supply sources and conditions of each system in relation to demand and other factors.

In general, drought conditions tend to have a greater impact on surface water sources compared to groundwater sources. Renewable surface water sources (as well as a limited amount of shallow aquifers) in the Phoenix region depend on seasonal precipitation, streambed infiltration, and snowmelt runoff for recharge. Because surface water sources depend on precipitation, atmospheric drought conditions have a greater effect on the vulnerability of CWSs relying on surface water flows and storage in reservoirs compared to those reliant on groundwater. Thus, since Cave Creek is 100% dependent on surface water and Buckeye is 100% reliant on groundwater, recent drought conditions render Cave Creek more vulnerable to water scarcity than Buckeye. Moreover, Cave Creek sits upon the Carefree Aquifer, which because of its shallow depth and geologic makeup, is reliant on seasonal precipitation for recharge and is thus sensitive to climate variability, drought, and excessive groundwater mining. Since 2006, however, the Town has not relied on the aquifer for any potable uses due to the availability of CAP water as well as groundwater quality problems and an inability to remedy them in a cost effective manner.
After decades of drawdown in the Carefree aquifer, a decrease in groundwater pumping by Cave Creek and the neighboring community of Carefree has allowed the water table to rise slightly in some areas. Currently, artificial recharge is limited to the single golf course in town, but wastewater from an existing treatment facility is being considered as a potential added source of recharge to bolster current recharge efforts. Augmenting recharge that occurs during seasonal precipitation events with artificial recharge water supplied through the wastewater treatment plant will help to counteract the negative effects of groundwater pumping in and around Cave Creek and ensure a future source of water as demand grows or surface water supplies declined due to climatic, institutional or other factors.

Because the CAP canal runs through the northern tip of the Buckeye Planning area, the CWS is granted a small allotment of 406 acre feet of CAP water. This allotment is scheduled to decrease annually until 2034, at which point the CWS will only hold an allotment of 25 acre-feet. Unlike Cave Creek and several established CWSs in the Phoenix metropolitan area, Buckeye does not have the means to transport the CAP surface water into developed regions of their service area. Instead, the 600-plus square mile planning area of Buckeye relies upon two primary sub-basins for water. Each sub-basin consists of a series of large, ancient, and extremely deep contiguous aquifers. In contrast to the Carefree aquifer, the Lower Hassayampa and West Salt River Valley aquifers are buffered from short-term climatic variation and drought because they don’t rely on annual or seasonal precipitation for recharge. However, long-term vulnerability is
increased because the aquifers are essentially a non-renewable resource based on recent climatic conditions. According to the Town planning documents, if growth continues and water conservation mechanisms do not reduce GPCD from 169 to 125 by the 2105, the ancient aquifers will only be able to provide for 80% of water demand in Buckeye (Town of Buckeye 2007).

In Buckeye, the geological arrangement and composition of the aquifers creates a situation in which groundwater from the north and east portions flows south and west towards the central section of the Buckeye planning area, despite existing cones of depression northeast of Buckeye (Figure 9) (ADWR 1999). Continued development in Buckeye is expected to deepen cones of depression, thus increasing the flow of water westward. Existing and developing cones of depression in Buckeye could potentially create massive problems for nearby agricultural and private residential wells that are not as deep or as powerful as municipal wells. Despite existing cones of depression, reliance on deep aquifers buffers the municipal CWS from the effects of meteorological drought and biophysical sensitivity, providing the area with a long-term, yet finite supply of water for municipal uses.
Despite only having one source of water and after twelve years of exposure to below average precipitation, Buckeye has not experienced a noticeable decrease in water supplies nor has it experienced outages, which are common in Cave Creek. According to two water management interviewees, the only drought effects the town has felt are not directly related to physical exposure to the slow-onset hazard, but instead relate to increased requirements mandated by state agencies for conservation and planning in the face of a meteorological drought. When asked whether Buckeye was in a state of drought, the Director of Public Works replied, “I think we are in a drought because everyone tells us we are.” Furthermore, he added:

"drought has not impacted Buckeye except by the Governor's initiatives which we have had to respond to. I mean the only real impact of the drought is that we've needed to respond to the Governor's initiatives. And otherwise, I can't think of any way that we have been affected by it."
The Engineering Manager and Hydrologist for Buckeye backed the Directors statement while adding that the current drought has lowered the amount of natural stream recharge occurring in the Hassayampa River. They both stressed that to counter the potential effects of lowered natural recharge, the Town must increase artificial recharge. If artificial recharge is not increased, continued meteorological drought could have a negative effect on groundwater supplies available for use in Buckeye.

Because Buckeye is fully reliant on groundwater, State Law requires the municipal provider to recharge 67% of the groundwater pumped for CWS needs. On the contrary, Cave Creek relies fully on renewable CAP water and is not required to participate in any local or regional recharge operations. Currently, to meet recharge requirements in the GMA, the Buckeye CWS relies on the Central Arizona Groundwater Recharge District (CAGRD) to handle their recharge obligations. In a June 2006 article about the effects that rapid growth are expected to have on the CAGRD, and by association, homeowners in Buckeye, the High Country News explained that as demand for water in the region grows, competition for surplus renewable water supplies will increase, along with the costs of recharge and the additional infrastructure improvements (such as canals and desalinization plants) that may be necessary to keep up with demand (Jenkins 2006). The article goes on to speculate that if this scenario occurs the average annual household recharge fee could rise from $70 per year to over $2000.
increasing the impacts of water scarcity on lower income CWS customers in Buckeye.

In addition to the potential financial burden of continued enrollment in the CAGRD due to reliance on non-renewable groundwater, the CAGRD program does little to reduce the sensitivity of the local aquifers in Buckeye because the recharge is done elsewhere. In response to this issue, the Town of Buckeye recently passed a comprehensive effluent recharge/reuse ordinance that requires 30% of water demand to be reused or recharged through local irrigation systems and detention areas. The ordinance reduces the town’s recharge obligation to 37%, reduced reliance on the CAGRD, drives down demand on the Hassayampa and West Salt River Valley aquifers, and augments supplies of local groundwater, thus reducing future sensitivity and overall vulnerability to water scarcity.

In addition to effluent recharge in Buckeye, intense irrigation of agricultural land incidentally recharges the aquifers. However, as growth continues and land use transitions from agriculture to other uses, municipal water demand will increase, incidental recharge will diminish, and vulnerability will rise. A precise number for the amount of acres expected to transition from agriculture to residential was not available, but according to the Phoenix AMA Third Management Plan, ADWR predicts that urbanization will result in a decrease of non-Indian cropped acres from 161,797 acres in 1995 to 133,131 by 2025.

In the Cave Creek portion of the Carefree Aquifer municipal groundwater wells fail to meet the new federal standards for arsenic and the current water
treatment facility cannot remove the naturally occurring arsenic and other contaminants efficiently enough to meet daily demand. Thus, sensitivity of the CWS is increased because groundwater cannot be readily used as a potable source. Partly because of the inability to adequately treat groundwater, the CWS meets 100% of their municipal water demand with CAP water, which is subject to other institutional factors such as junior rights to Colorado River water.

The availability of higher quality CAP water allowed Cave Creek to avoid the high cost of rebuilding their water treatment facility to adapt to increased arsenic standards. CAP water is a renewable source, which ADWR considers to be more sustainable than groundwater in the long-term. However, because surface water is more sensitive to climatic variation and drought, the Cave Creek CWS is relatively more vulnerable to water scarcity in the near term, especially due to reliance on a distant source of water based on junior rights to an over allocated resource! If the amount of water in the CAP canal was to decline, whether due to biophysical, institutional or other perturbations, the Cave Creek CWS does not have the capacity to switch to an alternative source that can supply a sufficient amount and quality of water to the town. In fact, infrastructure malfunctions have occurred frequently over the study period, causing disruptive outages throughout the town. In February 2008, for example, a water line broke and caused a massive outage throughout downtown Cave Creek. As the Assistant Utilities Manager explained in the Sonoran News: "When they turned the CAP (Central Arizona Project) line back on it was behaving like there was an air lock (bubble) in the line. When they checked the level in the CAP canal they found it
was down to 12 feet because repairs were being made.” The article goes on to reveal that the intake valve for the Cave Creek CWS CAP connection is at a height of fourteen feet, two feet above the CAP water level (Riggs 2008b). Ultimately, a scheduled maintenance event along the CAP canal resulted in a water outage because the CWS was not able to augment supplies with groundwater during its maintenance operations. In the future, longer term disruptions could be more detrimental due to reliance on limited, low quality water supplies and infrastructure.

Within the Buckeye planning area, water quality in the Lower Hassayampa aquifer differs from that in the West Salt River Valley Aquifer, creating geographically determined sensitivity. The Lower Hassayampa aquifer is generally undeveloped and holds high quality groundwater. According to the Buckeye Hydrologist, CWS wells pulling from the Hassayampa aquifer that contain naturally occurring contaminates (such as arsenic) are engineered or "zoned" to only pull from layers of the aquifer containing high quality water. The West Salt River Valley aquifer is highly developed and contains high levels of arsenic and other natural as well as human-induced contaminates. Unlike Cave Creek, Buckeye has no easy access to an alternative source of higher quality surface water, and therefore, the portions of Buckeye reliant on the West Salt River Valley aquifer must rely on expensive treatment facilities to treat groundwater for potable uses. Reliance on low quality groundwater requires high treatment costs and major capital expenditures, which have the potential to strain financial resources and
thereby decrease financial flexibility, increase sensitivity, and heighten overall CWS vulnerability.

In Buckeye, a steady supply of good quality groundwater and an aggressive recharge ordinance combine to reduce the vulnerability of the CWS to water scarcity. But as time progresses, water levels in the non-renewable aquifers will undoubtedly drop, which will make high quality water scarcer while increasing the need for costly treatment, possibly where facilities do not exist now. Unless the responsibility of treatment becomes a collaborative, regional project, existing and future treatment facility updates and needed capital expenditures will become the responsibility of the Town of Buckeye and similar municipalities as water quality drops, potentially stressing financial and human resources and increasing the vulnerability of the CWS. According to one Councilperson, this combination of time-sensitive factors has spurred the town council to consider lowering current local water quality standards to be more in line with less strict federal standards. If they lower the quality standards now, the argument goes, water of a decent quality will be available for a longer period, as opposed to higher quality water being available for a shorter period of time. As it stands, the town has opted to keep standards high and count on financial resources from future growth and advancements in treatment technology to cope with the inevitable decrease in groundwater quality. By keeping the standards high, Buckeye is currently avoiding the financial burden that comes with treating low quality water, while possibly transferring the financial and biological risks to future CWS customers.
In sum, this analysis illuminates that exposure to drought does not by itself create a vulnerable CWS. In the case of Buckeye, a reliance on groundwater combined with mandated groundwater recharge decreases the current sensitivity of the CWS to drought and safeguards the town from biophysically-based vulnerability to water scarcity. In the near term, an abundance of moderate to high quality groundwater allows the Buckeye CWS to continually supply water during a period of long-term drought. However, as growth continues, the sensitivity of the Buckeye CWS will rise and threats of water scarcity will become more imminent. Aging infrastructure and declining water quality will most likely strain the capacity of the town to continue delivering quality water in an economically efficient manner. To cope with this scenario in the future, Buckeye may have to raise water rates or transfer municipal resources away from other, non-essential services and programs to cover increased treatment and operations costs. Meanwhile, the Cave Creek CWS, which is almost equally exposed to meteorological drought, might be less vulnerable and more sustainable in the long term. Even though surface water piped in through the CAP canal is more sensitive to the effects of short-term climatic variation, Colorado River water may be more viable as a long-term source of water for the Town because the CAP water is renewable source. Yet the region is granted junior water rights to Colorado River water, so if flows along the Colorado decrease due to long-term drought or climate changes, vulnerability to water scarcity may ultimately increase.

