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Are We Prepared? Increased Drought Vulnerability Due to Climate Change and State Drought Plan Preparedness

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Are We Prepared? Increased Drought Vulnerability due to Climate Change and State Drought Plan Preparedness

Thesis directed by Professor Paul Chinowsky

Climate change is one of the largest uncertainties surrounding water resources throughout the end of the century. Warming temperatures have a cascading effect with regard to water, driving up natural and human demand. Changing climatic patterns will also increase the risk of extreme events. One of the costliest and misunderstood natural disasters is drought. In recent years drought planning has moved from a mode of crisis/reactionary management to one of risk/preparedness management. While this shift in planning has occurred in some states, others have not moved beyond reactionary planning. Climate change has the potential of increasing the frequency and severity of drought through the end of century. This research quantifies the increased risk of drought due to climate change and analyzes the state drought policy of a region with amplified drought risk. The research finds that many states lack the inclusion of climate induced drought risk when planning. Finally, recommendations for addressing increased drought risk due to climate change at a state level are provided.

Dedication

To my parents and family for supporting me through all my education and listening to me as I increasingly become obsessed with water!

Acknowledgments

I want to acknowledge my advisor Dr. Paul Chinowsky for keeping me on track and focused on my scope while still encouraging me to follow my own research passions. Thanks for taking me on a research assistant back when I was a freshman! Also, thanks to all my friends who have read drafts of my report and double checked my spelling.

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Introduction

When most think of the impacts of climate change, rising sea levels and intensifying storms come to mind. One aspect of climate change often overlooked is its intensifying effect on droughts. Although drought has been sparsely studied, shifting drought patterns due to climatic change have the potential to affect more than 30% of all land by the end of the century (Wilhite 2016, Boehlert et al. 2015). Drought lacks a universal definition and its disparate effects vary depending on the local state of human activity. For these reasons, it is difficult to equate historical drought to future vulnerabilities, exacerbating the complexity of drought preparedness planning (Logar et al. 2013). It is a wicked problem.

Drought was first officially identified as a threat to the United States in 1997 by the Federal government. The National Drought Policy Act of 1998 was passed to establish an advisory commission to provide advice and recommendations on the creation of an integrated, coordinated Federal policy designed to prepare for and respond to serious drought emergencies (The National Drought Policy Act of 1998). The commission spent two years studying the various impacts of drought and prepared a report with their findings. Drought was identified as a problem due to the high economic and social impacts, it's difficulty of prediction, and its prevalence in all climates. The report estimated the 1988-1989 drought and 1976-1977 drought each cost $6 billion dollars or more (The National Drought Commission, 2000). Drought, more than other types of natural disasters, has potentially longer domino effect on those directly and indirectly effected. The direct impacts of a drought can cascade throughout industries. Due to the difficulty of quantifying all these indirect effects, there has been little research on the true cost of drought.

Out of the National Drought Policy Act of 1998 the National Integrated Drought Information System (NIDIS) Act of 2006 was formed. This agency mandate was to integrate drought research, building upon existing federal, tribal, state, and local partnerships to help build a national early warning drought system. Since its creation, NIDIS has developed a national drought early warning system and continues to fund drought related research (What is NIDIS?). NIDIS also works closely with states and communities to help plan for drought and raise public awareness and education about droughts. No other federal policy was enacted from the National Drought Policy Act, although a National Drought Preparedness Act of 2003 was introduced, it never made it out of committee.

To this day, drought continues to have a huge impact on the economy and threaten the well-being of the American citizens. With the added risk of climate change, drought could become one of the costliest natural disasters for the US faces on a regular basis. It is imperative that government agencies recognize this risk to reduce vulnerability of the population going forward.

Research Question

Given the potential change to historic drought patterns that climate change is introducing, the focus of this research is to determine if state agencies are addressing this increased risk. Due to the localized effects of drought and lack of national policy, state level policy is the main avenue for preparing for drought. Therefore, this research asks the question of how specific states are preparing for increases in drought severity due to climate change. This overall question provides the basis for the two main objectives addressed by this research:

1. What is the national impact of climate change on the severity of drought through the end of this century.
2. How are state and local entities recognizing and responding to increased or decreased drought vulnerability due to climate change.

These objectives cover a full range of what a water manager who is tasked with planning for drought should know to effectively prepare for drought.

Contribution

The contribution of this effort will be to help bridge the gap between climate induced drought risk and drought mitigation planning policy. To effectively plan for our changing future, it is crucial to understand potential impacts that our changing world will face. Currently drought is being planned for, but many entities fail to recognize the increased risk of drought due to climate change. This research aims to provide a twofold analysis linking the ideas of drought risk due to climate change to state drought planning efforts. This effort will add to the literature of water resources management by comparing different planning approaches and suggesting ways in which states can improve their planning to reduce the increased risk of droughts from climate change.

Thesis Overview

This paper includes five main sections: literature review, methodology, Climate change analysis results, state drought plan results and discussion. The literature review covers topics ranging from the definition of drought to how climate change will affect drought, to how drought is currently being planned for. Key ideas include the localized nature of drought and costliness of reactionary policy to drought events.

In the second section the two methodologies are described. In the first analysis, the change in drought risk due to climate change in specific regions will be accounted for using the methodology adapted from Strzepek et al. 2010. The potential increase or decrease in drought months will be determined based on a historical and future projection of the Palmer Drought Severity Index (PDSI). Even though the PDSI has its limitations (Alley 1984), its long record of use makes it useful to compare to historical events to future impacts that could occur from a drought. This methodology will be used to generate a range of change in drought months for each general circulation model (GCM) approved by the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment (AR5). The analysis will be performed utilizing the Infrastructure Planning and Support System (IPSS; Schweikert et al. 2014, Chinowsky et al. 2012) for ease of analysis and data visualization. Analysis will be performed initially on a HUC-2 watershed level. This analysis will show the general trend of areas in the US that could potentially see increased impacts due to drought over the next part of the century.

After identifying a HUC-2 watershed with increased drought risk due to climate change, the second analysis will be detailed investigation of a selected sub-region. A higher resolution (HUC-4) of the climate change drought vulnerability analysis will be used to determine specific areas of the watershed that might be disproportionately affected. At the same time, a regional analysis of drought vulnerabilities of the selected region regional will be performed, identifying both direct and indirect drought vulnerabilities. Direct vulnerabilities include agricultural, power generation, and water supply interruptions. Indirect vulnerabilities incorporate changes in food prices, trade losses, unemployment, and deteriorated water/air quality among others. (Ding et al. 2011).

The final analysis will determine if regional or state-wide plans thoroughly address the selected sub region's vulnerabilities. of the selected sub regions is addressed thoroughly by regional or state-wide plans. The analysis will examine the selected sub-region's drought plans to determine climate-related drought preparedness using an adapted methodology from Wilhite et al. 2014. Special consideration will be given to the type of planned responses: proactive or reactive. Literature has stated that proactive, risk management focused drought plans will result in significant economic savings over crisis management only plans (Gerber et al. 2017, Fu et al. 2013). Drought planning that proactively manages drought risk will achieve much more favorable outcomes in the face of increased drought vulnerability.

In the discussion and conclusions sections, recommendations will be made on how states can improve their drought planning process to increased risk due to climate change. This will provide tangible goals and recommendations to each state and allow for discussion of further research. Finally the discussion and conclusion will provide recommendations as to what, if any, national drought policy should be formed.

Literature Review

The objectives of this research build upon four main sections of literature: drought indices, drought impacts, drought planning/preparedness policy, and climate change and drought risk. These provide the background for how drought is currently being planned for and how climate change is or is not being incorporated at the planning level. A summary of the key ideas and papers covered is found in the table below.

