ON THE PRECIPICE OF TRANSITION: WATER, CROPS AND ADAPTATION IN PINAL COUNTY, ARIZONA

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ABSTRACT

Population growth and development in the western region has strained the Colorado River system, which is responsible for sustaining the lives of 40 million people spanning across seven states. In addition to increasing competition for water from stressed water systems, Arizona's future water security is threatened by the worsening impacts of climate change. Droughts in the western US are expected to become more intense, more frequent, and longer in duration. Rising regional temperatures and drier, harsh climate conditions increase surface water evaporation and further diminish water supplies (Melillo et al. 2014). Arizona's agriculture industry faces the most substantial challenges as water conditions change. This study focuses on Pinal County in central Arizona. The county is located between the Phoenix metropolitan area to the north and Tucson to the south. Encompassing five small municipalities, Pinal County includes 1,174,727 acres of farm land (Census of Agriculture 2012). Historically a major agricultural producer for the state, Pinal County is currently the top cotton and barely producer in Arizona and second in durum wheat and alfalfa hay production (Census of Agriculture 2012). With the threats of climate change and changes in water allocations looming, agricultural water users in Pinal County will face increasing challenges.

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INTRODUCTION

The voices of experts and political leaders in recent news coverage indicate a critical time for Arizona water management:

> "The Colorado River, and the entire Southwest, has shifted to a new hotter and drier climate, and, equally important, will continue to shift to a hotter and drier climate." (Brad Udall in Schwartz 2019)
>
> "The hydrology is grim . . . the risks are mounting to communities, agriculture, recreation and the environment." (Kevin Moran in Weiser 2019)
>
> "What I do have a problem with is . . . all of this money going to allow farmers to plant super water-needing crops like pecans and cotton . . . because of this crisis, we're . . . throwing them back [on] groundwater . . . and we're going to be getting more fissures and subsidence." (John Kavanaugh in Fischer 2019)
>
> "We can't keep pretending that water is physically available when it's not . . . It's just a recipe for disaster." (Kathy Ferris in Gardiner 2019)

After almost two decades of drought, coupled with climate change and population growth, water use in Arizona is on the precipice of a dramatic transition. This transition has been spurred by the falling levels of water in Lake Mead, designated as an indicator of condition of the Colorado River system. When levels in Lake Mead drop below 1,075 feet, the federal government is required to step in and reduce water allocations to all states using Colorado River water. In March 2019, the level was at 1,088 feet (Schwartz 2019) and reaching 1,075 feet has been called a virtual certainty for 2020 if current uses continue (Weiser 2019). To protect water resources and attempt to avoid federal intervention, states have created a Drought Contingency Plan. On April 3, 2019, members of Congress from the seven Western states using Colorado River water introduced the Colorado River Drought Contingency Plan (DCP) (Gibson 2019). When implemented, the terms of the agreement, a product of years of negotiations, will result in significant water cuts, especially in Arizona.

In Arizona, the DCP will at first entail cutting 192,000 acre-feet of Colorado River water for the state (Davis 2019). An acre-foot of water is about 326,000 gallons and is widely equated to the amount of water that is used by a typical family of two for one year. These cuts are specific to water in the Central Arizona Project (CAP), which moves water from the Colorado River in the Northwestern part of Arizona to Central Arizona, the areas around Phoenix and Tucson where most of the population resides. Initial cuts will entail about one-third of the entire annual delivery of water through the CAP, increasing to half of total current CAP water when Lake Mead drops below 1,075 feet (Davis 2019). The first water cuts in Arizona will be from agricultural uses. Experts predict that this will result in 40 to 60 percent of agricultural fields fallowed in Central Arizona and the loss of crops will have especially significant impacts on the dairy industry (Gibson 2019).

The most dramatic impacts to agriculture will be felt in Pinal County. The county lies between Phoenix and Tucson and is a top producer of alfalfa and cotton, which are very water intensive, as well as beef and dairy products, which depend on alfalfa production. Pinal uses more CAP water than other counties, with CAP water accounting for about half of the water used in agriculture. Under the DCP, this water will no longer be available. Due to the severity of these impacts, Arizona's DCP process was temporarily stalled as Pinal County farmers put a wrench in the negotiations until they were offered a mitigated supply of CAP deliveries through 2023 and $9 million to develop improved well infrastructure to access more groundwater (Gibson 2019). However, groundwater supplies are far from infinite, with many fearing depleted aquifers. Pinal County is also one of the fastest growing areas of the state, and groundwater depletion threatens planned housing developments (Gardiner 2019). Switching to groundwater is not a long-term solution, and there will be unprecedented changes to agriculture in the coming years. Pinal county farmers face a challenging transition, one that will leave agriculture in the county dramatically altered.

This project focuses on Pinal County and examines the capacity of individual crop growers as well as irrigation districts to adapt to the challenges posed by increasing state water demands and regional water security concerns. With water restrictions coming, agricultural water users in Pinal County will experience increasing challenges in securing water supplies for crop production. These challenges will depend on how water allocations have been and are negotiated, the relative influence of other regional water-users, and what sources of support and resources agricultural producers have access to. The purpose of the project is to provide place-based empirical examination of adaptive capacity focusing on adapting to changing water availability for irrigated crop agriculture in Pinal County. I examined how water allocation will change in Pinal County and how the field crop sector will be impacted. I will also identify approaches, policies and management changes that have been initiated to address transitions in Pinal County agriculture and what barriers may preclude effective responses to these changes.

LITERATURE REVIEW

In this section, I provide background information and context for this case study. First, I provide an overview of the legal structure and priority system that governs consumptive use of the Colorado River, followed by a brief history of water development in the Western US and select federal reclamation projects. Then I will give an overview of the approval and construction of the Central Arizona Project (CAP), along with the priority structure that governs deliveries of CAP water to current users. A literature review about Arizona's groundwater supplies and the creation of the Arizona Groundwater Management Act follows. The next section in the literature review discusses climate change projections, impacts of climate change on water supplies in the US Southwest and provides context about the agriculture sector in Arizona. I then describe the study area and provide context about agricultural water supplies in Pinal County. The last section is a literature review about the theoretical approach used in this study and how it was employed.

Water Development in the Western US

Prior appropriation and Federal Reclamation projects

The transformation of the American west began in the early twentieth century, as valuable minerals and federal support drew populations away from the eastern coast toward westward expansion (Water in the U.S American West 2012). In a land where no laws governed the stores of fresh water and untouched earth, a boom in population uncovered the urgent necessity to decide who could utilize water resources and for what purpose. Early settlers concentrated in mining camps in the region adopted the Spanish legal doctrine of "first in time, first in right" or "prior appropriation" as the first set of rules governing water use in the American west (Jacobs and Colby 2007). This legal framework, which remains the foundation for western water policy, gave the rights of any supply of water to the first users who could put the resources to "beneficial use" (Benson 2012). The rights to use of those resources would remain in perpetuity with seniority to the earliest users in times of future scarcity.

The federal government encouraged western settlement and urged settlers to stake claims for private water rights for agricultural production to build the region's economy. The government reserved a portion of western water stores to be used for public lands and for designated native populations. Western water resources were determined to be a public good, but the states were given full authority to create policy and institutions to govern the use of the remaining and essentially the entirety of the surface water resources in the region (Getches 2001). Decades of contentious debate about the authority of federal and state water policies and conflict over water sources crossing political boundaries has resulted in the evolution of institutional structures to govern the scarce and variable water supplies of the western region of the United States (Water in the U.S American West 2012).

With the passing of the Federal Reclamation Act of 1902, the federal government took responsibility for "the construction and maintenance of irrigation works for the storage, diversion, and development of waters for the reclamation of arid and semiarid lands" (USBR 2019). With federal funding, dams and storage reservoirs were constructed on most western rivers, increasing capacity for irrigation of agricultural lands.

The Federal Reclamation Act of 1902 officially gave the federal government the power and responsibility to head the country in water development projects. The National Irrigation Association was the government institution created to expand the nation's irrigated agricultural land (August et al. 2007). The people of the state lobbied Theodore Roosevelt to build the Roosevelt Dam on the Salt River in 1911, which was the largest dam to be built in the world at the time (Jacobs 2004). From that point, dams were built on virtually every surface water supply in the west and miles of diversion canals were developed for irrigation (Water Education Foundation 2007). As resources became more accessible and demands for growth and economic development increased water resource needs, previously negotiated water rights based in prior appropriation were contested against constitutional rights and conflicts over water allocations between western river basin states prompted the need for interstate compacts to find resolutions (Schlager, E. et al. 2012).

1922 Colorado River Compact

Use of water from the Colorado River, one of the most valuable river systems in the western region, prompted such conflict among its basin states and the further expansion of the legal structures governing western water resources (Water in the U.S American West 2012). Originating in Colorado, the river flows southwest to the Sea of Cortez, and passes through Utah, New Mexico, Nevada, Arizona and California. The seven Colorado River basin states, after years of conflict, determined that the prior appropriation state laws were not adequate or comprehensive enough to allocate the river's resources equitably among them to meet their respective needs. The first piece of legislation that became the foundation for the Law of the River, was the Colorado River Compact of 1922.

The Colorado River Compact divided the seven river basin states into upper and lower basin states and determined to split the 15 million-acre-feet (MAF) in half between them. The upper basin states of Wyoming, Colorado, Utah and New Mexico were allotted 7.5 MAF while California, Arizona and Nevada were set to share 7.5 MAF (Pearce 2007). However, paleohydrolic studies have shown that when projections were completed to inform the Colorado River Compact of 1922, the river's resources were overestimated because of unusually high streamflow during the past 15 years, and therefore water was over-allocated (Meko et al. 1995). Users have been given rights to Colorado River water that does not exist, creating a "structural deficit" in the system.

Initially, Arizona refused to ratify the compact because it did not specify each individual state's allotment and feared the rapidly growing state of California would be quick to use the entirety of the lower basin states' allotment. California had its own agenda and was interested in developing the Hoover Dam and the All-American Canal at the time in order to store and gain access to Colorado River water of its own. To strike a deal, California agreed to the proposal of the Boulder Canyon Project Act of 1928. The act limited California's water allotment to 4.4 MAF and assigned Nevada 0.3 MAF and Arizona 2.8 MAF (LaBianca 1998). In addition to the specifications, it authorized the construction of the Hoover Dam and the All-American Canal (Benson 2012). In the coming two decades, California experienced rapid growth as a result of its successful reclamation efforts while Arizona's development grew at a much slower rate.

The Central Arizona Project

Construction of the CAP delivery system

The majority of the growth in Arizona was occurring in the central part of the state and the 2.2 MAF of Colorado River water was useless without a way to deliver it to the developing land. Because Arizona was simply unable to turn their paper water rights into actual use, their allotment was being used by California, who did have infrastructure to access the water. Arizona claimed California was receiving its portion of the river unfairly. The state attempted to bring California to the Supreme Court three times to address this issue with no avail (Jacobs and Colby 2007). Finally, Arizona ratified the Colorado River Compact and the Boulder Canyon Project Act and began developing a proposal for what would become the largest water diversion project in the history of the United States.

The proposed Central Arizona Project (CAP) would deliver 1.5 MAF of Arizona's water allotment from the main stream of the Colorado River through the central and southern parts of Arizona. California contested the project because of the understanding that, if Arizona is able to access its water allotment, California would no longer have free range to consume beyond its own allotment. After years of congressional debate, California agreed to support the CAP under the condition that, in the case of a future water shortage, river water supply would be cut from the CAP's allotment before any was cut from California or Nevada's supply. Arizona agreed and the CAP was authorized as part of the Colorado River Basin Act of 1968. This detail of the compact, calling for CAP water cuts in the case of a shortage, is now a crucial factor in the future of Arizona's water security.

After the Colorado River Basin Project Act of 1968 was signed by President Johnson, construction of the CAP began and was completed in November 1992 with construction costs near $5 billion (Hanemann 2002). Construction was funded by the federal government and The Central Arizona Water Conservation District (CAWCD) was assembled to provide a means for Arizona to repay the federal government for the construction of the CAP. The CAP Repayment Obligation contract includes revenue generated from the sale of

CAP water through sub-contracts with municipal, industrial, tribal and agricultural water users.

The CAP is a 336-mile system of diversion canals from the main Colorado River stream and diverts about 10% of the river into pipes, across a mountain range rising 3,000 vertical feet. It begins at Lake Havasu and carries water through Phoenix and continues south to its termination at a reservoir southwest of Tucson. Of Arizona's 2.8 MAF entitlement of Colorado River supplies, CAP delivers approximately 1.5 MAF through a "system of aqueducts, tunnels, pumping plants and pipelines" to Maricopa, Pinal and Pima counties, where 80% (5 million) of the state's population lives (CAWCD 2019).

Figure 1: Map of the CAP with Maricopa, Pima, and Pinal Counties.
From: Arizonaexperience.com

The CAP system outlines four water use categories: Municipal and Industrial, Indian, Non-Indian Agriculture (NIA) and Excess. Water users have long term sub-contracts for

CAP water and they are organized in a priority structure. First priority Municipal and Industrial (M&I) subcontracts are with users in the Phoenix and Tucson Metropolitan areas. Indian subcontracts are equal in priority to M&I and are held by tribes for agriculture and non-agricultural use. Second in priority are NIA subcontracts used for irrigation and last priority is the Excess subcontracts that are used for water banking when supplies are available and include the short term “Agriculture Settlement Pool” contract (CAWCD 2019).

Managing Arizona’s Groundwater Supplies

Arizona’s groundwater hydrology

Arizona sits on a diverse and rich aquifer province. Groundwater, present in all regions under the Earth’s surface, is only accessible where geologic conditions are suitable. Having seeped underground over time scales of days to millennia, groundwater is stored and moves slowly through aquifers, or permeable beds of soil and rock. Groundwater can reach the surface through natural springs discharging into streams, lakes or reservoirs, or pumped to the surface with use of wells and man-made pumps (The Groundwater Foundation 2017). Arizona can be divided into three water resource provinces based on the type of aquifers present. The northern part of the state is classified as the Plateau Uplands Province, to the South is the Central Highland Province and the southern part of the state is classified as the Basin and Range Lowlands Province (August et al. 2007). The geologic differences between these provinces greatly influence the availability and quantity of groundwater resources found in each.

The Colorado Plateau province contains several large groundwater basins including the Coconino and Navajo sandstone basins (Anderson et al. 2007). The Central Highland area divides the northern and southern province with various rugged mountain ranges at high elevations. Groundwater availability is limited, with the major watersheds feeding the Gila River (Jacobs 2004). Finally, the Basin and Range Lowlands Province is characterized by broad alluvial basins and mountain ranges. The combination of the high elevation mountains and metamorphic rock structures that are impervious to water allow for precipitation to runoff and be stored in large amounts in the unconsolidated sediments below the valley floors (Anderson et al. 2007). These basins provide considerable groundwater for the state.