In Cave Creek, short-term water outages have already negatively affected the CWS. The temporary scarcity was not caused by exposure to biophysical
perturbations, but rather, by insufficient infrastructure. The adaptive capacity of both community water systems is decreased by their reliance on sole sources of water at present. Their undiversified water portfolios leave them more vulnerable to water scarcity than older communities in the region that have access to different surface and groundwater sources of suitable qualities and with the potential to treat and distribute water to safety standards based on demand.

**Social Factors**

To evaluate the role that the social characteristics of a CWS have on vulnerability to water scarcity, this thesis considers how demographics, community ethic, civic involvement, and growth differentially affect the vulnerability of the two case studies. It is generally accepted that communities with higher median incomes, higher housing values, and higher levels of educational attainment have more access to financial and informational resources at the individual and community level. It is also often assumed that wealthier communities have easier access to decision makers and decision-making processes. Having more resources and access to policy-making tends to decrease sensitivity and increase adaptive capacity by increasing financial and political flexibility. In other words, those with access to money and power have the resources to buffer themselves from water scarcity by individually purchasing water, purchasing more efficient infrastructure, or exerting pressure on local policy makers to do so on behalf of the community.
The Town of Cave Creek exhibits a higher median income, higher housing values, and higher than average educational levels than the Town of Buckeye or Maricopa County as a whole (Table 2). These factors serve to increase the adaptive capacity at the individual and community level by increasing the financial and knowledge-based resources available to the CWS. Areas with higher incomes and housing values, such as Cave Creek compared to Buckeye, are more sensitive to water scarcity in that they tend to have higher per capita water use. However, just as agricultural water use can serve as a buffer in times of scarcity, high per capita water use can also be viewed as enhancing adaptive capacity. Communities with water-rich lifestyles and high non-essential water use rates may be able to reduce their water use to basic needs only in times of scarcity, while communities with already low water use rates may not be able to decrease demand as much while still meeting basic water needs during times of scarcity.

According to interviewees in Cave Creek, per capita water use is kept down through the enforcement of conservation ordinances and through an overarching community ethic that values desert living and resource preservation. This ethic is made visible on the landscape by an abundance of xeriscaped home lots, right of way medians, and open desert preservations. Despite this desert-wise ‘ethic,’ average GPCD for Cave Creek was 276 for 1992-1996. For the same period, Buckeye's average GPCD was 209 (Note: This is the most recent data consistent across both case study areas). The Town of Carefree, which lies just west of Cave Creek, has similar socio-economic traits but lacks the municipal
conservation ordinances and desert-wise community ethic found in Cave Creek.

The GPCD rate for the same period for Carefree was 665, more than double that of Cave Creek (ADWR 1999).

Table 2. Demographics characteristics influencing vulnerability across the two community water systems (U.S. Census 2000)

<table>
<thead>
<tr>
<th>Community Characteristic</th>
<th>Buckeye</th>
<th>Cave Creek</th>
</tr>
</thead>
<tbody>
<tr>
<td>Race (%White, one race)</td>
<td>73%</td>
<td>95%</td>
</tr>
<tr>
<td>Median Age</td>
<td>30</td>
<td>45</td>
</tr>
<tr>
<td>Median Household Income</td>
<td>$35,383</td>
<td>$59,937</td>
</tr>
<tr>
<td>Individuals below the poverty line</td>
<td>18.8%</td>
<td>7.8%</td>
</tr>
<tr>
<td>Median value of owner occupied single family home</td>
<td>$86,400</td>
<td>$270,500</td>
</tr>
<tr>
<td>Percent (%) of owner-occupied housing units</td>
<td>67%</td>
<td>82%</td>
</tr>
<tr>
<td>Percent of population (25 years or older) with Bachelor's degree or higher</td>
<td>10.3%</td>
<td>40.9%</td>
</tr>
</tbody>
</table>

Analysis of socio-economic factors in Buckeye reveals a relatively high level of social sensitivity and a low level of associated adaptive capacity. The 2000 data show that Buckeye has a lower median income and housing value, and lower levels of educational attainment in relation to Cave Creek (Table 2). In addition, Buckeye has a lower rate of home ownership than Cave Creek. Applying the literature on social vulnerability, the combination of these factors suggests that Buckeye residents have less access to political, financial, and knowledge-based resources than their counterparts in Cave Creek. In addition, Buckeye has a higher rate of poverty and housing foreclosures than Cave Creek, and thus, residents may have less financial flexibility to cope with increasing institutional mandates, such as groundwater recharge obligation fees and special district taxes.
System sensitivity is slightly reduced by a higher average household size and higher density development, both of which reduce per capita water use and cumulative water demand.

Community involvement in Cave Creek is higher than in Buckeye. With an informed and active citizenry, Cave Creek may at first seem to have higher degree of adaptive capacity, which ultimately could decrease vulnerability. However, over a year of observation, this was ultimately not found to be the case in Cave Creek. At several Town Council meetings attended during this research, all of those in Cave Creek were packed to capacity with residents waiting to speak their mind on issues ranging from the purchase of the water company to sound ordinances, among other matters such as immigration. Public comments revealed a strong sense of independence founded on private property rights, limitations on government power, and exclusivity regarding in-migration to the town. The Planning Director for Cave Creek commented on public involvement in Cave Creek when he joked, “Cave Creek has a strong Not In My Back Yard attitude…we have a lot of BANANA around here. As in Build Absolutely Nothing Anywhere Near Anyone.” He went on to joke that the Cave in Cave Creek stands for Citizens Against Virtually Everything.

Although community involvement is generally seen as positive in terms of mitigating vulnerability to risks, the level and type of public involvement in Cave Creek may actually serve to decrease adaptive capacity by limiting the amount of resources and institutional flexibility the town has in developing and implementing water scarcity mitigation and coping measures. For example,
despite a need for increased water storage, the citizenry of Cave Creek resisted the installation of two new water tanks because they felt the tanks were an eyesore on the otherwise pristine Cave Creek landscape. Another example of high public involvement limiting adaptive capacity was when the majority of residents unsuccessfully resisted the towns’ plans to annex commercial property that, in time, would provide needed tax revenue for water system capital projects and public works property maintenance. On the inverse, high levels of public participation force town officials to thoroughly analyze drought and scarcity mitigation options and to transparently set their water and land use plans and priority-setting agendas. Forced transparency, which is absent in Buckeye, often leads to heated debate. But according to interviewees, continuous public debate on water issues has the general effect of educating the public on water scarcity while potentially establishing buy-in for system improvements and conservation efforts, both of which can increase institutional adaptive capacity by buffering the CWS against the effects of drought and climate change.

The community ethic of Buckeye is much harder to gauge than that of Cave Creek, because the town is in a state of rapid transition. Buckeye is a mix of old and new, where the new is greatly outweighing the old. Some town's people want to preserve their agricultural roots, but unlike in Cave Creek, preserving water intensive agricultural land does little to reduce the demand placed on the aquifers. However, preserving agricultural uses during a period of growth may constitute a form of adaptive capacity because they create a buffer of non-essential uses that can be curtailed during a time of stress. Despite agricultural
interests in the area, strong stances for farmland preservation or against growth are not apparent after nearly two years of frequent visits to Buckeye community meetings. When questioned about the future of growth in Buckeye and its implications, most community members and decision makers expressed overwhelming excitement, with a slight sense of anxiety. In general, the Town exhibits a pro-growth mentality, which may increase vulnerability in the future.

Community involvement in Buckeye is much lower than in Cave Creek, potentially making Buckeye more sensitive to water scarcity. Based on observations over the study period, public involvement was limited to participation in the recent general planning process. The citizenry seemed highly interested in the growth of Buckeye, especially as it pertained to zoning, transportation, downtown revitalization, public safety service expansion, and annexation. However, comments regarding water resources were limited and tended to focus on water rates and the creation of recreation-based water amenities (i.e. splash parks, man-made lake), as opposed to water quality or availability. According to the literature, a high degree of involvement in the planning process creates buy-in from the community, but considering the lack of public conversations on water, it appears that deliberation on water issues is reserved for local decision makers and managers. Without support for water resource planning and conservation efforts, and with buy-in from the community for continued growth, development, and water-consuming activities, the adaptive capacity of the CWS is reduced. By adopting a public stance in support of unlimited growth and disparate land-use and water-resource plans, public officials
and staff professionals are acting in a way that may ultimately increase vulnerability by increasing long-term demand in the face of limited supplies.

The Town of Cave Creek hopes to decrease their sensitivity to water scarcity by driving down household water demand. To aid in this endeavor, the Town sponsors several desert landscaping classes and demonstration projects. They offer free irrigation audits to their customers as a way of decreasing outdoor water use, which accounts for 70% of total water use in the region. Forced transparency, recent CWS outages, and the condemnation of the water company have led the town to take advantage of many forms of information dispersion to enhance water conservation. The Town engages the community in water and fire issues through pamphlets, newsletters, specialized websites, an emergency reverse dial code red system and, most blatantly, through the instillation of large yellow street signs that communicate levels of water risk and request associated levels of conservation. All of these efforts can reduce sensitivity by reducing demand and increasing flexibility. Most of all, unlike Buckeye and many other communities in the region, the Town of Cave Creek actively addresses water scarcity in the desert instead of hiding or ignoring it. By addressing water issues directly, Cave Creek increases public awareness and primes the citizenry for otherwise unpopular mitigation strategies that may be necessary in the future, thereby potentially increasing conservation and preparedness to buffer against the effects of drought and climate change impacts. Yet whether or not these efforts will prove successful in reducing water use and reducing vulnerability during a long-term period of water scarcity has yet to be determined.
The Buckeye CWS does not offer educational workshops and conservation programs aside from one leak-detection program. In order to reach their goal of 125 GPCD, planning documents list a multitude of future education efforts ranging from in-school conservation presentations to xeriscaping workshops. With public participation already lacking in regards to water issues and conservation, adaptive capacity through education and advocacy may be less effective than in Cave Creek. Unlike Cave Creek, the Buckeye CWS had no effective emergency information dispersion network, thus adaptive capacity is slightly reduced compared to Cave Creek.

When asked what the major issue facing Cave Creek was, all interviewees quickly replied: growth! In the fast-growing region, growth rates combine with the biophysical availability and institutional factors, such as land use plans and development style, to create varying levels of system sensitivity and vulnerability. In 2003, Cave Creek began a process that will eventually result in the annexation of eleven square miles of state land, bringing the total planning area to 40 square
miles (Ropp 2006). The growth rate for Cave Creek over the last ten years was only 2.5%, significantly lower than the five-year county average of 20.4% and much lower than Buckeye’s five-year growth rate of 199%. Despite reduced sensitivity due to a comparatively slow growth rate, Cave Creek town officials still spoke at length about the challenges they face trying to manage incoming growth and conserve water while retaining the rural, independent desert community ethic. To meet this challenge, decision makers and land use managers subscribe to a growth management culture that exercises extreme caution and applies conservation measures in land-use planning and plat approval processes. Interviewees explained that by choosing to zone the majority of annexed land as large lot residential, they are retaining the community identity while reducing future stress on limited surface water supplies delivered through the CAP canal. Reducing potential stress on the single surface water source reduces sensitivity and overall vulnerability to water scarcity. The Mayor of Cave Creek said that if Cave Creek did not annex the land in question, the City of Phoenix would, resulting in "11 square miles of look-a-like houses and every fast-food restaurant imaginable between Carefree Highway and the Spur Cross Ranch Conservation Area" (Ropp 2006).