Table 1. Main Areas of Focus and Key Papers

Area of Focus	**Key Ideas**	**Crucial Papers**
Drought Definitions and Indices	- Drought Lacks a universal definition - Drought indices are useful but many lack long records making them difficult to apply to future scenarios	Van Loon et al 2016 Palmer 1965 Mckee et al 1993
Drought Impacts	- Drought have large economic impacts for nations - Droughts have a variety of direct and indirect impacts that effect all aspects of a community	Wilhite et al 2007 Logar et al 2013 EPA 2017 Board 2010
Drought Planning and Preparedness Policy	- Many have recognized the need for risk management versus crisis management planning when it comes to drought - Even though resources are available, many communities do not plan for drought	Logar et al 2013 Gerber & Mirzabeav 2017 Fu et al 2013 Wilhite et al 2014
Climate Change and Drought Risk	- Climate change has the potential to change drought intensity, frequency, and timing - Institutions are not prepared for climate change induced risk	Dai 2011 Finnessey et al 2016 Fu & Tang 2013

Drought Definitions and Indices

Drought lacks a universal definition, making response and preparation difficult. In general, droughts occur when there is a departure from a normal amount of water at any point throughout the water cycle (Van Loon et al 2016, Palmer 1965, Tallaksen & Van Lanen 2004, Gerber & Mirzabaev 2017). Droughts are naturally occurring phenomena throughout all climate zones, occurring even in the wettest and driest climates. Unlike other natural disasters, droughts are characterized by slow onsets, diffuse damages and convoluted beginnings and endings. These general definitions do not accurately capture the nuances of drought and increase the complexity of planning for the nebulous disaster (Wilhite et al 2014).

Four main subsections of drought have been identified throughout the literature: meteorological, agricultural, hydrological, and socioeconomic (Van Loon et al 2016, Bachmair et al 2016). Drought events are localized, dynamic events and can include aspects of each type of drought as it progresses. Meteorological droughts derive from a deficit in precipitation. This type of drought generally proceeds other types of drought. Meteorological droughts impact rain-fed agriculture disproportionally (McWilliam 1986). If a meteorological drought persists an agricultural drought can form. These droughts are characterized by a decrease in soil moisture, especially with regard to minimum soil moisture needed for efficient crop growth. Once an agricultural drought has significant time to mature, a hydrological drought can then occur. Hydrological droughts arise from decreased surface and subsurface supplies. These types of droughts are most noticeable to the public, due to lower water levels in reservoirs and lakes. The final type of drought is a socioeconomic drought. This type of drought occurs when human demand for water overtakes the hydrologic supply of the water source in question. These types of drought can be man-made under normal hydrologic conditions or can exacerbate an existing drought.

Drought is especially difficult to plan for. Under the best circumstances, aspects of droughts like the slow on set, diffuse spatial distribution, and uncertainty regarding the start and ends of droughts make it challenge to respond to (Bachmair et al 2016). One method to determine the onset of a drought is through drought indices. These indices range from streamflow, precipitation, temperature, reservoir/lake levels and soil moisture to remote sensing data and combined drought indicators such as the US Drought Monitor, the Combined Drought Indicator, the Palmer Drought Severity Index (PDSI) and the Standard Precipitation Index (SPI) (Board 2010, Bachmair et al 2016, Keyantash & Dracup 2002). The drawback of many drought indices is the lack of long records, which are helpful for identifying historical patterns. Additionally, many drought indices are developed for specific localities, making it difficult to transfer to other locations with different climatic patterns. The PSDI and SPI have the advantage of long reference periods or the ability to back calculate accurately. Additionally, drought is an extremely localized event and therefore not all indices are suited for each area. It is best to have specific indices for the area in question. While all these indices are wildly used for drought monitoring, the PDSI and the SPI have been wildly adopted for use due to their long record and ease of calculation.

One of the oldest drought indices was developed in 1965 by Palmer at the University of Nebraska. The Palmer Drought Severity Index (PDSI) is based off a water balance method that considers soil moisture as the main indicator for a drought designation (Palmer 1965, Guttman 1998). Because it considers the potential evapotranspiration along with precipitation records, it is best for quantifying a hydrologic drought. Even though the PDSI is one of the longest recorded drought indices, it has many draw backs. First, a key portion of the calculation relies on the potential evapotranspiration, which has no universally accepted calculation method (Alley 1984). This calculation can sway the results to show overall drier conditions than expected depending on the method chosen for the calculation of potential evapotranspiration. The PDSI takes calculated evapotranspiration and then performs a water balance method that incorporates the precipitation to determine the water balance in the soil moisture. This calculation also considers a two-layer soil moisture calculation. This aspect of the calculation can be generic or incorporate specific soil types for the location in question. For this analysis a generic soil type was utilized for the study versus accounting for the differences in soil types across the United States. This will simplify the overall computation of the analysis. Additionally, the PDSI was developed in the mid-west plains and does not accurately represent other areas of the country as accurately and arbitrarily estimates the runoff from precipitation events (Alley 1984). Other draw backs include the inability to incorporate snow or storage into the model. This renders the model incomplete for the purposes of drought monitoring in areas where the hydrologic cycle is dominated by snow melt. Finally, the values of the PDSI themselves do not reflect anything on their own (Alley 1984). They must always be compared to one another in relation to a standardized normal.

Despite these drawbacks PDSI has been used extensively to quantify drought under climate change (Bonsal et al 2013, Burke & Brown 2008, Coats et al 2013, Cook et al 2010, Cook et al 2013, Dai 2011, Dai 2013, Rosenweig & Hillel 1993, Seager et al 2008, Taylor et al 2013, Strzepek et al 2010). This is a preferred method to many drought climate change analyses because the PDSI calculation incorporates the potential evapotranspiration directly. The calculation of potential evapotranspiration utilizes temperature as a direct input. Studies by Cooke et al 2014 and Dai 2011 have shown that increased evapotranspiration might play a larger role in the future of drought risk than precipitation patterns. Evapotranspiration will increase the water demand of plants in each area as temperatures rise, which will continue to degrade drought conditions caused by changing precipitation patterns.

An alternative to the PDSI is the Standard Precipitation Index. While the Standard Precipitation Index (SPI) was only developed in the 1990s, it has emerged as one of the key drought indices utilized by institutions. Developed by Mckee et al in 1993, the SPI is a probability index that measures drought based on the degree to which precipitation diverges from the historical mean in each period for a given geographical area. Because it relies on precipitation only, it is easily back calculated and in fact requires a historical mean to determine divergence. Due to its probabilistic nature and ability to accurately represent drought in a variety of topographies and seasons, the SPI has become an important indicator throughout drought planning (Guttman 1998). Even though SPI has been widely adopted, it does not adequately represent the changes in potential evapotranspiration (Feng & Fu 2013, Scheff & Frierson 2014, Cook et al 2014). Therefore, SPI is not a good indicator for drought driven by a warming climate. Nevertheless, SPI is used extensively in drought planning and can provide an alternative assessment as to how climate change will impact the future of droughts.

Drought Impacts

Even though droughts are a naturally occurring part of every climate, many institutions are not prepared for them (Fu et al 2013, Fu & Tang 2013). Droughts have huge economic impacts throughout society. The 2002 drought caused $1.4 billion in economic impacts in South Dakota (Diersen 2003). Similarly, the recent drought in California had an estimated economic impact in agricultural sector only of $2.7 billion in 2015 alone (Howitt 2015). But, the true cost of drought remains unknown partly due to a lack of a universal methodology (Logar et al 2013). Many methodologies fail to consider the indirect impacts of drought and rather focus on the visible impacts such as crop failure or hydropower decline. Larger national studies that try to encompass some indirect effects have found that drought costs an estimated $6 to $8 billion annually in the USA (Knutson 2001) and over €100 billion over the last 30 years in Europe (Europea, C 2007).

In additional to the nebulous nature and large economic impacts of drought, droughts have large spatial and temporal extents (Wilhite et al 2007, Finnesseey et al 2016). This adds complexity when determining impacts and responses of various institutions. Droughts can last as short as couple of months, or as long as decades. Additionally, humanity is changing its risk to droughts by changing land use patterns, anthropogenic global climate change and increasing population growth. These factors increase the socioeconomic demand on hydrologic systems, amplifying drought vulnerabilities during and after an event (Ding et al 2011, Fu & Tang 2013, Finnesey et al 2016).