There are two types of aquifers that exist in these three regions. First are the thick alluvial deposits of basin fill that are found on the Basin and Range Lowlands Province and second are the sedimentary rock units found on the Plateau Uplands Province. The Central Highland Province contains a mix of these (Anderson et al. 2007). The Plateau Uplands Province are made of porous sedimentary rock that allows water to flow rapidly through them. Groundwater can flow between aquifers that are adjacent as long as there are no impermeable geologic barriers. The amount of groundwater that is stored in each of these aquifers is altered by the inflow and outflow of water through the aquifers. Inflow consists of the precipitation and surface water that seeps into the aquifers and contributes to recharge while outflow is the water that is pumped directly from aquifers through wells or water that is discharged naturally from springs into reservoirs, streams and lakes. Groundwater depletion occurs when the outflow of groundwater is much greater than the inflow, and the aquifer is unable to recharge adequately. Continuous groundwater depletion can have serious consequences for future water resource management and the surrounding land and ecology.

Irrigated agriculture's role in historic groundwater overdraft

Against the scientific recommendations of geologist John Wesley Powell to avoid establishing agriculture in the arid southwest, congress provided legislative support for settlers to begin cultivating lands in central and southern Arizona in the late eighteen hundreds. These early settlers were attracted to the perennial flows of the Gila, Salt and Verde Rivers in central and southern Arizona and established agricultural lands first with use of existing prehistoric irrigation canals left by the Hohokam people. By 1889 more than 150,000 acres of land were being irrigated in the Phoenix area (Anderson 1991).

The historical surface water law in Arizona was "prior appropriation." As stated above, this legal doctrine governs that senior water rights belong to the person who first inhabits the land. This "first in time, first in right" concept rewards the earliest settlers in the state with the greatest privileges to accessible surface water and requires newer settlers to absorb water cuts in times of scarcity. Groundwater, on the other hand, was governed in Arizona by the "reasonable use" doctrine. This framework allows for anyone to pump groundwater at any rate, as long as they are able to use the water for a beneficial purpose, although "beneficial use" is not defined (Jacobs 2004). Several legal battles occurred in the early 1900's when extensive groundwater resources were discovered underlying most all of the land in Arizona. Also, landowners with streams began to notice the impact of groundwater pumping close to their surface water supply as a result of the cone of depression created from pumping.

Policy makers grappled with how to categorize water and the concept of "subflow" entered the debate. Hydrologist Clesson Kenny illustrated how some groundwater flows in distinct channels in predictable ways and is considered “subflow” while some flows through unknown and inconsistent channels. This characterization was taken into consideration in the Supreme Court case, Maricopa County Municipal Water Conservation District No. 1 v. Southwest Cotton Company (1931). The ruling of the case was that, according to Arizona’s prior appropriation laws, “one can only appropriate water flowing in a defined channel, with ascertainable bed and banks” (Pearce 2007). This meant that “subflow” would be governed as surface water and remain separate from the remaining groundwater supply in undefined channels. In other words, this maintained the false premise that groundwater and surface waters exist in separate hydrologic systems, and also reaffirmed the “reasonable use” doctrine, allowing anyone to pump groundwater as long as they could prove to be using it in a beneficial way.

Groundwater pumping increased during World War II as the demand for agricultural products, such as cotton, increased in support of the war effort (Anderson 1991). Farmers in the central and southern parts of Arizona benefitted from commodity crop payments and insurance policies from the United States Farm Bill. Technological advances in well pumping and cheap power production increased groundwater usage to a rate beyond many individual aquifers’ ability to recharge. Unbridled by any specific groundwater management laws, at the height of unsustainable groundwater usage in Arizona between 1950 and 1980, pumpage averaged 4.8 MAF per year and was occurring at 200 times greater a recharge rate in certain basins (Anderson 1991).

With time, agricultural producers, and other water users in the state to a lesser extent, reached a peak of pumping 2.3 million acre-feet per year of groundwater in excess of natural recharge (Arroyo 2018). Aquifer productivity dropped and the depth to the water table continued to lower until some aquifers eventually subsided and compacted. Groundwater basins were depleting and issues with land subsidence and water quality became a critical concern by the 1960s and 1970s (Maguire 2007). These impacts to the land and the resource prompted policy makers in the state to acknowledge the need for a substantial legal governing framework for groundwater pumping and to secure an alternative sustainable water supply moving forward. The Groundwater Management Act (GMA) was adopted in 1980 to address these concerns.

Arizona's Groundwater Code

The GMA reflected the changing priorities of the state and aimed to shift dependence on groundwater resources, accommodate urban growth, limit agricultural expansion, and provide incentives to secure alternative water sources for future security and development (Pearce 2007). Most importantly, the act created the Arizona Department of Water Resources (ADWR) and assigned the institution full control of state groundwater management. ADWR was tasked with creating a comprehensive map of groundwater basins and four basins were labeled Active Management Areas (AMA) where usage was limited by the state. A fifth AMA was established in 1994.

The overall goal of the GMA is to, in time, achieve a balance between groundwater withdrawals and natural and artificial recharge of groundwater basins in the state (Maguire 2007). The primary management goal for the Phoenix, Prescott and Tucson AMAs is "safe yield" by 2025, and this goal is achieved by securing and utilizing alternative water supplies, discouraging further expansion of groundwater use and enforcing water conservation measures to reduce existing uses until equilibrium is achieved and groundwater withdrawal does not exceed recharge (Pearce 2007). The management goal for the Santa Cruz AMA is to maintain “safe yield” and the management goal for the Pinal AMA is to “preserve (the agriculture) economy for as long as feasible, while considering the need to preserve groundwater for future non-irrigation uses” (ADWR 2019). Establishment of the groundwater code provided a means for allocation of the states groundwater supplies. Existing groundwater users were given grandfathered rights that allowed them to either continue irrigation for agriculture, continue to develop former agricultural land for urban use, or to continue use for industrial purposes such as mining and electricity generation (Pearce 2007).

Three major components of the GMA are as follows. First, the act prohibits new irrigation within active management areas with use of any kind of water. Second, the GMA regulates the construction of all wells in the state with use of licensing. This allows the ADWR to monitor the construction of wells and also collect important data from registered wells. The third component is the Assured Water Supply Rule which requires any new residential subdivision to legally and physically secure a 100-year supply of water in order to receive a building certificate from the ADWR (Jacobs 2004).

Figure 2 : Map of the Active Management Areas (AMAs)
for the Arizona Ground Water Management Act. From: Grand Canyon Institute

Climate Change, Water and Arizona Agriculture

The effects of climate change are being observed and predicted around the world. As global emissions of greenhouse gasses continue to be produced, climate conditions are changing at an increasingly rapid rate, with overall trends indicating a warming global climate. The National Climate Assessment reports that global average temperatures have increased by 1.8°F from 1901 to 2016, with no observational evidence supporting any credible natural explanations for such marketable warming (NCA 2018). The International Panel on Climate Change's Fifth Assessment Report supports this perspective and both indicate that human influence, primarily through emissions of heat trapping gasses released in the process of burning fossil fuels for production and development, is the dominant cause of observed climate warming since the mid-20th century. (NCA 2018, 5th IPCC 2013).

Rising average land and ocean temperatures have been observed to propel changes in human and natural systems that are associated with increased risk for vulnerable populations and ecosystems. Natural disasters and severe weather events resulting from temperature rise vary regionally, and include increases in droughts, floods, and some other types of extreme weather; sea level rise; and biodiversity loss (IPCC, 2012a, 2014a; Mysiak et al., 2016; Chapter 3 Sections 3.4.5–3.4.13). In the arid and semi-arid regions of the world, rising land temperatures and decreasing precipitation will make for unprecedented dry conditions.

The semi-arid Southwestern region of the US, occupying one-fifth of the nation's land area and encompassing the states of Arizona, California, Colorado, Nevada and Utah, is already experiencing relatively severe climate change impacts, and will continue to in the future as the climate warms. Areas in the region will have "the hottest and driest climate in the United States" (NCA 2018). The decade from 2001-2010 was the hottest in the 110-year record in the Southwest, almost 2°F higher than historic averages with significantly more heat waves (Melillo et al. 2014). Regional temperature projections include an increase between 2.5°F and 5.5°F by 2041-2070. In addition, climate change is intensifying drought: as stated in the 3rd National Climate Assessment (Melillo et al. 2014), in the next 25 years, the Southwest region will face more frequent droughts that are longer in duration.

Home to over 60 million people, 90% of whom live in urban areas, the Southwestern region boasts a population growth rate 30% above that of the national average (NCA 2018). Large urban centers like Los Angeles, Phoenix, Denver and Las Vegas exist alongside expansive agricultural land and economic powerhouse industries like the technology sector in Silicon Valley (NCA 2018). Water storage and delivery infrastructure has allowed for the nearing 20% of the nation's population to inhabit the desert environment, however, with significant cost to the region's river systems and groundwater basins. Climate change coupled with water scarcity can threaten this development.

Because of the aridity of the region, surface water resources are relatively scarce and highly vulnerable to climatic variations. Precipitation in the form of snow falling at high elevation mountain ranges feeds the region's major river systems and their tributaries, such as the Colorado, the Rio Grande and the Sacramento Rivers, providing the most crucial water supply for the growing human population (NCA 2018). Vital water supplies stored as snow-pack gradually melt and provide water security during the dry summer months when rain is scarce. Hotter average temperatures have reduced annual snow-pack as snow precipitation decreases and shifts in snowmelt timing amplify water supply shortages or "hydrological droughts" in the Southwest region (NCA 2018). Also, rising temperatures from climate change increase surface water evaporation causing river-flow reductions and dwindling reservoirs, creating harsh conditions for sustaining water supplies (Melillo et al. 2014). Thus, climate becomes another user of water shrinking Colorado River water resources.

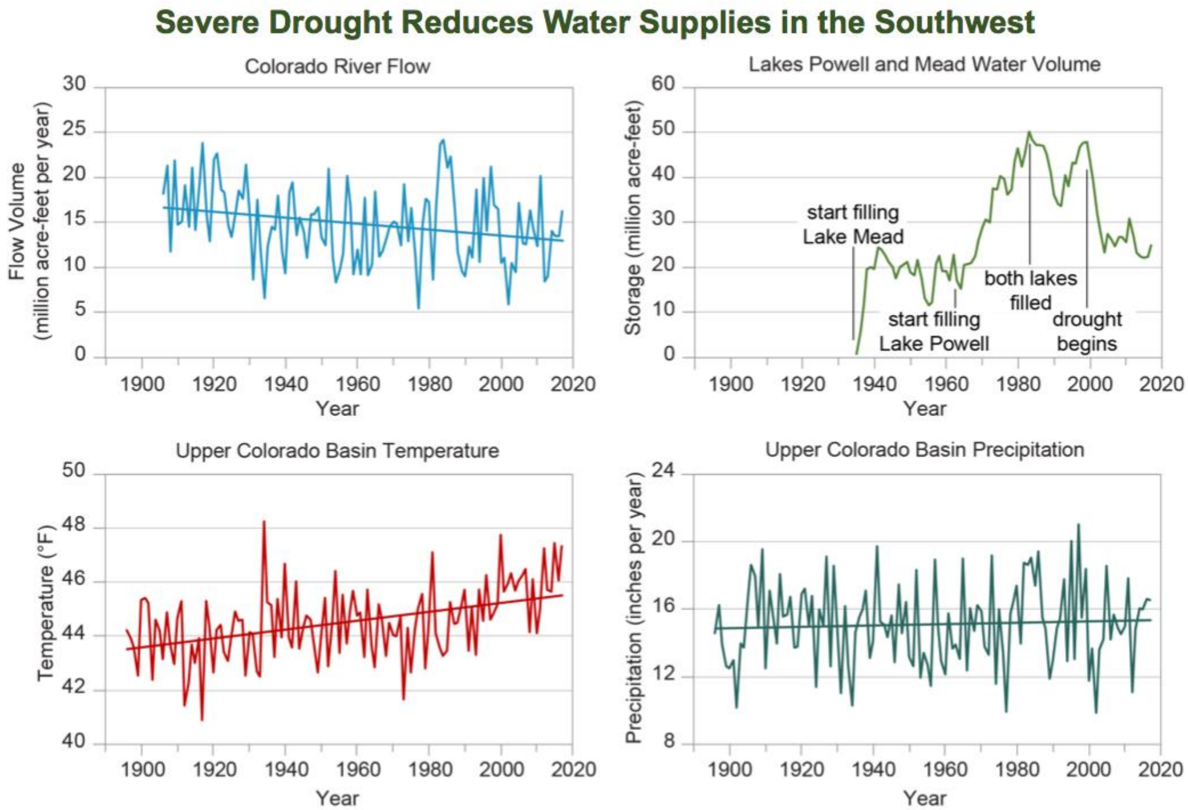

Figure 3: Drought projections on the Colorado River and Lake Mead Water levels
From: Colorado State University, CICSNC, PRISM Climate Group, Oregon State University

Climate change along with increasing water use has stressed the Colorado River system and reduced its annual flow to critically low levels. The Lake Mead reservoir, located west of Las Vegas on the boarder of Nevada and Arizona, serves as the indicator for the condition of the river. Over the past 18 years, water levels in Lake Mead have fallen 130 feet and the reservoir has lost 60% of its volume, leaving it at the lowest recorded level since it was filled in 1936 (NCA 2018). These changes threaten western development, but especially the agricultural sector, which will experience water shortages before other users.

Agriculture and water in Arizona

Irrigated cropland in Arizona is largely dependent on surface water from the Colorado River and is vulnerable to variations in supply. Arizona has three major growing regions with unique crop production profiles dependent on the climate, soils and available water sources in the area (Frisvold, 2004). The western, main-stem Colorado River region encompasses Yuma, La Paz and Mojave counties, has a total of 295,395 acres of irrigated cropland and specializes in the production of vegetables (including lettuce), hay, durum wheat and cotton (Census of Agriculture 2012). This region has on-stream access to Colorado River water supplies with senior priority.

The central region, located just west of Phoenix and south until Tucson, encompasses Pinal, Maricopa and Pima counties, has a total of 448,901 acres of irrigated cropland and specializes in alfalfa hay, durum wheat and upland cotton (Census of Agriculture 2012). This region's access to surface water supplies is through the CAP canal system and it also has a history of heavy reliance on groundwater pumping for irrigation.

The Southeastern region encompasses Cochise and Graham counties, has a total of 102,405 acres of irrigated cropland and specializes in hay, corn for grain, cotton and pecans (Census of Agriculture 2012). The field crop sector also supports a robust dairy and cattle industry and combined, Arizona's agribusiness contributes a record $23.3 billion in sales to the state's economy (Bickel et al. 2018). Arizona's agricultural exports are said to contribute to national and global food security, and according to Berardy and Mikhail "disruptions to Arizona agricultural production would have negative impacts for the food security of urban centers Phoenix and Tucson, as well as cities that have significant imported food from Arizona, including Los Angeles, San Diego, Las Vegas, and El Paso" (2017).