The benefits of large lot zoning in Cave Creek are accentuated by an abundance of very strong conservation ordinances and development fees, most of which are not found or not as aggressive in the town of Buckeye. Sensitivity is reduced by local institutional agreements that, for example, indirectly limit household water use by requiring the use of native desert landscaping, limiting the
use of turf to small enclosed areas in the rear of single-family residences only, and
limiting building footprints and requiring large buffers of undisturbed desert
between homes. If not tended to appropriately, however, desert-like landscaping
can be just as water intensive as turf grass and native landscape ordinances can
prove ineffective at reducing GPCD.

Comparing the GPCD rates of Cave Creek and neighboring Carefree in
relation to their distinct conservation ordinances, or lack thereof, shows that the
efforts put forth by Cave Creek to reduce outdoor demand may have proven
successful. In addition to legally binding ordinances, many developers operating
within Cave Creek recognize the value that the community places on open space
and, therefore, grant large swaths of undisturbed desert within their developments
to local land trusts as conservation easements. This directly limits density and
population growth within the CWS service area, thus reducing relative demand
and associated vulnerability. Both Cave Creek and Buckeye charge impact or
development fees for all new construction projects within the towns. The fees are
charged per unit and are meant to provide funds to the town for utilities
infrastructure and municipal governance. The impact fees in Cave Creek are
some of the highest in the metropolitan region, averaging between $30,000 and
$35,000 per single-family dwelling. Approximately $8,200 of each impact
assessment goes toward fees associated with water connection (Staff Report
2007). While town officials worry that exorbitant impact fees are exclusionary,
they insist that the fees are necessary to repay the debt incurred by purchasing the
water company and installing and updating the old and inadequate infrastructure.
A slow growth rate combined with a cautionary growth management culture, a water conscious and conservation-oriented development style, and high impact fees allow Cave Creek to continue growing without major increases in cumulative water demand or decreases in financial flexibility, thereby reducing the sensitivity and increasing the adaptive capacity of the Cave Creek CWS to water scarcity. Despite the positive influence of growth on reducing vulnerability in Cave Creek, the CWS is still fully reliant on one source of surface water for all potable uses, and thus adaptive capacity is lower than in nearby rapidly growing communities with diverse water portfolios. In contrast, due to an aggressive annexation policy and an abundance of relatively affordable housing, Buckeye is growing at a pace that places it among the fastest growing cities in America. With its current population estimated at 40,467, the town is projected to grow to 419,146 people by the year 2030 (Table 2). At build-out Buckeye is slated to be larger in population and area than the nearby central city of Phoenix (Town of Buckeye 2007). With such a rapid rate of growth, keeping pace with the necessary institutional and infrastructural investments to support the community is difficult.
Table 3. Projected population and housing units (Maricopa County Association of Governments)

<table>
<thead>
<tr>
<th>Municipal Planning Area</th>
<th>2005</th>
<th>2010</th>
<th>2020</th>
<th>2030</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cave Creek</td>
<td>4,845</td>
<td>5,781</td>
<td>7,815</td>
<td>9,656</td>
</tr>
<tr>
<td>Buckeye</td>
<td>32,735</td>
<td>74,906</td>
<td>218,591</td>
<td>419,146</td>
</tr>
<tr>
<td>County Total</td>
<td>3,681,025</td>
<td>4,216,499</td>
<td>5,230,300</td>
<td>6,135,000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Municipal Planning Area</th>
<th>2005</th>
<th>2010</th>
<th>2020</th>
<th>2030</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cave Creek</td>
<td>2,231</td>
<td>2,681</td>
<td>3,659</td>
<td>4,522</td>
</tr>
<tr>
<td>Buckeye</td>
<td>9,470</td>
<td>25,895</td>
<td>81,485</td>
<td>163,523</td>
</tr>
<tr>
<td>County Total</td>
<td>1,479,767</td>
<td>1,685,134</td>
<td>2,104,440</td>
<td>2,502,040</td>
</tr>
</tbody>
</table>

Growth in Buckeye is increasing the vulnerability of the CWS to water scarcity for several reasons. First, the 2000-2005 growth rate of nearly 200% has materialized in an extremely fragmented landscape. Providing services to geographically dispersed development increases sensitivity and reduces adaptive capacity by stressing human and financial resources and making system redundancy more difficult to attain. In January of 2006, the Buckeye Town Manager was asked to explain why the town had neglected to carry out the proper water quality tests in the airport service area, to which she responded, "The issues for Buckeye are really related to growth. There are immense resource demands that new growth is creating" (Romero, 2006). The interviewee did not answer the question directly but instead eluded that the reason testing procedures were not followed was because the rapidly growing CWS lacks capacity.
Second, vulnerability is increasing due to an aggressive, non-precautionary growth management culture. Decision makers in Buckeye do not consider the availability of renewable water to be a restraint on growth, that is, beyond what is required by state law. At a general planning public meeting, one Buckeye resident questioned the planned growth, asking, “What about water, we live in the desert, where do all these people plan on getting water from?” In response, the planning consultant replied, “we plan like there will be water and adjust our plans later if there is none.” This version of non-precautionary planning is in direct opposition to planning efforts in Cave Creek. When the issue of water availability limiting growth was raised with interviewees from Buckeye, most took a technocratic stance, explaining that advances in conservation engineering, water treatment, and delivery systems would combat future shortfalls in supply, decreases in water quality, or increases in state mandated limitations on groundwater extraction. While the technocratic paradigm is still popular in many southwestern areas, hazard and environmental scholars and professionals realize the unintended effects that technocratic solutions have on system vulnerability. Technocratic solutions to water scarcity, for instance, may decimate the ecosystems from which water is drawn while creating false perceptions of security and postponing or transferring risks to other areas.

Lastly, the development style that characterizes growth in Buckeye increases CWS sensitivity and vulnerability. High-density housing is generally considered more water-wise, yet Buckeye lacks local institutional agreements in high and low density areas, such as conservation ordinances, codes, and fees, that
typically reduce sensitivity. Currently, Buckeye only has a few conservation ordinances and codes that limit water-intensive landscaping in public right-of-ways and industrial lands. No landscaping codes limit the use turf or citrus on commercial or residential property. As a result, as population growth continues cumulative demand for water will likely rise, increasing sensitivity.

Like most growing communities in the Phoenix metro region, Buckeye relies on development agreements to partially relinquish the Town from the responsibility of making initial capital investments by requiring for-profit developers to fund, build, and convey treatment facilities as part of the master planned community-building process. While these agreements help to decrease the towns financial burden for infrastructure development, town officials have admitted that the development fee schedule is insufficient to cover the financial burden that system upgrades and maintenance will create in the future. Despite being nearly debt free, the recommended budget report in Buckeye for the 2006-2007 fiscal year states,

“…compared to the demand for services from the Town, the necessary continuing revenue growth to meet this demand has proven unsustainable. Decision will need to be made as to which services have a higher overall priority than others as they compete for the limited new revenue available.” (Buckeye 2006, i)

Rapid fragmented growth guided by a pro-growth management culture combines with a lack of conservation efforts and an insufficient fee schedule to stress municipal resources while doing little to reduce cumulative water demand. Thus, the adaptive capacity of the CWS is decreasing while sensitivity increases. The negative effect of this combination of factors on CWS vulnerability to water
scarcity is currently buffered by Buckeyes reliance on groundwater. However, as the town continues to grow and take responsibility for conveyed infrastructure, demand will increase, aging infrastructure will require updates, water quality will likely decline, and state mandates on groundwater extraction will tighten, leaving Buckeye in a heightened state of vulnerability over Cave Creek and other CWSs with slow or steady growth, diversified water portfolios, and enhanced institutional capacity to provide community services.

Social characteristics combine with multifaceted growth characteristics to decrease vulnerability in Cave Creek relative to Buckeye. Wealthier, more educated residents signify heightened financial flexibility and access to decision-making processes, both of which contribute heavily to the adaptive capacity of those living within the Cave Creek CWS service area. The opposite can be said for those living in Buckeye, although rapid growth makes it difficult to analyze the changing socio-economic factors in the CWS service area. In Cave Creek, a community ethic characterized by conservationism, independence, and exclusivity combine with a high degree of public involvement to decrease the flexibility of the Cave Creek CWS while at the same time forcing due process, transparency, and more informed decision making. These factors, coupled with real experiences with short-term water outages, interact to ultimately create hesitant, yet eventual buy-in for public water conservation programs that reduce sensitive to water scarcity. In Buckeye, a general pro-growth community ethic combined with comparatively low levels of public involvement and technological optimism
among planners decrease potential buy-in for public conservation programs which also reduces the capacity of the town to adapt to or cope with water scarcity.

The rate, style, and management of growth in Cave Creek reduce the vulnerability of the CWS, while in Buckeye these factors increase the vulnerability of the CWS to water scarcity. Cave Creek decision makers manage the town's low growth rate in a cautious manner, charge high impact fees, and have developed stringent conservation ordinances, all of which have the potential to reduce sensitivity and increase the adaptive capacity of the CWS. In Buckeye, decision makers don't exercise the same caution while managing a significantly higher rate of growth. In addition, the town charges insufficient impact fees and, in comparison to Cave Creek, has limited conservation ordinances. With a rapidly growing and fragmented CWS, and without sufficient fees and institutional agreements, sensitivity to risks increases and the capacity of the Buckeye CWS to cope with physical or social perturbations decreases, thereby increasing the overall vulnerability of the CWS to water scarcity relative to Cave Creek in the future.

**Institutional Factors**

Institutions attached to a CWS influence vulnerability by mediating the effects of physical and social perturbations on the system. The effect that such institutions have on a CWS depends on the capacity to adapt to or cope with perturbations such as drought, growth, or infrastructure failure. To analyze the role of institutional factors on CWS vulnerability to water scarcity, this thesis
considers characteristics of both the formal organizations and infrastructure attached to each CWS. CWS ownership, water rate structure, the level of internal expertise and staff, and institutional knowledge characterize the formal organizations influencing vulnerability, while infrastructure age, system redundancy, water storage capacity, and the availability of back-up power supplies (e.g., to pump and distribute water) characterize the infrastructure component of the institutions that reduce exposure and sensitivity to scarcity while enhancing adaptive capacity.

In the spring of 2007, after over a year of negotiations, the Town of Cave Creek purchased the Cave Creek Water Company for 19.5 million dollars, thus reducing their long-term vulnerability to water scarcity. According to the Cave Creek Town Manager, as a strategic move to consolidate several private service areas in the north Valley in the fall of 2005, Global Water Company, a massive statewide private provider, purchased the physical assets and accounts of the CWS from its original private owner. The Town of Cave Creek had been planning to purchase the company for several years and was outbid at the last moment by Global Water Company. In response, the Town condemned and purchased the water company, claiming that public ownership was necessary for the health and welfare of the community. Despite its heavy price tag and resistance from concerned residents, every interviewee in Cave Creek agreed that the purchase was necessary to ensure a secure future for Cave Creeikers. In 2006, the Mayor was quoted as saying, "Without having control of its water, it does not have control of its future. Our intention is that Cave Creek have water not only for
tomorrow but for its future” (Stinson 2006). During the same period of time, a Councilperson and local resident, George Ross, elaborated on the Mayor’s position:

“The town wants to bring the future under control by controlling water and as we know her in Arizona, water is the future...We feel that the community should be controlling its water rather than having a private concern controlling the water. Our business is service to the public. Their business is profit and we don’t want to deal with that compromise” (Cave Creek Councilperson)

"The reason the town of Cave Creek wanted to buy this company was to secure this precious commodity. That's what this was all about. Are we going to control this precious resource or are we going to allow a private company to siphon it off to the highest bidder?" George Ross (Staff 2007)

Attaining control of the CWS reduced the long-term vulnerability of Cave Creek to water scarcity. As a public water provider, the Town of Cave Creek has more management and financial flexibility than that of a private provider. Unlike private water providers, which have no governance powers, public water providers are managed by municipalities which can adjust water rates and pass legally binding conservation and zoning ordinances. These mechanisms can be employed to decrease demand as a means of coping with scarcity in advance or in reaction to drought or climate variability. In addition, public entities have increased purchasing power and access to public infrastructure dollars through state and federal grant and loan programs as well as tax levies. Mechanisms such as these were used in Cave Creek to reduce vulnerability by purchasing the water company and beginning the system updating process.