Even with a multitude of drought indices available, it is difficult to determine how any given drought event will impact a community. Due to the nebulous nature of drought and modifications of the natural world by humans, each drought event has a unique effect on the given area (Wilhite et al 2007). Drought impacts come in two main forms: direct impacts and indirect impacts. These impacts can be broken up by industry and generally intensify as droughts persist. Multiple papers have summarized the impacts that drought can have on society including work by Wilhite et al 2007, Logar et al 2013, Bachmair et al 2016, Pérez y Pérez & Barreiro 2009, EPA 2017, Board 2010, Li et all 2011, and Ross & Lott 2003. The classic example of drought impacts are agricultural impacts. Issues such as decreased yield and withering crops are generally highly publicized during a drought. Often the direct impacts to the agricultural industry are felt first due to sensitivity to the water cycle. Beyond the direct impacts on agriculture, decreased yields can have indirect impacts on food prices, decreased economic activity in farming areas among other unforeseen impacts.

Another highly visible sector effected directly by droughts are water providers. During droughts, water provides take a financial hit from decreased water sales and potential increases in treatment costs. On a more localized level, people on private wells can see groundwater levels drop, leading to decreased water quality and potentially a drying out of wells. These direct impacts have far reaching indirect impacts that deal with the equity of water supply and quality of life issues. If water does have to be partially shut down, who gets to keep their water on? How shut downs effect the populous can illuminate larger systemic problems thought a community.

The effects of water providers are early effects that the community and society can feel during a drought. On a community wide level, decreased water supplies can cause both private and public landscaping to become stressed or killed. Droughts are often associated with increased wild fire risk (Balling et al 1992, Heyerdahl et al 2002) and they also dramatically reduce the capability for firefighting. Additionally, droughts lead to increased respiratory ailments, increased heat stroke and increased political unrest. The drought in Syria has been traced to high levels of civil unrest and was a contributing factor in the rise of the current conflict in this area (Kelley et al 2015).

Many of these direct drought impacts have lasting economic implications. Decreased land prices and land subsidence can occur especially in long droughts. Farmers are the first most notably impacted by droughts. Stressed farms can lead to increased food prices and a supply side economic shortage. If a drought persists, there can be considerable reduction in economic development (Brown et al 2013).

Droughts can severely impair the production of hydropower and tourisms industries especially rafting and snow sport industries. These indirect impacts will accumulate a larger economic impact as a drought persists.

Finally, droughts have many negative impacts for the natural environment. Droughts increase stress on natural ecosystems which in turn leaves them vulnerable to infestations. Notably, in the Rocky Mountain Region, droughts in the mid-2000s helped proliferate the spread of the bark beetle (Hart et al 2014). Water short environments lead to lower stream flows, reservoir levels, lake levels, and decreased wetland areas. Decreased water levels can negatively impact fish and wild life. Drought can be a contributing factor in increased wind and water erosion. Overall these impacts, can affect the pattern of the natural ecosystem for years to come even post drought (Wilhite & Glantz 1985).

Drought Planning and Preparedness

Droughts can affect every ecosystem and every human environment, but many communities in the USA and internationally lack awareness of the risks drought pose to them (Fu et al 2013, Fu & Tang 2013). Most states in the USA have a state drought plan, but to varying degrees of robustness (Fu et al 2013). Recently there has been increased awareness of the effects and vulnerabilities to drought throughout the world. In response governments and high-level agencies have started providing basic guidelines for drought planning/preparedness (Wilhite et al 2014). While many high-level planning frameworks exists, there is still a lack of national or basin wide plans. Many of these planning issues are due to lack of specific awareness and lack of location specific information to form a drought plan (Ding et al 2011).

Two main responses to drought have emerged over the years: crisis management and risk management. These differ in effectiveness and execution. Crisis management consists of simply reacting to a drought crisis (Logar et al 2013, Gerber & Mirzabeav 2017, Fu et al 2013). This mode of planning is essentially not planning. Crisis management disincentivize populations to proactively prepare for drought on their own, thereby increasing their vulnerability to future droughts (Wilhite et al 2014). This lack of planning can lead to a higher reliance on institutions for relief during and after droughts, which in turn yields a higher cost for organizations responding to drought emergencies. Crisis management is the prevailing mode of planning for many areas all over the world. Only recently has there been a shift towards proactive planning, which has been termed risk management (Wilhite et al 2007).

Risk management has been recognized as reducing vulnerability to drought before it occurs and having a pre-prepared plan for how to react during such an event. Its main features include a focus on mitigation and building the institutional capacity for droughts (Gerber & Mirzabeav 2017, Fu et al 2013, Logar et al 2013). Risk management requires a recognition that droughts are natural hazards of the climate and must be addressed to lessen the impacts when it occurs. Like with most preparatory planning, risk management can have upfront costs that can dissuade institutions from investing. Regardless, there has been an international recognition of the benefits of risk management and a push from international organizations to move towards this type of planning (Wilhite et al 2014, Alliance 2009, Board 2010).

Since the recognition of risk management and its benefits, there have been many papers outlining the steps and strategies to implement the risk management framework. These steps are broadly defined as early warning systems, vulnerability assessments, mitigation actions, prediction methods, staged drought protocols, legal/institutional responses to drought, and updating and keeping a relevant plan (Gerber & Mirzabeav 2017, Wilhite et al 2014, Board 2010).

Early warning systems consist of integrating drought indices like the PDSI, SPI, precipitation levels, temperature combined into a hazard analysis. Early warning systems provide institutions with the ability to track in real time the drought potential of a region.   They are critical for initiating a reaction to the drought before it becomes severe. Hazard analyses generally include an inventory of an areas vulnerabilities and how drought indices can be used to track the develop of these vulnerabilities (Fu et al

2013). The hazard analysis leads directly into a vulnerability assessment, which focuses on the human impacts of drought (Gerber & Mizabaev 2017). To determine potential impacts of an area, historical impact assessments can be performed. Additionally, a vulnerability assessment can illuminate how specific industries might be affected and groups of people that are more at risk from a drought. Finally, the vulnerability assessment can help identify areas more prone to drought.

After the early warning systems and vulnerability assessments are completed, mitigation actions to combat drought impacts should be developed. Many mitigation options for drought are simply water conservation opportunities throughout a water system (Wilhite et al 2014). These range from increasing efficiency within households by upgrading to water efficient appliances or on a systems level, decreasing the wasted water in an industrial process. These combined with other mitigation actions such as increasing water supply options, establishing drought reserves, repairing water distribution leaks can help improve efficiency of a system, thereby increasing the resilience to drought overall (Board 2010).

To enhance early warning systems, predictive models can be used to help identify potential signs of drought. Additionally, these models can be configured to model potential future drought impacts. Predictive models include seasonal models that consider snowpack and seasonal climate predictions to the global circulation models (GCMs) that help identify long term planning. These predictive models allow for institutions to start responding to potential drought impacts months before the peak season of summer. Predictive models help institutions and organizations develop stages of droughts which leads to a staged drought response plan (Board 2010). This pre-determined set of actions when certain thresholds are passed are paramount in eliciting a quick and effective drought response. This staged drought response can be used for public education before and during a drought response.

The final aspects of crisis management are the delegation of responsibilities among institutions during a drought response and the updating of the drought plan. By setting these tasks up preemptively confusion is reduced, and responses are expedited. A streamlined process is more effective and loses less time to counter impacts of a drought. Finally, by stating which organizations or sub-set of groups are responsible for the up-keep of the drought plan ensures the plan is up to date and ready for implementation at a moment notice (Board 2010). With a pre-determined updating schedule, the drought planning process continues to stay relevant and incorporating the latest research in drought resilience.

Climate Change and Drought Planning

One of the biggest uncertainties of the 21st century is how climate change will alter our natural and built systems. Climate change has been at the forefront of global discussions since the founding of the United Nations Intergovernmental Panel on Climate Change (IPCC) in 1988. The early work of the IPCC focused on creating an understanding of the science of global climate change and mitigation options. A prominent shift has been made more recently to include vulnerability assessments, adaptation options, and the financing of climate-resilient projects (Stocker, 2014). The IPCC's Fifth Assessment Report (AR5) concluded that: "Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and sea level has risen." (IPCC 2014). Increased global temperatures have far reaching effects, many of which experts can only speculate how they will affect our societies.

