Adaptation to Extreme Droughts in Arizona, Georgia, and South Carolina: Evaluating Adaptive Capacity and Innovative Planning and Management Approaches for States and Their Community Water Systems

by

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List of Abbreviations

ACC – Arizona Corporation Commission
ADEQ – Arizona Department of Environmental Quality
ADWR – Arizona Department of Water Resources
ANOVA – Analysis of variance
ASDPP – Arizona State Drought Preparedness Plan
AWBA – Arizona Water Banking Authority
AG – Adaptive governance
AM – Adaptive management
AMA – Active Management Area
AIM – Adaptive and integrated management
BMP – Best management practice
CAP – Central Arizona Project
CAS – Complex adaptive systems
CISA – Carolinas Integrated Sciences and Assessments
CLIMAS – Climate Assessment for the Southwest
CLM – Cumulative logit models
CWS – Community water systems
CWSS – Community Water Systems Survey
DRC – Drought Response Committee
EHC – Event history calendar
EPD – Environmental Protection Division of GDNR
FERC – Federal Energy Regulatory Commission
GDMP – Georgia Drought Management Plan
GDNR – Georgia Department of Natural Resources
GEE – Generalized estimating equations
GSWP – Georgia State-wide Water management Plan
GWCIP – Georgia Water Conservation Implementation Plan
ICG – Interagency Coordinating Group
IPCC – Intergovernmental Panel on Climate Change
IRP – Integrated resource planning
IWRM – Integrated water resources management
LHC – Life history calendar
LDIG – Local Drought Impact Group
MNGWPD – Metropolitan North Georgia Water Planning District
MTC – Monitoring Technical Committee
NGO – Non-governmental organization
NIDIS – National Integrated Drought Information System
RISA – Regional Integrated Sciences and Assessments

SCDHEC – South Carolina Department of Health and Environmental Control
SCDNR – South Carolina Department of Natural Resources
SCDRP – South Carolina Drought Response Plan
SCEMD – South Carolina Emergency Management Division
SCSWP – South Carolina State Water Plan
SECC – Southeast Climate Consortium
SERRP – The State of Arizona Emergency Response and Recovery Plan
SES – Social-ecological systems
SPI – Standardized Precipitation Index
SRFC – Southeast River Forecast Center
SRP – Salt River Project
SPRNCA – San Pedro Riparian National Conservation Area
STIS – Space-Time Intelligence System
U.S. – United States
USGS – U.S. Geological Survey
USEPA – U.S. Environmental Protection Agency
WDCP – Water development and conservation plans

Abstract

Arizona, Georgia, and South Carolina have experienced extreme droughts within the past decade. Droughts of even greater intensity will likely increase in the coming years, and other stresses such as population growth will compound the effects of climate variability and change on water resources in these and other states. Decision makers need frameworks that expand the range of options and instill the flexibility necessary to adjust to the predicted and unpredicted changes they will face. Research suggests that innovative approaches such as drought preparedness, integrated water resources management, and adaptive management might instill such flexibility and improve adaptive capacity to droughts.

I investigate these approaches at the state and local levels, with an emphasis on the operation of community water systems (CWS). I combine quantitative and qualitative mixed methodologies to measure and characterize adaptive capacity. Also, I look more closely at the largest urban CWS in Arizona and Georgia to evaluate the timing, bridges, and barriers for implementing these approaches in relation to the onset of droughts.

Across the states, I find that factors contributing most to adaptive capacity include (but are not limited to) flexible and iterative drought triggers/indices/monitoring and local drought plans/planning, state-backed comprehensive planning and informational support systems, and regional forums for collaborating between communities. I identify potential conflicts in balancing state regulation and support with local CWS drought preparation and response. I also uncover a mix of positive and negative relationships between the onset of droughts and management approach implementation in Georgia, while in Arizona, the relationships are mainly negative. In Arizona, a ‘culture of conservation’ has developed within large CWS and their publics, but adaptedness to the arid conditions has created cognitive barriers that could limit stronger conservation efforts during more extreme droughts. In Georgia, although droughts serve as ‘windows of opportunity’ to

innovate, the cyclical implementation of approaches suggests that there are important impediments to their more permanent adoption in the future.

Broadly, my findings suggest that there are tensions in building adaptive capacity at various spatial scales, as well as potential tradeoffs between the proactive and reactive elements of adaptive capacity.

Chapter 1
Overview

1. Introduction

Multiple environmental stresses increasingly threaten the sustainability of human activity and the ecosystems upon which we depend (National Research Council, 2007). Climate change presents an overlying pressure that mostly exacerbates these already existing stresses in a manner that challenges our ability to achieve sustainability (World Bank, 2009). Moreover, certain human-environment sectors, such as water systems, are particularly vulnerable to climate change and other stresses (Adger et al., 2007).

Within the water sector in many regions throughout the United States (U.S.), rapid population growth is increasing demand for high quality water resources, and pressures on water supply and quality from current climate variability are likely to become even more pronounced with climate change. Together, these stresses highlight the importance of researching the overlapping topic of water resources, high-growth regions, and climate variability and change (National Assessment Synthesis Team, 2000; Lettenmaier et al., 2008). This dissertation focuses on extreme drought events in several high-growth states within the Southeast and the Southwest. It particularly emphasizes community water systems (CWS), or the public, private, and non-profit suppliers of drinking water, for they represent one of the most important set of actors in water resources governance vulnerable to the impacts of climate variability and change.

In terms of making decisions in the face of multiple stresses and climate change, there is growing interest among managers and policy makers to understand not only the magnitude of the impacts and their anticipated consequences, but also what they can do to prevent, respond, and adapt to these impacts (Beller-Simms et al., 2008). However, even as climate model downscaling improves, scientists recognize an inevitable amount of uncertainty associated with impact projections that are likely to persist (Carter et al., 2007; Christensen et al., 2007; Paeth et al., 2008). This context of high uncertainty and high stakes creates increased demand from decision makers for tools and models of governance and management that can increase flexibility and expand the range of response options necessary to adjust not only to changes science can predict with some degree of confidence now, but also to those science has yet to identify.

Operating in this grey area of decision making under uncertainty, researchers and resource managers have increasingly sought to explore and identify those aspects of the system they can more easily manipulate and change; namely the governance, management, and institutional approaches that can increase flexibility and adaptive capacity of water systems to climatic variability and change (Adger et al., 2007). While there is a rich emerging literature hypothesizing how different innovative institutional frameworks and management paradigms such as drought preparedness, integrated water resources management (IWRM), and adaptive management (AM) may shape water systems' adaptive capacities to climate impacts (Pahl-Wostl et al., 2007), there has been relatively little empirical research that systematically tests such assumptions. There has also been an insufficiency in research that attempts to characterize adaptive capacity at multiple spatial and temporal scales. Furthermore, questions remain regarding the mechanisms that foster the adoption and implementation of those innovative arrangements that are purported to increase adaptive capacity (e.g., drought preparedness, IWRM, and AM).

The overarching goal of this dissertation is to investigate empirically how to build adaptive capacity to extreme droughts in two U.S. regions facing rapid population growth and climate variability and change. I outline three broad research goals for making theoretical, methodological, and policy applicable advancements to the field of adaptation and sustainability studies:

1) to improve adaptive capacity assessments by combining insights from two prevalent global-change frameworks, vulnerability and resilience;
2) to measure and characterize adaptive capacity to determine which governance, management, and institutional approaches contribute most to adaptive capacity across various scales;
3) and to further characterize adaptive capacity in understanding the dynamics, bridges, and barriers surrounding the adoption of innovative management and

institutional approaches over the past decade in one sub-group of CWS; large urban public water systems.

Accomplishing these three goals will contribute to adaptation and sustainability science by refining and applying theory regarding the approaches that are more closely associated with higher adaptive capacity, and demonstrating novel methodological techniques for adaptive capacity assessment, including the combination of qualitative and quantitative analyses, as well as a new adaptation data collection tool. Also, in this pursuit I will develop and test a set of critical spatial-temporal indicators for measuring management and institutional approaches and the adequacy of these approaches for successfully managing extreme drought events in the study regions. From a policy perspective, the indicators, methodologies, and findings should provide important baseline information for much needed social-institutional monitoring and understanding of drought-related adaptations within the two study regions. More broadly, the work should help improve frameworks for assessing adaptive capacity and adaptations in systems that are outside of the purview of this study; particularly by linking with already existing decision-support tools like the National Integrated Drought Information System (NIDIS) (http://www.drought.gov).

This dissertation is organized as follows. In Chapter 2, I review the conceptual origins of adaptive capacity and make the case for bringing together vulnerability and resilience literatures for improving adaptive capacity assessments. Chapter 3 applies the main arguments from Chapter 2 to more comprehensively measure and characterize adaptive capacity to extreme droughts at the state and local CWS-levels. I use survey data, telephone interviews, and archival research to examine impacts of recent extreme droughts in three states in the Southeast and Southwest; Arizona, Georgia, and South Carolina. The research combines detailed qualitative and quantitative analyses within and between these states to evaluate the role of drought preparedness, IWRM, and AM for increasing adaptive capacity. In Chapter 4, I focus on larger urban CWS within two of these states, Arizona and Georgia, to investigate the development of innovative management approaches and the bridges and barriers to CWS adaptation (i.e., a detailed characterization of adaptive capacity) over time. Specifically, this chapter draws on qualitative and quantitative data obtained using an event history calendar (EHC) to explain why certain approaches develop (or not) in relation to the onset of drought events. Finally, in Chapter 5 I conclude with a summary of the key findings from the preceding chapters and describe how collectively, the results can contribute to both theoretical advancements and policy application.

The remainder of Chapter 1 provides a brief background of the literatures informing this research (which I rehash and elaborate upon in subsequent chapters), a glimpse at the research design and methodologies that I utilize throughout the dissertation (including details on the case selection process and descriptions of the recent Southwest and Southeast droughts), and a concise synopsis of the key messages and findings in Chapters 2, 3, and 4.

2. Adaptive Capacity and Water and Drought Governance

2.1. Drought, Climate change, and Community Water Systems

Freshwater systems throughout the world will experience significant stress as a result of climate change, such as increased droughts and floods, less predictable and more intense storms, and decreased water quality and ecosystem health (Kundzewicz et al., 2007; Bates et al., 2008). Droughts are particularly threatening to the U.S., as they will likely increase in frequency, duration, and intensity in many regions throughout the country. Recent climate change models for the Southwest project drought intensification due to higher temperatures and a poleward moving jetstream that will worsen already dry conditions (Lenart et al., 2007). In the Southeast, increasing mean temperatures and increasing extreme events will likely exacerbate already existing water quality issues and increase problems with water availability (Karl et al., 2009). In these and other U.S. regions, superimposing droughts and climate change upon pre-existing stresses associated with high population growth rates will combine to place intense pressure on freshwater availability and quality.[1]

Despite growing evidence of such stress and vulnerability, regional climate impact and adaptation analyses in the U.S. are under-prioritized (National Research Council, 2001, 2007; National Oceanic and Atmospheric Administration, 2009). To

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[1] For instance, the West and the South have experienced 12.1 percent and 11.5 percent increases in growth, respectively, between 2000 and 2008. Updated figures for these regions and each state are accessible through the U.S. Census Bureau, http://www.census.gov/popest/states/NST-pop-chg.html.

improve preparedness and response to the negative effects of climate-driven stressors, there is a need for research on adaptation to climate change within the U.S., particularly within the highly vulnerable water sector (Adger et al., 2007). My research examines these issues in the context of states and CWS (i.e., public and private water providers).[2] Specifically, in Chapter 3, I investigate adaptive capacity and drought planning and management within and between three U.S. states and their CWS that have experienced similarly extreme drought events. In Chapter 4, I take a closer look at larger urban public water systems in two of these states, as urban settlements house the majority of the world's population and urban populations will increase in the coming years.

CWS are not the largest users of freshwater resources,[3] but they represent an integral component of the water sector. From 1950 to 2000, the percentage of people in the U.S. receiving their drinking water from CWS grew from 62 percent to 85 percent (Hutson et al., 2004). Given the important role of CWS, it is critical that researchers understand both the potential impacts of climate change and extreme droughts on water suppliers, as well as the effectiveness of potential adaptation options (Cromwell et al., 2007; Smith et al., 2009). Furthermore, the increased visibility and accountability of CWS during times of drought places these systems under intense pressure to perform, which in some cases results in innovation and, in others, conformity to more tested and conservative practices and approaches. Whether innovative approaches contribute to higher adaptive capacity, and the factors motivating and/or facilitating these more innovative approaches are the main focuses of Chapters 3 and 4, respectively.

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[2] USEPA defines CWS as "a public water system that supplies water to the same population year-round." CWS may be publically or privately owned. The term 'CWS' is commonly accepted throughout the water management community, and thus used in this research. However, the term is not necessarily used harmoniously across other departments and agencies at the federal, state, and local levels. For example, USGS makes no mention of CWS in describing its interpretation of 'public supply', but the definition is very similar; "water withdrawn by public and private water suppliers that furnish water to at least 25 people or have a minimum of 15 connections. Public supply water may be delivered to users for domestic, commercial, industrial, or thermoelectric-power purposes. Some public-supply water may be delivered to other public suppliers or used in the processes of water and wastewater treatment." For sources and more information, please see http://www.epa.gov/ogwdw/pws/factoids.html; and http://pubs.usgs.gov/circ/2004/circ1268/pdf/circular1268.pdf.

[3] Recent statistics show that CWS account for approximately 11percent of freshwater use across the U.S., third to thermoelectric power and irrigation, respectively (Hutson et al., 2004). For more information, see http://pubs.usgs.gov/circ/2004/circ1268/pdf/circular1268.pdf.

2.2. Adaptive Capacity

Adaptive capacity is the ability of a system to prepare for and respond to climate variability and change in order to cope with the consequences, moderate damages, or take advantage of the opportunities created by climate stress (Adger et al., 2007). In other words, it is the ability of a system to prepare for stresses and changes in advance or adjust and respond to the effects caused by the stresses (Smit et al., 2001). A fundamental contribution of this dissertation is a conceptual review of adaptive capacity in Chapter 2 that traces its origins and development in the adaptation, global change, and sustainability science discourses; particularly emphasizing its prevalence in both vulnerability and resilience frameworks.

A second critical element of my research (explored in Chapters 2, 3, and 4) is an attempt to improve adaptive capacity assessments, which are steadily growing (Brooks and Adger, 2005; Schröter et al., 2005; Polsky et al., 2007; Tol and Yohe, 2007; Engle and Lemos, 2010). To date, such assessments have affirmed the integral role that institutions, governance, and management play in determining a system’s ability to adapt to climate change (Adger, 2001; Yohe and Tol, 2002; Ivey et al., 2004; Brooks et al., 2005; Haddad, 2005; Eakin and Lemos, 2006; Agrawal, 2008; Engle and Lemos, 2010). Adaptive capacity analyses grounded in a vulnerability framework are actor-centric and often generalized to other contexts for policy recommendation and prescription (Nelson et al., 2007), as evidenced by products such as politically and managerially digestible maps, indices, and rankings (Kelly and Adger, 2000; Cutter et al., 2003; O'Brien, Leichenko et al., 2004; Brooks et al., 2005; Schröter et al., 2005). However, these studies have tended to center on aggregate assessments at the national level that are too coarse for capturing local nuances (Ivey et al., 2004; O'Brien, Leichenko et al., 2004; Brooks et al., 2005; Ford et al., 2008), leave out key process variables that more accurately explain the dynamics of the systems under examination (O'Brien, Eriksen et al., 2004; Nelson et al., 2007), or are often performed at a single spatial scale and/or are merely ‘snapshots’ in time (Vincent, 2007). Adaptive capacity analyses grounded in a resilience framework more centrally focus on system interactions, feedbacks, and processes (Nelson et al., 2007), attempting to consider the complex relationships and interconnectedness inherent in issues related to sustainability and multiple stresses. However, the resilience framework struggles to translate adaptive capacity into practice, as the studies are often single cases that make operationalization and generalization of adaptive capacity indicators and determinants difficult (Wilbanks and Kates, 1999; Carpenter and Brock, 2008).

In Chapter 2, I present one alternative to assessing adaptive capacity in a manner that draws from constructive elements of both vulnerability and resilience frameworks. In Chapter 3, I test the assessment approach by collecting and analyzing data quantitatively and qualitatively to measure and characterize adaptive capacity at the state and local CWS-levels. Chapter 4 offers a more in-depth characterization with respect to large urban CWS.

2.3. U.S. Water Law and Management

Water management in the United States is complicated by a complex overlay of competing institutional jurisdictions, laws, and bureaucratic missions at various scales. At the federal level alone, jurisdiction spans a significant number of Congressional committees, sub-committees, cabinet-level departments, independent agencies and White House offices (Deason et al., 2001). In general, water quality is regulated by the Federal Government, while water quantity is handled by the states (Wright, 1998). Mainly, the Federal Government manages water quality through the Federal Water Pollution Control Act Amendments of 1972 and 1990 (Clean Water Act and its amendments), and the 1974 Safe Water Drinking Act (Deason et al., 2001). While these two Acts have contributed to significant improvements in water quality, there is still little integration of water quality goals with water supply, drought management, or and land-use planning issues.[4]

Water allocation and supply approaches have been historically dominated by water availability and regional development goals. In the water-scarce regions of the West and Southwest, management has relied upon the prior appropriation doctrine, which emphasizes that the first to claim stake on the water owns the rights to that water; the impacts of which are thoroughly documented (Reisner, 1986). Prior appropriation treats water as a property right, and in doing so creates incentives for using these rights (i.e.,

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[4] There are few laws that integrate water quality with water allocation, with the exception of Section 401 of the Clean Water Act. This statute allows for states to limit activities, including water withdrawal, on a given stream if the quality of the water is threatened (Wright, 1998).

using the water before someone else uses it). In the historically water-abundant regions of the East and Southeast, the riparian doctrine has developed to allocate water according to land ownership by limiting adjoining land owners of a water resource to use water ‘reasonably’ (Wright, 1998; Deason et al., 2001; Fort, 2003). Hybrid approaches have recently developed, such as the regulated riparian approach in the Eastern U.S. which requires a state-issued permit for water withdraws (Wright, 1998).

Despite the maintenance and operation of massive federal infrastructure projects implemented more than half a century ago, the role of the Federal Government has been relatively limited with respect to water allocation policy. Even in situations where the Federal Government would have obvious jurisdiction over states (e.g., interstate water issues), the preferred federal approach is to take a less dominant role and allow states to negotiate their own agreements (Fort, 2003). The states in this research present a mix of water laws and policies, each affecting adaptive capacity differently, which I describe in Chapter 3.

In addition to the competing jurisdictional responsibilities, historically, U.S. water management has prioritized structural approaches to managing water. ‘Manifest destiny’ attitudes, along with the depression era New Deal initiatives brought irrigation, flood control, and navigation assistance, ultimately helping to manage climate variability (Sabatier et al., 2005; Gerlak, 2006). The resulting construction of these engineering projects aimed at controlling and diverting water throughout the various regions has left a system that favors supply-side management. The impact of this legacy reaches all the way down to CWS, where demand-side, or nonstructural approaches, such as efficiency gains, conservation and curtailment, improved metering, zoning, and innovative institutional arrangements have received less attention. There are signs that demand management is increasing in CWS over the past few decades, but nonetheless, both supply and demand approaches play an important role for drought planning and management, which I preview below, but more thoroughly evaluate in Chapters 3 and 4.

2.4. U.S. Drought Planning and Management

Due to drought’s close relationship with water allocation and availability, states and local entities play the primary roles in determining drought planning and management efforts. Until recently, drought response has been reactive rather than preparatory throughout most of the U.S. This reactive approach to droughts has essentially led to a crisis-driven management mentality and thus greater vulnerability of humans and ecosystems (Hayes et al., 2004). At the same time, the most prominent proactive measures have relied upon infrastructure for storing and diverting water for varying regional and sectoral needs, with little attention to long-term mitigation planning or demand management approaches.

Encouragingly, states have recently begun to initiate more proactive 'drought preparedness' efforts (i.e., monitoring/early warning/prediction, risk/impact assessment, and mitigation and response) (Hayes et al., 2004; Jacobs et al., 2005; Wilhite et al., 2005). This recent surge of activity is evidenced by a greater number of state drought plans[5] and the proliferation of tools to aid these state drought planning initiatives (e.g., the 10-step planning process) (Wilhite, 2009). Another promising development is the recent creation of NIDIS, which represents a national-level effort to convey pertinent drought information to practitioners at various stages of the drought management process. The web portal provides information on indicators, databases, forecasts, impact tracking, partnership opportunities, research initiatives, and other various tools and services to aid decision making.

In this dissertation, I seek to address several remaining gaps in understanding between U.S. drought planning and management and adaptive capacity. Chapter 3 provides detailed descriptions of each state's drought planning and management processes and structures, and analyzes their influence on adaptive capacity based on recent extreme drought events. Furthermore, I focus specific sections of Chapter 3 and the entirety of Chapter 4 on the analysis of CWS; whether they adopt certain management and governance approaches, how these approaches interact with state-level initiatives, and how these approaches might develop over time and thus influence adaptive capacity and adaptations to climate change. An important component of these CWS analyses is to investigate the role of 'adaptive and integrated management' approaches in building adaptive capacity, which I describe briefly below.

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[5] As of October, 2006, 37 states had drought plans. For more information, see http://www.drought.unl.edu/mitigate/status.htm.

2.5. Adaptive and Integrated Management

As climate changes and water resource problems become more complex, traditional command and control management approaches will likely become less effective (Johnson, 1999). Studies have suggested that more flexible, participatory, collaborative, and learning-based designs are more innovative and positively affect drought management and adaptive capacity (Kallis et al., 2006; Cromwell et al., 2007). However, there has been limited empirical testing of such assumptions beyond single in-depth case studies. This leaves key questions relating to the most effective piecing together of approaches, which determinants to emphasize, and how the most innovative approaches develop over time; particularly in the context of CWS. Two approaches that have received considerable attention in the adaptation and water management fields for their potential to increase adaptive capacity are integrated water resources management (IWRM) and adaptive management (AM). IWRM is geared toward decentralizing institutions at the river basin or watershed scale and linking various elements of water resources planning, such as groundwater and surface water management. In doing so, it strives to unite management across multiple scales and a multitude of stakeholder interests (Blomquist et al., 2005). AM is primarily concerned with managing uncertainty through formalized experimentation and learning processes (Lee, 1993; Huitema et al., 2009).

Blending of IWRM and AM paradigms is an increasing practice (e.g. ‘adaptive co-management’, ‘adaptive governance’, and ‘Integrated Resource Planning’ (IRP)) (Beecher, 1995; Howe and White, 1999; Olsson et al., 2004; Folke et al., 2005; Cromwell et al., 2007; Plummer and Armitage, 2007; Nelson et al., 2008). Furthermore, there is some overlap between the academic and professional literatures in that IRP operationalizes some of the IWRM and AM concepts (e.g., emphasis on conservation, long-term planning, balancing supply and demand management, etc.). This merging of AM and IWRM in the various climate and water related literatures often results in a failure to place these paradigms into operation around crisp indicators and measurements; ultimately leaving the individuals and entities that serve to gain from their implementation less likely to use them in practice (Biswas, 2004; Medema et al., 2008).

In Chapters 3 and 4, I address this issue directly by reviewing characteristics of the IWRM and AM paradigms and operationalizing them into the context of U.S. drought planning and management. In Chapter 3, I include drought preparedness with IWRM and AM to test the influence of the various approaches captured in these paradigms on adaptive capacity in Arizona, Georgia, and South Carolina. In Chapter 4, I use a slightly modified grouping of these management variables to analyze Arizona and Georgia CWS' adoption of these innovative approaches over the past decade, so as to identify the bridges and barriers to adaptation. The empirical research in both Chapters 3 and 4 uses a mixed methodology design that draws from traditional and novel data collection and analysis techniques, which I describe next.

3. Research Design and Methodology

In this section, I present the research questions and hypotheses, and provide an overview of the state-selection process, a description of the drought events of interest in each of the states, and a brief review of the mixed methodologies that I use throughout this dissertation.

3.1. Research Questions and Hypotheses

The questions that motivate the empirical portions of this dissertation (mainly Chapters 3 and 4) seek to address the goals that I outline in the beginning of this chapter. Specifically, in Chapter 3 I ask:

1) what are the management, institutional, and governance approaches at various scales (particularly the state and CWS levels) that contribute to or inhibit the building of adaptive capacity to extreme droughts, that is, which approaches are most associated with higher adaptive capacity?
2) how can we improve adaptive capacity assessments to more adequately capture its dynamic, nested, and poly-centric nature in a manner that can be operationalized and applicable to decision makers?

At the state-level, I expect that Arizona, Georgia, and South Carolina will have unique factors contributing to adaptive capacity, but that there will also be common themes across the three states. Specifically, I hypothesize that factors related to drought preparedness will be most innovative and influential to building adaptive capacity in

Arizona (because of the arid environment), factors related to water management will be most innovative and influential to building adaptive capacity in Georgia (because of recent water reform and regulated riparian water laws), and that factors related to drought preparedness and water management will be less innovative and influential to building adaptive capacity in South Carolina (because it is not historically arid and surface water falls under the riparian doctrine). At the CWS-level, I hypothesize that each states' CWS will have a unique set of management approaches associated with higher adaptive capacity because of the mechanisms (i.e., institutional, and governance) that have developed over the years to prepare for and respond to droughts, and that the largest CWS will demonstrate the highest adaptive capacity, because of more resources for drought planning and management. Also, I posit that adaptive capacity assessments that more explicitly consider indicators around multiple spatial and temporal scales will unveil both new methodological advancements and also new challenges that researchers will need to consider in future assessments.

In Chapter 4, I ask:

1) when do CWS implement innovative drought planning and management approaches in relation to extreme drought events?
2) what facilitates or inhibits CWS from adapting and adjusting their approaches?

I hypothesize that in both Arizona and Georgia, some of the 'soft' management approaches (e.g., long-term planning and climate information use) will demonstrate positive associations with the onset of droughts (both immediate and delayed relationships), while others, particularly the 'hard' management approaches (e.g., infrastructure, supply diversity, etc.) will not demonstrate significant relationships. Also, as with the state-level analysis in Chapter 3, I hypothesize that each states' large urban CWS will have a unique set of bridges for and barriers to implementing innovative approaches because of the state-specific mechanisms (i.e., management, institutional, and governance) that have developed over the years to prepare for and respond to droughts. Thus, there will be unique ways that adaptive capacity develops over time and is manifested between states.

3.2. State Case Selection

I used spatial data to reconstruct extreme drought events that have occurred in each of the regions within the past decade (1999 to 2009).[6] I looked at the most recent decade as the time interval of analysis because the impacts of drought and the decisions related to managing drought can spread over several years. The time interval did not extend beyond the most recent decade, because details of the innovative management approaches gathered from interviews, surveys, and event history calendars were likely to get progressively less reliable beyond this period.

State selection depended on the presence of a significant extreme drought event in the past decade. I identified states and the associated drought periods by their drought intensities at the 'extreme' level based on the Standardized Precipitation Index (SPI), developed by McKee et al., (1993). The SPI is a method for providing a comparable metric across locations for the evaluation of climate stress on hydrological processes. The metric is based on past climate conditions and the probability of precipitation for various time scales (e.g., 1, 2, 3, 6, 9, 12, and 24 month intervals) (Hayes, 2006). Through a normalization and standardization process, the values can be compared across regions, based on the standard normal distribution, where a +2 or -2 (extreme wetness and extreme dryness, respectively) are indicative of a dry or wet period that is experienced 2.3 percent of the time (Edwards and McKee, 1997). Additionally, unlike other drought indices, the timing of the dry period is universally defined as crossing the threshold of +1/-1 (moderately wet/dry), and ends when the sign is reversed (Hayes, 2006). From a meteorological standpoint, this allowed me to compare drought episodes in different states that had similar extremenesses; with assumingly different governance and management responses to these extreme episodes.

The SPI data exist at the climate division level, which I obtained from the National Oceanic and Atmospheric Administration's National Climate Data Center (NCDC).[7] I selected cases (states) that have experienced extreme drought (i.e., less than or equal to a SPI of -2) consecutively at short-medium and longer-term SPI calculations

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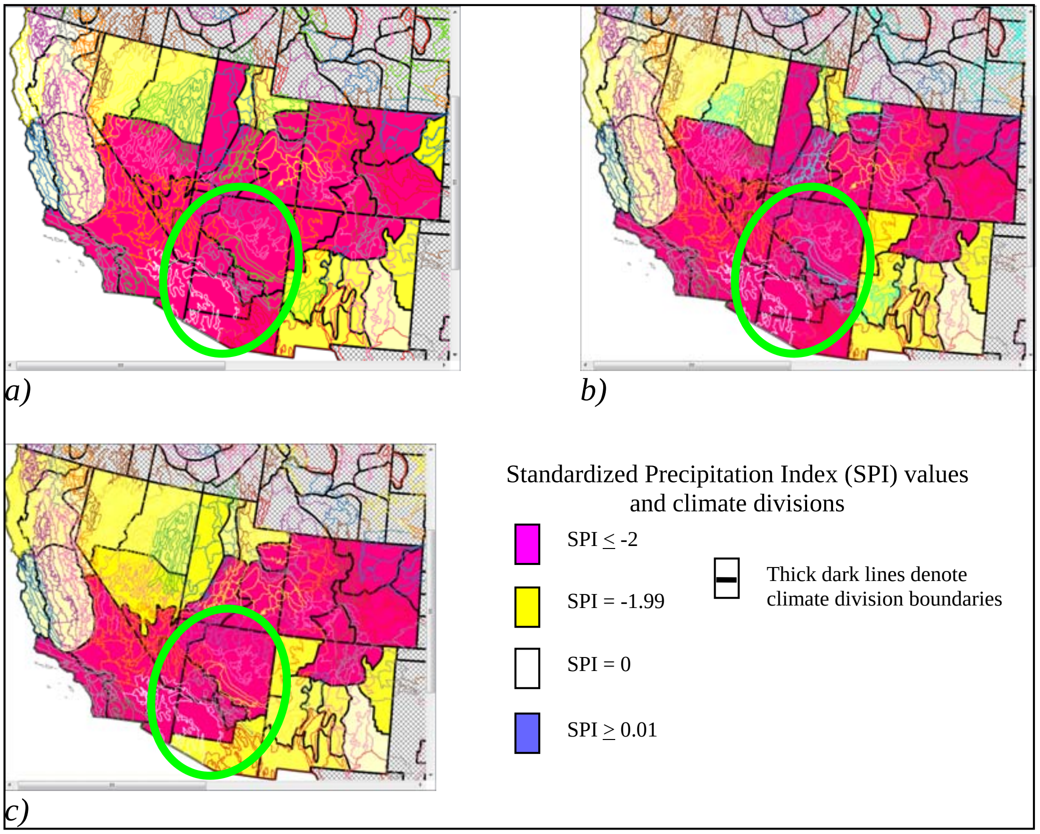
[6] I relied on ESRI's ArcGIS and TerraSeer's Space-Time Intelligence System (STIS) for analyzing and displaying the spatial data. I used Excel and MATLAB to convert the data into database files appropriate for use in both ArcGIS and STIS. All of the data locations were characterized in decimal degrees for latitude and longitude, and are projected on the North American Datum 1983.

[7] To access the NCDC data, see http://www7.ncdc.noaa.gov/CDO/CDODivisionalSelect.jsp.

across the majority of the state (i.e., 6, 9, and 12 month SPI values). I illustrate the selection process in *Figure 1.1*, which depicts the process for selecting Arizona. The multiple time scale approach effectively captures short-medium scale soil moisture responses to precipitation and longer-scale stream flow and ground water responses to precipitation, which allows for greater uniformity in comparing the climate stresses across regions. I also aimed to account for preexisting conditions that might have affected the system's response if examined within only one SPI time slice. The second selection criterion was that states must be experiencing rapid population growth (i.e., above 10 percent within the past decade).

Figure 1.1: SPI values in the Southwest U.S for August, 2002; *a)* 12-month, *b)* 9-month, and *c)* 6-month. Dry areas become increasingly yellow as the SPI values increase, and become pink when they pass 'extreme' values of -2. Conditions are no longer dry when the SPI enters positive values and turning map in those areas blue (not depicted in this particular figure). Arizona is circled in green.



In the end, this procedure helped facilitate my selection of Arizona, Georgia, and South Carolina as the three cases for this study.[8] After using the SPI data to guide selection of these states, I conducted preliminary interviews with climatologists and research scientists, water and drought managers, and non-governmental organizations (NGOs) in each state. Part of the purpose of these interviews was to understand better the time period within which the drought impacts occurred. Combining the systematic identification of the drought events using the SPI with expert perceptions of the time periods that the drought was most severe allowed for a more realistic inquiry into the preparation and responses surrounding these events. In the end, the drought periods of inquiry that guide this dissertation research are: 2001 – 2005 for Arizona and 2006 – 2008 for Georgia and South Carolina. Notably, all three states also satisfied the second selection criterion, with growth rates in Arizona, Georgia, and South at 26.7 percent, 18.3 percent, and 11.7 percent, respectively.[9]

3.3. The Southwest and Southeast Droughts

Using past extreme events as potential proxies for how systems might prepare for and respond to future climate change stress is well documented in the adaptation literature (Adger et al., 2007). While the merits of this approach are debatable (discussed more thoroughly in Chapter 2), my research assumes that humans and ecosystems will adapt and that there are systematic lessons to learn from these past experiences. It also assumes that a focus on adaptive capacity helps to identify variables that may facilitate better system actions in the face of future climate changes. Nonetheless, it is helpful to understand the droughts studied in this research and their relation to climate change.

In the Southwest, previous multiyear droughts, including the drought in this study, are attributed to La Niña and cooler sea surface temperatures in the Pacific Ocean (Seager et al., 2007). There is evidence that future extreme multiyear droughts in the Southwest

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[8] Project scope and budgetary constraints allowed me to investigate three states for the research presented in Chapter 3 and two states for the research presented in Chapter 4. An additional impetus for choosing Arizona was that earlier interactions with key informants allowed me to more efficiently and effectively conduct my research in this state. I decided to include two states in the Southeast because of variation of water laws and rights. While most of the Southwest falls under the prior appropriation doctrine, the Southeast has a mixture of riparianism and regulated riparianism. Georgia's surface water falls under regulated riparianism, while South Carolina's is remains within riparian doctrine (Wright, 1998). Such variation of water laws, rights, and regulations makes for interesting comparisons of adaptive capacity, as highlighted in Chapters 3 and 4.

[9] See U.S. Census Bureau, http://www.census.gov/popest/states/NST-pop-chg.html.

associated with La Ninã events will be exacerbated by changing base conditions under climate change, that is, poleward expansion of sub-tropical dry zones due to rising humidity and moisture divergence (Lenart et al., 2007; Seager et al., 2007). Researchers also note that the extreme aridity associated with the drought of interest for this study is indicative of what the 'new climatology' of the Southwest might resemble (Seager et al., 2007).

In the Southeast, multiyear droughts like the one examined in this study are weakly attributable to La Niña and cooler sea surface temperatures in the Pacific Ocean in winter months, and more strongly associated with random atmospheric variability in summer months (Seager et al., 2009). Models of future climate changes for the Southeast project general increases in precipitation and evaporation, leaving uncertain the precise impacts of climate change on drought occurrence in the Southeast (Seager et al., 2009). However, using tree ring data, researchers have shown that meteorological characteristics of the 2006-2008 drought were not unique in comparison to earlier droughts in recent decades and previous centuries' droughts (e.g., the 1998-2002 drought was as severe); indicating that multi-decadal droughts are not only possible, but have occurred in this region (Seager et al., 2009). Further, the relative meteorological normality of the recent drought is troublesome (regardless of its lack of association with climate change), considering the acute impacts of this drought on socio-economic systems in the region, which land use changes and population growth exacerbated (Manuel, 2008). This suggests that with or without climate change, even more severe droughts are possible and likely in the Southeast.

3.4. Archival Research, Telephone Interviews, Structured Surveys, and Calendars

The first data source for this dissertation was archival data; mainly state-level formal drought and water plans, statutes, and legislation that were all available online. The second data source was collected through semi-structured telephone interviews with an average of six key informants in each of the three states and several individuals at the national scale that could speak across all three states. For these interviews, I targeted individuals with proven experience in water, climate, and/or drought policy and management issues. The majority of the questions focused on how state and CWS management operated with respect to the extreme drought events. *Appendix 1* depicts a sample of the interview questionnaire, and the interview process is described in more detail in Chapter 3. The third data source came from the Community Water Systems Survey (CWSS).[10] The CWSS queried CWS managers in multiple states, including Arizona, Georgia, and South Carolina. The survey gathered information on preparation and responses to recent drought events, as well as the management approaches implemented before and after the droughts. Population and response rates for Arizona, Georgia, and South Carolina were 429 systems and 14 percent, 606 systems and 16 percent, and 293 systems and 13 percent, respectively. *Appendix 2* depicts an example of the complete CWSS, and I further discuss the details of the survey in Chapter 3.

These three data sources serve as the foundation for the adaptive capacity assessment in Chapter 3. The archival and telephone data allow me to conduct detailed qualitative comparisons of the patterns and key factors affecting adaptive capacity within and between states. The CWSS data provide quantitative measures of adaptive capacity (dependent variable) and management approaches (independent variables). I use these quantitative data in a multi-step assessment process that measures and characterizes adaptive capacity by first creating linear regressions to evaluate the approaches most associated with higher adaptive capacity and then performing cluster analyses to identify similar groupings of adaptive CWS types. In the end of Chapter 3, I combine insights from both the qualitative and quantitative analyses to discuss adaptive capacity of the three states and their CWS.

In Chapter 4, I used an event history calendar (EHC) to compile the fourth and final data source used in this research (only in Arizona and Georgia). The approach draws from life history calendar (LHC) methods, which seek to gain detailed information on individuals by linking personal events with other ‘external’ events, or the ‘environmental context’ during the period of interest (Axinn et al., 1999). LHC methods have received significant attention in the sociology, psychology, and anthropology disciplines, but to the best of my knowledge, they have not been adapted and applied to the contexts I am

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[10] I administered the CWSS with fellow University of Michigan doctoral student, Christine Kirchhoff. We collaborated on this portion of our data collection endeavors because our study populations overlapped significantly, and we deemed a more lengthy single effort more effective than two individually administered shorter surveys.

investigating. I specifically used this tool in my research to collect qualitative and quantitative temporal data in an efficient, flexible, and systematic manner.

For the EHC interviews, I target the largest urban CWS in each state because they likely have more resources to guide innovation and have more at stake based on the large number of people dependent upon them; increasing both the likelihood of identifying the implementation of innovative approaches as well as the applicability of my results.[11] I interview senior-ranking managers in each system, with the criterion that the participant had significant experience in operating their system over the majority of the previous decade. I successfully completed 35 face-to-face interviews; representing 80 percent and 72 percent of the largest systems targeted in Arizona and Georgia, respectively. *Appendix 3* shows an example of the EHC, and Chapter 4 describes the EHC and the process for conducting interviews with the EHC in more detail.

The data collected with the EHC are both quantitative and qualitative. The numbers provide quantitative measures of management implementation over time, and the notes add rich descriptive information. I employ statistical panel analyses on the quantitative data to create models in SPSS that help explain the relationships between the timing and magnitude of innovative management approaches and the timing and magnitude of extreme droughts. The qualitative data, analyzed in Nvivo, complement the panel analyses by identifying dominant barriers or bridges to adaptation within and between each state for each of the management approaches. I elaborate upon these analyses and the benefits of a mixed methodology approach in Chapter 4.

4. Summary of Key Findings

The primary role of Chapter 2 is to set up the empirical analysis in Chapters 3 and 4. I accomplish this by first reviewing the concept of adaptive capacity and then by making the case for more focused investigations into adaptive capacity; assessments that both measure and characterize adaptive capacity by combining insights from vulnerability and resilience frameworks.

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[11] Another motivation for investigating large urban CWS is that my findings in Chapter 3 indicate that they are generally more adaptive and innovative.

In Chapter 3, I first evaluate the archival data and the telephone interviews to identify important factors within each state that are influencing adaptive capacity. While each state has processes, institutions, and characteristics that are uniquely contributing to adaptive capacity (which I describe in great detail in Chapter 3), I find that some the general factors contributing to adaptive capacity to extreme droughts across the three states include: 1) flexibility in both drought triggers/indices/monitoring and local drought plans/planning; 2) state-backed comprehensive planning and informational support systems; 3) iterative regional forums for collaborating between communities; 4) consideration of climate change in planning processes at state and local levels; 5) and an active and accessible Regional Integrated Sciences and Assessments program. Also, across all states I find that it is important to more accurately align public perceptions with the realities of how water is supplied and drought is manifested in each region.

Based on these findings, I advance several recommendations in each state for bolstering adaptive capacity to future extreme droughts. For example, further linking water to growth in Arizona (either through expanded authority of the state water department or more directly providing local authorities the power to enforce existing legislation) and embarking on a statewide water planning process would likely improve overall adaptive capacity to extreme droughts. Also, Arizona might consider requiring more comprehensive vulnerability assessment and drought mitigation measures within already mandated local plans, hiring additional staff at the state-level to focus specifically on drought planning, and strengthening regional drought collaboration efforts. In Georgia, decision makers might consider requiring, implementing, and enforcing formal local drought plans, and linking them with state drought plans and processes (which also need updating). Also, eliminating the recently legislated restrictions on more stringent local curtailments during times of drought could help Georgia foster a more proactive and planned approach to drought management. In South Carolina, officials might improve adaptive capacity by implementing more comprehensive water planning approaches, such as passing regulated riparian legislation, and by embarking on a statewide water planning process. Also, the state might consider a comprehensive drought mitigation/preparedness planning process, removing drought indices from being codified in legislative processes to increase their flexibility and assure their continual improvement, and spearheading climate change planning pilot projects in receptive communities to demonstrate the benefits of such planning to the rest of the state.

Also in Chapter 3, I take an in-depth look at CWS adaptive capacity by operationalizing the assessment process previewed in Chapter 2. My attempt to measure adaptive capacity based on surveyed drought impacts proves to be more difficult than I originally anticipated. I am unable to find statistically significant relationships between the management approaches implemented in CWS and higher adaptive capacity. In fact, the few significant associations are in the opposite direction than expected. Therefore, I am unable to conclude which specific management and institutional approaches at the local CWS-level are associated with higher adaptive capacity. Still, these findings (or lack thereof) yield methodological insights for improving future assessments, such as combining social survey data with physical and environmental data to more accurately measure adaptive capacity. Moreover, I illustrate cluster analysis as a useful tool for identifying similarly ‘adaptable’ groupings of systems. One can use these clusters to analyze within and/or between groupings to obtain even more detailed understandings of adaptive capacity. I use the findings from the cluster analysis and the CWSS descriptive statistics, which show that larger urban CWS tend to be more innovative and adaptive, as a partial justification for the research presented in Chapter 4.

Taken together, the findings in Chapter 3 unveil tensions between what builds adaptive capacity at various scales. I find links between management, governance, and institutional processes and factors between state and CWS-levels, as well as potential conflicts between structure, regulation, organization, and mobilization of state resources, and flexibility and autonomy of local CWS. In some situations, officials can institute measures that they perceive to be beneficial for the state, but in fact limit the adaptive capacity of CWS. In essence, the major challenge is balancing structure, guidance, and policy certainty with flexibility. I suggest that future investigations should not only consider the multiple scales at which adaptive capacity is built and realized, but how adaptive capacity is interacting between these scales. To the extent that my results are generalizable, I find that it might be best to start with ‘regulated flexibility’ through local preparedness and planning, while providing the necessary support and resources at higher scales.

In Chapter 4, the EHC proves to be a very useful tool for collecting qualitative and quantitative data for adaptation studies. In the approximately fifteen management approaches that I evaluate using panel analysis, I find that there are a handful of approaches in both Arizona and Georgia that are significantly associated with the drought indices. In Georgia, there is a mix of positive relationships (implementation of the approach increases as drought increases over time) and negative relationships (implementation of the approach decreases as drought increases over time). In Arizona, the relationships, when significant, are mainly negative. I complement these quantitative analyses with qualitative analyses to offer possible explanations for these findings.

I comprehensively evaluate the bridges and barriers in each state for each of the management approaches to explain these positive and negative relationships (or lack of a statistically significant relationship). These analyses unveil that there are important local and state nuances involved with implementing each of the innovative management approaches, but general tensions emerge within each state that will pose challenges for building future adaptive capacity. Broadly, in Arizona, I find that a ‘culture of conservation’ or a ‘conservation ethic’ has developed within large CWS and their publics, which has created a demand for knowledge and information (including climate information) and has secured a financial commitment to long-term planning and infrastructure projects to improve drought preparedness. However, adaptedness to the arid environment has also created perception and cognitive barriers that may make it difficult for the state to move from a culture of conservation to a culture of drought preparedness or climate-change preparedness. In Georgia, I conclude that droughts serve as windows of opportunity to increase implementation of innovative management approaches, since the historical absence of a culture of conservation allows for more immediate improvements during drought events (i.e., there is more low hanging fruit in Georgia than in Arizona). However, the cyclical nature of the implementation of these approaches with droughts suggests that there are impediments to their more permanent adoption.

These broader findings of a ‘culture of conservation’ in Arizona and ‘windows of opportunity’ in Georgia suggest that there might be a true tradeoff between proactive and reactive elements of adaptive capacity. I conclude Chapter 4 on this theoretical note before reviewing the key findings of the dissertation in Chapter 5.

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Chapter 2
Adaptive Capacity

1. Introduction

One of the most encompassing goals of global change research is sustainability. Achieving this goal has proven extremely difficult, however, given various competing social interests for the provisioning of ecosystem goods and services (Robards et al., In Review) and the myriad pressures of multiple environmental stresses (National Research Council, 2007); both of which challenge our ability to manage Earth's resources sustainably. The increasing threat of climate change exacerbates these difficulties, as the shear magnitude of the problem and the potential to challenge existing paradigms beyond the thresholds of historical practice make it one of the most complex and far reaching issues humans have ever encountered. By no means is a changing climate the only significant problem that science and society faces, but it is a problem that directly challenges previous conceptions of sustainability. It means that our activities need not only be viewed through a sustainability lens, but also a climate-smart lens; one that explicitly considers the implications of climate change on our actions and vise versa (World Bank, 2009).

While discussions of sustainability in relation to climate change frequently pertain to prevention or mitigation, there are similarly important sustainability implications regarding the ways that ecosystems and society will adapt to climate change. In other words, how can our systems prepare for and respond to the expected or experienced impacts of climate change in a manner that is sustainable, balances various competing social interests, and takes into account multiple environmental stresses?

The global change community has experienced a recent wave of activity in this traditionally under-researched area known as adaptation (Pielke Jr. et al., 2007); particularly through the frameworks of vulnerability and resilience. Broadly speaking, vulnerability means susceptibility to harm (Eakin and Luers, 2006), and resilience means the ability to persist in the face of change (Folke, 2006). Both vulnerability and resilience frameworks have a history full of alternative characterizations and interpretations, and the two are not merely opposite sides of the same coin (Gallopín, 2006). Despite continued debate with respect to definitions and the precise relationships between the two literatures, there is considerable demand for understanding the causal relationships between adaptation and sustainability, and the types of decision-support tools and metrics that can facilitate sustainable outcomes. Such demand warrants a more concerted focus on what unites the two literatures rather than what divides them.

One pivotal concept in both the vulnerability and resilience literatures that bridges these traditions is adaptive capacity, or adaptability; meaning the ability of a system to prepare for stresses and changes in advance or adjust and respond to the effects caused by the stresses (Smit et al., 2001). Ultimately, increasing adaptive capacity will help systems prepare for varying ranges and magnitudes of climate impacts, while allowing for flexibility to rework approaches if deemed at a later date to be on an unsustainable trajectory. Researchers have much to gain from drawing on both vulnerability and resilience frameworks to improve our understanding of adaptive capacity and help systems move closer to achieving climate-smart sustainability.

In this chapter, I review the concept of adaptive capacity. More specifically, I illustrate how adaptive capacity serves as a common thread within the vulnerability and resilience literatures and how drawing from only one of the frameworks limits our ability to sufficiently understand and assess adaptive capacity; mainly that vulnerability's treatment of adaptive capacity is well suited for practical implementation, but leaves out the consideration of critical system components, while resilience's treatment of adaptive capacity captures the dynamic, nested, and polycentric nature of adaptive capacity, but its application faces present-day policy and cognitive barriers. Finally, I conclude that a greater focus on understanding adaptive capacity might help in achieving climate-smart sustainability, if only by combining insights from both vulnerability and resilience frameworks.

2. The Growing Importance of Adaptive Capacity

2.1. Origins in Adaptation

In simple terms, adaptive capacity describes the ability to adapt. Earlier works in sociology and organizational and business management provide the historical underpinnings for adaptive capacity; describing it as a requisite property for leadership and organizational success, for it maintains a repertoire of potential solutions to unforeseen problems and unpredictable variations, and allows for learning and adjustment despite the existence of its unalterable features (Parsons, 1964; Chakravarthy, 1982; Staber and Sydow, 2002). The term has proliferated in recent years through its use in the context of climate change, mainly in conjunction with the term ‘adaptation’. To understand the conceptual advancements of adaptive capacity, it is helpful to first trace the development of the word upon which it is based; adaptation.

Biologically, adaptation refers to an organism’s response to its surrounding environment. The foundations of this concept are evident at least as far back to Darwin’s seminal work on evolution and natural selection. To Darwin, adaptation was a response to the environment, or ‘special climate’, within which an organism lived (Darwin, 2005). Later, ecologists and biologists engaged in discussions regarding the differences between mutation and natural selection, and adaptation. Scientists generally perceive mutation and natural selection to take place on a genetic level. That is, the genes are selected upon based on the ability for the organism to persist, given the environment it faces. Adaptation on the other hand, involves learning and adjustment. Smit and Wandel (2006) state that from a physiological perspective, adaptation “…broadly refers to the development of genetic or behavioral characteristics which enable organisms or systems to cope with environmental changes in order to survive and reproduce” (pg. 283).

Not surprisingly, the field of anthropology provides the bedrock for focusing on the adaptations of humans to their environment. Many anthropological works on the subject characterize societal or cultural adaptations to past climate variability. As recent examples, Brooks (2006) looks at extreme climate variability roughly 5,000 years ago to explain the development of sophisticated social structures, and Orlove (2005) examines case studies of past adaptations to climate variability in Central America, Greenland, and the United States Great Plains. Among various contributions from these and other anthropological works, the primary message is that humans are inherently adaptive creatures. When faced with adversity, such as climate stress, we will adapt.

This innate ability to adapt to our environment is what is referred to as reactive or autonomous adaptation, which represents a response to a stress that has already occurred. This form of adaptation often dominates the adaptation to climate change discourse (Tompkins and Adger, 2005). However, reactive adaptation does not always end well, as Rappaport (1977) shows through the term ‘maladaptation’, or adaptation that does not moderate harm, but instead exacerbates it. Maladaptation illustrates that adaptation is a complicated issue, occurring on different spatial and temporal scales, and based on competing cultural contexts and social goals (Turner et al., 1990; Wilbanks and Kates, 1999; Adger et al., 2005; Orlove, 2005). These complex processes make it difficult to understand when a particular adaptation will be sustainable or maladaptive.

In addition to reactive adaptation, many scholars recognize that humans have the unique ability to anticipate future stresses, and are thus capable of taking proactive adaptation measures to lessen the perceived negative impacts from these future events. Therefore, the complementary concept to reactive or autonomous adaptation is anticipatory or planned adaptation (Frankhauser et al., 1999). Such adaptations are predicated upon our ability to understand what the future might resemble, but are also influenced by our ability to have learned from our past experiences; particularly what worked (and did not) in similar circumstances. Holland (1995) writing from a complexity science perspective notes that “agents adapt by changing their rules as experience cumulates” (pg. 10). This suggests that humans learn from past experiences and apply that knowledge to future circumstances. With climate change, the past is not necessarily prologue (Milly et al., 2008), but there are important lessons that we can apply from previous experiences in considering anticipatory adaptations, especially in identifying the governance, institutions, and management mechanisms that might better facilitate, not inhibit, reactive and proactive adaptations (i.e., those mechanisms that increase adaptive capacity) (Adger, 2001; Haddad, 2005).

Finally, political ecology seeks to analyze ecological problems through underlying social, political, economic, historic, and environmental contexts (Escobar, 1999). Schroeder (1999) offers questions from the political ecology field that are applicable to the conceptualization of adaptation, such as: 1) What is being adapted? 2) On whose behalf? 3) Who is in the position to define adaptation? 4) Who determines when adaptation is achieved? and 5) To what extent does adaptation amount to a simple shift in resource access and control? These challenging questions are increasingly common in international climate change policy debates, and also contribute to the conceptual development of adaptation by encouraging the examination of the social structures and histories leading to different adaptation options and decisions.

2.2. Adaptive Capacity Takes Hold in Climate Change Discourse

Humans and the systems within which we live adapt or adjust to our environments in both reactive and anticipatory manners. These two features of adaptation can be traced back to United States climate-change reports in the early 1990s, such as in *Preparing for an Uncertain Climate* (U.S. Office of Technology Assessment, 1993). The concepts of reactive and anticipatory adaptation have since formed the heart of the Intergovernmental Panel on Climate Change's (IPCC) characterization of adaptation, which defines it as an "adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects" (Parry et al., 2007). But successful adaptations, whomever or whatever defines them as such, are not forgone conclusions. Rather, a system's adaptive capacity influences the ultimate potential for implementing sustainable adaptations. In the face of uncertainty, adaptive capacity is a critical system property, for it describes the ability to mobilize scarce resources to anticipate or respond to perceived or current stresses. Adaptive capacity varies between different contexts and systems, and it is not equally distributed (Adger et al., 2007). Therefore, it is important to identify what builds adaptive capacity, or similarly, what functions as barriers or limits to adaptations (Adger et al., 2009).

The IPCC summarizes the determinants of adaptive capacity in Chapter 18 of the third assessment report of Working Group II as economic resources, technology, information and skills, infrastructure, institutions, and equity (Smit et al., 2001). Various fields and disciplines have defined and treated adaptive capacity differently since the IPCC report and have subsequently expanded upon this initial characterization. For example, from a political economy and geography perspective, Adger (2003) suggests that communities are limited in their abilities to adapt by their abilities to act collectively.

Moreover, social capital, trust, and organizations greatly influence this capability to act collectively (Adger, 2003; Pelling and High, 2005). For planned adaptations to occur, a variety of underlying factors such as effective economic structures must first be in place. Perhaps most importantly in the growing adaptive capacity literature, there has been an affirmation of the integral role that institutions, governance, and management play in determining a system's ability to adapt to climate change (Yohe and Tol, 2002; Ivey et al., 2004; Brooks et al., 2005; Haddad, 2005; Eakin and Lemos, 2006; Agrawal, 2008; Engle and Lemos, 2010).

Scholars in the development studies field have introduced important questions surrounding the distribution of adaptive capacity between populations and communities. Dow et al. (2006) discuss the disparate abilities of groups to adapt to climate change, highlighting lower levels of adaptive capacity associated with poverty. This demonstrates the social justice issues implicit in adaptive capacity. Mainly, developing nations and poorer communities are the least capable of adapting because they lack the resources and institutions to mobilize these resources. This injustice is exacerbated by the fact that the initial impacts from climate change are primarily linked to developed countries' industrialization processes – that is, the emissions associated with decades of economic growth in wealthier nations and communities are now hurting poorer areas (through climate-change impacts) that did not benefit from this growth in the first place.