Water rates in the Cave Creek CWS have been assessed using the same flat rate structure since 1986. The outdated rates, set by the previous private
owner, are charged at a price per gallon that is the same regardless of usage. This rate structure increases sensitivity because it does not offer incentive for demand reduction at the household level. As the new owners of the CWS, the Town is in the process of restructuring the rate system into a tiered rate structure that will require higher water users to pay more per gallon than relatively modest users. Tiered rate structures rely on economic forces to encourage conservation and are becoming more widely used across the Phoenix AMA. When and if Town officials in Cave Creek restructure the rate system, non-essential household water demand may decrease, thus decreasing system sensitivity. According to several local officials, reducing individual household demand will allow the CWS system to accommodate growth without a significant increase in cumulative demand. This practice has been debated under the auspices of demand hardening, which suggest that highly efficient water uses prevent flexible reductions in demand during short-term periods of shortage. In communities where demand hardening has occurred, water use is less malleable and less effective for reducing demand as a strategy for mitigating scarcity. Given relatively high per capita rates of water use, demand in Cave Creek has not hardened and there is at least some room for reduction in non-essential water use.

The Town of Buckeye has owned and operated the Buckeye Water Company since the 1940’s. Management and operations are handled within the Utilities department, which operates under the Buckeye Public Works Department. Like Cave Creek, public ownership of the water company reduces the vulnerability of the CWS by increasing adaptive capacity and decreasing
system sensitivity. The water utility relies on a tiered block rate structure, which decreases sensitivity to water scarcity by helping to reduce water demand. The majority of customers served by the Buckeye CWS are charged using a block or tiered rate structure. However, according to the Public Works Director, a limited number of customers living in the Sonoran service zone pay a reduced monthly and per gallon rate due to a remnant arrangement from a complicated development bargain. In general, the rate structure in Buckeye is more aggressive than most water companies in the Phoenix metropolitan region. In 2007, the average monthly charge for 7,500 gallons of water in Maricopa County was $28.27, compared to $34.78 (excluding Sonoran customers) in Buckeye and $28.99 in Cave Creek (WIFA 2007). Considering the average household income in Buckeye is significantly lower than in Cave Creek, the block rate structure, which financially penalizes the highest water users, may be one reason for the relatively low demand rates in Buckeye.

In addition to the Town of Buckeye water utility, five private providers operate within the Buckeye planning area. Private providers operating within the Buckeye planning area decrease adaptive capacity and increase system sensitivity within the CWS. The presence of privately managed service areas interrupt the potential connectivity between the Buckeye CWS service zones while making system redundancy more difficult and decreasing the adaptive capacity of the entire CWS. Private provider service areas are clearly defined by the Arizona Corporate Commission (ACC) and are not permitted to expand if a municipal provider is willing to serve a new area of development. While public documents
stress the importance of working closely with these providers, interviewees in Buckeye expressed their frustration with private providers. Their comments generally target small providers, who have not made necessary improvements to reduce system sensitivity by ensuring high quality water and service for Buckeye residents. When discussing the privately owned Valencia Water Company, a subsidiary of Global Water, the Buckeye Vice Mayor, who lives within the Valencia service area bulked: “Global Water has terrible water. If you buy a home in some of the developments that Global supplies, you must sign a note that you will not give that water to kids under nine years old because it damages their teeth.” According to the 2006 Valencia water quality report, a concentration of 3.8 ppm of fluoride was recorded in an active well. The federal water quality standard for fluoride requires concentrations less than 4 ppm and public reporting for any concentration over 2 ppm. In an attempt to decrease system sensitivity in 2006, the Town of Buckeye filed a condemnation suit against an unnamed private provider. The suit was unsuccessful.

In addition to ownership, expertise, staffing, and knowledge play heavily into vulnerability at the local level by influencing institutional flexibility. Purchasing the CWS in 2007 required the Town of Cave Creek to create a Utilities Department from scratch, an institutional change that minimizes capacity because of limited knowledge and experience in local water management. The Utilities Department consists of a Department Manager and Assistant Manager, both of whom are considered local experts in their field. To allow time for the maturation of the utilities department, the town contracted with Arizona American
Water, a large private provider, to manage and operate the CWS until March 2008.

Institutional knowledge is gained through a process whereby knowledge is produced, stored, organized, embedded, applied, and reproduced through continual practice and organizational experience. Formal institutions with a high degree of knowledge are more aware of the potential for risks and associated losses, and therefore, generally manage resources and make decisions in a more prudent, equitable, and suitable manner than those with little to no institutional knowledge (Diaz and Rojas 2006). While the town is still building capacity to manage the newly acquired water company, members of the Cave Creek town council along with land use planners and water managers, exhibit a high level of professional expertise, local hydrologic knowledge, and precaution in water resource decision. However, these positive attributes are overshadowed by a clear lack of institutional knowledge.

Due to the hostile condemnation suit, Global Water Resources did not share any information with the town at the time of purchase. The result is a severe increase in sensitivity due to a lack of institutional knowledge. Town officials were given no usage data, water quality data, or underground or surface infrastructure blue prints for the aging CWS. When asked about the transition of ownership, the Assistant Utilities Manager said,

“[Global Water Company] took all of their employees, all the maintenance records, everything. We don’t really have any good maps of exactly where the waterlines are. We’re trying to work with a poorly engineered system. It’s like flying an antique airplane.”
The Planning Director backed this statement by saying,

““The water operators all stayed with the previous water company and went to work in another municipality. With that went the historical knowledge of where things are. It’s a lot like remodeling a house. You don’t know what you’re dealing with until you open a wall.”

The lack of institutional knowledge was made blatantly clear in a recent Sonoran News article. As potable water gushed from a broken waterline, the article reports that public works maintenance crews searched the surrounding desert with metal detectors for the nearest shut off valve (Riggs 2008a). As the Utilities Department grows and underground infrastructure is discovered and documented, institutional knowledge will increase, thereby decreasing sensitivity, increasing flexibility and adaptive capacity, and decreasing vulnerability overall. Unfortunately, as many interviewees lamented, underground infrastructure is not identified until an outage or leak is detected on the surface, leaving the town in a constant game of cat and mouse.

In Buckeye, water and land use managers and operators exhibit a high level of expertise and general hydrologic knowledge, which lowers vulnerability to a certain degree by increasing adaptive capacity. However, the adaptive capacity of Buckeye, like Cave Creek, is limited by a lack of institutional and local knowledge within the CWS. Institutional knowledge regarding the legacy of agricultural water management may be high in Buckeye, but due to fundamental difference in the application of water rights, treatment, and delivery, this institutional knowledge does not transfer well to the management of a growing, increasingly (sub)urban CWS. Longtime local farmer and Manager of the
Roosevelt Irrigation District, which serves the agricultural sector in Buckeye, commented on the challenges that land-use changes are placing on local water management,

"We’re in pretty good shape managing irrigation water. We’ve got a lot of history. We’ve got experience and quite frankly we do a pretty good job of managing that, I think. But the new challenge will be meeting the demands of the urbanites that are moving here and supplying them with good quality drinking water—good quality, safe drinking water. And that is going to be a challenge."

Within the Buckeye municipal CWS, place-specific institutional knowledge is considered low because most public works and community development managers and staff are not residents of Buckeye, are new to their position, and are not experts in semi-arid water management. According to Town officials, three out of every five town employees have been employed with the town for less than two years. Due to rapid growth, the infrastructure in place today is triple what it was only seven years ago. Previous to the recent development boom, the CWS was small and not at risk of depleting their aquifers. Therefore, management of the system was basic and in-depth hydrologic understanding wasn’t necessary.

While evaluating the progress of water management in Buckeye, the Vice Mayor said,

“This is a little bit behind the eight ball and I think we need to buckle down and work a lot harder at it. The time is now. Of course you have to realize that we went from 12,000 people to 40,000 in less than four years. So all of a sudden things that were only laughed about three years ago, four years ago are very serious.”

In Buckeye, rapid growth is combining with low placed-based institutional knowledge to increase vulnerability. Without baseline knowledge of local
hydrologic processes, CWS sensitivity and vulnerability are increasing rapidly as cumulative water demand continues to grow. Without baseline knowledge of local hydrology, for example, the Town was not able to efficiently manage their non-renewable water supplies and unable to continue growing while meeting comprehensive water and land use planning requirements, such as the Assured Water Supply certification process, mandated by the State of Arizona. To allow for continued growth while abiding by state mandates, the Town of Buckeye hired a local experienced full-time professional water resource hydrologist/geologist and initiated the Lower Hassayampa Sub-Basin Hydrologic Study. Completed in November of 2006 by an independent consulting firm, the study described the hydrologic conditions of the Lower Hassayampa subbasin, Buckeye’s main source of water for the future, and applied a series of ten supply and demand scenarios to a sub-basin hydrologic computer model. The model projected the effect that the supply and demand scenarios would have on the sub-basin over the next 100 years, the time period required by ADWR in order to attain a certificate of Assured Water Supply. The staff hydrologist for Buckeye elaborated on long-term water resource planning efforts in a joint interview with the Buckeye Engineering Manager: "We're planning for 100 years, but we really have to look beyond 100 years. We can't just use up the water and say 'okay, what happens in year 101,' we're looking beyond 100 years." The Engineering Manager went on to add that they are, "looking at the perpetual sustainability of water supplies regardless of any ADWR official cutoffs." By initiating a gain in knowledge, the town reduced its uncertainty about local hydrology while meeting regulatory
requirements and reducing system sensitivity and overall vulnerability. As the Buckeye Mayor stated in a press release, “We now have a tool that will allow us to more accurately predict the impact of proposed development on our water supply, and manage this precious natural resource responsibly” (Buckeye 2007).

Water system infrastructure characteristics are a major institutional determinate of CWS vulnerability. To assess the effect that infrastructure has on CWS vulnerability, infrastructure age, system redundancy, water storage capacity, and power supplies must be considered. In general, older infrastructure developed at a time when demand for water was much lower tends to be pieced together with outdated, low capacity pumps, pipes and canals that are prone to rust, leaks and bursts. Older infrastructure is considered to be more sensitive to increases in demand and to overall water scarcity. System redundancy, storage capacity, and back-up power supplies directly affect adaptive capacity. These supply-side mechanisms provide alternative sources of water or power to cope with short-term perturbations such as infrastructure failure or electrical storms.