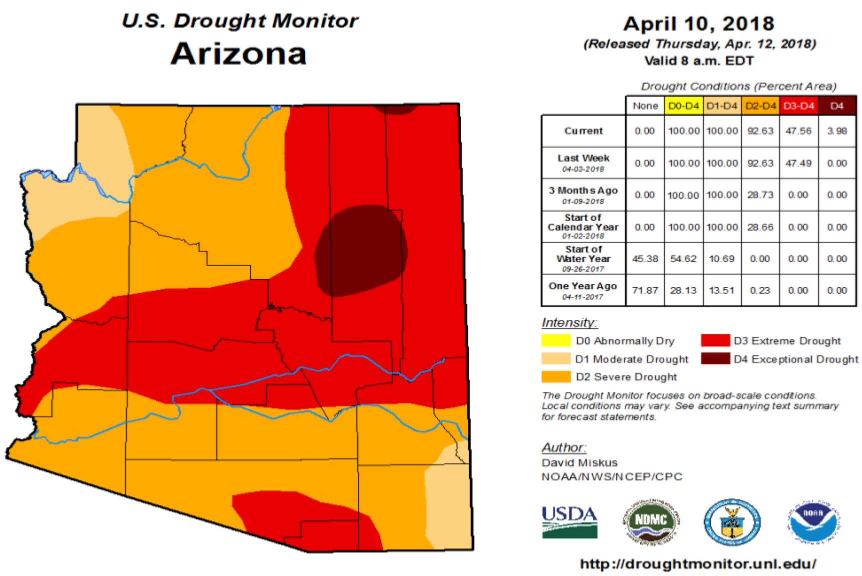

Figure 4: Map of drought conditions in Arizona as of April 10th, 2018. From: NOAA

Water shortages for Pinal County agriculture

Located in the central part of the state, Pinal County extends 5,365 square miles and has a population of 375,770 (US Census 2010). The major cities in the county are Casa Grande, Coolidge, Eloy, Maricopa and the Town of Florence. Pinal County has 938 farms on 1,174,727 acres of farm land (Census of Agriculture 2012). The market value of crop and livestock product sales in Pinal County in 2012 was $927,737,000, a 16 percent increase from 2007 (Census of Agriculture 2012). It has the third highest market value of agricultural products sold in the state.

Figure 5: Map of Pinal County with Active Management Areas designated.

From: University of Arizona

Cropland makes up 25.8% of total farmland in Pinal County and 221,997 acres is actively irrigated and harvested (Census of Agriculture 2012). It is the top producer of cotton in the state with 148 cotton farms (38% of state total) over 85,225 acres (43% of state total acres in cotton). Pinal county also has 67,831 acres of cropland in forage crop production, including hay, haylage, grass silage and greenchop which make up 29.1% of the county's crop sales (Census of Agriculture 2012).

Crop growers in Pinal County utilize approximately half imported CAP water and half groundwater for irrigation. The county extends into three Active Management Areas, but almost half (42%) falls within the Pinal AMA (Bickel et al. 2018). Crop growers have Grandfathered Irrigation Rights to pump groundwater allocated through the states groundwater code and have access to a supply of Colorado River water delivered through the CAP. Water demand is controlled by four major irrigation districts: Central Arizona Irrigation and Drainage District (CAIDD), Maricopa-Stanfield Irrigation and Drainage District (MSIDD), Hohokam Irrigation and Drainage District (HIDD), and San Carlos Irrigation and Drainage District (SCIDD). The districts aggregate water supplies for delivery to their member growers. The largest irrigation district is the Maricopa Stanfield Irrigation and Drainage District, encompassing 148,000 acres, 89,000 acres of which have a recent history of irrigation. The district operates 78 miles surface water canals, and 484 irrigation wells, whished are leased from landowners (ADWR 2019). 80 groundwater wells are connected to the main (CAP) water distribution system. The second largest district is the Central Arizona Irrigation and Drainage district which includes 87,600 acres of irrigated land and operates 350 leased wells (CAIDD 2019). This research focuses on crop growers located within the Pinal AMA that are members of the MSIDD and CAIDD.

Climate change and over-allocation of water, coupled with expanding regional demand, will continue to intensify pressures on agricultural water users in central Arizona, with most drastic reductions in future supplies projected to occur in Pinal County in the central growing region. Deliveries of Colorado River water through the CAP will soon be restricted in accordance with the new Drought Contingency Plan (DCP). Irrigation districts and their member growers in the county will face significant challenges in securing adequate water supplies as these restrictions occur, requiring them to adapt their management and operation strategies accordingly. This adaptation depends on the adaptive capacity of both individual growers and of irrigation districts who work to supply growers with water. Next, I will discuss the theoretical approach that guided this research and introduce the concept of adaptive capacity.

Theoretical Approach: Adaptive Capacity

Resilience theory offers a useful understanding of adaptation and enforces the importance of adaptive capacity for social-ecological systems. Proponents of resilience theory argue that social and ecological systems are inherently linked and that the survival of both depends on the ability for social-ecological systems to rebound and reorganize during and after periods of change (Nelson et al. 2007, Walker et al. 2002, Walker et al. 2004). Adaptation involves changes in social-ecological systems in response to actual and expected impacts of climate change in the context of interacting non-climatic changes. Adaptation strategies and actions can range from short-term coping to longer-term, deeper transformations, aim to meet more than climate change goals alone, and may or may not succeed in moderating harm or exploiting beneficial opportunities (Moser SC, Ekstrom JA 2010). A growing number of scholars have applied ideas from resilience theory to understand social systems (Cote and Nightingale 2012, Hatt 2013).

This includes the concept of adaptive capacity, which has been increasingly applied to understand how social systems (including individuals and organizations) will respond to the challenges posed by climate change and other stressors (Gupta et al. 2010, Engle 2011). Adaptive capacity relates to the characteristics that allow a system to respond to changes (Gupta et al. 2010, Engle 2011). Put differently, the "forces that influence the ability of the system to adapt are the drivers or determinants of adaptive capacity" (Smit and Wandel 2006). In terms of social systems and organizations, specific characteristics have been identified as important for building adaptive capacity. I will use this concept to examine barriers to and enhancers of adaptive action. These include leadership, equity, technology, infrastructure, flexibility, learning, economic resources, and fair governance (Folke et al.

2002, Smit and Wandel 2006, Adger et al. 2007 – from Juhola, Gupta et al. 2010). Publications suggest that with these characteristics social systems should have the ability to adapt to changing conditions, such as climate change. This work remains largely theoretical and Engle (2011, 2013) stresses the need for case studies to empirically explore adaptive capacity. This project will provide an important empirical analysis of adaptive capacity in a natural resource sector. However, rather than using predetermined indicators of adaptive capacity to direct this study, factors that enhance the adaptive capacity of Pinal County crop growers will emerge from the data.

Identifying barriers to adaptation may be just as important as identifying indicators of adaptive capacity (Engle 2011). In their report on climate change, the National Research Council has called for more social science research to develop a better understanding of the barriers that may constrain adaptive capacity (NRC 2010). The adaptive capacity literature discusses general barriers that decrease the likelihood of effective adaptation responses. Barriers have been defined as factors that can delay, inhibit, or impede the adaptation process (Moser and Ekstrom 2010). Barriers are also defined as obstacles that can be overcome with concerted effort, creative management, change of thinking, prioritization, and related shifts in resources, land uses, and institutions (Moser and Ekstrom 2010).

The Intergovernmental Panel on Climate Change (IPCC) recognizes potential barriers to adaptation including financial barriers, information barriers, cognitive barriers, and cultural barriers. Others have cited lack of leadership, inadequate institutional support, constraints imposed by previous policies, conflicting mandates, lack of coordination, limited human resources, failed collective decision-making, poor communication, values and beliefs, and uncertainty over information (Moser and Ekstrom 2010, NRC 2010, Tompkins 2010, Littell et al. 2012). At the individual level, barriers can relate to values, beliefs, perceptions, and knowledge (Adger et al. 2009). Frequently, identifying and overcoming barriers is in fact the primary target and focus of the initial adaptation effort (NRC 2010, GAO 2009). Understanding barriers remains an important component of understanding adaptive capacity (Engle 2011). This study looks at what can enhance adaptive capacity as well as the barriers to adopting adaptive actions.

Adaptive capacity represents an important concept for agricultural producers who are increasingly facing environmental change. Climate change poses unprecedented challenges for the agriculture sector in the US. According to the most recent National Climate Assessment (2018), in the next 25 years agricultural production in the US will be increasingly disrupted and threatened by extreme weather events, heat, and changes in precipitation. Climate change will also impact US water supplies, and combined with rising water demand for the country's municipal, industrial and energy sectors, has the potential to limit water availability for agriculture, especially in the arid Western region (Leung et al., 2004; Barnett et al., 2005; USDA FS, 2012; Elliot et al., 2014; Marshall et al. 2015).

In Arizona, climate change combined with the mismanagement of Colorado River water resources is driving change forward faster than most agricultural producers anticipated. Facing a dramatic cut in water available for agriculture, growers must adapt quickly. This project assesses the adaptive capacity at two levels in Pinal County: 1) for crop growers acting individually, and 2) for irrigation districts who must re-navigate how much and how they will supply water to growers. I will examine factors and processes that increase adaptive capacity at both levels as well as the barriers that may inhibit positive adaptive actions. Next, I will introduce my research questions and methods.

RESEARCH QUESTIONS AND METHODS

The goal of my thesis project was to examine the capacity of the crop production sector in Pinal County, Arizona to adapt to changes in water allocation. The following research questions guided the study:

1. **How will water allocation change in the future for the Pinal County field crop production sector and what extent of adaptation is necessary?**
2. **What approaches and management changes have been initiated to address transitions in the Pinal County field crop production sector and what factors can increase capacity to adapt to changes in water allocation?**
3. **What barriers may preclude effective responses to changing water allocation and reduce adaptive capacity?**

To examine the above research questions, I used semi-structured interviews (Holstein and Gubrium 1995) with public water management officials and agriculture agency employees at the state and county levels, leaders in the agriculture community and representatives from the municipal and private sectors of central Arizona's water development and management. Preliminary research provided an initial list of public water management agencies, agricultural advocacy organizations and private water development firms from which key informants were identified. These individuals are involved in negotiations and decisions regarding water resource management and agriculture in Arizona. Further respondents were identified through snowball sampling, which involves identifying additional participants from each interviewee (Coleman 1958).

I conducted 19 interviews in person and over the phone and stopped when no new information was being discovered (Charmaz 2006). I conducted these interviews between August and December of 2018. In addition, I also included 11 interviews with water managers and employees at agriculture agencies in Phoenix that were conducted previously on projected water cuts in the Spring of 2017. These interviews were conducted in person, and were between 30 minutes and an hour in length and were recorded. Altogether, a total of 30 interviews were analyzed for this study.

Table 1: *List of interview respondents by type and the number of respondents who participated.*

Respondent Type	Number of respondents
Agriculture agencies	N=8
Water departments	N=4
Irrigation district representatives	N=4
Private water companies	N=1
City water municipalities	N=3
University water resource research centers	N=4
Environmental NGOs	N=1
Water special interest groups	N=4
Leader grower	N=1

The semi-structured nature of these interviews allowed for the discovery of information that is relevant to the respondents (Hay 2000). I conducted these interviews with a degree of predetermined order, still allowing for flexibility in the way issues are addressed by the informants (Dunn 2005). The questions were written to encourage open-ended answers with most emphasis on the interviewee elaborating points of interest (Denscombe 2005). I composed 10 primary interview questions to initiate discussion and several secondary questions used as prompts to encourage respondents to expand on issues (Hay 2000).

Interviews lasted between 30 minutes and 1 hour and were recorded by an audio-tape recorder and with a call recorder application for the phone interviews. I also took brief notes during the interviews, but not so as to disrupt the conversational flow with the respondents. I wrote notes on the general tone of the interview, key themes and repeated statements immediately following each of the interviews. I followed a human subject's protocol throughout this research process, as was approved by the Internal Review Board at Northern Arizona University.

I transcribed the audio tape recordings and phone call recordings of the interviews to facilitate analysis. Thematic analysis assisted in the search for overarching patterns that unite individual perspectives and experiences within the qualitative data set (Ayers 2008). I conducted a latent content analysis and search for themes emerging in the transcripts. I used a coding system to organize data based on different underlying meanings within the transcript text (Hay 2000).

I also analyzed the dataset in terms of what will enhance and constrain adaptive capacity. I used general indicators for adaptive capacity, including leadership, equity, technology, infrastructure, flexibility, learning, economic resources, and fair governance to guide my thematic analysis (Folke et al. 2002, Smit and Wandel 2006, Adger et al. 2007 – from Juhola, Gupta et al. 2010). I used potential barriers to adaptation listed by the Intergovernmental Panel on Climate Change including financial barriers, information barriers, cognitive barriers, and cultural barriers, and additionally barriers such as lack of leadership, inadequate institutional support, constraints imposed by previous policies, conflicting mandates, lack of coordination, limited human resources, failed collective decision-making, poor communication, values and beliefs, and uncertainty over information to guide my thematic analysis and understand what factors might constrain adaptive action(Moser and Ekstrom 2010, NRC 2010, Tompkins 2010, Littell et al. 2012).

RESULTS AND DISCUSSION

1. How will water allocation change for the agriculture sector in Pinal County, and what extent of adaptation is necessary?

The Need for Adaptation: water allocation changes

Prompted by interview questions, respondents began each interview by describing the current allocation and use of water for irrigation of cropland in Pinal County. Responses indicated that crop growers in the county utilize a combination of groundwater supplies, which are regulated under the state's groundwater code, and surface water supplies from the Colorado River delivered through the Central Arizona Project canal system for irrigation (1,16,4)[1]. Growers are members of one of six irrigation districts operating in the county, and rely on the districts to deliver an aggregate water supply to their fields at a set annual rate.

When asked about how water allocation will change, respondents consistently brought up two pieces of legislation that outline agreements that determine the cost and amount of CAP water deliveries the irrigation districts have access to, and thus can provide to their member producers: the 2004 Arizona Water Settlements Act and the 2007 Interim Guidelines for Lower Basin Shortages and Coordinated Operation of Lake Powell and Lake Mead. Below I will summarize interview responses illustrating how these two agreements govern water allocation for the field crop production sector in Pinal County.

Respondents also consistently noted current negotiations at the state level that are likely to change the amount of CAP water delivered to the irrigation districts in the near future. After discussing the two acts listed above, I will summarize interview responses

[1] Numbers in the results section represent specific interview respondents, who were each assigned a number.

about Arizona's Drought Contingency Plan negotiations and how shortage sharing agreements will restrict CAP deliveries to the agriculture sector in Pinal County. These sections demonstrate the extent to which water allocation will change for crop production in Pinal County, and the level of adaptation necessary to respond to these changes.