Despite this increase in attention to adaptive capacity (due in part to the issue of climate change), a guiding framework to measure, characterize, predict, and/or bolster adaptive capacity has been slow to develop. To date, most of conceptual and methodological treatment of adaptive capacity has resided in either a vulnerability or resilience framework. Below, I briefly describe vulnerability and resilience frameworks, and highlight the similar role that adaptive capacity plays in each.

2.3. Adaptive Capacity in Vulnerability Literature

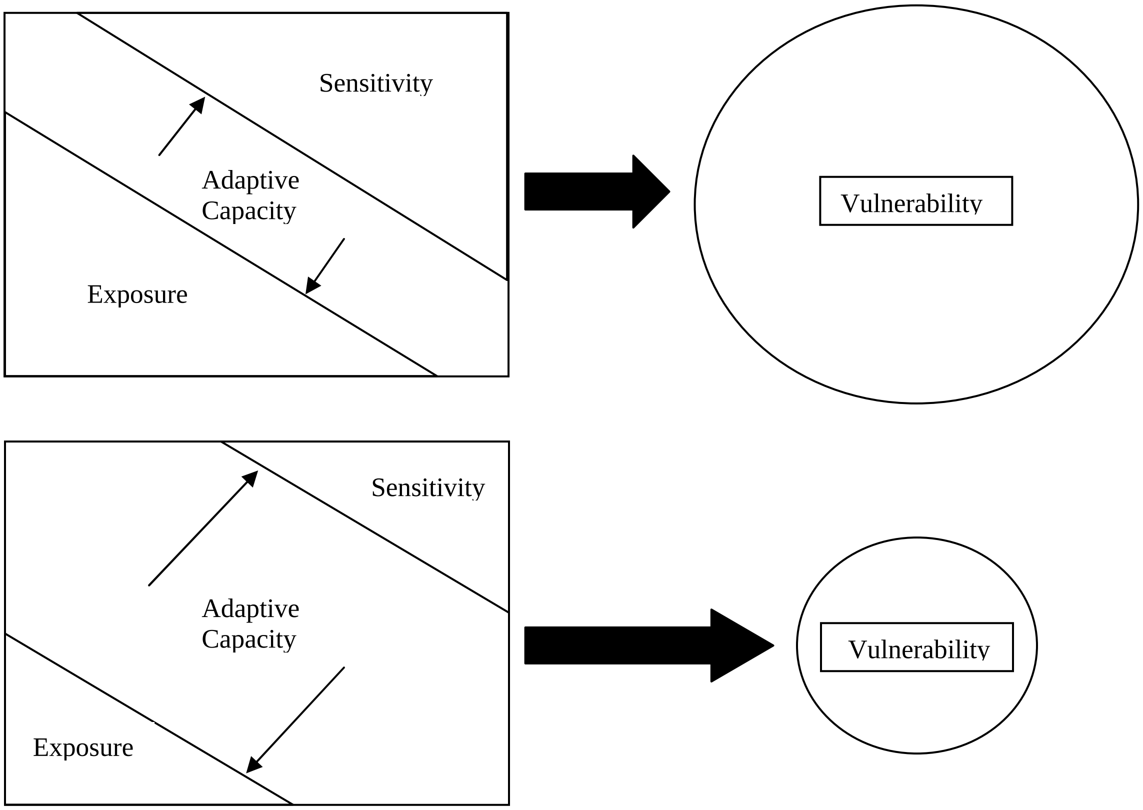
Vulnerability, broadly defined as susceptibility to harm, has its roots in hazards-risks research, with geography, poverty and development, food securities, and political ecology also influencing its conceptual development (Eakin and Luers, 2006). In the hazards field, researchers consider vulnerability a key component of risk; risk being a function of a hazard and the probability of that hazard occurring (Brooks et al., 2005).

Early hazards-risk vulnerability studies emphasized the physical system (e.g., agricultural production, human settlement, etc.), or the hazard itself (e.g., flooding, coastal erosion, hurricanes, fires, etc.). More recently, other disciplines have pushed for the consideration of the underlying social conditions that make humans vulnerable (Adger, 2006). Specifically, political ecology and geography have focused on ‘social vulnerability’ by emphasizing socio-economic, demographic, cultural, and political characteristics, as well as the role of institutions and governance for shaping vulnerability (Adger, 1998; Cutter et al., 2003).

Schröter et al. (2005) illustrate the concept of social vulnerability through the example of famine. They argue that rather than focusing on the physical stress of the system as the cause for famine, such as drought, it is more informative to look at the social, economic, and political marginalization of individuals and groups as the causes of that famine. Presently, there is a limited, but growing body of vulnerability research committed to the dual consideration of the biophysical and social aspects that make a system vulnerable (Clark et al., 1998; Luers et al., 2003; O'Brien, Leichenko et al., 2004; Polsky et al., 2007). For example, in the context of drought, such vulnerability assessments might include the stress (the drought itself), the biophysical factors (soil, plant, and hydrologic responses) the demographic factors (dependence on surface water), and social factors (the political, economic, and institutional factors that led to the dependence on surface water).

From this perspective, the IPCC illustrates vulnerability through three basic concepts. First, exposure is the extent to which the system is physically in harm’s way. Second, sensitivity is how affected a system is after being exposed to the stress. And third, adaptive capacity represents the system’s ability to prepare for and adjust to the stress, mainly to lessen the negative impacts and take advantage of the opportunities (Smit et al., 2001; Adger et al., 2007). In other words, adaptive capacity affects vulnerability by modulating exposure and sensitivity (Yohe and Tol, 2002; Adger et al., 2007). Because of its unique position as being shaped by human actions and as influencing both the biophysical and social elements of a system, adaptive capacity is considered critical for reducing vulnerability (Eakin and Luers, 2006). *Figure 2.1*, below, illustrates how adaptive capacity plays a critical role in determining vulnerability.

Figure 2.1: A basic depiction of adaptive capacity's role in influencing vulnerability. Adaptive capacity affects a system's vulnerability through modulating exposure and sensitivity.



Undoubtedly, conflicting interpretations of the exact definitions and boundaries between exposure, sensitivity, and adaptive capacity continue to linger (Gallopín, 2006; Füssel, 2007), but the basic role of adaptive capacity is generally accepted as a desirable property, or positive attribute of a system for reducing vulnerability. The resilience literature also depicts adaptive capacity as a desirable system property, but in somewhat different terminology.

2.4. Adaptive Capacity in Resilience Literature

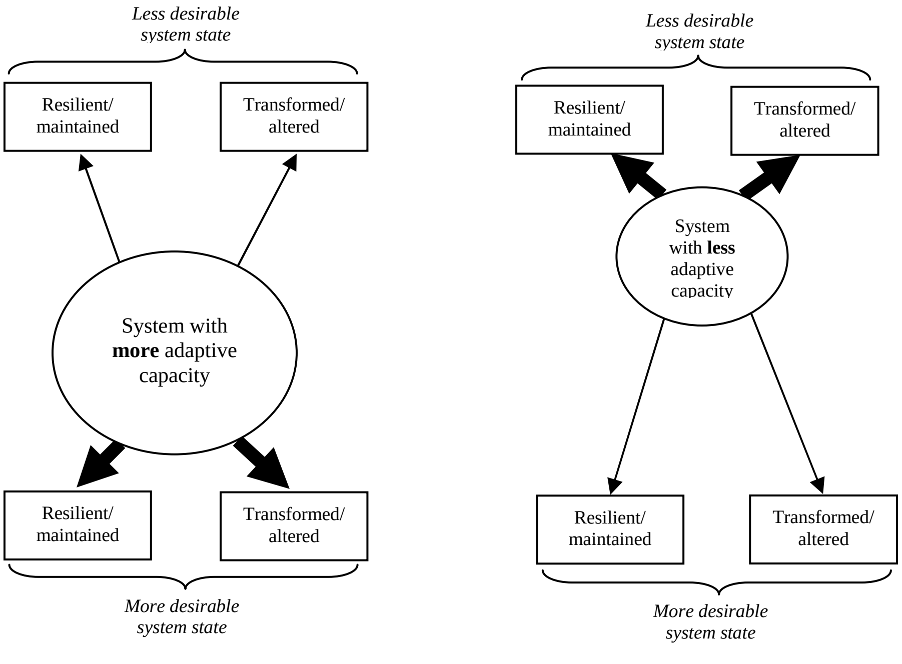
Resilience, meaning the ability for a system to persist and maintain relationships in the face of disturbance and change (Holling, 1973), is rooted in ecology sciences and theoretical and mathematical modeling methodologies (Gallopín, 2006; Janssen et al., 2006). Complexity theory, systems theory, and the agent-based modeling community also contribute to the development of the resilience framework.

After studying for years the relationships between different species, Holling (1973) found that these systems did not center on an equilibrium or focal point. Rather, the relationships and the system could follow alternative patterns, with the most interesting relationships being those that operated close to a theoretical boundary that if passed, would tip the system into disorder. Such complex systems operate in the ‘domain of attraction’, and the ‘boundary of the domain of attraction’ represents a tipping point that throws the system into flux. As originally conceived by Holling, resilience captured the ability of the system to fluctuate within the domain of attraction without being pushed over the boundary. Resilience theory later acknowledged multiple stable states (Gallopín, 2006; Nelson et al., 2007); thinking of the ecosystem as a constantly changing, constantly stressed phenomenon, represented a paradigm shift in the ecological sciences that ultimately led to the development of adaptive management (Holling, 1978).

Although originating in the natural sciences, the resilience perspective increasingly includes human contributions to system dynamics, as shown by the expanding scholarly focus on social-ecological systems (SES) (Walker et al., 2006). Since the human element in ecosystems is one of the most change-causing forces, it makes sense to adopt the coupled SES as the unit of analysis in resilience research (Folke, 2006). That is, to understand the interlocking mechanisms within and across systems, the resilience paradigm argues that scholars need to study human and environmental systems and their interactions together. As such, the human components (e.g., institutions, infrastructure, culture, etc.), and the environmental components (e.g., geological, climatological, biological, etc.) create a coupled complex SES (Gallopín, 2006). While resilience research continues to face the challenge of focusing more intently on social aspects of SES (Adger, 2006), the concept of adaptive capacity has begun to receive more attention in this literature (Carpenter and Brock, 2008; Pahl-Wostl, 2009).

Adaptive capacity in resilience studies, often described as ‘adaptability’, is the capacity of actors in the system to manage and influence resilience (Walker et al., 2004). Humans influence resilience by facilitating interactions between human and environmental components of a system (Walker et al., 2006). Thus, the more adaptive capacity within a system, the greater the likelihood that the system will be resilient in the face of climate stress (i.e., humans will facilitate social-ecological interactions in a desirable manner to maintain the system state, or the status quo). However, the resilience framework also depicts adaptive capacity as a property that can facilitate transitions or transformations. Transformation means moving to a new system state when the current state is untenable, oftentimes when the system is in a resilient, but undesirable situation (Walker et al., 2006). In managing resilience, adaptive capacity influences a SES by modulating between maintenance of the status quo and transformation of the system to a new state, depending on which is most 'desirable' (see *Figure 2.2*). For example, during a drought, a system with higher adaptive capacity will be more capable of managing water resources to 'weather' the drought without significant hardship; ultimately returning the system to its original pre-drought state. If the drought is so extreme that returning to the original pre-drought state is untenable, then this system with higher adaptive capacity will be more flexible and pose a greater likelihood of transforming to a more 'desirable' (i.e., sustainable) state (e.g., one that eliminates irrigation and agricultural production, or perhaps one that ties population growth to long-term water availability).

Figure 2.2: A basic depiction of adaptive capacity's role in managing resilience. Systems with higher adaptive capacity are more likely to settle back into or transition to a desirable system state (left portion of the figure), while those with less adaptive capacity are likely to be pulled back into or transition to a less desirable system state (right portion of the figure).



As with the vulnerability framework, resilience scholars identify governance and institutions as critical variables affecting adaptive capacity. For example, Lebel et al. (2006) suggest that bolstering the capacity of societies to manage resilience is important for sustainable development, since enhancing resilience may be more desirable in some occasions, while transformation may be more desirable in others. Therefore, the more adaptive capacity accumulated within a system, the greater chance the system will end up in a ‘desirable’ state (again, see *Figure 2.2*). This is congruent with key factors affecting adaptive capacity in the vulnerability literature, further illustrating the similar conceptualization of adaptive capacity between both frameworks. However, each framework has limitations in its approach to adaptive capacity, specifically with respect to how researchers operationalize vulnerability and resilience (and thus adaptive capacity). I now turn to a discussion of these limitations before illustrating the benefits of a concerted focus on adaptive capacity that draws from both perspectives.

3. Discussion

3.1. Current Limitations of Focusing on Vulnerability or Resilience

Despite evidence for a blending of vulnerability and resilience literatures into a unified vernacular for sustainability science (Janssen et al., 2006), there is reason to believe that there remains some division between the two frameworks. Perhaps the most frequent criticism is that the resilience community still insufficiently deals with the social aspects of SES, while the vulnerability community continues to insufficiently deal with the ecological/environmental aspects of SES (Adger, 2006; Janssen and Ostrom, 2006).

In terms of operationalizing vulnerability and resilience, the frameworks essentially suffer from opposite problems when researchers apply them to decision making. Vulnerability is actor-centric and more easily translatable to application and policy outcomes (Nelson et al., 2007). One can see this phenomenon in the numerous studies that characterize vulnerability of an actor or set of actors to a particular stress, which often result in politically and managerially digestible maps, indices, and rankings (Kelly and Adger, 2000; Cutter et al., 2003; O'Brien, Leichenko et al., 2004; Brooks et al., 2005; Schröter et al., 2005). However, in this pursuit researchers often leave out key process variables that more accurately capture the dynamics of the systems under examination (O'Brien, Eriksen et al., 2004; Nelson et al., 2007), and assessments of adaptive capacity in this context are often performed at a single spatial scale and/or are merely ‘snapshots’ in time (Vincent, 2007).

On the other hand, resilience is more centrally focused on SES interactions, feedbacks, and processes (Nelson et al., 2007). As such, it attempts to consider the complex relationships and interconnectedness inherent in issues related to sustainability and multiple stresses. The caveat, however, is that it is difficult to translate the concept into practice, causing resilience researchers to resist systematically measuring, assessing, or characterizing adaptive capacity – that is, there are numerous case studies focusing on assessing resilience and adaptive capacity within one particular system, but operationalization and generalization are discouraged (Ostrom et al., 2007). The first reason for the difficulty to draw insights that are generalizable to various policy contexts is that the scales and borders upon which decision makers base policies usually present a mismatch with the ecological boundaries of the system (Cumming et al., 2006). For example, a resilience approach might suggest examining system dynamics and policy implications within a watershed or groundwater basin, but the social, cultural, and political boundaries that affect these systems rarely align with the natural boundaries. This does not suggest that the challenge is insurmountable, but rather that it serves as a potential roadblock for placing resilience into operation.[12]

The second source of the difficulty in making resilience applicable to policy is that practitioners often interpret the concept differently from scholars. This mainly occurs because of subtle inconsistencies in its characterization over the years. Resilience falls along a spectrum of interpretation, with ‘engineering resilience’, or return to a single, stable equilibrium on one end, and ‘social-ecological resilience’, or reorganization, renewal, adaptation, and learning on the other end (Folke, 2006). The more contemporary scholarly interpretation is ‘social-ecological resilience’, but in practice, resilience is still frequently understood along the lines of ‘engineering resilience’. Perhaps it is human

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[12] Vulnerability research does not necessarily treat adaptive capacity as static, but operationalizing it tends to gloss over the multiple spatial and temporal dimensions of the concept. Resilience theory more effectively captures the dynamic and malleable nature of adaptive capacity, but doing so causes methodological difficulties in measuring and assessing it. Hence, there has been a tradeoff between accurately capturing the full nature of adaptive capacity and developing methods to measure and assess the concept – a tradeoff that I hope to begin to reconcile in this research.

nature to resist change and strive to maintain the status quo, because decision makers often use the concept of resilience to evoke a sturdy, robust, or stalwart state of affairs; one that can quickly bounce back to its initial conditions. One can find examples of this interpretation of resilience in recent assessments and reports focusing on resilience (Sperling et al., 2008; United Nations Environment Programme, 2009; The H. John Heinz III Center for Science Economics and the Environment and Ceres, 2009). Related to the confusion regarding 'engineering resilience' versus 'ecological resilience', there are some resilience researchers that do not necessarily view a resilient system state as a ubiquitously positive attribute (Walker et al., 2006). This further clouds the term's interpretation and application, in that widespread calls for increasing resilience in practice may miss the theoretically negative properties associated with a resilient state, such as when an oppressive but resilient government is able to persist and adjust to change and disturbance.

It is important to note that numerous vulnerability and resilience scholars recognize the potential linkages between vulnerability and resilience frameworks (Turner et al., 2003; Eakin and Luers, 2006; Young et al., 2006; Janssen et al., 2007; Nelson et al., 2007; Polsky et al., 2007; Vogel et al., 2007). However, many of these efforts do not necessarily build upon the common, albeit somewhat differently conceptualized connection they share through the concept of adaptive capacity. For example, in their attempt to more closely link vulnerability studies with resilience research, Turner et al., (2003) mention the importance of adaptive capacity as a central concept for coupled SES, but stop short of presenting a framework for assessing adaptive capacity. In a more recent example, Cutter et al. (2008) offer a thorough review of the conceived relationships between adaptive capacity, vulnerability, and resilience. The authors conclude that vulnerability and resilience are separate, but linked concepts.[13] I expand upon this idea, but suggest that the separate concepts of vulnerability and resilience are most aptly linked through adaptive capacity. *Figure 2.3* illustrates the linking of vulnerability and resilience through the common concept of adaptive capacity by adding to the conceptualization presented in Cutter et al. (2008).

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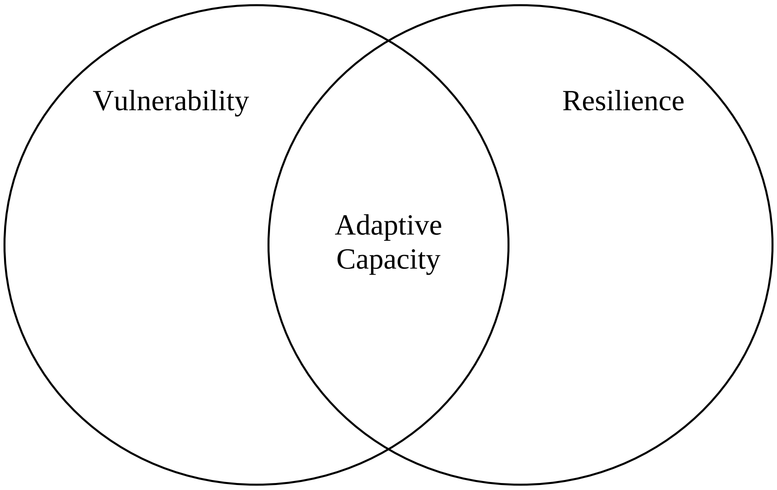
[13] The authors also make similar arguments as presented in this dissertation, specifically in emphasizing the need to operationalize the dynamic and multi-scale nature of resilience and integrate insights from multiple literatures.

Figure 2.3: Vulnerability and resilience frameworks as linked through the concept of adaptive capacity. This depiction builds off of Cutter et al. (2008), where the authors present a similar overlapping framework, to which I add adaptive capacity in the intersecting space.



Not only might a more concerted focus on adaptive capacity prove insightful for fostering climate-smart sustainability, there are benefits in drawing from both vulnerability and resilience traditions to more fully understand adaptive capacity, which I discuss below.

3.2. The Case for Focusing on Adaptive Capacity

As noted earlier, the concept of adaptive capacity has its origins in organizational theory and sociology, but it has received a major contemporary focus within adaptation studies; most notably those synthesized by the IPCC. Adaptive capacity is unique in that it is a property that human beings can shape and manipulate, but as characterized in the literatures, it affects both social and ecological systems. Moreover, it is integral to both the vulnerability and resilience frameworks. I suggest that there are benefits to a more focused research agenda that explores the nuances of adaptive capacity. Specifically, adaptive capacity is a familiar concept, both literatures view it as positive property, it is translatable to decision makers through its emphasis on governance, institutions, and management, and it plays a critical role in fostering climate-smart sustainability.

Adaptive capacity is a universally positive system property. A system simply cannot have too much of it and it is never described in negative terms. As discussed previously, adaptive capacity is the positive dimension of the generally positive (but sometimes negative) concept of resilience. As the original definition suggests, resilience is system-maintaining in the face of stress and change (Holling, 1973). Conceptual developments have pushed resilience to more broadly include resilience as a property that maintains the system's original identity when the circumstance is desirable, but also to allow the system to transform to a new stable state when the original system is undesirable (Folke, 2006). This subtle shift to include multiple stable states recognizes that as originally conceived (i.e., as persistence), resilience could be negative. By broadening the definition of resilience to establish it as a ubiquitously positive system property, it makes it difficult to distinguish resilience from adaptive capacity. Moreover, resilience scholars do not universally accept this broadened definition, as evidenced by works that seem obliged to note that resilience is not always desirable (Walker et al., 2006), and as discussed earlier, practitioners often interpret resilience superficially to mean 'bouncing back' to the original system state. The scholarly debate regarding whether resilience is always positive or can sometimes be negative and the cognitive barriers that practitioners encounter with interpreting resilience provide justification for focusing more intently on the concept of adaptive capacity. A better understanding of how to improve adaptive capacity, a universally positive property, might increase our ability to foster more desirable outcomes when a system experiences stress. Whether such an outcome is system-maintaining (resilient), or system-altering (transformed) will depend on the system's ability to draw from its adaptive capacity to facilitate the most desirable and sustainable outcome.

Vulnerability is clearly not desirable. Unlike resilience, there is little confusion in characterizing vulnerability as a negative property. However, there are potentially subtle policy ramifications by describing an individual or population as being highly vulnerable versus having less adaptive capacity. Governmental organizations and researchers from developed nations are often the facilitators of vulnerability assessments. In addition to the potentially demeaning nature of external actors characterizing other actors as vulnerable, focusing on indicators that highlight negative system attributes could offer less hope to populations struggling to develop sustainably. From a policy perspective, the incentives or disincentives are likely similar for increasing adaptive capacity and decreasing vulnerability (since the former is part of the latter and also closely related to governance, institutions, and resources). Psychologically however, the framing of an issue has motivational effects on one’s behavior, which are subject-and context-dependent (Rothman and Salovey, 1997). To the best of my knowledge, though, there has been little attention to the psychological ramifications of framing research in the context of one’s vulnerability or adaptive capacity. While this appears as matter of semantics, one might ponder his/her personal desire for being characterized in the context of vulnerability or adaptive capacity.

Perhaps most importantly, vulnerability and resilience frameworks are coherent and consistent in their prioritization of management, governance, and institutions for influencing adaptive capacity (Yohe and Tol, 2002; Ivey et al., 2004; Brooks et al., 2005; Haddad, 2005; Eakin and Lemos, 2006; Lebel et al., 2006; Agrawal, 2008; Engle and Lemos, 2010).This linking of vulnerability and resilience frameworks through the governance and management mechanisms associated with adaptive capacity is perhaps best illustrated by the recent uptick in adaptive management (AM) and adaptive governance (AG) research. AM and AG generally suggest realigning decision-making to the natural scale and embracing the idea that natural resource systems and the stresses that they experience are dynamic and unpredictable (Lee, 1993). The approaches emphasize flexibility, coordination and deliberation amongst diverse stakeholders, integration within and between various levels of institutional and actor/organizational networks, and experimentation and learning (McLain and Lee, 1996; Johnson, 1999; Dietz et al., 2003; Olsson et al., 2004). Although AM and AG are rooted in resilience research (Holling, 1978), recent investigations into AM and AG have begun to focus on adaptive capacity as a target property, with some cases explicitly stating that the ultimate goal of AM and AG is to increase adaptive capacity and limit vulnerability (Pahl-Wostl, 2007, 2009). Other than the AM and AG literatures, there is evidence that adaptive capacity not only links vulnerability and resilience, but that it is also translatable to policy application. Examples are thus far limited, but as Eakin and Lures (2006) point out, the United Nations Development Programme’s Adaptation Policy Framework offers useful guideposts for carrying out adaptive capacity assessments in practice (Brooks and Adger, 2005). Therefore, focusing on the management, governance, and institutional approaches that increase adaptive capacity could help reconcile resilience and vulnerability frameworks into even more theoretically sound and policy applicable assessments.

Finally, climate change will likely exacerbate already existing environmental stresses (Goklany, 2007; National Research Council, 2007; Grist, 2008; World Bank, 2009), presenting new threats to humans and ecosystems through increased vulnerability and decreased resilience (Lemos et al., 2007). Adaptations in preparing for and responding to these stresses could potentially be maladaptive, contribute to additional greenhouse warming, and ultimately be in conflict with the ideals of sustainability (Kane and Shogren, 2000; Adger, 2001; Tol, 2005). Adaptive capacity can play a key role in navigating this complex landscape through its emphasis on evaluating key policies, management, governance, and institutional dimensions within society that threaten successful adaptations that are sustainable, and climate-smart (Folke et al., 2002; Lemos et al., 2007).

3.3. Previous Adaptive Capacity Limitations and Some Remedies

Adaptive capacity is not a new concept. Still, despite its long history and continued presence in the global change literature, adaptive capacity has yet to receive significant attention. Although there are likely numerous reasons for this minimal focus on adaptive capacity, I discuss two of the greatest limitations to date and their possible remedies; the latent nature of adaptive capacity and how to sufficiently assess it.

First, adaptive capacity is difficult to gauge because of its latent nature, meaning that researchers cannot directly measure it until after its realization or mobilization within a system. One remedy for this is to empirically investigate actions surrounding past stress events (e.g., droughts, floods, storm surges, fires, etc.) for gauging adaptive capacity. Researchers can then use this knowledge as a proxy for how systems might mobilize (or not) their adaptive capacity to prepare for and respond to future climate changes. This approach is well documented and supported in the adaptation field (Adger et al., 2007), as it exposes system structures when they are most challenged (Folke et al., 2005), and when adaptive capacity is most likely assessable. It is not necessary that the climate stress be directly associated with climate change – only that the events are extreme enough to elicit societal actions so that we might learn what seems to work (or not) in extremely stressful situations. Like all stress tests, there is certainly a possibility that the stresses associated with climate change far exceed what the systems have experienced in the past; rendering learning from historical extreme events incongruous to the task at hand. Such an explanation implies that there is no insight to gain for climate-change adaptation and other future stresses from past actions. While this is a plausible explanation, it is also possible that most changes will occur gradually, stretching the boundaries of previous extremes, and with societies and institutions adapting along the way. If surprises do occur, the incremental adaptations that preceded these surprises might help decision makers buy valuable time for more appropriate responses (e.g., new innovations, paradigm shifts, etc.), presumably aided by having high adaptive capacity. Moreover, it is possible that rather than focusing on which specific adaptations were most effective during these periods of gradual and rapid change, it might be more useful to understand what structures, relationships, processes, and other variables allowed for (or blocked) the facilitation of such adaptations (i.e., adaptive capacity).

Related to the latency issue, the second limitation involves adaptive capacity assessment. The methods for measuring and characterizing adaptive capacity vary greatly, and include (but are not limited to) case studies, survey techniques, modeling, mapping, and ethnography. Stemming from vulnerability analyses, researchers have tended to use aggregated indices that assess adaptive capacity based on a set of assumptions of its theoretical determinants (Ivey et al., 2004; Brooks et al., 2005; Smit and Wandel, 2006). These studies are helpful for providing generalizability and policy application, but they inadequately consider a fundamental contribution of the resilience framework. That is, that adaptive capacity is context-specific and likely shaped by dynamic variables that are not easily generalizable and do not carry equal weight between contexts. At the same time, however, the descriptive case studies and systems models of adaptive capacity inspired by the resilience framework (Ford and Smit, 2004; Carpenter and Brock, 2008) present difficulties for placing adaptive capacity into operation.

It is important to note how I distinguish between measuring and characterizing adaptive capacity. I consider measuring an attempt to directly assess the amount of adaptive capacity within a system at a given time so as to understand what factors determine this capacity; in this case based on the response to a recent stressful event (i.e., the extent to which the system was impacted, mobilized and responded is a measure of its adaptive capacity). I consider characterizing an attempt to assess adaptive capacity based on predetermined system attributes, mechanisms, or indicators that are purported in the literature to increase adaptive capacity. While measuring is perhaps more difficult because of the latency issue, characterizing is somewhat limited in its ability to advance theory as to what affects adaptive capacity. In other words, measuring aims to build theory while characterizing primarily applies theory.[14] Research that attempts to measure and characterize adaptive capacity in the same study can offer both theoretical and policy applicable contributions. A recent example attempting to do this is Engle and Lemos (2010), where the authors characterize adaptive capacity under the assumption that ‘good governance’ is indicative of higher adaptive capacity, and then use case studies from past climatic events to measure and verify that ‘good governance’ actually did lead to higher adaptive capacity. This approach is somewhat limited in scope however, in that it does not first test which types of governance and management approaches (from a broad range of possibilities) are more important for adaptive capacity.

The empirical research that I present in Chapters 3 and 4 attempts to reverse the order of Engle and Lemos (2010) approach by first measuring adaptive capacity (Chapter 3) and then characterizing it (Chapters 3 and 4). The benefit from this approach is that the theory built during the measurement process (i.e., which management, institutional, and governance approaches were associated with higher adaptive capacity) can inform the subsequent characterization adaptive capacity (i.e., which systems are implementing these management and governance approaches). In this procedure, even if the measurement proves difficult and/or inconclusive, one can still fall back on a thorough characterization based on previous theory. In other words, one can only gain from attempting to measure adaptive capacity before characterizing it. Below, I briefly describe this measurement/characterization process, which I discuss in more detail in Chapter 3. I illustrate contributions of both vulnerability and resilience frameworks in this adaptive capacity assessment; specifically a process that considers the context specificity, nested, and dynamic properties of adaptive capacity (i.e., as treated in resilience literature) in a manner that lends itself to systematic operation (i.e., as treated in vulnerability literature). The purpose is not to review the strategies for addressing the latency issue, or the methodologies for assessing and characterizing adaptive capacity.

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[14] This does imply that one cannot advance theory by characterizing adaptive capacity. Rather, I view it more as an ancillary benefit to the process, not necessarily the purpose of it. Such ancillary theory-building benefits are in fact evident my characterizations of adaptive capacity in both Chapters 3 and 4.

Rather, I offer one potential way forward for assessing adaptive capacity that evaluates adaptive capacity from analyses of past events and also takes into consideration important principles of the vulnerability and resilience frameworks.

There are two steps to the adaptive capacity assessment that I use in this dissertation. The first step is to analyze the impacts of recent stress events (in this case, extreme droughts) that a grouping of similar systems (e.g., SES with similar functions and attributes) has experienced to a relatively uniform extent. Bounding the assessment by these criteria allows for a first glance at adaptive capacity. It helps single out adaptive capacity by controlling for exposure and sensitivity; that is, the lower the negative impacts, the more adaptive capacity within the systems. In addition to evaluating adaptive capacity as the dependent variable through the inverse of the impacts, it is important to also assess variables within the system that theoretically determine adaptive capacity (i.e., the independent variables). Since both vulnerability and resilience scholars have deemed management, institutions, and governance as particularly important, one key area to assess is the implementation of a suite of management and governance approaches that might be associated with improvements in adaptive capacity at different spatial scales. While the possibilities for which approaches to include in the assessment are likely infinite, I investigate drought and water management approaches that have gained particular attention as innovative; integrated water resources management (IWRM), adaptive management (AM), and drought preparedness. I examine these approaches at the local community water systems (CWS) level and the state-level. This first step allows researchers to build theory in assessing which particular variables are more closely associated with adaptive capacity in the given system(s). Thus, the first step provides a systematic assessment of adaptive capacity across similar systems in a manner that broadens its applicability beyond a single system. It also helps narrow the multitude of theorized determinants of adaptive capacity to a more localized/regionalized suite of approaches that captures the nuances affecting adaptive capacity within these systems, while at the same time providing clues for the limits of other approaches.

The second step specifically addresses the dynamic nature of SES and adaptive capacity. It involves looking at a multiple periods in time (such as similar stress events impacting the systems), to evaluate whether systems actually prepared for, or adapted/adjusted to the previous stress event. The rationale behind this assumption is if the system adapted or adjusted (regardless of whether it was negatively impacted by the previous event), then the capacity to do so had to have existed. For this step, it is particularly useful to look at whether the system(s) implemented or improved upon the management and governance approaches that proved to be important contributors to adaptive capacity during the first step.

I have greatly simplified the description of this methodology for illustrative purposes. The important elements of the procedure are that it draws from both vulnerability and resilience frameworks to attempt to measure and characterize adaptive capacity in that it; 1) prioritizes management, governance, and institutional analysis; 2) addresses the latency issue by attempting to directly measure adaptive capacity ex-post extreme events when systems are most likely to mobilize that capacity; 3) looks across time and space at actual adaptations of key variables to characterize adaptive capacity in a given group of systems; and 4) is both systematic for generalizations and policy application, and includes a step for tailoring the determinant variables to each unique system under investigation. There are many ways that one could expand upon or alter this basic procedure, and it is certainly not the only method for advancing the assessment of adaptive capacity. Still, I have presented this brief illustration to suggest that adaptive capacity research is not only possible, but that it researchers can make such assessments more robust by bridging vulnerability and resilience frameworks.

4. Summary

Building adaptive capacity is by no means a panacea for climate-smart sustainability, but it can increase the likelihood of achieving such outcomes. With its roots in adaptation studies and organizational theory, adaptive capacity has gained greater attention through the issue of climate change as documented in the works of the IPCC. The concept is uniquely situated within two predominant paradigms in the global change research community; vulnerability and resilience. However, studies that investigate vulnerability or resilience often neglect to emphasize the importance of adaptive capacity and its assessment. Moreover, when applied independently, vulnerability and resilience frameworks frequently fall short of placing a rich understanding of adaptive capacity into operation. Treatment of adaptive capacity in the vulnerability literature translates well into policy application, but often leaves out dynamic system components and processes like adaptation, learning, and multiple scales. Treatment of adaptive capacity in the resilience literature captures the evolving, nested, and polycentric nature of adaptive capacity, but is difficult to apply broadly to decision making because of divergent conceptual interpretations and its context specificity.

Adaptive capacity is a common thread between vulnerability and resilience frameworks, in that it is a positive system attribute and it is highly influenced by management, governance, and institutions. To overcome previous limitations in understanding adaptive capacity (i.e., those presented by applying vulnerability and resilience frameworks independently, as well as issues with latency and assessment), I propose drawing from both vulnerability and resilience frameworks to measure and characterize adaptive capacity. In the next chapter, I describe in further detail one attempt to operationalize adaptive capacity using this combined approach. I use a mixed methodology that includes quantitative and qualitative analyses to first measure and then characterize adaptive capacity in U.S. drought planning and management. In Chapter 4, I take a closer look at the management, governance, and institutional approaches within local water systems purported to increase adaptive capacity to droughts. Specifically, the empirical work I present in Chapter 4 investigates the timing of implementing these approaches and the mechanisms that facilitate or inhibit the adopting of these approaches (i.e., a deeper characterization of adaptive capacity by examining the bridges and barriers to adaptation).

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Chapter 3

Measuring and Characterizing Adaptive Capacity in U.S. Drought Planning and Management

1. Introduction

Like many states throughout the United States (U.S.), Arizona, Georgia, and South Carolina have experienced severe multiyear drought events during the past decade. Regardless of whether researchers can attribute the events in these three states to anthropogenic climate change, there is strong scientific evidence indicating that climate variability and droughts similar in intensity, if not even more extreme, will plague the Southwest and Southeast in the coming years and decades (Lenart et al., 2007; Seager et al., 2007; Seager et al., 2009). Furthermore, pressures from growth have compounded the effects of climate variability and change on water resources in these states. Prior to the recent economic recession, all three were amongst the most rapidly growing states in the U.S., with growth exceeding 10 percent in the period 2000-2008.[15] It remains to be determined whether these population growth rates and the corresponding economic expansion in the Southwestern and Southeastern U.S. will return to staggering pre-recession levels, or what the exact impacts from climate change will be on these regions. Unfortunately for water managers, most of the short and long-term decisions about future water security, responding to water quality and quantity issues, and the daily operation of complex water systems cannot wait for more precise projections to guide these difficult choices. In this context of high uncertainty and high stakes, water and other resource managers need tools and frameworks for management, governance, and institutions that expand the range of options and instill the flexibility necessary to adjust not only to changes science can predict with some degree of confidence now, but also to those changes science has yet to identify.

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[15] These and other recent population growth statistics are available at the U.S. Census Bureau, http://www.census.gov/popest/states/NST-pop-chg.html.

While there is a rich emerging literature hypothesizing how different innovative institutional frameworks and management paradigms such as integrated water resources management (IWRM) and adaptive management (AM) may shape water systems' adaptive capacities to climate and other stresses (Pahl-Wostl et al., 2007), there has been relatively little empirical research testing such assumptions, particularly in the context of U.S. drought planning and management. The recent droughts in Arizona (2001-2005), Georgia (2006-2008), and South Carolina (2006-2008) provide cases in which extreme droughts affected a large portion of the state for several consecutive years. Whereas these cases share similar drought intensities, there were differing management, institutional, and governance approaches in place within these states that influenced the magnitude of drought impacts.

In this chapter, I compare and contrast drought planning and management in Arizona, Georgia, and South Carolina at the state and local levels, with an emphasis on the operation of community water systems (CWS).[16] I combine archival data and in-depth semi-structured interviews with officials and water experts with a structured mail/online survey of CWS managers to explore the influence of drought planning and management on adaptive capacity. As discussed in Chapter 2, I draw from vulnerability and resilience frameworks to measure and characterize adaptive capacity. The ultimate goal of this chapter is to offer empirical evidence to help answer the following research questions:

1) what are the management, institutional, and governance approaches at various scales (particularly the state and CWS levels) that contribute to or inhibit the building of adaptive capacity to extreme droughts, that is, which approaches are most associated with higher adaptive capacity?
2) how can we improve adaptive capacity assessments to more adequately capture its dynamic, nested, and poly-centric nature in a manner that can be operationalized and applicable to decision makers?

At the state-level, I hypothesize that Arizona, Georgia, and South Carolina will have unique factors contributing to adaptive capacity, but that there will also be common themes across the three states. Specifically, I anticipate that factors related to drought

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[16] For a more detailed description of CWS and USEPA's definition of these systems, see Chapter 1, footnote 2, or see http://www.epa.gov/ogwdw/pws/factoids.html; and http://pubs.usgs.gov/circ/2004/circ1268/pdf/circular1268.pdf.

preparedness will be most innovative and influential to building adaptive capacity in Arizona (because of the arid environment), factors related to water management will be most innovative and influential to building adaptive capacity in Georgia (because of recent water reform and regulated riparian water laws), and that factors related to drought preparedness and water management will be less innovative and influential to building adaptive capacity in South Carolina (because it is not historically arid and surface water falls under the riparian doctrine). At the CWS-level, I hypothesize that each states' CWS will have a unique set of management approaches associated with higher adaptive capacity because of the mechanisms (i.e., institutional, and governance) that have developed over the years to prepare for and respond to droughts, and that the largest CWS will demonstrate the highest adaptive capacity, because of more resources for drought planning and management. Also, I posit that adaptive capacity assessments that more explicitly consider indicators around multiple spatial and temporal scales will unveil both new methodological advancements and also new challenges that researchers will need to consider in future assessments. In answering these questions and evaluating these hypotheses, this research seeks theoretical and practical advancements that might be useful to policy makers, drought planners, water managers, and adaptation and sustainability researchers.

The next section provides background on adaptive capacity, as well as a review of the innovative water and drought planning and management approaches in the U.S. that I evaluate in this chapter. Then, I present the research design and methods of inquiry, with particular attention on the process for assessing adaptive capacity and the innovative water and drought planning and management approaches. In the subsequent section, I provide the results of these assessments, and conclude with a discussion of the key factors contributing to or inhibiting adaptive capacity within and between Arizona, Georgia, and South Carolina, as well as applications and limitations of these findings.

2. Background

2.1. Adaptive Capacity

Adaptive capacity is the ability of a system to prepare for and respond to climate variability and change in order to cope with the consequences, moderate damages, or take advantage of the opportunities created by climate stress (Adger et al., 2007). More simply, it is the ability of a system to prepare for stresses and changes in advance or adjust and respond to the effects caused by the stresses (Smit et al., 2001). Assessments that include adaptive capacity are only in their nascent stages, but are steadily increasing in numbers (Brooks and Adger, 2005; Schröter et al., 2005; Polsky et al., 2007; Tol and Yohe, 2007; Engle and Lemos, 2010). As pointed out in Chapter 2, there have been few analyses that focus specifically on adaptive capacity, despite a growing agreement in the adaptation literature that governance, institutions, and management are key determinants of adaptive capacity and thus vulnerability and resilience (Adger, 2001; Berkes, 2002; Yohe and Tol, 2002; Ivey et al., 2004; Brooks et al., 2005; Haddad, 2005; Eakin and Lemos, 2006; Engle and Lemos, 2010). Their role is vital for creating an enabling environment through which adaptations can take place, that is, they either build or inhibit adaptive capacity. As climate changes and water resource problems become more complex, traditional command and control management approaches are thought to become less effective (Johnson, 1999). Studies suggest that more flexible, participatory, collaborative, and learning-based designs positively affect drought management and adaptive capacity (Kallis et al., 2006; Cromwell et al., 2007; Tompkins et al., 2008).

Most adaptive capacity research has tended to center on aggregate characterizations at the national level that do not capture context-specificity and local nuances, or have focused on small-scale case evaluations that make generalization difficult (Wilbanks and Kates, 1999; Ivey et al., 2004; O'Brien, Leichenko et al., 2004; Brooks et al., 2005; Ford et al., 2008). Also, assessments have not readily examined the inherently dynamic nature of adaptive capacity and its determinants over time (Vincent, 2007). This leaves key questions regarding the most effective piecing together of strategies and which mechanisms and approaches to emphasize at various scales, and such questions are only beginning to be addressed in the literature (Cutter et al., 2008).

As previewed in Chapter 2, the research presented in Chapter 3 helps address some of these gaps by combining vulnerability and resilience frameworks to assess adaptive capacity. Through the collection and analysis of quantitative and qualitative data, I measure and characterize adaptive capacity and the factors influencing it across different scales (spatial and temporal) in each state. The lessons learned from these extreme drought situations may help identify the structures, relationships, processes, and other variables facilitating or inhibiting adaptations (i.e., adaptive capacity), and ultimately improve actions in the face of climate changes yet to be experienced.

2.2. U.S. Water and Drought Planning and Management

Worldwide, freshwater systems will experience significant stress as a result of climate change. Among projected impacts are increased droughts and floods, less predictable and more intense storms, and decreased water quality and ecosystem health (Kundzewicz et al., 2007; Bates et al., 2008). In the U.S., studies suggest that droughts will increase in frequency, duration, and intensity. The latest climate change projections for the Southwest indicate that droughts will intensify due to higher temperatures and a poleward moving jetstream, exacerbating already dry conditions (Lenart et al., 2007). The Southeast will likely be hit hard by both increasing mean temperatures and increasing extreme climatic events (Karl et al., 2009). Such impacts will exacerbate already existing water quality issues and increase problems with water availability. Moreover, many of the U.S. regions expected to experience increases in drought also have some of the highest population growth rates in the nation,[17] which places further stress on diminishing freshwater sources.

Community water systems (CWS), although not the largest sector of users of freshwater resources,[18] are an integral component of the water sector for maintaining lifestyles, livelihoods, and meeting basic human needs, while also playing a critical role in the vitality of ecosystems and natural processes. From 1950 to 2000, the percentage of people in the U.S. receiving their drinking water from CWS grew from 62 percent to 85 percent (Hutson et al., 2004). Considering the importance of CWS, it is critical that we understand both the potential impacts of climate change and extreme droughts on water suppliers, as well as the effectiveness of potential adaptation options (Cromwell et al., 2007; Smith et al., 2009).

In terms of water allocation and supply, in the water-scarce regions of the West (including the Southwest), management has relied upon the prior appropriation doctrine,

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[17] Growth rates for the West and the South are presented in Chapter 1, footnote 1, and are available at http://www.census.gov/popest/states/NST-pop-chg.html.

[18] CWS freshwater use is presented in Chapter 1, footnote 3, and for more information, see http://pubs.usgs.gov/circ/2004/circ1268/pdf/circular1268.pdf.

which emphasizes that the first to claim stake on the water owns the rights to that water; the repercussions of which are thoroughly documented (Reisner, 1986). Prior appropriation identifies water as a property right, and in doing so creates incentives for using these rights (i.e., using the water before someone else uses it). In the historically water-abundant regions of the East (including the Southeast), water management has relied upon the riparian doctrine, which indirectly allocates water according to land ownership by limiting adjoining land owners of a water resource to use water 'reasonably' (Wright, 1998; Deason et al., 2001; Fort, 2003). Hybrids of both approaches have sprouted recently, such as the regulated riparian approach in the East which requires a state-issued permit for water withdrawals (Wright, 1998). In this research, there is a mix of prior appropriation doctrine (Arizona), riparian doctrine (South Carolina surface water), and regulated riparian doctrine (Georgia and South Carolina groundwater). Furthermore, each state approaches drought planning and management somewhat differently.

National drought management coordination has been generally sparse in the U.S., leaving states and local governments in charge of drought planning through a combination of water supply and demand approaches. Until recently, states have prioritized responding to rather than preparing for severe droughts. This reactive approach has led to greater vulnerability due to reduced self-reliance, fewer incentives for preparedness, and a lack of coordination across institutions and sectors; essentially placing drought management in the hands of crisis managers (Hayes et al., 2004).

Currently, best management practices for 'drought preparedness' fall into three basic categories; monitoring/early warning/prediction, risk/impact assessment, and mitigation and response (Wilhite et al., 2005). Many states have historically maintained monitoring and drought response approaches, but frequently lacked institutionalized impact/risk assessment and cohesive mitigation strategies. More recently, states have begun to initiate drought preparedness processes (Hayes et al., 2004; Jacobs et al., 2005; Wilhite et al., 2005), as evidenced by a greater number of state drought plans[19] and the proliferation of tools to aid these state-level drought planning initiatives (e.g., the 10-step

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[19] State drought plan statistics are presented in Chapter 1, footnote 5, and for more information, see http://www.drought.unl.edu/mitigate/status.htm.

planning process) (Wilhite, 2009). Another promising development is the recent creation of the National Integrated Drought Information System (NIDIS) (http://www.drought.gov), which represents a national-level effort to convey pertinent drought information to practitioners at various stages of the drought planning and management process. Inclusion of all three components (i.e., monitoring/early warning/prediction, risk/impact assessment, and mitigation and response) likely improves drought preparation and response. Yet despite this advancement in understanding and the recent uptick in drought planning activity around the U.S., significant gaps remain.

First, although researchers suggest that the three components of drought preparedness can and should be implemented and integrated across state and local scales, the relationship between and influence of state and local initiatives on adaptive capacity has received little empirical examination. For instance, decision making powers and authority in drought preparation and response are different across states, and whether officials prioritize state planning and management and/or local drought preparedness has not received significant empirical attention in the context of actual drought events. Moreover, it remains to be determined which particular aspects of these arrangements most effectively bolster adaptive capacity. This chapter provides detailed descriptions of each state’s drought planning and management processes and structures, and analyzes their influence on adaptive capacity based on the recent extreme drought events.

Second, CWS have received little empirical attention in the research community regarding their ability to effectively manage extreme droughts and climate change. This is problematic because CWS comprise the most basic level of water governance, responsible for allocating and delivering water during droughts (Pirie et al., 2004). They are also among the first systems to experience drought and climate-change impacts, so decisions at the CWS-level can significantly influence overall drought preparation and response. In addition to exploring the influence of drought preparedness on adaptive capacity (mainly at the state-level), this research specifically analyzes the extent to which CWS implement adaptive management and integrated management approaches, how proactive and adaptive they are leading up to, during, and following the drought events, and ultimately how these factors influence adaptive capacity.

2.3. Adaptive and Integrated Management for Drought Preparation and Response

Perhaps the two approaches that have received the most attention in the adaptation and water management fields for their potential to increase adaptive capacity are adaptive management (AM) and integrated water resources management (IWRM). While both share similar organizing principles, they have separate origins and tend to prioritize different aspects of water governance. IWRM, whose formal foundations can be traced to the 1977 United Nations Water Conference (Biswas, 2004), is geared toward decentralizing institutions around major river basins (or a particular watershed scale) and joining together various elements of water resources planning, such as groundwater and surface water management. In doing so, it strives to integrate management across multiple scales while incorporating a multitude of stakeholder interests (Blomquist et al., 2005). AM has its roots in resilience theory (Holling, 1978), and is primarily concerned with managing uncertainty through formalized experimentation and learning processes (Lee, 1993; Huitema et al., 2009).

At their cores, IWRM is most often described as reforming broader institutional structures of water governance and consensus building/conflict resolution amongst competing interests, whereas AM is more commonly associated with operational and management processes of water governance, iterative social learning and problem solving, and an emphasis on the importance of leadership, networks, and policy windows (Medema et al., 2008; Savenije and Van der Zaag, 2008). Both IWRM and AM jointly emphasize participatory and democratic decision-making, interdisciplinary problem-solving, collaboration, trust-building, information and knowledge use, and multiple interacting governance scales (polycentricism) (Blomquist et al., 2005; Pahl-Wostl et al., 2007; Kallis et al., 2009). Frequent blending of concepts and principles from both approaches is widespread in the academic and professional literatures (e.g. 'adaptive co-management', 'adaptive governance', and 'Integrated Resource Planning' (IRP)) (Beecher, 1995; Howe and White, 1999; Olsson et al., 2004; Folke et al., 2005; Cromwell et al., 2007; Plummer and Armitage, 2007; Nelson et al., 2008), and distinguishing between the two in practice is increasingly difficult.[20] Furthermore, there is some overlap between the academic and professional literatures in that IRP operationalizes some of the

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[20] Perhaps the most distinguishing characteristic of AM from IWRM is its emphasis on experimentation and hypothesis testing.

IWRM and AM concepts (e.g., emphasis on conservation, long-term planning, balancing supply and demand management, etc.).

In this research, I bring together defining characteristics of both the IWRM and AM paradigms into the context of U.S. drought planning and management, along with the three key elements of drought preparedness (reviewed above). To simplify throughout the remainder of the chapter, I refer to this grouping of approaches as adaptive and integrated management (AIM) (see *Figure 3.1*).[21] Again, although various literatures imply that IWRM, AM, and drought preparedness are important approaches for increasing adaptive capacity, there has been little empirical testing of such assumptions. Therefore, I operationalize these AIM approaches to test which specific factors contribute to greater adaptive capacity (described in the research design and methodology section, below). I also test the importance of ‘climate information use’, because of its purported relevance to climate change and extreme drought management, although the IWRM, AM, and drought preparedness literatures do not specifically include it in their frameworks. In the next section I present the AIM measures that I operationalize in this research and outline the methodology for testing which approaches associate more closely with higher adaptive capacity at the state and local CWS-levels in Arizona, Georgia, and South Carolina.

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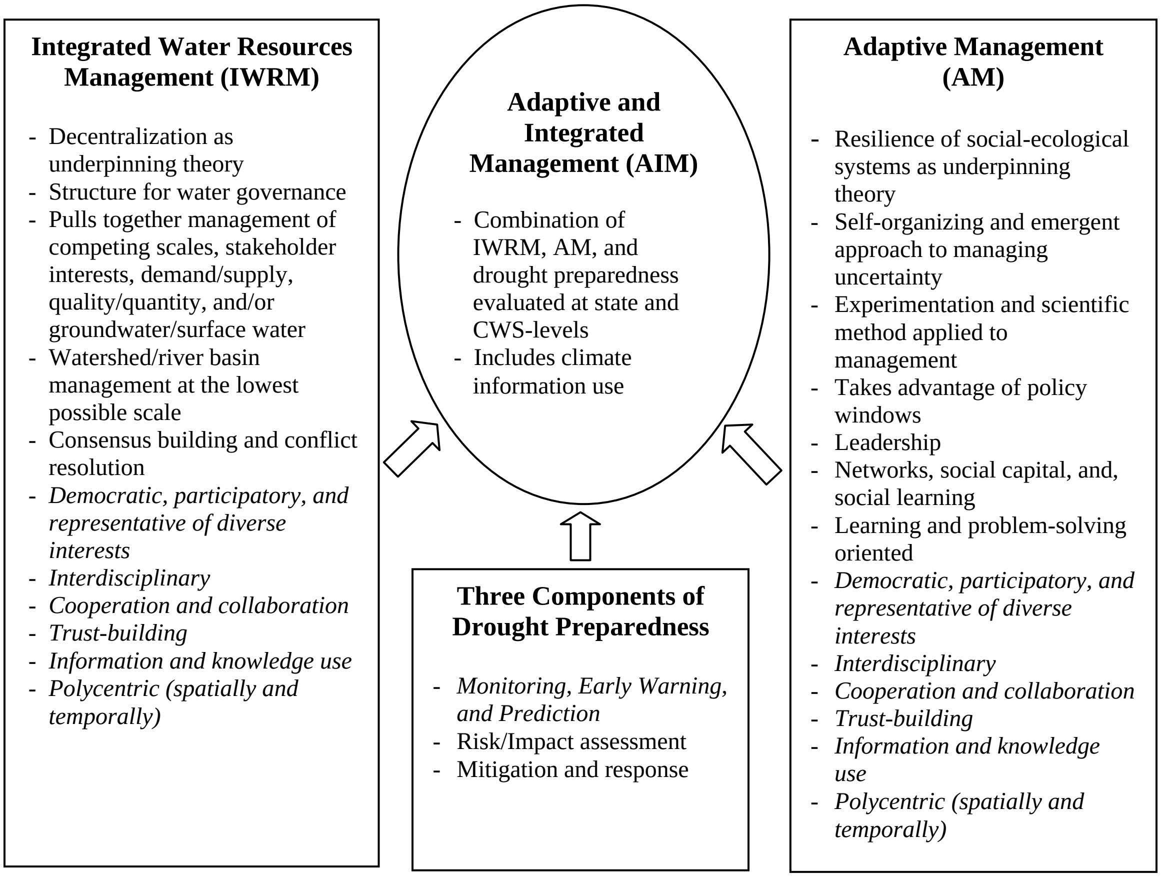
[21] While much of the literature speaks interchangeably about IWRM and AM, few researchers explicitly acknowledge when they are merging these paradigms together. Pahl-Wostl et al. (2007) and other efforts by the NeWater Project (http://www.newater.info/) have been working to formalize the integration of the two paradigms into what they term ‘adaptive integrated water resources management’. Therefore, my work builds off of these ongoing efforts by operationalizing ‘adaptive and integrated management’ in the context of U.S. drought planning and management, and by attempting to systematically assess the relationship between factors that comprise adaptive and integrated management and adaptive capacity.

Figure 3.1: Innovative water and drought planning and management approaches evaluated in this research. Obvious areas of overlap in the three literatures are identified in italics.