In Cave Creek, aging infrastructure exacerbates the negative effect that low institutional knowledge has on CWS vulnerability. Throughout the study period, headlines in the Sonoran News (serving Cave Creek and the North Valley) frequently reported water outages throughout the town. Concurrently, the West Valley View (serving Buckeye and the West Valley) did not report a single water outage in the Buckeye area. All of the Cave Creek water outages were not attributed to a lack of CAP water, but were instead directly related to faulty or insufficient infrastructure. Often, the situations were made worse by a lack of
institutional or operator knowledge. Much of the Cave Creek CWS infrastructure was built in the 1950’s and has only been updated and repaired on an as needed basis.

The original system was built to accommodate a small groundwater dependent population. The CAP line was installed in the early 1990’s to avoid arsenic in the area’s groundwater. However, when the pipeline was installed the existing treatment plant and distribution system were not updated to accommodate CAP water. As a result, the existing system is a hodge-podge of pieced together components, each with a different supply capacity and most lacking accessible or appropriately placed shut off valves. The Assistant Utilities Manager for Cave Creek recalled a recent incident when, during a repair to the main CAP pipeline, workers were forced to let the water carried through nearly eight miles of pipe gush into the desert because there wasn’t a shut off valve anywhere near the site of the repair. He went on to compare the previous upkeep and expansion of the infrastructure system with a vivid analogy, stating, “Essentially, the previous owners put Band-Aids on a bleeding artery, and when the Band-Aids failed they went and put another Band-Aid on…”. He added that the goal of the Town, and his department specifically, is to fix the infrastructure problems permanently through systematic prioritized infrastructure investments.

Until recently, a severe lack of water storage in Cave Creek greatly decreased adaptive capacity and increased vulnerability by failing to absorb short-term increases in demand and decreases in supply. One of the first challenges the Town surmounted after purchasing the water company was to increase above-
ground water storage. Prior to the recent installation of two new storage tanks, which many of the towns people objected to, the CWS had only 660 thousand gallons of storage capacity. Even at full capacity, the previous storage tanks were emptied during daily morning peak times, leaving the system with no back-up supply to buffer the community from breakages along the CAP line or distribution network. Installing two new tanks has increased storage capacity to 3.1 million gallons, providing approximately a two-day back-up supply during the off-peak season and a one-day supply during the peak summer season. Increasing water storage greatly increased the adaptive capacity of the CWS. In June of 2008, the Cave Creek Utilities Manager was quoted in the Sonoran News as saying:

“We started with the new tanks on April 30th and everything has run smoothly ever since. Last summer we couldn’t shut down for a few hours to do a line repair, now we can shut down the system for a whole day now that we have the new tanks on line.” (Riggs 2008c)

The Cave Creek CWS currently provides system redundancy through a connection with the neighboring Carefree CWS and through an emergency arsenic system that treats normally unused groundwater. However, interviewees stated that both emergency connections only serve to keep water in the lines during shortages and cannot provide enough water or pressure to prevent partial or whole system outages for extended periods of time. Decision makers hope to eventually hook the CWS into the neighboring City of Phoenix CWS, but at this point, insufficient system redundancy increases vulnerability because it does little to buffer the system from short-term perturbations.
Electrical storms frequently cause power outages across most climate regions, potentially disrupting the delivery of water. Groundwater and surface water pumps, distribution booster stations, and treatment facilities rely on electrical power to keep a CWS in operation. The Cave Creek CWS isn't fit with back-up generators or fuel to power the system during electrical outages. In September of 2007, Cave Creekers experienced three straight days of water outages, two of which were directly linked to a loss of electrical power. Outages such as this create real problems for local service sector businesses. In the summer of 2007, several local restaurateurs had emergency water tanks trucked in and placed on site so that business would not suffer every time the CWS went down. Aside from the cost of trucking in water, local tavern owner Larry Wendt called the water outages a "huge hassle" and went on to add, "Every time the water system goes down we have to replace all the filters and that costs $500 to $600 plus we have to replace the back-flow equipment and all kinds of dirt comes through the lines" (Riggs 2008b). While frequent water outages caused by insufficient or failing infrastructure create obvious problems for individuals and business owners, water outages draw public attention to the need for further investment in the system and justify the Towns often unpopular and financially intensive long-term strategy for CWS improvement.

In Buckeye, the infrastructure that forms the backbone of the CWS generally reduces the vulnerability of the system. First, the majority of extraction, treatment, storage, and distribution infrastructure was built within the last ten years, meaning it is more efficient and less sensitive to age-related breaks or
system failures. Also, most of the new infrastructure was designed using a master planning process resulting in a highly efficient, standardized system that can be easily expanded to accommodate future growth. Because of the fragmented geographic dispersion of growth in Buckeye, and because the CWS utilizes groundwater pumps as opposed to surface water canals, the service area is broken down into four individual service zones. Each zone has its own distinct wells, treatment, storage and dispersion network. All of the zones, except the airport zone (which does not serve residential customers), have sufficient storage capacity to absorb short-term increases in demand and reductions in supply. However, if growth continues and planned infill occurs within each service area, additional storage will be necessary. Updates to storage and other infrastructure improvements will most likely be funded through special district taxation, which increases the town's financial flexibility by requiring that residents directly benefiting from the updates pay for by the capital improvements. Each service zone is fitted with a series of back-up electricity generators and fuel that can be used in a power outage to pump, treat, and distribute potable water, further increasing adaptive capacity. Overall, newer infrastructure with sufficient capacity and backup power supplies reduce sensitivity and increase adaptive capacity in Buckeye, thereby decreasing system vulnerability.

Fragmented leapfrog development prohibits Buckeye from tying together distinct service zones to attain system redundancy and increase adaptive capacity. As an alternative means of system redundancy, the water company requires that each existing and new system contain at least two groundwater wells. While a
back-up well can provide water if the main well goes down, the back-up well
generally feeds from the same source of groundwater. Therefore, in the case of
potential local groundwater contamination, both wells may need to be taken off-
line, leaving no redundancy in the system. According to the Buckeye general
plan, a guiding document adopted by the Town in 2008, as the municipal service
areas expand to accommodate growth, the town intends to tie the service zones
together, with the goal of eventually connecting the entire system and making it
fully redundant. Once this begins to happen, the adaptive capacity of the CWS
will rise. However, if the recent slow-down in growth and rise in foreclosures
continues, the market may stifle infill, making it difficult to tie the dispersed
systems together. Further, if growth does not persist, fragmentation from leapfrog
developments will continue to pose access and resource problems for public
works staff and the Town as a whole.

Based on an analysis of the characteristics of the formal institutional
organizations and infrastructure systems associated with the two Community
Water Systems, Cave Creek appears more vulnerable to water scarcity at present.
This is particularly evident in recently experienced outages in the service territory,
albeit temporarily. Both CWS's are privy to the same suite of institutional coping
mechanisms associated with public ownership, which increases the potential for
operational flexibility and, by extension, adaptive capacity. As public entities,
both water systems are able to adjust water rates as a demand-side mechanism to
reduce sensitivity and vulnerability in anticipation of scarcity. The Buckeye
Water Company did so by implementing an aggressive tiered water-rate structure,
while Cave Creek continues to use a flat-rate structure to charge below-average rates for water consumed. Broad-based expertise in each organization is high, increasing adaptive capacity, yet insufficient staffing in Cave Creek and rapid increases in staffing in Buckeye stress the capacity of each organization. A severe lack of institutional knowledge about the newly acquired water system in Cave Creek drastically increases the sensitivity of the CWS. Institutional knowledge in Buckeye is somewhat lacking in terms of the increasingly urban CWS, but by initiating gains in knowledge and staff, the area is decreasing its sensitivity and vulnerability. Finally, the adaptive capacity inherent in the infrastructure component of the Cave Creek CWS is less suited to absorb short-term increases in demand or power-related outages than the infrastructure in Buckeye. In addition, the infrastructure in Cave Creek is much older than in Buckeye and, therefore, is more sensitive to breakage and increasing demand.

**Synthesis and Concluding Thoughts**

Analyses of the many institutional, biophysical and social factors that influence the exposure, sensitivity, and adaptive capacity of the CWSs of Buckeye and Cave Creek, Arizona have revealed similar levels of vulnerability to water scarcity born of very different factors and the interrelationships among them. Ultimately, vulnerability to water scarcity in the CWS's is also contingent upon the time frame considered and the degree to which current plans and initiatives are realized and successfully implemented. Despite favorable social and biophysical characteristics within the Cave Creek CWS, a severe lack of capacity—due mainly to institutional factors—exacerbates vulnerability in the
near term. If Cave Creek is able to increase the capacity of their infrastructure and formal organization in the future, they are likely to be less vulnerable to water scarcity in the longer term. In Buckeye, favorable institutional characteristics increase adaptive capacity and lessen vulnerability in the short term, but biophysical and social characteristics are likely to exacerbate vulnerability in the long term.

Atmospheric drought conditions are similar in both communities, yet biophysical characteristics of the individual water sources lead to temporal variation in vulnerability. In the near term, Buckeye is less vulnerable than Cave Creek to biophysically constructed water scarcity. However, as time progresses, exposure-based vulnerability in Cave Creek is likely to persist depending on climatic conditions in the Colorado River Basin, while vulnerability in Buckeye is likely to rise because Buckeye doesn't have access to renewable surface water and depends on an abundance of high quality groundwater. Although this buffers the community from the effects of climatic variation in the short term, the long-term sustainability of this water governance strategy must be called into question. Despite recharge programs in Buckeye, water quality will likely degrade as water levels in the Hassayampa and West Salt River aquifers decrease, thereby heightening sensitivity and eventually stressing the ability of the CWS to deliver high-quality potable water at a price comparable to the regional average. On the contrary, Cave Creek depends on moderate quality surface water delivered through the CAP canal. Surface water is more sensitive to short-term meteorological drought and climatic variation, but as a renewable water source, is
less vulnerable to long-term water scarcity. In the event that overall flows on the Colorado River decrease, biophysically constructed vulnerability in Cave Creek could eventually increase in the face of the prior appropriation water rights. Under current inter-state and international water right agreements, this situation would be exacerbated because Arizona holds junior rights to Colorado River water.

An analysis of social characteristics, including demographic characteristics, community ethic, civic involvement, and growth rates, shows that these factors lessen vulnerability in Cave Creek and exacerbate vulnerability in Buckeye in the near and long term. In Cave Creek, higher than average median incomes, educational attainment, and housing values signify increased access to financial resources and decision making processes that enhance the communities’ ability to cope with the negative effects of water scarcity. Although uncertainties and data inadequacies make it difficult to analyze the effect that rapidly changing socio-economic conditions have in Buckeye, median income, educational attainment, and housing values signify a lower degree of adaptive capacity. In Cave Creek, moreover, a high level of community involvement in decision-making processes, compounded by an independent, slow-growth, conservationist ethic, reduce the sensitivity of the CWS to water scarcity by increasing participation in water conservation programs and planning. In Buckeye, community involvement is much lower and is underlined by a pro-growth community ethic, which may stifle public buy-in for conservation programs if Buckeye is faced with a biophysical or social perturbation.
In Cave Creek, the style, rate and planning culture related to growth lessen vulnerability, while these same factors exacerbate vulnerability in Buckeye. In Cave Creek, low density, steady development guided by an aggressive conservation-oriented planning culture, conservation ordinances, and higher than average impact fees decrease cumulative demand on the CWS and increase financial flexibility for enhanced adaptive capacity. On the contrary, rapid, fragmented growth guided by comparatively less aggressive conservation ordinances and impact fees increase the sensitivity of Buckeye to water scarcity and does little to increase adaptive capacity. The fact that Buckeye relies on an easily accessible, plentiful source of groundwater allows the town and CWS to grow rapidly without experiencing water scarcity. As growth continues and water tables and quality drop, however, continued rapid growth may stress the finite groundwater resources, resulting in socially constructed water scarcity.