2004 Arizona Water Settlements Act

Respondents acknowledged the critical role of the 2004 Arizona Water Settlements Act (AWSA) in shaping current water management challenges. Signed into law by President Bush in December and enacted in January of the following year, the act was written to settle disputes regarding water rights for the Gila River Indian Community (GRIC) and the Tohono O'odham Nation, and outline debt repayment ($2 billion) to the federal government for the construction of the Central Arizona Project (Bark 2009). Two of Arizona's 21 congressionally recognized tribes, the GRIC and the Tohono O'odham Nation had been engaged in years of litigation to try to quantify and identify the water source to settle their federal reserved water rights, which they had been granted through the 1908 Winters vs. United States supreme court decision. With surface-water supplies over-allocated, tribal water settlements did not generally include the allocation of un-allocated water rights, but rather reallocation of previous water rights through agreements with non-tribal water users, in this case, Colorado River water delivered through the CAP.

Irrigation districts in Pinal County to this point had been utilizing Non-Indian Agriculture (NIA) priority CAP water for irrigation through subcontracts with the Central Arizona Water Conservation District (CAWCD), junior in priority only to municipal and industrial (M&I) subcontracts. Because the cost of construction of the CAP exceeded projections by several billion dollars, the cost of CAP water was higher than originally expected. As respondents reported, the challenge for irrigation districts in Pinal County came in the 1990s when full repayment for the construction of the CAP system began (13, 9). With the full price cost of CAP water, the irrigation districts, who had invested in infrastructure like turnouts and lateral turnouts to deliver CAP water to their individual member producers, experienced "great financial hardships" when producers could not afford the cost of their water supplies (9, 19, 13). To remedy this, the irrigation districts, on behalf of their member producers in Pinal County, entered into an agreement with the GRIC and the Tohono O'odham Nation, which would become the AWSA.

According to respondents, the AWSA settled repayment obligations to the federal government for the construction of the CAP system, codified how water was going to be allocated within the CAP subcontract system to agriculture, and resolved long standing tribal water rights claims for the GRIC and the Tohono O'odham Nation (5,13,17,19). Among the agreements outlined in the act, the irrigation districts relinquished their high priority NIA water rights, and "in exchange, the districts where given a contract for CAP water supplies at a subsidized price. The contract was written to go through 2030" (13, 19). The GRIC and the Tohono O'odham Nation were given second priority NIA water rights subcontracts and in return, the irrigation districts received subcontracts for 400,000 AF of water, at a third of the full price cost of CAP water, but lower in priority to both M&I and Indian contracts, which was named the "agriculture settlement pool" (5). As one respondent explains, "The irrigation districts ultimately took a step down in priority from level to level" (13).

Since this agreement, the irrigation districts and their member producers in Pinal County have benefitted from the low cost of CAP water to supplement groundwater supplies, while also planning for incremental reductions. The "agriculture settlement pool" subcontracts were written to expire in 2030, and are "subject to calendar generated reductions", declining to 300KAF in 2017, 225 KAF in 2024, and set to completely expire in 2030, with supplies no longer available to the districts (4,9,10). In 2017, the pool was reduced to 300KAF. One respondent explains: "Because of the agreements that were a part of the 2004 Arizona Water Settlements Act, Pinal agriculture has always known that the Ag Settlement Pool was stepping down to zero by 2030". (4) However, as several respondents pointed out, the "agriculture settlement pool" subcontracts were written to be "subject to availability" as is stated by the CAWCD.

This means that the "agriculture settlement pool" is not a firm supply, and would "be made available for irrigation districts only when supplies are available beyond the higher priority on-stream uses" (4, 9). As one respondent aptly summarizes: "The rights themselves did not have fixed quantities, they were variable in supply anticipating that there would be cutbacks or variability in the amount that would be available. (9) Accordingly, the "agriculture settlement pool" was categorized as an "excess" supply that would only be delivered to the irrigation districts only if there is enough water available after higher priority needs are met. In other words, in times of shortage, the excess ag settlement pool may not be available for the districts. This element of the AWSA is very important in determining future changes in water supply for producers in Pinal County.

The next section covers a subsequent agreement that was made between the seven basin states, in light of high consumptive use and extended drought on the Colorado River system, to outline projected shortages in the river basin and determine thresholds for triggering restrictions of water deliveries to users. I will first introduce the agreement and then share further findings from interviews.

2007 Interim Guidelines for Lower Basin Shortages and Coordinated Operation of Lake Powell and Lake Mead

Respondents agreed that provisions in the 2007 Interim Guidelines made now a critical transition time for water management. This set of guidelines for operation and regulation of the Colorado River was adopted following the driest eight-year period on the river in a 100-year recorded history (USBR 2007). During this time, water levels in the two largest reservoirs on the river, Lake Powell and Lake Mead, declined to 54% capacity (USBR 2007). Regional demands for water continued to increase, however, as the lower division states of California, Arizona and Nevada made use, and in some years exceeded, their apportionment of 7.5MAF of water deliveries released from the Lake Mead reservoir. To this point the Department of the Interior had no set guidelines for restricting water deliveries from Lake Mead to the lower basin states in response to low reservoir levels and drought conditions. With on-stream system water storage of the Colorado River reduced to half of its capacity, the Department of the Interior recognized the need for coordinated and more efficient operation of the river's two largest reservoirs, including guidelines for water delivery restrictions to users in the lower division states.

Respondents explained that the lower basin shortage sharing guidelines were written in accordance with the 1922 Colorado River Compact, The Boulder Canyon Project of 1928 and the Colorado River Basin Project Act of 1968. The river's estimated 15MAF annual flow was first divided in half for allocation between the four upper division states (Wyoming, Colorado, Utah and New Mexico) and the three lower division states (Arizona California and Nevada) in accordance with the 1922 Colorado River Compact. Allocation between the lower division states was quantified with the passing of the Boulder Canyon Project Act of 1928. Further negotiations between the lower division basin states resulted in the passing of the Colorado River Basin Project Act of 1968, which outlines that Arizona's entitlement of Colorado River water delivered through the Central Arizona Project is junior in priority to California and Nevada's entitlements, meaning Arizona water users will experience the most significant delivery restrictions in times of shortage.

Building on these previous agreements, a Shortage Allocation Model was developed to outline the percentage of water deliveries restricted from each of the lower division states. The first stage of shortages was set to occur when surface water levels in Lake Mead drop below 1,075 feet in elevation. At this stage, Arizona water users who received water through the Central Arizona Project will absorb 80% of the total shortages outlined in the guidelines (USBR 2007). These guidelines, which were written to be in place until 2026, will have the biggest impact on water supplies for agricultural water users in the central part of Arizona who receive water through the CAP.

According to the CAP delivery priority structure, the excess "agriculture settlement pool", being junior in priority to Municipal and Industrial and Indian contracts, will experience the majority of stage one delivery restrictions. Shortages are determined through the Bureau of Reclamations August 24-month study, as a respondent explained, which project surface water levels of Lake Mead on January 1st of the following year. As of June 25th, surface water levels were recorded at 1,077 feet, but the August 2018 24-month study determined that Lake Mead would be above 1075 feet on January 1st, with no shortages occurring in 2019. The August 2019 24-month study will project the surface levels of Lake Mead on January 1st of 2020 and determine whether a stage one shortage will be triggered.

When asked about these restrictions, respondents explained that when a stage one shortage occurs, water deliveries through the CAP will be restricted by 320,000AF (29). Some of these restrictions will be from the lowest CAP priority “other excess” pool while the remainder will cut into the 300,000 AF of the excess “agriculture settlement pool” by approximately 50% (4,6). The agriculture sector in Pinal County will face serious challenges when these restrictions occur, which are more than 50% probable to occur in 2020, reducing their CAP water supply down to 105,000AF. Since the adoption of the 2007 Interim Guidelines, the hydrologic conditions on the Colorado River have worsened, however, and the seven basin states have been tasked with creating even more restrictive shortage guidelines that will further impact Pinal County agriculture water supplies.

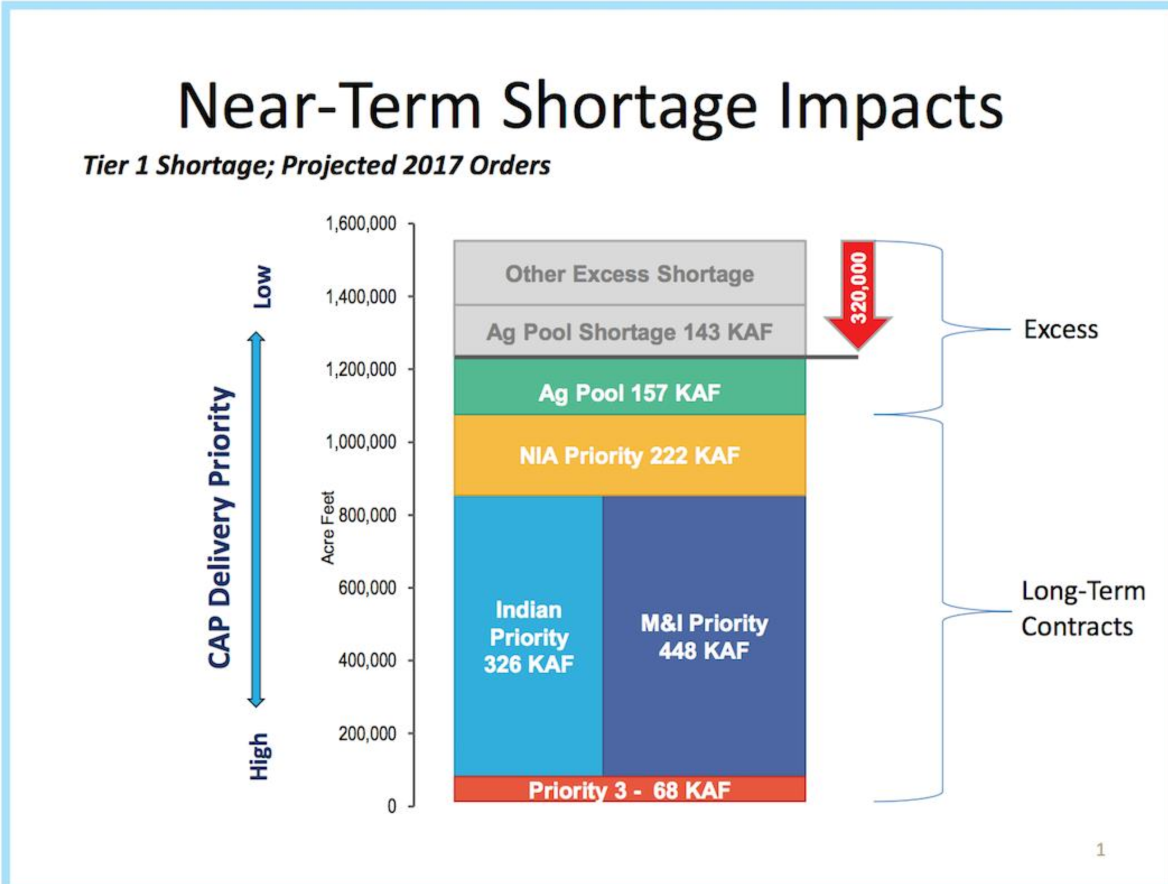

Figure 6: Colorado River Near-Term Shortage Impacts.

From: Central Arizona Project.

Colorado River Drought Contingency Planning

Drought conditions have persisted in the Southwestern US for two decades, and as previously mentioned, have proven to threaten the water security of the states in the region. The Colorado River Basin, which extends 246,000 square miles, provides critical water and power resources to the seven surrounding states and Mexico (Stern 2019). Since the long-term drought began in the year 2000, natural flows in the Colorado River have declined 2.1 MAF to an and estimated average of 12.9MAF annually between 2008 and 2018, a 2.1MAF reduction from the historical average of 15MAF annual flow (Stern 2019).

One respondent presented a handout during the interview with information that stated: "Forecasted unregulated inflow for 2018 as of June 18th (2018) is estimated as 47% of average" (19). The United States Bureau of Reclamation states that "drought conditions in the Colorado River Basin have led to marked fluctuations and decreases in water elevations at key Colorado River reservoirs" (Stern 2019). Table 2 shares some examples of respondents' views on current water management challenges.

Table 2: Quotes from interviews representing views on water management challenges.

"The Colorado River system has always been over-allocated since its beginning. There needs to be big discussions on a reallocation that makes more sense based on the amount of water in the Colorado River now." (22)
"It is a widely known fact that the Colorado River was over-allocated by 1.2 million AF. And this is just considering the water for human use, rather than for environmental uses as well." (24)
"There is no question that it is not sustainable the way that we are doing it now and that we need to change. But we do not know when the tipping point is." (21)
"There is always variability but we want to continue to be conservative by planning and adapting . . . Hope is not an effective planning strategy." (20)
"No one thought we would ever have a problem delivering the agreed amount of surface water to agriculture until 2030, but the drought has changed that." (5)

When asked about conditions affecting regional water security, several respondents noted a connection between climate conditions and reductions in Colorado River water supplies. While some respondents noted shifts in the melting time of annual snow pack as affecting Colorado River water supplies (22, 17), others reported evapotranspiration as causing significant water loss (22, 24). One respondent supported their statement with information on a fact sheet that reported: "Colorado River basin above Lake Mead-

Seasonal snowpack peaked at 73% of median on March 30th 2019" (19). Another interviewee aptly summarized: "Climate is another user of water. Municipalities, industry, agriculture, and climate are all users. The climate can give us water or take it away." (22)

In 2012, the USBR published the Colorado River Basin Supply and Demand study to attempt to project whether the river's supplies would be able to meet future water demands. The report acknowledges the variability of the Colorado River system and the uncertainty surrounding future water security with a "likelihood of increasing demand for water throughout the Basin coupled with projections of reduced supply due to climate change" (CRBSD 2012). Interview responses reflected an awareness of the uncertainty and unpredictability of future regional water and climate conditions. For example, one responded stated: "We just don't know how bad [the drought] will be and for how long and we really don't know if the bad hydrology will continue" (5).

What has been agreed upon by water managers and policy makers in the seven basin states and Mexico is that water levels in Lake Powell and Lake Mead have declined beyond what past hydrology models projected. The current hydrologic conditions of the Colorado River Basin have worsened beyond those reflected in the hydrology and climate models that were used to inform the writing of the 2007 Interim Guidelines for Coordinated Operations in Lake Powell and Lake Mead, and one respondent explained that "projections did not predict this worsening hydrology, with reservoir elevations seven times deeper than were projected for this time" (19).

After a decade of reservoir operation following the adoption of the 2007 Interim Guidelines, during which time consumptive use of Colorado River water exceeded annual flows, and climate conditions intensified drought in the Southwest region, water managers representing the seven basin states agree that additional regulatory actions were needed to avoid reaching critical elevation levels in Lake Powell and Lake Mead that would cause "temporary or prolonged interruptions in water supplies, with associated adverse impacts on the society, environment, and economy of the Colorado River Basin" (DCP Agreement 2018). One respondent explained that "the risk of Lake Mead falling below 1025' in the year 2026 has doubled since the development of the 2007 Interim Guidelines. Under "Stress Test" hydrology, the risk is about six times larger" (19) and another cautioned that "the extremes of the models of drought show that if we do not slow the water use down, we could have whole system collapse, or really draconian water cuts, so this is a big reason to find other solutions" (20).