Integrated Water Resources Management (IWRM)

- Decentralization as underpinning theory
- Structure for water governance
- Pulls together management of competing scales, stakeholder interests, demand/supply, quality/quantity, and/or groundwater/surface water
- Watershed/river basin management at the lowest possible scale
- Consensus building and conflict resolution
- *Democratic, participatory, and representative of diverse interests*
- *Interdisciplinary*
- *Cooperation and collaboration*
- *Trust-building*
- *Information and knowledge use*
- *Polycentric (spatially and temporally)*

Adaptive and Integrated Management (AIM)

- Combination of IWRM, AM, and drought preparedness evaluated at state and CWS-levels
- Includes climate information use

Adaptive Management (AM)

- Resilience of social-ecological systems as underpinning theory
- Self-organizing and emergent approach to managing uncertainty
- Experimentation and scientific method applied to management
- Takes advantage of policy windows
- Leadership
- Networks, social capital, and, social learning
- Learning and problem-solving oriented
- *Democratic, participatory, and representative of diverse interests*
- *Interdisciplinary*
- *Cooperation and collaboration*
- *Trust-building*
- *Information and knowledge use*
- *Polycentric (spatially and temporally)*

Three Components of Drought Preparedness

- *Monitoring, Early Warning, and Prediction*
- Risk/Impact assessment
- Mitigation and response

3. Research Design and Methodology

3.1. Instruments and Data Collection

I combine qualitative and quantitative data to characterize drought planning and management and measure adaptive capacity to recent extreme drought events in each of the states. My research focuses on a drought in Arizona that occurred roughly from 2001-2005, and Georgia and South Carolina droughts, spawned by similar meteorological conditions, that occurred from 2006-2008. These three states and corresponding drought periods were selected by identifying medium-long term (6, 9, and 12 month) Standardized Precipitation Index (SPI)[22] values at or below the 'extreme' level (-2) that

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[22] The SPI was developed by McKee et al., (1993). It is a method for providing a comparable metric across locations for the evaluation of climate stress on hydrological processes. The metric is based on past climate conditions and the probability of precipitation for various time scales (e.g., 1, 2, 3, 6, 9, 12, and 24 month intervals) (Hayes, 2006). Through a normalization and standardization process, the values can be compared across regions, based on the standard normal distribution, where a +2 or -2 (extreme wetness and extreme

occurred on a widespread scale throughout each of the states.[23] First, I conducted preliminary face-to-face interviews with climatologists and research scientists, water and drought managers, and non-governmental organizations (NGOs) in each state to ascertain that I had accurately identified the time period within which the drought and its impacts occurred. Second, management, institutional, governance, and drought impacts data were collected using archival research, semi-structured interviews, and an online/mail survey. I use the archival and semi-structured interviews to qualitatively characterize drought planning and management and adaptive capacity in each of the three states. I use the online/mail survey to quantify drought impacts, AIM approaches, and adaptive capacity of CWS around the time of the extreme drought events. In the discussion section, I pull together insights from all three sources to broadly characterize adaptive capacity and the factors influencing it in each of the states.[24]

The archival data are mainly state-level formal drought and water plans, statutes, and legislation; all available online. The semi-structured interviews consist of 30-60 minute telephone conversations with an average of six key informants with proven experience in water, climate, and/or drought policy and management issues in each of the three states and several individuals at the national scale who could provide insight relevant to all three states.[25] *Appendix 1* depicts a sample interview questionnaire. The majority of the questions focused on how experts perceive state and CWS management

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dryness, respectively) are indicative of a dry or wet period that is experienced 2.3 percent of the time (Edwards and McKee, 1997). Additionally, unlike other drought indices, the timing of the dry period is universally defined as crossing the threshold of +1/-1 (moderately wet/dry), and ends when the sign is reversed (Hayes, 2006). From a meteorological standpoint, this allows me to compare drought episodes in different states that have similar extremenesses; with assumingly different governance and management responses to these extreme episodes. For more information on the selection of cases, see Chapter 1.

[23] While these cases represent similar drought intensities and levels of extremeness, they are not ‘identical’ events, and the droughts could not have manifested themselves uniformly within each state. The purpose of the research is not to identify perfectly comparable cases within and between states, but rather widespread drought events of similar intensity that likely tested the effectiveness of drought planning and management; unveiling the adaptive capacity in these systems.

[24] Using past extreme events as potential proxies for how states and CWS might prepare for and respond to future climate change stress is well documented and supported in the adaptation field (Adger et al., 2007). Investigating governance and management during the most abrupt changes and disturbances exposes system structures when they are most challenged (Folke et al., 2005).

[25] This includes representatives from state agencies (e.g., water, environment, emergency management, and corporation commission agencies) and federal agencies (e.g., USGS, Bureau of Reclamation, Army Corps of Engineers, and the National Resource Conservation Service). I also interviewed water and climate related NGO leaders, technical experts (e.g., state climatologists, river forecast center staff, and Regional Integrated Scientific Assessment scientists), and professional association executives (e.g., state and regional utility organizations). The 22 interviews were conducted from May-November, 2009.

with respect to the extreme drought events in their states. I also queried these experts about what makes the state and CWS more or less adaptable, and actions the state has taken to bring about more innovative management (including the effectiveness of drought plans, the identification of potentially restrictive legislation, etc.). Finally, I asked informants directly to characterize the adaptive capacity within the state(s).

I coded these data in Nvivo software based on descriptive (e.g., water and drought management/legislation) and analytical (e.g., characteristics affecting adaptive capacity) categories. The results of the coding are depicted below in the results section and the coding categories are reported in *Appendix 4*. The data help illustrate management and governance characteristics in each state, and allow for an assessment of their influence on adaptive capacity. The interviews also help me to explore patterns and identify key factors that help define the institutional spaces within which CWS operate and adapt.[26]

The third data source comes from the Community Water Systems Survey (CWSS).[27] The survey represents a census of CWS in multiple states, including Arizona, Georgia, and South Carolina.[28] Survey population and response rates for Arizona, Georgia, and South Carolina were 429 systems and 14.2 percent, 606 systems and 16.0

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[26] Relying on multiple expert judgments, as I do in this research, increases the validity of the results. However, one might question the reliability of the coding and characterization process. Reliability generally increases with the use of multiple coders (Perreault and Leigh, 1989), but studies have shown that this is not necessarily the true with data that require coders to evaluate the importance of the information in the context of a larger response (Crittenden and Hill, 1971). Therefore, the intra-reliability of coding complex relationships and processes (e.g., influences on adaptive capacity) can improve by a single person coding text multiple times at multiple periods (Perreault and Leigh, 1989). In this research, I conducted at minimum two waves of coding for each interview transcript (i.e., one round of open coding using free nodes, followed by a second and/or third round of structured coding using tree nodes).

[27] I developed and administered the CWSS with a fellow University of Michigan doctoral student, Christine Kirchhoff. We collaborated on this portion of our data collection endeavors because our study populations overlapped significantly, and we deemed a more lengthy single effort more effective than two individually administered shorter surveys. The frames (lists) were obtained using USEPA's website or provided by individuals in the various state water agencies. The study populations were refined to include all non-transient systems organized around water management. Through this process, most public institutions (e.g., prisons, schools, airports, etc.) and private associations (home owners associations, mobile home parks, etc.) were removed; leaving mostly private water companies and municipal utilities. We kept public institutions and private associations that had a water related title (e.g., 'water improvement district', 'water association', 'well group', etc.), because they have likely implemented some formal water management processes, as indicated by their titles.

[28] We designed the instrument using principles outlined in the survey methodology literature to improve response accuracy and decrease errors (e.g., non-response, measurement, non-coverage, and sampling errors) (Dillman, 1991; Schwarz and Oyserman, 2001). A pilot test was carried out in Michigan (a state not included in the survey population), and additional feedback was incorporated based on preliminary interviews with water and climate experts in Arizona, Georgia, and South Carolina from January-February, 2009. We administered the survey in April 2009 and received all responses within three months.

percent, and 293 systems and 12.6 percent, respectively. *Table 3.1* shows the response rates and representativeness of the survey data.[29] The CWSS employed several techniques that likely improved response rates, such as multiple methods of response (online and mail),[30] multiple notification and contact (pre-notification, survey, and follow up), and personalization (Duncan, 1979; Fox et al., 1988).[31]

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[29] Although the sample is not perfectly representative (it is slightly over representative of larger systems), it closely resembles the population, as depicted in actual and expected counts in *Table 3.1*. Regarding response rates, the Arizona Department of Water Resources (ADWR) and a doctoral student at the University of South Carolina recently surveyed water providers in their states and had higher response rates than the CWSS; 29 percent and 42 percent, respectively (ADWR, 2004; Mizzell, 2008). We expected slightly lower rates in our survey than in these previous surveys, due to the fact that the CWSS had essentially combined two short surveys into one longer survey. Rather than further fatiguing the respondents (who have been surveyed numerous times in the past several years), we determined that our response rate would benefit from a more lengthy single survey. One cannot determine if the response rate would have been higher by sending the surveys independently. However, given the respondent fatigue from previous studies, our 'outsider' status (conducting the survey from a university in a distant state), and no official backing from the Governor and/or a state regulatory agency (as was the case in the previous surveys in Arizona and South Carolina), our response rates are adequate to perform statistical analyses.

[30] We used Qualtrics for the online version, which allowed us to administer the survey in a manner very similar in structure and layout to the mail survey; increasing consistency between the two data collection methods.

[31] Once collected, survey responses were double-entered into SPSS by two separate individuals, and a data comparison program was run in Stata to check for consistency between the two versions. After correcting any errors and cleaning the data, online survey and mail survey data were combined into a single database. It is important to note that while this double-entry and cross-check process essentially eliminated data entry errors, there remains a possibility that respondents made mistakes when completing the survey; a type of error that is beyond our control. There were several instances when a single CWS submitted both a mail and online survey. The primary reason was that they seemed to have initiated an online survey and decided along the way to switch to the mail survey. In the rare event that the same CWS completed two surveys, but were done by two different people, we kept the survey with the most complete data, which was usually the mail survey.

Table 3.1: CWSS survey response rates with representativeness statistics. System size is based on EPA categorizations of people served; very large > 100,000, large 10,001-100,000, medium 3,301-10,000, small 501-3,300, and very small 25-500.

CWS size	Response statistics	**Arizona**		**Georgia**		**South Carolina**	
		Sample	Population	Sample	Population	Sample	Population
Very large	Count	6	10	4	12	2	7
	Expected count	1.4	10	1.9	12	0.9	7
	Percentage represented	9.80%	2.30%	4.10%	2.00%	5.40%	2.40%
Large	Count	8	41	13	78	12	61
	Expected count	5.8	41	12.5	78	7.7	61
	Percentage represented	13.10%	9.60%	13.40%	12.90%	32.40%	20.80%
Medium	Count	7	42	17	104	6	71
	Expected count	6	42	16.6	104	9	71
	Percentage represented	11.50%	9.80%	17.50%	17.20%	16.20%	24.20%
Small	Count	16	122	35	229	14	115
	Expected count	17.3	122	36.7	229	14.5	115
	Percentage represented	26.20%	28.40%	36.10%	37.80%	37.80%	39.20%
Very small	Count	24	214	28	183	3	39
	Expected count	30.4	214	29.3	183	4.9	39
	Percentage represented	39.30%	49.90%	28.90%	30.20%	8.10%	13.30%
Total counts		61	429	97	606	37	293
Total response rate		**14.20%**		**16.00%**		**12.60%**	

Appendix 2 depicts an example of the complete CWSS. The primary purpose for using the survey instrument is to gauge adaptive capacity and to assess the management approaches implemented during and since the specific extreme drought periods of interest, by creating multiple linear regressions and cluster analyses in each state. In this pursuit, I consider a multi-step process for assessing AIM approaches and adaptive capacity.

3.2. Analysis of AIM Approaches and Adaptive Capacity

I assess AIM approaches and adaptive capacity at two levels – the broader state context and the local operation of CWS – by combining qualitative and quantitative data gathered using the methods described above. In this section, I describe the assessment process.

The state-level characterization draws from the archival and telephone interview data to describe in detail the processes, institutions, initiatives, and relationships within each state related to drought planning and management. I categorize these descriptions within the three components of drought preparedness (monitoring/early warning/prediction, risk/impact assessment, and mitigation and response) and climate change information use, and identify the most prominent factors at the state-level affecting adaptive capacity. I include state-level descriptions of physical characteristics, drought history, and water management since the interview data indicate that these factors also directly affect drought preparation and response.

From the state-level, I move to testing which specific AIM approaches implemented (or not) by CWS are associated with higher adaptive capacity. Using the underlying principles depicted in *Figure 3.1*, I operationalize the approaches into management actions, as measured by the CWSS. Managers were asked to report those approaches in operation leading up to/during the drought, and at present time or in the immediate future (post-drought). *Table 3.2* includes a summarized description of the operationalized AIM approaches (column 3), and the full set of questions is located in *Appendix 2*, question ‘M1’.

Table 3.2: AIM approaches, system attributes, and adaptive capacity variables operationalized and assessed in the CWSS.

Dependent variables		**Independent variables**	
Adaptive capacity 1: Inverse of drought impacts on various aspects of CWS management	*Adaptive capacity 2*: Dynamic measures before, during, after drought event	*AIM approaches*: Variables tested for their influence on *Adaptive capacity 1*	*System attributes*: Variables potentially influencing adaptive capacity and possibly controlled for in regression of *Adaptive capacity 1* on *AIM approaches*.
1. Water deliveries	1. Inverse of drought impacts (see *Adaptive capacity 1*)	1. System integrated, regionalized, or backed-up with other CWS	1. Size (population served)
2. Ecosystems	2. Important *AIM approaches* identified in *Adaptive capacity 1* and measurement implemented after the drought. Or, alternatively, the number of AIM approaches implemented since the drought in a CWS, compared to the number in place before and during the drought	2. Coordination and planning water supply decisions with other CWS	2. Primary water source (ground, surface, purchased surface, etc.)
3. Water quality	3. Extent of proactively changing normal management approaches or practices to prepare for and respond to this drought	3. Participation in regional planning initiatives	3. Ecoregion
4. Budget/finances		4. Collaboration with the *state* government on drought issues	4. System type (public v. private)
5. Social/customer conflict		5. Collaboration with *federal* government on drought issues	5. Annual budget
		6. Cross-sector collaboration	
		7. Short-term weather information use	
		8. Medium and long-term information use	
		9. Climate change scenarios or impacts information use	
		10. Information from multiple agencies/groups	
		11. Communication of ‘uncertainty’ with customers	
		12. Public participation encouraged	
		13. Conflict-resolution procedures	
		14. Drought plan with preparation and response procedures	
		15. Long-term water management plan	
		16. Water management plan updated regularly	
		17. Climate change considered in water management plan	
		18. Multi-year-decadal drought planning	
		19. Experimentation with water supply/demand options	
		20. Tracked and recorded water demand and supply	
		21. Drought impacts monitoring, evaluation, and reporting	
		22. Financing and resources available to implement new approaches	

I assess CWS adaptive capacity in two steps. The first is a *measurement* of adaptive capacity to test the importance of AIM approaches at the CWS-level, which relates to a specific point in time, the drought event. The second is a *characterization* that builds off of the first, but uses multiple indicators of adaptive capacity to group CWS into clusters based on processes and changes leading up to, during, and after the event; providing a richer characterization of CWS adaptive capacity. I base the first measure on the inverse of the impacts from the drought events, as reported in question ‘R1’ of the survey (see *Appendix 2*). The impacts variables are depicted in *Table 3.2* (column 1). Assuming that the exposures are similar, and by controlling for sensitivity and CWS system attributes (also shown in *Table 3.2*, column 4), the lower the impacts, the more adaptive capacity within the system. I then create multiple linear regression models in each state to evaluate which AIM approaches are most significantly associated with adaptive capacity. Although the drought events are similar in extremeness, I treat each state with separate regressions. This allows for the possibility of different AIM approaches being more significant in one state over another.

This first measurement tests the AIM variables that are more closely associated with positive outcomes (fewer impacts) in each state. While this will help identify potential areas for CWS to prioritize in the future, refine theory,[32] and provide a snapshot measure of adaptive capacity, it falls short of evaluating adaptive capacity in its dynamic nature. Therefore, the second step uses a set of proxies for adaptive capacity at different points in time to identify groupings and clusters of CWS that demonstrate similar adaptive (or not) characteristics. I plan to use the significant AIM variables identified in the first measurement to help further characterize adaptive capacity in the second measurement, that is, whether the CWS have implemented these significant AIM variables post-drought. Not only is this an assessment of adaptations, and thus adaptive capacity (i.e., the adaptive capacity to do so had to exist), it also gauges CWS ability to

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[32] To attempt to tease out the important AIM variables in each state and test theory using multiple linear regression models, I need a single dependent variable measurement for adaptive capacity directly linked to the drought event. Therefore, the first step is most beneficial for quantitatively measuring and testing theory, while the second step seeks a broader description of adaptive capacity based on multiple points in time (and thus multiple characterizations of adaptive capacity). Both steps of the CWS assessment and the state-level assessment are combined in the discussion to provide a detailed description of adaptive capacity of CWS to extreme drought events in each of the three states.

learn from the drought and implement (or continue to implement) more effective approaches. For this characterization, I assume that one can identify clear relationships in the regression models between positive outcomes and the management approaches in operation during the droughts. As an alternative characterization of adaptations and learning, I also consider how many AIM approaches CWS have implemented since the drought, compared to the number in place before and during the drought.

In addition to the inverse of drought impacts and whether CWS implemented AIM variables post-drought, the characterization process (i.e., the second step of the assessment) uses CWSS data to further gauge if systems actually changed, adapted, or adjusted in relation to the drought events. The multiple indicators used in this second step to characterize adaptive capacity into clusters of CWS are located in questions 'R1', 'R3', and 'M1'of the survey (*Appendix 2*) and identified in *Table 3.2* (column 2). It is important to note that because the second step also includes the drought impacts measure, there is a possibility that the characterization and clustering exercise will inform the measurement of adaptive capacity (mainly achieved through the first step). For example, if the cluster analysis unveils 'adaptable' groups that share common system characteristics and also similar drought impacts, it might further illuminate what determines adaptive capacity. *Figure 3.2* depicts the adaptive capacity assessment process and the relationships between the two steps with respect to the drought event.[33]

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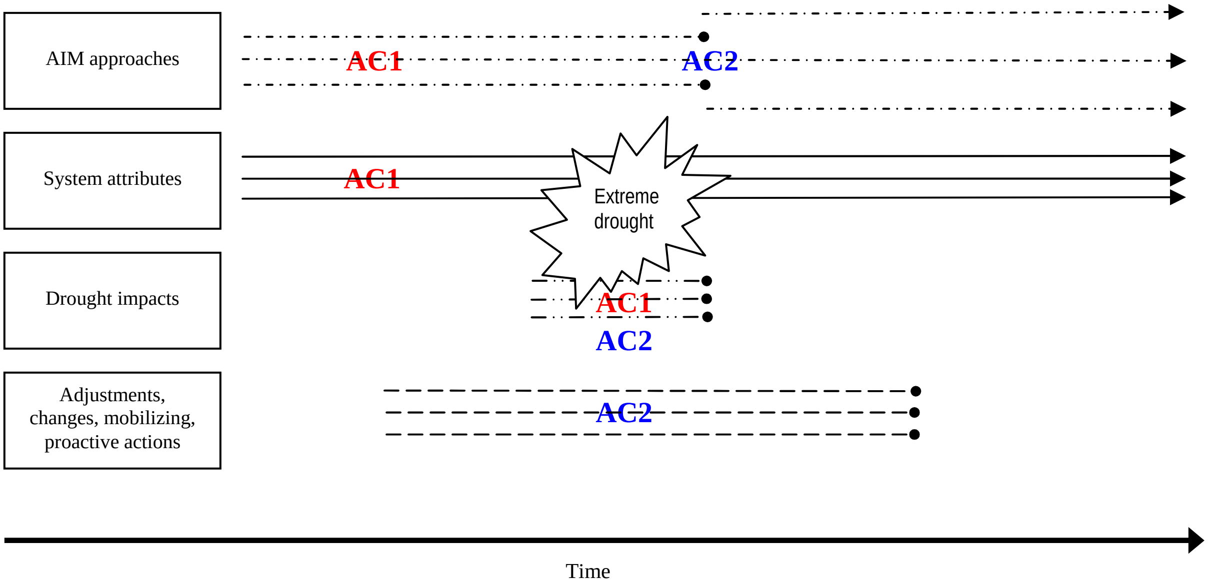
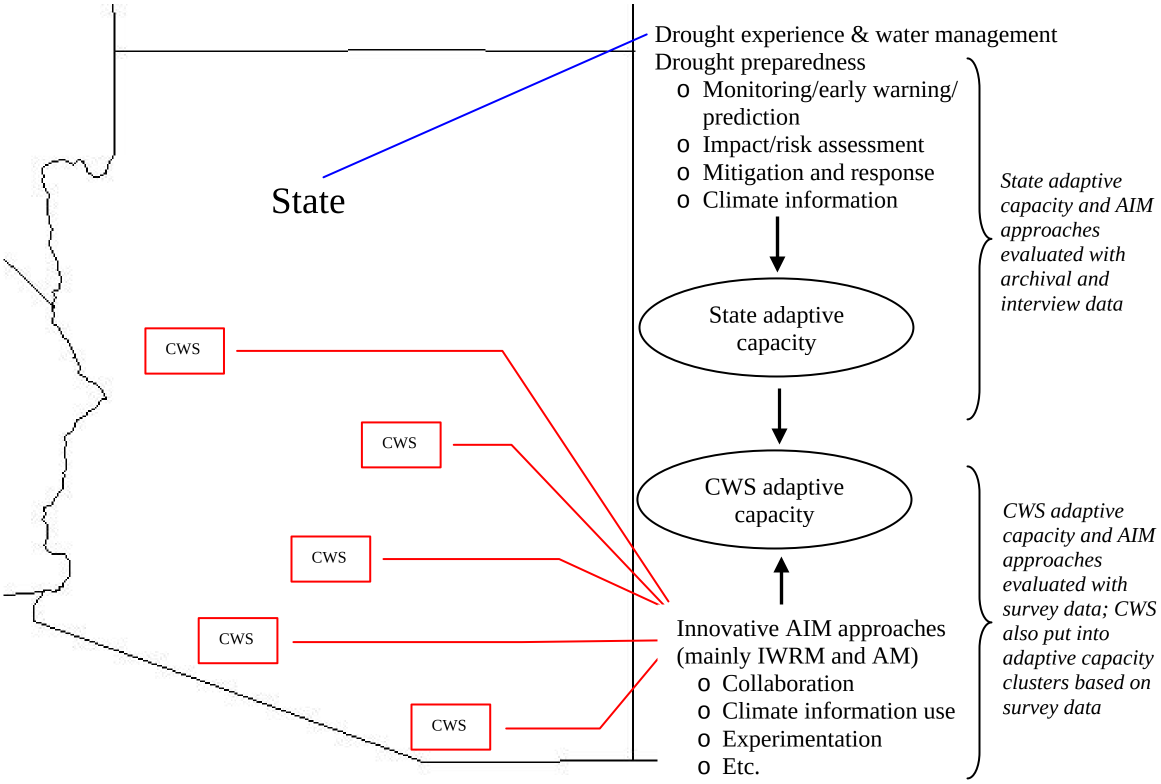
[33] This assessment method makes several additional assumptions worth noting. First, the extent to which a manager accurately reports impacts and management mechanisms might be associated with his/her CWS' adaptive capacity. In other words, being well aware and knowledgeable of the drought impacts on the system might indicate better leadership, flexibility, etc. Unfortunately, there is limited amount of drought impacts reporting for CWS to test this assumption, which suggests the need for future impacts assessments. Second, it assumes that the drought events were severe enough across each of the three states to stress CWS to the level that facilitated the realization/mobilization of adaptive capacity, and thus in its first measure, a snapshot of adaptive capacity is possible by examining the inverse of the impacts reported in these systems. I am relatively comfortable with this second assumption for two reasons. First, the CWSS reported high impacts in ecoregions and watersheds throughout each of the states, even in areas that some of the key informants identified as less severely hit by the droughts. Therefore, the droughts were physically severe enough to stress systems throughout each state. Also, controlling for the ecoregion in the regressions not only helps to take ecosystem sensitivity into consideration, but also regional exposure to the droughts. Another reason that I am comfortable with this assumption is that the adaptive capacity characterization used in this research moves beyond this single snapshot in time, and further groups CWS based on dynamic indicators of adaptive capacity (i.e., adjusting proactively and reactively to the drought, etc).

Figure 3.2: Two-step CWS adaptive capacity assessment. The first measurement (AC1) is based on the inverse of drought impacts and identifies important AIM approaches for each state, while controlling for significant system attributes. The second characterization (AC2) identifies CWS clusters of adaptive capacity based on multiple indicators of adaptive capacity (before, during, and post-drought), including the inverse of drought impacts and system attributes (from AC1), adaptations in AIM approaches, and adjustments and flexibility surrounding the drought.



In summary, the complete assessment process described in this chapter examines the influence of state-level drought planning and management on state and CWS adaptive capacity, evaluates the importance of AIM approaches for determining adaptive capacity of CWS, and provides a characterization of adaptive capacity based on vulnerability and resilience frameworks. It uses multiple sources and data at different scales to increase the robustness of the findings. I illustrate the relationships investigated in this research and the data used to operationalize adaptive capacity and AIM approaches in *Figure 3.3*.

Figure 3.3: Conceptual model showing the relationships between the AIM approaches and adaptive capacity at different scales, and the data used for their assessment (illustrated in the context of Arizona).



4. Results

4.1. State Analysis

I present the findings from the telephone interviews and archival data to evaluate state-level adaptive capacity to extreme droughts in Arizona, Georgia, and South Carolina. In addition to drought preparedness and the use of climate information, I describe the physical/social characteristics and drought experience, as well as water planning and management, since these factors ultimately affect adaptive capacity. After describing each state by the six categories (i.e., physical/social characteristics and drought experience, water management and planning, monitoring/early warning/prediction, vulnerability/risk assessment, mitigation and response, and climate change information and knowledge use), I synthesize the data to identify the major influences of these factors on adaptive capacity.

Arizona[34]

Physical-Social Characteristics and Drought Experience

There is a history of climate variability in arid Arizona, with extreme droughts and monsoon floods often occurring in the same years. Most populated areas benefit from a highly developed groundwater system, with limited surface water generally supplementing large urban areas through the Central Arizona Project (CAP) and the Salt River Project (SRP). While problems with drought are more immediately apparent with respect to surface water availability, the overdraft of aquifers affects ecosystems and fossil water supplies. Drought and water management intersect with many issues in Arizona, although droughts were not a major policy concern until the late 1990s. Transfers of water rights from agricultural to public use have recently facilitated rapid urban expansion. Land-use policies are fairly weak, and there is limited regulation of water use at the state-level. During the 2001-2005 drought, most CWS problems were associated with surface water and rural water systems. Cities generally have more resources (e.g., canals and large water portfolios), but at the height of the drought, large reservoir capacities were down to 12 percent. The droughts also increased wild fire risk, as evidenced by the Rodeo-Chediski fire, which burnt 500,000 acres and destroyed 150 homes. In 2005 and 2006, a wet winter and summer brought an end to the drought, filling up the reservoirs within the year.

Water Management and Planning

Major water-related agencies include the Arizona Department of Water Resources (ADWR) – manages water supply and CWS oversight through rules, regulations, and the provision of technical support – the Arizona Corporation Commission (ACC) – regulates private CWS – the Arizona Department of Environmental Quality (ADEQ) – oversees water quality regulation and technical support – and the Arizona Water Banking Authority (AWBA) – stores unused Colorado River water to be used in times of shortage. Surface water use requires a permit, based on prior appropriation doctrine, and holders can designate and transfer permits to in-stream flows as a beneficial use. Groundwater

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[34] Arizona information comes from personal communication with key informants, and the following sources and documents: (Wright, 1998; Jacobs and Morehouse, 2003; Governor's Drought Task Force, 2004, 2004, 2004; Jacobs et al., 2005; ADWR, 2007; ADEM, 2008; ADWR, 2009; Greenhouse and Wahl, 2009; ADWR, 2010).

use also requires a permit in all non-small domestic Active Management Area (AMA) withdrawals, and small wells are exempt from most regulation. There is no immediate recognition between ground water and surface water rights, and water transfers between regions require special approval from ADWR. Major water legislation includes the 1980 Groundwater Management Act – created ADWR to oversee water use in five AMAs that require an 'assured' 100-year water supply – the 2007 Adequate Water Supply Legislation – allows counties to require developments to show 100 years of adequate groundwater supply – and the 1922 Colorado River Compact and 2007 Shortage Agreement Amendment – identifies Arizona as junior rights holder to California (a concession in 1968 to have CAP authorized by the U.S. Congress), cedes a portion of Arizona's water to California during shortages, and allows the state to store water underground in excess years through the AWBA. There is no comprehensive statewide water management plan in Arizona, but there is a state conservation strategy (linked to the state drought plan, below). Several local watershed partnerships have formed over the past decade, with ADWR and the involvement of various state and federal agencies. CWS are required to have conservation plans, and conservation-oriented (e.g., inclining block-rate) rate structures are encouraged, but not mandated. Some cities have focused on desert vegetation (xeriscaping) and rainwater harvesting to foster a culture of water conservation, and CWS use of effluent/reclaimed water is a common practice, particularly in larger CWS for non-potable uses (e.g., watering lawns).

Monitoring, Early Warning, and Prediction

Arizona compiles annual water use and availability reports by groundwater basin and AMA (36 total). ADWR's Arizona Water Atlas provides comprehensive information on seven planning areas. NGOs, universities, agencies, and partnerships (e.g., Arizona NEMO, Climate Assessment for the Southwest (CLIMAS), etc.) play a significant role in gathering, synthesizing, and distributing information and studies. There are several tools available online for CWS, such as drought status reports and the AZ Drought Watch. The 2004 Arizona State Drought Preparedness Plan (ASDPP) requires drought monitoring through a state Monitoring Technical Committee (MTC), and supports county-level monitoring through Local Drought Impact Groups (LDIGs). Legislation adopted in 2005 (House Bill 2277) requires all CWS to have a drought plan, which outlines locally-relevant triggers and drought stages declared and implemented by local governments during times of severe drought. The MTC methodology for determining drought status (short and long-term) is based on the SPI and stream flow information, and is frequently updated and improved. After drought triggers are hit, the MTC, LDIGs, and an Interagency Coordinating Group (ICG) examine detailed regional triggers to assist with drought alert declarations (abnormally dry, moderate drought, severe drought, extreme drought) and local responses according to individual CWS drought plans. It is easier to enter drought status than exit, making it a conservative planning methodology.

Vulnerability/Risk Assessment

ASDPP identifies historical impacts/vulnerabilities on the state and regional levels by various sectors. CWS are required to implement 3-tiered drought plans, parts of which focus on identifying and reducing drought vulnerabilities. LDIGs play a role in local vulnerability and risk assessment, primarily through impacts monitoring and reporting. AZ Drought Watch allows impacts reporting across a variety of categories and scales.

Mitigation and Response

ADWR administers the ASDPP, which consists of three parts; technical impacts/vulnerability analysis, a statewide water conservation strategy,[35] and an operational drought plan, all of which help mitigation and response (e.g., descriptions of institutional organization and structure, sector and regional analyses, drought declaration and alert processes, and overall plan implementation). The ASDPP also lays out the coordination of 3 groups – the MTC, LDIGs, and ICG. The MTC reports to the ICG twice yearly on drought status recommendations and the ICG meets quarterly, regardless of drought conditions. CWS are required to have a 3-tiered drought plan; a water supply plan (water strategies, needs, and reporting), a drought preparedness plan (meeting CWS needs during droughts and water shortages), and a water conservation plan (increasing efficiency, and reducing waste). For the drought preparedness plan, systems highlight voluntary and mandatory actions for the four drought levels declared by their local governments, with level 4 being their 'worst-case' scenario (most plans are responsive). Beyond this, the Governor can evoke mandatory restrictions, which were not declared

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[35] The statewide water conservation strategy complements, but is not officially part of, the drought plan.

during the 2001-2005 drought. The ASDPP process has persisted in non-drought years, and has endured a change of Governors. LDIGs help develop county-level and regional plans in advance of a drought to minimize impacts when droughts occur. ADWR Conservation Offices (statewide and regional) also help in drought mitigation. For several years, ADWR had at least one person devoted to drought planning and management. CLIMAS also has an active role in drought planning and mitigation. The State of Arizona Emergency Response and Recovery Plan (SERRP), most recently updated in 2005, highlights drought in its incident annex, which identifies organizations for statewide drought assessment, response, and recovery actions. Private water systems follow different processes and requirements for drought responses. Outside of a state emergency, ADWR cannot force CWS to restrict water (but ACC can in private CWS).

Climate Change Information and Knowledge Use

Uncertainty in precipitation projections have caused many managers to operate under the assumption that they need to work with less water and prepare for increased variability. SRP, the U.S. Bureau of Reclamation, the University of Arizona, and several large water systems began collaborating on climate predictions for the Lower Colorado River during the 2001-2005 drought. The University of Arizona also worked with SRP on tree-ring studies, and long-term climate projections. There is strong University and extension service presence (formal and informal) in building drought and climate knowledge, with CLIMAS providing a considerable amount of support (e.g., online tools, workshops, research collaborations). Researchers and agencies are actively reaching out to water managers to understand what information is most useable and helpful. Though information and knowledge is readily available, it is a persistent challenge to entice water managers to seek out such information.

Georgia[36]

Physical-Social Characteristics and Drought Experience

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[36] Georgia information comes from personal communication with key informants, and the following sources and documents: (Wright, 1998; Christy et al., 2002; GDNR Board, 2003; Draper, 2005; Kundell, 2005; Perdue, 2007; GEMA, 2008; Water Council, 2008; GDNR/EPD, 2009; Kundell, 2009; MNGWPD, 2009, 2009).

Georgia has historically experienced abundant rainfall (well above the amount needed to sustain human and ecosystem needs). Significant climate variability has historically affected Georgia. However, several high-growth decades leading up to the present were associated with abnormally low climate variability. Northern communities (above the continental fall line) are mainly surface water (headwaters) and reservoir dependent (federal), whereas the South is primarily groundwater dependent (e.g., the Floridian Aquifer). Population density is much more concentrated above the fall line, with a larger overall population dependent on agriculture in South Georgia. Water availability and drought issues oftentimes interact with other issues, such as growth and flooding. Population influxes into North Georgia from 1990-2000 forced municipalities to consider more aggressive water planning. Shortly after the recent drought, floods plagued much of the state at various points throughout 2009. The 1998-2002 drought is often compared to the recent 2006-2008 drought, as many consider the preparation, response, coordination, and communication during the recent event far superior to the earlier drought. Most of the 2006-2008 impacts on CWS were in North and Northeast Georgia, where Lake Lanier dropped to a 90-day supply of water in 2007. The 'green industry’ (i.e. landscaping) was greatly impacted by the drought, and engaged in substantial lobbying efforts to limit water restrictions, whereas the golf course industry worked proactively with the state to implement best management practices. In 2008, Tropical Storm Fay helped start refilling reservoirs, and most of state has been drought-free since March 2009.

Water Management and Planning

The Georgia Department of Natural Resources (GDNR) oversees water quantity and quality issues across the state by establishing rules and managing regulatory activity. Within GDNR, the primary unit focused on water is the Environmental Protection Division (EPD). EPD regulates both public and private CWS. Surface water use requires a permit above 100,000 gal/day/month, based on the regulated riparian doctrine, and the same is true for groundwater use. There is no immediate connection between ground water and surface water rights. Minimum flows must be maintained for dam and reservoir operation, and regional councils will consider additional base-flow requirements, as outlined in the Georgia Statewide Water Management Plan (GSWP). Banking is only beginning to be considered (it is currently prohibited in the Floridian Aquifer), and transfers are generally only permitted when communities straddle watersheds/basins. Major water legislation includes the 2000 Flint River Drought Protection Act – maintains flows in the Flint River through a voluntary auction of agriculture permits during drought years – the 2001 Metropolitan North Georgia Water Planning District Act – established the Metropolitan North Georgia Water Planning District (MNGWPD) to create water policies and plans on a regional/intergovernmental basis (15 counties and 90+ cities) – the 2004 Georgia Comprehensive State-wide Water Resources Management Planning Act – formed a legislative/agency council to develop a state-wide comprehensive water management plan – and the 2008 Comprehensive Statewide Water Management Plan (HR 1022 and SR 701) – the GSWP is the product of the 2004 Act that guides future water development, conservation, and permitting decisions within the state and 11 regions (MNGWPD plus 10 others) along county lines; with an attempt to follow watershed/groundwater basin boundaries. The process requires each region to produce water development and conservation plans (WDCP), which EPD will integrate with the GSWP by 2011. WDCP will pull from a GSWP accompanying document, the Georgia Water Conservation Implementation Plan (GWCIP), which emerged in 2009 and identifies benchmarks for water conservation in seven sectors, including CWS.[37] In general, water has been abundant, inexpensive, and often considered a right in Georgia, with low CWS base rates and decreasing block rate structures a common occurrence. Conservation-oriented rate structures are a new practice, and many small systems do not have the resources to implement these structures. Use of effluent/reclaimed water is not common in Georgia, as it is generally considered to be cost-prohibitive. Finally a decades-long regional water conflict between Georgia, Alabama, and Florida has yet to be resolved.[38]

Monitoring, Early Warning, and Prediction

Water availability data benefit from a long running relationship between USGS and EPD, with an EPD employee located in the USGS Georgia office. Universities play a

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[37] The GWCIP was originally called for in Georgia's 2003 state drought plan, and reaffirmed in the GSWP; serving as a de facto link between the drought and water plans.

[38] The tri-state water conflict has been ongoing for two decades. While it might indirectly influence adaptive capacity in Georgia, I do not focus on the conflict itself in this research, but instead the state-level water legislation, policy, and approaches (which may or may not be indirectly influenced by the conflict).

role in gathering, synthesizing, and distributing information and studies, and water-related NGOs and partnerships are active in producing information on water policy, flow regimes, recharge, and drought tracking (e.g., Southeast River Forecast Center (SRFC)). Water use reporting for CWS is only required during drought events. Under the Georgia Drought Management Plan (GDMP), the EPD director, working with the State Climatologist Office, uses a host of indices (percent of normal, SPI, stream flow, soil, groundwater, and reservoir levels) on various timescales (1, 2, 3 12, and 24 months) to monitor and declare droughts in nine climate divisions. Once a trigger is hit, the State Climatologist Office facilitates the organization of the Drought Response Committee (DRC) to evaluate and make recommendations about response (according to four drought stages). It is easier to enter drought status than exit, making it a conservative planning methodology. The GDMP describes the indices and triggers as guidelines to be corroborated by what is occurring ‘on the ground’, having purportedly learned from South Carolina not to legislate or codify their indices and triggers. Even when under EPD rules and regulations in the future, the GDMP triggers will serve primarily as guidance.

Vulnerability/Risk Assessment

GDMP alludes to the need for the state, CWS, and other sectors to conduct future vulnerability assessments, but few if any have. Local drought planning and assessment is absent, but future requirements are possible, which would likely include risk/vulnerability assessment.

Mitigation and Response

The 1998-2002 droughts helped motivate the 2003 GDMP, which outlines preparation and response, and is scheduled for 5-year updates (although it has not been updated since its creation). GDNR (EPD) takes the lead in creating the DRC, and outlines the drought declaration process, agency organization, pre-drought strategies (state and local), responses (state and local), and indicators/triggers in nine climate divisions. The entire GDMP has not come under EPD rules and regulations (only the outdoor water use portion has), making implementation of mitigation measures difficult. Stringent pre-drought mitigation strategies at local levels will likely be required in the future under rules and regulations.[39] The GDMP also called for the GWCIP, which was ultimately produced in conjunction with the GSWP. It has yet to be determined how the GSWP will relate to the GDMP. Currently, the GSWP requires regional planning councils to estimate future water supplies and plan for shortages that exist 95 percent of the time, with the remaining 5 percent presumably covered by the GDMP. HB 1281 adopted in 2008 disallows CWS from exceeding state provisions in drought responses and pre-drought strategies, which was originally encouraged in the GDMP. Prohibiting stricter water curtailment measures than the state is reportedly a political decision to appease the 'green' industry (i.e., landscapers and turf companies). The 1981 Georgia Emergency Management Act includes drought as a hazard for which the Governor can declare a state of emergency and authorize state-level assistance and response. During the 2006-2008 drought, measures outlined in the GDMP were insufficient, resulting in the Governor ordering CWS to reduce water use by 10 percent from previous year levels through a 2007 emergency declaration. The Southeast Climate Consortium (SECC) does not have a very active role in drought planning and mitigation beyond the agricultural sector. Finally, there is no individual at the state-level devoted specifically to drought coordination/management.

Climate Change Information and Knowledge Use

There is some skepticism in the legislative and executive branches regarding the validity of climate change, and therefore, recent attempts to consider climate change (e.g., special high-level committees to examine the impacts of climate change on the water sector), have not materialized. Any climate change work in agencies is minimal and not advertised, but state officials are gradually beginning to develop an understanding of the impacts of climate change on water and drought planning, allowing them to use existing frameworks like the GSWP at a later date as climate change knowledge and expertise grows. The SECC focuses on drought, but mainly in the agricultural sector, and there is minimal university/extension support for water management and climate change. Many local managers in Georgia have yet to identify

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[39] Officially, Georgia requires water conservation and drought ordinances for CWS to obtain water withdrawal permits. However, these 'plans' are rarely produced by the CWS, or not enforced (often overridden) by the State. The limited number of CWS that were able to produce these documents for my research confirmed that these ordinances are essentially purposeless in their current form.

and understand 'the worst case scenario', further complicating future climate change planning.

South Carolina[40]

Physical-Social Characteristics and Drought Experience

Like Georgia, South Carolina receives substantial rainfall and has a history of climate variability. Conflicts with growth are less pronounced than in Georgia, as the development is not as concentrated in one region or basin. The North and West are highly dependent upon surface water (interstate basins) and reservoirs (federal and private), and areas south of the continental fall line are significantly dependent on groundwater. Groundwater pumping in the coastal plains raises concerns about subsidence and salt-water intrusion. South Carolina also experienced a drought from 1998-2002 when some CWS came close to running out of water. The 1998-2002 drought is often compared to the recent 2006-2008 drought. In both events, rains arrived in time to avoid emergency declarations. Interestingly, the earlier drought was managed much like a disaster, while the 2006-2008 drought was managed in a calmer, more focused manner. Collaboration increased during the recent drought, particularly in the Catawba-Wateree and Yadkin-Pee Dee basins, where strong relationships developed between various interest groups. The state worked closely with the Army Corps to plan earlier reservoir releases and develop low in-flow protocols with the Federal Energy Regulatory Commission (FERC) during hydropower facility relicensing.[41] Many initiatives that developed during the drought have continued, even after the drought period, and are beginning to extend beyond drought issues. Most of the 2006-2008 drought impacts on CWS were upstate and in western South Carolina. A wet 2009 led to all counties in South Carolina exiting drought status within the year.

Water Management and Planning

Major water-related agencies include the South Carolina Department of Health and Environmental Control (SCDHEC) – water regulatory agency in charge of

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[40] South Carolina information comes from personal communication with key informants, and the following sources and documents: (SCDHEC, 1986; Wright, 1998; SCDNR, 2000-2001, 2000-2001; Knutson and Hayes, 2001; Badr et al., 2004; SCDHEC, 2006; Mizzell, 2008; SCEMD, 2009).

[41] 'Low in-flow protocol' is a term specific to the FERC relicensing process, representing the procedures for reservoir operation during periods of low flow into the reservoir.

monitoring groundwater withdrawals – and the South Carolina Department of Natural Resources SCDNR – responsible for planning, policy, and technical support, with little regulatory authority. SCDHEC regulates both public and private CWS. Surface water follows the riparian doctrine, with no withdrawal permits required (water monitoring and reporting is required for large CWS dependent upon surface water). Groundwater use requires permits above three million gallons/month, based on regulated riparian doctrine, and the state is divided into three categories, from most to least stringent regulations; capacity use areas (coastal plain counties), notice of intent counties, and registration counties. There are is no immediate connection between ground water and surface water rights. Banking is not explicitly considered, but state committees have begun to suggest exploring the issue. Because surface water regulation is lacking, base-flows are only applied in federal operations, and transfers are allowed (above one million gal/day or 5 percent of 7Q10 flows requires a permit). The most significant water legislation is the 1967 Water Resources Planning and Coordination Act (amended in 1993), which created the State Water Commission (which in the amended Act was dismantled and responsibilities divided amongst SCDHEC and SCDNR). The 1993 amendments also required the production of the South Carolina State Water Plan (SCSWP) as a guiding document (first produced in 1998, with a follow up in 2004). Several Governors' Water Law Review Committees have also guided water management through executive order (often after serious droughts) over the past few decades to report on and make recommendations to the Governor, legislature, and agencies for changes and additions to state water policies. The most recent committee reported in 2004. Legislative efforts are underway to establish a regulated riparian surface water permitting system, and state officials are considering the reestablishment of a single agency to deal with water issues (like the earlier State Water Commission). In general, water has been abundant, relatively inexpensive, and often considered a right in South Carolina, with low CWS base rates and decreasing block rate structures a common occurrence (to recruit industry). Conservation-oriented rate structures are a new practice, and use of effluent/reclaimed water is not common in South Carolina, as it is too expensive and not readily explored. Finally, special purpose districts, under the purview of the state, are powerful entities that add a layer of complexity in coordinating and planning for water and growth.

Monitoring, Early Warning, and Prediction

Water availability and use data has occasional gaps and problems and is not readily and easily accessible, likely due to funding limitations within SCDNR (e.g., most of Federal activities require cost-sharing). Universities play a role in gathering, synthesizing, and distributing information and studies, and water-related NGOs and partnerships are active in producing information (e.g., Carolinas Integrated Sciences and Assessments (CISA)). Groundwater reporting is required for most CWS, and surface water use reporting is required for large systems. The 2000-2001 amendments of the 1985 Drought Response Act[42] codify drought triggers based on several indices (Palmer Index is the primary tool) for entering four drought levels (incipient, moderate, severe, and extreme). The amendments also establish a Drought Response Committee (DRC) at the state-level and four drought management areas (and corresponding DRCs) based on river basins to evaluate regional and local conditions and determine if SCDNR or Governor action is needed beyond local government and CWS efforts. CWS have system-specific triggers, as outlined in their drought plans/ordinances. SCDNR's Office of the State Climatologist serves as the Drought Information Center during droughts. After a trigger is hit, DRCs and personnel are mobilized and the relevant alert phase can be declared. Two consecutive periods of drought conditions are required to enter each phase, and there are no clear rules for exiting a drought.

Vulnerability/Risk Assessment

The 2000-2001 amendments of the 1985 Drought Response Act require CWS to have drought management plans and response ordinances. Plans must be consistent with the South Carolina Drought Response Plan (SCDRP). Neither the local plans nor the SCDRP outline vulnerability/risk assessments, but CWS plans require assessing system capabilities, agreements, alternative supplies, and pre-drought efforts. In addition to monitoring, CISA is working to characterize drought vulnerability.

Mitigation and Response

Most mitigation and response actions are outlined in the 2000-2001 amendments of the 1985 Drought Response Act. The Act and its subsequent regulations require

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[42] South Carolina was one of the first states with state-level drought legislation. For more information on the 1985 Drought Response Act and its amendments, see http://www.dnr.sc.gov/climate/sco/Drought/drought_regulations.php.

iterative planning and meeting through the DRCs (even during normal conditions). In addition to establishing DRCs and state triggers, it requires local drought plans and response ordinances, outlines conflict resolution/mediation measures, and gives the Governor the power to declare a state of drought emergency. The local plans/ordinances align CWS-specific triggers and responses with state-declared drought levels (up to a 30 percent reduction for extreme drought), giving significant drought management responsibilities to the local level. The flexibility in restrictions caused some tensions with neighboring states that had declared state-wide emergencies during the 2006-2008 drought (i.e., South Carolina was perceived by other states to not be wide-sweeping enough in its response measures). While enforcement and content of the local plans/ordinances is mixed, some CWS approached the state about curtailing water beyond what was called for in their plans and ordinances (and many revise and change them after droughts). Once severe or extreme alerts are declared, SCDNR, upon recommendation from the DRCs, can require mandatory reductions. There is no state-wide drought mitigation and management plan, but several plans have called for such future actions to increase preparedness. South Carolina has one of the oldest drought *response* initiatives in the U.S. In emergencies, the South Carolina Emergency Management Division (SCEMD) implements the SCDRP, also a part of the 1985 Drought Response Act. The SCDRP identifies state-level actions to provide relief from severe or extreme drought conditions that have reached a level of disaster beyond the scope of the CWS and DRCs, such as when communities are rationing water, or relocation is required. During the 2006-2008 drought, a state of emergency was not declared, as the corresponding drought responses at the local CWS-levels proved generally sufficient. Also, SCDNR and DRCs tried to ascertain that state drought declarations considered low in-flow protocols in Federally-managed basins (i.e., trying to make low-inflow protocols consistent with the severity of state drought alert declarations so as not to confuse the public). Finally, at one point South Carolina was the only state that had a full-time drought program coordinator/manager, but the position has since gone unstaffed.

Climate Change Information and Knowledge Use

There is some skepticism regarding the validity of climate change within governments and the general population, but the 2006-2008 droughts increased discussion regarding potential impacts. State agencies and the scientific community show a greater acceptance for considering climate change in management decisions, but officials do not readily advertise these efforts, given the generally negative sentiment surrounding the issue. Areas traditionally resistant to climate change planning (e.g., rural conservative areas) have shown signs of gradual acceptance and progress. CISA has an active role in producing climate change knowledge and tools, such as the drought assessment tool that is working to identify drought impacts and vulnerabilities.

Based on the data reported above, I identify the following contextual influences on state adaptive capacity in *Table 3.3*.

Table 3.3: Evaluation of state-level adaptive capacity to extreme droughts. Each state is assessed according to six categories that are integral to state-level drought planning and management. Each cell is divided between inhibitors to adaptive capacity (top of cell) and contributors to adaptive capacity (bottom of cell). The four shades represent increasingly positive contributions to adaptive capacity (darker signifies higher adaptive capacity).

	Arizona	**Georgia**	**South Carolina**
Physical-Social Characteristics and Drought Experience	~ Physical buffers exhausted through earlier agricultural transfers ~ Perceived public disincentive to conserve, and difficulty understanding drought ~ Long-tern repercussions from growth --- ~ Arid climate pushes CWS to innovate and develop robust/diverse water portfolios ~ Abundant groundwater supplies (but in 'planned decline')	~ Historically abundant/cheap water limits planning and innovation ~ Droughts are easily forgotten and hard to understand (e.g., landscape remain 'green') ~ Population areas are surface dependent, water scarce, and lack agricultural buffers ~ Water-intensive lobbies (e.g., landscapers and turf companies) ~ Long-term repercussions from growth ---~ 1998-2002 drought served as a wake-up call ~ Some water intensive industries have been proactive (e.g., golf courses)	~ Historically abundant/cheap water limits planning and innovation ~ Surface water dependence, and aquifers suffer from saltwater intrusion --- ~ Learned from 1998-2002 drought, which improved 2006-2008 actions ~ Collaborative attitudes and forums put in place from recent drought ~ Low inflow protocols implemented by FERC, and Army Corps altered releases ~ Growth less concentrated to one region/basin
Water Management and Planning	~ Limited authority of ADWR outside of AMAs ~ No statewide water management plan ~ Water staff and resources suffer from budget cuts (drought and CWS personnel) ~ Surface and groundwater not linked ~ Watershed partnerships mixed results; need time and political/leadership commitment --- ~ Adequate/assured supply and banking programs ~ Policy certainty with shortages results in more robust internal dependence ~ In-stream flow as beneficial use of water rights	~ Full potential of GSWP not realized (watershed, motive, and longevity concerns) ~ GWCIP lacks regulatory authority, with WDCP conservation measures likely to be voluntary ~ Unclear links between GSWP, WDCP, and GWCIP ~ Unresolved interstate/regional conflict ~ Little size distinction in regulating CWS --- ~ GSWP and MNGWPD provide a framework for iterative and integrated planning across water uses, sectors, and scales ~ GDNR regulates all public and private CWS ~ Agriculture transfer program in the Flint Basin ~ Many water supply techniques 'untapped'	~ Surface water not regulated, base-flows not recognized, and transfers allowed ~ No statewide water management plan beyond informal SCSWP ~ Regulatory and advisory roles segmented between SCDHEC and SCDNR ~ Special purpose districts add complexity --- ~ Private and public CWS treated similarly by SCDHEC ~ Many water supply techniques 'untapped' ~ Interstate conflicts being addressed

Monitoring	~LDIGs not a requirement and difficult to sustain -- ~ Statewide committee is continuous, iterative, and works with regional/local levels ~ Conservative drought monitoring methodology is flexible and iterative, and triggers associate with locally-defined responses ~ LDIGs help with local reporting and monitoring ~ Information is abundant and multi-sourced (e.g., CLIMAS plays a very active role)	~ Monitoring on state and regional levels by EPD and DRC, with little local nuance or interaction between scales ~ Coordinated monitoring lacks permanence ~ Triggers associate with regional responses and are not locally-specific ~ Water use reporting required for CWS only during drought -- ~ Conservative drought monitoring methodology is flexible and meant to guide declarations	~ Triggers are legislated, and are less flexibility and iterative ~ Coordinated monitoring lacks permanence ~ Water use/availability data gaps and sometimes inaccessible -- ~ Monitoring on state, regional, and local levels through SCDNR, DRCs and CWS ~ Drought monitoring and triggers align with Federal, regional, and local responses ~ CISA has an active role
Vulnerability/ Risk Assessment	~ LDIGs not mandatory, and not active in all areas ~ CWS local drought plans vary in detail/quality -- ~ Coordinated at various levels; state drought plan, LDIGs, and CWS drought plans ~ LDIGs flexibly assume various roles to fill needs	~ Lacks formal institutional/management organization at state, regional, and local levels -- ~ GDMP calls for, but does not follow through with vulnerability/risk assessments	~ SCDRP or regulations do not discuss vulnerability/risk assessment -- ~ Local CWS drought plans help implicitly through reviews of system capabilities, agreements, alternative supplies, and pre-drought efforts ~ CISA working to characterize vulnerability
Mitigation and Response	~ CWS drought planning is difficult to enforce, and most plans are responsive ~ Different responses for public and private CWS, and ADWR cannot force local restrictions ~ Coordination within and between CWS and LDIGs is minimal -- ~ 'Local/regional -> state approach'; Local plans followed first, with attempts to regionally coordinate, and the state as a back stop if all else fails ~ ASDPP includes multiple plans and three interactive committees that have persisted in 'wet years' and Governor turnover ~ 3-tiered CWS planning required for all CWS, including worst case scenario planning ~ Coordination between agencies and between state and local efforts ~ Active CLIMAS role, and ADWR staff devoted to drought and CWS ~ 2001-2005 drought, no state-wide emergency	~ 'State/regional -> local -> state approach'; State identifies regional drought levels, with local responses pre-determined by the state, and the state as back stop if all else fails ~ GDMP not iterative, comprehensive, or universally enforceable (to date) ~ 2008 HB 1281 counters GDMP allowance of stricter local measures ~ Drought stages and restrictions are difficult to enforce at the local level, because of insufficient staff ~ SECC plays a limited role, and no GDNR staff devoted to drought ~ 2006-2008 drought, GDMP was insufficient, requiring emergency declaration -- ~ GDMP cutting edge at the time, and informed Arizona's drought plan ~ GWCIP serves as de facto link between the GSWP and GDMP, but more formal link is needed ~ 2006-2008, CWS responded to emergency	~ Mitigation at state and regional levels lacking ~ Full time drought coordinator no longer exists (at the time it was the only one in the nation) ~ Perception problems with other states in not declaring emergencies -- ~ 'Local -> regional -> state approach'; Local ordinances followed first, with SCDNR forcing stronger restrictions at the recommendation of DRCs, and the Governor declaring emergencies if the previous actions fail ~ DRCs are iterative, and local plans/ordinances are adjustable and iterative ~ Consistency of drought levels at federal, state, and local levels ~ Local and regional efforts are iterative and collaborative, moving beyond drought issues ~ Conflict resolution measures outlined in Drought Response Act ~ Early leader in drought planning ~ 2006-2008 drought, no state-wide emergency, or

	declared	declaration with 15 percent reduction	drought management area restrictions required
Climate Information and Knowledge Use	~ Uncertain precipitation projections ~ Difficulty getting decision makers to use the information -- ~ 2001-2005 drought increased climate-related work, tools, and resources (including ways to increase information use) ~ Assume more variable and less water	~ Skepticism dominates legislature and executive branches ~ Worst case scenario difficult to comprehend -- ~ Avenues and iterative processes exist for including climate change in future plans	~ Skepticism in the general public, and state slow to consider climate change -- ~ Agencies and scientific community beginning to consider climate change planning, and previously resistant areas showing receptivity

4.2. CWS Analysis

For the first measurement of CWS adaptive capacity (see *Figure 3.2*), I examine the influence of AIM approaches on extreme drought impacts in each state (the inverse of impacts represents adaptive capacity). Because most of the five impacts questions show significant positive correlations within each state (*Table 3.4*),[43] I use factor analysis to reduce these dependent variables to one (Arizona and Georgia) or two (South Carolina) principal components.