Warming temperatures increases the atmosphere's ability to hold water, leading to an intensification of the water cycle (Durack et al 2012). In general, this leads to dry areas becoming drier and wet areas becoming wetter, making natural climactic phenomena like storms, floods, and droughts more intense. Regarding droughts, increased temperatures, especially from anthropogenic climate change, lead to higher potential evapotranspiration, which increases pressure on the existing water resources and exacerbates drought conditions when present (Trenberth 2014, Rind et al 2014, Wang

2005, Burke et al 2006, Sheffield & Wood 2008, Dai 2011, Dai 2013, Wehner et al 2011, Taylor et al 2013, Cook et al 2014, Prudhomme et al 2014, Zhao & Dai 2015). Warming temperatures can also alter the timing, location, and frequency of drought episodes (Boehler 2015, Ding et al 2011). This shift could lead to decreased time between drought events and reduce reaction times of institutions, especially if multiple droughts occur in succession (Wilhite 2016).

There have been significant improvements in drought planning and drought response in recent years, but there is minimal incorporation of risk that climate change poses to drought. Mainly, it is very difficult to incorporate climate information into drought planning (Wilhite et al 2014, Finnessey et al 2016). Often incorporating climate science into drought plans increased the already expensive upfront planning costs for drought (Fu & Tang 2013). Additionally, added uncertainties and general confusion as to how to incorporate this information exists. In recent years some states have taken steps to bridge the gap of climate incorporation into drought planning. The state of Colorado uses paleoclimate records, seasonal climate forecasts and climate model projections in their statewide plan to help incorporate the changing climate into drought planning (Finnessey et al 2016). The state of Colorado has outlined in detail ways in which to incorporate climate information into their planning via their Municipal Drought Management Plan Guidance Document. The document is intended to help provide utilities in Colorado the resources to complete a full risk management drought preparedness plan.

Methodology

In order to determine the inclusion of climate change risk in drought policy, there will be two main sections of analysis: climate change drought risk analysis and state drought plan analysis. The first analysis will determine the drought risk added by anthropogenic climate change by determining the change in drought frequency and severity. This analysis will identify areas of the country with elevated risk of drought from climate change. After identifying a region of the USA with higher drought risk, the state drought plans of the region will be analyzed to determine if these state agencies are addressing their increased risk. Finally, the research will identify areas in which states can increase their capacity to prepare and respond to drought.

State Drought Plan Methodology

The first analysis, drought risk quantification, will serve as the motivation for the second analysis, state drought plan analysis. Since the purpose of this research is ultimately to determine the preparedness of states, the second analysis will be discussed first followed by a discussion of the drought risk analysis. The state drought plan analysis will determine if states are prepared to address the increased risk of drought from climate change. Additionally, the analysis will provide insight and recommendations of areas that can be improved within a state drought plan to recognize this risk.

Questions of Concern

To determine if states have recognized the risk climate change adds to drought or nothing at all, state plans will be evaluated on five questions. These questions come from key concepts of drought preparedness identified in the literature review and if present, show significant risk identification and preparedness for drought from a state agency. Each question is designed to help build awareness of the coupled nature of climate change and drought risk. These questions were designed to be used during an initial planning phase to ensure risk was being adequately addressed. The questions are as follows:

1. Can your institution effectively identify the precursors of drought in your area before the peak warm season?
2. What aspects of the community could be susceptible to hardship during a drought?
3. Would a change in precipitation pattern highly effect your ability to supply water to your community?
4. Could increase sustained heat impact your ability to supply water to your community?
5. What steps are you planning for your customer to take during a drought?

Questions one and two allude to the preparedness of a community, without alluding to the elevated risk from climate change. By identifying specific drought indices and how to designate a drought before peak summer season, officials can lessen the time of response, making a drought more manageable. Additionally, question two directly inquiries about the vulnerability of areas in the community. These could include industries that rely heavily on water, agricultural producers, and communities that lack the capacity to respond to hardship. Therefore, identifying these communities and industries beforehand can reduce the overall vulnerability.

Questions three and four directly address how climate could impact a state's water supply. These questions are aimed to have practitioners consider where their water comes from and how they utilize their supply. Areas that rely heavily on precipitation could be negatively impacted if global precipitation patterns change, while areas dominated by snowpack could be more effected by sustained heat. As temperatures become warmer, plants and animals generally require more water to accomplish the same goals, making sustained heat a big driver of demand for supply systems.

Finally, question five identifies how a state would implement a reaction to drought. By stating goals for their constituents, states can start to prepare information campaigns to help in times of drought. This planning helps identify areas in which the current system can be improved and optimized thereby reducing drought risk. A statement of how states will ask consumers of water to respond indicates thought about how the water is used system wide and what areas could be reduced in time of drought.

Levels of Maturity

State plans will be evaluated on their ability to answer all five questions. The questions build upon themselves and therefore by answering each question with increasing detail will demonstrate a state's preparedness for drought risk from climate change. There are five levels a state drought plan can achieve; each level has increased detail and leadership buy in. Level zero indicates a lack of awareness of how climate change is connected to drought risk. An agency at level zero has failed to recognize that climate change will play a role in drought risk going forward.

A level one plan recognizes the coupling of drought risk and climate change but only at a high level. Plans exhibiting level one would state many of the questions but would either lack answers or answers provided would lack details. There would be no concrete policy on how to deal with the challenges faced or how to find answers to the questions.

Level two plans are characterized by having some protocols for achieving answers to questions they currently lack. Additionally, level two plans recognize the public needs to be informed about the changing drought risk. At level two, there is minimal plans for how this communication campaign will occur.

Level three plans recognize the role climate change will play in drought risk and how it will affect other aspects of the drought planning process. For a level three plan, questions four and five have been answered thoroughly. Although these plans have recognized that climate change will affect their drought risk, there is only ideas of to include climate change when making decisions.

Level four plans include a written plan for incorporating climate change into drought risk including addressing information needed, how it will be incorporated, and a communication plan. Level five goes beyond level four by formalizing a climate change integration plan. Level five plans incorporate climate change into the formal plan of drought monitoring and the communication of drought risk coupled with climate change. The five levels are summarized in the table below.

Table 2. Maturity Level for State Drought Plan

Maturity Level	**Description**
Level 0	No mention of drought risk and climate change coupled together
Level 1	Discussion of drought risk and climate change, more at the leadership high level. Lacking details but starting to set up the process and background to implement the drought and climate change risk
Level 2	Larger mention of drought risk from climate change with specific processes how to coordinate learning the information. Minimal plans for communicating the risk
Level 3	Mention of drought risk from climate change with a focus on how this will affect other aspects of the drought planning process. Includes ideas of how it could be incorporated into planning but no concrete plan.
Level 4	Plan for incorporating drought risk from climate change including addressing information needed, how it will be incorporated and a communication plan.
Level 5	Formal plan of how to incorporate drought risk and climate change including addressing what information is needed, how its incorporated into planning and drought monitoring and how it used to communicate the drought risk and climate change.

The final aspect of this analysis will be determining areas in which the state drought plans can improve. From the stated framework, state drought plans will be reviewed on areas they are not addressing or areas which require more detail. This will ideally be used as a guide for states to build a robust drought plan.

Drought Climate Change Methodology

Infrastructure Planning and Support System (IPSS)

To perform the first analysis, the Infrastructure Planning and Support System (IPSS) developed by the Institute of Climate and Civil Systems (Schweikert et al. 2014, Chinowsky et al. 2012) was modified to include drought risk by incorporating the Palmer Drought Severity Index (PDSI) and the Standard Precipitation Index (SPI). These indices are used to quantify changing drought risk from climate change. Changes in frequency and severity of drought can be quantified by comparing drought indices from modeled historic baselines to projected climate scenarios. As discussed in the literature review, PDSI incorporates evapotranspiration making it better at quantifying the impact of a warming climate while SPI is a widely used index used to gain another interpretation of how climate could affect drought risk.

IPSS incorporates the forty-two approved General Circulation Models (GCMs) from the Intergovernmental Panel on Climate Change (IPCC) to determine a range of possible future climate scenarios. These scenarios have equal likelihood of occurring and depend upon several variables including human rate of greenhouse gases, other emissions and pollutants. IPSS, the main data processing tool for this project, utilizes the GCMs as input for its cost and risk analysis platform. All drought indices will be calculated from GCMs in the IPSS system and will output to MatLab and Excel, with further processing in ArcGIS.