An analysis of the formal institutional organizations and infrastructure systems associated with each case study CWS shows that Cave Creek is currently more vulnerable than Buckeye to water scarcity. The formal organizations were analyzed according to their respective states of ownership and water rate structures, as well as by the expertise, capacity, and institutional knowledge of their staff. Both CWS are publicly owned and therefore have similar levels of operational flexibility and associated adaptive capacity. Both have the ability to freely restructure and raise their water rates to reduce sensitivity to water scarcity. However, the Cave Creek Water Company continues to charge flat below-average rates, while Buckeye has implemented a tiered rate structure and charges higher
than average rates. The tiered structure in Buckeye creates incentive for customers to conserve water and reduce sensitivity. The staff of both water companies have high levels of expertise, but the capacity of each staff is stressed in unique ways.

In Cave Creek, insufficient staffing stresses the institutional capacity to cope with even minor perturbations and growth, whereas in Buckeye, rapid growth is beginning to outstrip the capacity of the public works staff despite massive hiring throughout the municipal sector. Local knowledge in Cave Creek may be higher than in Buckeye, but an acute lack of institutional knowledge negates local hydrologic information, thus reducing adaptive capacity and exacerbating vulnerability. Local and institutional knowledge are lacking to a lesser degree in Buckeye, but gains in knowledge are reducing the negative effect this has on adaptive capacity and vulnerability. In addition to being more vulnerable than Buckeye with respect to formal organization, Cave Creek is also more vulnerable to water scarcity considering its infrastructure. Despite improvements in water storage and wastewater treatment, the outdated, pieced-together infrastructure in Cave Creek is prone to breakage and highly sensitive to increases in demand and power outages. Newer, high capacity, redundant infrastructure in Buckeye increases adaptive capacity, reduces sensitivity, and lessens the vulnerability of the CWS to scarcity.

In sum, Cave Creek is more vulnerable to water scarcity in the near term, while Buckeye is more vulnerable in the long term. Infrastructure failures due to an outdated and insufficient distribution system have led to temporary, yet acute water shortages throughout Cave Creek. Without proper documentation of the
existing distribution system, water system operators and decision makers are forced to make repairs and plan improvements in an inefficient, resource consumptive manner. However, as new storage and distribution infrastructure is brought online and institutional knowledge begins to accumulate, adaptive capacity will increase and sensitivity will decrease. With conservation ordinances in place and a long-term, renewable source of surface water to fuel some low-density growth, vulnerability will likely decrease into the future. On the contrary, reliance on a plentiful source of groundwater has allowed Buckeye to grow without obstruction. In recent years, however, the national housing foreclosure crises has wreaked havoc throughout the Phoenix metropolitan area, and in the West Valley in particular.

According to a recent report in the East Valley Tribune, the average home price in one Buckeye housing development has declined 32 percent in one year due to economic deterioration and ensuing foreclosure crises (Taylor 2009). Fragmented growth has already been stifled, signaling that the Town’s plan to eventually tie together existing infrastructure to enhance redundancy and adaptive capacity will likely fall short in the near future. With development at a near standstill, it is likely that development fees, which interviewees repeatedly pointed toward as a revenue stream, will not be sufficient to fund future upgrades to aging infrastructure. Lastly, and most importantly, Buckeyes full dependence on a finite, non-renewable, source of groundwater will drastically increase their vulnerability to water scarcity well into the future.
Chapter 6

Discussion

This thesis sought to identify the factors abating and exacerbating differential community water system vulnerability to water scarcity in the face of rapid peri-urban growth. To achieve this objective, I analyzed two case study communities on the periphery of the Phoenix metropolitan area—Cave Creek and Buckeye—in Arizona. Cave Creek was chosen because it is a growing community that is reliant on surface water and currently is suffering from scarcity. Buckeye was chosen because it is a rapidly growing, groundwater dependent community. Both CWS exhibit characteristics similar to other CWS along the periphery of Phoenix. I used the Vulnerability Scoping Diagram (Polsky et al. 2007) to guide a grounded, comprehensive, placed-based vulnerability assessment that comparatively considered how the biophysical, social and institutional conditions and interactions of each community determine exposure, sensitivity, and adaptive capacity to water scarcity.

What follows is a discussion of how this research contributes to the existing body of literature in the field of vulnerability research and the pragmatic goal of vulnerability reduction. In particular, I will explain how this work has elaborated on the nature of causal factors associated with placed-based vulnerability, following calls by Polsky et al. (2007) to establish a comprehensive framework for assessing, comparing, and understanding the vulnerability of coupled human-natural systems (Cutter et al. 2000; Cutter 2003a; Downing et al. 2005; Turner et al. 2003). In this chapter I will 1) explain how this research fills
gaps in the literature by pointedly discussing how biophysical, social and institutional factors interact to affect vulnerability, 2) explore the role that uncertainty plays in determining and planning for vulnerability reduction, 3) make recommendations for reducing vulnerability across the two communities, and 4) identify future research goals.

Comparative Vulnerability Using the VSD

The VSD approach is innovative in its 1) capacity to capture quantitative and qualitative information and 2) applicability to any stress or hazard acting upon a system of any size or type. The model is meant to guide the researcher in a scoping exercise to identify the dimensions, components and appropriate measures that reflect the exposure, sensitivity, and adaptive capacity associated with a unit or entity exposed to a hazard or risk—in this case, the exposure of the community water systems, or CWS, to water scarcity. Polsky et al (2007) call for the VSD to be used in future research to build a library of VSD case studies that can be compared and generalized through a meta-analysis. Along with other research, this study contributes to generalizable and context-specific knowledge as well as the development of a vetted set of factors that can be applied and assessed by non-academic decision makers to determine appropriate anticipatory measures for hazard mitigation and adaptation. Alone, my study employed this comparative approach to determine the unique and common factors that affect the vulnerability of water systems operating within the Phoenix region.
Contributions to the Vulnerability Literature

Through over a half-century of research, academics and practitioners have focused conversations of vulnerability around a myriad of causes, outcomes and processes. A review of the literature in hazards research, political ecology, climate change adaptation, and water governance reveals common calls for future research. Aside from using the VSD as a graphical tool to guide, organize, and present research, this project addresses previous calls to understand the role that multiple stresses—such as growth, climate change, and institutional pressures—have on overall system vulnerability (Wilhite et al. 2005; Yarnal et al. 2009). This study also fulfills the research call for integrative, placed-based vulnerability assessments that incorporate the biophysical, social, and, especially, the institutional factors that interact to create differential vulnerability (Dow et al. 2007; HERO 2004; Polsky et al. 2007). Lastly, this research fulfills a pragmatic need for the identification of specific processes or system characteristics that are 'proven' to affect vulnerability to water scarcity at the local (CWS) level (Ivey et al. 2004).

Biophysical, Social and Institutional Vulnerability

Exposure - Geographic Heterogeneity, Scale and Time

Assuming that a hazard is acting upon a system or landscape that is homogeneous, geographically isolated, and static can lead to prescriptive, one-size-fits-all adaptation strategies. These strategies often fail to consider differences in local resources, institutional choices or political boundaries and
simultaneously fail to provide adequate flexibility for coping with the dynamic nature of vulnerability (Cutter 2003a; Downing et al. 2005; Folke 2006; Wescoat 2003). Simply mapping regional drought status without accounting for heterogeneity of water sources and local water quality within and among community water systems, for example, would lead to an inaccurate picture of vulnerability. This research shows that despite similar states of drought across community water systems, dissimilar water sources and varying water quality problems interact to create differential exposure to risks. In Buckeye, a high degree of drought exposure in terms of lack of precipitation is almost fully counteracted by the availability of groundwater with acceptable quality. While the population is exposed to drought, Buckeye’s ‘fossil’ groundwater is not affected by current climate conditions, thereby lessening overall vulnerability to climate-induced water scarcity. By contrast, Cave Creek is more exposed to drought because of its reliance on surface water supply. Vulnerability in Cave Creek is exacerbated by the fact that surface water for Cave Creek is conveyed from the distal Colorado River, the biophysical and institutional conditions affecting which extend beyond the metropolitan region to the Upper Colorado Basin; therefore, to assess the vulnerability of Cave Creek one must consider the drought status of the entire upper and lower Colorado Basins. This situation is not unique in arid cities, where factors at nested geographic scales often influence system vulnerability at the local level (Downing et al. 2005; Turner et al. 2003; Wescoat 2003).

An integrative vulnerability assessment of the Cave Creek and Buckeye community water systems revealed differential vulnerability to water scarcity in
the near and long term. In Cave Creek a current inability to treat and use poor-quality groundwater increases near-term vulnerability. However, their reliance on a renewable source of water makes them less vulnerable to water scarcity that would otherwise be caused by eventual long-term groundwater depletion. Similar to the Ogallala case study region in Kansas (Yarnal et al. 2009), Buckeye is less vulnerable to water scarcity in the near term because their supply of high quality Paleolithic groundwater isn't subject to drought conditions. However, if the municipality does not diversify its water sourcing, no matter what individual or system-wide conservation efforts are implemented, the reliance on a non-renewable water source will necessarily increase vulnerability over time. On the contrary, communities in Massachusetts and Pennsylvania that draw on good quality groundwater are comparably less vulnerable in the near and long term, because the karst topography in these communities allows aquifers to recharge seasonally through climatic precipitation, thereby supplying a renewable source of water, illustrating that water source alone does not determine exposure-based vulnerability. Water quality and other regional dynamics must be considered together to determine the vulnerability of community water sources to scarcity.

Social Vulnerability Revealed through Grounded Assessments of Growth and Community Culture

This research successfully reveals socially constructed vulnerability to water scarcity. Using an integrative, placed-based, qualitative framework and grounded research methods led to the inclusion of demographic sensitivities and growth rates in this assessment, along with considerations of community ethic,
involvement, and development style. Incorporating qualitative factors into the assessment and analyzing their likely effects over time and in relation to each other made the analysis somewhat more subjective, yet the result is a contextually rich narrative capable of informing responsive recommendations for vulnerability reduction and research alike (as further discussed below). The unique influence that growth and community involvement have on CWS vulnerability in discreet places is illustrative of the need to fully understand the context in which all factors, social and biophysical, are acting to cumulatively exacerbate or mediate vulnerability over time.

Growth has a large but nebulous effect on system vulnerability. To fully understand the effect that growth has on discreet communities, characteristics of growth—such as development style, geography and rate—should necessarily be included in the vulnerability assessment process. As Yarnal et al. (2009) stress in their synthesizing work on land use and water resource vulnerability across diverse regions, the impact that growth has on current and future sensitivity can easily be misinterpreted, particularly when site-specific factors such as development style and geography (placement of homes in relation to existing infrastructure) are not incorporated into the analysis process. A similar case can be made for the Buckeye study area, where available socio-economic and GIS data were outdated because of rapid growth since the last U.S. Census. To simply know that the population of the town is 32,735 (Maricopa Association of Governments) (U.S. Census 2000 data listed a population 6,537) and that their
GPCD rate is 209 (a number contested between state and local sources) does little to explain their vulnerability to water scarcity.

In-depth interviews, field research and document review revealed that the growth rate in Buckeye increased to nearly 200% over a five-year period, and that growth is materializing in a geographically dispersed and fragmented landscape. In Buckeye, in recent years rapidly expanding water services and the associated infrastructure to accommodate fragmented growth along the urban fringe is just beginning to stress the town’s financial and human resources.