Table 3.4: Pearson Correlations between dependent variables for the first adaptive capacity measurement. Associations are generally positive, except for the social/customer conflict measure for South Carolina. The negative relationship is bolded in red.

	Arizona					**Georgia**					**South Carolina**				
	WD	*E*	*WQ*	*BF*	*SC*	*WD*	*E*	*WQ*	*BF*	*SC*	*WD*	*E*	*WQ*	*BF*	*SC*
Water delivery (WD)	1	.60**	.63**	.55**	.27*	1	.50**	.48**	.50**	.35**	1	.52**	.68**	.77**	**-.04**
Ecosystems (E)	.60**	1	.32*	.29*	.39**	.50**	1	.40**	.45**	.26*	.52**	1	.25	.44**	.41*
Water quality (WQ)	.63**	.32*	1	.62**	.20	.48**	.40**	1	.41**	.34**	.68**	.25	1	.48**	.05
Budget/ finances (BF)	.55**	.29*	.62**	1	.38**	.50**	.45**	.41**	1	.61**	.77**	.44**	.48**	1	.18
Social/ customer conflict (SC)	.27*	.39**	.20	.38**	1	.35**	.26*	.34**	.61**	1	**-.04**	.41*	.05	.18	1

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

In South Carolina, the question regarding social/customer conflict shows less of a positive correlation with the other impacts questions, and actually demonstrates a slight negative correlation with the water deliveries question. As a result, South Carolina reduces to two principal components, and thus, two equations for the regressions. The principal components in Arizona and Georgia explain 52.7 percent, and 54.4 percent of the variance, respectively. In South Carolina, the first component captures 41.0 percent of the variance, and the second component explains 26.4 percent (with a cumulative total of 67.4 percent). *Table 3.5* shows the correlations of the five impacts questions with the principal components in each state, and *Appendix 5* reports the complete results from the factor analysis. The rotated component matrix reported under South Carolina in *Table 3.5*

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[43] Throughout the statistical portions of this dissertation, I assume a 0.10 significance as evidence for a marginal relationship and 0.05 or below as evidence for a much stronger relationship.

helps to illustrate the influence of the social/customer conflict measure on the components, and thus the different relationship between it and the other impacts measures.

Table 3.5: Contributions of the five 'impacts questions' to each of the principal components, as indicated by correlations with their respective components. Drought impacts were each measured on a scale from 1-6 (no impacts to severe impacts). The factor analysis identifies components with eigenvalues greater than 1.

Drought impacts	**Arizona**	**Georgia**	**South Carolina**	
	Component matrix	Component matrix	Rotated component matrix	
	Component 1	Component 1	Component 1	Component 2
Water delivery	.850	.785	.925	-.034
Ecosystems	.702	.678	.617	.598
Water quality	.748	.696	.461	.003
Budget/finances	.760	.829	.773	.210
Social/customer conflict	.532	.687	-.049	.959

Table 3.6 reports descriptive statistics on each of the principal components; mainly the range of impacts (negative to positive, indicative of fewer to greater impacts) and standard deviations. It is important to note that the impacts are standardized within each state, not between the states, so the ranges differ in *Table 3.6*.

Table 3.6: Number of CWS captured in the principal components analysis by state and the range of the resultant impacts measures. Minimums indicate least impact values and maximums indicate highest impact values. Values are standardized within, but not between states, with a mean = 0 and standard deviation = 1.

Principal component	*N*	*Minimum*	*Maximum*
Arizona – Combined drought impacts	54	-.99226	4.13777
Georgia – Combined drought impacts	87	-.98119	3.07780
South Carolina 1 – Combined drought impacts (minus social/customer conflict)	35	-.71553	3.04048
South Carolina 2 – Mainly social/customer conflict drought impacts	35	-.62565	3.87337

For the independent variables, I investigate the AIM approaches most associated with lower impacts (the principal component(s) depicted in *Tables 3.5* and *3.6*). In terms of number of AIM approaches implemented, there is a clear positive relationship between CWS size and number of approaches in all three states (see *Figure 3.4* and *Table 3.7*). It is noteworthy however, that Arizona shows an overall increase in AIM approaches implemented on average within systems post-drought, whereas Georgia and South Carolina show declines in AIM approaches implemented post-drought. In *Appendix 6*, I report the total sum and proportion of CWS implementing each AIM approach before/during and presently/in the immediate future within and between states. I also illustrate descriptive relationships between various CWS attributes and drought impacts in *Figure 3.5*, below.

Figure 3.4: Average number of AIM approaches implemented by system size within and between states. On average, CWS report less AIM approaches implemented post-drought or in the immediate future.

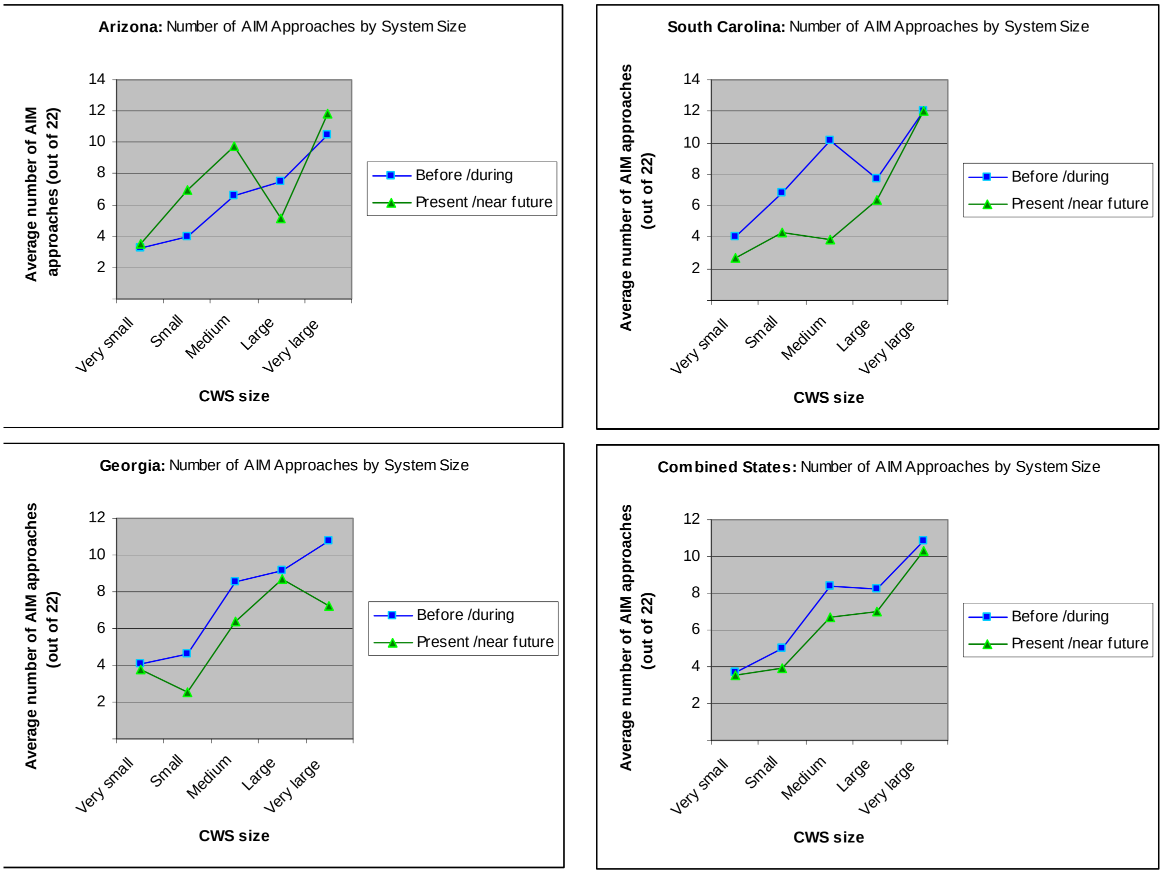

Table 3.7: Average number of AIM approaches implemented by CWS size surrounding the extreme drought event in each state; out of 22 approaches presented in the survey. Arizona shows average increases since the drought in all but ‘large’ systems, and Georgia and South Carolina show average decreases since the drought in all but ‘very large’ systems in South Carolina. Total CWS averages are bolded in red.

	Arizona		**Georgia**		**South Carolina**		**Combined states**	
	AIM approaches before/ during	AIM approaches present/ near future	AIM approaches before/ during	AIM approaches present/ near future	AIM approaches before/ during	AIM approaches present/ near future	AIM approaches before/ during	AIM approaches present/ near future
Very large	10.50	11.83	10.75	7.25	12.00	12.00	10.83	10.33
Large	7.50	5.13	9.15	8.69	7.75	6.33	8.24	6.97
Medium	6.57	9.71	8.56	6.38	10.17	3.83	8.41	6.66
Small	4.00	6.92	4.59	2.53	6.79	4.29	4.98	3.92
Very small	3.22	3.52	4.08	3.73	4.00	2.67	3.69	3.58
Total across all systems	**5.18**	**6.16**	**6.07**	**4.64**	**7.70**	**5.16**	**6.12**	**5.21**

The aggregate number of approaches implemented does not highlight which specific AIM approaches are more closely associated with fewer impacts from the drought and higher adaptive capacity. Given the modest sample size in each state and the large number of potential AIM variables (22), I consider each AIM approach and CWS attribute individually for the model fitting process. To do this, I select those AIM approaches (and control for system attributes) that most significantly correlate with the principal components (dependent variables) for each state. To control for ecological and environmental conditions (i.e., sensitivity), I automatically include ecoregions in the regressions, regardless of whether they are significantly correlated with the principal components. *Table 3.8* depicts the significance levels from the bivariate analysis of the dichotomous AIM approaches using independent samples T-tests for equality of means. The table also shows the significance levels from the bivariate analysis of the system attributes, which are not dichotomous variables, using one-way analysis of variance (ANOVA). The AIM approaches and system attributes in *Table 3.8* correspond with columns 3 and 4, respectively, in *Table 3.2*.

Figure 3.5: Relationships between key CWS system attributes and reported drought impacts (*see Table 3.6*). Note, the scales for the y-axes are not the same and the range of each state's principal component(s) varies slightly (*Table 3.6)*. Therefore, these between-state comparisons are relative, not absolute, and are displayed here to illustrate general trends between the states.

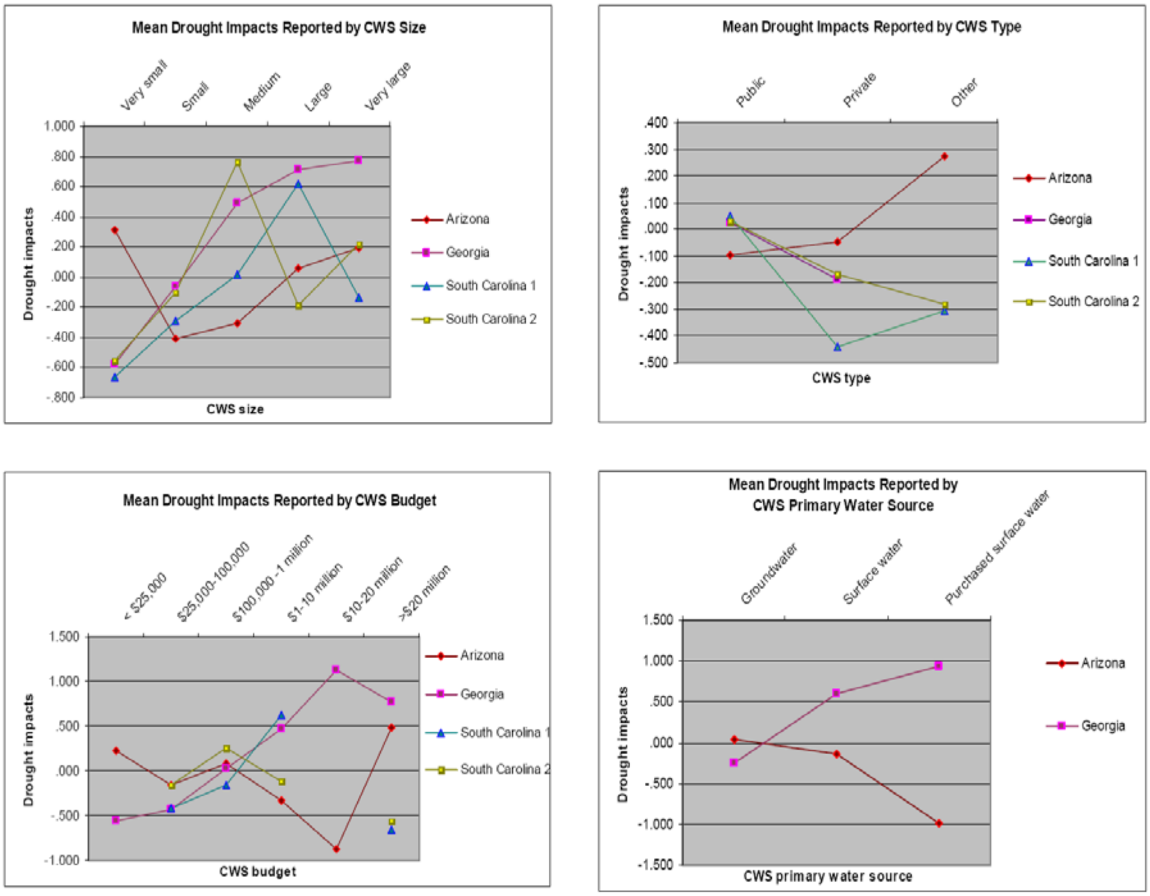

Table 3.8: Bivariate analysis to identify AIM approaches and system attributes significantly correlated with principal components in each state. The AIM approaches (dichotomous) use independent samples T-test for equality of means, and the system attributes (multi-category) use one-way ANOVA. Cells report the mean differences (T-test) or mean square between groups (ANOVA), and significance levels are in parentheses; red bolded cells indicate significance at or below 0.05, and black bolded cells indicate significance at or below 0.10.

AIM approaches implemented *before/during* the drought (corresponding with column 3 in *Table 3.2*, and question M1 in *Appendix 2*) and system attributes (corresponding with column 4 in *Table 3.2*)		**Arizona** Combined drought impacts	**Georgia** Combined drought impacts	**South Carolina 1** Combined drought impacts (minus social /customer conflict)	**South Carolina 2** Mainly social /customer conflict drought impacts
AIM approaches	*1 before/during*	.242 (.49)	.365 (.19)	.007 (.98)	.336 (.33)
	2 before/during	**.696 (.04)**	**1.17 (.00)**	.559 (.11)	-.012 (.97)
	3 before/during	-.161 (.60)	**.729 (.00)**	.436 (.21)	.243 (.48)
	4 before/during	.053 (.86)	**.563 (.01)**	.437 (.22)	**.628 (.03)**
	5 before/during	.957 (.44)	**.618 (.04)**	.074 (.88)	.217 (.66)
	6 before/during	.448 (.18)	.395 (.12)	-.430 (.12)	**.651 (.07)**
	7 before/during	.534 (.17)	.143 (.55)	**.717 (.02)**	**.579 (.06)**
	8 before/during	.364 (.30)	**.511 (.05)**	**.664 (.05)**	**.682 (.05)**
	9 before/during	.029 (.96)	**.807 (.06)**	**1.10 (.09)**	.484 (.26)
	10 before/during	**1.04 (.02)**	**1.06 (.00)**	**.869 (.10)**	.304 (.44)
	11 before/during	.227 (.50)	**.745 (.00)**	**1.03 (.07)**	.217 (.60)
	12 before/during	.418 (.19)	**.603 (.08)**	-.058 (.91)	.149 (.76)
	13 before/during	.228 (.41)	**.452 (.07)**	1.14 (.17)	.539 (.24)
	14 before/during	**.709 (.02)**	**.783 (.00)**	**.450 (.09)**	.330 (.42)
	15 before/during	.254 (.41)	**.672 (.00)**	-.329 (.39)	**.680 (.07)**
	16 before/during	**.652 (.06)**	**.513 (.04)**	-.342 (.25)	.133 (.71)
	17 before/during	- .051 (.92)	.055 (.91)	N/A	N/A
	18 before/during	- .159 (.72)	.511 (.49)	.026 (.97)	.701 (.34)
	19 before/during	**.749 (.09)**	.578 (.13)	.104 (.89)	.837 (.26)
	20 before/during	.102 (.72)	**.867 (.00)**	**.773 (.00)**	.644 (.19)
	21 before/during	**.814 (.09)**	**1.29 (.00)**	**.529 (.10)**	.366 (.29)
	22 before/during	-.127 (.69)	.387 (.11)	**.642 (.09)**	-.034 (.92)
System attributes	*System type*	.203[a] (.818)	.294 (.60)	.326 (.73)	.119 (.89)
	Budget	.843 (.49)	**8.91[a] (.00)**	**2.32 (.06)**	.517 (.69)
	Ecoregion	2.03[a] (.16)	**3.18 (.01)**	1.55 (.20)	1.01[a] (.47)
	Population group	1.78[a] (.18)	**13.07[a] (.00)**	1.59 (.17)	1.26 (.29)
	Primary source	.576 (.57)	**5.62 (.00)**	N/A	N/A

[a] Levene's test for homogeneity of variances indicated unequal variances. Here, I use Welch's test to determine equality of means with unequal variances between groups. In these cases I report Welch’s test statistic and its significance level, instead of the mean square from the one-way ANOVA.

Before fitting the regression models, however, it is important to ascertain that the significant AIM approaches in each state are independent from one another. To do this, I run a collinearity test, which illustrates that the AIM approaches selected for the regression model fitting are in fact not highly collinear with one another. *Table 3.9* describes the AIM approaches included in the regression models (those at or below a significance level of 0.05; as identified by the red values in *Table 3.8*) and the largest condition index for each state.[44] It also reports the system attributes included in the regression models (ecoregions and those attributes at or below a significance level of 0.05). The complete collinearity statistics are reported in *Appendix 7*.

Table 3.9: Summary of terms included in the regression models for each state. The terms are identified at or below the 0.05 significance level in *Table 3.8*. The AIM approaches also include the largest condition index, based on the variables at or below 0.10 in *Table 3.8*, to illustrate that they are not highly collinear with one another.

State principal components (dependent variables)	*Predictors (independent variables)*		
	AIM approaches		*System attributes*
	Approach	*Largest condition index*	
Arizona – Combined drought impacts	2, 10, 14	4.60	Ecoregion
Georgia – Combined drought impacts	2, 3, 4, 5, 8, 10, 11, 14, 15, 16, 20, 21	8.16	Ecoregion, budget, population group, primary source
South Carolina 1 – Combined drought impacts (minus social/customer conflict)	7, 8, 20	6.23	Ecoregion
South Carolina 2 – Mainly social/customer conflict drought impacts	4, 8	5.06	Ecoregion

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[44] A condition index below 30 (preferably below 15) generally indicates that the terms are not highly collinear with one another (Faraway, 2005).

Table 3.10: Regression model results. Column ‘B’ shows the magnitude and direction of influence. Significance is bolded in red for 0.05 or less, black for 0.10 or less, and bolded italics for 0.20 or less. Observed power is reported in the final column. R squared, adjusted R squared and N values are reported at the bottom of the table. The last variable in a system attributes category (e.g., ecoregions) is the reference variable (e.g., in Arizona, ecoregions 1-3 are compared to ecoregion 4)

	Predictor	*B*	*Standard error*	*Significance*	*Observed power*[a]
Arizona[c]	Intercept	.367	.388	.349	.152
	Approach 2	.464	.347	***.189***	.257
	Approach 10	.604	.470	.206	.241
	Approach 14	.262	.329	.432	.121
	Ecoregion 1	-.281	.449	.536	.094
	Ecoregion 2	-.859	.423	**.049**	.510
	Ecoregion 3	-.652	.528	.224	.226
	Ecoregion 4	0[b]			
Georgia[d]	Intercept	-1.184	1.104	.289	.182
	Approach 2	-.159	.467	.735	.063
	Approach 3	-.007	.328	.982	.050
	Approach 4	.134	.223	.553	.090
	Approach 5	.226	.349	.521	.097
	Approach 8	-.350	.353	.327	.163
	Approach 10	.764	.376	**.048**	.511
	Approach 11	.040	.251	.874	.053
	Approach 14	.112	.258	.666	.071
	Approach 15	.129	.266	.630	.076
	Approach 16	-.161	.356	.653	.073
	Approach 20	.255	.241	.294	.180
	Approach 21	.933	.343	**.009**	.757
	Budget - <$25,000	-.456	.803	.573	.086
	Budget - $25,000-100,000	-.401	.717	.579	.085
	Budget - 3 $100,000 -1 million	-.541	.773	.488	.105
	Budget - $1-10 million	.194	.686	.778	.059
	Budget - $10-20 million	.227	.705	.749	.061
	Budget - >$20 million	0[b]			
	Ecoregion 2	2.458	.886	**.008**	.774
	Ecoregion 3	.723	.632	.259	.201
	Ecoregion 4	.207	.690	.766	.060
	Ecoregion 5	.659	.734	.374	.142
	Ecoregion 6	.056	.741	.940	.051
	Ecoregion 7	0[b]			
	Size - Very large	.759	.832	.366	.145
	Size - Large	.574	.592	.338	.158
	Size - medium	-.171	.661	.797	.057
	Size -small	.331	.331	.321	.165
	Size - Very small	0[b]			
	Primary source - Groundwater under direct influence of surface water	1.200	.983	.228	.223
	Primary source - Groundwater	.222	.475	.642	.074

	Primary source - Surface water	-.014	.436	.974	.050
	Primary source - Purchased surface water	0[b]			
South Carolina 1[e]	Intercept	-.916	.528	.094	.388
	Approach 7	.218	.420	.608	.079
	Approach 8	.467	.383	.232	.218
	Approach 20	.461	.485	.349	.151
	Ecoregion 2	-.120	.756	.875	.053
	Ecoregion 3	.639	.435	***.153***	.295
	Ecoregion 4	-.020	.410	.961	.050
	Ecoregion 5	0[b]			
South Carolina 2[f]	Intercept	-.852	.364	.026	.618
	Approach 4	.411	.326	.218	.230
	Approach 8	.619	.317	**.060**	.473
	Ecoregion 2	.538	.706	.452	.114
	Ecoregion 3	.836	.397	**.044**	.530
	Ecoregion 4	.069	.386	.860	.053
	Ecoregion 5	0[b]			

[a] Computed using alpha = 0.05
[b] This parameter is set to zero because it is redundant.
[c] R Squared = 0.273 (Adjusted R Squared = .172), N = 50
[d] R Squared = 0.675 (Adjusted R Squared = .460), N = 74
[e] R Squared = 0.270 (Adjusted R Squared = .114), N = 35
[f] R Squared = 0.318 (Adjusted R Squared = .201), N = 35

Interestingly, there appears to be relatively few significant relationships between AIM approaches and impacts/adaptive capacity. In *Table 3.10*, a negative sign associated with the values in column 'B', would indicate that having that approach or attribute is related to fewer impacts (and thus is indicative of higher adaptive capacity), and a positive number would indicate the presence of that approach or attribute is related to more impacts (and thus lower adaptive capacity). In all four regression models, however, there is a mix of negative and positive signals, with most of the statistically significant relationships occurring in the opposite direction than expected, that is, there is a 'significant' association between several of the AIM approaches and greater impacts, or lower adaptive capacity. For example, in Arizona, adaptive capacity shows a negative relationship with approach 2 (coordination and planning water supply decisions with other CWS),[45] and a positive relationship with ecoregion 2 compared to ecoregion 4 (i.e., ecoregion 2 – central/western Arizona, including the metro Phoenix and Tucson regions – has a significantly lower impacts mean than ecoregion 4 – southeastern Arizona). However, the overall test for ecoregion, significance level of 0.14, is not significant

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[45] This relationship is only significant at the 0.18 significance level. All other significant relationships identified here are at the below the 0.10 significance level.

below the 0.10 level (not shown in *Table 3.10*). In Georgia, adaptive capacity shows negative relationships with approaches 10 and 21 (medium and long-term information use, and drought impacts monitoring, evaluation, and reporting), and a negative relationship with ecoregion 2 compared to ecoregion 7 (i.e., ecoregion 2 – extreme northeast Georgia – has a significantly higher impacts mean than ecoregion 7 – extreme northwest Georgia). The overall test for ecoregion (not shown in *Table 3.10*), significance level of 0.01, indicates that it is a significant variable. The second regression model in South Carolina, representing social/customer conflict, shows a negative relationship between adaptive capacity and approach 8 (information from multiple agencies/groups), and a negative relationship with ecoregion 3 compared to ecoregion 5 (i.e., ecoregion 3 – northwest South Carolina – has a significantly higher impacts mean than ecoregion 5 – the coastal plains). However, the overall test for ecoregion, significance level of 0.16, is not significant below the 0.10 level (not shown in *Table 3.10*). The first regression model, representing the remaining drought impacts, shows only a slight negative relationship between adaptive capacity and ecoregion 3 compared to ecoregion 2 (i.e., ecoregion 3 – northwest South Carolina – has a slightly higher impacts mean than ecoregion 2 – extreme north South Carolina). However, the overall test for ecoregion, significance level of 0.38, is not significant below the 0.10 level (not shown in *Table 3.10*). I interpret these finding in the discussion section, below.

As noted earlier, the inclusion of drought impacts in the cluster analysis (the characterization exercise) helps to inform the adaptive capacity measurement process. I present the cluster analysis results in detail below, but it is important to note that the more adaptable clusters tend to contain the larger CWS. Moreover, while these systems exhibit adaptable characteristics, they also tend to be the systems that report higher drought impacts, or lower adaptive capacity as measured by the first step in the assessment process. These seemingly contradictory results have methodological implications, which I revisit in detail in the discussion section.

The lack of clear associations between AIM approaches and fewer impacts (i.e., adaptive capacity) requires a slight alteration of the characterization/cluster analysis. I capture the ‘learning’ and ‘flexibility’ component of adaptive capacity by calculating the difference between the number of AIM approaches implemented leading up to and during the drought and the number of AIM approaches in place presently or in the immediate future in each CWS. To accomplish this, I categorize CWS by the aggregate number of AIM approaches between the two points in time as increasing, decreasing, or remaining constant. Combined with the other measures for the cluster analysis (proactiveness, mobilization, flexibility, etc.), I provide a more nuanced characterization of what constitutes adaptive types of CWS in each state. Also, because CWS size appears as an important system attribute in the descriptive statistics (i.e., with respect to the aggregate number of AIM approaches implemented), I include it as a grouping variable in the cluster analysis. The cluster analysis is a statistical exploratory tool that uses commonalities between cases' variables to identify unique clusters (clusters of CWS in this research). In each state, the cluster analysis results in two optimal clusters of adaptive CWS types, with 44, 75, and 34 CWS analyzed in Arizona, Georgia, and South Carolina, respectively. The results from the two-step cluster analysis are shown in *Table 3.11*.

In Arizona, in comparison to Cluster 2 (A2), Cluster 1 (A1) has fewer impacts, less mobilizing and changing, a slightly greater percentage of CWS with more AIM approaches post-drought, and tends to have smaller CWS. Like Arizona, Georgia's Cluster 1 (G1) has fewer impacts, less mobilizing and changing, and tends to have smaller CWS than its Cluster 2 (G2). However, unlike Arizona, G1 shows a lower percentage of CWS with more AIM approaches post-drought. South Carolina is slightly different than Arizona and Georgia in that its drought impacts are separated into two principal components (see *Tables 3.5* and *3.6*). Cluster 1 (S1) has less social/customer conflict (principal component 2) than Cluster 2 (S2), but the reverse is implied for the other drought impacts (principal component 1). S1 shows greater mobilizing and changing, no CWS with fewer AIM approaches post-drought, and has the two very large systems in the South Carolina sample. Again, across all three states the cluster analysis reveals that the larger systems tend to report behavior indicative of higher adaptive capacity, but these same systems also tend to report higher drought impacts. These very interesting patterns of adaptive types, combined with the regression results and the state-level analysis, are discussed in greater detail in the next section.

Table 3.11: Characterizing adaptive capacity using a two-step cluster analysis. Each state results in two optimal and distinctive clusters with respect to drought impacts, mobilizing and changing in relation to the drought, adaptations and changes of AIM approaches post-drought, and CWS size. Continuous variables are reported by each cluster's mean (centroid) and standard deviation for that variable, and categorical variables are reported by each cluster's frequency (number of CWS) and percent of total for that variable.

Cluster profiles			**Arizona**		**Georgia**		**South Carolina**	
			Cluster 1 (A1)	**Cluster 2 (A2)**	**Cluster 1 (G1)**	**Cluster 2 (G2)**	**Cluster 1 (S1)**	**Cluster 2 (S2)**
Drought impacts centroids	*Principal component 1*	Mean	-0.23	0.40	-0.65	0.70	1.21	-0.35
		Standard deviation	0.71	1.12	0.38	1.05	1.22	0.57
	Principal component 2	Mean	N/A	N/A	N/A	N/A	-0.04	0.03
		Standard deviation	N/A	N/A	N/A	N/A	0.51	1.13
Mobilizing and changing in preparation for and response to the drought centroids	*Extent of changing normal management approaches or practices*	Mean	1.46	3.61	1.46	3.42	2.75	1.73
		Standard deviation	0.91	1.85	0.87	1.46	1.28	1.04
	Extent of moving towards more supply management oriented approaches	Mean	1.46	3.78	1.22	3.26	3.63	1.35
		Standard deviation	0.76	1.59	0.53	1.45	1.06	0.63
	Extent of moving towards more demand management oriented approaches	Mean	1.62	3.89	1.22	3.16	3.87	1.38
		Standard deviation	0.98	1.61	0.53	1.42	0.64	0.70
AIM approaches frequencies: direction of change post-drought	*-1 (net decrease)*	Frequency	5	5	17	20	0	20
		Percent	50.0%	50.0%	45.9%	54.1%	0.0%	100.0%
	0 (no net change)	Frequency	8	4	15	7	6	4
		Percent	66.7%	33.3%	68.2%	31.8%	60.0%	40.0%
	1 (net increase)	Frequency	13	9	5	11	2	2
		Percent	59.1%	40.9%	31.3%	68.8%	50.0%	50.00%
Population group frequencies	*Very large*	Frequency	2	3	0	3	2	0
		Percent	40.0%	60.0%	0.0%	100.0%	100.0%	0.0%
	Large	Frequency	3	4	0	10	3	7
		Percent	42.9%	57.1%	0.0%	100.0%	30.0%	70.0%
	Medium	Frequency	0	7	0	13	1	5
		Percent	0.0%	100.0%	0.0%	100.0%	16.7%	83.3%
	Small	Frequency	7	3	20	10	2	11
		Percent	70.0%	30.0%	66.7%	33.3%	15.4%	84.6%
	Very small	Frequency	14	1	17	2	0	3
		Percent	93.3%	6.7%	89.5%	10.5%	0.00%	100.0%

To augment the state-level qualitative telephone interview data, I also show the levels of perceived barriers in each state from the survey by CWS size, as compared to reported drought impacts measured by the principal component(s) in each state (*Table 3.12*). Noteworthy in *Table 3.12* is that on average, CWS surveyed in Arizona perceive more barriers than Georgia and South Carolina, except for regulatory barriers (where

Georgia reports slightly more). CWS in South Carolina perceive the least barriers across the three categories. Also, all three states report financial/capital barriers as the most prevalent, followed by regulatory/legal, and then information/technical. Another interesting relationship depicted in the table is that in Arizona there is both a general increase in impacts and perceived barriers as system size increases (with a slight dip in impacts reported in large CWS). A similar relationship is depicted in South Carolina, except that reported impacts decrease considerably with the very large systems. In Georgia, the same trend is also prevalent, with a similar outlier as South Carolina with very large systems (except the relationship is opposite; drought impacts are highest, but there is a decrease in perceived barriers).

Table 3.12: Perceived barriers to changing management operation and drought impacts reported by state and CWS. Barriers are reported as mean levels on a scale from 1-6 (none to a lot), and drought impacts are represented by the mean of the principal components illustrated in *Table 3.5*. The scales of the drought impacts are uniquely standardized within each state, not between states, and thus not directly comparable across states. Total averages are bolded in red.

	CWS size	*Regulatory / Legal barriers*	*Financial / Capital barriers*	*Information / Technical barriers*	*Combined barriers by CWS size*	*Drought impacts 1*	*Drought impacts 2*
Arizona	Very large	2.83	5	2	3.28	.195	
	Large	1.86	4.14	1.86	2.62	.062	
	Medium	3	4.57	2	3.19	-.309	
	Small	2.29	3.87	2.29	2.82	-.413	
	Very small	2.3	3.57	1.91	2.59	.311	
	Total average	**2.39**	**3.98**	**2.02**	**2.80**		
Georgia	Very large	1.75	1.75	1	1.50	.774	
	Large	3.62	3.75	1.58	2.98	.709	
	Medium	2.6	3.73	2.13	2.82	.488	
	Small	2.71	3.21	2.06	2.66	-.065	
	Very small	1.39	3	1.35	1.91	-.581	
	Total average	**2.43**	**3.24**	**1.77**	**2.48**		
South Carolina	Very large	1.5	3.5	1.5	2.17	-.141	.219
	Large	2	2.58	1.42	2.00	.621	-.189
	Medium	1.75	2.25	1.25	1.75	.013	.764
	Small	1.29	2.77	1.57	1.88	-.287	-.105
	Very small	1	2.67	1	1.56	-.663	-.552
	Total average	**1.59**	**2.68**	**1.44**	**1.90**		

5. Discussion

5.1. Understanding and Increasing Adaptive Capacity

The goals of chapter are to assess adaptive capacity to extreme droughts at several scales and offer empirical evidence for the governance and management approaches that affect such capacity. I also seek methodological improvements to adaptive capacity assessments. In this section, I synthesize the key findings and policy lessons learned for improving adaptive capacity within each state, and then conclude by discussing the broader methodological and theoretical implications of this research.

Table 3.13 summarizes the major factors contributing to adaptive capacity to extreme drought across all three states (a synthesis of *Table 3.3* and section 4.1 of this chapter), as gathered from the telephone interview and archival data.

Table 3.13: Major factors influencing adaptive capacity to extreme droughts in Arizona, Georgia, and South Carolina. This synthesis is derived from the telephone interviews and archival research, as reported in *Table 3.3* and section 4.1.

Drought Planning and Management Categories	**Major factors inhibiting adaptive capacity**	**Major factors contributing to adaptive capacity**
Physical-Social Characteristics and Drought Experience	Buffers (e.g., agricultural) exhausted; growth limits supply and/or 'hardens demand'; public perception issues around drought and water supply decrease incentives to conserve	Dry climate and/or a specific drought serves as an impetus for innovation or as a wake-up call (e.g., increased supply diversity or conservation measures)
Water Management and Planning	State agency authority over water resources insufficient or segmented; comprehensive statewide water management plan/planning lacking and/or not clearly linked to drought preparedness	Iterative and integrated management framework in operation; water conflicts are successfully negotiated; clear plan to address future water shortages; surface and groundwater regulated
Monitoring	Permanence of monitoring lacking; local nuances not incorporated; drought triggers/indices legislated, water information insufficient	Flexible and iterative triggers/indices; continuous integrated and multi-level monitoring (state, regional, and local); drought declarations are 'conservative'; abundant and innovative methods for supplying information and monitoring drought
Vulnerability/ Risk Assessment	Not mandatory and/or inadequate when conducted	Performed at various scales, particularly the local-level; RISAs active in helping characterize vulnerability
Mitigation and Response	Local drought planning lacking and/or difficult to enforce; sparse mitigation at state and regional scales; state determines response efforts and/or policies restrict local actions; insufficient drought planning and management staff	Handled first at the local-level, coordinated regionally, and state-level serves as line of last defense; iterative state-level planning and continuous support; comprehensive drought preparedness plan; RISA plays an active role
Climate Information and Knowledge Use	State officials and/or public skeptical about climate change; knowledge of impacts difficult to translate into decision-making	Recent drought(s) increased interest and use; individual officials and communities showing sings of receptivity for pilot projects

The multiple in-depth interviews and archival sources allow me to attribute a fairly high degree of confidence with respect to the findings associated with the qualitative data. Next, I use these qualitative data (summarized in *Table 3.3* by state and synthesized in

Table 3.13 across states) to discuss factors affecting adaptive capacity in each of the three states and touch on the major themes that are evident across Arizona, Georgia, and South Carolina.

Arizona’s arid climate and geography have had positive and negative impacts on its overall adaptive capacity to extreme droughts. These factors have forced the state to pursue an aggressive agenda on drought, and have encouraged CWS to innovate in ways that far exceed Georgia and South Carolina (e.g., effluent reuse, conservation-oriented rate structures, etc.). However, combined with the pressures from growth, CWS in Arizona have little physical flexibility to obtain additional water sustainably by transferring between regions and agricultural permit holders. Despite Georgia’s relatively abundant water supply, it faces similar physical constraints to adapting as Arizona. Many CWS in the Atlanta metropolitan region are threatened by a lawsuit that could take away their major water source, Lake Lanier, and groundwater supplies and transfers of agriculture rights that could help augment supply are located hundreds of miles away to the south. Hypothetically, officials could loosen laws to accommodate additional infrastructure and transfers, but experts identified serious political tensions between the North and South and ecological concerns that would make any such decisions unlikely and unsustainable. South Carolina appears to face less physical constraints to adapting than Georgia, but salt water intrusion threatens coastal groundwater for long-term supply and drought buffers. The collaborative forums and initiatives that have developed in South Carolina during the drought bodes well for adaptive capacity, and the indication that the state is taking advantage of the opportunity presented by the FERC relicensing to implement low-inflow protocols illustrates the state’s adaptive capacity; making sustainable drought responses more likely in the future.

More generally across Arizona and Georgia (and to a lesser extent, South Carolina), experts suggest that perception greatly influences overall adaptive capacity to extreme droughts. Arizona’s robustly engineered solutions that bring surface water to the metropolitan regions have actually provided inhabitants with a false sense of security, and often decrease motivation for customers to conserve water. Water systems serving rural areas, on the other hand, lack the resources to adapt, but often possess important experiential understanding of drought impacts. Furthermore, the growing opposition toward emigration (from other states into Arizona) has fostered an anti-conservation attitude amongst some urban Arizonans, for they fear that conservation would catalyze further population growth (i.e., hardening of water demand). A similar cognitive disconnect tied to the public's historical relationship with water exists in Georgia. Here though, drought is difficult to understand because much of the foliage remains green during a drought, and thus there is often a lag in public understanding around the seriousness of the issue. These findings indicate that adaptive capacity can suffer from misalignment of the general public's perceptions and understanding about drought and water supply. Therefore, to increase overall adaptive capacity to extreme droughts, it is important to engage the public to not only instill a conservation ethic, but also to more accurately align their perceptions with the realities of how water is supplied and drought is manifested in each state.

Another interesting finding from the telephone interviews is that experts in Georgia and South Carolina suggest that CWS and state officials learned from a drought that preceded the one studied in this research (1998-2002) and applied the lessons from this experience to the recent drought. Learning and adapting between these two specific events in Georgia and South Carolina was not directly measured in the CWSS, but the survey found that the tendency to learn and adapt from the *recent* drought event appears to be more pronounced in Arizona than in Georgia and South Carolina. Only in Arizona did the number of AIM approaches generally increase in implementation throughout CWS post-drought. This suggests that even though experts perceive Georgia and South Carolina as having learned from previous events, CWS in these states can further benefit from understanding what makes CWS more adaptive in the Arizona case. One should interpret this finding cautiously however, as more time has elapsed since the Arizona event and thus CWS have had more time to adapt and learn.

Turning to water planning and management, adaptive capacity has greatly increased within Georgia in recent years, particularly through the GSWP and MNGWPD institutional structures. Despite some experts describing several missed opportunities and drawbacks with these initiatives, there is a general sentiment that these frameworks improve adaptive capacity to extreme droughts by making long-term planning more integrated, comprehensive, and iterative. Also, the regional planning approach allows for more flexibility and better alignment with local CWS needs. Several issues have yet to be resolved, such as if officials will link the water planning process with drought planning, whether CWS conservation efforts will be mandatory, and if regional councils will persist after each WDCP is submitted. The extent to which the answers to these outstanding issues is 'yes' will greatly improve overall adaptive capacity. Therefore, to increase adaptive capacity, officials in Georgia might consider maintaining an iterative regional water governance structure (beyond just the WDCP process) that links with GDNR. The structure could also serve as the organizing unit for regional drought planning and management; providing both a regional drought response committee and facilitating local drought planning within the region through ordinances and conservation plans that are actually enforced.[46]

South Carolina's water planning and management shows significant gaps in approaches that could increase adaptive capacity. Experts highlight the persistence of the riparian doctrine for surface water and the absence of a comprehensive water plan as decreasing adaptive capacity throughout the state. These two factors illustrate that the state has not adequately confronted or planned for long-term water stress, and that the piecemeal approach provides less assurance and understanding of future water availability. To ensure that adaptive capacity is not unevenly skewed toward upstream CWS in South Carolina, officials might implement more comprehensive water planning approaches, such as passing regulated riparian legislation, or embarking on a statewide water planning process like Georgia. Fortunately for South Carolina, drought planning and management at the local level has helped provide some clarity during extreme

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[46] In early May, 2010, Georgia passed SB 370, the Georgia Water Stewardship Act of 2010. The bill requires GDNR and its sub-agencies to examine and revise internal policies by August 2010 to help create a culture of water conservation throughout the state. While it lends state technical assistance and 'encouragement' to CWS to implement best management practices (which include the development of an infrastructure leakage index, water-loss detection programs, and the categorization of CWS by geographical size and service population), the legislation does not noticeably improve upon and enforce CWS conservation and drought planning, as it continues to rely mainly on voluntary conservation measures. Exceptions include more permanent statewide outdoor water restrictions between 10 a.m. and 4 p.m., as well as a measure that requires all CWS to have conducted a water-loss audit by 2013. Also, SB 370 maintains language that makes it difficult for CWS to implement more stringent water restrictions than the State. However, the legislation allows CWS to file for variances in non-drought periods (in addition to drought periods, as was originally the case prior to SB 370). To view the legislation's text, please see http://www.legis.state.ga.us/legis/2009_10/fulltext/sb370.htm.

droughts, replacing part of the capacity lost through insufficient water planning and management.

Water planning and management in Arizona is designed to maximize use of a limited supply of water, and thus managers and officials incrementally build adaptive capacity with each innovation and advancement in supply and demand approaches. Whether that water will ultimately be available, however, is a different issue altogether. Groundwater legislation within the AMAs, water banking, and regional shortage agreements have improved adaptive capacity through monitoring and preservation of scarce resources and encouraging more redundancy within and between CWS. The limited influence of ADWR and lack of water regulations in rapidly growing ‘rural’ areas outside of the AMAs, are diminishing other gains in adaptive capacity. And although officials prioritize drought planning and management, the state lacks a comprehensive water management planning process like Georgia. Therefore, further linking water to growth in Arizona (either through expanded authority of ADWR outside AMAs or more directly providing local authorities the power to enforce adequate supply legislation) and embarking on a statewide water planning process would likely improve overall adaptive capacity to extreme droughts.[47]

Next, the implications of drought preparedness and climate information on adaptive capacity in each state are perhaps even more important to consider, as they show distinctive differences, but also striking similarities between states. One of the national drought experts I interviewed described state drought preparedness as a horserace; “One comes to the front, others model their approach, build off of it, and then take the lead.” While the only direct borrowing from another state reported in the interviews was Georgia’s drought plan influencing Arizona’s drought preparedness plan, the states likely learned from one another (and other states) in developing their drought preparedness approaches. This implies that there is potential for more formal cross-state interactions and collaborations to accelerate learning.

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[47] There have been recent efforts to improve long-term statewide water planning through the Governor’s Blue Ribbon Panel on Water Sustainability (e.g., see http://www.azwater.gov/AzDWR/waterManagement/BlueRibbonPanel.htm). However, the longevity and permanence of the resulting process and product are highly uncertain, given severe budget and staff cuts affecting ADWR in 2010. These cuts also threaten key programs and processes, such as AMA offices, drought planning initiatives, etc. that have contributed greatly to increasing adaptive capacity.

To extend the horserace analogy to the influence of drought preparedness measures and climate information and knowledge use on adaptive capacity, Arizona has likely taken the lead, followed by South Carolina and then Georgia (again, summarized in *Table 3.3*). There are several elements of Arizona's approach that contribute considerably to high adaptive capacity. For one, there is a strong and clear state role that provides a consistent and comprehensive drought plan and management structure (iterative and interactive statewide committees), the backstop for state drought emergency declaration and coordination if necessary, and multiple scales and avenues for high quality information, monitoring, predicting (including a very active Regional Integrated Sciences and Assessments (RISA) – CLIMAS). The state continually reshapes and improves upon the drought triggers, and works with regions to refine and apply the triggers to local circumstances. Moreover, mitigation and response are handled initially at the local CWS-level (with ongoing technical and planning support by the state), and avenues for regional collaboration, planning, and monitoring, are provided through the LDIGs. Within the required CWS drought and conservation plans, systems are encouraged to plan for their 'worst case scenario'. As one national drought expert put it; "Drought planning and preparedness are great approaches for preparing entities for the variability they will see in the future. As a part of that process, if you think of the worst case scenarios and incorporate them into the planning process, it will help even more." The newly implemented drought monitoring and impacts reporting systems will also help officials and CWS more accurately understand vulnerability to climate change, further increasing adaptive capacity. The state and CWS have made significant strides in terms of using climate information in their planning and management decisions, but broader use of such tools would improve adaptive capacity. To overcome several additional adaptive capacity detractors in Arizona, the state might consider requiring more comprehensive vulnerability assessment and mitigation measures within the local plans, hiring additional staff to focus specifically on drought planning, and strengthening the roles of LDIGs as regional drought entities by providing more incentives (or perhaps requirements) for LDIGs and CWS to meet regularly and coordinate within regions.

Like Arizona, South Carolina drought mitigation and response starts with local CWS drought ordinances and plans, which in South Carolina are supported by monitoring and planning at the state and regional levels through DRCs. The local drought plans help identify vulnerabilities through CWS self assessments of capabilities, supplies, and pre-drought options. The state also serves as a backstop during times of drought emergencies, and the RISA (CISA) is quite active in providing high quality and useable drought information and tools. Aspects of South Carolina's drought preparedness that tend to diminish its adaptive capacity include a lack of state drought mitigation planning (the state only has a drought response plan), codified triggers, and loss of staff devoted to drought planning and management. In addition, the skeptical sentiment toward climate change limits the extent to which decision makers and officials can incorporate planning for climate change into management and legislative initiatives. Therefore, to further build adaptive capacity to extreme droughts, South Carolina might consider a statewide drought mitigation/preparedness planning process, removing the drought indices from legislative processes to increase the flexibility of their use and assure their continual improvement, and spearhead climate change planning pilot projects in receptive communities to demonstrate the benefits of such planning to the rest of the state.

When developed in 2003, Georgia's drought declaration stages, triggers, and indices were quite innovative, as evidenced by their role in informing the ASDPP. Despite the fact that these triggers and Georgia's drought management plan informed Arizona's preparedness plan, the GDMP and the state-level drought planning process is limited in its level of detail, lacks iteration, and does not provide a structure or clear guidance for local communities. For example, the GDMP recommends that local systems perform vulnerability and risk assessments, but there is little further guidance for these assessments, and GDNR does not require or enforce such assessments. This is perhaps an artifact of the level of commitment that the state has devoted to drought preparedness since the GDMP in 2003. Unlike Arizona and South Carolina, which require and enforce drought planning at the CWS-level to capture the local nuance of impacts and responses, Georgia relies upon universal drought responses that correspond with drought stages declared regionally by the DRC (e.g., all households under stage 3 drought can only water every other day). In addition to the lack of local drought planning, since the 2006-2008 drought the state has barred CWS from implementing water restrictions that exceed state-level restrictions, without special approval. Although monitoring and triggers are flexible, well coordinated monitoring and methodological improvements are less likely due to the impermanence of the DRC during wet periods and little if any regional/local based monitoring. Additionally, the RISA (SECC) does not play an active role in drought planning and management for CWS, and climate change skepticism pervades the public; limiting the extent to which decision makers and officials can incorporate planning for climate change into management and legislative initiatives. Thus, to build flexibility and adaptive capacity in Georgia, decision makers might consider requiring, implementing, and enforcing formal local drought plans like Arizona and South Carolina, that link to strong, clear, state drought plans and processes. Updating the 2003 drought plan and the methods through which droughts are declared can improve adaptive capacity, as might eliminating the restriction of more stringent CWS measures during times of drought. There is strong evidence from Georgia's 2007 emergency response for starting drought preparedness at the local level. When given the broad mandate and flexibility by the Governor for each CWS to reduce water use by 10 percent through whatever means necessary, CWS responded with near 15 percent reductions (much better than the generic drought responses outlined by the GDMP). Rather than making systems scramble to implement best guesses in a reactive manner, as was the case in 2007, it could serve Georgia well in terms of adaptive capacity to foster a more proactive and planned approach at the local level. Finally, officials might also want to consider providing more resources for the RISA and/or formalizing its role in drought planning and management processes. Also, the state might consider spearheading climate change planning pilot projects, as recommended in South Carolina.

Drilling down from these broader state-level factors affecting adaptive capacity to extreme droughts, I turn to the survey results to help focus more intently on assessing CWS adaptive capacity within each state. The descriptive statistics in *Figure 3.*5 show that lower impacts (and higher adaptive capacity)[48] are more closely associated with private over public CWS in all three states. The expert interviews support this finding in Arizona, in that private systems can quickly cut back on water through curtailment tariffs, whereas public CWS have to go through an oftentimes more drawn-out local board

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[48] Trends in the descriptive statistics regarding adaptive capacity may be less robust if some systems did not accurately report impacts in the survey, as discussed further in this section.

approval process. It is unclear why this relationship between CWS types holds in Georgia and South Carolina, since both states regulate public and private CWS in the same manner. One possible explanation is that the bureaucratic cultures and oftentimes larger sizes associated with public systems could decrease flexibility compared to the private systems. The relationship between higher adaptive capacity in surface water dependence over groundwater dependence in Arizona, and the reverse relationship reflected in Georgia, is also supported by the state-level interviews. Experts indicated that CWS receiving surface water in Arizona use it to augment and buffer their array of supplies, whereas in Georgia, surface water is the primary (and often sole) source of water for many CWS; a source that is immediately impacted by droughts in Georgia. The lack of a clear trend between CWS budget and adaptive capacity implies that taken alone, financial resources are not necessarily a strong indicator of impacts and adaptive capacity.

Perhaps the most interesting finding shown from the descriptive statistics is that although there are some exceptions, there are generally increasing relationships in each state between CWS’ size and: 1) drought impacts; and 2) number of AIM approaches implemented within a CWS. These findings appear to be contradictory to the expected result that AIM approaches are associated with fewer drought impacts (i.e., higher adaptive capacity). One can interpret these findings several ways. First, it might imply that larger systems, while more impacted (i.e., less adaptable), are working to increase their adaptive capacity through implementing more AIM approaches than the smaller systems. That is, they are more physically exposed and have more to lose than the smaller systems, thus requiring more AIM implementation to try to minimize impacts (which is made possible by more resources, such as human capital, funding, etc.). Alternatively, given that more is at stake within these larger systems, it is possible that the larger systems might more accurately understand and report impacts than the smaller systems, or be more inclined to report greater impacts because even the slightest disruptions are interpreted as significant. This second interpretation would indicate methodological limitations of this research (i.e., the reporting and tracking of drought impacts contains errors), which ultimately could be skewing the first measurement of adaptive capacity. Because of the potential for measurement error in the drought impacts survey data, I associate only a mild degree of confidence to the first measurement of CWS adaptive capacity – the regression analysis. Still, my interpretations of the regression analyses are ultimately made more robust when combined with the cluster analyses and the expert interviews. Below, I take a closer look at adaptive capacity of CWS in each state.

In Arizona, the significant negative relationship between regional coordination and planning of water supply decisions and lower adaptive capacity is by itself, difficult to interpret. Does that particular AIM approach actually lead to lower adaptive capacity? The small sample sizes and potential measurement errors in self reporting impacts suggest a cautious interpretation of this result and warrant a closer look into the adaptive capacity groupings (i.e., the cluster analysis). The cluster analysis is very helpful in providing a more illustrative depiction of adaptive types, for it extends the analysis to other time periods to capture organization, learning, and proactiveness. The most obvious distinctions between the two Arizona clusters are in the impacts category and the mobilizing and changing category. The CWS in the cluster containing the higher impact mean (and thus lower adaptive capacity as measured in the first step) also contain a higher level of mobilizing and changing management approaches surrounding the drought. There is not a clear distinction between CWS size and implementation of AIM approaches post-drought in the Arizona clusters. However, even in the cluster with the lower drought impacts mean, a considerable number of CWS show a net increase in AIM measures post-drought. Thus, from the cluster analysis, there is evidence to support that there is a high level of adaptive capacity in Arizona CWS, as indicated by adaptive behavior in both clusters (regardless of reported drought impacts).

Contrary to the reported impacts in the survey, the expert interviews indicate that the smaller, more rural CWS in Arizona experienced the greatest impacts, while the larger urban systems were relatively unscathed. *Figure 3.5* supports the experts' claims that the smallest CWS experienced the highest impacts. The larger systems however, show increasingly greater impacts in the survey, and perceive greater barriers to change (*Table 3.12*), which the expert interviews do not necessarily support. Based on the survey results alone, this suggests that in Arizona, the smallest systems have the least adaptive capacity, and the small-medium systems have the most, with larger systems demonstrating progressively less adaptive capacity. The direct interpretation of this would imply that there could be a threshold related to system size, with the small-medium systems demonstrating the most adaptive capacity, and the larger systems losing that capacity as their assets, responsibilities, sensitivity, and exposure expands (i.e., they gain greater stake and face greater barriers as their size increases). However, the expert interviews suggest that this is not the case, which is why I more confidently conclude that measurement error is confounding this finding. That is, the greater stakes at risk for larger systems during extreme droughts makes them more likely to exaggerate impacts, because any small change to the CWS is experienced as a significant impact. Also, larger systems may be more likely to perceive barriers because they are more aware of the barriers that CWS generally face.