The solution proposed by the Secretary of the Interior is for the basin states to devise drought contingency plans, which will outline conservation and management measures beyond those defined in the 2007 interim guidelines. This is to reduce the risk of reservoirs reaching critically low levels, thus avoiding drastic water shortages in the future. In accordance with the boundaries outlined in the 1968 Boulder Canyon Project Act, Wyoming, Utah, Colorado and New Mexico were advised to develop the Upper Basin Drought Contingency Plan, while the Lower Basin Drought Contingency Plan was made the responsibility of Arizona, California and Colorado.

Arizona's DCP Implementation Plan

Respondents described 2018-19 as a unique and critical time for Arizona, as water managers and policy makers were in the midst of deciding on water delivery restrictions to build upon those outlined in the 2007 Interim Guidelines in order to develop Arizona's

Drought Contingency Plan (DCP). Arizona state legislators, drawing from previous agreements and priority water rights structures, have been in the year-long process of determining which water users in the state will experience further restrictions of Colorado River water deliveries, because according to one interview respondent, “Under DCP, the state of Arizona is going to be asked to leave more water in Lake Mead than they do under the 2007 guidelines”(5). Respondents discussed the impact that DCP restrictions would have on the agriculture sector in Pinal County and explained that under the DCP, “Pinal County would lose the entirety of its CAP allotment”(6). One respondent summarized: “The two realities as of now are that the districts either lose half of the [CAP] water under the 2007 guidelines or they lose all of the CAP deliveries under the DCP” (6), and another further specified that CAP deliveries under a stage one shortage of the 2007 guidelines would be reduced down to 105,000AF, and under current DCP negotiations would be reduced down to zero (17).

When asked about how DCP CAP water restrictions will impact the total water supply accessible to the irrigation districts in Pinal County, respondents explained that the irrigation districts are generally unprepared for these restrictions that entail cutting off their entire CAP water supply in the coming years (13). The two largest irrigation districts, Maricopa Stanfield Irrigation and Drainage District (MSIDD) and Central Arizona Irrigation and Drainage District (CAIDD) have been developing the necessary infrastructure to pump groundwater to replace the “agriculture settlement pool” CAP supplies that are set to be incrementally reduced through 2030 according to the Arizona Water Settlement Act (13). The districts have been putting millions of dollars into developing groundwater infrastructure to prepare for reductions of CAP supply, but with DCP, are facing restrictions of their CAP supply ten years earlier than expected because of the "troubling hydrology and over-allocation of the Colorado River system" (4). One respondent summarized the situation by stating:

> "MSIDD and CAIDD deliver about 300KAF a year in each district which is roughly half groundwater and half CAP water. However, they are entitled to deliver 240K of groundwater, but they really do not have the capability to do it now. So, if they lost all of their CAP water, it would really be reduced down to just 150K of groundwater and probably not really even that much" (13).

According to interview respondents, DCP restrictions are a major concern for the irrigation districts and their member growers in Pinal County because they mean that they will lose half of their total water supply and are currently unable to produce enough groundwater to make up for the reduction (4). With these conditions and significant CAP water delivery restrictions projected to occur as soon as 2020, the irrigation districts in Pinal County face challenges in providing adequate water supplies to meet the needs of their member growers. These challenges will require the districts to adapt and make changes quickly in response to their reduced water supply. In addition, individual growers will have to adapt to using less water and face many challenges. The next section covers the approaches and adaptive actions that the irrigation districts and their member growers can take to respond to these changes in water allocation.

2. ***What approaches and management changes have been initiated to address transitions in Pinal County agriculture and what factors can increase capacity to adapt?***

Opportunities for Pinal County irrigation districts to adapt to water allocation changes

Drawing from the concept of adaptive capacity, in this section I discuss interview results related to opportunities for adaptation and ways to increase adaptive capacity. First, I discuss options for the irrigation districts, who make decisions about water sourcing and distribution. Then I discuss options and opportunities for individual growers.

Agriculture mitigation in the Arizona's DCP Implementation Plan

With water allocation drastically changing in the coming years, the irrigation districts in Pinal County, MSIDD and CAIDD, will need to adapt quickly. As discussed in the previous section, Arizona's DCP negotiations originally outlined that the entirety of CAP water deliveries for agriculture would be restricted, reducing the total water supply for the irrigation districts in Pinal County by half. It was reported that the districts are currently unprepared for this level of reduction of total water supply, and face challenges in meeting the water needs of their member growers with groundwater supplies alone. As DCP negotiations progressed, stakeholders representing the irrigation districts in the county advocated for an "agriculture mitigation program" to be included in the DCP.

The agreements that were made and added to Arizona's DCP Implementation Plan, which legislators passed on January 31st 2019, include a set amount of CAP water deliveries to offset the CAP restrictions that the agriculture sector in Pinal County was originally going to absorb, and also $9million in funding to accelerate the development of groundwater infrastructure to supplement the reductions in CAP supply (Phoenix City Council Report 2019, ADWR 2019).

Respondents discussed the importance of securing a mitigated water supply to be made available to the irrigation districts when the DCP is implemented. Five respondents reported that the objective of the agriculture mitigation negotiations was to advocate for other water users in the state to share the burden of Arizona's CAP delivery restrictions, allowing for the irrigation districts to receive 105,000AF of annual CAP water, equaling the amount they were set to receive with a stage one shortage according to the 2007 Interim guidelines (4,20,5,13,17). One respondent described the negotiations by explaining, "the idea of agriculture mitigation in the DCP is to provide enough water to the districts that would not make them any worse off than they would be under the 2007 guidelines" (5).

An Arizona Republic news article, published after the completion of the interviews for this study on February 1st, 2019, the day following the passing of Arizona's DCP legislation, reports details regarding the mitigation agreements:

> "Under the deal, the agriculture districts will get 105,000 acre-feet per year from 2020 through 2022. That water is slated to come from a list of entities, including cities that otherwise would have banked the water underground, the private water company Epcor, and CAP water that is stored in Lake Mead and Lake Pleasant." (James 2019)

These mitigated water deliveries will be accessible to the irrigation districts in Pinal County through 2022, while the DCP Implementation Plan as a whole is set to be in effect through 2026, the same year that the 2007 interim guidelines were written to expire, at which time a "new set of shortage guidelines on the river [will] have to be negotiated among the seven states" (5). The mitigated water supply included in the DCP gives the irrigation districts in Pinal County more time to develop groundwater infrastructure to supplement diminishing CAP supplies. In other words, additional water was allocated to Pinal County to give irrigation districts a small amount of additional time to transition to groundwater. In this case, this additional time increases their ability to adapt, but only to a certain extent.

Another important element that was included in the DCP in addition to the mitigated CAP water supply is $9 million in funding for the irrigation districts to accelerate the development of groundwater infrastructure and increase the percentage of groundwater supply in their total water supply. Respondents explained the importance of this funding for the irrigation districts to accelerate the development of groundwater infrastructure. One respondent aptly summarized:

> "The districts have determined that they can agree with the DCP agreement with mitigation and funding, because they always knew they would go back to primarily pumping groundwater, but they thought they had until 2030. They are now being asked to go to that a decade sooner. This [funding is needed] in order to give them what they are calling a "glide path" to install that infrastructure". (5)

The financial support included in the DCP for accelerating groundwater infrastructure development will aid the irrigation districts in adapting to changes in water allocation. Funding will likely be used to dig better and deeper wells, and at least temporarily, increase access to groundwater. Switching to groundwater, however, may represent only a short-term surge in adaptation that will have to be followed by other strategies or an inability to further adapt after groundwater supplies are diminished, punting the problem to the future.

Both the mitigated water supply and the funding offered in the DCP at least temporarily increase the adaptive capacity of the irrigation districts in Pinal County by allowing them to meet the water needs of their member growers' in the short term with groundwater supplies when CAP supplies are restricted. Another reality for the irrigation districts in the county is that they will likely have to respond to reduced CAP supplies by fallowing a percentage of land that is currently in production. As one respondent summarized, "shifting to greater groundwater pumping is going to be one response to shortage. The other is some level of involuntary fallowing" (9). The next section covers adaptation through fallowing of cropland in the MSIDD and CAIDD.

Reduced water supply leads to reduction of acreage in production

When asked about how the irrigation districts in Pinal County will respond to CAP delivery restrictions, respondents consistently reported that a significant percentage of cropland will be forced to be fallowed because of lack of sufficient water supply in the CAIDD and MSIDD (13,5,10,6,7,15). As one interview participant explained, "some land is being taken out of production and the other purposes aren't there yet, it is just going to be idle land"(13). Table 2 illustrates some respondents views on the extent of fallowing land. Most respondents indicated that anywhere from 30%-60% of cropland will likely go out of production in response to reduced water supplies. In 2018, there were 60,000 acres farmed in MSIDD and more than that in CAIDD "because [CAIDD] has had less land developed to residential use than MSIDD has had over the last couple decades"(5).

Table 3: Quotes about percentages of cropland that will be fallowed.

"Loss of 40-60% of total water supply from irrigation districts will result in 50-60% fallowing and corresponding loss of jobs, equipment purchases, sales tax, and create massive dust and environmental hazards on vacant farmland." (13)
"Even under a mitigated DCP plan, [there is a] potential of going from 90% cropped to 55 or 60% cropped in [the MSIDD] district. They believe that is as low as they can go without creating huge economic hardship." (5)
"There needs to be some sort of new bucket of water that goes down there or there is going to be a big loss of farmland." (7)
"Not all of the fields would go dry, but a lot will probably go fallow." (24)

One respondent provided an example of a growing operation in the county and how the operation will be affected by reductions in CAP supply:

> "One farmer has 4,000-5,000 acres in MSIDD growing cotton and grossing $30-40 million annually. The farm employs up to 1,200 people during peak harvest and has long term contracts with Walmart, Costco, ALDIs and Kroger (2,800-3,000 semi-loads per year). Loss of 40-60% of total water supply will reduce acreage which can be farmed to approximately 1,800 acres" (13).

These responses to reduced CAP supply demonstrate adaptive capacity at the irrigation district level. Mitigation and funding included in the DCP will allow the districts in Pinal County to respond to changes in their total water supply by increasing the capacity of groundwater pumping. Fallowing of crop land in production in the districts decreases the water needs in the districts and is another approach to adaptation. The next section discusses adaptive action that takes place at the individual landowner and grower level and outlines their options and opportunities. Growers are not always the landowner, therefore they are discussed separately.

Adaptation for landowners through changes in land use

Land conversion is a viable adaptation action for owners of agricultural land in Pinal County. Land use in central Arizona has undergone a significant transformation in the past several decades. Selling land to development interests for conversion to municipal or industrial development has long been a lucrative option for agricultural landowners in central Arizona. The Phoenix metropolitan area has grown exponentially in the past several decades, replacing thousands of acres of agricultural land with subdivisions and commercial lots for industry. Respondents discussed the development patterns in the area, explaining that urban growth in Maricopa County in particular was rapid in the early 2000s, and one participant explained that "in the late eighties and early nineties, Maricopa county had 325K acres of irrigated agriculture. By 2010, it was down to 225K, almost a third of cropland was consumed in those years" (1,17,18,12). Further south in Pinal County, many agricultural landowners also took advantage of the economic opportunity to sell their land for future development. As respondents explained, much of the cropland in Pinal County was sold to development interests during the housing and land boom of the early 2000s and "growers got a lot of money for their land" that was expected to be converted to residential development and supporting commercial and manufacturing industries (2,15,6).

While some projected growth did occur in the county with the expansion of city centers like Maricopa City and Casa Grande, respondents explained that the recession in

2007 brought development in Pinal County to a "screeching halt" (13). One participant summarized: "When the big land boom was on, land developers were running around and laying out plots with the county. There was an excess of 160 plots laid out that never got built on" (12). It was also explained by interview participants that, because of tax valuation, speculative landowners who purchased agricultural land at the time with the expectation to develop it in the future, generally leased land back to growers to continue crop production (10,17). As one respondent outlined, "In Pinal County, the assessed value ratio for agricultural land is approximately $500 an acre for tax purposes. If it is vacant land, it is approximately $5,000 an acre" (10). For this reason, much of the crop production in Pinal County takes place on leased land.

Adaptation through land conversion, according to several respondents, has positive implications for the economy and reduces water use in Pinal County Because less water is used domestically and industrially per area than on agricultural land. When asked about current and future land conversion in Pinal County, interview participants consistently indicated that development is likely to pick up in the county "once a building boom really hits" (2, 13, 18). Land conversion is one approach to adapting to changing water conditions for the agriculture sector in Pinal County, but is dependent on larger social and economic factors.

Table 4: Quotes illustrating respondents' opinions on future land conversion.

"As development happens around Casa Grande, Florence and Eloy, land will be taken out of production for development" (4).
"I foresee a lot more urbanization as we see our urban centers growing and thriving" (6).
"I think there will be a lot more residential and commercial and it is in the so-called sunbelt corridor, between Phoenix and Tucson" (13).
"There will not be anywhere near the amount of agriculture that is occurring now because economic development and growth will replace a significant portion of agricultural water use over time" (16).
"In the long run, the agriculture land will disappear" (28).

Respondents indicated that conversion of cropland in the county for residential and industrial development is likely to occur in the future, and some provided examples of where it is already taking place. Table 4 illustrates respondents' views on future land change in the county. Several respondents stated that they were already seeing changes. One respondent explained that a "hydro-powered fuel vehicle production plant, Nickola Motors, is being developed on 430 acres of retired farm land" (15) outside of Coolidge and another stated that farmland is being converted into a racetrack in the county (12). One interviewee explained, "I see a lot more residential areas being developed and along with that I see those supporting commercial and retail centers being developed" (6).

Two respondents noted that development in Pinal County is likely to continue, especially along the I-10 highway, because of its location in the center of the "Sun Corridor" which "starts up in Prescott or north Phoenix and goes all the way south of Tucson and maybe even further down to the boarder of Mexico" (13, 17). Pinal County has been viewed as a "bedroom community" and it is always of interest in county development plans to bring industry in to have jobs located in the county and increase tax base (6,15). Another respondent explained: “Alfalfa does not have a very high economic output per acre compared to semi-conductors, for example, at an intel plant. The economic output of Pinal County will likely increase as agricultural land is converted to development” (4).

In terms of water use, four respondents stated that land conversion from crop production to residential or industrial development would reduce water use per acre (11,15,16,18). Another participant proclaimed to be a proponent of development occurring on retired agricultural land as opposed to development on desert land because it requires a conversion of water use rather than an additive water use (1 0). Table 5, contains examples of quotes from respondents about the water implications of these changing land uses.

Table 5: Quotes from interviews about water implications of changing land use.