Similar expansion patterns in Massachusetts have led to increased vulnerability by disrupting the local hydrologic cycle, worsening non-point source pollution, increasing demand, and stressing the respective CWSs ability to access new water sources and expand infrastructure outside of the urban core at a pace in-line with land consumption (Yarnal et al. 2009). In Buckeye, master planned developments tend to have small lots with xeriscaped yards that require little irrigation. If, however, Buckeye continues to rapidly expand its service area to accommodate the leapfrog development style characteristic of the western peri-urban Phoenix region, vulnerability may increase as it has in peri-urban communities in Massachusetts. In Cave Creek low density development is slower and slightly more water intensive in terms of landscaping, yet not as geographically dispersed as Buckeye. Comparing these three case study communities shows that the effect that growth has on overall vulnerability is not only contingent on the rate of population change but also on geography and style of development.
In Cave Creek, the complex relationship between civic involvement, the community ethic, and system vulnerability illustrates the value of grounded assessment using qualitative social factors. Grounded assessment further reveals the limitations of quantitative social vulnerability assessment. For example, an assessment approach employing only quantitative indicators such as socio-demographic characteristics (e.g., SOVI index; Cutter et al. 2003b) would have failed to capture the role that community involvement and ethic plays in diminishing the adaptive capacity of Cave Creek. A community ethic that values water-wise desert living is limited by a strong level of community involvement that touts small government, private property rights, and independence, while often valuing aesthetics over function or need. During the research period, this combination of characteristics formed a situation wherein the ability of the CWS to increase adaptive capacity through major investments in storage and infrastructure were hindered by an active citizenry that objected on the basis of fiscal conservatism and the unattractive sight of water storage tanks. The community ethic and level of community involvement were much harder to gauge in Buckeye. During comparatively slightly less well-attended community planning meetings attendees offered few water related comments, ranging from concern for water security to calls for more water intensive recreational opportunities, illustrating that a high level of community involvement does not necessarily lead to increased community resilience. The effect that community involvement has on vulnerability depends greatly on the ethic of that involvement.
The strong level of community involvement and unique community ethic found in Cave Creek may continue to limit the range of adaptive mechanisms available to the CWS. However, over time, if water-related issues continue to make front page in the local press while emergency repair costs climb and education and awareness programs continue to grow, the strong willed citizenry may begin to prioritize water issues over small government and fiscal conservatism. In this case, decision makers may be able to leverage the inherent underlying strength of the active citizenry to increase adaptive capacity and reduce vulnerability through supply- and demand-side mechanisms such as infrastructure improvement and voluntary reductions in water consumption.

**Institutional Factors - The Major Driver of Vulnerability**

Consideration of institutional factors revealed major disparities in the degree and composition of CWS vulnerability. Following the VSD framework for comprehensive vulnerability assessment, factors including institutional knowledge, CWS ownership, water fees, institutional agreements (e.g. conservation ordinances, land and water use planning statutes, etc.), and infrastructure age, capacity and redundancy were explored. Comparing the findings of this research to case studies at varying geographic scales and using divergent assessment approaches (discussed below) shows that the most pressing drivers of vulnerability are often institutional, as opposed to biophysical perturbations such as drought, floods or even climate change.
As in other works, the findings of this research show that drought is a relative term and that the relationship between an atmospheric drought and its impact on a community are not necessarily linear (Dow et al. 2007; Hersh and Wernstedt 2002; Yarnal et al. 2009). Assuming that the potential impact of a perturbation will parallel the severity of the perturbation overlooks the important role that institutional strength has in mediating losses. For instance, Cave Creek and Buckeye, Arizona as well as Worcester, Massachusetts are all rapidly growing peri-urban towns. The former are in a semi-arid region receiving less than eight inches of rain a year while the latter receives an average of over 43 inches a year. In the summer of 1999, a generally wet year for Worcester, a brief yet severe five-month drought caused rainfall to drop close to an all-time, seasonal low, forcing the CWS to implement progressively restrictive and expensive, emergency-based, demand- and supply-side coping strategies (e.g. voluntary residential reductions, outdoor watering bans, and emergency water purchases from neighboring CWS, etc) in order to continue service (Hill and Polsky 2006). In contrast, the Phoenix metro region is in the throes of a drought that has lasted over ten years—driving down Colorado River water in reservoir storage to all-time lows—yet neither Cave Creek nor Buckeye (or other towns in the Phoenix region) have had to implement emergency coping strategies in order to continue service during a time of drought induced stress. The difference between the Phoenix and Massachusetts cases is in large part due to differences in the institutional policies and the storage, treatment, and conveyance infrastructure afforded to each.
Institutional arrangements form the basis for the range of options that a CWS has in planning for or reacting to multiple stresses such as rapid growth and drought. Agreements made at the regional, state and federal level can often decrease sensitivity and increase adaptive capacity by demanding long-term water and land-use planning and emergency preparedness. However, it can be argued that mandating larger scale regional, state and federal agreements without also increasing local capacity can stress local systems as they deal with day-to-day operations while meeting compliance and reporting requirements at multiple scales (deLoe et al. 2006; Hersh and Wernstedt 2002). In Buckeye, interviewees expressed their concern over meeting increased planning, study and reporting requirements involved with the Groundwater Management Act and Assured Water Supply program. Buckeye hired a staff geologist to absorb the stress that these programs placed on their staff. Communities without the financial resources to hire or contract professionals to fill the capacity gap would likely be stressed by increased institutional demands. Communities that are able to invest in additional expert staff or consultation services enhance their capacity to meet increasing mandates and the capacity of the CWS as a whole.

At the local level, Cave Creek and Buckeye employ different planning and development policies, emergency preparedness plans and rate structures that influence their demands for water and the availability of financial resources afforded to each. These factors result in dissimilar vulnerability between the communities. Although the effects of acute water scarcity in Buckeye were not experienced during the research period, a lack of local planning and development
policies that require aggressive water conservation measures may lead to increased vulnerability in the future. On the contrary, Cave Creek employs comparatively aggressive conservation-oriented development and landscaping policies that may decrease or at least moderate demands on water resources in the future. Despite different capacities for emergency communication, both CWS have emergency drought plans and the legal authority to mandate non-essential demand-side reduction measures via their municipal governments. Having a plan and the authority to execute the plan are factors identified for increasing adaptive capacity (Ivey et al. 2004; Yarnal et al. 2009). Buckeye aims to limit household demand using a conservation-oriented increasing block-rate fee structure, Cave Creek does not. In sum, both communities employ institutional strategies to reduce vulnerability but both communities’ falls short of comprehensive vulnerability reduction. While Cave Creek fails because of their lack of conservation oriented rate structures, Buckeye fails due to a lack of conservation-minded planning and growth-oriented development policies.

Both Cave Creek and Buckeye seek to reduce institutional vulnerability by keeping water demands down through conservation-ordinances or tiered rate structures while transferring capitol infrastructure costs to the homeowner (via developer-funded infrastructure or impact fees). However, reducing per capita demand to stretch finite groundwater supplies or limited surface water rights over a larger population leads to a "catch 22" commonly found in CWS management and accompanying vulnerability research (Hill and Polsky 2006; Yarnal et al. 2009). Expanding and updating costly infrastructure to accommodate new and
existing users while holding community-wide demand and subsequent revenues static will likely stress the financial capacity and political tolerance of a town such as Cave Creek. Additionally, reducing per capita demand to a minimum in order to add additional connections can lead to demand hardening. If non-essential water demand is already extremely low, emergency conservation during temporary shortages becomes much more difficult. Further, assuming that impact fees from planned future developments will provide revenue to tie together the dispersed existing infrastructure means that if growth slows, as it has in Buckeye and the nation in general, the CWS will have difficulty attaining the redundancy needed to enhance resilience and adaptive capacity of water delivery infrastructure.

Finally, no matter what the cause, limited institutional strength is especially dangerous for CWS institutions, as compared to other public service institutions. Often, long-term water security issues are hidden from public view, literally buried underground and thus not garnering the public’s attention, political support or involvement, and budgetary urgency that more visible issues (such as transportation systems and recreation facilities) receive (Hersh and Wernstedt 2002). In Buckeye, the hidden sensitivity of the CWS was exemplified during the Community Master Planning process where the tendency was to focus on visible, short-term services and amenity-oriented planning, as opposed to long-term infrastructure and water security planning. In Cave Creek, short- and long-term water security has been more at the forefront of recent planning initiatives. This is not because of long-term fiscal prioritization, political responsibility, or
community foresight, but instead because major infrastructure malfunctions and subsequent public outcry have shed light on the town’s lack of adaptive capacity and heightened sensitivity to water scarcity. As is common in the aftermath of a hazard, the visible impacts of infrastructure failure are forcing the town to deal directly with their shortcomings and forcing local decision makers to dedicate political attention and public funds to infrastructure improvements, as well as human resources to increase adaptive capacity in anticipation of the next perturbation.

_Vulnerability Reduction in the Face of Uncertainty_

Natural hazards and vulnerability research carried out in all disciplines deals inherently with the problem of uncertainty. Research charged with projecting the uncertain impact that hazards will have on human-environmental systems into the future assesses the effects that past and current hazards (such as drought) have on modern systems. Assessing how vulnerable a system is in terms of exposure, sensitivity and adaptive capacity allows the researcher to project how the system will perform under future periods of biophysical or social stress, such as climate change or large fluctuations in growth. Projecting which factors will make a system more or less vulnerable to stress in the future allows for the development of anticipatory and place-appropriate adaptation or mitigation strategies, despite uncertainty over whether the hazard will occur or how severe it will be.

While climate change research has been unable to produce unanimous
projections as to the effect climate change will have on precipitation regionally or globally, consensus has grown around the projection that urban water systems in arid and semi-arid environments will likely be the most severely affected (Morehouse et al. 2002). Researchers agree that temperatures throughout the Colorado basin will rise, forcing increased evapotranspiration, decreased soil moisture and seasonal snowpack, and increased variability in seasonal runoff patterns (National Research Council 2007). Ultimately, this combination of factors will result in decreased flows along the Colorado River. A 2007 report issued by the Scripps Institution of Oceanography projected that Lake Mead, the largest reservoir in the Lower Colorado River basin, will be dry by 2021 if climate change and population growth within the basin continues at current rates. Due to climate uncertainties, lack of resources, and a tendency toward technical pragmatism along with a lack of political will, planning for climate change adaptation at the local level is generally lacking despite the fact that climate change impacts will necessarily be felt and coped with by local CWSs and their respective institutions (Hersh and Wernstedt 2001; Ivey et al 2002). Massive regional infrastructure investments and innovative inter-state shortage sharing and water banking policies increase the overall adaptive capacity of the multi-state CAP service area. However, if factors related to climate change and population growth continue to drive down flows along the Colorado River, Cave Creek, neighboring growing peri-urban communities, and other CAP-dependent water systems stand to suffer major disruptions to their ability to deliver water in an efficient, cost-effective manner.
Cave Creek and other communities relying on surface water sources—which are more sensitive to climate conditions—must grapple with the uncertainty of climate change, while rapidly growing communities that rely on non-renewable groundwater, such as Buckeye, must deal more with the uncertainty surrounding population growth. The build-out plans for approximately 22 master planned developments within and surrounding Buckeye paint a long-term vision of the town as a large continuous community. According to its master plan, growth will provide the revenue needed to expand operational services and infrastructure to provide quality service over a large area while creating a system with low sensitivity and a high number of redundancies.