Again, considering these data together, one should interpret the negative relationship between regional coordination and adaptive capacity in the Arizona regression analysis cautiously, since larger systems might be over-reporting impacts (and/or smaller systems possibly under-reporting impacts). In addition to the methodological implications for measuring adaptive capacity, described below, the regression and cluster analysis results in Arizona suggest that while CWS tend be adaptive and flexible, there are some systems that do not appear to be learning and adjusting. Officials and managers might devote priority attention to these types of systems, and also work with the larger systems that have higher stakes to understand how they build and maintain adaptive capacity while addressing perceived barriers.

Like Arizona, Georgia and South Carolina also show a handful of significantly negative relationships between AIM approaches and adaptive capacity. In Georgia, these two AIM approaches are medium and long-term information use, and drought impacts monitoring, evaluation, and reporting.[49] In South Carolina, the AIM approach associated with social/customer impacts is information from multiple agencies/groups. As with the Arizona case, one could interpret these negative relationships in several ways. First these findings could imply reverse causation. That is, CWS are using this information because of their lower adaptive capacity, as opposed to having lower adaptive capacity because

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[49] In Georgia, ecoregion also appears to be significantly associated with adaptive capacity. This could be occurring because sensitivity is in fact a significant factor in predicting adaptive capacity in Georgia, or because the exposure was less uniformly experienced across the state. The expert interviews support the latter explanation, with respondents indicating that North Georgia was more severely exposed than the South. Regardless, when controlling for ecoregion, several AIM approaches are still identified in the regression as significantly associated with impacts and adaptive capacity.

they use this information. Based on my conclusions in the case of Arizona and on the expert interviews however, the more plausible explanation is that this finding is more attributable to measurement error; that is, systems implementing these AIM approaches are more aware of and more accurately report drought impacts than those CWS that do not implement these approaches.[50] As in the Arizona case, however, it is helpful to combine these findings with the cluster analysis, perceived barriers results, and interviews to gain a more complete depiction of adaptive capacity in Georgia and South Carolina.

In Georgia, the expert interviews suggest that adaptive capacity is less a matter of system size and more a matter of physical characteristics and geography. The cluster analysis reveals, however, that the more adaptive cluster (mobilizing, changing, and adapted post-drought) has the higher drought impact mean and tends to include the larger systems. As in Arizona, this implies that the larger CWS have more at stake, and due to their greater implementation of AIM approaches, are more accurately/liberally reporting drought impacts. Unlike Arizona however, some of the larger systems were significantly impacted by the droughts (as supported by the expert interviews), so in some cases the impacts may not be over-reported in Georgia. Furthermore, the largest systems report the fewest perceived barriers. In addition to methodological implications (i.e., difficulty in measuring drought impacts), these findings suggest that the smaller systems in Georgia are either self-sufficient and have high adaptive capacity, or need better tools and information to more accurately understand and track drought impacts. Similarly, some of the larger systems in Georgia with higher stakes are either more accurately reporting impacts or face serious adaptive capacity deficiencies. Perhaps this is due to a different type of barrier that these larger systems face altogether; physical/geographical barriers (which unfortunately were not queried in the survey). All of these interpretations likely carry some validity, but I most confidently accept the explanation that measurement

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[50] All three of the approaches showing negative associations with adaptive capacity (and higher impacts) in Georgia and South Carolina are in fact those related to climate information use and monitoring/reporting. It is likely the case that the systems in these states actually employing this information are able to more accurately understand and report impacts with the aid of this information and these tools; thus reflecting lower adaptive capacity in the survey (because they report higher impacts than the systems not using the tools and information). This further suggests that measurement errors are at play in reporting drought impacts, but it also affirms the importance of using climate information (from a variety of sources) and monitoring, tracking, and recording to more accurately capture future drought impacts.

errors in reporting drought impacts are driving these results. From a practical standpoint, the findings, particularly the cluster analysis, indicate that officials and managers in Georgia might consider encouraging CWS to consistently employ AIM approaches, as well as working with the larger systems to identify ways to increase their flexibility and remove the barriers that are currently restricting their abilities to adapt.

Interpreting the CWS adaptive capacities' in South Carolina is slightly more challenging. The reduction of drought impacts into two principal components is in itself an interesting finding, for it implies that CWS in South Carolina experience social/customer conflict separately from other drought impacts. Are social/customer conflicts less pronounced when drought impacts are high? This is difficult to discern from the descriptive statistics and regressions alone. The cluster analysis is very helpful in this situation, as it identifies a cluster of CWS with low social/customer conflict and high impacts in the one drought principal component, and another cluster with the opposite relationship. The cluster with the low social/customer conflict impacts also demonstrates the most mobilization and change, as well as greater AIM implementation post-drought and larger CWS. Such a finding suggests that in the cluster that reports high water deliver, water quality, ecosystem, and budget/financial impacts from the drought, the CWS have found ways to resolve social conflicts and collaborate on solutions during the drought. The expert interviews support this finding, in that they report significant improvements in collaboration and relationship building between CWS and other interests in several river basins. Not only was the drought the impetus for collaboration in these cases, representing that they were able to take advantage of the drought as an opportunity (i.e., high adaptive capacity), but these CWS learned from previous periods of drought (e.g., 1998-2002) that had resulted in significant social conflict. Also, as is the case with Arizona and Georgia, these larger CWS in South Carolina implement more AIM approaches. Therefore, I most confidently associate the negative association between high drought impacts (and lower adaptive capacity) and the use of information from multiple sources identified in the regression with measurement error; that is, the CWS reporting more impacts are actually more adaptable, drawing from an arsenal of information to address drought impacts in a collaborative manner (as evidenced by the lower social conflict in the cluster analysis). In addition to methodological implications in measuring adaptive capacity, these findings suggest that officials and managers in South Carolina might greatly benefit from supporting more collaborative forums for CWS and other stakeholders to resolve drought conflicts. However, the fact that CWS in South Carolina reported the lowest perceived barriers of all three states, might imply that there is a delicate balance between more state regulation and involvement, and CWS flexibility to collaborate, organize, and collectively deal with drought. Such tensions between the scales of drought planning and management deserve further attention, as do the methodological implications of this research.

5.2. Research Implications, Measurement Improvements, and Next Steps

The results from this research have several theoretical and methodological implications. Mainly, the multiple spatial and temporal dimensions on which I assess adaptive capacity provide a more in-depth assessment than previous studies. Explicitly considering the polycentric institutions that influence adaptive capacity, drawing from both resilience and vulnerability research to inform the assessment, and incorporating multiple sources and types of data unveils several important theoretical insights. From this research, it appears as though the most adaptable are states that relegate drought preparedness to the local level, allow flexibility in triggers, plans, and monitoring, provide a comprehensive planning and informational support system, offer iterative regional forums for (or at least remove limitations to) collaborating between systems and locales, consider climate change in their planning processes, and have an accessible RISA that is active in water management and drought planning efforts. More broadly, the expert interviews and survey data reveal that there are tensions between what builds adaptive capacity at the state-level and what builds adaptive capacity at the CWS-level. Not only are they linked to one another, there is a potential tradeoff between structure, regulation, organization, and mobilization of state resources, and flexibility and autonomy of local CWS. In some situations, officials can institute measures that they perceive to be beneficial for the state, but in fact limit the adaptive capacity of the CWS.

In the case of Georgia, for instance, determining generic drought responses at the state-level, rather than locally relevant responses, fails to capture and mobilize the system-specific adaptive capacity at the local level – instead relying on crisis management that is reactive rather than proactive. Not only is this less sustainable and inefficient, it leaves CWS feeling frustrated and overlooked, which might not bode well for future state attempts to motivate CWS into action during a drought emergency. South Carolina, on the other hand, by codifying its triggers and indices, hinders flexibility at both the state and CWS-levels in providing what amounts to too much structure to the drought declaration process. However, the tension between state and local influences on adaptive capacity is not simply a matter of states disengaging as a means of removing themselves as barriers to CWS. In other words, constraining CWS adaptive capacity might not be universally due to too much regulation, but actually the opposite might be the case; too little regulation and direction. Again in South Carolina, the lack of surface water permitting provides CWS and other water users with little guidance or policy certainty for long-term water decisions, diminishing future adaptive capacity. And in the Georgia case, CWS might perceive future regulations that would require local drought plans as another barrier, but evidence from Arizona and South Carolina indicates that this requirement increases adaptive capacity. Arizona appears to be working through the complexities associated with balancing state regulation and involvement with local flexibility. However, while the regional LDIGs provide a bridge between the state and local CWS, these initiatives lack the continuity and requisite involvement of CWS that would improve adaptive capacity even further.

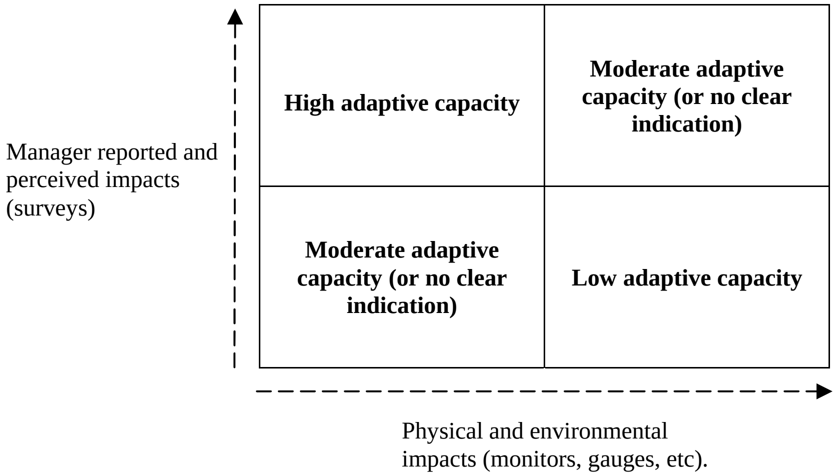
The above examples illustrate the tensions in building adaptive capacity to extreme droughts across spatial scales, a broader finding to which I attribute a fairly high degree of confidence, given the multitude and diversity of data that I use to arrive at this conclusion. In essence, the challenge for building adaptive capacity in a polycentric world reduces down to finding the proper balance between structure/guidance/policy certainty and flexibility at each scale. Therefore, future investigations should not only consider the multiple scales at which adaptive capacity is built and realized, but how adaptive capacity is interacting between these scales. From a policy perspective, striking the appropriate balance between structure and flexibility remains a constant challenge. To the extent these results are generalizable to other contexts, it might be best to build adaptive capacity with ‘regulated flexibility’ through local preparedness and planning, while providing the necessary support and resources at higher scales.

Although the process described in this research for assessing adaptive capacity represents potential methodological gains, there are also several weaknesses in this approach that warrant consideration for future assessments. Most importantly, the first measurement of adaptive capacity as the inverse of the drought impacts may not be the best measurement as it has been used in this research. Except for the case of Georgia, it appears that the problem is most likely not from controlling for sensitivity and keeping exposure relatively uniform, but rather it is a matter of how managers perceive and report impacts within their systems. Therefore, I am unable to conclude from the first measurement of adaptive capacity (the regressions) which AIM approaches are most associated with adaptive capacity.

These measurement errors allow me only to speculate on the following additional points. First, from a theoretical and practical perspective, if systems were reporting impacts in the survey in a manner that matched the relative severity of other metrics (e.g., physical and environmental measures not assessed in this research), then the results suggest that larger CWS may actually experience increases in adaptive capacity at the expense of greater risk (more at stake, more exposed). In other words, the largest systems while most adaptable, might also be the most at risk. Further, there may be a threshold of CWS size around which adaptive capacity increases but risk does not, in which case one might be able to identify an ideal CWS size for maximizing adaptive capacity.

Second, from a methodological perspective, knowing that there is variation in the perception and reporting of drought impacts might be helpful for improving future adaptive capacity assessments. Combined with physical and environmental instrumental data, manager-reported impacts survey data could be used to one’s advantage to arrive at a new indicator of adaptive capacity; one that links the relative level of a manager’s perceived system impacts with physical and environmental metrics to gauge over and/or under-reporting. I speculate that the extent to which the survey impacts data (how managers perceive impacts) aligns with the physical and environmental impacts data could be indicative of adaptive capacity (see *Figure 3.6*). In the end, the influence of manager-reported impacts deserves further attention in future studies. This is especially important given that the higher reported impacts (and perhaps more accurately reported impacts) are linked to climate knowledge, drought monitoring, and multiple sources of information; implying that it is important to increase information use to increase accuracy of reporting.

Figure 3.6: Manager's perception of impacts and physical/environmental impacts as a potential proxy of adaptive capacity.



Again, the measurement errors associated with reporting drought impacts makes it difficult to interpret the relationship between CWS' implementation of specific AIM approaches and impacts/adaptive capacity. Therefore, I leave unanswered one of the motivating questions for this research, 'which management, institutional, and governance approaches are most important for building adaptive capacity?' It is, however, apparent from my findings that larger CWS tend to implement more AIM approaches than smaller systems across all three states. As indicated by the cluster analyses, larger systems also seem to mobilize proactively and reactively, and adapt and learn post-drought. A closer investigation into when and why (or why not) these larger urban systems implement AIM approaches would help decision makers and managers understand the dynamics of extreme drought in relation to innovative management implementation (e.g., when certain AIM approaches are implemented, which systems are early adopters, what keeps some systems from adoption, etc.). Finally, this research highlights the importance of perception; not only with respect to how managers report impacts, but also the role that public perception plays in drought preparedness. Thus, we turn to Chapter 4, which seeks to answer some of these remaining issues in larger urban CWS in Arizona and Georgia.

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Chapter 4
Adaptation and Innovation in Urban Community Water Systems

1. Introduction

Community water systems (CWS) are an integral component of the water sector for maintaining lifestyles and livelihoods, meeting basic human needs, and ensuring ecosystem vitality. CWS vary considerably across ‘system attributes’, such as type of system (public or private), organization and governing structure, water source, customer base, and resource availability (e.g., staff and budget). However, one of the most common factors by which regulators and researchers distinguish CWS is in relation to system size, or the number of people served by a particular system. By definition, larger CWS service a greater number of individuals, and thus tend to be more urban in nature; with many urban areas being public water systems associated with city, county, or other municipal governments. As mentioned in previous chapters, from 1950 to 2000, the percentage of people in the U.S. receiving their drinking water from CWS grew from 62 percent to 85 percent (Hutson et al., 2004). This percentage is likely to increase in the coming decades, particularly in the rapidly growing urban areas of the Southeast and Southwest, which face mounting pressures from growth and development. The increasing dependence of humans and ecosystems on CWS, combined with the potential impacts of climate change and extreme droughts on water suppliers, will make the delivery of high quality water increasingly difficult and uncertain for large urban CWS in the future (Cromwell et al., 2007). Therefore, it is critical for researchers and managers to gain a better understanding of adaptive capacity and potential adaptation options for CWS (Cromwell et al., 2007; Smith et al., 2009).

In Chapter 3, I presented descriptive statistics suggesting that the largest CWS are generally more innovative than smaller systems in the management approaches they implement, and are also more adaptive in preparing for and responding to extreme drought events. While some of this activity is likely attributable to funding levels and sheer necessity (i.e., high stakes requires them to be more progressive), there is substantial variation in the levels and types of innovative approaches employed by these larger CWS. Exactly what motivates or prevents the adoption of innovative approaches in these larger urban CWS is unclear. This chapter seeks to elucidate this issue by exploring how and why CWS adaptive capacity develops over time. Specifically, I seek to answer the following two-part research question:

1) when do CWS implement innovative drought planning and management approaches in relation to extreme drought events?
2) what facilitates or inhibits CWS from adapting and adjusting their approaches?

I hypothesize that in both Arizona and Georgia, some of the ‘soft’ management approaches (e.g., long-term planning and climate information use) will demonstrate positive associations with the onset of droughts (both immediate and delayed relationships), while others, particularly the ‘hard’ management approaches (e.g., infrastructure, supply diversity, etc.) will not demonstrate significant relationships. Also, as with the state-level analysis in Chapter 3, I hypothesize that each states’ large urban CWS will have a unique set of bridges for and barriers to implementing innovative approaches because of the state-specific mechanisms (i.e., management, institutional, and governance) that have developed over the years to prepare for and respond to droughts. Thus, there will be unique ways that adaptive capacity develops over time and is manifested between states. In answering these research questions and evaluating the hypotheses through a thorough characterization of urban CWS adaptive capacity, I aim to help advance adaptation theory and make practical contributions to water management decision-making.

I use a novel tool, the event history calendar (EHC), to collect quantitative and qualitative data from senior-level CWS managers in Arizona and Georgia.[51] The EHC is similar to the ‘life history calendar’ (LHC) used in anthropology and sociology disciplines to collect temporal data on individuals. I use the EHC to gather temporal data on CWS management, tracking the implementation of innovative approaches similar to those outlined in Chapter 3. By investigating the timing and motivations behind

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[51] Again, resources limit the investigation in Chapter 4 to these two states.

implementing innovative approaches, I hope to identify patterns of management and institutional activity (or lack thereof) surrounding drought events in Arizona and Georgia that might help decision makers anticipate how large CWS are likely to function in relation to future extreme drought events and climate change, and how adaptive capacity interacts with droughts. This understanding could aid state, city, and local officials with designing and targeting programs and initiatives in a more efficient, effective, and sustainable manner. Furthermore, comparing the adaptation and adoption of innovative approaches within and between Arizona and Georgia might help identify common bridges and barriers that these and other urban CWS face; providing practical insight for decision makers for building adaptive capacity by strengthening the bridges and removing the barriers. Such knowledge is not only useful for improving water management and drought preparedness, but it has broader applications to understanding adaptation of social systems to climate change, that is, systematically analyzing bridges and barriers might contribute to theory by identifying general themes and patterns regarding the temporal dynamics and characteristics of adaptive capacity.

In the next section of this chapter, I discuss the research design and methodology, which includes an in-depth description of the EHC. Next, I report the results of the quantitative and qualitative analyses, and then discuss these findings. Finally, I conclude by outlining future avenues for research and offer ideas for improving similar studies.

2. Research Design and Methodology

2.1. Innovative Management Approaches and Adaptive Capacity

In Chapter 3, I group together and operationalize a host of innovative water and drought management variables as ‘adaptive and integrated management’ (AIM). Whereas in Chapter 3 these variables are placed the context of state and local CWS, here in Chapter 4, I look at the timing and motivations for implementing innovative drought and water management approaches specifically at the CWS-level.[52] Because of this specific focus on the CWS-level in this chapter, I refer to the approaches investigated here more broadly as ‘innovative approaches’ that CWS may or may not implement. I also move

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[52] Although state-level management influences local CWS management (which I discuss in Chapter 3 and subsequent sections of Chapter 4), in this chapter I do not specifically examine the development of state-level approaches over time.

away from using the AIM terminology because although still informed by drought preparedness, integrated water resources management (IWRM), and adaptive management (AM) literatures, I include several additional management factors that I do not directly investigate in Chapter 3.

The most notable addition to the 'innovative approaches' that I investigate in this chapter are those presented in the water resources management and planning literature; specifically integrated resources planning (IRP). IRP holds as its central guiding principle that people desire water related services, not necessarily more water, and therefore emphasizes low-cost demand management to complement the dominating paradigm of seeking additional supply (Beecher, 1995). The approach is innovative because focusing on increasing conservation and reducing unaccounted water loss is more sustainable than the traditional solution; augmenting supply (Howe and White, 1999). Beyond stressing conservation pricing, leak detection, and other measures that decrease customer demand and improve efficiency of water deliveries, IRP puts many of the IWRM principles into operation, such as stakeholder engagement and long-term planning (Cromwell et al., 2007). Implementing IRP increases the flexibility of the CWS, which ultimately improves the ability of managers to explore a portfolio of adaptations to climate change (Cromwell et al., 2007). *Table 4.1* outlines the 'innovative approaches' I explore in this chapter, and highlights the main bodies of literature (i.e., IWRM, AM, and IRP) from which these approaches originate.

Table 4.1: Operationalizing drought planning and management 'innovative approaches', as described in the IWRM, AM, and IRP literatures. The 'M' label preceding each approach is from the event history calendar (*Appendix 3*), which I keep here only to make it easier to refer to and report the variables throughout the chapter. I also classify each variable as either hard or soft, and as either a mechanism or a characteristic; variables (rows) with similar classifications are grouped together and are shaded accordingly.

Approaches and Mechanisms (*and their origins in the literatures; IWRM, AM, and/or IRP*)	Explanation	Basic Classification (Hard v. Soft; Mechanism v. Characteristic)
M5 Supply diversity (*IRP, AM*)	Actively seek and secure water from a diversity (spatially and source-type) of sources within the region	Hard, Mechanism
M6.1 Infrastructure – supply (*IRP*)	Build additional and upgrade existing infrastructure to better manage supply (e.g. drought contingency reservoirs, wells, etc.)	Hard, Mechanism
M6.2 Infrastructure – demand (*IRP*)	Build additional and upgrade existing infrastructure to better manage demand (e.g. improved metering and monitoring, leak detection, etc.)	Hard, Mechanism
M1 Conservation (*IRP*)	Conservation promoted through education, incentives, hiring conservation staff	Soft; Mechanism

M3 Rate-structure (*IRP*)	Conservation-oriented rate structure that is always in place and is effective in reducing water use, and preferably leaves little impact on water system revenues	Soft, Mechanism
M4.1 Collaboration – local/regional (*IWRM, AM, IRP*)	Coordinate with city, county, and other water system managers on water resources and drought planning	Soft, Mechanism
M4.2 Collaboration – State/Fed (*IWRM, AM, IRP*)	Coordinate with State and/or Federal managers on water resources and drought planning	Soft, Mechanism
M4.3 Collaboration – other (*IWRM, AM, IRP*)	Coordinate with others outside the traditional 'water sector' (e.g., emergency planners, land-use planners, watershed groups) on water resources and drought planning	Soft, Mechanism
M7 Climate-information and scenarios (not necessarily distinguished from other information *in IWRM, AM, and IRP*)	Medium and long-term climate information (e.g., historical information, seasonal forecasts, regional and hydro-meteorological models, etc.), and climate change impacts scenarios	Soft, Mechanism
M8 Uncertainty communication (*AM*)	Communicate the idea of 'uncertainty' inherent in water management decisions with customers (e.g., city council, shareholders, public, etc.)	Soft, Mechanism
M9 Stakeholder and customer participation (*IWRM, AM, IRP*)	Provide avenues for and encourage stakeholder and customer input into management decisions (particularly longer-term decisions)	Soft, Mechanism
M10 Interaction with natural processes (*IWRM, AM, IRP*)	Explicitly consider and plan for relationships between the water system's activities and natural/environmental processes	Soft, Mechanism
M11 Thinking 'outside of the box' (*AM*)	Formulate hypotheses and experiment with novel approaches for managing supply and demand uncertainty; monitor and evaluating the experiments and alter practices accordingly	Soft, Mechanism
M13 Long-term drought planning (*AM, IRP*)	Iterative and long-term drought planning, emphasis on mitigation, and planning for longer and longer drought periods (e.g., 5-year drought, 20 year drought, etc.)	Soft, Mechanism
M2 Autonomy (*AM*)	Independent decision-making and a governance structure that allows flexibility to make quick decisions and changes at the local level	Soft; Characteristic
M12.1 Leadership – system (*IWRM, AM*)	Work with other similar systems to innovate, and present the system as a model from which others can learn	Soft, Characteristic
M12.2 Leadership – individual (*AM*)	Leadership and an innovative philosophy are institutionalized within the system (i.e., success is not dependent on a single or a few leaders)	Soft, Characteristic
M15 Perception of the problem (*IWRM, AM, IRP*)	System and customers perceive extreme drought and climate change as an imminent threat	Soft, Characteristic

Sources: Based on various sources within the peer-reviewed and professional literatures (Beecher, 1995; Howe and White, 1999; Olsson et al., 2004; Blomquist et al., 2005; Folke et al., 2005; Wilhite et al., 2005; Cromwell et al., 2007; Pahl-Wostl, 2007; Medema et al., 2008; Raadgever et al., 2008).

Several of the variables depicted in *Table 4.1* are difficult to characterize as being 'implemented' or operationalized into practice, per se, but are rather more accurately envisaged as properties or characteristics of the CWS at a given point in time. For example, local autonomy (M2) and strong system and individual leadership (M12.1 and M12.2) are purported to increase flexibility, adaptive capacity, and resilience (Folke et al., 2005; Pahl-Wostl, 2007). However, they are more akin to qualities of a system that are present (or not) over time; not necessarily approaches that managers consciously implement. Another example is perception of the problem (M15). Systems within which managers and the public are on the 'same page' as one another, and more completely understand the dynamics of drought are more likely to effectively and sustainably prepare for and respond to droughts and other climate related phenomena.

Furthermore, in *Table 4.1* (column 3), I delineate the innovative approaches along two classifications. First, I classify the variables as either ‘hard or ‘soft’ approaches. Hard approaches are those that imply something tangible, such as infrastructure, whereas soft approaches are those that do not immediately include something tangible, such as planning and collaboration. Second, I classify the variables as either ‘mechanisms’ or ‘characteristics’. Mechanisms are those approaches that managers implement or do, such as communicate uncertainty and experiment and think outside of the box. Characteristics on the other hand, are those qualities or properties that systems have, such as a leadership and autonomy. By classifying the approaches in this manner, I hope to investigate whether there are patterns of relationships between droughts and the implementation of such groupings of approaches. For instance, I expect that an emphasis on ‘hard mechanisms’ will not correlate closely with the onset of droughts, as these approaches theoretically take longer to mobilize and implement. On the other hand, my analyses might uncover unexpected patterns, such as in the above example where extreme droughts could be associated with a greater likelihood of implementing ‘hard mechanisms’, even though hard mechanisms are generally thought of as longer-term decisions. In addition to understanding adaptations of individual CWS approaches surrounding drought events, investigating broader patterns within and between states might have theoretical implications for understanding the development of adaptive capacity.

As discussed in previous chapters, research has shown that management, governance, and institutions are important for determining adaptive capacity. Also noted in previous chapters, I distinguish between adaptive capacity assessments that ‘measure’ and adaptive capacity assessments that ‘characterize’. This chapter presents more of a ‘characterization’ of adaptive capacity, for it assumes that the innovative approaches outlined in *Table 4.1* contribute to adaptive capacity. In other words, investigating the development of innovative approaches over time and the bridges and barriers that CWS face in adopting these innovative approaches, is by extension an investigation into the development of adaptive capacity over time and the bridges and barriers to building adaptive capacity.

2.2. The Event History Calendar

I rely on an event history calendar (EHC) method to gather temporal data on the implementation of the innovative approaches outlined in *Table 4.1*. The approach is adapted from life history calendar (LHC) methods, which seek to gain detailed information on individuals by linking personal events with other 'external' events, or the 'environmental context' during the period of interest (Axinn et al., 1999). LHCs are a useful method for collecting categorical, ordinal, or interval data (often quantitative) on the timing and sequencing of life events, and are more cost and time effective than panel studies (Freedman et al., 1988). The technique makes memory recall easier through a matrix of visual cues and an interactive and dynamic interview process (Axinn et al., 1999). The method has received significant attention in the sociology, psychology, and anthropology disciplines, but to the best of my knowledge, it has not yet been adapted and applied to contexts I am investigating in this study.

In my research, I seek detailed information on CWS by linking the development of innovative management approaches with personal and other significant events occurring during the period of interest. While the LHC is interested in personal and individuals' histories, aided by recalling external events, the EHC is interested in system histories and external event information, aided by recalling personal histories.[53] Another defining characteristic of the EHC is that it is designed to gather qualitative data to complement the quantitative data. In the end, the main driver behind adapting the LHC to create the EHC has been one of necessity, for I need a tool that can record temporal data in an efficient, flexible, systematic, and precise manner.

To collect these data using the EHC, I targeted the 20 to 25 CWS serving the largest number of people in both states, along with any regional wholesale or collaborative initiatives (e.g., Salt River Project and the Central Arizona Project). I

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[53] While memory recovery is always a concern for acquiring information from respondents about the past, it is less worrisome the more recent the events in question (Belli, 1998). I am less concerned about accurate memory recall in my research because it focuses on recent landmark events and personal milestones to reorient the respondent, and the level of detail that I request during the interviews is not too specific (e.g., low, medium, or high implementation).

identified these systems using the same frames (lists) from the Community Water Systems Survey discussed in Chapter 3.[54] During the summer of 2009, I spent three to four weeks in each state conducting the face-to-face EHC interviews. The guiding criterion for interviewee selection was that the participants needed to have significant experience in operating his/her system over the majority of the previous decade. I initially targeted the most senior managers, usually holding the title of ‘Utilities Director’, ‘President’, ‘Superintendent’, or ‘General Manager’. If not available, or if new to their particular system, I recruited the second most senior and/or experienced manager, and so on down the line. In some instances, the interview also included a senior-level manager from the water resource and/or environment side of the CWS, usually holding the title of ‘Environmental Resources Director’ or ‘Water Resources Director’. Inclusion of two high ranking managers from slightly different perspectives of the CWS seemed to improve the overall quality of the interview.[55] I successfully completed 35 face-to-face interviews with senior-level managers; representing 80 percent and 72 percent of the largest systems targeted in Arizona and Georgia, respectively.[56]

Appendix 3 shows an example of the EHC and its accompanying questionnaire. The interview is interactive and conducted sitting next to the manager(s). The calendar itself is a large document, approximately 1.5’ wide by 3’ long. The management variables of interest (see *Table 4.1*) are portrayed in the rows, and the time periods are depicted in the columns. There is significant ‘white space’ to the right of the grid for note taking. Each of the ten years is divided into two periods, winter and summer,[57] since water management decisions are commonly remembered along seasonal terms. This division also provides more data points and precision around the timing of changes.

The flow of the interview follows a fairly structured pattern. The interviewer explains the nature of the calendar, and then walks through the ‘pre-defined’ events on

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[54] I identified participants using CWS lists available on USEPA’s websites and from state agencies, as well as internet searches. I contacted and recruited participants through email messages and telephone calls.

[55] Roughly 50 percent of the CWS brought one or two extra individuals to the interviews to help improve their reporting accuracy.

[56] The interviews lasted between 60 and 140 minutes, with the average interview requiring 90 minutes to complete.

[57] Winter is defined as January through June, and summer is defined as July through December. I define the previous decade as the period between summer 1999 and winter 2009, resulting in 20 time periods for each row.

the calendar that help to begin situating and reorienting them around significant national and state-wide events throughout the decadal period (e.g., Presidential elections, state water policies, and other noteworthy events that all of the managers will remember).[58] The interviewer then works with the manager to identify at the bottom of the calendar, any important local events that may or may not be directly related to the CWS. This process helps further facilitate memory recall and reorientation by thinking about local developments with respect to the timing of the national and state events. The final step before posing the questions of interest involves respondents identifying personal events, such as career advancements, age milestones, significant events related to their children, and other events that can serve as important memory anchors. Reporting the personal events serves as one final layer to the memory recall process, and helps the participants more accurately orient the management of their system with respect to the local, state, and national events. In addition, sharing personal events (both the interviewer and interviewee) can serve to ‘break’ the proverbial ice that is routinely present at the onset of an interview.

The remainder of the interview includes walking through each row (management approach) and assigning numbered values during each of the time periods. Most of the questions are meant to solicit the amount of emphasis placed on the particular approach at each period of time (i.e., 0 = none, 1 = a little, 2 = some, but could have done more, 3 = to the fullest extent possible for a CWS).[59] Again, the innovative approaches that I assess with the EHC are the variables identified in *Table 4.1*. During the interviews, the participants are encouraged to focus intently on when the numbers may have been changing, and to use the events identified in the beginning of the interview to aid in recalling the precise timing of these changes. Finally, for each question, the interviewer is constantly recording notes in the white space as the respondent describes when, why, and how these approaches were or were not implemented.

A significant advantage to using the mixed-methods data collection approaches (Axinn and Pearce, 2006), such as the EHC, is that the collected data are often both

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[58] I identified many of these pre-defined events while conducting the telephone interviews for Chapter 3.

[59] One of the questions has a slightly modified scale to fit the nature of the question. For M15, perception of the problem, I assign a -1 to only the customers seeing drought as a serious issue, 0 to neither the public or the system seeing it as a serious issue, 1 to only the system seeing it as a serious issue, and a 2 to both the public and the system seeing drought as a serious issue.

quantitative and qualitative. One can use the data individually for separate statistical or text analyses, but I have elected to combine the numerical data with the notes to add texture to the analyses, and hopefully improve the robustness of the findings. I first use statistical analyses to evaluate relationships and patterns between the timing of the management approaches and how they relate to drought periods. I am primarily interested in unveiling the extent to which CWS implement innovative management approaches in relation to drought events and how emphasis on these approaches changes over the 10-year period. Second, the qualitative data provided by the interview notes helps identify what managers perceive as barriers or bridges to implementing these approaches. It is important to note that during the EHC interviews, one should allow for some flexibility in the interviews, so as not to limit oneself to these variables. For example, I also asked managers to report system-specific approaches that they perceived to be particularly innovative or unique throughout the course of the interview. While not reported in this chapter, such information will ultimately help generate detailed descriptions on early adopters, leaders, and outliers that might serve as examples, ‘lessons learned’, or ‘best management practices’ for other CWS and state-level managers hoping to facilitate innovation.

2.3. Analyses

I use panel analysis to answer the first part of the research question related to the adoption of innovative approaches surrounding extreme drought events. More specifically, I compile the data from the EHCs into SPSS software and use generalized estimating equations (GEE) and cumulative logit models (CLM) to unveil statistically significant relationships between the timing and magnitude of innovative approaches (those in *Table 4.1*), and how the adoption of these approaches corresponds (or not) with the timing and magnitude of extreme droughts. I identify the management approaches as the dependent variables in these models, and the Standardized Precipitation Index (SPI) values for each CWS as the independent variables.[60] GEE is the most appropriate panel analysis method, because it accounts for dependent variable data that are likely

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[60] The SPI data are compiled for each CWS based on the climate division within which the municipality they serve resides. The SPI data are available through the National Climatic Data Center; http://www7.ncdc.noaa.gov/CDO/CDODivisionalSelect.jsp#

correlated, as is the case with the management approach variables. The CLM that I fit using GEE to compute predicted probabilities of implementing each management style as a function of droughts is the most applicable method because the dependent variables (management approaches) are ordinal and discrete.[61] While I perform these statistical analyses for each state separately,[62] I also broadly compare the results across states in the discussion section of the chapter to identify similarities and differences between Arizona and Georgia.

The 6-month SPI is most appropriate as the main independent variable, because it corresponds with the timeframe (6-month increments) on which I collect the management approach data with the EHC. For instance, the 6-month SPI for the winter 2004 period on the EHC captures the relative severity of precipitation levels during that period for the six months leading up to and including June (i.e., January 2004 through June 2004). An added benefit to using the 6-month SPI is that as a medium-term indicator, it serves as a bridge between short and long-term manifestations of drought (e.g., the 6-month SPI is often significantly positively correlated with the 3-month and 12-month SPI).

In addition to investigating the timing of management approaches for a given period with that period's corresponding 6-month SPI, I examine a one-season (six months) 'lag', and a two-season (twelve months) 'lag' of the 6-month SPI indicators as additional independent variables across all of the systems. For example, I evaluate the 6-month SPI value for winter 2004 as a predictor of management approach implementation for the summer 2004 (one-period lag) and the winter 2005 (two-period lag). This allows me to evaluate not only if there is a direct association between drought periods and innovative management approach implementation, but also whether the response is

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[61] The numbers of CWS included in these quantitative analyses are 18 for Arizona and 16 for Georgia However, for each system there generally 20 observations for each management approach (20 time periods), making total observations for each approach approximately 360 and 320 for Arizona and Georgia, respectively

[62] The levels of implementation (e.g., 0, 1, 2, 3) are not standardized across states. Managers were asked to consider what they conceive as physically possible for a system to implement, and this interpretation is likely limited to what they know about other systems in their region. In this regard, Arizona tends to generally have a more innovative approach to water and drought management than Georgia, so a '3' in Arizona is often more innovative than a '3' in Georgia. As such, an absolute comparison between the magnitudes of management implementation between Arizona and Georgia is not possible, so I separate the statistical analyses by state. However, it is possible to perform a relative qualitative comparison between the types of approaches that develop with respect to droughts and the barriers and bridges these CWS face in each state.

immediate or delayed (by one or two periods on the EHC). I infer an immediate response when the 6-month SPI (no lag) is significant in the GEE, but the lagged droughts are not significant, and delayed responses (either one season or two season delays) when the one-period lag is significant and the others are not, or the two-period lag is significant and the others are not. I also consider a response where the 6-month SPI (no lag) and the one-period lag are significant, but the two-period lag is not, as more of an immediate response. And I deduce a more delayed response when both the one and two-period lags are significant, but the 6-month (no lag) is not. These two interpretations help account for systems that might have implemented an approach near the break-point of a period (e.g., July/June or December/January), but are possibly more aligned with the preceding period. One final inference that I make is that if all three are significant, the 6-month (no lag), and the one and two-period lags, then there is an association with drought periods, but no clear indication as to whether the implementation of the approach is more immediate or delayed (there is likely a mix of immediate and delayed across CWS).

It is important to note two caveats of the panel analysis. First, I evaluate only one and two period lags because additional lag periods would omit progressively more data at the beginning stages of the timeframe; reducing the power of my results and making it increasingly difficult to distinguish significant relationships from random noise. For example, adding a third lag period (i.e., an 18-month lag) would completely eliminate the entire first year from the analysis. Another important caveat is that I only investigate a ten-year period. Some approaches might already be systematically implemented at the beginning this timeframe, making it difficult to detect longer-term relationships between dry conditions and the implementation of certain management approaches. Therefore, I specifically address these caveats by using the qualitative data to verify and identify patterns that the panel analyses uncover (and those they do not uncover), and I take these issues into consideration when interpreting and discussing the results.

After statistically analyzing patterns of innovative management adoption I turn to the qualitative data mainly to answer the second part of the research question; what is facilitating or inhibiting adoption of these approaches? This analysis serves the primary purpose of identifying dominant barriers or bridges to adaptation within and between each state. To accomplish this, I enter the hand-written notes from the EHC into electronic format for Nvivo analysis. In Nvivo, I employ two ‘waves’ of coding to identify bridge and barrier categories that managers report as reasons for or for not implementing each approach. My coding methodology allows for identification of multiple bridges and barriers for each CWS and each management approach, if identified accordingly by the interviewee. In most cases systems identified at least one bridge or barrier for each innovative approach, but there are occasional instances where a manager provides no explanation. I compile the findings by ‘counts’ within each of the bridges and barriers categories and I identify and describe the coding categories in the ‘results’ section and *Appendices 8* and *9*.[63]

An important advantage of a mixed methodology approach that uses quantitative and qualitative data, made possible with the EHC, is that the data can complement one another and ultimately lead to more robust results. For example, after performing the panel analysis, if implementation of a management approach is positively correlated with drought and immediate, the qualitative data will help identify the dominant bridges that facilitate its immediate adoption. If the approach is positively correlated with drought but delayed by one or two periods, the qualitative data will help identify the dominant barriers or reasons for not immediately implementing the approach. If the approaches are not significantly related to drought events, or are significant in the opposite direction than anticipated (i.e., they are negatively associated with droughts), then the qualitative data will help identify potential explanations for these relationships (or lack thereof), such as when the relationships with drought are perhaps longer-term or outside of the time period of study (as I referred to above in discussing the caveats of the panel analyses).

A better understanding of when and why innovative management approaches develop (or not) in relation to droughts could be useful to decision makers at various levels of management. CWS may find it helpful to know which combination(s) of innovative approaches that they and their neighbors have been implementing provide the most positive influence on drought planning and management. In a similar vein, state-level planners may be able to use the findings to formulate policies that encourage management activities that have the greatest impact on improving drought preparedness

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[63] The number of systems examined in the qualitative analysis for Arizona and Georgia are 19 and 16, respectively. There is one additional system in Arizona for the qualitative analysis because the manager had decided against providing quantitative measures for the management approach, due to time limitations.

and response. Further, they may find the results useful for more effectively timing and targeting various policies that help overcome barriers and strengthen bridges. In addition, managers and planners in states and regions outside of the purview of this study might use the fundamental components of the data collection and assessment methodology to create similar or more detailed analyses within their respective states/regions.

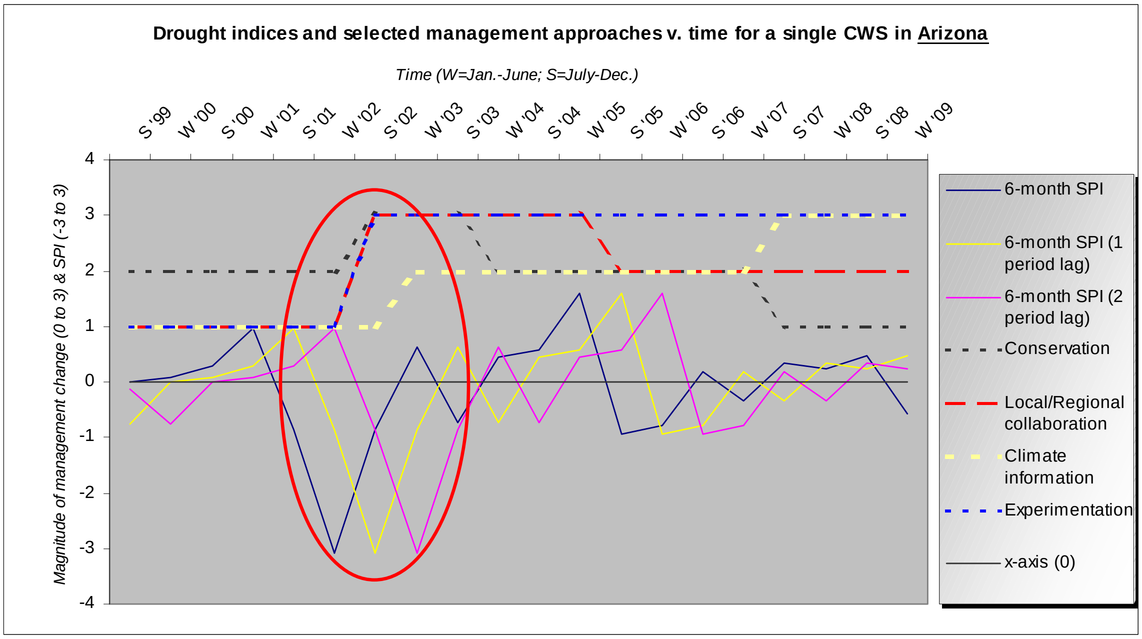
3. Results

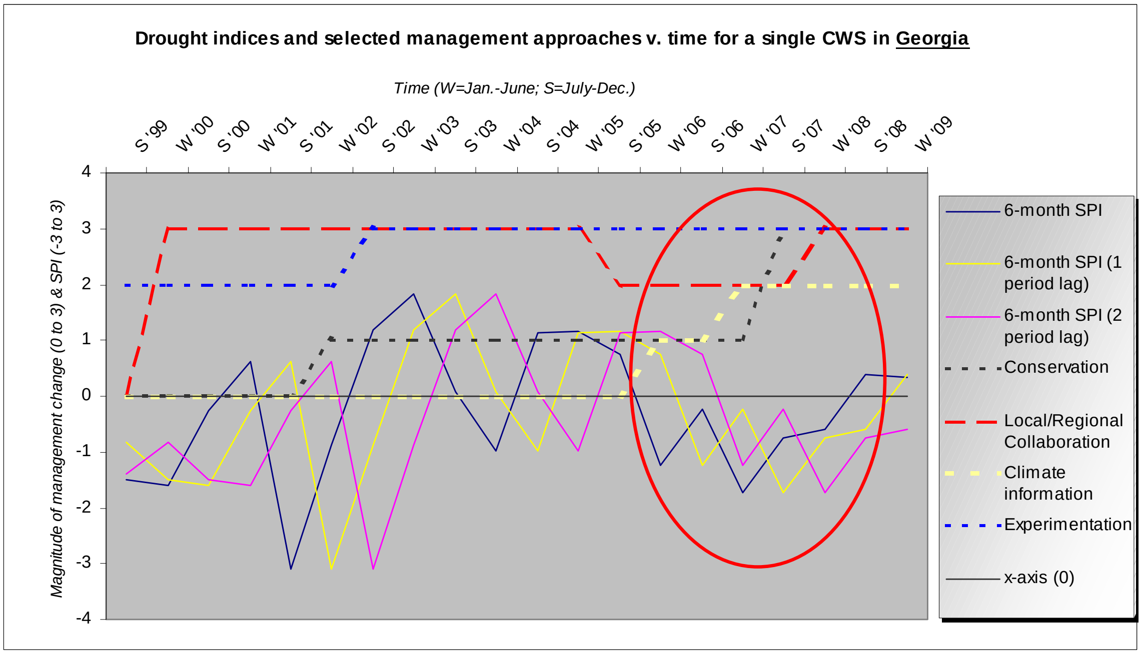
I report the results in two steps. First I compile the findings from the panel analyses for each innovative management approach, highlighting those approaches significantly associated with the drought indicators. Second, I report the qualitative coding results and underscore the most common bridges and barriers that CWS face in each state.

3.1. Timing of Innovative Approach Adaptation and Implementation

To gain a better understanding of the panel analyses that I perform in this chapter, it is helpful to visualize the management variables changing over time. The charts in *Figure 4.1* place the 6-month SPI and its ‘lags’ on the same graph as a small subset of the innovative approaches in each state. I identify drier and wetter conditions by increasingly negative and positive SPI values, respectively. The SPI is based on the standard normal distribution, where a +2 or -2 (extreme wetness and extreme dryness, respectively) are indicative of a dry or wet period that is experienced 2.3 percent of the time (Edwards and McKee, 1997). The timing of the dry period is universally defined as crossing the threshold of +1/-1 (moderately wet/dry), and ends when the sign is reversed (Hayes, 2006). Also, depending on the climate division, each CWS will have slightly different drought index values. Again, most of the values for the management variables correspond to the extent to which each was implemented during a given time period (0 = none, 1 = a little, 2 = some, but could have done more, 3 = to the fullest extent possible for a CWS). It is important to keep in mind that *Figure 4.1* displays only a handful of the management approaches for *one* CWS in each state. I include *Figure 4.1* for its illustrative nature, as it highlights the types of relationships that the panel analysis will investigate across all of the participating CWS in each state for all of the management variables. In *Figure 4.1,* the red ovals showcase examples of the types of relationships between drought events and the implementation of innovative approaches that the panel analyses will explore.

Figure 4.1: Visualizing changes in precipitation/drought and innovative approaches over time. The top graph shows an example from one CWS in Arizona and the bottom graph shows an example from one CWS in Georgia. Solid trend lines depict the 6-month SPI and its lag periods, and the dashed trend lines depict changes in four of the management variables. The red ovals identify hypothetical examples of relationships (e.g., timing between droughts and management implementation) that are explored in the panel analyses.





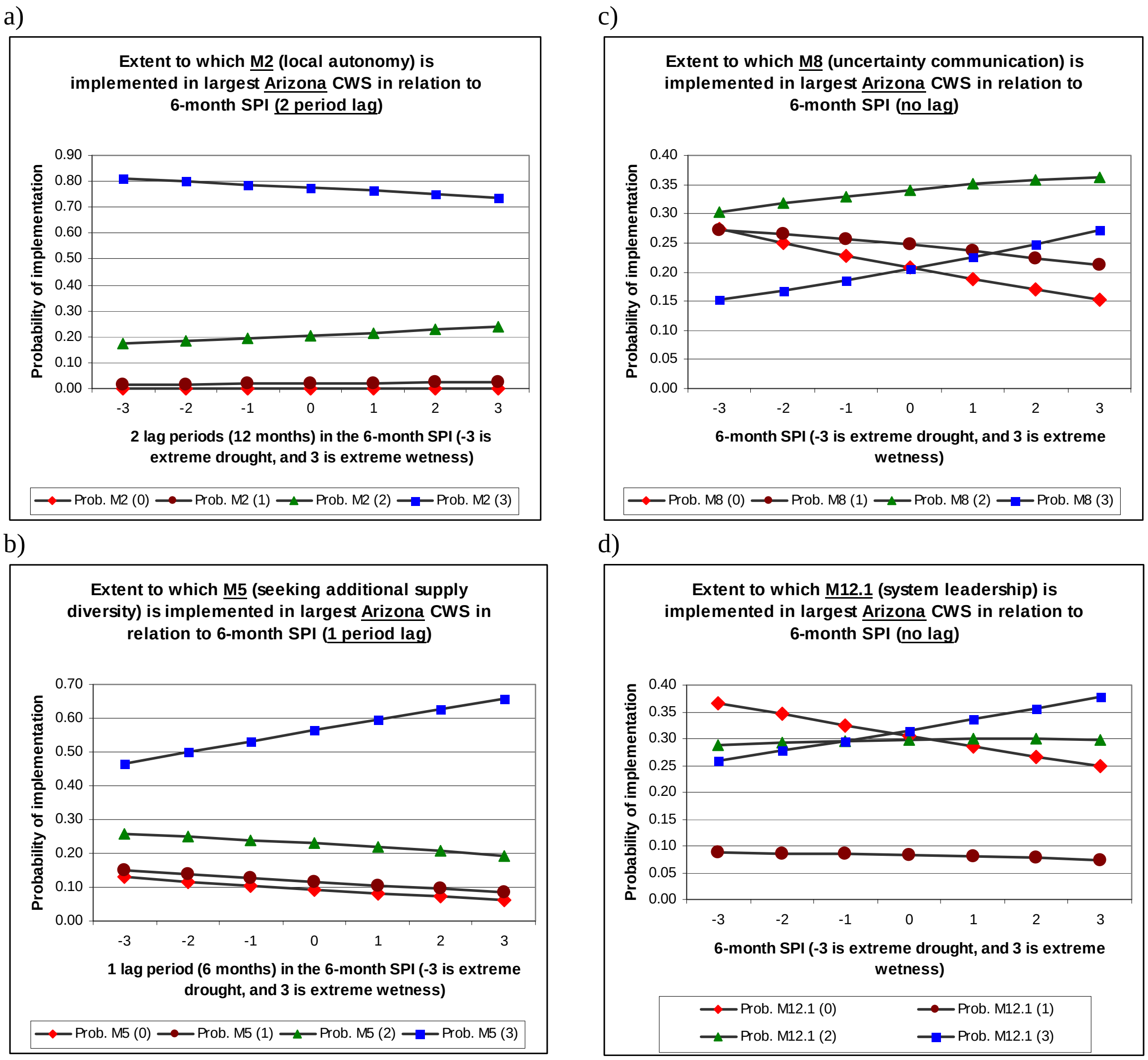
The results from the GEE panel analyses, which I perform across all systems for each state individually, are depicted in *Table 4.2*, below. The significant relationships between the drought indicators and the management approaches are bolded. One noteworthy finding illustrated in *Table 4.2* is that there are multiple management approaches in each state that show significant relationships with the drought indicators. Not only are the significant relationships often different in each state across management approaches, but there is variation in both the indicator(s) with which the approaches are associated (the current SPI and/or the lags), and the directions of the relationships. For example, there is a significant positive relationship between autonomy (M2) and the 2-period lag drought in Arizona, but not Georgia, and between conservation (M1) and the 2-period lag drought in Georgia, but not Arizona. Also, approaches in both states, such as some of the collaboration variables (M4.1 and M4.3) and long-term drought planning (M13), are significantly associated with multiple SPI categories (current, lag 1, and/or lag 2), albeit not necessarily the same categories in each state, nor with the same direction of association with respect to the droughts.

Table 4.2: Relationships between management approach implementation and drought indices. Results show the Wald Chi-Square values from the generalized estimating equations analysis, with statistical significance in parentheses. Significant relationships at the 0.10 level are bolded, with significant positive relationships between drought and the management approach shaded with thatched lines and significant negative relationships shaded in grey.

Management variables (*dependents*)		**Arizona drought indices (*independents*)**			**Georgia drought indices (*independents*)**		
		6-month SPI (current)	6-month SPI (1 period lag)	6-month SPI (2 period lag)	6-month SPI (current)	6-month SPI (1 period lag)	6-month SPI (2 period lag)
M5	Supply diversity	2.131(.144)	**7.017 (.008)**	2.415 (.120)	.264 (.608)	.174 (.677)	.347 (.556)
M6.1	Infrastructure - supply	.081 (.775)	.249 (.618)	.466 (.495)	.281 (.596)	1.517 (.218)	.024 (.876)
M6.2	Infrastructure - demand	2.026 (.155)	.072 (.788)	.468 (.494)	.191 (.662)	.087 (.768)	2.513 (.113)
M1	Conservation	.595 (.441)	.115 (.735)	.040 (.841)	.005 (.945)	1.365 (.243)	**3.130 (.077)**
M3	Rate-structure	2.585 (.108)	1.37 (.242)	.035 (.851)	1.023 (.312)	2.498 (.114)	2.328 (.127)
M4.1	Collaboration - local/regional	**8.437 (.004)**	**5.883 (.015)**	1.473 (.225)	**3.779 (.052)**	2.092 (.148)	.122 (.727)
M4.2	Collaboration - State/Fed	**3.247 (.072)**	2.605 (.107)	1.061 (.303)	.189 (.664)	.367 (.545)	2.020 (.155)
M4.3	Collaboration - other	**5.898 (.015)**	**6.898 (.009)**	**6.639 (.010)**	**5.068 (.024)**	**9.300 (.002)**	**9.052 (.003)**
M7	Climate-information and scenarios	.769 (.380)	.929 (.335)	.395 (.530)	**3.331 (.068)**	1.806 (.179)	1.982 (.159)
M8	Uncertainty communication	**7.655 (.006)**	**3.572 (.059)**	1.345 (.246)	.656 (.418)	1.431 (.232)	.216 (.642)
M9	Stakeholder and customer participation	.182 (.670)	1.759 (.185)	.397 (.529)	**2.946 (.086)**	2.098 (.148)	.098 (.754)
M10	Interaction with natural processes	.687 (.407)	.437 (.508)	.183 (.669)	.061 (.804)	.137 (.711)	1.455 (.228)
M11	Thinking 'outside of the box'	.844 (.358)	.320 (.571)	1.107 (.293)	.093 (.761)	.008 (.927)	.032 (.858)
M13	Long-term drought planning	**5.923 (.015)**	**3.345 (.067)**	.440 (.507)	2.454 (.117)	**2.980 (.084)**	**5.676 (.017)**
M2	Autonomy	1.243 (.265)	1.159 (.282)	**3.976 (.046)**	2.423 (.120)	2.387 (.122)	1.543 (.214)
M12.1	Leadership - system	**5.876 (.015)**	**4.563 (.033)**	1.014 (.314)	.002 (.965)	.220 (.639)	2.161 (.142)
M12.2	Leadership - individual	.153 (.696)	.543 (.461)	.670 (.413)	**4.735 (.030)**	**3.490 (.062)**	1.500 (.221)
M15	Perception of the problem	.980 (.322)	.540 (.463)	1.122 (.289)	**3.654 (.056)**	**7.759 (.005)**	**12.971 (.000)**

While *Table 4.2* shows the significant relationships and directionality between the management approaches and the 6-month SPI and its lags, there is no indication as to the magnitude of management approach implementation one might expect for various levels of the drought indicators. To demonstrate how one would examine such relationships, I fit CLM using the panel data for the management approaches that are statistically significant in the GEE analyses. Using the GEE estimated drought coefficients and cutpoints for level of management approach implementation (e.g., 0, 1, 2, 3), I compute predicted probabilities of implementing each management approach as a function of the 6-month SPI, one-period lag, and two-period lag, where significant. The models are helpful for predicting the likelihood of the management approach being implemented to a certain extent (e.g., 0, 1, 2, 3, or -1, 0, 1, 2) with respect to varying levels of the drought indicators (e.g., -3, -2, -1, 0, 1, 2, 3). The complete findings and raw data from the CLM are reported in *Appendix 10*. In *Figures 4.2* and *4.3* I illustrate examples of several of the CLM results for each of the states.