“There are some studies done by ADWR stating that, as land is converted from farming to residential development, ultimately it can be more water efficient if it is done correctly” (11)
“Lower water use per acre when agricultural land is converted for municipal or industrial development because these use less water per care. For example, cotton requires 6-7AF per acre for production. Development and municipal uses are 3-4AF per acre” (15)
“Overall, I would see the conversion from ag to municipal reducing water use”(16)
“I think an urbanized area does use a little less water than farming. In fact, . . . I think they pretty much cut the amount of water in half.” (18)

Most respondents felt that options to convert land to non-agricultural purposes would be beneficial for the region in terms of water use and economic growth. These changes in land use ultimately depend on the cumulative decisions of individual landowners.

Adaptation at the individual grower level

With the outlined restrictions of CAP water deliveries, crop growers in Pinal County will have to make changes in their growing operations with access to less water. As the previous section discussed, the MSIDD and CAIDD will have their total water supply reduced by 40%-60% when DCP CAP delivery restrictions take place. There are efforts being made at the irrigation district level to make up for CAP delivery restrictions by increasing groundwater pumping, but it is highly likely that their member growers will receive less water when CAP delivery restrictions occur. The predominant field crops that are grown in Pinal County are cotton (85,225 acres) and forage crops like alfalfa hay (67,831 acres) (2012 USDA Census).

When asked about changes that crop growers have and can make in their growing operations to respond to reduced water deliveries, interview participants consistently brought up several different options. Six respondents reported that changing irrigation practices and updating to more efficient irrigation systems to conserve water and maintain production is one of the main options for growers to adapt to reduced water supply (17,18,12,1,2,22). Surface irrigation through flood or furrow irrigating is the most common practice for crop growers in the region, particularly for cotton production. With this system, growers have ditches or “furrows” dug between each row of crops, and flow water down the rows so that it can seep into the soil. This practice not only requires a great deal of water, but as one respondent explained, it is 70-75% efficient at best and also compacts the surface of the soil and does not allow rain precipitation to infiltrate and absorb into the soil, but rather causes it to run off (22,18). In contrast, as seen in Table 6, many respondents saw the benefits of switching to drip irrigation. Sub-surface drip irrigation systems, which are installed beneath the soil and designed to "just give [the] plant what it needs and no more", were reported to be as high as 90% efficient and also, improve the absorption of rain precipitation into the soil (18,12). One respondent, a cotton grower in the county, gave this example of how they were able to increase the water efficiency of their operation by installing drip irrigation:

> "Our irrigation efficiency has improved by 30%. When we were on furrow, we used to use 7 1/7 acre feet a year to grow a cotton crop and today with the drip we are somewhere between 5-5 ½. The big difference is that we have bumped our average yield up from 2 ½ to our average over the last 6 or 7 years is over 3 bales. "(12)

Table 6: Quotes illustrating views on the benefits of drip irrigation as an adaptation.

"Drip irrigation is a technology that is being used to reduce water use for irrigation." (1)
"The best technology for low water use is drip irrigation.": (2)
"The irrigation efficiency is 90% plus on some drip irrigation systems." (18)
"In general, surface water can be 70-75% efficient (at best), while a sprinkler can be 80-85% efficient, and drip can be 90%." (22)

Another adaptation action that participants reported crop growers can take to respond to changes in water allocation is to change the type of crops that they grow. As respondents explained, cotton and alfalfa hay are high water use crops (4, 18). In the face of reduced water supplies, growers could switch to crops that use less water or, as four respondents reported, could switch to low water use or drought tolerant versions of crops (5,18,11,26). When asked about options for switching to alternative crops that use less water, five respondents mentioned a viable option for growers to switch to growing "guayule", which is a crop that produces rubber (2,1,4,17,18). As one respondent explained, the University of Arizona Cooperative Extension is currently working on research on "irrigation, agronomic topics, and economic models" with hope to "launch guayule production in the next five to ten years on a commercial level" in Pinal County (2). Table 7 provides examples of respondents viewing growing guayule as a viable option.

Table 7: Quotes from interviews about growers converting to guayule production.

"Guayule is an alternative low water use crop that is used to produce rubber." (1)
"There is a crop being researched (Guayule) that is used to produce rubber." (4)
"There is a Guayule project developed to see how it works to grow this rubber substitute in Pinal County." (17)
"Guayule could provide a good alternative for farmers." (18)

Another alternate crop that was reported by respondents to be a viable option to switch to in order to reduce water use is hemp. As one respondent explained: "hemp is a water efficient crop that can get two or three cuttings out of it every year in Arizona versus other climates where they might only be able to get one" (6). According to respondents, the Arizona state legislature passed legislation that approved a hemp production pilot program starting in August, 2019 (6,12). A third option that one respondent reported is the possibility of growers switching to producing high valued specialty crops like herbs and organic crops for export to China (3).

In addition to upgrading to more efficient, drip irrigation and switching to producing crops that use less water, growers in Pinal County have the option of taking portions of acreage out of production (see Table 8) and deficit irrigating to respond to lower water supplies. Five respondents reported that with a reduction in water supply, crop growers in Pinal County will have to make decisions about taking acreage out of production (4,9,1,22,13). In order to achieve the highest yield, growers can choose to lay off portions of their land and use their water supply to increase the yield on the acres they do keep in production. Alternatively, one respondent discussed deficit irrigation as an adaptation option. One respondent described the practice of deficit irrigating and stated:

> "Alfalfa is extremely dependent on how much water you put on it and how many tons per acre it produces. With deficit irrigating, you spread out the irrigation and irrigate a little less to save water". (4)

Table 8: Quotes illustrating options involving growers taking land out of production.

"In order to have the optimal amount of water, some farmers will selectively grow certain acres. For example, if they have 10 acres and they have enough water to grow a decent crop on 10 acres, they might fallow 3 acres to grow an amazing crop on the remaining 7 acres." (4)
"Folks will have to decide to lay off some of their land that they might otherwise put into production." (9)
"With water shortages, growers will be forced to make decisions about what acreage to keep in production and which to fallow." (1)
"Some land will go out of production. For example, maybe a farmer has 100 acres but will only plant 50." (22)

A final adaptation option that emerged from interview responses was the option for farmers to supplement water supplies with treated wastewater. Five respondents reported that growers in Pinal County have utilized the option of contracting with municipalities for a supply of "effluent" or "reclaimed" wastewater to use for irrigation (11,3,14,8,16). For example, one respondent reported that a farmer near the town of Florence has a contract to buy treated effluent that he uses for irrigation in place of pumping groundwater (3).

Another respondent discussed a grower in the Coolidge area that purchases class C effluent from the city to irrigate cotton and hay crops (14). This alternative source of water could potentially provide needed water to keep some lands in production.

Respondents also identified programs and research developments that can increase adaptive capacity. Four respondents discussed federal funding to help growers with on-farm efficiency such as National Resource Conservation Services Environmental Quality Incentives Program (EQUIP) contracts and funding allocated through the Conservation Title of the US Farm Bill (2,6,9,12). Another respondent noted that funding in the Farm Bill made available to irrigation districts to make irrigation improvements on behalf of their member growers will be helpful in adapting to these changes (5). Also, pilot experimental programs to help growers “determine the feasibility of using different irrigation methods, such as drip, and the feasibility of growing different crops” would increase the capacity for growers to make changes, as well as partnerships to “cushion the downside risk” of growers attempting these changes (17).

Several respondents noted important research efforts that contribute to increased adaptive capacity, including research about drought tolerant plants, solving drought and water scarcity problems, efficient irrigation systems, and sustaining populations dependent on groundwater (18, 4). Also, research on new technologies to “access groundwater differently that might be less expensive” and experimentation on new drip irrigation technology were identified as contributing important knowledge to increase adaptive capacity (17,5). In the next section, I will focus on the challenges and constraints to adaptation at the irrigation district level and individual grower level.

3. What barriers may preclude effective responses and reduce adaptive capacity?

Barriers to adaptation at the irrigation district level

Barriers to increasing groundwater production

With restrictions of CAP deliveries set to reduce total water supplies available to the irrigation districts in Pinal County, they have been taking actions to adapt. One adaptation measure that the irrigation districts have been working on is increasing groundwater pumping to make up for the loss of CAP supplies. As previous sections outlined, the districts have advocated for a mitigated water CAP water supply to be included in the states Drought Contingency Plan. This mitigation will allow 105,000 AF of CAP water to be delivered to the districts annually until 2023. Along with this, Arizona's DCP Implementation Plan includes state funding to be allocated to the districts to accelerate development of their groundwater infrastructure so that they can effectively supply an increased amount of groundwater to their member growers.

When asked about this approach, interview respondents consistently brought up several challenges that the districts have and will continue to face in effectively responding to CAP restrictions by increasing groundwater supplies. Several respondents reported that there are financial barriers to this method of adaptation. As previously mentioned, the MSIDD and CAIDD took control of the operable wells in Pinal County in the late eighties. Since then it has been the responsibility of the districts to maintain the wells and delivery systems, some of which, as one respondent explained, were 20-50 years old when they took over operation of them and have since gotten 40 years older (5).

As previously discussed, the irrigation districts, planning on substantial CAP restrictions by 2030, have been preparing for increasing groundwater production and as one respondent stated: "these irrigation districts have been running around for four or five years now and looking at the wells on these farms and spending a lot of money bringing them back up to speed"(12). Another respondent also reported that the districts have spent a great deal of money to preserve the wells they operate and connect them to existing canal systems (5). Interview responses indicate, even with the investments the districts have made to refurbish and maintain groundwater wells, their infrastructure still does not have the capacity to produce sufficient groundwater supplies to make up for CAP restrictions in the coming years. Five respondents noted that funding for the transition from a total water supply made up of 50% CAP water and 50% groundwater to 25% CAP water and 75% groundwater is a barrier the irrigation districts face (5,12,15,2,4). As illustrated in Table 9, many respondents cited the cost of more groundwater pumping as a barrier to this adaptation strategy.

Table 9: Quotes illustrating financial challenges to well development in Pinal County.

"It is expensive to pump groundwater." (4)
"Refurbishing wells that are currently installed and need to be cleaned and re-drilled requires a lot of work and that work is expensive." (2)
"The transition from CAP water to groundwater takes a lot of time because and the wells are very expensive." (4)
"Many of the wells in the area are out of date. It will require millions of dollars in investments to refurbish wells." (15)

Another economic barrier that emerged from interview respondents is the cost of energy to pump groundwater that will increase water rates as this transition takes place (see Table 10). As two respondents noted, a total water supply in the districts that includes half CAP water has been more cost effective for the districts because CAP supplies are cheaper than groundwater pumping because of electrical costs. (11,18). As four respondents noted, the energy required to pump a greater supply of groundwater will increase the cost of the water the irrigation districts deliver to their member growers (12,21,4,25). One respondent mentioned a hope for new technologies to make access easier and cheaper:

> "Are there new technologies that we are not even aware of that can be developed that can allow us to access groundwater differently that might be less expensive. If it is less expensive, perhaps it can allow growers to continue to make money while farming less and that is one thought." (5)

Table 10: Quotes from respondents about energy costs as a barrier to groundwater use.

"I don't think we will get back to the point to where we were pumping before because I think power rates are going to prohibit some of these wells from going back into production." (12) "It is all going to be tied to whether they can afford the energy to pump water or not." (12) "They may get to a point where it's not economically feasible if they have to use too much electricity to pump, and they won't be able to afford to get their water this way." (21) "Groundwater pumping takes a lot more money because it uses more energy than having surface water for irrigation." (25)

Interview participants also reported that the irrigation districts face significant engineering challenges in transitioning to delivering a greater proportion of groundwater to their member growers when CAP delivery restrictions occur (Table 11). As one respondents reported:

> "Back in the late 80s and early 90s all of the irrigation districts that have subcontracts for CAP water took out very significant, many millions of dollars of debt to build infrastructure within their irrigation districts to distribute this CAP water efficiently"(4).

As CAP deliveries are restricted from the districts, and they are faced with the challenge of delivering sufficient water to their member growers, the way the infrastructure was built to efficiently deliver surface CAP water deliveries, as several respondents explained, makes it difficult to switch to delivering primarily groundwater (9,4,24). The districts are tasked with integrating groundwater wells to feed into existing CAP water delivery canals.

Table 11: Quotes from respondents about infrastructure as a barrier.

"There are some physical infrastructure issues related to them converting to groundwater use." (9) "Transitioning to groundwater is challenging because they have these irrigation systems that are based on water coming from one turnout on the CAP canal." (4) "There is a big engineering challenge in trying to utilize some of the existing (CAP) delivery infrastructure." (4) "Also, many parts of the system for farms/irrigation are designed specifically for CAP water, not non-CAP water, so there may be problems related to infrastructure." (24) "They have designed their distribution systems around CAP supply in many cases and their laterals and conveyance distribution systems and even the field geometry may not be optimally set up for switching supply." (9)

There were also several interview respondents that discussed with more specificity the challenges related to infrastructure when CAP deliveries are reduced. As several respondents explained, a base flow of CAP water allows water to be pushed across the landscape through the irrigation canals to reach all of the acres in production (13,4,28,24,16). One respondent summarized this barrier well by explaining:

> "CAP water helps get water to all the land and it moves the water through the canals at a flow, which is called a head, fast enough to move it across level fields. Without the CAP water to do that, entire fields cannot be irrigated in many cases. "(13)

Another respondent explained that the water pressure or "head" that CAP water provides in the delivery systems is how the systems operate efficiently (4). As CAP deliveries are reduced, respondents explained that it will be challenging to produce enough groundwater to replace the CAP water and create enough "head" or pressure at the top of fields to push the water across the landscape and maintain the efficiency of the delivery systems. One respondent explained,

> "When you have a big CAP supply, you can push a lot of water and it can go across a quarter mile section, but when you have a groundwater supply, you may have in total the same amount of water, but the flow is not as large so it won't go as far." (9)

Another respondent described difficulties related to flow: "farmers need high flow rates for their systems to work properly, which they may not be able to get from groundwater" (28).

Interview participants also identified concerns related to groundwater levels, land subsidence and water quality with increased groundwater pumping in the county. As previous sections outlined, the construction of the CAP and implementation of the Groundwater Code were intended to reduce unsustainable groundwater pumping in the area that was causing aquifer depletion and land subsidence and fissuring. Three respondents reported that, with the delivery of CAP water to districts to supplement groundwater over the past several decades, groundwater levels have stabilized and even increased in some areas (18,9,15). Eight interview participants expressed concern about increased groundwater pumping having a negative effect on the water table, worsening land subsidence in vulnerable areas and producing low-quality water that may not be suitable for application on field crops (21,13,15,22,9,16,12,18). Table 12 provides some examples of respondents concerns about water quality.

Table 12: Quotes illustrating respondents concerns about well water quality.