However, the recent national economic crisis has taken hold locally, challenging the growth-oriented vision of decision makers, investors and residents. In the first half of 2008, Buckeye faced 468 housing foreclosures—386 more than in the same period of 2007. In October of 2008, only seven of the 22 approved master planned communities were still under construction (PBS 2008). Attempting to tie together and service water systems spread over a 600 square mile planning area will likely prove difficult, stressing the human and financial resources of the town’s CWS. With a nation-wide recession growing worse by the month, communities that chose to grow their systems based on optimistic economic and population projections are faced with maintaining infrastructure and services with limited growth revenue.

Compounding the issue of uncertain growth, climate change and prolonged drought may stress surface water sources used by neighboring
communities and irrigation districts forcing groundwater dependent communities such as Buckeye to compete for finite groundwater sources. According to a worst-case scenario sensitivity analysis of the Phoenix AMA using population projects for the year 2025, under a five-year drought, with agriculture held at 1995 levels and without the delivery of junior CAP allocations, the proportion of demand not met by surface water would be 68% (as compared to 20% in the baseline year of 1995) (Morehouse et al 2002). Under this scenario, current consumptive lifestyles would be unattainable while water providers and exempt well-users throughout the Valley would be forced to make unheard of investments to deepen wells and update treatment facilities. Regional water management institutions and strategies geared toward adaptive capacity would likely fail and vulnerability would increase for even the most historically secure CWS in the AMA—those with diversified water portfolios—as they too would be forced to compete for shrinking groundwater supplies.

**Recommendations for Reducing Vulnerability in Cave Creek and Buckeye**

Since the passage of the Groundwater Management Act of 1980, Arizona has been applauded for the state's progressive water policy and drought planning efforts. Despite a comprehensive state-wide plan for reducing groundwater overdraft, local water systems have unique aspects heightening their vulnerability, especially those in outlying and rural communities that experience rapid growth without access to diverse water sources. CWSs in the southwest and other semi-arid and arid communities simultaneously facing natural hazards and social
pressures such as rapid growth cannot reduce the likelihood of drought. Therefore to reduce vulnerability, or the potential for losses, they must increase the adaptive capacity and reduce the sensitivity of their systems through a suite of supply- and demand- side management strategies.

Building Institutional Capacity for Adaptation

This research confirms that the challenges faced by CWSs are not uniform across, or even within, climate regions. As a result, local vulnerability reduction strategies should go beyond ‘one size fits all’ approaches. For strategies to be effective and responsive to changing social and biophysical conditions locally, they must be developed in conjunction with stakeholders at the appropriate scale considering the local social and biophysical context of vulnerability. Furthermore, with increasingly limited financial and water resources, CWSs should consider the costs and benefits of any investment into supply and demand side reduction programs. The cost of implementing a strategy should be weighed against the potential water savings. Incorporating cost-benefit analysis, downscaled climate change information, accurate population projections, and hydrologic data into a decision making process that is already constrained within a complex multi-level institutional structure requires a high degree of institutional capacity that is not found at the local level in the Phoenix metro area or in small towns generally.

To alleviate this stress and reduce vulnerability across many locations and sectors, professionals within academic and regional water management sectors should focus their efforts on increasing local institutional capacity and improving
water governance by refining data to the local scale, creating user-friendly cost-benefit analysis tools and developing adaptable, cost-efficient, effective best practices for demand reduction and sustainable supply augmentation. It is yet to be determined if local decision makers and planners would take full advantage of these tools. However, vulnerability could be reduced if they were to utilize refined data and locally vetted best practices to better plan and manage their systems under current and future scarcity scenarios.

**Efficiency, Source Diversification and Redundancy**

Supply-side mechanisms for vulnerability reduction generally involve supply augmentation and redundancy. As is common in all realms of resource management, including energy, before investments are made to diversify supplies or build redundancy in water sources and delivery infrastructure, the existing system should be tweaked for optimum efficiency. In CWS management, the institutional side of the system should be tweaked for efficiency through conservation oriented water pricing, customer education and other policy changes (discussed below) while the physical system is improved through leak detection and repair—both of which are partially underway in Cave Creek and Buckeye.

The most effective, yet difficult, vulnerability reduction strategy for communities relying on a singular water source is source diversification. Purchasing water rights and/or investing in groundwater treatment infrastructure to augment supplies increases adaptive capacity and reduces overall local vulnerability. However, in the Southwest and many dessert regions existing
resources are over-allocated and contested, making diversification extremely difficult. Diversification requires heavy financial investment which requires widespread community buy-in and strong political will. Garnering the long-term financial and political support necessary to diversify CWS sources can stress the capacity of management institutions while increasing competition for finite resources. Community water systems that are challenged with everyday operations, such as Cave Creek, may find it especially difficult to implement diversification measures. If communities are able to raise the financial resources and community support needed to diversify their water portfolios, short-term local CWS vulnerability will decrease. However, diversifying local CWSs can ultimately increase regional short and long-term vulnerability if done without drastically increasing CWS efficiency and conservation or without consideration of regional conditions such as upstream communities, groundwater budgets and ecosystem water needs.

A CWS can use effluent, as Buckeye has, to diversify their system without increasing local or regional vulnerability. Building redundancy into a system through zoning and connecting water-delivery infrastructure, as Buckeye plans to do, requires a heavy financial investment. However, incorporating redundancy into a CWS, especially during as opposed to after development, can increase adaptive capacity and reduce local vulnerability to short-term perturbations without increasing short or long-term regional vulnerability.
Local and Regional Policy

As awareness grows regarding the negative impact that massive groundwater withdrawal and surface water diversion have on the environment, federal and state policies are making it more difficult to develop new sources of water for supply diversification. Simultaneously, worsening economic conditions are making large-scale supply-side capital investments harder to fund. In response, vulnerability reduction within the water management sector has recently moved away from supply augmentation and toward the adoption of policies that have the potential to reduce demand. Based on this research, three recommendations for policy geared toward vulnerability reduction can be made. These policies seek to permanently build efficiency and conservation into development and operations. Institutionalizing efficiency and conservation through policy reduces the need for short-term or emergency-oriented demand reduction measures. Requesting or requiring users to reduce consumption only during peak periods of stress can lead to the hydro-illogical cycle wherein vulnerability is increased because conservation efforts are often abandoned during brief wet periods despite long-term drought conditions.

First and foremost, policy should mandate that long-term land and water use planning be done in conjunction to ensure the availability of high quality reasonably priced water for existing CWS customers and those reliant on private groundwater wells. Arizona law requires municipalities to conduct long-range, voter-sanctioned land-use planning and requires developers to show 100 years of assured water supply, however, these two planning processes are conducted
independently. As a result, long-term water security or the lack thereof does not constrain aggressive land-use development and annexation. As evidenced in Buckeye, community land-use planning is conducted without consideration of how growth will increase pressure on finite groundwater supplies, thus degrading water quality and increasing treatment costs and household CAGRD groundwater recharge assessments—all of which increase individual and CWS vulnerability.

Second, local policies related to land-use planning and development should incorporate strong conservation initiatives that mandate water efficiency or conservation. Communities should adopt resource efficient building and landscaping codes, limit the percentage of impervious surface allowed and require the reuse of effluent for all non-potable water uses. These policies should apply to all land-use types (residential, commercial, industrial, etc) and be implemented on a regional mandatory basis. Adopting water wise development policies on a regional as opposed to municipal basis, as Las Vegas has done, reduces the likelihood that communities will use lax water and land use development requirements to compete for growth.

Lastly, CWS rate schedules should be designed to reward conservation. Increasing block rate structures and high use surcharges can reduce demand in some communities, especially those with lower than average household incomes and correspondingly decreased disposable income. A comprehensive cost-benefit analysis that considers accurate growth and demand projections should be done before rate schedules are changed to determine how subsequent reductions in revenue will affect the ability of the CWS to update aging infrastructure, expand
services to accommodate growth, or tie together existing infrastructure if growth completely stalls in light of economic conditions.

**Future Research**

Very few vulnerability assessments engage the respective population in post-reporting credibility discussions. Allowing participants and other decision makers in both towns, and possibly at the regional management level, to discuss and critique this narrative would likely be a contentious process. However, allowing for participant feedback will add credibility to the results, recommendations and assessment process or VSD. In addition, engaging stakeholders in a post-hoc discussion will likely create a needed social space to discuss long-term and nuanced issues that typically take a back seat to daily operations and short-term planning processes at the local level. Future vulnerability assessments should consider such participatory processes to enhance their applications to decision- and policy-making.

To add to the VSD library and more fully understand CWS vulnerability, future research should identify the role that additional biophysical, social and institutional characteristics have on system vulnerability in the urban core and along the periphery of Phoenix. For example, additional case studies should explore how system size, private ownership, and source diversification affect overall vulnerability and more specifically, the vulnerability of discreet populations and sectors (agriculture, industry, residential, etc). Furthermore, as climate change science advances and regional models are scaled down,
projections should be incorporated into the case study assessment framework to identify potential points of weakness and strength within local systems. Also, case studies should seek to understand how systems exposed to drought perform while simultaneously coping with multiple natural hazards such as fire and flood.

While disagreement still exists regarding what metrics and data should be used to quantify vulnerability at all scales, at the local CWS scale this research highlights dimensions of the system that have already proven to more or less mediate the impacts of drought. Performing additional case study research will add to the growing library of vulnerability assessments done using the VSD and allow for more valuable generalizations as to which factors affect vulnerability to community water systems. The factors revealed through this and future assessments should be incorporated into existing and developing local and regional water and land use management decision-making tools. Incorporating nuanced, yet influential, characteristics such as local institutional capacity and growth management culture into existing and respected decision-making vehicles provided by the Decision Center for a Desert City and Arizona Drought Planning Commission will empower local and regional decision-makers to engage in anticipatory hazard and climate change mitigation and adaptation planning.

Conclusions

This thesis has identified the factors that moderate and exacerbate vulnerability to water scarcity in two peri-urban CWS in the semi-arid Phoenix metropolitan area. Using a grounded assessment framework advised by the
literature on human-environmental systems and natural hazards, a qualitative analysis was completed to better understand which factors are most critical for reducing the vulnerability of community water systems to scarcity. In regard to biophysical factors, aquifer characteristics played the largest role in determining differential vulnerability between the case study areas. Drought status—a factor that would be expected to have a large impact on vulnerability—did not. In modern or developed water systems, the impact of drought is more or less mediated by a complex system of institutional and social factors. Vulnerability in both communities is increased by having only one potable water source. Cave Creek and other surface water reliant communities are more vulnerable to short-term climatic perturbation but less vulnerable to long-term water scarcity and the reverse can be said for groundwater dependent communities. While having the greatest potential impact, source diversification is the least appropriate strategy for vulnerability reduction considering the overall regional over-allocation of surface water rights, regional groundwater overdraft condition and decreasing availability of growth related revenue.

Aside from water source, in terms of institutional factors, infrastructure and institutional knowledge had the greatest effect on differential vulnerability. Failing infrastructure and limited institutional knowledge in Cave Creek created temporary water outages and real negative impacts. Interestingly, short-term vulnerability spurred the community to conduct long-term water system planning, despite their relatively lower long-term vulnerability. On the contrary, Buckeye, a community yet to suffer water outages or inconveniences but considered
extremely vulnerable to long-term water scarcity in the future, has invested significantly less energy into long-term water resource planning. Neither community has seriously considered the impact that climate change will have on their CWS. Exploring scenarios for long-term climate change adaptation is outside the capacity of already stressed local management institutions and thus a gap that regional management and academic professionals should address. However, as was discovered through the research process, filling this gap requires experts know their audiences needs in order to translate data into recommendations and decision-making tools that local agencies value.
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