Figure 4.2: Arizona examples of predicted probabilities of management approaches where relationships are significant with 6-month SPI, one-period lag, and/or two-period lag values. Management approaches are highlighted in each graph's title, along with the specific drought indicator. The y-axis represents the probabilities, and the x-axis the SPI level (i.e., -3, -2, -1, 0, 1, 2, 3) for the given drought indicator. The probability of the approach being 0, 1, 2, or 3 (none, low, medium, or high) at each level of the drought indicator is depicted by the various trend lines.



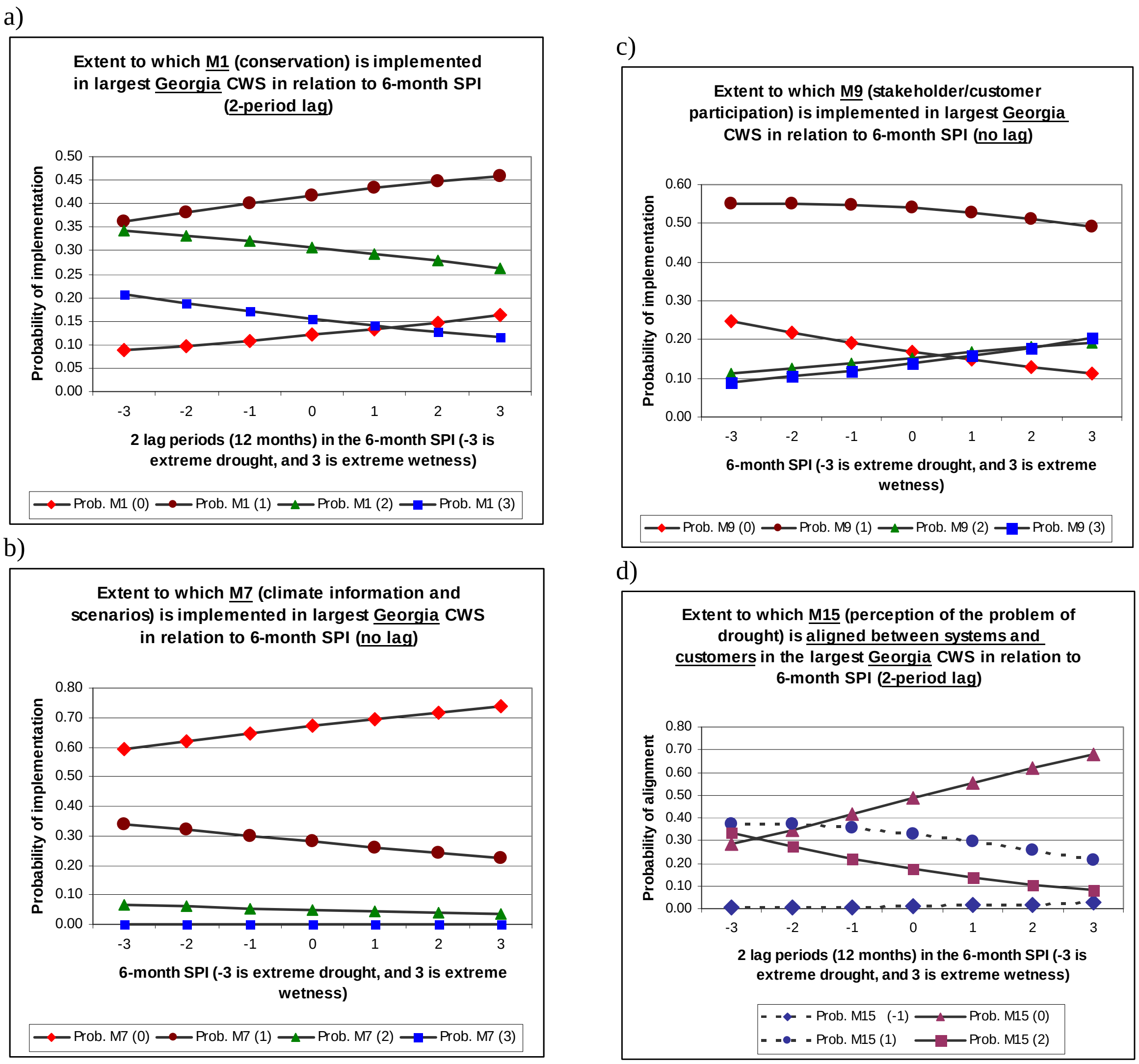
a) Extent to which M2 (local autonomy) is implemented in largest Arizona CWS in relation to 6-month SPI (2 period lag)

c) Extent to which M8 (uncertainty communication) is implemented in largest Arizona CWS in relation to 6-month SPI (no lag)

b) Extent to which M5 (seeking additional supply diversity) is implemented in largest Arizona CWS in relation to 6-month SPI (1 period lag)

d) Extent to which M12.1 (system leadership) is implemented in largest Arizona CWS in relation to 6-month SPI (no lag)

Figure 4.3: Georgia examples of predicted probabilities of management approaches where relationships are significant with 6-month SPI, one-period lag, and/or two-period lag values. Management approaches are highlighted in each graph’s title, along with the specific drought indicator. The y-axis represents the probabilities, and the x-axis the SPI level (i.e., -3, -2, -1, 0, 1, 2, 3) for the given drought indicator. The probability of the approach being 0, 1, 2, or 3 (none, low, medium, or high) or (-1, 0-, 1, 2, for M15) at each level of the drought indicator is depicted by the various trend lines.



The models illustrated above are not the main focus of this chapter. I am most interested in the directional relationships between droughts and the implementation of management approaches.[64] Still, I present these examples here to illustrate first that Arizona systems are generally predicted to have higher implementation of management approaches than Georgia across a range of selected approaches (i.e., greater proportion of 2's and 3's). Second, I include the CLM analysis to demonstrate how such modeling exercises might aid state and local decision makers. One application of this method would be for CWS to compare their patterns of implementation to similar systems to determine whether they are lagging behind or are ahead of the curve. By monitoring drought indicators, managers and officials might be able to better anticipate the extent to which a management approach may or may not be implemented in CWS with respect to the SPI; aiding overall drought preparation and response. For example *Figure 4.3, graph 'a'*, shows there is an increasing likelihood that CWS in Georgia will implement conservation measures to a greater extent as the two-period lag of the 6-month SPI becomes increasingly negative (more drought). Recognition and understanding of this positive, yet delayed association between droughts and implementation of conservation measures might help CWS, state, and local decision makers better mobilize resources to move systems from a '2' to a '3', or catalyze this response to occur more immediately, if warranted (e.g., preparing citizens for imminent extreme conservation measures, or removing barriers so as to implement the measures more quickly, etc.). Another application would be for state officials to contemplate what the ideal timing and magnitude of implementation would look like for any given approach, and then work with systems to model past behavior to compare where they are to where they want to be.

One of the most important findings from the GEE and CLM depicted in *Table 4.2* and illustrated in *Figures 4.2* and *4.3* is that there is a mix of positive and negative associations between implementing the approach and the drought indicators. Moreover, nearly all of the relationships in Arizona are negatively associated with drought, whereas Georgia demonstrates relatively equal numbers of positive and negative relationships. In

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[64] I place less emphasis on the CLM analysis in this dissertation because I am more confident in the directional relationships reported using the EHC then the reported magnitudes of implementation; that is, I am less comfortable accepting the assumption that managers within a given state interpret the scale of implementation uniformly across systems. Because of these reservations in the magnitude data, it is most appropriate to demonstrate the potential application of CLM analysis as a decision-support tool.

the discussion section, I consider these and other findings from the panel analysis in the context of the qualitative data, but first, I report the results of the coding exercise.

3.2. Bridges and Barriers for Innovative Approaches

In *Tables 4.3* and *4.4*, I display the ‘counts’ for each of the barriers and bridges categories from the qualitative data coding that I performed with Nvivo software. The broad categories are the same for both Arizona and Georgia, but the details for how a particular barrier/bridge emerges in each state can be considerably different (as noted in the discussion section, below). In-depth descriptions of each category and examples in each state are located in *Appendices 8* and *9*. The way to interpret these tables is not to focus on absolute numbers, per se, but rather relative comparisons between various barriers/bridges categories in each state.

As shown in *Table 4.3*, in Arizona, the four most common barriers are: 1) perception and cognitive; 2) financial; 3) staff, personalities, and relationships; and 4) water source, availability, and quality. The three management categories in Arizona facing the most barriers are: 1) local autonomy (M2); 2) perception of the problem of drought (M15); and 3) system leadership (M12.1). Similarly, the four most common bridges in Arizona are: 1) learning and education, knowledge exchange, and research/reports/studies; 2) financial; 3) long-term and iterative planning; and 4) infrastructure. The three management categories in Arizona with the most bridges are: 1) supply diversity (M5); 2) experimentation and ‘thinking outside of the box’ (M11); and State or Federal collaboration (M4.2).

Table 4.3: Barriers and bridges for adaptation and adoption of innovative management approaches in the largest Arizona CWS. Cells represent total barrier/bridge counts mentioned across all systems. Dark shaded cells show the most frequently cited barriers/bridges, and light shading shows the next most frequently cited. Total barriers and bridges are highlighted in yellow.

Arizona Barriers	M5	M6.1	M6.2	M1	M3	M4.1	M4.2	M4.3	M7	M8	M9	M10	M11	M13	M2	M12.1	M12.2	M15	***Barrier Total***
Communication, messaging, and the media	0	0	0	1	0	0	1	0	0	1	0	0	0	0	0	0	0	2	5
Customer demand	0	1	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	3
Demographics	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
Financial	0	2	1	1	0	0	0	0	0	0	0	1	0	0	11	1	1	0	18
Geographic and physical	1	0	0	0	0	1	0	0	1	0	0	0	0	1	0	2	0	2	8
Growth	0	0	1	1	0	0	0	0	1	0	0	0	0	0	0	1	0	0	4
Ignorance and information	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	3	5
Infrastructure	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	1	4
Institutional	0	0	2	0	1	0	0	0	0	1	3	1	0	0	1	2	0	0	11
Leadership	0	1	1	0	0	0	0	0	0	2	2	0	0	0	1	0	0	0	7
Legal and rights	2	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	4
Long-term planning	1	0	0	0	1	0	0	0	0	0	0	0	0	0	2	0	0	0	4
Perception and cognitive	0	0	1	0	0	1	3	0	1	1	6	1	0	3	0	0	1	2	20
Political	1	0	0	0	2	1	0	0	0	0	0	1	0	0	0	1	0	2	8
Regulatory, legislative, and policies	0	0	0	0	0	0	1	0	0	0	0	3	1	0	7	0	0	0	12
Risk and cautiousness	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
Size	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	2	0	3
Staff, personalities, and relationships	0	1	3	3	0	1	0	2	0	1	1	1	0	0	0	4	1	0	18
Time	0	1	0	0	0	0	0	0	0	1	0	1	1	0	0	1	3	1	9
Trust, confidence, and skepticism	0	0	0	0	0	0	0	0	1	3	1	0	0	0	0	1	0	3	9
Water source, availability, and quality	1	0	0	1	0	0	0	0	3	1	0	1	0	4	0	1	0	2	14
Management Approach Total	6	6	10	7	5	4	5	3	8	12	14	11	3	9	24	15	8	18	168

Arizona Bridges	M5	M6.1	M6.2	M1	M3	M4.1	M4.2	M4.3	M7	M8	M9	M10	M11	M13	M2	M12.1	M12.2	M15	***Bridge Total***
Communication, messaging, and the media	0	0	0	2	0	3	1	3	0	3	11	0	1	1	0	0	2	1	28
Conservation	0	0	0	0	3	0	0	1	0	0	1	0	1	1	0	1	0	1	9
Customer demand	1	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0	4
Demographics	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	2
Drought events	1	1	0	1	0	1	2	0	3	2	0	3	0	2	0	0	0	3	19
Drought planning	1	0	0	1	0	4	8	0	2	1	1	0	0	0	0	0	0	1	19
Emergencies and reducing vulnerability	2	1	1	1	0	0	0	2	0	0	0	1	0	0	0	0	0	1	9
Environmental	0	0	0	0	0	0	0	0	0	0	1	0	2	1	0	0	0	0	4
Financial	2	3	3	5	6	1	2	1	0	1	4	0	5	0	0	1	0	0	34
Geographic and physical	0	1	2	0	0	0	1	0	0	0	0	0	1	0	0	3	0	2	10
Growth	3	5	0	1	0	0	0	0	0	0	0	2	0	1	0	0	1	0	13
Historical	5	7	6	3	0	0	2	0	1	1	0	1	0	0	0	1	2	1	30
Infrastructure	12	0	0	1	0	1	3	0	0	1	3	2	4	0	0	3	0	1	31
Institutional	1	0	0	0	0	2	1	1	0	0	3	0	2	0	1	2	2	0	15
Leadership	2	0	3	1	0	2	1	4	0	1	0	3	6	1	0	0	6	0	30
Learning and education, knowledge exchange, research, reports, and studies	0	1	2	3	1	3	3	4	10	2	2	5	4	9	0	0	1	1	51
Legal and rights	9	1	0	0	0	1	0	0	0	0	0	2	3	0	0	0	0	0	16
Long-term and iterative planning	4	2	0	3	0	1	5	4	3	4	1	2	2	2	0	0	1	0	34
Political	1	0	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	1	5
Professional organizations and formal regional initiatives	1	0	0	2	0	8	6	2	1	0	0	1	2	2	1	2	1	0	29
Regional collaboration	6	2	0	2	0	0	1	0	5	0	0	2	4	4	1	3	0	0	30
Regulatory, legislative, and policies	1	0	0	5	0	2	8	0	0	1	2	1	1	2	0	0	0	0	23
Size	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	2	0	5
Staff, personalities, and relationships	1	1	0	7	0	0	0	3	1	0	0	2	4	1	0	0	7	0	27
Technical and monitoring	1	1	2	0	0	0	0	0	4	0	0	5	4	4	0	0	0	0	21
Time	4	1	2	1	0	1	0	0	0	0	0	1	0	1	0	0	1	1	13
Trust, respect, and credibility	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	1	4
Water source, availability, and quality	0	0	1	0	1	0	0	1	0	3	0	2	6	1	0	0	0	1	16
Management Approach Total	58	27	22	40	13	30	44	27	30	20	30	36	54	33	5	20	26	16	531

Table 4.4: Barriers and bridges for adaptation and adoption of innovative management approaches in the largest Georgia CWS. Cells represent total barrier/bridge counts mentioned across all systems. Dark shaded cells show the most frequently cited barriers/bridges, and light shading shows the next most frequently cited. Total barriers and bridges are highlighted in yellow.

Georgia Barriers	M5	M6.1	M6.2	M1	M3	M4.1	M4.2	M4.3	M7	M8	M9	M10	M11	M13	M2	M12.1	M12.2	M15	***Barrier Total***
Communication, messaging, and the media	0	0	0	0	0	0	1	0	0	1	0	0	1	0	0	0	0	4	7
Customer demand	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Demographics	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	1	0	1	5
Financial	3	1	1	1	2	1	2	1	0	1	1	0	0	1	5	0	0	0	20
Geographic and physical	6	0	0	0	0	2	1	0	0	0	0	0	1	1	0	0	0	0	11
Growth	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1	0	0	3
Ignorance and information	0	0	0	0	0	0	0	0	1	3	3	0	0	0	0	0	0	1	8
Infrastructure	0	1	0	1	0	0	1	0	0	0	0	0	0	2	0	0	0	3	8
Institutional	3	0	0	1	0	0	0	0	0	1	1	1	3	1	0	0	0	0	11
Leadership	0	0	0	2	0	0	0	0	0	1	4	1	1	0	0	0	0	0	9
Legal and rights	5	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	6
Long-term planning	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Perception and cognitive	2	3	0	1	2	1	1	0	1	3	5	3	1	4	1	0	2	2	32
Political	0	0	0	1	5	2	2	1	0	1	1	0	0	1	0	1	1	2	18
Regulatory, legislative, and policies	3	1	0	0	0	0	3	0	1	0	0	1	1	3	5	0	0	0	18
Risk and cautiousness	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	2	0	4
Size	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	2
Staff, personalities, and relationships	0	0	0	1	0	0	1	2	0	0	0	0	0	0	1	0	2	0	7
Time	0	0	1	0	1	1	1	0	0	0	0	0	0	1	0	1	0	1	7
Trust, confidence, and skepticism	0	0	0	0	0	0	0	1	2	6	3	0	0	1	0	0	0	2	15
Water source, availability, and quality	4	0	0	3	0	0	0	1	0	0	0	1	1	4	0	0	0	0	14
Management Approach Total	26	6	2	13	11	7	14	7	6	17	19	7	10	20	13	4	7	17	206

Georgia Bridges	M5	M6.1	M6.2	M1	M3	M4.1	M4.2	M4.3	M7	M8	M9	M10	M11	M13	M2	M12.1	M12.2	M15	***Bridge Total***
Communication, messaging, and the media	0	0	0	1	0	1	1	3	0	3	6	0	1	0	2	2	3	5	28
Conservation	0	0	0	0	3	0	0	1	0	0	2	0	0	0	0	1	0	0	7
Customer demand	1	0	1	0	0	0	0	0	0	0	0	1	1	0	0	0	0	1	5
Demographics	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Drought events	3	0	1	4	1	1	2	1	2	2	0	1	0	3	0	0	0	7	28
Drought planning	2	0	0	1	0	0	3	0	0	0	0	0	0	0	0	0	0	0	6
Emergencies and reducing vulnerability	3	0	0	2	0	1	1	1	0	1	0	0	0	0	0	0	0	0	9
Environmental	0	0	0	0	0	0	1	0	0	0	2	0	1	0	0	0	0	0	4
Financial	0	0	3	5	3	0	1	0	0	2	4	3	3	2	0	0	1	0	27
Geographic and physical	6	0	1	0	0	3	1	0	1	0	0	1	0	0	0	0	0	1	14
Growth	1	2	1	0	0	0	1	0	0	0	0	2	0	0	0	0	0	0	7
Historical	3	1	6	1	0	0	0	0	0	0	0	2	0	0	1	1	2	0	17
Infrastructure	8	0	0	1	0	0	0	2	1	1	0	6	5	3	0	2	0	2	31
Institutional	2	0	0	0	0	3	0	1	0	0	5	1	6	0	3	6	1	0	28
Leadership	1	3	3	1	1	4	2	3	2	1	4	6	6	0	2	0	7	0	46
Learning and education, knowledge exchange, research, reports, and studies	1	0	0	1	0	2	3	2	4	3	4	3	1	1	0	6	2	0	33
Legal and rights	3	0	0	0	0	1	0	0	0	1	0	1	1	1	0	0	1	2	11
Long-term and iterative planning	4	0	2	1	5	1	4	1	1	1	1	2	0	1	0	0	2	1	27
Political	1	0	0	0	1	0	0	1	0	0	1	0	0	0	0	0	1	0	5
Professional organizations and formal regional initiatives	0	0	0	1	0	16	3	1	0	0	2	0	1	0	0	7	0	0	31
Regional collaboration	4	0	0	2	0	0	0	0	1	0	0	3	1	1	0	0	0	0	12
Regulatory, legislative, and policies	2	0	0	11	9	7	7	1	1	0	1	8	5	1	0	0	0	5	58
Size	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	3	1	0	6
Staff, personalities, and relationships	0	0	1	5	0	1	0	1	0	2	2	2	0	1	1	7	7	0	30
Technical and monitoring	1	1	0	0	0	1	0	0	1	0	0	0	6	1	0	1	1	0	13
Time	0	0	3	0	0	1	0	2	0	0	0	0	0	0	0	1	1	0	8
Trust, respect, and credibility	0	0	0	1	1	0	0	2	0	1	0	0	0	0	3	1	0	2	11
Water source, availability, and quality	1	1	0	0	0	0	0	0	0	2	0	5	4	0	0	0	0	0	13
Management Approach Total	47	8	22	39	24	45	30	23	14	20	34	47	42	15	12	38	30	26	516

As shown in *Table 4.4*, in Georgia, the four most common barriers are 1) perception and cognitive, 2) financial, 3) political, and 4) regulatory, legislative, and policies. The three management categories in Georgia facing the most barriers are 1) supply diversity (M5), 2), long-term drought planning (M13), and 3) stakeholder and customer participation (M9). Similarly, the five most common bridges (two are tied for the fourth most) in Georgia are 1) regulatory, legislative, and policies, 2) leadership, 3) learning and education, knowledge exchange, and research/reports/studies, and 4) both infrastructure and professional organizations and formal regional initiatives. The three management categories in Georgia with the most bridges are 1) supply diversity (M5), 2) interaction with natural processes (M10), and local or regional collaboration (M4.1).

Tables 4.3 and *4.4* also show that CWS generally report more bridges than barriers. This is not surprising, given that these larger systems tend to be the quite innovative and are eager to share the reasons for implementing these innovative approaches. Still, there are a considerable number of barriers reported in each state. Another pattern to note is that CWS in Arizona report more bridges than Georgia, which makes sense given that there are more Arizona CWS than Georgia CWS included in this study. However, despite having fewer CWS in the analysis, systems in Georgia broadly report more barriers than Arizona. This likely has implications for the development of adaptive capacity in each state. I now consider these and other major findings as I discuss the results of the quantitative and qualitative analyses.

4. Discussion

I combine the results from the panel analysis with the coding analysis to paint a clearer picture of the dynamics surrounding drought events and innovative management adoption. First, I discuss the implementation of individual management approaches in each state; whether they are associated with drought events, along with their major bridges and barriers, when applicable. Second, I summarize broader themes within and between states that I draw from this research with respect to the timing and reasoning behind implementing innovative management approaches (or not).

4.1. Taking It One Approach at a Time

To more fully understand the timing of innovative approaches in relation to the drought events, I investigate each approach in reference to the results reported in *Tables 4.2*, *4.3*, and *4.4*, and *Appendices 8*, *9*, and *10*. Listing the approaches by classification category (hard v. soft, and mechanism v. characteristic), makes it easier to then look within and between states to identify broader patterns in the data. For each individual approach, I place the states into one of five types, following the basic guiding question: Does implementation of the management approach show a significant positive association(s) with drought events in the panel analysis (*Table 4.2*)? For each type, I ask a basic question of the qualitative data, described below.

- <u>Type 1</u>: yes and immediate
  - Question: what are the most common bridges that facilitate its immediate adoption?
- <u>Type 2</u>: yes and delayed by one or two periods
  - Question: what are the most common bridges and also the dominant barriers or reasons for not immediately implementing the approach?
- <u>Type 3</u>: yes and no clear distinction as to immediate or delayed
  - Question: what are the most common bridges that facilitate its immediate adoption in some systems and common barriers or reasons for not immediately implementing the approach in other systems?
- <u>Type 4</u>: no and significant negative association with droughts
  - Question: does this association make sense, and what do the qualitative data suggest as explanations (bridges/barriers or other explanatory events) for these relationships?
- <u>Type 5</u>: no and no significant negative association with droughts
  - Question: what bridges have allowed for its early and consistent implementation (irrespective of drought cycles), and/or barriers

that preclude its implementation (also irrespective of drought cycles)?

In discussing each approach below, I first identify the corresponding type (i.e., the bolded numbers in parentheses at the beginning of each approach's description), then report the one or two most dominant bridges and/or barriers behind the numbers in the corresponding cells of *Tables 4.3* and *4.4*. Then, for each state I also provide richer descriptions for how and why these bridges and/or barriers emerge by synthesizing the qualitative data behind the cells of *Tables 4.3* and *4.4*; offering direct quotes from the CWS managers where appropriate.

'Hard, Mechanisms'

M5: Supply diversity (Arizona, **4**; Georgia, **5**)

Supply diversity (both source and spatial diversity) has the most bridges associated with it compared to all of the other innovative approaches in Arizona. The major bridge category is 'infrastructure'. Either infrastructure decisions occurring before the period of inquiry in this study, or the completion of a specific project not directly related to the drought (e.g., surface or reclaimed water treatment plant, drilling wells, pipeline from an adjacent water source, etc.) likely makes this relationship appear negative. Another possible explanation for the negative relationship is that these oftentimes multi-year projects are in some way motivated by extreme droughts, but the lag period is out of the purview of this study. Regardless, the true relationship is probably not negative, since many of the CWS report consistent prioritization on supply diversity. For example, the following represents a common comment from Arizona CWS;

> "We were really proactive with reclaimed water, beginning in 1996…we also shifted away from groundwater and have obtained as much surface water as possible…we've also done a lot of aquifer storage and recovery and have taken old production wells and have stored some of the reclaimed water there to be recovered later."

This reflects a generally innovative sentiment around securing supply diversity that appears to have existed for many years in Arizona. CWS also frequently cited 'legal and rights' bridges, noting ongoing efforts to secure additional water rights through Native American settlements or formal watershed adjudication processes.

As with Arizona, supply diversity is also associated with the most bridges in Georgia. However, CWS in Georgia associate supply diversity with some of the more dominant barriers too. The mix of numerous bridges and barriers might help explain the lack of a significant relationship with droughts in the panel analysis. The major barrier is 'geographic and physical'. Groundwater as a diversification option is limited, due to many large CWS being located near the continental fall line. For example, one system complained that; "There is no room for reservoirs of any size. Groundwater here is not good. We may get 50 gallons per minute, but it would mean that we'd need 1400 wells to be pumping through the cracks in the rocks and the sustainability of that is questionable." These geographic issues, and also having reached physical build-out to jurisdictional borders, have precluded many systems from constructing drought contingency reservoirs. However, these drought contingency reservoirs, when built, represent important 'infrastructure' bridges for Georgia systems; particularly those that took earlier progressive actions to build them before the legal landscape for such actions turned less favorable, which highlights another important barrier in Georgia, 'legal and rights'. Here, the CWS often mention limitations on water transfers and further manipulation of stream flows as also inhibiting supply diversification.

M6.1: Infrastructure - supply (Arizona, **5**; Georgia, **5**)

This approach has always been a high priority in Arizona, as CWS consistently report constructing additional supply infrastructure as a continuous endeavor; shown by the dominant 'historical' bridge. The most common answer was a brief, but assertive "always" or "we have always been aggressive here". While many managers indirectly associate the infrastructure supply prioritization to the realities of living in an arid environment, 'growth', the second most cited reason, suggests that droughts and dry conditions are not necessarily the only or even primary reason for building additional supply infrastructure. As one system suggested; "This is ongoing. There are always new wells and new lines….and we're always adding new tanks. We have a 20-year growth plan and revisit it every five or ten years with our capital improvement program." Another system remarked; "Always. As we've grown, we've recognized that if we stop building our infrastructure and get behind the growth curve, we're in big trouble. We've had an explosion of growth here and as a result we had an aggressive capital improvement program when I came." Increasing infrastructure to meet accelerating demands and move systems 'ahead of the growth curve' has larger implications for how CWS might effectively manage future extreme droughts and climate change; that is, many conservation and efficiency gains (e.g., those mentioned in M6.2, M3, and M2 below) may be rendered imperceptible through 'hardened demand', or efficiency replaced by demand increases.

Georgia faces similar pressures from growth as Arizona. However, the urgency to build additional supply and better manage demand does not appear to be as significant as in Arizona. The major bridge for additional supply has been 'leadership', or a specific leader within the CWS that has either helped instill a 'get more water' mentality, or was an early visionary that perceived the need for additional water supplies. For example, one CWS suggested that a particular leader within the system has instilled a philosophy that; "We can't have too much. You never know what is going to happen." Leadership was also pertinent to earlier supply infrastructure decisions, as another CWS reflected;

> "In 2007, the Lieutenant Governor and others stood on the Capitol steps and said that reservoirs may be the future to solving Georgia's water problems. Well, the same thing was said during the previous droughts in the 1980s. We were fortunate to have a forward-thinking Chairman at the time that listened to this and took it seriously…He decided that we needed a new reservoir and it was constructed [in the late 1980s]."

One major barrier in this category in Georgia is 'perception and cognitive'; that is, managers feel complacent with the supply they have or feel that the ability to build new infrastructure for supply is outside of their responsibility or control.

M6.2: Infrastructure - demand (Arizona, **5**; Georgia, **5**)

As with supply infrastructure, the major bridge for demand infrastructure implementation in Arizona is ‘historical’. Keen attention to metering and fixing leaky pipes has been something that most systems have focused on basically since their inception. For example, one system noted that; “We’ve accounted for almost every drop since the mid 1970s”, and another “We’re metering everything, from day one”. Only poor relationships and dynamics between staff and departments have detracted from this focus in the occasional system; as evidenced by the most common barrier being ‘staff, personalities, and relationships’.

Although systems in Georgia generally allude to higher rates of unaccounted water loss, they too point to a ‘historical’ prioritization, not a specific drought event(s), as the driving force behind building infrastructure to better manage demand. In Georgia (and somewhat in Arizona too), CWS allude to a subsidiary explanation; that ‘financial’ motivations often underpin this historical emphasis. For instance, one CWS summed this sentiment up well, stating; “We’ve worked hard on this for a long time. If you’re losing water and there’s no revenue for it, then you need to do this.”

Looking across the ‘hard mechanism’ panel data (*Table 4.2*), there are few, if any significant relationships between the onset of droughts and the implementation of the approaches. With respect to the one negative association in Arizona, supply diversity, the qualitative data offer a counter explanation; that a generally continuous emphasis on this approach likely predates the timeframe of this study. Thus, the values tend to be generally ‘high’ in this category in Arizona, irrespective of droughts, and the association is more attributable to coincidence (or perhaps increases in population as shown by the role of ‘growth’ as a bridge in supply infrastructure). The data suggest that such an ‘historical’ emphasis on hard mechanisms is not quite as evident in Georgia, except for in the case of demand infrastructure. Interestingly, some CWS reference important decisions by predecessor leaders to build reservoirs during previous droughts. However, the CWS do not report this relationship consistently enough to make general statements about qualitative links between previous droughts and the implementation of hard mechanisms in Georgia. One general finding in Georgia is that ‘geographic and physical’ and ‘legal and rights' barriers tend to dominate the barriers to implementing 'hard mechanisms', such as the abovementioned drought contingency reservoirs.

'Soft, Mechanisms'

M1: Conservation (Arizona, **5**; Georgia, **2**)

In Arizona, both the major bridge and barrier with respect to conservation is 'staff, personalities, and relationships'. A closer look into the bridging aspects of this category reveal that systems often cite a long standing devotion to conservation (often in place prior to the past decade), as evidenced by key staff members assigned to work within the system and with the public to increase conservation and water-use efficiency. Also important are the positive relationships between staff, departments, and customers that foster a conservation mentality within the communities that the CWS serve. For example, one system stated;

> "In 2001 is when we hired our first conservation specialist. In the winter of 2006, we hired an assistant conservation specialist as a part time position. This put 1.5 employees out of 37 devoted strictly to conservation. When we got the assistant, we were really able to pick up on our water audits. That's when we come into the home and work one-on-one between the conservation specialist and the customer."

The barriers associated with 'staff, personalities, and relationships' show that departures in key personnel in charge of conservation initiatives, or adversarial relationships between staff can detract from CWS emphasis on conservation. For example, one manager confessed that; "We had a conservation person, but he left. He was here [for two years recently], but he was fired for not minding his own business."

In Georgia, there is a positive, yet delayed (two-period lag) association with this approach and droughts. The most common explanation for this delay is that CWS often feel that they have plenty of water to meet their needs when droughts begin to encroach upon their systems, as shown by 'water source, availability, and quality' being the major barrier. Hence, in Georgia, CWS often perceive conservation measures as not immediately necessary and as bringing on superfluous costs to the system (by selling less water). Related to this, the major bridge in Georgia for implementing conservation measures is ‘regulatory, legislative, and policies’. Here, conservation measures required or encouraged by the state water agency are the primary impetus for action (through the statewide water plan or the Metropolitan North Georgia Water Planning District (MNGWPD)). This bridge is summed up well by the following comment; “In 2003 the Metro North Georgia Planning District plan came out and we followed it. The plans had a timeline of implementation and we were forced to do [conservation]”. And another system commented on the Governor’s forced conservation ordinance, which most managers more fittingly refer to as restrictions or curtailment; “In 2008 was when the Governor put on restrictions in our region. They were on 100 percent….and people got used to watering on Monday and their grass still being green on Friday. They worked; they worked very well.” Based on the lagged relationship, if the state continues to be the primary facilitator of conservation and/or curtailment in the future, there is room for accelerating the timing of such conservation requirements as extreme droughts begin to develop.

M3: Rate-structure (Arizona, **5**; Georgia, **5**)

Systems in Arizona tend to have fairly aggressive rate structures that follow the ‘inverted or increasing-block’ model, which charges higher rates for greater consumption along several ‘tiers’ of water use. The predominant bridge is ‘financial’ (i.e., the systems can make more money with the rates), but systems also report implementing the rates specifically to induce a conservation ethic amongst customers through price signals. One manager’s comments captured this dual purpose of the increasing-block rate structures; “It definitely takes conservation into account, but it’s not the main criterion. It’s based mainly on meeting operational expenses and getting our revenues to match expenses.” The major barrier, ‘political’, was evident in a few CWS, which often related to pushback from a timid or politically vulnerable city council. For example, one particular system mentioned that they were; “…considering adding a fourth tier, but the Council doesn’t have the backbone now to do it…They came to us…to get money they needed for their general fund. They don’t want to make it look like they’re raising rates to pay themselves through us.”

Georgia has traditionally had flat rates, or even rates that follow the ‘decreasing-block’ model; charging higher users less to attract growth and industry presence. Barriers to changing this approach are also mainly ‘political’, as managers often try to increase rates during periods when it will be more politically palatable (e.g., lower-use winter months). A major bridge that has pushed rates toward a greater conservation focus has been through state ‘regulatory, legislative, and policy’ efforts, such as the MNGWPD and the statewide water plan. Systems also cite recent iterations of city master plans or long-term water planning as an additional bridge to more conservation-oriented rate structures. The ‘politics’ barrier and the ‘regulatory, legislative, and policy’ bridge are illustrated well by the following comment;

> “Because of the [MNGWPD] plan and the state putting on the restrictions, it was an easier sell to the Board to make [the rates] more strict. It made it easier to get public and political acceptance to bring these rates, and even so, there was some political resistance.”

M4.1: Collaboration - local/regional (Arizona, **4**; Georgia, **4**)

Both Arizona and Georgia show a negative relationship in this category as drought increases. This could be due to an insular response to drought that forces CWS to be more parochial in their approaches. However, the qualitative data suggest otherwise; specifically that both states have strong ‘professional organizations and formal regional initiatives’ bridges that have gradually bolstered local collaboration at various points throughout the past decade (or even precede the past decade). These initiatives and organizations are not necessarily attributed to droughts, but some of the data suggest that such efforts might be indirectly related to previous dry spells that stimulated cross-system conversations (making the negative relationships in both states perhaps reflective of longer relationships that are outside of the two lag periods of the panel analysis).

For example, one Arizona system recalled that; “The East Valley Water Forum really started back in the early 2000s, but it wasn’t planning around drought issues until 2006. It was primarily concerned with ground water issues, but now has gone to more of a drought focus too.” Also in Arizona, systems discussed other voluntary regional forums that include a drought focus, such as the Arizona Municipal Water Users Association and the Northern Arizona Municipal Water Utilities Association.

In Georgia, most systems specifically mentioned the Georgia Association of Water Professionals as the avenue through which they had increased their local/regional collaboration over the past decade. One manager proudly stated, "…the industry as a whole is working well together through [the Georgia Association of Water Professionals]. Over the years things have gotten a whole lot tighter and even so with our collective work on drought." Interestingly, some CWS reflected that the regulatory pressure to work together through MNGWPD and statewide water planning has been a positive influence on local/regional collaboration. For instance, one system admitted that; "Prior to the Metro District we did not talk with others, other than survey what they were doing. Now we do. We talk with others at the meetings a lot."

M4.2: Collaboration - State/Fed (Arizona, **4**; Georgia, **5**)

As with local/regional collaboration, the decreasing relationship with drought in this category for Arizona is likely due to processes preceding or extending well beyond drought periods. Most CWS attribute coordination with agencies to 'regulatory, legislative, and policies' that require it. The major motivators for the moderate level of coordination have been the Groundwater Management Act of 1980, and the more recent Governor's Drought Task Force (the regulatory impacts of these were realized many years after its creation), both of which mandate coordination with the Arizona Department of Water Resources (ADWR). As one system put it; "We've always been working with the state and federal levels, since 1980, but mainly because it's been regulatory driven."

Like Arizona, the major bridge in Georgia for this category is 'regulatory, legislative, and policies', which also represents the major barrier for state and federal collaboration in Georgia. Levels of collaboration with the State are low, and with the Federal government they are even lower. While CWS often view collaboration as an adversarial relationship (hence, a barrier), some CWS stress that the state is increasingly attempting to build a collaborative spirit. Mainly, systems speak positively of these relationships in the context of longer-term water supply and watershed studies. For example, one system remarked that; “The state basically tells us how it’s going to be, but they do try to involve the utilities. They at least listen to our concerns.” Another system offered that; “The state is seen mainly as regulators, but we do see a greater willingness to listen to our problems and wanting to address our concerns.” Thus, working to get ‘regulatory, legislative, and policies’ towards a more collaborative feel (more as a bridge and less as a barrier) might bode well for improving state-CWS relationships and collaboration (and ultimately adaptive capacity).

M4.3: Collaboration - other (Arizona, **4**; Georgia, **3**)

Collaboration across sectors and other organizations (e.g., with land-use planning departments, watershed groups, etc.) is fairly low in Arizona, and not many reasons are mentioned for this, other than ‘staff, personalities, and relationships’, or poor dynamics between personnel or departments. Perhaps droughts magnify these poor relationships, further limiting cross-sector collaboration because entities work to address their individual needs. In describing one of the other city departments, one manager described this oftentimes negative relationship;

> “They’re working in a world with another reality. One with four colors really. In fact, we should be [in the other room] with them right this minute at the State’s ‘assured water supply’ meeting, and we’re not. We were invited but decided not to go because it wasn’t worth it.”

As with M4.1 (local/regional collaboration), another possible explanation for the negative relationship is that it takes a long time to establish cross-sector collaboration processes (i.e., by the time they really get off the ground, the droughts could be over and a wet period may have developed). Managers in the CWS able to find reasons to collaborate primarily point to themselves or another strong leader for spearheading dialogue through an inter-departmental committee, or a specific research endeavor or master city/water planning initiative that commands a cooperative and collaborative process.

In Georgia, there is a positive relationship in this category with drought. The most common bridges are ‘communication, messaging, and the media’ and ‘leadership’. The data tell the story that a somewhat more inclusive city and cross-sector attitude might be developing in Georgia during droughts. Although the level of collaboration remains fairly low in magnitude, meetings, councils, and particular managers help facilitate collaboration. However, like Arizona it tends to fluctuate with local personalities and relationships; making it highly dependent upon individuals to initiate it. An example of this can be found in the following comment; "With local government agencies, it kind of ebbs and flows. It's dependent upon the local personalities…We had a good relationship with the department that I came from, because of my history there." This dependence on staff relationships and leadership provides a possible explanation for why the uptick is immediate in some systems and delayed in others, as shown by the positive relationship across all three of the drought indicator time periods. Managers might benefit from working more intently on fostering and sustaining relationships so such channels can be more quickly mobilized during droughts, or to instill an attitude similar to the system that commented; "We collaborate with them. It never hurts anything from talking. We never ignore anyone. The more at the table the better, because it's better to get the objections to what we're doing up front rather than later."

M7: Climate-information and scenarios (Arizona, **5**; Georgia, **1**)

There generally tends to be significant climate-information and scenario use in Arizona. The dominant bridge in this category is 'learning and education, knowledge exchange, research, reports, and studies'. Managers most commonly mention a tree-ring study commissioned by several of the largest water providers and conducted through the University of Arizona in the middle of the decade. It investigated Arizona climates over millennia, and helped CWS expand their understanding of what a worst-case scenario in the region might entail; ultimately leading managers to seek and use additional climate knowledge for decision making. One system summarized, "So the recent use of climate change information really signifies the moving from unreliable information to more confirmed information, as we saw with…the big 2007 [IPCC] report. That's when it really started for us then." CWS also refer to information exchange with innovative CWS in the region and nearby states, and studies conducted 'in house' that have bolstered their reliance on climate information and scenarios. The major barrier is 'water source, availability, and quality', in that some systems feel their particular source (usually groundwater) is buffered from climate changes; rendering climate information less important.

The positive and immediate uptick in climate information and scenario use in Georgia is also mainly attributed to the ‘learning and education, knowledge exchange, research, reports, and studies’ bridge. Managers point less to a specific report or study and more to heightened awareness during the recent drought period as increasing climate information use. However, the increase is generally from no use at all to low use, and no CWS report ‘high’ use in this approach. As one system put it; “We are more aware of longer and more severe droughts, so it’s something that’s on our radar.” Furthermore, the information is more likely related to climate variability and not necessarily climate change. This helps explain why the main barrier to adopting this approach is ‘trust, confidence, and skepticism’ surrounding the issue of climate change, or a general disbelief that CWS should be preparing for climate impacts. For example, one system opined; “We’re conscious of climate change, but as far as it being important to us? Personally, I’m not sure if it’s long term drought or climate change. Is the human influence statistically valid? I don’t know.” Taken together, the bridge and barrier suggest that an increased receptivity during drought events might serve as opportunities to overcome skepticism and train managers to use climate information, since associated impacts are fresh in their psyche.

M8: Uncertainty communication (Arizona, **4**; Georgia, **5**)

Clearly articulating the uncertainties associated with water management is a difficult task, but CWS in Arizona that are able to accomplish it point to ‘long-term and iterative planning’ as the major motivating force or bridge. Some managers have designed recent iterations of the planning process to include multiple scenarios for droughts, water availability, and demand to improve this communication, and others highlight recent plans’ conclusions as dramatically shifting their philosophies for how they talk with customers about uncertainty. Still, the negative association with droughts might be related to the major barrier facing uncertainty communication in Arizona; ‘trust, confidence, and skepticism’. Some of the systems’ customers convey a nervousness about water supply issues during droughts; fears that are often exacerbated during drought periods. One CWS proclaimed;

> "We don't communicate uncertainty, but rather the need for diversifying our portfolio. What we want is confidence in our customers' minds; for them to know that we will sustain our water supply. At the same time we want to emphasize that it's limited."

In drought circumstances, systems have to walk a fine line between emphasizing conservation and downplaying supply uncertainty to boost customers' confidence in the system; hence the decreasing relationship here with droughts.

Managers in Georgia cite 'communication, messaging, and the media' bridges for improved uncertainty communication; particularly through formal public education campaigns. Like Arizona however, there is a significant barrier conveying this information to CWS' customers; 'trust, confidence, and skepticism'. Managers were blunt in saying things like; "Communicating to the public that we don't know what we're doing is a bad idea"; and "The average customer is oblivious, and we want them to be. As long as they turn on the tap and water is there, we're doing our job." Thus, many systems in Georgia report that despite their efforts to increase channels for communicating uncertainty, they still prefer an 'out of site, out of mind' approach.

M9: Stakeholder and customer participation (Arizona, **5**; Georgia, **4**)

As with communicating uncertainty (M8), managers are reluctant to take any action to engage the public in water management processes in both states. While some CWS in Arizona see stakeholder participation as mudding the decision-making process for the worse, many of the systems welcome it with multiple avenues for public involvement (e.g., public meetings, community water committees, etc.), hence the 'communication, messaging, and the media' as the dominant bridge. Whether the public uses these avenues, however, is a different story altogether. In some cases, apathy prevails as a 'perception and cognitive' barrier. One system complained;

> "The avenues for participation are there, but they're rarely used. We provide literature for distribution and invite the public to the Board meetings, but it's

> seldom, if ever that we get people showing up. It's apathy until something goes wrong."

Thus, not surprisingly, it is rare that the public are offered and/or engage in the opportunity to participate in more strategic decisions like drought and water resources planning.

Systems in Georgia also refer to 'communication, messaging, and media' and 'institutional' bridges in the form of websites, marketing materials, water board meetings, and even the occasional city water council or citizen academy. Also similar to Arizona, there are major 'perception and cognitive' barriers – mainly the apathetic attitude of customers towards water issues. These barriers are increasingly problematic in Georgia, particularly since there is less of a conservation ethic to begin with in the state. Interestingly, some of the systems are adamantly opposed to public and stakeholder participation, justified by their belief that the public is not informed enough to make a meaningful contribution, particularly during periods of drought (hence the negative relationship). These 'leadership' barriers are evident in several of the CWS comments; "We want an educated public, but on other decisions like long-term supply, their input is not beneficial. It's not a democratic process, nor should it be."; and then there is the system that likens the CWS-customer relationship to a doctor-patient dynamic;

> "When you have a problem, when you're sick, do you ask all of your friends which operation you need, or do you ask the doctor? It's the same in our system. If there are experts that might have insight into an issue we'll listen to them for sure."

While these are valid concerns, particularly in the short-term, if stakeholder and customer participation does in fact contribute to adaptive capacity, then these CWS attitudes definitely represent barriers to achieving such participation. Thus, the negative and immediate association with this approach and drought in Georgia suggests that under crisis circumstances like drought, these negative attitudes and a de-emphasis toward participation from managers might prevail over the bridges they have laid to foster public involvement.

M10: Interaction with natural processes (Arizona, **5**; Georgia, **5**)

In Arizona, the dominant barrier for considering connectivity between water management decisions and natural processes is ‘regulatory, legislative, and policies’. Several CWS point specifically to the ADWR, the Groundwater Management Act, and the Central Arizona Groundwater Replenishment District as not sufficiently reconciling surface and groundwater processes and policies. Some suggest that these barriers encourage ‘lock-up’ of the aquifer through ‘paper exchanges’ of water (i.e., pumping in the aquifer and replacing it in another location not connected to the aquifer, or with water that hypothetically exists underground, but overdraft has made physically disappear – making it only a ‘paper’ right). Still, some of the same CWS hold out hope that ADWR will soon formally recognize a connection between surface and water resources. Major bridges relate to ‘learning and education, knowledge exchange, research, reports, and studies’ and ‘technical and monitoring’. Specifically, modeling of resources, formal studies, and ‘in-house’ research help the systems learn about natural processes within their communities. Two particular comments capture these bridges. First;

> “There is a direct relationship between us and the water resources. We’ve known that and that’s why we track things so closely…About 14 percent of the water soaks into the granite rocks…We’ve had to learn about the nature of how this area works to get here where we are.”

And the second comment;

> “In [the late 1980s] we had a ‘recharge only’ engineering mentality. If a weed grew, we killed it because it would have taken our water. Well, we noticed that even in these sterile conditions, people were looking at 100 different species of birds with a telephoto lens. So we integrated habitat into the process and learned a lot. We may have been the first in the state to pull the lining out of our ponds and let the plants grow.”

Systems in Georgia primarily reference ‘regulatory, legislative, and policies’ as the motivating force behind implementing this approach. Either because the state requires them to through withdrawal and consumptive use permits, or because CWS anticipate future mandates, systems frequently attribute the consideration of natural processes to regulations. This regulatory bridge relates to the dominant barrier, ‘perception and cognitive’. While managers in Georgia generally convey a strong commitment to this approach, the occasional system perceives this approach as outside of their control and/or responsibility. Thus, there is an interesting interplay between regulation facilitating the approach and complacency from the regulation that serves as a barrier to the approach (similar to some of the state-CWS tensions discussed in Chapter 3).

M11: Thinking 'outside of the box' and experimentation (Arizona, **5**; Georgia, **5**)

Both Arizona and Georgia cite ‘leadership’ as the most prominent bridge to experimentation with novel approaches and ‘thinking outside of the box’. Specifically, CWS in both states point to changes in senior-level management or local government officials that brought this type of thinking with them. For example, in Arizona, one system summed it up well;

> “[The Director] has really brought this on more so. He is a really inquisitive fellow. He’ll come up to you and ask these questions, ‘Do you know what will happen to ‘x’ if we do ‘y’? Do you know?’ And if you don’t he’ll say, ‘go find out – go do it.’ He wants to know what will happen. Before [the Director], we didn’t really have the opportunity to do that, and we weren’t thinking that way.”

And in Georgia, one manager specifically said; “We have this formal [experimentation] process, but we also do it on an informal basis too. The more formalized process was started, or I should say expanded upon by me when I got here.” In Georgia, many CWS link these changes in leadership structures with a subsequent shift in the institutional culture of the system towards innovation. They report strong support for taking technical risks and a ‘not take no for an answer’ attitude that has developed within their systems. For example, one system remarked; “We’ve got an attitude here that’s all about continuous improvement. It really instills pride when we do things better.” And another system confirmed;

> “Thinking outside of the box is a priority. The last thing people will say in my office is that we’re doing it that way because that’s the way we’ve always done it’…and I tell my staff this all the time – they don’t pay us to tell them that we can’t do it. We’re paid to think of how to make it happen.”

While this institutional culture seems more generally established in systems across Arizona, managers in Georgia are perhaps more eager to share these experiences, perhaps because they perceive them to be more novel and recently innovative.

M13: Long-term drought planning (Arizona, **4**; Georgia, **2**)

In Arizona, the clear frontrunner in the bridge group for this approach is ‘learning, education, knowledge exchange, and research and reports’. Studies on Colorado River flow with the Bureau of Reclamation, the tree-ring research described earlier (in M7), tools made available through the Regional Integrated Sciences and Assessments (RISA), and ‘in house’ analysis of local drought indicators help lead to planning for droughts on longer and longer time scales. For example, one system recounted that that their drought planning has been aided by;

> “…looking at CLIMAS [the RISA] and long-term projections on Colorado River flow. And we know that a recent Scripps study says that the time will come when the Colorado will not meet all of our needs – especially in the Lower Basin states…So in the next 20 years we’ll be looking for ways to meet the customers’ needs without this water.”

The timescales upon which this learning takes place however, may mask a positive relationship with drought events. In other words, the relationship likely appears negative in the panel analysis because the research and studies that may or may not have been spurred by drought periods (e.g., the tree ring study) take fairly long to conduct and then internalize. As one system recalled; “[Drought planning] has extended because we’ve changed some of our assumptions…We assumed that we would never have a shortage on the Colorado River, but that study made us change our assumptions.” Turning to the major barrier to long-term drought planning, ‘water source, availability, and quality’, those systems that perceive their water to be climate-proof commonly refer to their aquifer as their long-term drought plan. For example, one CWS confessed that; “If the Salt River Project (SRP) and the Central Arizona Project (CAP) were to reduce flows, we’ve got water below us and we’ll pump and deliver it even if the state told us we couldn’t. Our drought strategy, our backup plan, is our aquifer.”

Managers in Georgia directly reference specific 'drought events' and also 'infrastructure' as the major bridges for this approach. Thus, the positive relationship depicted in the panel analysis between this approach and drought in Georgia is not surprising, given that CWS were often quick to mention the drought directly as the reason for increased long-term planning. For example, on system remarked;

> "[Long-term drought planning] has increased of course with these two droughts in the past decade. The last one was more severe. We used to get a little rain during the droughts which allowed the system to recover, but with this drought there were a lot of periods with no rain…So since the droughts we've started to do more things with supply and storage."

This result is somewhat contradictory to the relationship described in Arizona, above. Perhaps the difference is more associated with the level of magnitude of the approach in Arizona versus Georgia. In Arizona, there is already considerable long-term drought planning. Whereas in Georgia, there is more room for increasing long-term drought planning, for example, by conducting feasibility studies for drought contingency reservoirs. The delayed response in Georgia is also interesting, and perhaps explained by the major barriers, 'perception and cognitive', and 'water source, availability, and quality'. CWS tend to question why longer term planning is useful, given that the state and region receive historically abundant amounts of rainfall, and droughts typically last a maximum of three years. The back-to-back droughts during the past decade may have served as an impetus to consider longer-term planning (as also evidenced by the slight uptick in climate information use in M7), but the perception barriers around their water sources are difficult to overcome; hence the lagged association.

Looking across the 'soft mechanisms' panel results (*Table 4.2*), one major pattern appears to be mainly negative relationships or no relationships in Arizona, and a mix of positive and negative relationships in Georgia. The negative relationships are particularly interesting, and the qualitative data offer three potential explanations for such relationships. Starting with Arizona, the relationship may truly be negative with drought, as suggested in the collaboration (M4.1 and M4.3), and uncertainty communication (M8) approaches. With collaboration, there is a small amount of evidence suggesting that systems might respond to drought by becoming more insular, parochial, and introverted to address their individual systems' needs, but a truly negative relationship might actually be more closely associated with uncertainty communication. Here, the desire to instill confidence and trust over a sense of panic might help explain this negative relationship in Arizona. This highlights the important role of 'trust, confidence, and skepticism' barriers within CWS and their publics in Arizona.

An alternative explanation for the negative associations between droughts and 'soft mechanisms' in Arizona is either that they are actually positive relationships, or that there is simply no direct association. That is, the processes initiated by the approach, or the approach itself, develop over longer periods of time and/or are outside of the ten-year period I assess in this study (no lag, one-period lag, and two period-lag), and may or may not be directly related to drought cycles. The qualitative data provide evidence to support such a positive relationship with respect to some of the approaches, particularly in the state coordination (M4.2) and long-term drought-planning (M13) approaches (with some evidence in local/regional collaboration (M4.1) and cross-sector collaboration (M4.3) in the systems that are able to find ways to collaborate through long-term city planning initiatives). With M4.2 and M13, processes like a tree-ring research study and the Governor's Drought Task Force ultimately resulted in CWS drought conservation and preparedness planning three to five years after the extreme drought period. A factor supporting the apparent lack of association argument is that CWS in Arizona are generally innovative in their drought planning and management approaches to begin with.[65] Thus, the negative associations could be more attributable the higher overall values in these approaches, such as the collaboration variables (M4.1, M4.2, and M4.3), that is, they already had relatively high levels of the approach preceding the decade. I discuss this issue further after reviewing the 'soft characteristics' approaches, below.

The negative associations in Georgia may actually be occurring for similar reasons as in Arizona. First, a true negative relationship may be evident in public and customer participation (M9). Here, CWS report decreased interest in engaging stakeholders in the decision-making process because the stakes are too high and the public's knowledge too low during droughts to justify their involvement. M9 also unveils

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[65] This aligns with the results from Chapter 3 that show Arizona CWS as generally more adaptive than the other two states.

important ‘trust, confidence, and skepticism’ barriers, similar to the case of uncertainty communication (M8) in Arizona. In local/regional collaboration (M4.1), there seems to be processes established as a result of an earlier drought period, from which the impact on the approach’s implementation occurred several years after the drought (suggesting a positive relationship not captured by the time-lags investigated in this research). Here, the most commonly cited processes are the MNGWPD and the statewide water planning efforts initiated in the early 2000s, but which did not really affect systems until the mid 2000s.