"The longer-term issue is really about groundwater levels. Both the physical volume and to an increasing extent the quality." (9)
"With CAP delivery shortages, there is going to be nothing but well water in these districts and all of a sudden the quality and salinity is an issue." (12)
"With increased groundwater pumping, water quality is a concern. As you get deeper in different areas, the water will become more brackish and some of it won't be able to be applied for agriculture." (16)
"With groundwater pumping, sometimes the water is not the best quality, depending on where you are at, and so there will be some soil water issues in terms of how different water qualities are going to react with the soil." (18)

One respondent pointed out that this method of adapting to reduced CAP supplies in the county by increasing groundwater pumping is counterintuitive to the state's achievement in implementing groundwater regulations:

> "If CAP water is held from central Arizona, farmers will have no recourse except to go back to pumping groundwater. That was the major reason why most of the entities agreed that they needed to have a CAP in the first place, to reduce groundwater pumping, which has all kinds of negative consequences." (13)

Table 13: Quotes illustrating views on groundwater as a viable strategy for adaptation.

"Everyone knows that reliance on groundwater is not sustainable in the long term." (13)
"If groundwater use increases due to cuts in CAP supplies, the water table will drop again." (15)
"Increased groundwater pumping may cause land subsidence and dropping of the water table." (22)
"All of central and southern Arizona has some level of vulnerability to subsidence, but because of soil configuration, there are some areas where there were historically tens of feet of land subsidence." (9)
"There are potentially very negative consequences to pumping more groundwater: the quality will go down and land subsidence and fissuring will get worse." (9)

A potential consequence that could occur with an increase in groundwater use for agriculture, according to respondents, is the impact it could have on approval for future development projects (7,16). The challenge is that "existing groundwater could be used for future development, which economically speaking is a higher value use" (4). As respondents pointed out, however, agriculture's Irrigation Grandfathered Rights to pump groundwater in the Pinal AMA exist in perpetuity, affording them the option of increasing pumping to make up for CAP restrictions (17,4,1). Respondents recognized that increasing groundwater pumping for irrigated agriculture will likely ignite further conflict between the agriculture and municipal and industrial sectors and one respondent called this conflict the largest divisive spot in what is going on in the county (4,16,17).

In general, due to these challenge and barriers, most respondents admitted that pumping more groundwater is not a reliable long term strategy. Based on historical trends of groundwater use, switching to 100% groundwater without reducing agricultural crop types or acreages will likely reduce the water table. This could result in subsidence and fissures as the water table drops. Table 13 provides examples of respondents' concerns about increased pumping of groundwater as an adaptation strategy. Table 14 summarizes all of the barriers and challenges related to this strategy identified by respondents.

Table 14: Summary of respondents' views on barriers to increasing groundwater pumping.

General category	Specific Responses
Economic (N=12)	Cost of groundwater well refurbishment (n=5), cost of energy to pump groundwater (n=7)
Infrastructure (N=8)	Infrastructure was built specifically for delivering CAP supplies (n=4), insufficient head to push water across landscape with majority groundwater (n=4)
Environmental concerns (N=9)	Water quality (n=4), land subsidence and drop in water table (n=5)
Conflict between sectors (N=5)	Agriculture has IGR to pump groundwater (n=2), increased pumping could impede future development (n=3)

Barriers to fallowing percentage of land acreage in production

The second adaptation option of delivering less water to member growers, thus forcing a large percentage of crop land out of production, is consequential for the local and regional economies, according to interview respondents. The crop production sector in the county is a foundational industry requiring ancillary support businesses like equipment and agro-chemical companies. These all provide jobs for the local population and other businesses that provide residential services. Respondents indicated that agribusiness is an important foundational industry and an economic driver in Pinal County (6,15). As one respondent explained:

> "It contributes $23.3 billion to the economy, so those are big economic numbers that contribute to the state economy. Agriculture, like mining and logging, are primary industries that, without them, other industries could not exist." (26)

Six respondents indicated that losing a substantial percentage of acreage in production because of reduced water supplies would negatively impact the local economy and one respondent stated: "It is not that we are just going to lose a few hundred farms, it is that the businesses and the families and the industry that those farms support and underlie, that is going to go away too" (6).

With less crop production in the county, fertilizer and pesticide companies, farm equipment dealers and other industries that provide ancillary support and make up the agribusiness industry of Pinal County will experience the effect of lower sales and may have to close as a result. These industries provide jobs for the local population in the county and there will likely be a loss of jobs as these companies close (1). One respondent also identified that there is the possibility of the multiplier effect taking place as the agribusiness industry in Pinal County shrinks, with potential impacts to non-agricultural businesses like hair salons and accountant offices that rely on business from the local community (17). Table 15 provides additional examples of these concerns.

Table 15: Quotes illustrating concerns about economic impacts to the region.

"There may only be a few hundred farmers in Pinal County, but they support car dealerships, implement dealerships, feed companies and fertilizer companies that are all located in Pinal County." (6)
"There will be impacts to the local economy if the agriculture industry is significantly reduced. Industries that provide ancillary support to the agriculture industry such as equipment dealers, and feed and fertilizer companies will be impacted." (1)
"When you look at the gamut from the farmers, to the individuals that work for the farmers, to the suppliers that provide the chemicals to the heavy equipment used on farms, agriculture is a multimillion dollar industry for Pinal County." (11)
"Transitioning away from agricultural production in the county will also force other companies out that are intertwined with the agriculture industry, such as pesticide companies." (15)

Many respondents also identified the close integration of the field crop sector and the cattle and dairy production industries in Pinal County as a challenge for the state's economy if substantial crop acreage is taken out of production. Demand for forage crop production like alfalfa hay is driven by the four major feedlot operations and 25 dairies located in the county (13). Dairy and beef are the two highest valued agricultural products in Arizona, and much of that production is concentrated in Pinal County, which ranks in the top 1% of all U.S Counties for milk sales and cattle inventory (26, 13). As one respondent explained, "There has been quite a movement over time of dairies into Pinal County from Maricopa County. As urban growth took over land in Chandler, dairies relocated to the rural areas in the neighboring Pinal County" (17). Forage crop production in close proximity to dairies and feedlots keeps feed costs low, and four respondents identified increased operation costs for dairies and cattle operations as a significant consequence if substantial crop land is fallowed because of a lack of water (6,15,18,1).

A number of food manufacturing companies including Shamrock, Daisy Brand Foods, Franklin Foods, Erhman Dairy Desserts and Abbot Labs Baby Foods source product from dairies in the county and this increase will likely impact their cost of operation as well (13). The effect of this, three respondents noted, will likely be reflected in increased food costs for the public, including the Phoenix metropolitan area's population exceeding four million and Tucson (4,18,17,5). Consumers have enjoyed "some of the lowest food and dairy prices in the state" for local products coming out of Pinal County, and if the dairy and cattle industries are impacted by reduced water supplies for crop production, as one respondent warned, "if you start importing your milk from California and Mexico, it is going to get really expensive"(18). Table 16 illustrates examples of respondents concerns about the challenges and impacts that could be experienced in the dairy sector.

Table 16: Quotes illustrating challenges to the local diary industry.

“Pinal farmers grow alfalfa and grain that dairies feed to their cows and they are able to source this feed more locally and it is a lot more affordable for them to get it in state.” (6)

“Also, there has historically been cattle production in the county and a transition away from agriculture will likely result in a reduction of dairies in the area as well.” (15)

“I would say that some of those dairies that are in Pinal County might have a tough time finding cheap feed.” (18)

“From a crop production standpoint, dairies in the area rely on local production for their feed source. There will be a ripple effect if agriculture were to be significantly reduced or removed entirely from Pinal County.” (1)

Interview respondents also identified environmental consequences that will worsen from fallowing large portions of land in the county. Three respondents expressed concern for worsening air quality with more fallowing (12,7,10) as one respondent stated:

> “Unless there are some kind provisions that, when they shut off the water, they get some kind of vegetation established there for cover, it is going to be a dust bowl and exposed to wind erosion and we will see a lot more effects of wind in the air like dust blowing across highways.” (18)

Another concern that was identified was the potential for noxious weeds taking over fallowed cropland (12,7).

Barriers to land conversion in Pinal County

The crop production sector in Pinal County is set to lose 40-60% of its total water supply when Arizona’s DCP Implementation plan is put into effect. One option available to the agriculture sector is to stop production on actively irrigated cropland and change the use of the land with construction of a residential development, commercial retail center or industrial development. Much of the cropland in the county is owned by developers and leased to growers to continue production for tax valuation purposes until future development takes place.

However, with current water challenges in the state and Arizona's Groundwater Code regulations, proposed development projects may not be able to get approval to begin construction. A proposed development project in the Pinal AMA is required to demonstrate access and rights to a 100-year supply of water in accordance with Arizona's Groundwater Management Act in order to be granted a building certificate. The Arizona Department of Water Resources updated the Pinal AMA hydrology model in 2014, which outlines the amount of groundwater available in the basin and how much of the water is allocated. According to respondents, the hydrology model indicates that most of the groundwater in the basin is already currently allocated and not available to future development projects (11). Six respondents identified this barrier to converting cropland and expressed that water availability for development projects to secure building certificates through the ADWR will likely create problems with land use in Pinal County (11,5,3,17,12,1). Table 17 provides examples of these concerns.

Table 17: Quotes illustrating barriers to development in Pinal County.

“There is just no way developers will get 100-year water supply certificates on groundwater.” (13)
“Under 100-year water supply rules, there does not appear to be enough water to be counted on to replace all of agriculture with houses or commercial and industrial development. And then then question is, do you really want to?” (5)
“There is big uncertainty about what is going to be the rate of development. And, connected to that, uncertainties about whether there will be the water available to support that development.” (17)
“We are getting to the point where, unless we have some other sources of water, you are not going to see everything being developed.” (12)

As CAP water deliveries are restricted from the crop production sector in Pinal County, growers face challenges in securing enough water to continue production. As one respondent explained,

> “If the farmers can not pull off the CAP canal and it is too costly to pump out of the ground, and development can’t get any type of certificates to build houses, you may just see things come to a complete stop” (11).

Groundwater regulations in the Pinal AMA may prevent development from taking place on agricultural land and could result in a scenario where crop growers are forced to retire land from production with no possibility of conversion of the land to other uses. One respondent identified this concern and stated: “I hope you don’t just see thousands and thousands of idle acres because of a lack of water supply but I suppose that is a possibility” (13). For agricultural landowners who have yet to sell their land to prospective development interests, this barrier has the potential of making their “property less valuable because developers might not be able to get the water rights to develop that property" (1).

Barriers to individual grower adaptation

With restricted CAP deliveries, crop growers in Pinal County will have to adapt their management and operation strategies in response to reduced water supplies. Interview respondents reported that there are several options for adaptation that growers have and can continue to take to respond to a reduced water supply. First, they can switch to a more efficient drip irrigation system to conserve water and maintain acreage in production, they can switch to growing crops that use less water, they can use deficit irrigation practices or choose to reduce their acreage in production. They can also stop farming and they can try to access a supply of reclaimed water to supplement their reduced surface and groundwater supplies. Owners of the land could try to sell it for other uses.

Respondents identified barriers that inhibit growers from making these changes, barriers that reduce their capacity to adapt. For example, drip irrigation systems increase on-farm water efficiency to 90% in some cases, but are expensive to install and risk averse growers may not want to make that initial investment if they feel they will either not have water to farm all of their acreage in the future, or cannot make enough income to pay for that investment (22,2,5,14,13,14,18,20,30). Also, as previously mentioned, many of the growers in Pinal County lease their land and with short term leases, are not willing to invest the $2,000-$2,5000 an acre to upgrade their irrigation system on land that they do not own (1, 2,18,26,28). Also, "absentee landowners" as one respondent pointed out, who have plans to convert the land to residential or commercial real estate, are generally not likely to make this investment either (18). Even if growers do have the resources to upgrade their irrigation systems, drip irrigation requires a more intensive form of management, and as respondents reported, drip irrigation does not work effectively for all crops (22,25,5,29). Table 18 shows specific interview responses about these barriers.

Table 18: Quotes illustrating barriers to drip irrigation as an adaptation strategy.

"Drip irrigation is very costly and lots of farmers do not have long term leases on their land. Short term leases shield landowners from making an investment in a drip irrigation system." (2)
"If someone does not have a 20-year lease, they are not going to be able to make up their money and potentially lose, so they do not invest in drip irrigation, and most of our farmers in this county lease land." (2)
"Another issue is that a lot of farmers lease land, and maybe have 10-year leases but do not know if the lease will be renewed, so it makes no sense to invest in drip." (26)
"A lot of farms in Central Arizona are on leased land, so the owners may not want the farmers to invest in expensive drip irrigation." (26)
"It is really hard for farmers who are renting land for themselves or to others to heavily invest in irrigation systems or other infrastructure. Even if drip is "better," they cannot justify the costs based on how long they will be on the land." (28)

Barriers to switching to different crops that require less water are related to inflexible market conditions. Water intensive crops like alfalfa have a high market value, especially considering the regional market demand for feed supply for local dairies and feedlots (9,4,17,18). Although growers may want to reduce water use per acre by planting different crops, "when you are farming, it is all about economics. Just because something uses less water, if you can't make money off it, you are not going to plant it" (12). Also, respondents explained that it is not possible to switch to a different crop if there is not a reliable market developed to sell the crop (13,18,9). There were also concerns identified about the increasing cost of operation and inputs combined with stagnant or variable commodity prices (2). As one respondent explained, “some farmers are receiving the same price for the crops as they did 20 years ago, while inputs (like materials, equipment, cost of water) are all going up. Farmers have to be price takers, not price setters” (27). Respondents described farmers being locked into the types of crops they grow. Even though alfalfa and cotton use the most water, growers have “momentum” (4) growing them and are also “there are connected distribution systems that would cause some impediments in terms of changing to different crops” (9).

Barriers to using deficit irrigation practices and fallowing portions of land that were identified relate to farm income as well. When growers deficit irrigate, they give their crops less water, but sacrifice on yield (4). Otherwise, growers can reduce their acreage in production and grow a more robust crop on less acres, but both practices can result in less income for the grower. This is a challenge when profit margins are tight and especially so when growers lease their land and may have a difficult time affording their rent (4). As one respondent described: “When farmers do not have enough water to farm everything, they will probably have to go back to landlords that are absentee owners and try to renegotiate a rent” (12). Additionally, growers have capital invested in specialized equipment for their operations, like cotton harvesting instruments that cannot be used for any other crop, and as one respondent noted, “generally the challenge there is that they don’t want to have to restructure everything and get rid of a bunch of equipment they don’t need any more and get a bunch of new specialized equipment for a new crop” (6).

Barriers related to supplementing with reclaimed water include concerns about the quality of treated water and possible contamination from pharmaceuticals and heavy metals in wastewater (12). Also, even when wastewater is treated and leaves the treatment plant as high quality effluent, degradation can occur during transport through canals, for example from grazing cattle (8). In addition, proximity of growing operations to treatment plants was reported as a barrier and increased competition and cost of reclaimed water for non-irrigation uses may prevent farmers from being able to access reclaimed water supplies (8,18).