General Circulation Models (GCMs)

It is uncertain how the concentration of greenhouse gasses will affect the atmosphere and life on planet earth in the future. To combat these unknowns, climatologists develop models to determine potential future climate scenarios. Global Circulation Models (GCMs) are developed by climate labs, like NCAR, all over the world. These numerical models take into consideration how energy and mass flow around the world and use their best prediction to determine the future climate (Alliance 2009). The models range from simple energy balance models to complex Earth System Models (Flato et al 2013). Each model has a different approach to the complexity and idealization of its future model run. Some models are highly idealized and can be used to model the future with less computational power, while other models account for real life interactions, making them increasingly complex and increasingly computationally difficulty.

Since there is inherent uncertainty with predicting the future, no one model is more predictive than any other model. Each model has as much of a chance of occur or not occurring as every other model. In the fifth report of the IPCC, 21 of these GCM models were approved as potential futures (IPCC 2014). Although all of the models are approved as global models, based on individual characteristics, some models have been shown to be more accurate in replicating past climate events in specific geographic locations. This creates a broader discussion about the appropriate selection of models for given geographic locations. Rather than attempt to select the "best" models for this study, the approach was adopted to consider all models which incorporate the United States as a geographic zone and which were approved by the IPCC.

A second element of climate modeling are the emissions scenarios which each model considers as input to the climate projection future. These Representative Concentration Pathways (RCPs)represent the long-term effect of human activities and the long-term natural effect of the climate (Collins et al 2013). Four RCP scenarios were originally developed to model conditions ranging from no control of emissions with continued growth of GHG producing industries to aggressive control of emissions. The scenarios provide "internally consistent sets of time-dependent forcing projections that could potentially be realized with more than one underlying socioeconomic scenario" (Collins et al 2013). Meaning, these pathways can represent the differences in potential future scenarios based on emissions.

When the GHG concentrations from each scenario are provided to the GCM models, different climate projections are produced based on the individual modeling choices selected for each GCM. The results from two RCPs are utilized, 4.5 and 8.5, representing a middle-of-the-road scenario and a more extreme emissions scenario respectively. When combined with the 21 GCMs, this combination produces 42 sets of climate scenario projections. In turn, the 42 scenarios are used to determine potential impacts of climate change. Even though this broad set of GCM data can be useful, the models come with deep uncertainty and the information can be difficult to incorporate into practical policies even at the best of times (Mote et al 2011, Alliance 2009, Finnessey et al 2016).

In this study, the 42 scenarios are used as the basis for the drought projections. Specifically, each GCM gives a temperature and precipitation profile for a historic modeled baseline and a predictive modeled scenario through 2100. This temperature and precipitation data is used to calculate the PDSI and SPI for each month in each time period: early (2020 – 2044), mid (2045- 2069), late (2070-2095) century. Differences between the total number of months in each severity category is compared to quantify the drought risk from climate change.

Hydrologic Unit Code (HUC)

Droughts are localized events that can affect watersheds or multiple watersheds. Since droughts are defined by the lack of water resources, this analysis will be performed at the watershed level. Analysis at the watershed level aims to incorporate water's natural flow path and the institutions that share said water resources. Watersheds effected by drought can have repercussions for downstream users.

Developed by the USGS, the Hydrologic Unit Codes (HUCs) divide the USA into watershed basins with various degrees of scale (Seaber et al 1987). Due to the nested nature of watersheds, the number of watersheds increases as HUC levels increase (i.e. Moving from HUC-2 to HUC-4 increases total number of watersheds). There are twenty-one different HUC-2 regional watersheds for the United States, including Alaska, Puerto Rico and Hawaii. Once broken down into the HUC-4 regions the number of watersheds jumps to 221. For the purposes of this analysis,

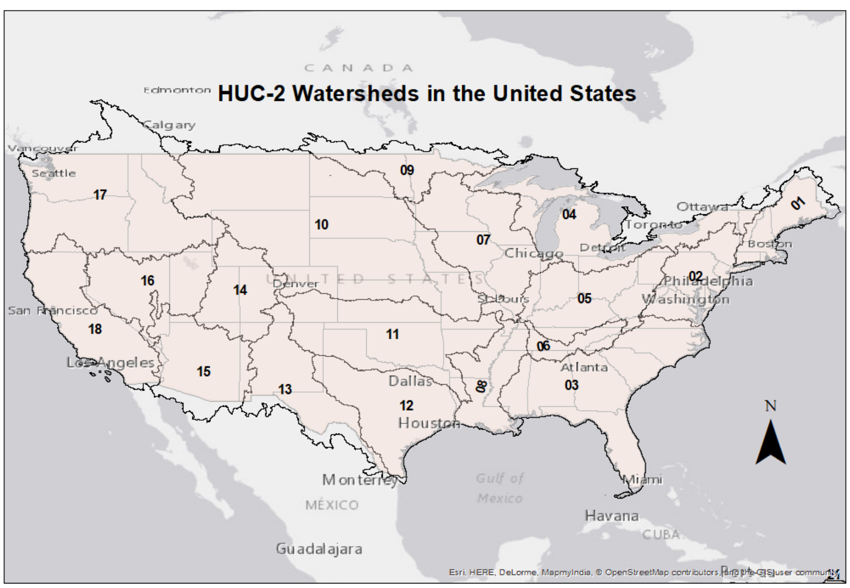

Figure 1. HUC-2 Watersheds in the United States

only the HUC-2 regions of the continental US will be considered. This reduces the national analysis to eighteen HUC-2 regions pictured above. To obtain the data at a regional level, the drought indices must be interpolated and aggregated from the original GCM run. Each GCM is run at ¼ by ¼ degree resolution box. These boxes are aggregated together, averaged within each HUC-2 watershed, and reported as a single value per month. Each GCM will be compared to its historical modeled baseline period to determine the change in drought frequency and severity. In total, there will be 42 different model runs and 42 potential drought risk scenarios. This spread in scenarios will capture the breath of potential futures that could occur.

After the national analysis is complete, a HUC-2 region with increase drought risk will be identified for further analysis. The selected HUC-2 region will be broken into its HUC-4 watersheds for further analysis. This deeper analysis aims to illuminate the localized effect of drought risk within a larger region. Like with the HUC-2 regions, many HUC-4 regions cover multiple states and therefore have multiple policies regarding drought acting upon them. The interpolation and aggregation will be performed in the same manner of the national assessment of drought risk, in order to compare effectively between data sets. HUC watershed levels were used for the analysis because they are a recognized method for analyzing water resources. HUC watershed levels were used in a drought analysis by Strzepek et al 2010, which forms the basis for this methodology.

Figure 2. HUC-4 Watershed in the United States

Drought Indices Analysis

As alluded to in the literature review and the paragraphs above, the goal of the drought methodology is to determine the change in drought risk under the influence of anthropogenic climate change. This methodology is based off the work from Strzepek et al 2010 in which they modeled the effect of climate change on drought risk. In this paper, Strzepek et al modeled PSDI and SPI with four GCMs from the fourth assessment of the IPCC through the end of the century, comparing changes in drought months. In this analysis only the PDSI will be used due to time constraints of the project and its incorporation of temperature and precipitation directly. The SPI does not include temperature within its calculation and therefore is not directly linked to rising temperatures.

IPSS will be used to produce future drought risk scenarios which will be interpolated into a HUC-2 regional map. After identifying a HUC-2 region, further analysis will break down a HUC-2 region into its HUC-4 watersheds. Data will be represented in a series of tables and maps. Tables will summarize the total amount of months spent in each severity category. Time periods will be compared to the historic modeled baseline to ensure comparison of the same types of data. Below are some sample results tables.

Table 3. PDSI results table

PDSI	**Baseline: 1965 -1990**	**Early: 2020 - 2045**	**Mid: 2046 - 2071**	**Late: 2072 - 2097**
Severity Level	Number of Months	Change in Number of Months		
0 – (-1): normal				
(-1) – (-2): mild				
(-2) – (-3): moderate				
(-3) – (-4): severe				
(-4) >: extreme				

This analysis will be performed on the 21 IPCC approved GCMs each with two scenarios, providing 42 potential drought risk scenarios. Data will be aggregated to determine the median GCM scenario of increased drought risk. Special attention will be paid to the 95th and 5th percentile scenarios because these models represent the extreme cases of climate change. Data will also be displayed in a variety of box plot charts and maps to help visualize the spread of potential drought risk throughout the USA. For the in-depth analysis the selected HUC-2 region will have the same analysis performed. Similar charts and graphs will be made to show the localized nature of droughts within a HUC-2 watershed. It is expected HUC-4 regions will have different drought risk because different regional characteristics influence how climate change will impact drought. This in-depth analysis will serve as the motivations for the analysis of state drought plans within the selected region.