Interestingly, there are a number of approaches that appear to be positively associated with drought development in Georgia. Some show evidence of a more immediate relationship (i.e., not lagged), such as climate information use (M7), and to a lesser extent cross-sector collaboration (M4.3). M4.3 is also associated with lagged responses during droughts. Both conservation and (M1) and long-term drought planning (M13) show even clearer lagged relationships. There are important local nuances for why these ‘soft mechanisms’ develop (or not) in Georgia (and Arizona too for that matter). Still, the major bridges that contribute to the more immediate relationships with drought (i.e., not lagged) in Georgia are ‘learning and education, knowledge exchange, and research, reports, and studies’ that occur as droughts develop, and ‘professional organizations and formal regional initiatives’ (e.g., Georgia Association of Water Professionals and the MNGWPD) that serve as enabling platforms for quick information exchange and collaboration. ‘Leadership’ is also a very important bridge for fostering many of these ‘soft mechanisms’ (this is generally the case in Arizona too, along with ‘staff, personalities, and relationships’), as well as ‘regulatory, legislative, and policies’ bridges. The major barrier that might help to explain the positive, but lagged or temporary responses in Georgia, is ‘perception and cognitive’ issues. In other words, managers often see water resources and drought cycles as fairly easy to manage and predict (e.g., historically abundant rainfall and shorter drought periods), and are thus less reluctant to invest time and resources into more consistently emphasizing or implementing these ‘soft mechanisms’. This is particularly evident in climate information (M7), conservation (M1), and long-term drought planning (M13). Such barriers are reflected in the broader conclusion that Georgia has lower levels of innovation across many of these ‘soft mechanism’ approaches than Arizona; again, an issue to which I return after discussing the ‘soft characteristics’.

‘Soft, Characteristics’

M2: Autonomy (Arizona, **2**; Georgia, **5**)

This is the only approach in which Arizona shows a positive association with drought events (here a two-period lag). Local flexibility in decision making is generally high across systems and it increases with droughts. ‘Trust, respect, and credibility’ bridges between systems and other layers of governance seem to ‘grease the wheels’ of decision making and increase system autonomy during droughts. The dominant barrier is ‘financial’, revealing that although trust and credibility increase local autonomy, capital improvement programs and other financial decisions perhaps motivated during drought periods require several layers of approval (e.g., Boards, Commissions, etc.) before some of their decisions (and autonomy) can be exercised. A common explanation was; “[The Council or Board] approves the rates, the master plans, the technical assessments, the codes and ordinances, and the policy proposals. Once they’re done though, we’re free to operate.” Systems see checks and balances as ‘necessary evils’, but nonetheless, fostering more trust and credibility between CWS and their Councils/Boards may help more immediately increase flexibility and autonomy surrounding drought events.

Georgia’s major barriers to autonomy and flexibility are both ‘financial’ and ‘regulatory, legislative, and policies’. Both barriers are similar to Arizona’s, due to multiple layers of approval for local policies and capital improvement programs. Furthermore, systems occasionally reference the economic recession for lower levels of autonomy and flexibility, which may help explain why there is not a direct relationship with drought events (but instead more aligned with economic cycles). For example, one system reflected that; “There was a lot more flexibility before things got tight with the economic downturn…but during the times when we were booming though, we could basically buy whatever we wanted.” As with Arizona, CWS in Georgia that are able to get past such flexibility hurdles are mainly able to do so through well-established, ‘trust, respect, and credibility’ bridges that have been institutionalized within the local governance model (e.g., the Board/Council has grown to trust and respect the system's opinion).

M12.1: Leadership - system (Arizona, **4**; Georgia, **5**)

As mentioned in the discussion of many of the 'soft mechanism approaches', leadership is an important bridge, particularly in fostering experimentation and innovation. But what motivates this leadership? For the system to project itself as a leader amongst other systems, there are several important bridges in Arizona. First, managers point to their larger system 'size' and 'geographic and physical' (i.e., proximity) factors in relation to other smaller systems as bridges for CWS leadership. Systems often made comments such as; "Recently we've had some interest from some of our smaller neighbors that are now looking to us.", and; "They look up to us. We have people visiting from neighboring municipalities today…" Similarly, a 'regional collaboration' bridge, or an inclusive perspective on water resource management seems to have developed in many of these urbanized areas in Arizona, often around a specific infrastructure project. This encourages systems to push, pull, and challenge one another along the way to improve and innovate. For instance, one system reflected; "Now everyone sees it as we're in it together. It's more of a regional perspective to management." As with some of the 'soft mechanisms', there is little qualitative evidence to support the negative relationship with drought shown in the panel analysis. Instead, the general regional perspective and the dynamic where systems encourage one another seem to have existed for periods preceding this study. This is shown in the occasional barrier to system leadership, 'staff, personalities, and relationships', or when the CWS lack the staff and resources needed project themselves as a leader and build relationships across their respective region.

Georgia systems highlight 'staff, personalities, and relationships' as the major bridge contributing to system leadership. In many cases the CWS specifically reference 'professional organizations and formal regional initiatives', another major bridge, as affording them the opportunity to showcase and exercise this leadership. Staffs routinely present research, projects, and innovations at Georgia Association of Water Professional meetings and American Water Works Association conferences. Not only are these forums important for information exchange, they also help instill a sense of pride and ownership within their staffs. One CWS summed up these bridges well; “There’s a huge system leadership emphasis. We’ve gotten all kinds of Georgia Association of Water Professional awards…We tour people around here every chance we get and show off the system every chance we get. It’s a philosophical imperative for us.”

M12.2: Leadership - individual (Arizona, **5**; Georgia, **4**)

For this approach, I ask managers whether the system relies on one key leader, or multiple leaders to bring about innovative management approaches within the system. The assumption is that more innovative and adaptive systems are those within which a culture of leadership has been institutionalized throughout the CWS (i.e., not dependent on a single leader). Systems in both states articulated a somewhat surprising response in that the two are not necessarily mutually exclusive. That is, CWS often pointed to ‘staff, personalities, and relationships’ and ‘leadership’ as an important bridges for bringing about an overall innovative team and leader-laden team. In other words, to institutionalize innovation and leadership it first takes a strong leader or several strong leaders at key staff posts to enable it. For example, systems commonly mentioned a strong team that developed after individual ‘x’ arrived, or a staff within which a strong team dynamic forms through the senior-manager challenging them to excel and then take ownership over an aspect of the CWS. Several direct quotes help to further illustrate these points: First, Arizona CWS made comments such as; “…people were really on their own. I brought in leadership and began letting other staff lead their people too; and “When I was first interviewed, they asked my style of management and I told them, ‘I hire smarter people than me and then I get out of their way’, and this is true”; and “We’ve employed out of the box thinking. I can’t point to one person. It’s really all over the place here. If someone has an idea, everyone will quickly pick it up and they’ll pass the ball along and take it for awhile and run with it.” Also in Georgia, similar comments were prevalent; “…this institutionalizing depends on a key guy though wanting it to be institutionalized…So even institutionalizing is dependent on a key leader to communicate what they want”; and “…but if the leadership is not pushing it, it won’t stay that way…I’d really say that it became more institutionalized as the leaders have been more innovative"; and finally "We have good people but we instill it in our up and coming. It's a cultural thing".

In Arizona, 'time' serves as the most cited barrier. Institutionalizing innovation and leadership and forming a solid internal team does not occur immediately, but rather takes the right timing and placement (sometimes serendipitously) of leaders at a particular moment to allow for its development. In Georgia, the major barriers are 'perception and cognitive', 'risk and cautiousness', and 'staff, personalities and relationships'. These all relate back to the 'leadership' bridge though, as CWS often cite instances when key leaders were unable to overcome unmotivated or disengaged staff, or were hesitant to push employees to take chances and 'stick their necks out'. Finally, based on these qualitative data, there is little evidence explaining the negative relationship in Georgia between this innovative approach and droughts. It is likely more closely related to the longer time periods for an innovative culture to develop. For example, one particularly innovative system in Georgia remarked; "The key is that the process has been 30 years in the making. And it's been a long team effort throughout the whole deal."

M15: Perception of the problem (Arizona, **5**; Georgia, **3**)

In the qualitative data, both states report an increase in alignment between CWS and their publics perceiving drought and climate change as serious problems as droughts develop. This is evident in that 'drought events' represent the major bridge in both states. The relationship, however, is only statistically significant in Georgia, and it occurs at all three timescales (no lag, one-period lag, and two-period lag). This relationship reflects several potential dynamics occurring in Georgia CWS. Some systems report that they are always on the 'same page' as the public by effectively conveying to their customers when drought is a problem or not (usually it is mutually perceived as a problem only during drought events, although the occasional system sees it as a continuous long-term issue). This is demonstrated in *Figure 4.3, graph 'd'*, in that as drought increases, there is an almost one-to-one relationship between '0' decreasing (neither see it as a problem) and '2' increasing (both see it as a problem). Other CWS suggest that a lagged response is more evident in Georgia, which fluctuates with media attention or 'hype'; that is, they are only aligned with one another when the messaging becomes dire (as droughts peak). For example, on system remarked; “There was a period during the drought when there was some hysteria.” ‘Communication, messaging, and the media’ is further emphasized as a barrier in those situations when CWS do not perceive drought as a problem, while their customers interpret it as a problem. The general sentiment within CWS that they have a better understanding about droughts than the public is alluded to in statements such as; “The public spends part of its time being confused [by the media] about the water issue in the state.”

The dynamics around perception in Arizona are similar to Georgia, albeit not a statistical relationship with the onset of drought. CWS often report ‘communication, messaging, and the media’ barriers, or a particular situation when news outlets over-hype the issue, which occasionally engenders fear in the public. For the most part though, CWS cite ‘ignorance and information’ barriers, specifically criticizing their customers for possessing a blissfully ignorant attitude toward drought problems. On the surface, this might appear to contradict the picture that I have been painting of an innovative culture of conservation in Arizona. However, while CWS are very innovative and customers are well adapted to the need to conserve, customers tend to be either desensitized or apathetic to the added stress of a drought event. Moreover, when the public actually perceives drought as a serious issue, ‘trust, confidence, and skepticism’ barriers prevail. In this case their ‘blind trust’ or over-confidence in CWS to handle the problems helps them ‘wash their hands’ of the issue. The following quote highlights this problem in Arizona quite well;

> “From the customer’s standpoint, even if we get them the information on the seriousness of drought and climate change, I’m not sure they appreciate the long-term impacts. There’s a lot of apathy. The mass population sees us, the utility, as always being there no matter what, and they don’t need to think about it.”

Looking across the ‘soft characteristics’ panel data (*Table 4.2*) there are a mix of positive and negative approaches in Arizona and Georgia. In Arizona, autonomy (M2) represents the only statistically positive relationship across all of the innovative approaches examined in this study. ‘Trust, respect, and credibility’ bridges help to facilitate increased autonomy during droughts, while ‘financial’ factors perhaps limit a more immediate response. In Georgia, the perception of the problem of drought (M15) highlights the role that droughts play in helping align public and CWS perceptions, while ‘communicating, messaging, and the media’ represent significant barriers to aligning perceptions. Importantly, this is also an issue in Arizona, but CWS in this state suggest that ‘ignorance’ and ‘trust, confidence, and skepticism’ limit customers from taking their conservation-oriented mindsets to the next level during droughts.

The possible explanations for the negative relationships are similar to those discussed previously with respect to the ‘soft mechanisms’. Specifically, the negative relationships between drought and system leadership (M12.1) in Arizona, and individual leadership (M12.2) in Georgia, are likely due to dynamics that are out of the frame of this study (i.e., the approach was implemented well before the last decade, it takes long to develop with respect to droughts, or it is related to another non-drought factor altogether). It is also important to note in the system leadership approach it appears that ‘size’, ‘geography and physical’, and ‘regional collaboration’ bridges combine to create a long-standing and relatively informal collaborative dynamic amongst neighboring CWS in Arizona. Such a dynamic is somewhat evident in Georgia CWS too, but it mostly relates to individual systems sharing their experiences through professional organizations (less informal collaborating). Finally, in the individual leadership approach we learn that in order to instill a culture of innovation and an overall team of leaders, it takes a key individual (or several key individuals) to facilitate this dynamic in both states.

4.2. The Broad Picture and Implications for Adaptive Capacity

It is helpful to compare across the groups of innovative approaches, as classified by ‘hard mechanisms’, ‘soft mechanisms’, and ‘soft characteristics’. As expected, the ‘hard mechanism’ approaches tend not to show significant relationships with drought events, whereas the ‘soft mechanisms’ and ‘soft characteristics’ show a mix of positive and negative relationships. The ‘hard mechanisms’ finding suggests that droughts themselves do little to motivate the implementation of some of the slower-moving, long-term decisions like building additional infrastructure. A closer look at the differences between how ‘soft mechanisms’ and ‘soft characteristics’ develop in Arizona versus Georgia reveals interesting insights into the development of adaptive capacity.

First, it is important to note that the qualitative data reveal characteristics, processes, factors, and attitudes within each state and even within each individual CWS that are crucial for contributing to adaptive capacity. This is particularly evident in how the bridge and barrier categories, while sometimes the same between both states' CWS, are usually quite different. Thus, the nuanced explanations that emerge from the qualitative analyses offer challenges and opportunities to building adaptive capacity, not only in examining each of the innovative approach categories, but also in investigating some of the tensions that surface when looking across states. For example, 'regulatory, legislative, and policies' barriers and bridges are manifested quite differently between states. In Arizona, CWS infrequently refer to this category, and when they do, it is mainly that they see the need for more comprehensive policies that deal with ground and surface water concurrently. In Georgia, CWS often refer to state 'regulation, legislation, and policies' as a bridge or impetus for implementing innovative approaches. At the same time, CWS also frequently describe 'regulation, legislation, and policies' as a barrier, which reveals that there is a careful line that the state must walk between encouraging/mandating innovative approaches (i.e., adaptive capacity) and letting them develop organically. This finding is similar to the tension between states and CWS that I discussed in Chapter 3.

There are several more examples where the Arizona and Georgia cases unveil the tensions in building adaptive capacity. Finding the right balance between instilling trust and confidence without making the public complacent, desensitized, and ignorant is evident in multiple examples in Arizona as well as a few instances in Georgia. Also, there are interestingly different processes between the two states that have fostered a regional sense of collaboration and innovation. In Arizona, it has been a relatively natural collective attitude that has developed into an informal regional vision for water and drought management over the years. Whereas in Georgia, much of the regional collaboration is either associated with individual systems coming together to showcase their achievements through professional organizations, or with mandated formal collaboration and integration put forth by the MNGWPD and statewide water plan. In the end, these tensions suggest a difficult balancing act for decision makers in building adaptive capacity.

Second, at the highest level the analyses suggest that there may be a tradeoff between building long-term adaptive capacity and adaptive capacity to respond to more immediate crises.[66] That is, CWS (and perhaps other types of systems) may not theoretically be able to simultaneously encompass all aspects of adaptive capacity to a high degree. In other words, both the proactive and reactive elements of adaptive capacity may be in conflict with one another. I illustrate this potential tradeoff by describing a ‘culture of conservation’ in Arizona, and ‘windows of opportunity’ in Georgia.

As shown throughout the discussion, there is a general sense of innovation in Arizona, often reflected through those approaches that are either negatively associated with drought events or are not significantly associated with drought events (in either direction). In many of these cases, the qualitative data suggest that there has been a longer period within which the approaches have developed in Arizona, which CWS often attribute to ‘learning, education, knowledge exchange, and research, reports and studies’, ‘long-term and iterative planning’, ‘infrastructure’, and ‘financial’ bridges. What these data illustrate, and what managers consistently refer to in the interviews, is that these factors reflect a ‘culture of conservation’ or a ‘conservation ethic’ that has developed within large Arizona CWS and their customers. It is a culture that recognizes the utility of information (including climate information), and is financially committed to long-term planning and infrastructure projects to improve drought preparedness. Managers allude to the arid climate as an underlying motivator for this culture or ethic, but they are also quick to explain that arid conditions have not been the only impetus. The factors mentioned above (i.e., research, long-term studies, etc.), are also highly motivated by strong leaders within the systems, a collaborative regional attitude, and effective channels of communication and messaging.

The ‘culture of conservation’ that has developed in Arizona is not all positive for adaptive capacity, however. Long-term adaptedness to the arid climate and the bridges mentioned above may have helped foster a conservation ethic, or a culture of conservation, but there are still serious barriers that these systems and their publics face, particularly with respect to sudden climatic changes. Here, ‘perception and cognitive’

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[66] I distinguish between tradeoff and tension. Here, tradeoff implies a choosing of one over another (or others), and a tension implies that both (all) can be achieved if effectively balanced.

barriers are likely the most concerning. Systems that perceive themselves to be buffered by climate fluctuations because of their physical location or abundant groundwater resources, fail to adequately recognize the spatial and physical connectivity between climate and water processes. Maybe even more concerning is the complacent or desensitized attitude that customers frequently convey during droughts, as evidenced through the ‘blind trust’, apathy, and ignorance reported in M15 (perception of drought as a problem). This suggests that the long-term adaptedness in Arizona may limit CWS and the public from responding to more rapid changes in climate (e.g., more intense droughts), and from moving beyond a culture of conservation for drought preparedness and toward a culture of adaptation for climate-change preparedness. In other words, what Arizona possesses in longer-term proactive adaptive capacity established over the years might come at the expense of reactive adaptive capacity to more extreme droughts.

As shown throughout the discussion in Georgia, there are numerous innovative approaches that are positively associated with droughts. This pattern suggests two important phenomena that seem to be occurring in Georgia. First, the droughts serve as ‘windows of opportunity’ to increase implementation of the approaches. Because there is less of a culture of conservation in Georgia, there is more immediate room for improving and innovating (there is more low-hanging fruit) during drought events. Second, the cyclical nature of these approaches with droughts suggests that there are impediments to their more permanent implementation; that is systems might not be fully taking advantage of the windows of opportunity or face critical barriers to fostering a culture of conservation in Georgia beyond the drought periods. Essentially, what Georgia possesses in reactive adaptive capacity might come at the expense of longer-term proactive adaptive capacity.

5. Summary and Next Steps

As droughts increase in duration, frequency, and intensity with climate change, it is critical that water managers develop the adaptive capacity to prepare for and respond to these events. Previous research shows that a host of innovative management approaches likely contribute to such adaptive capacity, but there is little evidence for when and why these approaches develop over time, particularly in relation to the drought events themselves.

Methodologically, this research demonstrates the potential value of the EHC for adaptation research. Not only does it collect both qualitative and quantitative panel data that researchers or practitioners can use separately or as complements to one another, but one can employ it for rapid assessments, and use it as a tool for building a positive rapport between interviewer and interviewee. Those hoping to use the EHC in their own analyses might improve its utility by experimenting with its use in focus groups, gathering data from multiple interviews in the same organization, and changing the time periods of inquiry, to name a few examples. In sum, more studies using the EHC will contribute to methodological improvements, as well as increase the robustness of the results that employ the EHC. Additionally, widening the analysis to focus on more systems within each state and broadly to other states, and increasing confidence of the magnitude measure through better standardization across systems (to improve the CLM analyses and their application as decision-support tools) will help to better understand the dynamics between droughts and innovative management mechanisms, and the bridges and barriers that facilitate or inhibit their adaptation and implementation.

There are several other areas where additional research would benefit similar analyses in the future. First, data on shorter time scales (e.g., 1-month increments v. 6-month increments), or across a broader timeframe (e.g., 20 years) would help allow for the analysis of additional lag-periods, and thus more robust conclusions regarding the presence and directionality of significant associations between approaches and droughts. Also, one might consider altering the research design to study several states in same region, which would likely unveil important insights within and between states that share similar climate regimes and expected climate changes. Gathering and analyzing such data will be critical for extending the practical and theoretical contributions of this chapter.

Summarizing the quantitative analysis, the panel data show less of a direct link between innovative approaches and the onset of droughts in Arizona and a mix of positive and negative relationships between these approaches and droughts in Georgia. I complement these quantitative findings with qualitative analyses that in some circumstances offer evidence in support of these relationships, and in other situations offer alternative explanations (particularly in the cases where there are negative associations between the approach and drought events). Furthermore, the qualitative analyses identify important bridges and barriers to adaptation and implementation of each of the management approaches for both states.

The bridges and barriers help to convey the nuanced nature of adaptive capacity, and thus areas for states and CWS decision makers to focus on for implementing each approach. Furthermore, the analyses more broadly point to tensions in building CWS adaptive capacity, such as balancing the regulation of the innovative approaches with allowing them to informally and organically develop over time, or walking the line between instilling trust in CWS' customers while also avoiding the facilitation of customer complacency and apathy. These are critical challenges to building adaptive capacity that these and other states will need to address as climate change becomes an increasing reality.

At the highest level, a key challenge for building adaptive capacity to extreme droughts becomes how to promote a conservation ethic, while at the same time not becoming so adapted to drought cycles that it prevents taking advantage of windows of opportunity for further innovation when such openings present themselves. In many ways, the Arizona and Georgia cases provide evidence of a tradeoff between reactive and proactive elements of adaptive capacity. However, each case offers a way forward that could potentially suggest that this is more of a tension (i.e., not a tradeoff) that can be balanced in practice. In Georgia, a conservation ethic like Arizona's would help drought planning and management. Because there is less of a culture of conservation or an element of adaptedness to dry cycles, Georgia CWS and their customers have the opportunity to leap-frog some of the major barriers that now face Arizona CWS.[67] However, it is critical to find a way to retain an element of surprise or reactivity surrounding droughts, so that windows might continue to present themselves as opportunities for continual improvement. In Arizona, the conservation ethic needs reshaping into one that better appreciates shifts that climate change will bring, so as to be

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[67] As indicated in Chapter 3, footnote 46, Georgia recently passed legislation aiming to promote a culture of conservation. It should prove interesting to follow whether this culture can develop while also retaining reactive adaptive capacity.

able to take advantage of windows of opportunity that form during drought periods; similar to how Georgia now operates.

Still, these cases are insufficient for answering an important theoretical question that emerges from this research that deserves significant attention in future research; can systems simultaneously be well prepared and adapted (demonstrate high proactive adaptive capacity) and also be quick to respond (possess a lot of high reactive adaptive capacity)? In other words, is there a true tradeoff or decision that CWS and other systems must make between these defining attributes of adaptive capacity? Moreover, is there an ordering of how systems develop these elements of adaptive capacity (e.g., reactive capacity develops first and then decreases as proactive capacity increases)? In the end, understanding this dynamic between proactive and reactive elements of adaptive capacity will likely prove critical for transitioning toward a culture of adaptation for climate-change preparedness in these and other states.

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Chapter 5
Conclusion

1. Review of Purpose and Goals

My primary goal for conducting this dissertation research has been to make theoretical, methodological, and practical contributions to sustainability, global change, and adaptation studies. I have situated the research in the context of multiple stresses, water systems, and climate change to investigate empirically adaptive capacity to extreme droughts in two U.S. regions facing mounting pressures from growth and climate variability and change. In Chapter 1, I presented three general research goals to help achieve my primary goal (noted above):

1) to improve adaptive capacity assessments by combining insights from two prevalent global-change frameworks, vulnerability and resilience;
2) to measure and characterize adaptive capacity to determine which governance, management, and institutional approaches contribute most to adaptive capacity across various scales;
3) and to further characterize adaptive capacity in understanding the dynamics, bridges, and barriers surrounding the adoption of innovative management and institutional approaches over the past decade in one sub-group of CWS; large urban public water systems.

In the next section, I review the major findings and contributions (i.e., theoretical, methodological, and practical) from addressing these goals in each chapter, and I close with several broader recommendations and some thoughts regarding the future of adaptive capacity and adaptation research.

2. Major Findings and Contributions

Chapter 2 serves as the foundation upon which Chapters 3 and 4 are established. In Chapter 2, I strive to make the case for expanding adaptive capacity and adaptation research and improving upon previous assessment efforts by bringing together insights from vulnerability and resilience frameworks. I show that from a theoretical perspective, despite very different historical origins and some lingering disagreement between the two literatures, there is much in common between the frameworks; particularly their mutual emphasis on adaptive capacity. Also, there are practical motivations for a more concerted focus on what unites the two literatures (e.g., adaptive capacity) rather than what divides them, as evidenced by increasing demand for decision-support tools and metrics that can improve management, enhance understanding of the causal relationships within and between adaptation and sustainability, and help facilitate climate-smart sustainability. However, assessing adaptive capacity has faced limitations in each literature, mainly that vulnerability's treatment of adaptive capacity is well suited for practical implementation, but leaves out the consideration of critical system components, while resilience's treatment of adaptive capacity captures the dynamic, nested, and polycentric nature of adaptive capacity, but it is difficult to operationalize. Thus, in addressing the first research goal, Chapter 2 outlines a framework for improving adaptive capacity assessments by combining vulnerability and resilience insights and qualitative and quantitative analyses.

Chapter 3 places the arguments and framework of Chapter 2 into operation in the context of state and local community water systems (CWS) drought and water planning and management in Arizona, Georgia, and South Carolina. Ultimately, the chapter aims to address the first and second research goals in asking the following two empirical research questions:

1) what are the management, institutional, and governance approaches at various scales (particularly the state and CWS levels) that contribute to or inhibit the building of adaptive capacity to extreme droughts, that is, which approaches are most associated with higher adaptive capacity?

2) how can we improve adaptive capacity assessments to more adequately capture its dynamic, nested, and poly-centric nature in a manner that can be operationalized and applicable to decision makers?

I find that the states that are the most adaptable are those that relegate drought preparedness to the local level, allow flexibility in triggers, plans, and monitoring, provide a comprehensive planning and informational support system, offer iterative regional forums for (or at least remove limitations to) collaborating between systems and locales, consider climate change in their planning processes, and have a Regional Integrated Sciences and Assessments program that is accessible and active in water management and drought planning efforts. Theoretically, these findings point to important linkages and potential tensions regarding the factors that build adaptive capacity at various scales of management and governance.

In assessing local CWS adaptive capacity, the research presented in Chapter 3 also illustrates methodological challenges. The survey results show that larger CWS in each state tend to report greater impacts (i.e., less adaptive capacity), but also implement more innovative management approaches, while the cluster analysis reveals that the larger systems have more adaptable characteristics, despite reporting higher drought impacts. This somewhat paradoxical result (higher reported impacts accompanied by more adaptable behavior preceding and following the droughts) is likely attributable to methodological errors in self-reporting impacts/adaptive capacity. One possible explanation for the cause of these errors is that the higher stakes at risk in larger CWS might cause these systems to over-report drought impacts, because they internalize any small change to the CWS as a significant impact. Furthermore, the management approaches showing negative associations with adaptive capacity (and higher impacts) are in fact those related to climate information use and monitoring/reporting. It is likely the case that systems are able to more accurately understand and report impacts with the aid of this information and these tools; thus reflecting lower adaptive capacity in the survey (because they report higher impacts than the systems not using the tools and information). Combined, these results indicate that the system-reported impacts approach proves to be limited in its power to measure adaptive capacity in this research. Therefore, I am unable to conclude which specific AIM approaches implemented by CWS in each state are most associated with adaptive capacity.

Finally, the characterization of CWS adaptive capacity demonstrates the methodological and practical benefits of using cluster analyses and survey data to deepen our understanding of adaptive capacity. Methodologically, the cluster analysis highlights the utility of using past adaptations (both anticipatory/planned and autonomous/reactive) to learn about similarly adaptive groups within a region. From a practical perspective, decision makers and researchers can also use the cluster analysis to inform case selection processes. For example, my work identifies larger CWS as implementing more innovative approaches and tending towards more adaptable clusters; helping justify the in-depth characterizations of large urban systems that I perform in Chapter 4.

Chapter 4 begins with the assumption that certain innovative approaches (drought preparedness, integrated water resources management, integrated resources planning, and adaptive management) improve adaptive capacity; an assumption not necessarily made in portions of Chapter 3. I devote the bulk of Chapter 4 to addressing the third research goal in asking the following empirical research questions:

1) when do CWS implement innovative drought planning and management approaches in relation to extreme drought events?
2) what facilitates or inhibits CWS from adapting and adjusting their approaches?

I place these innovative approaches into operation by developing and employing an event history calendar (EHC) in the largest Arizona and Georgia CWS. One of the most important contributions of Chapter 4 is to show that methodologically, the EHC is a useful tool for collecting temporal data for quantitative and quantitative adaptive capacity and adaptation analyses. Also, my findings show (along with those from Chapter 3) that mixed methodologies that combine qualitative and quantitative data collection and analysis allow for richer and more robust theoretical and practical insights.

In Chapter 4, I demonstrate the benefits of a mixed methodology approach by examining changes in the implementation of innovative approaches as a function of droughts over the past decade. The approaches that I classify as ‘hard mechanisms’ do not show significant relationships with droughts in Georgia or Arizona. On the other hand, the panel analyses associated with ‘soft mechanisms’ and ‘soft characteristics’ show that in Georgia, there is a mix of positive relationships (implementation of the approach increases as drought increases over time) and negative relationships (implementation of the approach decreases as drought increases over time), and the significant relationships in Arizona are mainly negative. On the surface, this suggests that drought events more directly influence management decisions and adaptive capacity in Georgia than in Arizona. However, using the qualitative data, I demonstrate that many of the negative relationships are possibly related to longer-term processes influenced by drought events, or the approaches had already been implemented to a large extent prior to the period of study (particularly in the case of Arizona). Still, in a few of the approaches that are negatively associated with droughts, the analyses suggest that drought events might actually discourage the implementation of these innovative approaches.

The rich qualitative data unveil a host of bridges and barriers to adaptation. I analyze these data to identify the predominant bridges and barriers in each of the approximately eighteen management approaches in Arizona and Georgia. In doing so, I offer practical suggestions for where decision makers might focus for increasing adaptive capacity on an approach-by-approach basis. I also show how one might use data on the barriers and bridges in tandem with the quantitative panel analyses to create models that predict CWS management behavior. Such analyses might help state and local decision makers gauge where they currently are against where they eventually want to be – and ultimately how to arrive at this desired level of implementation for any given management approach.

While the local and state nuances for building adaptive capacity emerge in this approach-by-approach analysis, the research also uncovers several general theoretical insights worth noting. These theoretical insights pertain mainly to tensions and tradeoffs in building adaptive capacity. Specifically in Arizona, I find that a ‘culture of conservation’ or a ‘conservation ethic’ has developed within large CWS and their publics through various ‘bridges’ built over the years. However, such adaptedness to the arid conditions has created perception and cognitive barriers that might limit a shift from a ‘culture of conservation’ to a ‘culture of drought preparedness’ or ‘climate change preparedness'. In Georgia, although droughts serve as windows of opportunity to increase implementation of innovative management approaches (due to more low-hanging fruit), the cyclical nature of their implementation with respect to droughts suggests that there are important impediments to more permanently adopting such approaches that decision makers need to address. Thus, my work uncovers a potential tradeoff between proactive (e.g., 'culture of conservation') and reactive (e.g., 'windows of opportunity') elements of adaptive capacity.

3. Policy and Research Recommendations

As previously noted, this dissertation attempts to make theoretical, methodological, and practical advancements that are hopefully useful to policy makers, drought planners, water managers, and adaptation and sustainability researchers. Here, I make recommendations to researchers and decision makers based on my findings outlined above.

First, assessing adaptive capacity is not an easy task. While it is my hope that this dissertation has improved upon previous assessments, Chapter 3 illustrates the difficulty in gauging adaptive capacity from self-reported survey impacts data. Still, these challenges should not reduce the potential importance of such analyses, and therefore, future research should improve upon the limitations of my approach to further refine assessment methodologies. One such improvement would be to invest in more permanent and iterative social monitoring and impacts reporting initiatives (e.g., surveys and interviews) – possibly using these data in concert with physical and environmental data to better gauge adaptive capacity. Another improvement would be to build off of the cluster analysis exercise, which highlights the utility of using past adaptations (both autonomous/reactive and anticipatory/planned), to learn about similarly adaptive groups within a region. I also recommend that future investigations should not only consider the multiple spatial scales at which adaptive capacity is built and realized, but how different dimensions of adaptive capacity are interacting between these scales. This could provide useful information for policymakers in that some legislation, regulations, and initiatives, or lack thereof, while envisioned with good intensions at the state-level, might in fact inhibit local CWS adaptive capacity. Because my research uncovers various examples of these tensions between spatial scales in all three states, it seems especially important to recommend that one of the most effective ways to navigate the challenge of balancing structure, guidance, and policy certainty with flexibility, is to emphasize ‘regulated flexibility’. In the context of drought planning and management, this would entail state-required local preparedness, with institutional, informational, and financial support provided by states along the way. And while I do not detail them here in Chapter 5, Chapter 3 also offers specific recommendations for how decision makers in each state might alter their management, governance, and institutions to improve adaptive capacity.

The findings from Chapter 4 also highlight areas for improving adaptive capacity assessments. While the EHC proves to be a valuable tool for increasing the robustness of my findings, I suggest that future research should attempt to improve upon and expand the EHC technique as demonstrated in this dissertation. For example, investigators might consider applying it to focus groups, gathering data with it from multiple interviews in the same organization, and changing the time periods of inquiry. From a practical perspective, local and state decision makers might want to consider similar in-depth analyses of the bridges and barriers to adaptation as part of long-term adaptation and vulnerability analyses.

The potential tradeoff that I uncover between proactive and reactive elements of adaptive capacity is certainly a topic that warrants further exploration. If validated by future studies, this tradeoff may prove to be a complex challenge for drought adaptation policy and planning. That is, decision makers could struggle in the future with how to promote a conservation ethic (adaptive capacity related to proactive measures), while at the same time not becoming so desensitized or too well-adapted to droughts that it precludes systems from further innovating when windows of opportunity present themselves (adaptive capacity related to reactive measures).

But how might one apply these insights regarding the tensions and tradeoffs of building adaptive capacity at different spatial and temporal scales to broader adaptation policy and planning? My results point to the need for simultaneously investing in bottom-up and top-down efforts to address these tensions and tradeoffs, which might resemble the following:

1) The local level: Preparedness should begin at the local level in order to capture the nuances that contribute to adaptive capacity that decision makers might otherwise miss by applying broad-stroke policies at the state level. Communities might consider investing in adaptation planning, or at the very least, linking these planning processes with other ongoing long-term planning initiatives. These adaptation plans should involve worst-case scenario planning and an adaptive capacity assessment component, including an analysis of the bridges and barriers affecting adaptation.
2) The state level: As is the case in most emergency response, state entities should continue planning for and serving as the backstop when local efforts prove ineffectual or severely flawed. However, starting with the local level first would involve states *requiring* preparedness planning in cities, counties, towns and communities, along with a long-term commitment to providing the information, financial, and technical support throughout the preparedness planning processes. Included in this support role would be to begin compiling an adaptation database (i.e., adaptation-related initiatives identified by a variety of searchable factors, such as sector, spatial scale, major actors, type of project, cost, etc.) that other communities can eventually use to inform their adaptation planning processes, as well as establishing mechanisms for cross-community and cross-region learning.

Such state and local efforts would help to establish the institutional channels (e.g., formal forums and planning processes and informal networks) for collaborating amongst stakeholders and facilitating information exchange – a process that could ultimately help address the tradeoff in reactive and proactive elements of adaptive capacity. For example, investing in long-term and iterative planning processes would contribute to building proactive adaptive capacity, while the resources, institutions, and relationships associated with these longer-term processes could be used as forums and levers for taking advantage of climate surprises as they surface along the way (i.e., improving reactive adaptive capacity). In other words, ongoing planning processes could be used as a mechanism for improving climate preparedness (e.g., increasing the use of climate information) for stakeholders that are otherwise unreceptive to climate-change planning. Having the established institutional channels and relationships could also help remove impediments to building a longer-term culture of preparedness by using these events to educate stakeholders as to the potential risks, impacts, and adaptation options associated with future climate events.

Finally, while my research did not focus specifically on federal efforts, I would speculate that federal entities would play a similar role as states in the adaptation planning process (i.e., serve as the backstop when state and local efforts are ineffectual or severely flawed, set broad targets, requirements, and incentives, and provide technical and informational support).

4. A Hopeful Future?

Some within the global change field might find the pace and magnitude of the stresses our systems face to be daunting or even discouraging. Many look at the overlying stress of climate change as the proverbial ‘straw that could break the back’ of our planet’s sustainability. For evidence supporting this sentiment, we need not look beyond our most basic human need, water. As noted throughout this dissertation, freshwater systems already experience stress from pollution and population growth, and increased droughts and floods, less predictable and more intense storms, and decreased water quality and ecosystem health associated with climate variability and change only exacerbate difficulties for communities throughout the world to obtain high-quality drinking water.

It is a challenge for some researchers and decision makers to approach these issues with a sense of optimism and an attitude of hope. I am not one of them. The research presented in this dissertation helps reinforce that humans have the unique ability to design and implement management, governance, and institutional approaches that can increase our communities’ and ecosystems’ abilities to better prepare for and respond to climate change. While I focus specifically on drought events in the U.S. Southeast and the Southwest and their community water systems (CWS), the theoretical, methodological, and practical insights of my research suggest areas that we can strengthen or improve upon now that will increase our likelihood of achieving climate-smart sustainability.

Although the contributions of my dissertation are modest, I believe that future efforts of mine and other researchers along the lines of the work presented here will ultimately lead to paradigms, approaches, and tools that can help increase flexibility and expand the range of options necessary to persevere in an increasingly uncertain world of multiple environmental stresses and climate change.

Appendices

Appendix 1: Telephone interview questionnaire

Overview and informed consent:
*"Thank you for willingness to participate in this research. I have selected to interview you because of your knowledge regarding state and federal-level planning, management, and decision-making around climate and water issues in (**state**). You are one of roughly ten individuals that I am interviewing in (**state**) to gain a better understanding of how the state and region are prepared for and responding to climate and water stresses, and how state and federal-level decisions are influencing water management at local levels. I am particularly interested in the state's influence on community water systems (i.e., public and private water providers).*

I anticipate the interview to take 30 – 40 minutes. Your responses will not be recorded, but I will be typing notes on a computer as you answer the questions. I want to remind you that your participation is completely voluntary. Also, your responses will be kept strictly confidential and will only be used for the purpose of this research project. When referencing the interviews in the write-up of our results, no identifiable information will be attributed to you. There are no anticipated risks from this research. Still, if you do not want to answer a question, for any reason at all, just say so and I will skip it. Also, there is no penalty for declining to participate or terminating the interview early.

Finally, this study has been approved by the Institutional Review Board (IRB). Such approval is conditional upon the respondent's informed consent. By agreeing to complete this interview you are consenting to participate in this study.

Do you have any questions about the interview?

Do you agree to do this interview?"

After this interview is completed, if you have any questions please contact Nathan Engle by phone at (484) 695-6185 or email at nengle@umich.edu. You can also call the University of Michigan IRB, at (734) 936-0933 or email at irbhsbs@umich.edu. Another option is to contact Maria Carmen Lemos, the Project Advisor, by phone (734) 764-9315 or email at lemos@umich.edu."

Background and basics:
1. Could you please tell me a little about your job and your experience working on drought-related issues in (**state**)?

Climate impacts and their management:
2. Generally speaking, how have recent extreme droughts affected water availability and quality throughout the state?
    a. *Probe if they do not reference the identified drought period of interest*. How did the extreme drought of (**20XX – 20XX**) affect water availability and quality throughout the state?
3. How prepared and responsive has (**state**) been in addressing droughts?

    a. *Probe if they do not reference the identified drought period of interest*. How prepared and responsive was (**state**) in addressing the drought of (**20XX – 20XX**)?

Key policies and decisions

4. In your opinion, what three things does the state do that are most useful in helping CWS prepare and respond to droughts? What three things most constrain their preparation and response to droughts?

    a. *Probe and follow-up if they do not reference the state or federal levels*: What did the state/fed do well and how could the state/fed have done a better job?

5. Over the past decade, what have been the most important events, actions, decisions, or policies that have affected, positively or negatively, CWS management?

6. What do you think would need to be done for (**state**) to better foster the ability for CWS to prepare for and respond to droughts in the future?

Adaptive capacity:

7. The Intergovernmental Panel on Climate Change (IPCC) defines adaptive capacity as “the ability of a system to adjust to climate variability and climate change in order to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.” How would you describe (**state’s**) adaptive capacity with respect to extreme droughts and climate change over the past decade?

Interview wrap-up:

“Thank you very much for taking the time to speak with me. Before we end, I’d like to know if there are any issues or topics that I haven’t addressed that you believe are important for me to consider. Lastly, do have any questions for me? Thank you again for your time. Your input is invaluable.”

Appendix 2: Community Water System Survey

COMMUNITY WATER SYSTEM

Survey for Arizona Water Managers
April 2009

NATURAL RESOURCES
AND ENVIRONMENT
UNIVERSITY OF MICHIGAN

Thank you very much for taking the time to complete this survey. Your participation in the Community Water System Survey is completely voluntary. We are committed to respecting your privacy and the privacy of your system. To ensure confidentiality, the information you provide, as well as any findings and materials from this study will not be associated with your name or your specific water system. If you represent a water provider that serves more than one community, we are asking you to complete the survey for the largest community that you serve, as identified at the top of the enclosed letter.

* Survey key #:

R1. We would like to get a better understanding of **how extreme droughts have impacted** community water systems. The following questions refer specifically to the *extreme drought period of 2001 – 2005*. Please indicate the level of impact on your system, to the best of your memory, for the questions below. "1" means "no impact at all", "6" means "very severe impact", and "NA" means "not applicable".

	To what extent did this drought…	1 No impact at all	2	3	4	5	6 Very severe impact	NA
A.	…compromise your water system's ability to deliver water?	☐	☐	☐	☐	☐	☐	☐
B.	…negatively affect ecosystems in the community your system serves (for example, fires, in-stream flows, etc.)?	☐	☐	☐	☐	☐	☐	☐
C.	…negatively affect the water quality of your system?	☐	☐	☐	☐	☐	☐	☐
D.	…create negative economic effects for your water system?	☐	☐	☐	☐	☐	☐	☐
E.	…exacerbate water conflicts or disagreements?	☐	☐	☐	☐	☐	☐	☐

F. Were there any other drought impacts not described above (R1: A –E) that you care to share?

____

____

R2. Now we would like to know **how your water system managed** the *extreme drought period of 2001 – 2005*. Particularly, did you implement any of the following approaches, why or why not? Please mark one box for each question that most accurately reflects your system's management of this drought period.

Did your water system…		YES		NO	
		Voluntarily and self-initiated	To comply with State orders	Not needed or did not want to	Not permitted to do so
A.	…promote extra conservation efforts to decrease water use in the period surrounding this drought?	☐	☐	☐	☐
B.	…implement water restrictions to decrease water use in the period surrounding this drought?	☐	☐	☐	☐
C.	…have a conservation-oriented rate structure to decrease water use in the period surrounding this drought?	☐	☐	☐	☐
D.	…redo ordinances to respond to this drought?	☐	☐	☐	☐
E.	… build or seriously consider building new infrastructure in response to this drought (for example, digging wells, laying pipes, adding storage facilities, etc.)?	☐	☐	☐	☐
F.	… supplement water supply with *additional* water because of this drought (for example, purchasing and/or trucking in more water than usual)?	☐	☐	☐	☐

G. Were there any other management approaches not described above (R2: A –F) that you care to share?

____

____

R3. We are interested in understanding **how your system adjusted or altered its management approaches** during times of drought to manage impacts. To what extent did you change your normal approaches to effectively manage drought during the *extreme drought period of 2001 – 2005*? "1" means "not at all", "6" means "yes a lot", and "NA" means "not applicable".

Did your water system…		Not at all ← 1	2	3	4	5	→ Yes, a lot 6	NA
A.	…change normal management approaches or practices to prepare for and respond to this drought?	☐	☐	☐	☐	☐	☐	☐
B.	…move towards more supply management oriented approaches?	☐	☐	☐	☐	☐	☐	☐
C.	…move towards more demand management oriented approaches?	☐	☐	☐	☐	☐	☐	☐

M1. We would like a little more detail about **how water systems management has changed** over the past several years. This information will help with understanding the policies and approaches that support community water systems during droughts. Think about your system during the two time periods below; particularly how it may or may not have changed. Please check only those statements that accurately describe your water system for the given time periods. Note: You can check both boxes for a given statement if it was/is accurate for both time periods.

A. Mark all that applied to your system *leading up to and during the extreme drought period of 2001 – 2005*

B. Mark all that apply to your system's *present situation or what you are planning (based on what has been discussed) in the immediate future*

	Your water system…	***2001 to 2005***	***Presently, or in the immediate future***
1.	…was regionalized/backed up with other community water systems.	☐	☐
2.	…regularly coordinated with other water systems' managers to plan for limited water supply.	☐	☐
3.	…participated in regional water and drought planning initiatives.	☐	☐
4.	…worked with *state* government agencies and services to prepare for and respond to drought.	☐	☐
5.	…worked with *federal* government agencies and services to prepare for and respond to drought.	☐	☐
6.	…talked with professionals from other sectors to aid management decisions (for example, land-use planning, emergency planning, etc.).	☐	☐
7.	…used short-term weather information (for example, precipitation, temperature, flooding/drought forecasts, etc).	☐	☐
8.	…used medium-term and long-term information (for example, historical information, seasonal forecasts, regional and hydro-meteorological models, etc.).	☐	☐
9.	…used climate change scenarios or other climate change impacts information to inform longer-range water supply planning or management.	☐	☐
10.	…sought and used information and services from many different agencies and groups (for example, used online tools, commissioned studies, hosted presentations, etc.)	☐	☐
11.	…discussed the idea of 'uncertainty' in water management decisions with customers (for example, through meetings and reports).	☐	☐
12.	…sought input from customers to guide management decisions.	☐	☐
13.	…had procedures in place for resolving conflicts.	☐	☐
14.	…followed a drought plan that identified both drought preparation and response procedures.	☐	☐
15.	…had a long-term water management plan.	☐	☐
16.	…updated your water management plan regularly (every several years).	☐	☐
17.	…considered climate change in your water management plan.	☐	☐
18.	…planned for 10 to 20 year drought periods.	☐	☐
19.	…tried novel options for securing water supply and/or meeting demand.	☐	☐
20.	…closely tracked and recorded water demand and supply.	☐	☐
21.	…monitored, evaluated, and reported drought impacts as they occurred.	☐	☐
22.	…had adequate financing and resources to implement new approaches if necessary (for example, a sufficient operating budget, easy access to loans/grants to secure debt, enough technical staff etc.).	☐	☐

C. Generally speaking, were these changes in management a result of what your system learned from the extreme drought event?

☐ Yes ☐ No

M2. We are interested in identifying the **barriers and limitations** that water systems face. Please think about what you are doing now (or planning to do in the immediate future), in comparison to what you were doing during *the extreme drought period of 2001 – 2005*. "1" means "not at all", "6" means "yes, a lot", and "NA" means "not applicable".

Not at all ⟷ Yes, a lot

	Were/are changes in your system's management…	1	2	3	4	5	6	NA
A.	…obstructed by regulatory or legal barriers?	☐	☐	☐	☐	☐	☐	☐
B.	…obstructed by financial or capital limitations?	☐	☐	☐	☐	☐	☐	☐
C.	…obstructed by a lack of information or technical resources?	☐	☐	☐	☐	☐	☐	☐

D. Are there any other barriers or limitations not described above (M2: A – C) that you care to share?

____

____

M3. Revenue problems are common from implementing drought management measures (for example, water conservation and restrictions). Briefly describe how your system has managed to avoid or cope with such decreases in revenue associated with these measures.

____

____

____

M4. Please share with us what your water system has done in the past decade that you consider to be most innovative.

____

____

____

____

C1. There are many issues that Community Water Systems face. Please select the **three** issues that are the most important to your system.

☐ Aging infrastructure
☐ Climate change
☐ Drinking water treatment
☐ Drought
☐ Endangered species/In-stream flows
☐ Flooding
☐ Groundwater depletion
☐ Growth
☐ Lack of financial resources
☐ Land use planning
☐ Regulation/compliance
☐ Source water quality
☐ Training/human capacity
☐ Water rights/Additional water supply
☐ Other, please list___________________

C2. We are interested in understanding information use, information needs, and how systems use information to manage risk. Please think about the following statements and mark 'yes' or 'no' for each question or, where applicable, mark the appropriate box or boxes.

		Yes	No
A.	We regularly attend conferences, workshops, training, or other events to stay current on new water management approaches and issues.	☐	☐
B.	The past 100 year record of drought and precipitation is an appropriate indicator of future drought and precipitation events.	☐	☐
C.	Severe flooding has been a concern for my water system over the past decade. ***If you answered NO, skip to D.***	☐	☐
	C.1. Flooding impacted my system's ability to deliver water during the last decade (*check only one*): ☐ once ☐ twice ☐ three times or more.		
D.	More frequent severe drought or extreme precipitation events may make my system's water supply infrastructure or water treatment process less reliable.	☐	☐
E.	My system uses real-time monitoring data or real-time monitoring technology to monitor source water quality and/or quantity.	☐	☐
F.	My system uses forecasts such as those for precipitation, temperature, flooding, drought, reservoir levels, or other similar information to inform water system operation and management. ***If you answered YES, skip to G on the next page.***	☐	☐
	F.1. We do not use forecasts or similar information because the information is (*check all that apply*): ☐ not available for my system ☐ unreliable ☐ too uncertain ☐ other, ____________________________		
G.	My system uses tree ring data or other precipitation/drought event proxies to inform water supply planning or management. ***If you answered YES, skip to H.***	☐	☐
	G.1. We do not use tree ring or similar data because the information is (*check all that apply*): ☐ not available for my system ☐ unreliable ☐ too uncertain ☐ other, ____________________________		
H.	Climate change impacts on my water system are a concern.	☐	☐
I.	Our water customers/users ask us to consider climate change impacts in our longer-term planning or management.	☐	☐
J.	My system uses climate change scenarios or other climate change impacts information to inform longer-range water system planning or management. ***If you answered YES, skip to K.***	☐	☐
	J.1. My system does not use climate change scenarios or other climate change impacts information because the information is (*check all that apply*): ☐ not available for my system ☐ unreliable ☐ too uncertain ☐ other, ____________________________		
K.	My system uses a water system model or other software to assist with daily water system operation and/or management. ***If you answered NO, skip to L.***	☐	☐
	K.1. We use *climate forecasts or similar information* in our water system model or other software to assist with daily water system operation and/or management.	☐	☐
L.	My system uses numerical or other models to assist with longer-term water system planning. ***If you answered NO, skip to the next question, C3.***	☐	☐
	L.1. We use *climate information* in our numerical or other models to assist with longer-term water system planning.	☐	☐

C3. We would like to understand more about Community Water System information needs. In the space provided please indicate information you would like to have but cannot get.

____

____

C4. We are interested in learning where Community Water System supervisors/managers turn to for information. In Column [1] mark the boxes alongside the information sources you *most often use* to assist you with managing your system or for **general information**. In Column [2] mark the boxes alongside the information sources you *most often use* for **weather or climate information** (for example, precipitation, temperature, flooding, drought, reservoir levels, climate change, tree ring reconstructions, etc.). When indicating information sources, please consider the sources used within the **last 5 years**.

	Column [1] Mark *general information sources*	**Column [2]** Mark *weather or climate information sources*
Federal or Regional Information Sources		
1. Climate Assessment for the Southwest (CLIMAS)	☐	☐
2. Federal Emergency Management Agency (FEMA)	☐	☐
3. National Integrated Drought Information System (NIDIS)	☐	☐
4. NOAA/National Weather Service	☐	☐
5. Salt River Project	☐	☐
6. Southwest Climate Outlook	☐	☐
7. US Army Corps of Engineers	☐	☐
8. US Bureau of Reclamation	☐	☐
9. USDA/Natural Resources Conservation Service (NRCS)	☐	☐
10. US Environmental Protection Agency (EPA)	☐	☐
11. US Geological Survey (USGS)	☐	☐
12. Western Regional Climate Center	☐	☐
State Information Sources		
13. Arizona Department of Environmental Quality	☐	☐
14. Arizona Department of Health Services	☐	☐
15. Arizona Department of Water Resources	☐	☐
16. Arizona Division of Emergency Management	☐	☐
17. Arizona Drought Watch	☐	☐
18. Arizona Flood Warning and Drought Monitoring Website	☐	☐
19. Arizona Municipal Water Users Association	☐	☐
20. Arizona State Climatologist	☐	☐
University, Association, Non-profit, and Private Information Sources		
21. Arizona NEMO	☐	☐
22. Arizona State University	☐	☐
23. Arizona Water Institute	☐	☐
24. Northern Arizona University	☐	☐
25. University of Arizona and/or Cooperative Extension	☐	☐
26. Arizona Water and Pollution Control Association	☐	☐
27. Arizona Rural Water Association	☐	☐
28. American Water Works Association	☐	☐
29. Water Environment Federation	☐	☐
30. Engineer or other Consultant	☐	☐
31. Commercial Weather or Climate Information Vendor	☐	☐
32. News/Media	☐	☐

C5. Please list any other information sources you have used in the last 5 years not already marked in the spaces above:

____

____

C6. Understanding how often Community Water Systems collaborate with research or other organizations (i.e., universities, Extension offices, consulting engineers, research associations, etc.) is really important to us. How much do you collaborate with the following organizations?

		A lot	Some	A little bit	None	Never heard of organization
A.	Arizona State University, Dept. ______________________	☐	☐	☐	☐	☐
B.	Arizona Water Institute	☐	☐	☐	☐	☐
C.	Climate Assessment for the Southwest (CLIMAS)	☐	☐	☐	☐	☐
D.	Northern Arizona University, Dept. ___________________	☐	☐	☐	☐	☐
E.	University of Arizona, Dept. ________________________	☐	☐	☐	☐	☐
F.	American Water Works Association	☐	☐	☐	☐	☐
G.	Water Research Federation	☐	☐	☐	☐	☐
H.	Engineering or other Consulting Firms	☐	☐	☐	☐	
I.	Other (please describe ____________________________)	☐	☐	☐		

C7. How might research organizations better meet the needs of your water system?
____
____

Finally, we would like some basic information about you and your water system. Please mark the appropriate box, and where relevant, please give a response in the space provided.

D1. Water system ownership type:
☐ Public ☐ Private ☐ Other, please describe: ____

D2. Estimated daily water delivered, averaged over the last year:
________*millions of gallons per day (MGD)* or *acre-ft per day (AFD)*

D3. Estimated **peak** water delivered on a single day, over the last year:
________*millions of gallons per day (MGD)* or *acre-ft per day (AFD)*

D4. Do you meter your water?
☐ Yes ☐ No

D5. Please list the three primary categories of water users within your system, with the main user listed first, followed by the second highest, and the third highest (for example, 1. residential, 2. agricultural, 3. wholesale, etc.):

1. ________________________
2. ________________________
3. ________________________

D6. Does your water system **provide water to** other community water systems?
☐ Yes ☐ No

D7. Does your water system **purchase water from** other community water systems?
☐ Yes ☐ No

If you answered "Yes" to D6 or D7, please answer the following question. If you answered "No", skip to D9.

D8. **Approximately** how many systems are associated with the water you provide or purchase?

______# of other systems your system **provides water to**

______# of other systems your water is **purchased from**

D9. **Approximate** yearly total budget for your water system, including operation & maintenance, and planning:

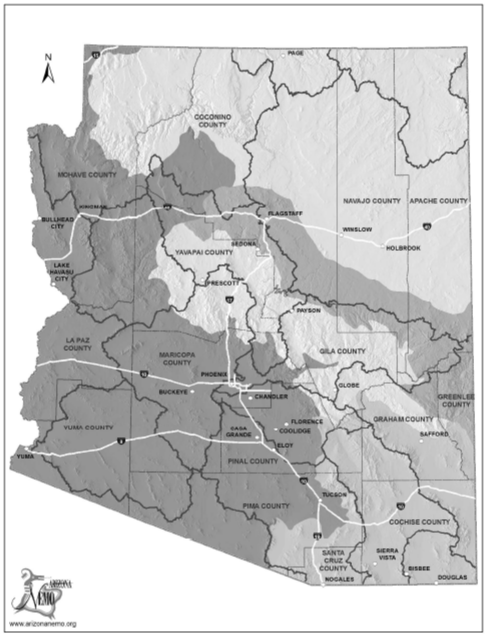
☐<$25,000 ☐$25,000-100,000 ☐$100,000 -1 million

☐ $1-10 million ☐$10 -20 million ☐>$20 million

D10. Including yourself, **approximate** number of staff who work for your water system:

Full-time: __________ Part-time: __________ Volunteer: __________

D11. Please indicate the location of the Community Water System you serve by placing an small 'X' on the map. This information will be used to identify the watershed and ecological region within which your system is located. Please be as precise as possible, with the center of the 'X' indicating the location of your water system.