Three respondents also identified grower knowledge and skills as barriers to effectively making adaptive changes in response to reduced water. For example, respondents mentioned the challenges related to learning new water management practices, learning how to grow different crops, knowledge of alternatives, and high value specialty crops that use less water (14,3,22). In general, individual growers face significant barriers to adopting adaptation strategies during this time of transition. Table 19 summarizes the types of barriers and challenges identified by respondents. These challenges will be difficult to navigate and without additional support and resources will serve to reduce growers' adaptive capacity in the coming years.

Table 19: Summary of barriers to individual grower adaptation.

<u>Switching crops</u> Inflexible market conditions (N=15)	High market value of water intensive crops (n=5), and lack of developed market for lower water use crops (n=3), dairy and cattle industry drives demand for alfalfa production (n=7), drivers for cotton production (n=4)
Prior investments and economic risk (N=10)	Cost of switching machinery (n=5), increasing of cost of operation and inputs(n=5)
Grower knowledge and skill (N=2)	(n=1), learning how to successful grow new crops (n=1), unaware of alternate high value specialty crops
<u>Drip Irrigation</u> Economic (n=17)	Initial investment with delayed economic return (n=8), possibility of losing water (n=2), production on leased land (n=7)
Grower knowledge and management (n=5)	Learning new irrigation and water management practices (n=2), drip irrigation does not work on all crops (n=3)
<u>Fallowing land and deficit irrigating</u> Economic (n=3)	Lower crop yields and less income (n=2), challenges with affording rent for leased land (n=1)
Environmental (n=5)	Air quality and dust (n=3), noxious weeds taking over vacant land (n=2)
<u>Reclaimed water</u> Water quality (n=2)	Removing all trace chemicals from wastewater (n=1), contamination of water during transport (n=1)
Access and availability (n=3)	Proximity of growing operation to treatment plant (n=1), increased demand for effluent makes it more challenging for farmers to access (n=2)

Adaptation and Adaptive Capacity in Pinal County Agriculture

Returning to the three research questions for this study, first there is a clear need for rapid and significant adaptation among irrigation districts and crop growers in Pinal County. Facing the loss of all CAP water in the coming years, they will to adapt to having less water and to obtaining their water entirely from other sources. Interviews illustrate the importance of previous agreements, namely the 2004 Arizona Water Settlements Act and the 2007 Interim Guidelines for Lower Basin Shortages and Coordinated Operation of Lake Powell and Lake Mead, in shaping the need for adaptation. In addition, all respondents agreed that the DCP now makes adaptation an immediate requirement. In summary, extensive and rapid adaptation is necessary for irrigation districts and crop growers in Pinal County.

Second, interviews indicate that there are specific adaptation options and ways to increase adaptive capacity for irrigation districts and crop growers. Irrigation districts can increase well infrastructure and capacity and will have a boost in financial resources from the $9 million allocated in the DCP. This additional funding increases their adaptive capacity in the short term. Districts will also increasingly have to consider cutting off water to certain areas as an adaptation strategy. This would result in fallowing certain croplands. Individual landowners can sell or use land for other purposes, including residential and industrial development, in ways that can support the regional economy. Crop growers can increase their adaptive capacity by diversifying cropping systems, switching to crops that use less water, increasing conservation and efficiency through adopting drip irrigation, and using reclaimed wastewater as an additional water source. These actions make growers less vulnerable in times of water scarcity and helps to sustain production. Some, although limited, resources from federal conservation programs can support these changes.

Lastly, many barriers constrain the adaptation of irrigation districts and crop growers and therefore reduce their adaptive capacity. By most accounts, they are unprepared for the rapid transition in water use called for in the DCP. For irrigation districts challenges include the aging infrastructure of wells, the expensive nature of pumping groundwater, the energy involved in pumping groundwater, engineering issues when trying to use former CAP infrastructure for groundwater, the quality of groundwater, and the limited nature of groundwater supplies. Fallowing land may hurt the local economy, including agricultural suppliers, dairies, and the service industry. Landowners may not be able to sell or use land for other purposes due the AMA requirements for a 100-year supply of water. For crop growers, adopting drip irrigation is often cost prohibitive. Switching to other crops is difficult due to investments in equipment, lack of knowledge, access to markets, economic risks, and a sense of "momentum." In addition, using wastewater as a strategy may be compromised by quality and availability issues. These barriers constrain options and reduce the adaptive capacity of the crop production sector.

The next few years will be critical for increasing adaptive capacity in the region. Based on these findings, recommendations for increasing adaptive capacity include providing more federal and state funding, not for groundwater pumping but for transitioning to drip irrigation and crops that use less water. In contrast, the federal government continues to encourage the production of water intensive crops like cotton and alfalfa through crop insurance and commodity support programs. Funds should instead be used for water conservation efforts that would increase growers' adaptive capacity. This could include programs to share knowledge and skills about new crops to help growers to transition. Equipment buy-out programs could help growers with the costs associated with switching crops. Ultimately, agricultural production in the area will have to decrease and supporting local economies during this transition will be critical. Education and jobs programs could be useful for assisting in new employment. Stakeholder involvement including tribes, the agriculture sector, and municipal and industrial development interests is critical to facilitate the best strategies to share diminishing water supplies moving forward. These efforts can help to address some of the barriers identified in this study and increase adaptive capacity for Pinal County growers.

CONCLUSIONS

Decades of mismanagement and extreme drought on the Colorado, the American West's "hardest working river," have reduced annual flows and reservoir volumes to their lowest levels in history, necessitating immediate intervening action from basin states (O'Donoghue 2019). Without such action to curtail consumptive use of the river's resources and allow for reservoir levels to rise, the future water security of nearly 40 million people, 5.5 million acres of irrigated farmland and numerous wildlife refuges and recreation areas is threatened (Colorado River Basin Study 2012). A basin-wide study conducted in 2012 also projects a further imbalance between water supply and demand in the coming 50 years as populations grow in the region and climate conditions worsen (CRBS 2012).

We are now entering a critical time of water resource transition in Arizona. Arizona's water profile will dramatically change in both supply and use as Drought Contingency Plan agreements outlining Colorado River water delivery restrictions are implemented across the basin. Approximately 70% of the states total water use in 2014 was for irrigated agriculture and this sector will absorb the entirety of the initial water cuts proposed in the DCP. Cropland in central Arizona is particularly vulnerable to future water cuts because its access to Colorado River water is through the CAP with water rights junior to all others in the state. The crop production sector in Pinal County is expected to have its total water supply reduced by approximately half to account for Arizona's DCP shortage sharing responsibility.

Agricultural landowners in central Arizona have historically adapted to a variety of changes such as fluctuating commodity prices, emerging regulations and economic incentives by selling farmland for conversion to other uses. Economic incentive and state water policy favoring municipal and industrial development served as the primary drivers for the sale of agricultural lands in previous decades, and much of the farmland in Pinal County is currently owned by speculative development interests. Water scarcity is a primary driver for converting agricultural land to municipal and industrial development in the future and this option is a viable adaptation strategy for agricultural landowners in Pinal County. Future development is likely to be constrained because of water availability, however, as residential and industrial development projects may be unable to secure building certificates by demonstrating access and water rights for 100 years of water to support their development. With CAP restrictions, if growers are unable to secure adequate water to produce on the land and development projects are unable to get approval for construction, many acres may lay fallowed with no potential future use.

Despite efforts and significant investments to increase groundwater pumping capacity, the irrigation districts in Pinal County are unprepared for approaching CAP water restrictions that will take place as soon as 2020. Groundwater currently makes up the half of water used for irrigation of cropland in Pinal County and irrigation districts work to supply the most efficient combination of water sources to their member growers in the county. Last minute DCP negotiations afforded the districts a mitigated supply of CAP deliveries through 2023 and state funding to advance groundwater infrastructure development, but they still face significant challenges in meeting the water needs of their member growers in the coming years with substantially less CAP water. Existing surface water delivery infrastructure was not designed for delivering groundwater without a solid base flow of CAP supply and the districts have significant engineering obstacles to overcome. The districts will face financial barriers in adapting to water allocation changes through increased groundwater pumping as many of the wells in their districts are old and require updating and re-drilling. They will likely struggle to keep water rates affordable for their member growers with the added cost of electricity to pump more water at greater depths.

Groundwater pumping, the primary adaptive strategy, is not a sustainable solution for future water security for agriculture in Pinal County because groundwater resources are finite and vulnerable to over-draft with serious resulting environmental consequences, as the state's history illustrates. Reverting back to groundwater pumping is likely to intensify conflicts between the agriculture and municipal and industrial sectors in the county as the districts make use of irrigation grandfathered groundwater rights allocated through Arizona's groundwater code that they have not had to access in previous decades because of availability of imported CAP supplies. Increased pumping for agriculture could potentially impede the approval of future municipal and industrial development projects that also rely on the demonstration of sufficient groundwater supplies for building certificates (Davis 2019).

Agriculture was expected to be largely phased out in central Arizona by this time with water and land use converting to make way for urban expansion (Bausch et al. 2015). This projection has been realized in the adjacent Maricopa County, but farm operation and rural land use in Pinal County has remained relatively stable in the past decades (Eakin et al. 2016). Agribusiness remains an important contributor to the county's economy, especially considering the high concentration of dairies and feedlots in operation. A reduction in crop production acreage could lead to less business for ancillary support industries in the county like agro-chemical, seed and equipment dealers. If these businesses are forced to close or relocate, this could in-turn lead to loss of jobs for workers in the county and less income could result in less economic activity in the county as a whole. Given the barriers identified, it is highly likely that the districts will not be able to affordably supplement the entirety of their reduced CAP supply with groundwater and a percentage of cropland will go fallow either temporarily or permanently because of lack of water. Taking land out of production will effectively reduce the water needs in the districts, but will have consequences for the local and state economies, and farmers and farm communities.

Changes in crop production will have impacts that ripple through the economy. A disruption in forage production like alfalfa hay, which dairies and feedlots rely on for an affordable feed supply could have economic impacts that reverberate beyond dairy and cattle production to the various food manufacturing operations in the county and all the way up the supply chain to potentially increasing the cost of dairy and meat products for consumers in Phoenix and Tucson. Forage crops like alfalfa hay are the second highest category of crops in production in Pinal County and demand for these is driven by the high concentration of dairy operations and feedlots in the county. These agricultural products not only make up a large part of the county's economy, but contribute significantly to Arizona's economy. In 2012, Pinal County milk sales neared $295 million, accounting for 39% of the states total milk sales while cattle and calf sales approached $315 million, making up almost half of the states total (USDA 2012).

Crop growers will soon face the reality of having access to less and more costly water supplies when DCP restrictions are implemented. They will be forced to make changes in their operation and management strategies in response. Much of the adaptation in Pinal County agriculture will happen at the individual grower level in terms of the ways in which water is used for production. Crop growers have and can continue to take adaptive action to respond to changes in water allocation, including installing high efficiency irrigation systems like drip irrigation, switching to producing less water intensive crops and veering away from cotton and hay production, taking acres out of production and deficit irrigating, or procuring a supply of effluent water for irrigation. These approaches are beneficial in that they allow growers to restructure their operations to continue producing with less water.

However, there are many challenges to adaptation. Drip irrigation is expensive to install and farmers may not have the capital to invest or may have a short lease on land owned by a developer who also does not want to invest in land they hope to convert in the future. Cotton and alfalfa hay growers are generally locked into growing those water intensive crops because they receive federal support through subsidies, their knowledge and equipment cater to growing those crops and there is a lack of a viable alternative market to begin production of different crops. Fallowing acreage will likely put growers in challenging economic situations where they may not be able to afford the rent for their land, low commodity prices and less acreage in production could reduce farm income, and may require growers incur more debt. Barriers to using reclaimed water to supplement for irrigation include water quality challenges and access and availability issues.

The future of agriculture in Pinal County will involve a significant transition. The area of land in production will likely decrease significantly. There is also the potential of remaining agricultural land to go back to unsustainable levels of groundwater pumping, considering the several billion dollars that will be invested in improving pumping capacity in the coming years. Pinal County agriculture wants more money in the future to assure they are able to develop groundwater infrastructure. Cities and industry interests lament that Pinal County agriculture "has received more federal farm subsidies than any other Arizona county — $571 million from 1995 to 2017, according to a database kept by the Environmental Working Group" (Davis 2019). They argue the county has a history of unsustainable groundwater pumping and should not receive any more financial support in the form of more funding. These arguments will only intensify.

The DCP is only the beginning of more water conflicts between users in Arizona and between the basin states. It is not a solution to the challenges on the Colorado River, but an intervention to reduce the chances of Lake Mead levels from reaching unrecoverable levels by 2026. There will still be a "structural deficit" on the river because of over-allocation and this will worsen as states in the upper basin make use of more of their water entitlements. Climate change is projected to continue unless significant reductions in greenhouse gas emissions occur globally. These factors combine to create the need for rapid adaptation and transition among Pinal County crop growers. This transition is not restricted to Pinal County, and other parts of Arizona and other states in the Southwest will increasingly have to adapt as heat and water scarcity reshape land use, economies, and livelihoods in the coming decades.

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APPENDIX A

Interview Guide 1

1. How is water for irrigation currently allocated in Pinal County?

2. If or when there is a cut in CAP water, what are the projected changes in water allocation for agriculture in Pinal County?

3. How will this affect groundwater use in the County?

4. Are there any planning efforts or policies being developed to facilitate changes in agriculture? What are they?
    a. What about switching to different crops?
    b. What about the use of new technology?
    c. What are the major barriers and challenges to a transition to lower water use in agriculture?
    d. What are the major barriers and challenges to a transition to using different water sources for agriculture?
    e. Are there any programs that would help producers with these changes?

5. Thinking in the next 20 or 30 years, what do you see as the major challenges for the agriculture sector?

6. Do you see land being taken out of agricultural production and used for other purposes?

7. With lower water levels and decreased snowpack, will there be enough water for agriculture in Pinal county to continue? For how long?

8. What do you see land use in Pinal County looking like in 20-30 years?

9. How do you see land use changing as a whole in Arizona the next 20-30 years?

10. What are the implications for changing land from agricultural production to urban development in Pinal County?

11. Is there anyone else you think I should talk to about this topic?

APPENDIX B

Interview Guide 2

1. How do you expect lower water levels in Lake Mead to change water access for Arizona, California, and Nevada?

2. If there are significant cuts, how is Arizona going to navigate between the water needs of different users, such as cities versus farms?

3. Will water shortages in Lake Mead lead to cuts for agriculture? When are these expected, and are they guaranteed to happen? What would these cuts look like? (e.g., limiting expansion of irrigation)

4. Do you expect any new groundwater legislation or regulation? Is this an avenue for water conservation and policy that is being pursued?

5. What water conservation measures have been or will be most successful for agriculture? What hurdles do farmers face in these transitions?

6. With lower water levels in lakes and rivers, along with decreased snowpack, will there be enough water for agriculture in Arizona to continue? For how long?

7. What role does the climate play in these questions/problems?

8. How can farmers in Arizona adapt to climate change?