Drought Climate Change Results

As stated in the methodology, the climate change analysis was performed with the current IPCC approved climate models. By utilizing all forty-two models, the climate analysis provides the largest range of potential drought scenarios from. To perform this analysis, IPSS was used to process the temperature data from the climate models and calculate the corresponding Palmer Drought Severity Index values. Results from this analysis are described below.

National Drought Analysis

The national analysis results show that mild drought will decrease through the end of the century and the occurrence of moderate, severe and extreme drought will increase. While these are the general trends there remains high levels of deep uncertainty throughout the process. Modeling the climate has its own uncertainties, then coupled with future manipulation creates a state of deep uncertainty.

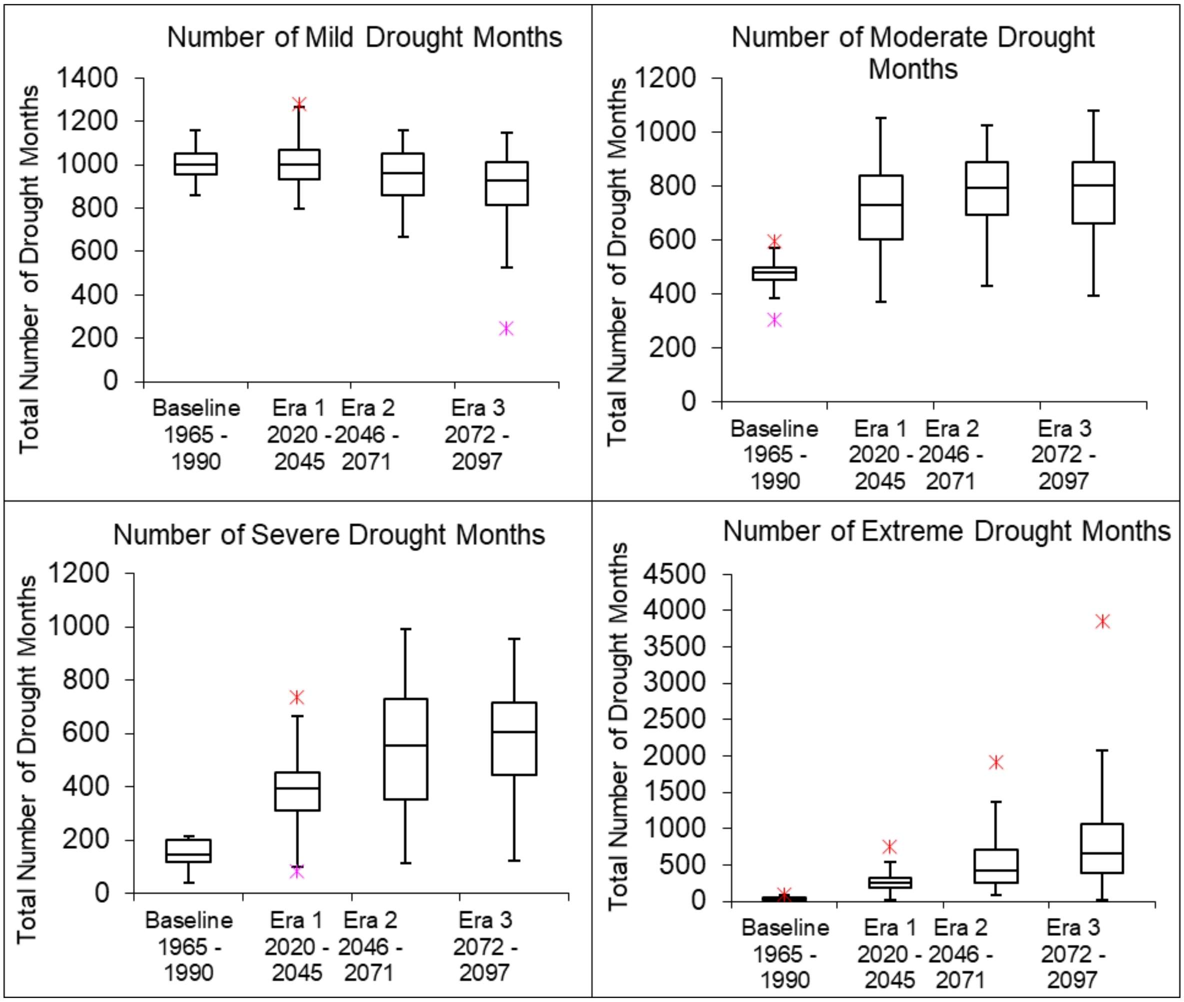

Figure 3. National Box Plots

As seen in the box plots above, there is a distinct pattern of increasing moderate, severe and extreme droughts and a decrease of mild drought through the end of the century. The box plots show the range of the different climate models on one graph which helps illustrate differences in climate predictions. Since no one climate scenario has a higher likely hood of occurring than any other climate scenario, each scenario should be considered when planning for future droughts. These box plots also show the deep uncertainty aspects of climate change modeling. As the data progresses through each era, the box plots range generally increase. This uncertainty cannot be minimized because its reliant on the choices of humanity going forward. Regardless of the path humans move toward, the drought models provide a wide range of potential drought scenarios for which to plan for. This trend identified by the box plots illustrated the general trend that motivates the rest of this analysis.

Another way to visual the changing risk of drought it to map specific model results through time. To do these two models were identified for closer analysis. These models were chosen because they represent 'worst case scenario' model results. The first model was chosen because it represents the most extreme model from the baseline scenario. The GFDL-CM3_85 model is developed by Geophysical Fluid Dynamics Laboratory, which is a branch of the National Oceanic and Atmospheric Administration (NOAA) located in Princeton, NJ. The table below summaries the changes in drought severity for the GFDL-CM3_85 model.

Table 4. Drought Month Results of the GFDL-CM3_85 Model

GFDL-CM3_85 PDSI	**Baseline: 1965 -1990**	**Era 1: 2020 - 2045**	**Era 2: 2046 - 2071**	**Era 3: 2072 - 2097**
Severity Level	Number of Months	Change in Number of Months		
(-1) – (-2): mild	860	7	-46	18
(-2) – (-3): moderate	458	100	191	374
(-3) – (-4): severe	201	77	138	456
(-4) >: extreme	101	30	164	657

The results in the table represent the change in total number of drought months in each severity category on a national level. These results are also visualized on the following page.