Thank you very much for completing this survey, your participation is invaluable!

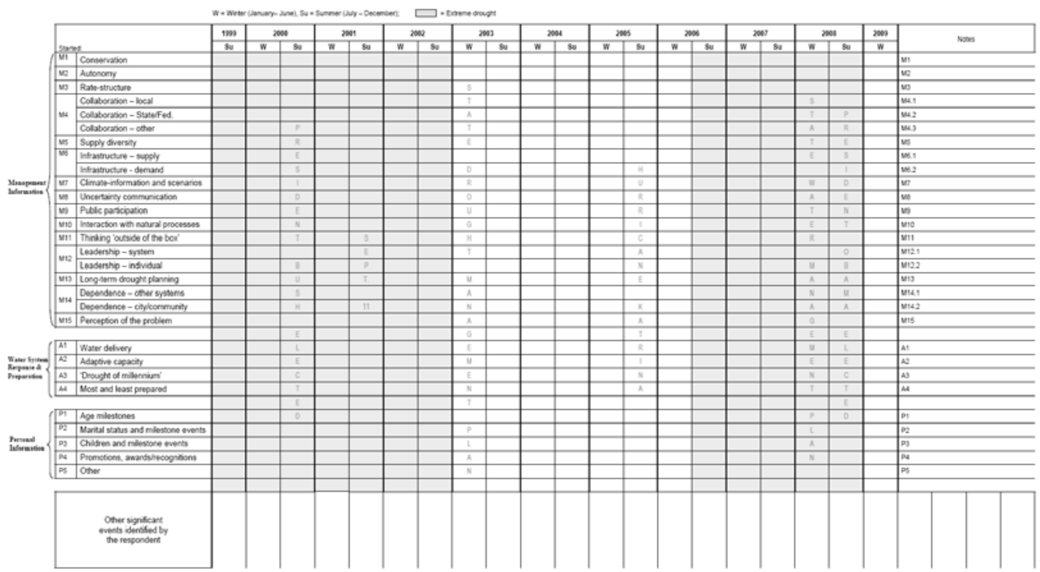
***If you would like an email summary of the results, please provide your email here:**

____

Please fold the survey into thirds, insert into the pre-paid envelope, and place in the mail

Nathan Engle and Christine Kirchhoff, University of Michigan, 2009

Appendix 3a: Event history calendar, as shown through the example of Georgia



W = Winter (January– June), Su = Summer (July – December); ▭ = Extreme drought

			1999	2000		2001		2002		2003		2004		2005		2006		2007		2008		2009	Notes
	Started		Su	W	Su	W	Su	W	Su	W	Su	W	Su	W	Su	W	Su	W	Su	W	Su	W	
Management Information	M1	Conservation																					M1
	M2	Autonomy																					M2
	M3	Rate-structure								S													M3
	M4	Collaboration – local								T										S			M4.1
		Collaboration – State/Fed.								A										T	P		M4.2
		Collaboration – other			P					T										A	R		M4.3
	M5	Supply diversity			R					E										T	E		M5
	M6	Infrastructure – supply			E															E	S		M6.1
		Infrastructure - demand			S					D					H						I		M6.2
	M7	Climate-information and scenarios			I					R					U					W	D		M7
	M8	Uncertainty communication			D					O					R					A	E		M8
	M9	Public participation			E					U					R					T	N		M9
	M10	Interaction with natural processes			N					G					I					E	T		M10
	M11	Thinking 'outside of the box'			T		S			H					C					R			M11
	M12	Leadership – system					E			T					A						O		M12.1
		Leadership – individual			B		P								N					M	B		M12.2
	M13	Long-term drought planning			U		T.			M					E					A	A		M13
	M14	Dependence – other systems			S					A										N	M		M14.1
		Dependence – city/community			H		11			N					K					A	A		M14.2
	M15	Perception of the problem								A					A					G			M15
					E					G					T					E	E		
Water System Response & Preparation	A1	Water delivery			L					E					R					M	L		A1
	A2	Adaptive capacity			E					M					I					E	E		A2
	A3	'Drought of millennium'			C					E					N					N	C		A3
	A4	Most and least prepared			T					N					A					T	T		A4
					E					T											E		
Personal Information	P1	Age milestones			D															P	D		P1
	P2	Marital status and milestone events								P										L			P2
	P3	Children and milestone events								L										A			P3
	P4	Promotions, awards/recognitions								A										N			P4
	P5	Other								N													P5
		Other significant events identified by the respondent																					

Appendix 3b: Event history calendar questionnaire

Thank you again for taking the time to do this interview. I will be asking you a series of questions about your water system over the past decade. The goal of the research is to gain a better understanding of how and why certain management approaches have developed over time, and how the water system has managed droughts. I have chosen to conduct this interview by using this event history calendar. Tools like this have been shown to be very effective for recording past experiences. I will begin by asking you about your personal history during this period, which is meant to orient you to this particular time period by situating the occurrences in your water system around events that have happened within your life. I have identified other noteworthy events on the calendar to further help with this orientation. I will also ask you to pin-point important local events that have occurred during this period to assist in remembering characteristics of your water system throughout the past decade. My hope is that we can work together to complete this event history calendar as accurately as possible.

Let me run through the layout of the event history calendar. As you can see, these are the categories of questions that I will be asking you throughout the interview (point to rows), and here are the periods over the past decade that each question will pertain to (*point to columns*). I am using summer and winter because climate and management decision are often remembered in seasonal terms, (e.g., ‘the drought during the summer of 2001 was a tough one’). Please note the approximate months I have chosen to assign to each season (*explain the seasons*). I have identified several prominent events that occurred throughout the decade. Some of these events might have directly impacted your water system; while others are identified because of their ability to orient you to this time period (*explain each of the events*).

Are there any events, climate or other (e.g., large infrastructure installation, local policies or community activities, etc.), that are particularly noteworthy that may help reorient you in this time period? (Record the events at the bottom of the page.)

Excellent – I would like to begin by learning a little about what was personally going on in your life during this time period.

Started: First of all, when did you start working here at your water system, and what is your background?

P1. Age milestones: Can you locate any milestone birthdays on the calendar (e.g., when you turned 30, 50, etc.)

P2. Marital status and milestone events: If you are or have been married, I’d like to identify significant events, like when you were married, milestone anniversaries and divorces, if that applies to you.

P3. Children and milestone events: If you have children, were any of them born during this period? Did any of them have milestone birthdays during this period (e.g., turned 16, 21, etc.) or milestone events (e.g., graduate high school or college, get married, etc.)?

P4. Promotions and awards/recognitions: Did you earn any promotions and/or experience career advancements during this period? Did you receive any significant awards or recognitions during this period?

P5. Other: Are there other noteworthy personal events that you would like me to record on this calendar?
(*Take a moment to review the calendar with them for accuracy.*)

Keeping these events in mind, I am now going to turn to questions regarding your water system. The first set of questions relate to the management functions and approaches during the past decade. We're going to run through each question to identify the emphasis your water system placed on the following approaches. Unless I tell you otherwise, I simply want you to identify it as 0 or 1, or none-little or significant-high (*If ask relative to what, say 'with respect to what you think is physically possible if you had all the resources in the world'*). I am particularly interested in when you feel the status has changed from (e.g., from 0-1 or 1-0). I don't expect you to have done all of these, or for there to necessarily be changes in all of these; you could have been doing them all along, or not at all, or some of them could have changed a lot. My goal is to accurately capture any changes took place. I'll give you a pencil too in case you think it's easier to help with completing the calendar.

M1. Conservation: Encouraging and promoting conservation efforts.

M2. Autonomy: Independent decision-making; how much autonomy you/your system has to make decisions and changes (every day management and operation) and has it changed over time?

M3. Rate-structure: Using a conservation-oriented rate structure, even if it affected your revenues. If so, how have the tiers changed over time (when added 2nd, 3rd, etc.). Follow up: How are the rate structures set?

M4. Collaboration – local: Coordinating with city or county officials/agencies on drought planning (e.g., meetings, local planning processes, etc.).
Collaboration – State/Fed.: …State and/or Federal officials and agencies for drought/water planning.
Collaboration – other: …others outside the traditional 'water sector'; (e.g., emergency planners, land-use planners, drought planners, watershed groups).

M5. Supply diversity: Actively seeking and securing water from a *diversity* sources within the region (spatially and source-type).

M6. Infrastructure - supply: Building additional infrastructure to better manage supply (e.g., reservoirs, new wells, new pipes etc.)
Infrastructure - demand: Building additional infrastructure to better manage demand (e.g., meters, fixing leaky pipes, etc.)

M7. Climate-information and scenarios: Medium and long-term climate information (e.g., historical information, seasonal forecasts, regional and hydro-meteorological models, etc.), and climate change impacts scenarios.

M8. Uncertainty communication: Communicating the idea of 'uncertainty' in water management decisions with your customers.

M9. Public participation: Providing avenues for and promoting customer input into your water system's management.

M10. Interaction with natural processes: Considering the relationship between your water system natural/environmental processes.

M11. Thinking 'outside of the box': Formulating hypotheses and experimenting with novel approaches for managing uncertainty, and monitoring and evaluating these experiments and altering practices accordingly.

M12. Leadership – system: Working with other systems to innovate, and presenting itself as a model from which others could learn.
Leadership – individual: Depending on a single leader/leaders (like yourself) to do the above things, or has this been institutionalized?

These last few questions require slightly different responses:

M13. Long-term drought planning: When, if ever, did you begin planning for *climate change*, and what time periods of drought have you planned for over this decade (e.g., 5-year drought, 20 year drought, etc.)? Follow up: Do you have your own drought prep./resp. plan? When created?

M14. Dependence – other systems: Meeting the needs of other water systems (e.g., wholesale to other systems, emergency system interconnections, etc.) and vise-versa (-1 = other systems very dependent upon yours, 0 = no dependence in either direction, 1 = yours very dependent upon other systems, 2 = high dependence in both directions.)
Dependence – city/community: Meeting the needs of your city/community (e.g., city budgets/profits, etc.) and vise-versa (-1 = other systems very dependent upon yours, 0 = no dependence in either direction, 1 = yours very dependent upon other systems, 2 = high dependence in both directions.)

M15: Perception of the problem: I want you to track perception of drought (and climate change) as a serious problem (0 = none, 1 = just the water system seeing it as a significant issue, 2 = the water system and your customers seeing it as a significant issue).

(*Take a moment to review the calendar with them for accuracy.*)

Now we're going to move to the everyday functioning of your system. Based on your knowledge and experience, please rate the status of your system for each of these categories over the past decade. These questions should be answered from (0=none, 1=low, 2=medium, 3=high). I am particularly interested in when you feel the status has changed from (e.g., from 'low' to 'medium', from 'high' to 'low', etc.)

A1. Water delivery: Your water system's ability to high deliver water.

A2. Adaptive capacity: I am going to describe a concept to you that I want you to rank in your water system over the past decade; adaptive capacity. The Intergovernmental Panel on Climate Change (IPCC) defines adaptive capacity as the ability of a system to adjust to climate variability and change to moderate potential damages, to take advantage of opportunities, or to cope with the consequences. Another way to think of it is the ability for your system to adjust responses to changing internal demands and external drivers.

A3. 'Drought of the millennium': Preparation of your water system for the hypothetical 'drought of the millennium'.

A4. Most and least prepared: When was your water system most and least prepared to successfully manage droughts? Why?

(*Take a moment to review the calendar with them for accuracy.*)

Thank you very much for taking the time to meet with me. Before we end, I'd like to ask if there are any issues or topics that I haven't addressed that you believe are important items to consider. Lastly, I'd like to ask if you have any questions for me. Thank you again for your time. Your input is invaluable.

Appendix 4: Primary coding categories for semi-structured telephone interview data

Water Resources and Drought Planning and Management (WRDPM)	Water Management (WM)	WPR	Water Permitting and Rights
		WLL	Water Law and Legislation (outside of major rights legislation)
		WMA	Water Management Agencies
		CCP	Climate Change Planning
		AMWM	Alternative Models for Water Management (on the horizon)
		BT	Banking and Transfers
		VPC	Valuing, Pricing, and Comodification
		PEC	Physical-Environmental Connections
		WPL	Water Planning
		WP	Water Plan
		WA	Water Availability
		SS	Security and Scarcity
		SWGW	Surface Water Dependence - Ground Water Dependence
		CEC	Conservation, Efficiency, and Consumption
		MM	Monitoring and Metering
		RS	Reservoirs and Storage
		WIK	Water Information and Knowledge
	Drought Planning (DPL)	GRDC	Governor's Role and Drought Committee
		DTWS	Declarations, Triggers, Warning Systems
		MP	Mitigation and Planning
		DP	Drought Plan
		RLPM	Regional and Local Planning and Management
		SLC	State-Local Coordination
	Drought Response (DR)	GNR	General Response and Emergency Management
		RE	Restrictions
		RDIT	Recent Drought Impacts and Timeline
		IOS	Intersection with Other Stresses
		PDEE	Previous Drought Events and Experience
		DWP	Drought and Water Politics
		CDIK	Climate and Drought Information and Knowledge
		CWSG	Community Water Systems General
		CCC	Collaboration, Coordination, and Conflict
Adaptive Capacity (AC)	Factors Inhibiting (BA)	CB	Cultural Barriers
		FSB	Financial and Staff Barriers
		FPB	Flood Planning Barriers
		PGB	Physical and Geographical Barriers
		LB	Legal Barriers
		IB	Institutional Barriers
		LGB	Legislative Barriers
		PB	Political Barriers
		RB	Regulatory Barriers
		PCBP	Perception, Cognitive, and Behavioral Barriers
		TTIB	Technical, Tools, and Infrastructure Barriers
		BB	Business Barriers
		CMB	Communication Barriers
		JCSB	Jurisdiction, Coordination, and Scale Barriers
		OB	Operational Barriers
		EB	Enforcement Barriers
		SD	State Disconnects
		IF	Inflexibility
	Factors Contributing (OP)	BAC	Basic AC Impression
		TAO	Take Advantage of Opportunities
		IM	Innovative Management
		FL	Flexibility
		PR	Proactive or Reactive
		CBR	Collaboration Bridges
		CMBR	Communication Bridges
		CPCBBR	Cultural, Perception, Cognitive, and Behavioral Bridges
		FSBR	Financial and Staff Bridges
		ITBR	Information and Technology Bridges
		LRLBR	Legal, Regulatory, and Legislative Bridges
		OBR	Operational Bridges
		PGBR	Physical and Geographical Bridges
		PBR	Political Bridges

Appendix 5: Factor analysis of the five drought impacts questions reduced to principle components

	Total Variance Explained									
	Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
		Total	% of Variance	Cum. %	Total	% of Variance	Cum. %	Total	% of Variance	Cum. %
Arizona	1	2.64	52.72	52.72	2.64	**52.72**	52.72			
	2	.983	19.66	72.38						
	3	.765	15.30	87.68						
	4	.328	6.57	94.24						
	5	.288	5.76	100.00						
Georgia	1	2.72	54.39	54.39	2.72	**54.39**	54.39			
	2	.839	16.77	71.16						
	3	.647	12.93	84.10						
	4	.451	9.02	93.11						
	5	.344	6.89	100.00						
South Carolina	1	2.27	45.34	45.34	2.27	45.34	45.34	2.05	**40.98**	40.98
	2	1.10	22.10	67.44	1.10	22.10	67.44	1.32	**26.45**	67.44
	3	.931	18.62	86.05						
	4	.459	9.18	95.23						
	5	.238	4.77	100.00						

The measures are reduced to one component in Arizona and Georgia and two components in South Carolina. The total percent of variance explained by each component is bolded in black.

Appendix 6: Proportion and sum of AIM approaches by state and across all three states

Approach	**Arizona (n = 57 valid, 4 missing)**		**South Carolina (n = 37 valid, 0 missing)**		**Georgia (n = 91 valid, 6 missing)**		**Combined states**	
	Proportion 'yes'	Sum 'yes'	Proportion 'yes'	Sum 'yes'	Proportion 'yes'	Sum 'yes'	Proportion 'yes'	Sum 'yes'
1 before/during	.21	12	.43	16	.31	28	0.30	56
1 after/present	.19	11	.32	12	.25	23	0.25	46
2 before/during	.23	13	.35	13	.22	20	0.25	46
2 after/present	.21	12	.22	8	.15	14	0.18	34
3 before/during	.33	19	.54	20	.42	38	0.42	77
3 after/present	.35	20	.35	13	.27	25	0.31	58
4 before/during	.39	22	.59	22	.51	46	0.49	90
4 after/present	.46	26	.38	14	.33	30	0.38	70
5 before/during	.07	4	.14	5	.15	14	0.12	23
5 after/present	.16	9	.05	2	.10	9	0.11	20
6 before/during	.23	13	.30	11	.27	25	0.26	49
6 after/present	.32	18	.22	8	.18	16	0.23	42
7 before/during	.19	11	.57	21	.35	32	0.35	64
7 after/present	.21	12	.41	15	.24	22	0.26	49
8 before/during	.23	13	.46	17	.25	23	0.29	53
8 after/present	.19	11	.30	11	.20	18	0.22	40
9 before/during	.11	6	.19	7	.07	6	0.10	19
9 after/present	.12	7	.22	8	.04	4	0.10	19
10 before/during	.16	9	.27	10	.14	13	0.17	32
10 after/present	.18	10	.16	6	.15	14	0.16	30
11 before/during	.26	15	.22	8	.26	24	0.25	47
11 after/present	.30	17	.14	5	.14	13	0.19	35
12 before/during	.30	17	.14	5	.14	13	0.19	35
12 after/present	.26	15	.05	2	.12	11	0.15	28
13 before/during	.26	15	.16	6	.27	25	0.25	46
13 after/present	.25	14	.16	6	.18	16	0.19	36
14 before/during	.33	19	.76	28	.46	42	0.48	89
14 after/present	.51	29	.38	14	.30	27	0.38	70
15 before/during	.32	18	.30	11	.46	42	0.38	71
15 after/present	.42	24	.24	9	.32	29	0.34	62
16 before/during	.23	13	.35	13	.30	27	0.29	53
16 after/present	.39	22	.19	7	.32	29	0.31	58
17 before/during	.12	7	.00	0	.05	5	0.06	12
17 after/present	.18	10	.11	4	.09	8	0.12	22
18 before/during	.14	8	.08	3	.03	3	0.08	14
18 after/present	.23	13	.11	4	.09	8	0.14	25
19 before/during	.12	7	.05	2	.10	9	0.10	18
19 after/present	.14	8	.05	2	.11	10	0.11	20
20 before/during	.54	31	.84	31	.68	62	0.67	124
20 after/present	.56	32	.49	18	.54	49	0.54	99
21 before/during	.12	7	.57	21	.27	25	0.29	53
21 after/present	.21	12	.27	10	.19	17	0.21	39
22 before/during	.28	16	.41	15	.33	30	0.33	61
22 after/present	.33	19	.35	13	.33	30	0.34	62
Before/after count		295		285		552	6.12	1132
After/present count		351		191		422	5.21	964

The row numbers correspond with ‘M1’ questions in *Appendix 2*.

Appendix 7: Collinearity diagnostics for each of the AIM approaches considered in the regressions

Arizona

Dimension	*Eigenvalue*	*Condition Index*	*Constant*	*M1 2*	*M1 5*	*M1 10*	*M1 14*	*M1 16*	*M1 19*	*M1 21*
1	4.158	1.000	.01	.02	.01	.01	.02	.01	.01	.01
2	.959	2.082	.08	.03	.19	.04	.05	.00	.10	.02
3	.787	2.299	.27	.01	.00	.01	.04	.04	.12	.16
4	.734	2.380	.03	.17	.15	.00	.02	.00	.30	.06
5	.446	3.053	.34	.08	.01	.05	.45	.13	.01	.03
6	.431	3.106	.01	.44	.00	.08	.12	.13	.29	.06
7	.288	3.801	.24	.01	.07	.57	.11	.36	.06	.06
8	.196	**4.604**	.02	.25	.56	.22	.19	.31	.10	.59

Georgia

Dimension	*Eigenvalue*	*Condition Index*	*Constant*	*M1 2*	*M1 3*	*M1 4*	*M1 5*	*M1 8*	*M1 9*	*M1 10*	*M1 11*	*M1 12*	*M1 13*	*M1 14*	*M1 15*	*M1 16*	*M1 20*	*M1 21*
1	8.619	1.000	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
2	1.222	2.655	.02	.03	.00	.01	.00	.00	.13	.00	.00	.08	.00	.01	.00	.02	.01	.01
3	.882	3.126	.00	.01	.00	.01	.11	.01	.04	.34	.02	.01	.00	.00	.00	.02	.00	.00
4	.776	3.333	.00	.01	.00	.04	.07	.13	.06	.04	.07	.01	.02	.00	.01	.07	.00	.01
5	.736	3.423	.00	.01	.00	.01	.11	.01	.10	.00	.01	.19	.15	.00	.00	.05	.00	.00
6	.691	3.531	.00	.01	.01	.01	.00	.00	.00	.00	.21	.10	.10	.00	.00	.00	.00	.16
7	.585	3.839	.10	.00	.04	.02	.05	.01	.10	.05	.00	.00	.04	.00	.00	.08	.05	.05
8	.488	4.204	.00	.07	.00	.04	.07	.01	.34	.06	.03	.04	.25	.00	.00	.01	.00	.04
9	.394	4.675	.02	.00	.02	.32	.01	.05	.06	.07	.13	.00	.04	.08	.02	.02	.02	.10
10	.330	5.107	.03	.00	.02	.01	.02	.26	.02	.13	.02	.17	.01	.00	.10	.34	.02	.01
11	.318	5.204	.03	.00	.00	.07	.09	.08	.00	.22	.37	.17	.02	.08	.00	.07	.03	.10
12	.263	5.729	.10	.03	.00	.21	.06	.00	.05	.01	.00	.00	.02	.52	.02	.05	.08	.00
13	.232	6.100	.00	.02	.26	.07	.04	.06	.00	.00	.03	.07	.02	.11	.40	.09	.03	.01
14	.197	6.619	.02	.42	.02	.00	.34	.18	.03	.07	.01	.02	.04	.00	.15	.01	.02	.41
15	.138	7.891	.50	.01	.18	.16	.00	.00	.01	.00	.09	.02	.15	.00	.17	.08	.56	.00
16	.129	**8.160**	.17	.38	.44	.02	.01	.20	.04	.00	.00	.11	.14	.18	.11	.08	.18	.10

South Carolina 1										
Dimension	*Eigenvalue*	*Condition Index*	*Constant*	*M1 7*	*M1 8*	*M1 9*	*M1 10*	*M1 11*	*M1 13*	*M1 22*
1	4.779	1.000	.01	.01	.01	.01	.01	.01	.01	.01
2	.918	2.282	.05	.05	.03	.00	.05	.08	.05	.00
3	.837	2.389	.00	.01	.00	.00	.01	.01	.52	.07
4	.665	2.681	.05	.00	.02	.37	.00	.01	.03	.13
5	.241	4.452	.59	.00	.37	.02	.10	.00	.16	.16
6	.226	4.595	.12	.15	.48	.15	.00	.07	.01	.42
7	.210	4.769	.16	.29	.01	.44	.40	.03	.05	.09
8	.123	**6.232**	.03	.49	.08	.01	.43	.80	.17	.13

South Carolina 2								
Dimension	*Eigenvalue*	*Condition Index*	*Constant*	*M1 4*	*M1 6*	*M1 7*	*M1 8*	*M1 15*
1	3.968	1.000	.01	.02	.02	.01	.02	.02
2	.788	2.244	.00	.00	.07	.05	.07	.39
3	.527	2.745	.04	.19	.46	.04	.01	.03
4	.329	3.475	.03	.19	.20	.00	.50	.35
5	.233	4.127	.18	.32	.16	.33	.34	.12
6	.155	**5.057**	.73	.28	.09	.56	.07	.10

A total condition index (bolded in black) below 15 is generally indicative of independent measures.

Appendix 8: Descriptions of barriers, illustrated through examples in both Arizona and Georgia

Barrier	Description	Examples (A=Arizona; G=Georgia) – Separated by semicolons
Communication, messaging, and the media	Avenues for discussing issues within and between CWS are lacking, or confusion around terminology and discussing water/drought issues limits implementation of the approach	**A**: Media create misperceptions around droughts that stick with the public a long time **G**: System has different 'audiences' that need to hear different information, sending mixed signals (e.g., planners want 'worst case scenarios' when projecting rates and elected officials want 'best case scenarios' when planning CIP)
Customer demand	Controlling water demand cycles and peaks makes it difficult to implement the approach, or demand has decreased enough that the management approach is perceived as irrelevant	**A**: Decrease in demand reduces the need for additional infrastructure **G**: Customers can easily afford water making it difficult to promote conservation
Demographics	Implementing approaches is difficult because of the demographic composition of customers	**A**: Heavy agriculture increases water use **G**: Wealthy county creates demand for manicured lawns, making conservation difficult
Financial	Local decisions involving money require multiple layers of approval, or CWS/local Budgets and revenue streams, lack of State and/or Federal support, or the economy and recession in general have stifled implementation of approaches	**A**: Rates and capital improvement project decisions require board approval **G**: Securing additional storage is too expensive
Geographic and physical	Location and topography determines and sometimes limits options for implementing approaches, or borders contribute to parochial attitudes and independent mind-frame	**A**: Nearest town to work with is 70 miles away; Adjacent systems had problems that were inputted onto their system, making them appear vulnerable to the public; Other supplies exist but are not in the system's geographic purview **G**: System takes care of its own needs and sees neighbors as competitors; Location makes it difficult to pump water up hill to customers
Growth	Dependence on or attention to growth limits implementation	**A**: City is dependent upon growth for revenue, and water feeds this growth **G**: Growth outpaced the ability to secure water supply
Ignorance and information	Limited understanding of water and drought affects behavior, use, perception, and ultimately management decisions, or insufficient information makes it difficult to implement the approach	**A**: System does not know the dynamics of its water sources, making it difficult to adequately plan for droughts; Complicated analyses are required for rate structure changes and capital improvement projects **G**: Public not informed enough to involve in decision making process; Only a few years of water data makes it difficult to inform decision making;
Infrastructure	The current 'built environment' limits certain management approaches, infrastructure decisions require multiple layers of approval that slow down the process, or infrastructure creates a false sense	**A**: Speed of development results in sub-standard infrastructure that deteriorates quickly; Inadequate ability to treat additional water supplies; Reservoirs

	of security or feeling of desperation	create opposite perception between managers and customers **G**: Newer development leaves little room for increases in efficiency; Purple pipes increase demand rather than replace existing use
Institutional	Forum, platform, or programs lacking to implement the approach, or governance structures and decision-making procedures within and between CWS/local entities or regionally between CWS prevents or limits implementation	**A**: System is institutionally blocked from making certain decisions, like securing additional water supply; City dips into CWS revenues, which decreases incentives for the system to innovate **G**: System is dependent upon a water authority, so innovation is less relevant and more controlled by higher processes; Army Corps determines reservoir releases, and thus his/her system's water supply; No citizen's committee for stakeholder input
Leadership	Key individuals choose not to implement approaches or innovate	**A**: Programs not implemented because leadership got in the way or did not promote it **G**: Manager feels that the public is best kept uniformed and removed from the problems that the system faces
Legal and rights	Lawsuits or legal processes to secure water rights slow down or prevent implementation	**A**: Central Arizona Project allocation is junior to neighbors, preventing additional supply for the system **G**: Tri-state water wars and endangered species concerns stop drought contingency reservoirs from being filled and will likely remain empty for the foreseeable future
Long-term planning	Planning horizons or procedures slow implementation, or inadequate long-term planning mentioned as a limiting factor	**A**: Poor planning creates heavy tax burden for customers, decreasing incentives for conservation rate structure; Augmenting groundwater with surface water is outside of current planning window **G**: Long-term planning decisions require many layers of approval, decreasing flexibility to implement infrastructure improvements
Perception and cognitive	Public or staff is apathetic, complacent, or desensitized, CWS feels it is not within their responsibility or capability to address an issue, or general feeling that there is no additional need to address the problem because the 'job has been finished'	**A**: General public does not care about drought until it is an emergency, which precludes them from taking an active participatory role in water planning **G**: System feels that it is the state's responsibility to plan for future water, negating their own need and responsibility to use climate information
Political	Political climate and election cycles determine the ability to implement an approach, elected officials are unable to think beyond immediate local interests or rely on water managers' decisions for reelection and political battles, powerful vocal opposition stifles innovation, or fear of losing water independence	**A**: Stricter conservation rates are not politically acceptable for Board members because of future electability; Interconnectedness limited by fears that water can be taken away in political grabs **G**: Restrictions loosened because of lobbying; Well-planned for water will be

		taken away by higher powers during serious droughts
Regulatory, legislative, and policies	Federal, state, or local government limits timing, magnitude, or enforcement of management approach due to statues, rules, or policies (or lack thereof) determined by agencies, legislatures, boards, or commissions	**A**: All policy decisions have to be decided on by the local Board **G**: Unable to implement restrictions that are more strict than those determined by the state; Too many local ordinances and state laws limit ability to adjust management; Some measures are required but not enforced by the state
Risk and cautiousness	An overly conservative and risk averse approach to management prevents implementation, or concern that external decisions will impact CWS decisions pushes them to be less innovative	**A**: Fear of criticism from a vocal minority stops management from seeking public input into decisions; Connecting with other systems could weaken the overall strength of the system **G**: Culture has developed in a system that punishes staff for taking risks and attempting to innovate
Size	CWS size, either large or small, plays a role in limiting implementation	**A**: Small size means that it is highly driven by a single individual and innovation is not engrained in the culture of the system **G**: Too large a system to see any benefit in working with neighbors to plan for drought
Staff, personalities, and relationships	Insufficient staff or resources at various scales, key CWS staff that were in charge of innovative programs were laid off or are single handedly responsible for its success, too many resources creates tensions with other resource-strapped CWS, conflicting personalities within CWS and governments, or negative relationships between CWS and other entities limits innovation	**A**: Conservation coordinator 'let go' because of the economy; Junior staff reluctant to step-up and take charge; Nearby regions envious of others' resources discouraging, collaboration; Conflicts between water resource directors and water quality directors **G**: Junior state agency staff are still adversarial to collaborating; Departmental turf issues prohibits collaboration
Time	Time (either too much or not enough) precludes managers from implementing approaches, projects coincide with other events or conflict with other initiatives that slow down their implementation, or previous decisions make implementing the approach unnecessary or irrelevant	**A**: City has been established within the past two decades and infrastructure improvements are not needed; State dragging its feet on adjudication process; Pace of growth facilitates a reactive rather than proactive approach **G**: Election cycles put pressure on the innovative governance arrangement and distracts managers from further innovating
Trust, confidence, and skepticism	Blind faith in the managers' decisions creates a disincentive for implementing the approach, difficulty in conveying the need for certain approaches because of the concern that the public will lose confidence in the CWS, or general distrust between entities or individuals stifles innovation	**A**: Collaboration is made difficult because past efforts have failed or planning projections have consistently led a system in the wrong direction; Rates and fees discouraging use are interpreted in a way that erodes confidence in the system **G**: Doubting the validity of climate change restricts the system's use of climate information and scenarios; Trust

		in the system's management contributes to the public's ignorance and complacency around droughts; Rarely use the word 'uncertainty' because the public will perceive that the system does not know what it is doing
Water source, availability, and quality	Sufficient or abundant water supply (perceived or actual) makes implementing the approach seem unnecessary, not enough water prevents implementation, or water quality is a limiting factor in pursing the approach	**A**: System can continue to pump groundwater for hundreds of years if surface water disappears; Neighboring community has poor water quality, which precludes collaboration **G**: Lowest river flow is still multiple times larger than the system's daily use, reducing the perceived need to conserve; Poor groundwater quality prevents diversification of water supplies; Area receives abundant rainfall every year

Appendix 9: Descriptions of bridges, illustrated through examples in both Arizona and Georgia

Bridge	Description	Examples (A=Arizona; G=Georgia) – Separated by semicolons
Communication, messaging, and the media	Channels and meetings for dialogue within and between CWS, local governments, agencies, and the public increases implementation, or media (for better or worse) brings attention to the issue an mobilizes action	**A**: Convey 'wise management' over 'conservation' when reservoirs are full so as to make sense to the public; Newspaper series on drought scared people into conserving **G**: Regular meetings help foster an innovative culture; State sends out letters to the public that clearly identify drought status, making it easier for system to implement conservation; Media informs the public in ways that the system's education campaign could have only dreamed of; Public has multiple avenues for providing input into management decisions
Conservation	Specifically mentioned that conservation is the motivating factor for the approach	**A**: Rate-structure motivated by conservation, not revenues; Experiment with better ways to foster a conservation ethic **G**: Public is more engaged because of conservation education
Customer demand	High water demands necessitates approach, decrease in demand leads to new approach, or customers request certain information or approaches that ultimately lead to improvements or innovation	**A**: Public concerned with environmental conditions in the community facilitates riparian habitat restoration and conservation; Decrease in water demand helps system focus on other priorities **G**: Customers want monthly bills to track their usage, which requires the system to install better meters to monitor their use; Spike in peak demand motivates managers to build an additional intake on the reservoir
Demographics	Citizen make-up influences the implementation of the approach	**A**: College community makes the public more active in water decisions **G**: Shift to lower income residents results in more water conserved
Drought events	Specific reference to an extreme drought event that led to the implementation of the approach, or referenced the approach not being implemented once the drought has subsided	**A**: Conservation ramped up during the 2001 - 2005 drought; Drought planning was prioritized as a result of the drought, especially at the state-level; Climate information use increased after 'wake-up call' from early 2000s drought **G**: Worked with other systems to plan for drought after they were dangerously close to running out of water; Interconnect with other systems because of dry periods
Drought planning	Specific reference to drought plans or drought planning process, leading to further implementation of the approach	**A**: Drought planning fostered regional collaboration; State Drought Task Force improved perception of the drought as a serious issue; Use of climate information increased when constructing a drought preparedness plan **G**: Looked to expanding regional reservoir capacity for drought contingency
Emergencies and reducing vulnerability	Times of emergency (other than referring to a specific drought event), or anticipating future water security problems and vulnerabilities stimulated the implementation of the approach	**A**: 9/11 spurred additional planning procedures and regional collaboration; Adjacent city's 'boil water notice' facilitated sharing of water supplies through interconnects to secure resources during future water security breakdowns

		G: Many of the system's interconnects were instigated by Y2K scare; Decisions made during a recent hurricane gave the system the opportunity to discuss uncertainty
Environmental	Ecological or environmental factors were influential in contributing to the approach's implementation	**A**: System worked with the State to change legislation that would ultimately lead to increased wetland habitat; Planned infrastructure not built because carbon footprint unsustainable **G**: Environmental NGOs are brought into the planning process to avoid future problems
Financial	Cost motivations, adequate financial flows, water pricing and rates, financial incentives for implementation, or the recession and state of the economy allow for or have necessitated a focus on the approach	**A**: Rate structure altered to focus on covering fixed costs with base rate, which reduces the disincentive to conserve; Work regionally to plan so as not to compete for scarce resources; Interconnects with other systems for wholesale reasons **G**: State fines the system less for piloting an innovative water program; Toilet rebate programs incentivize conservation; System has adequate funds to devote to innovation; Asset management improves decisions regarding when to make repairs
Geographic and physical	Location, boundaries, or topography requires innovation or increases options or likelihood for implementing approaches	**A**: Reaching 'build out' to its borders allows system to focus on other innovative approaches; Forced to innovate out of fear that Upper Colorado Basin users will take their water allocations; System works with communities at its borders due to convenience **G**: 'High location in watershed' necessitates seeking supply diversity, enabled by adequate physical space to build reservoirs and carry out experiments; Small portion of the system is within a less regulated watershed, increasing supply options
Growth	Growth allows for the approach or stimulates the need for innovation	**A**: Development fees have led to infrastructure improvements; Transition from agriculture to urban creates need for better drought planning **G**: Supply infrastructure added to keep pace with growth
Historical	Referred to as 'always' being implemented, or something that has been around for several decades before the period of inquiry	**A**: Conservation campaign dating back to the 1970s continues today; System working with the Federal government since the mid 1980s **G**: Fixing pipes and metering is consistently an objective, spending tens of millions of dollars over the past two decades; Sustainability and ecological issues an objective from day one
Infrastructure	Innovation is achieved through new additions to the 'built environment' or existing infrastructure, or infrastructure (or perceived need for it) leads to implementation of the approach	**A**: Regional drought planning occurred around the need to develop Central Arizona Project allocations; Supply diversity increased when reclaimed system and new plant came online; Low reservoir levels help communicate uncertainty to the public **G**: System's take-over of the stormwater utility forces collaboration with other local entities; Supply diversity and drought planning improved with contingency reservoir

Institutional	Formal structures that form the governance model help assure implementation of the approach, or a particular approach has been informally engrained into the institutional culture of the CWS or state	**A**: Intergovernmental agreement between adjacent counties leads to increases in collaboration; City formed a water policy committee which meets regularly; State institutionalized water banking; City and system share resources and services and thus pool management, staff, and administrative efforts **G**: Board composition and structure makes them more flexible than other systems and less likely to muddy decisions with politics; City gets bulk water from the County Authority, which is innovative; Innovation part of their mission statement
Leadership	Key individuals, most often senior managers or elected officials, or the CWS as a whole, are integral for promoting and implementing approaches, or project an innovative attitude toward management	**A**: Program implementation changed considerably when current manager arrived 10 years ago; System is known by its peers as being cutting edge with ecological issues, like riparian reserves; System recognizes that it takes a strong individual leader to institutionalize a leadership mentality **G**: System director given the ability by the Board to single handedly adjust water rates; Manager 'x' has a military leadership background, which influences his search for more supply diversity; Mayor anticipated the need for a regional reservoir decades ago, which has put the system in a better place than others in the region
Learning and education, knowledge exchange, research, reports, and studies	Learning and education through forums and opportunities for exchanging information and knowledge, or specifically mentions a longer term study, report, or research endeavor, which contributes to implementation of the approach	**A**: Examining rainfall in previous years helps determine conservation efforts for upcoming year and reduce uncertainty; Used adjacent city's drought plan that was available online as a template for their own plan; Learned how the groundwater system functions by tracking water data; One of several systems working with universities on tree ring studies, which increases climate information use **G**: System is actively engaged in conferences, civic groups, and writing papers to share information; Working with adjacent county to combine information sources to better communicate drought impacts; Customer surveys help system gauge demand; Long-term flow study in conjunction with the Army Corps helps understand drought dynamics
Legal and rights	Lawsuits or legal processes, including securing water rights, motivate action, or legal impasses help lead to implementation of the approach	**A**: Buying additional water rights from native populations increases supply diversity; Ongoing lawsuit finally settled, which allows the system to augment water supply **G**: 20-year water wars between Georgia, Alabama, and Florida have caused systems to work outside of ordinary channels to plan for droughts and prepare for potential reduction in supply; Water contracts keep systems committed to collaborating
Long-term and iterative planning	Planning (other than drought planning) that is revised, revisited, and reiterated on a cyclical or regular basis, or looks into the future helps initiate innovative	**A**: Master city/water plan helps identify areas that will benefit from conservation and supply diversification approaches; Scenario planning incorporates the most current information in

	approaches	each 5-year iteration **G**: System conservation plan brought about tiered rated structure; Rate model studies are updated every year and project for the subsequent five years; Strategic planning process fosters learning and innovation
Political	Decisions to implement the approach are motivated by politics, or acknowledgement of the political nature of water issues results in innovation	**A**: Political process of the Colorado River allocation have caused the system to seek additional water from a diversity of sources; System considering how to 'spin' and 'play their cards' during the wet period so as to continue to promote a culture of conservation **G**: Water Board is selected by a grand jury of citizens to serve four year terms, and the Board determines its own governing structure, ultimately limiting political pressures on the water system; System spends money on more water than they currently need, but projects to the public as if they need it now so that they have it for the future
Professional organizations and formal regional initiatives	An established professional or regional forum for interaction and collaboration facilitates innovation	**A**: Project ADD Water works regionally to diversify supply and seek additional resources; Eastern Valley Water Forum increases drought planning for all participating systems **G**: Georgia Association of Water Professionals and Association of Metropolitan Water Agencies provide avenues for system leadership and system-system coordination; Metro North Georgia Water Planning District increased conservation efforts
Regional collaboration	Collaboration (not regulated) between CWS or between CWS and State/Federal entities within the region facilitates the implementation of the approach	**A**: Work with the University of Arizona and Arizona State University on climate projections and tree ring studies; Partnering with similar sized systems to learn from one another **G**: Coordinate with Army Corps of Engineers to understand long-term flows on the Savannah River; Region collectively recognized the need to protect reservoir habitat and resources
Regulatory, legislative, and policies	Federal, state, or local government facilitates approach through enforcement of statues, rules, or policies (or lack thereof) determined by agencies, legislatures, boards, or commissions	**A**: State-required drought planning increases collaboration; System recognized it would not meet safe yield requirements for assured supply policy and collaborated regionally for additional supply **G**: Public perception aligns with system's perception of drought when system enforces water restrictions; Even though system is not thrilled, the Metro North Georgia Water Planning District and the Statewide Comprehensive Water Planning processes increase drought planning; Anticipated regulations have motivated manager to work with environmental community
Size	CWS size, either large or small, plays a role in facilitating implementation	**A**: Smaller size in comparison to neighboring systems pushes them to innovate at every position and role within the system **G**: As the larger system, others in the region turn to them for collaboration, guidance, and support; Size allows them to be the 'little brother' within the Metro District, but the 'big brother' in their

		basin
Staff, personalities, and relationships	General staff, important staff initiatives, or internal dynamics contribute to a culture within which innovation is a priority	**A**: Water department working with the planning department to implement rain water harvesting and xeriscaping; Two staff members devoted specifically to conservation; **G**: Several staff work with schools to improve conservation; Naturalist on staff helps assure attention to ecological issues; Inter-agency committees are successful because they are amicable
Technical and monitoring	Sophisticated analyses or monitoring using science, modeling, data, and technical expertise, or potential technological fixes support implementation of the approach or stimulate innovation	**A**: Collaboration with other systems that share a similar level of sophistication; Computer modeling helps strategically site wells and project water needs; Climate change incorporated into groundwater models, which supports regional collaboration; Manager uses ecological indicators to monitor and conservatively estimate annual rainfall **G**: Revising and experimenting is possible because they closely monitor key system variables daily; Hourly meter reads from radio towers improve efficiency and conservation
Time	Time (either too much or not enough) supports or motivates managers actions, projects coincide with other events or cycles which influenced their implementation, or previously ill-timed initiatives are altered to improve implementation of the approach	**A**: Regional wholesale provider altered timing of allocations due to customers needs for the information sooner, so as to improve their long-term planning; Timing of staff composition at key positions within the system and local government allowed for innovation **G**: Mature system's pipes were recently replaced, making it possible to focus on rebuilding wholesale meters
Trust, respect, and credibility	Implementation is facilitated or motivated by well established trust, respect , or credibility, which enables support and buy-in from stakeholders and officials for the approach	**A**: Trust between manager and the Board allow for more autonomy and flexibility in decision making **G**: Long-standing relationship with nearby university and professors ensures that the system will be at the cutting edge of science and research; Desire to maintain public's trust motivates the system to actively seek public input
Water source, availability, and quality	Limited water or poor quality necessitates innovation, or abundant water provides wiggle room for implementing approaches	**A**: Effluent treated like 'gold'; Water quality scare forced system to collaborate with other systems in the region **G**: Collaborations have increased around water quality because supply is less of a concern; Learning about aquifer depletion has resulted in the construction of a surface water treatment plant

Appendix 10: Cumulative logit models predicting the probability of a management approach being implemented with respect to drought indicators from 1999-2009

	Current		Probability																							
			M4.1 (0)	M4.1 (1)	M4.1 (2)	M4.1 (3)	M4.2 (0)	M4.2 (1)	M4.2 (2)	M4.2 (3)	M4.3 (0)	M4.3 (1)	M4.3 (2)	M4.3 (3)	M8 (0)	M8 (1)	M8 (2)	M8 (3)	M12.1 (0)	M12.1 (1)	M12.1 (2)	M12.1 (3)	M13 (0)	M13 (1)	M13 (2)	M13 (3)
Arizona	6 month SPI	-3	0.39	0.26	0.23	0.12	0.34	0.42	0.17	0.07	0.57	0.12	0.25	0.06	0.27	0.27	0.30	0.15	0.37	0.09	0.29	0.26	0.45	0.11	0.21	0.23
		-2	0.36	0.26	0.25	0.13	0.32	0.43	0.18	0.07	0.54	0.13	0.26	0.07	0.25	0.26	0.32	0.17	0.35	0.09	0.29	0.28	0.42	0.11	0.21	0.26
		-1	0.33	0.25	0.27	0.15	0.30	0.43	0.20	0.08	0.52	0.13	0.28	0.07	0.23	0.26	0.33	0.19	0.32	0.08	0.30	0.30	0.39	0.10	0.22	0.29
		0	0.30	0.25	0.28	0.17	0.28	0.43	0.21	0.09	0.50	0.13	0.29	0.08	0.21	0.25	0.34	0.21	0.30	0.08	0.30	0.32	0.35	0.10	0.23	0.32
		1	0.27	0.24	0.30	0.19	0.26	0.43	0.22	0.10	0.48	0.13	0.30	0.09	0.19	0.24	0.35	0.23	0.29	0.08	0.30	0.34	0.32	0.10	0.23	0.35
		2	0.25	0.24	0.31	0.21	0.24	0.42	0.23	0.10	0.46	0.13	0.32	0.09	0.17	0.22	0.36	0.25	0.27	0.08	0.30	0.36	0.29	0.10	0.23	0.38
		3	0.22	0.23	0.32	0.23	0.22	0.42	0.25	0.11	0.44	0.13	0.33	0.10	0.15	0.21	0.36	0.27	0.25	0.07	0.30	0.38	0.27	0.09	0.23	0.41

	1 period lag (6 months)		Probability																							
			M4.1 (0)	M4.1 (1)	M4.1 (2)	M4.1 (3)	M4.3 (0)	M4.3 (1)	M4.3 (2)	M4.3 (3)	M5 (0)	M5 (1)	M5 (2)	M5 (3)	M8 (0)	M8 (1)	M8 (2)	M8 (3)	M12.1 (0)	M12.1 (1)	M12.1 (2)	M12.1 (3)	M13 (0)	M13 (1)	M13 (2)	M13 (3)
	6 month SPI	-3	0.36	0.25	0.26	0.13	0.57	0.12	0.24	0.06	0.13	0.15	0.26	0.47	0.25	0.26	0.32	0.17	0.36	0.08	0.29	0.26	0.43	0.10	0.21	0.26
		-2	0.34	0.25	0.27	0.14	0.55	0.13	0.26	0.07	0.12	0.14	0.25	0.50	0.24	0.25	0.33	0.18	0.34	0.08	0.30	0.28	0.41	0.10	0.21	0.28
		-1	0.32	0.25	0.28	0.15	0.52	0.13	0.28	0.07	0.10	0.13	0.24	0.53	0.22	0.25	0.34	0.19	0.32	0.08	0.30	0.30	0.38	0.10	0.22	0.30
		0	0.29	0.25	0.29	0.17	0.50	0.13	0.29	0.08	0.09	0.11	0.23	0.56	0.20	0.24	0.35	0.21	0.30	0.08	0.30	0.32	0.35	0.10	0.22	0.33
		1	0.27	0.24	0.30	0.18	0.47	0.13	0.31	0.09	0.08	0.10	0.22	0.60	0.19	0.23	0.36	0.23	0.28	0.07	0.30	0.34	0.33	0.09	0.23	0.35
		2	0.25	0.24	0.31	0.20	0.44	0.13	0.33	0.10	0.07	0.09	0.21	0.63	0.17	0.22	0.36	0.24	0.27	0.07	0.30	0.36	0.30	0.09	0.23	0.38
		3	0.23	0.23	0.32	0.22	0.42	0.13	0.34	0.11	0.06	0.09	0.19	0.66	0.16	0.21	0.37	0.26	0.25	0.07	0.30	0.38	0.28	0.09	0.23	0.41

	2 period lag (12 months)		Probability							
			M2 (0)	M2 (1)	M2 (2)	M2 (3)	M4.3 (0)	M4.3 (1)	M4.3 (2)	M4.3 (3)
	6 month SPI	-3	0.00	0.02	0.17	0.81	0.57	0.13	0.25	0.06
		-2	0.00	0.02	0.18	0.80	0.54	0.13	0.26	0.07
		-1	0.00	0.02	0.19	0.79	0.51	0.13	0.28	0.07
		0	0.00	0.02	0.20	0.78	0.49	0.13	0.30	0.08
		1	0.00	0.02	0.22	0.76	0.46	0.13	0.31	0.09
		2	0.00	0.02	0.23	0.75	0.44	0.13	0.33	0.10
		3	0.00	0.02	0.24	0.74	0.41	0.13	0.35	0.11

Georgia	**Current**		Probability																							
			M4.1 (0)	M4.1 (1)	M4.1 (2)	M4.1 (3)	M4.3 (0)	M4.3 (1)	M4.3 (2)	M4.3 (3)	M7 (0)	M7 (1)	M7 (2)	M7 (3)	M9 (0)	M9 (1)	M9 (2)	M9 (3)	M12.2 (0)	M12.2 (1)	M12.2 (2)	M12.2 (3)	M15 (-1)	M15 (0)	M15 (1)	M15 (2)
	6 month SPI	-3	0.16	0.24	0.29	0.31	0.26	0.35	0.24	0.14	0.59	0.34	0.07	0.00	0.25	0.55	0.11	0.09	0.29	0.25	0.28	0.18	0.01	0.41	0.36	0.22
		-2	0.15	0.23	0.30	0.33	0.27	0.35	0.24	0.14	0.62	0.32	0.06	0.00	0.22	0.55	0.13	0.10	0.26	0.24	0.29	0.20	0.01	0.44	0.35	0.21
		-1	0.14	0.22	0.30	0.35	0.28	0.36	0.23	0.13	0.65	0.30	0.05	0.00	0.19	0.55	0.14	0.12	0.24	0.23	0.31	0.22	0.01	0.47	0.34	0.19
		0	0.13	0.21	0.30	0.37	0.30	0.36	0.22	0.12	0.67	0.28	0.05	0.00	0.17	0.54	0.15	0.14	0.21	0.22	0.32	0.25	0.01	0.49	0.33	0.17
		1	0.12	0.20	0.30	0.39	0.31	0.36	0.22	0.12	0.69	0.26	0.04	0.00	0.15	0.53	0.17	0.16	0.19	0.21	0.32	0.28	0.01	0.52	0.31	0.16
		2	0.11	0.19	0.29	0.42	0.32	0.36	0.21	0.11	0.72	0.24	0.04	0.00	0.13	0.51	0.18	0.18	0.17	0.20	0.33	0.31	0.01	0.54	0.30	0.14
		3	0.10	0.18	0.29	0.44	0.33	0.36	0.20	0.11	0.74	0.23	0.04	0.00	0.11	0.49	0.19	0.20	0.15	0.18	0.33	0.34	0.01	0.57	0.29	0.13
	1 period lag (6 months)		Probability																							
			M4.3 (1)	M4.3 (1)	M4.3 (2)	M4.3 (3)	M12.2 (0)	M12.2 (1)	M12.2 (2)	M12.2 (3)	M13 (0)	M13 (1)	M13 (2)	M13 (3)	M15 (-1)	M15 (0)	M15 (1)	M15 (2)								
	6 month SPI	-3	0.24	0.34	0.26	0.15	0.28	0.24	0.29	0.19	0.10	0.50	0.37	0.03	0.00	0.31	0.37	0.31								
		-2	0.26	0.35	0.25	0.14	0.25	0.24	0.31	0.21	0.12	0.52	0.34	0.03	0.01	0.37	0.37	0.26								
		-1	0.28	0.35	0.24	0.13	0.23	0.23	0.32	0.23	0.13	0.54	0.31	0.02	0.01	0.43	0.35	0.21								
		0	0.30	0.36	0.23	0.12	0.20	0.22	0.33	0.25	0.15	0.55	0.28	0.02	0.01	0.49	0.33	0.17								
		1	0.32	0.36	0.22	0.11	0.18	0.20	0.33	0.28	0.17	0.56	0.25	0.02	0.01	0.55	0.30	0.14								
		2	0.34	0.36	0.20	0.10	0.16	0.19	0.34	0.31	0.19	0.57	0.22	0.01	0.02	0.61	0.26	0.11								
		3	0.36	0.35	0.19	0.09	0.15	0.18	0.34	0.34	0.22	0.57	0.20	0.01	0.02	0.66	0.23	0.09								
	2 period lag (12 months)		Probability																							
			M1 (0)	M1 (1)	M1 (2)	M1 (3)	M4.3 (0)	M4.3 (1)	M4.3 (2)	M4.3 (3)	M13 (0)	M13 (1)	M13 (2)	M13 (3)	M14.1 (0)	M14.1 (1)	M14.1 (2)	M14.1 (3)	M15 (-1)	M15 (0)	M15 (1)	M15 (2)				
	6 month SPI	-3	0.09	0.36	0.34	0.21	0.24	0.34	0.27	0.15	0.09	0.48	0.40	0.03	0.43	0.34	0.11	0.11	0.00	0.29	0.37	0.34				
		-2	0.10	0.38	0.33	0.19	0.26	0.35	0.26	0.14	0.10	0.51	0.36	0.03	0.42	0.35	0.12	0.12	0.01	0.35	0.37	0.27				
		-1	0.11	0.40	0.32	0.17	0.28	0.35	0.25	0.13	0.12	0.53	0.32	0.02	0.40	0.35	0.12	0.12	0.01	0.42	0.36	0.22				
		0	0.12	0.42	0.31	0.16	0.30	0.36	0.23	0.12	0.15	0.55	0.28	0.02	0.39	0.36	0.13	0.13	0.01	0.49	0.33	0.17				
		1	0.13	0.43	0.29	0.14	0.32	0.36	0.22	0.11	0.17	0.57	0.24	0.02	0.37	0.36	0.13	0.14	0.01	0.55	0.30	0.14				
		2	0.15	0.45	0.28	0.13	0.34	0.36	0.21	0.10	0.20	0.57	0.21	0.01	0.36	0.36	0.14	0.15	0.02	0.62	0.26	0.11				
		3	0.16	0.46	0.26	0.12	0.36	0.35	0.20	0.09	0.24	0.57	0.18	0.01	0.34	0.36	0.14	0.15	0.03	0.68	0.22	0.08				

Management approaches depicted for Arizona and Georgia are significant at the 0.1 level in a generalized estimating equations analysis, and refer to scales 0, 1, 2, 3 or -1, 0, 1, 2; depending on the particular approach. Cells predict the probability of occurrence at a given level with respect to the 6-month SPI, a single lag period (6 months) for the 6-month SPI, or two lag periods (12 months) for the 6-month SPI.