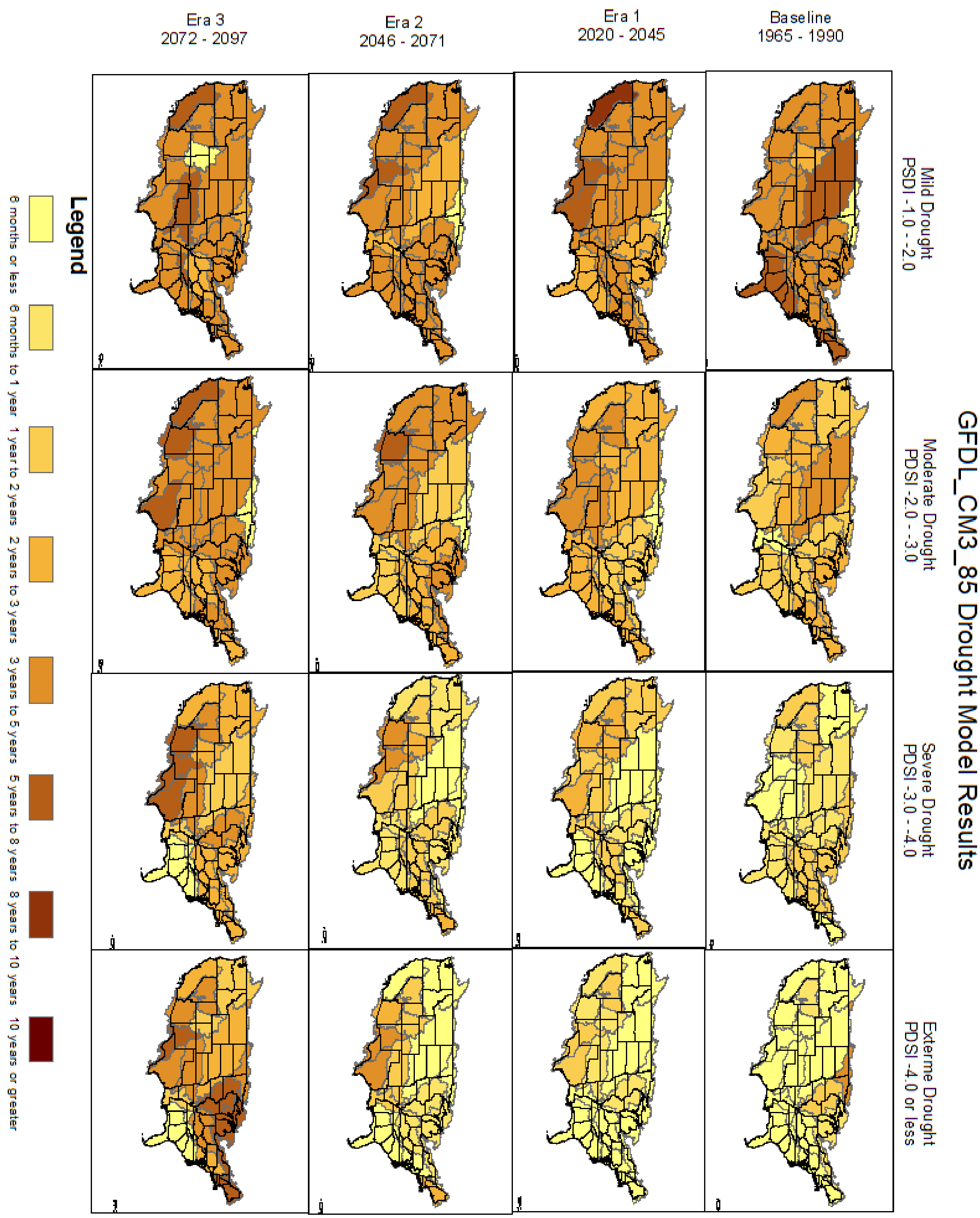

Table 5. GFDL-CM3_85 Drought Month Model Results

As seen on the pervious page, the extreme drought is increasing as designated by an increasing darkening color of the watershed. Additionally, the lightening of the mild drought throughout the end of the century is cause for concern.

But this is just one climate scenario. To prepare for the worst-case scenario the most extreme model for the extreme severity was also analyzed in detail. This model was chosen by taking the model that represents the upper quartile of the box plots for the extreme box plot graph. This model, MICRO-ESM-CHEM_85, was developed by the University of Tokyo, NIES, and JAMSTEC and includes many aspects of atmospheric chemistry within the model parameters. As state in the methodology and literature review, it is key to consider all the climate models because each scientific group assumes different parameters reactions to the climate system. These different assumptions of the future effects of climate change generate a wide range of potential outcomes. This model represents the most extreme drought scenario a drought planner should consider. The table below displays the results of this climate model followed by a visualization of the model results on the following page.

Table 6. Drought Month Results of the MICRO-CHEM_85 model

MICRO-ESM-CHEM_85 PDSI	**Baseline: 1965 -1990**	**Era 1: 2020 - 2045**	**Era 2: 2046 - 2071**	**Era 3: 2072 - 2097**
Severity Level	Number of Months	Change in Number of Months		
(-1) – (-2): mild	956	27	-250	-708
(-2) – (-3): moderate	501	526	438	-84
(-3) – (-4): severe	140	598	799	537
(-4) >: extreme	31	725	1884	3831

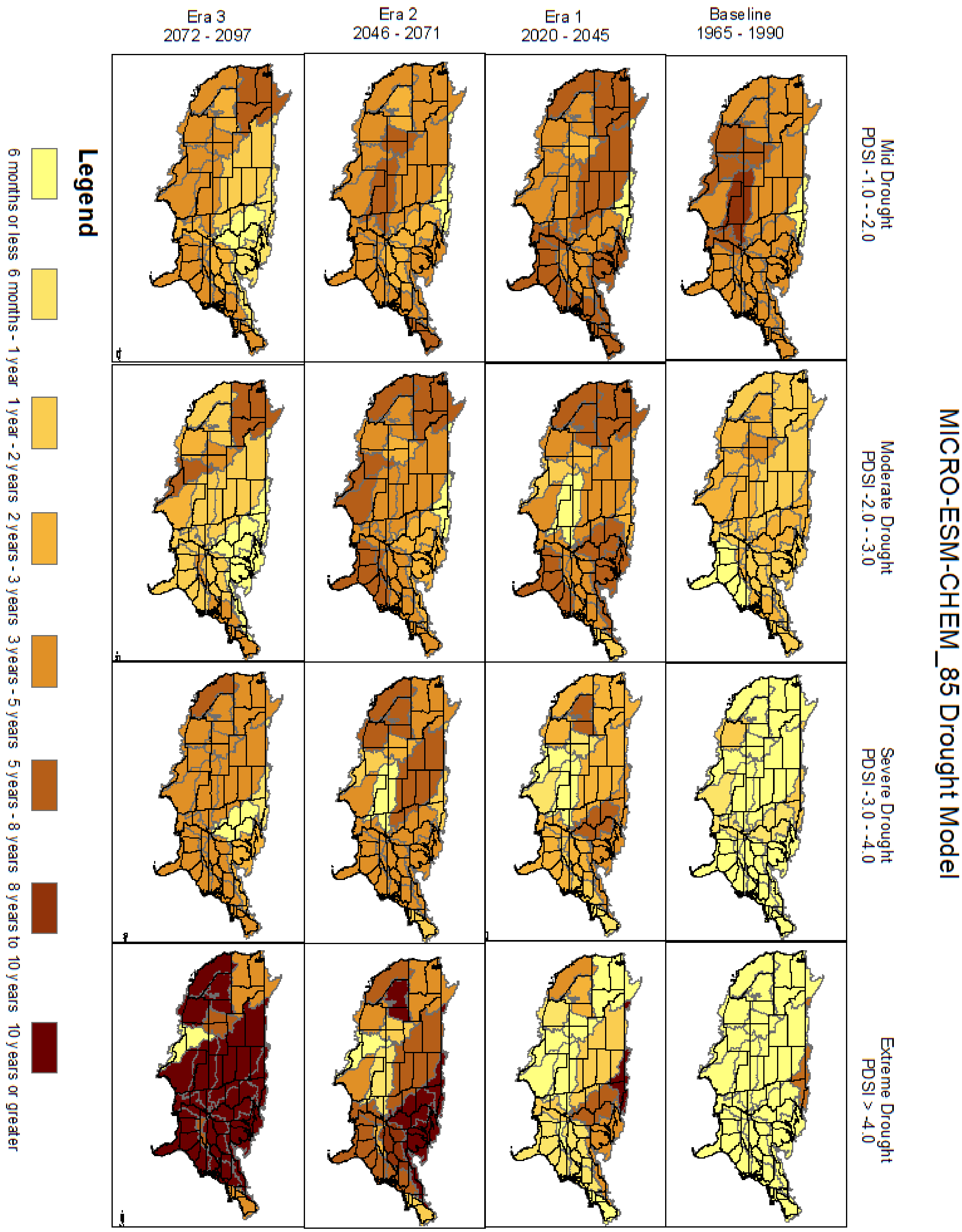

Table 7.MICRO-ESM-CHEM_85 Drought Month Results

The scales of the two models are kept equal for easy comparison between models. The MICRO-ESM-CHEM_85 model shows an extreme version of drought risk influenced by climate change. In this model, by the third era, most of the major water basins with the US experience more than 120 months, or 10 years, of extreme drought within a thirty-year period. This scenario is just as likely to occur as the more moderate scenario presented above. When preparing for drought it is important to keep in mind what the worst-case scenario could be. This type of drought has not been seen in the instrumented record, and therefore is not currently being planning for, but still might occur within the end of the century.

Colorado River Basins Analysis

As seen by the national graphs above, two basins with elevated drought risk due to climate change are the Upper and Lower Colorado River Basins. These basins are in the southwest United states, an area that has traditionally impacted by the effects of drought. Due to legal presidents, the Colorado river basin is split into two different basins. This analysis will consider these two basins separately but will show results maps of these basins concurrently.

Both the Upper and Lower Colorado River Basins exhibit the same trend as the national results. Mild drought months are decreasing through the end of the century, while moderate, severe, and extreme droughts are increasing through the end of century. Like the national results, box plots show the wide range of climate scenarios for each era, which exhibit the nature of deep uncertainty with increasingly wider ranges for later eras. The box plots of the Upper and Lower Colorado River Basins are presented in the graphs below.

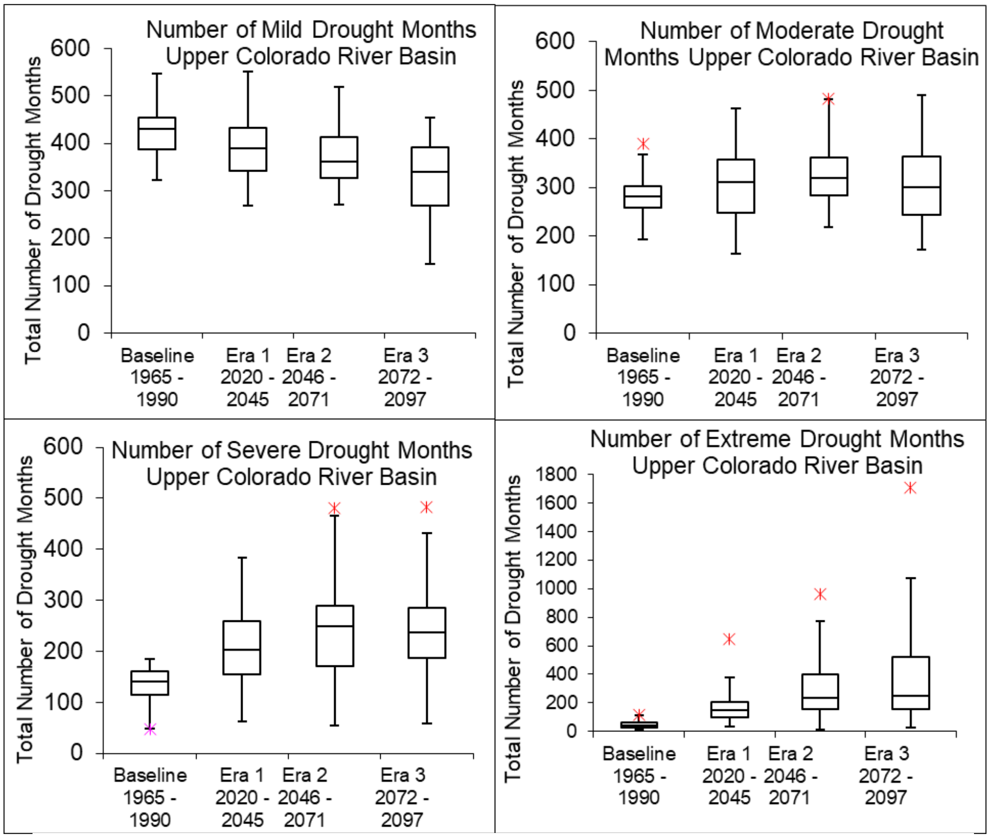

Figure 4. Upper Colorado River Basin Box Plots

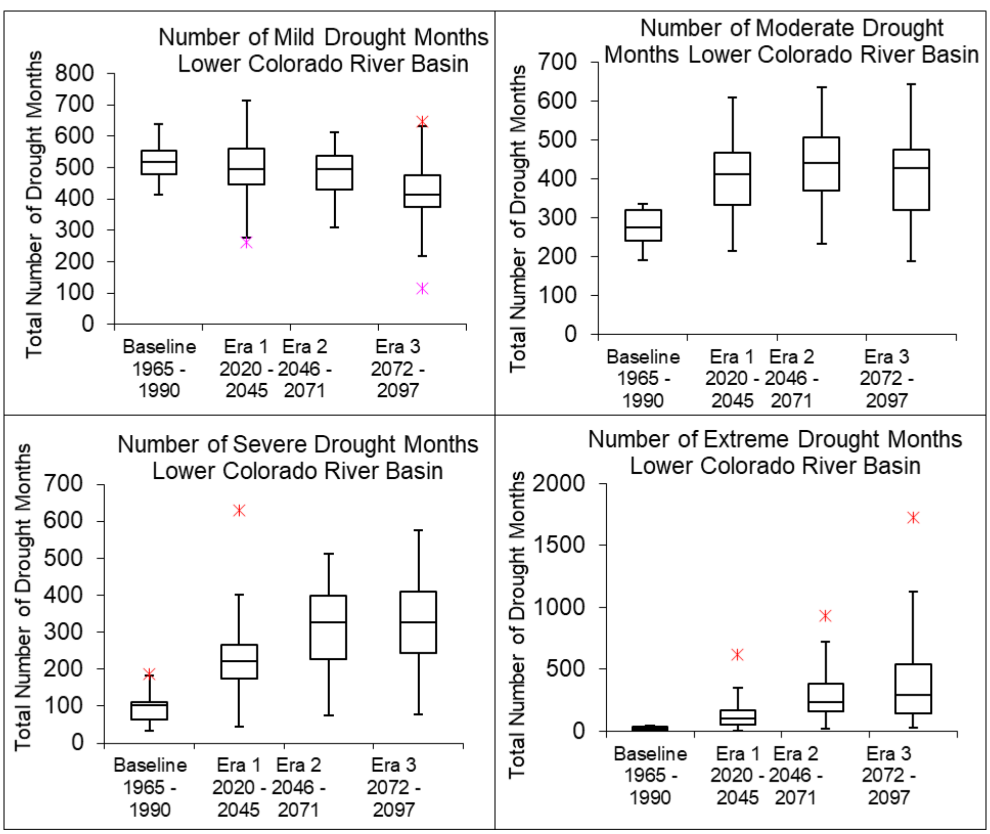

Figure 5. Lower Colorado River Basin Box Plots

These box plots mirror the National box plots, showing that the Colorado River Basin will likely see the same trend of less mild drought and more moderate, severe, and extreme drought. More severe droughts within the Colorado River Basin could exacerbate many water related issues within the basin.

In order to compare the national maps to the regional specific maps, the same models, GFDL-CM3_85 and MICRO-ESM-CHEM_85 were analyzed in depth. By using the same models as the national maps, these maps sever as a zoomed in look at the localized nature of drought. Again, this analysis was performed separately for each basin and the map shows both basins.

The first model, GFDL-CM3_85, represents the most extreme model based on the baseline period. This model developed by a substituent of NOAA represents a more moderate climate scenario. Nevertheless, this model still exhibits the same trend as the national maps.

Table 8. Drought Month Results of the Upper Colorado River Basin for model GFDL-CM3_85

GFDL-CM3_85 Upper Colorado Basin PDSI	**Baseline: 1965 -1990**	**Era 1: 2020 - 2045**	**Era 2: 2046 - 2071**	**Era 3: 2072 - 2097**
Severity Level	Number of Months	Change in Number of Months		
(-1) – (-2): mild	339	-19	29	0
(-2) – (-3): moderate	261	49	86	40
(-3) – (-4): severe	128	55	151	115
(-4) >: extreme	33	86	194	284

Table 9. Drought Month Results of the Lower Colorado River Basin for model GFDL-CM3_85

GFDL-CM3_85 Upper Colorado Basin PDSI	**Baseline: 1965 -1990**	**Era 1: 2020 - 2045**	**Era 2: 2046 - 2071**	**Era 3: 2072 - 2097**
Severity Level	Number of Months	Change in Number of Months		
(-1) – (-2): mild	428	18	-27	-81
(-2) – (-3): moderate	265	70	239	209
(-3) – (-4): severe	111	79	215	278
(-4) >: extreme	16	94	253	511

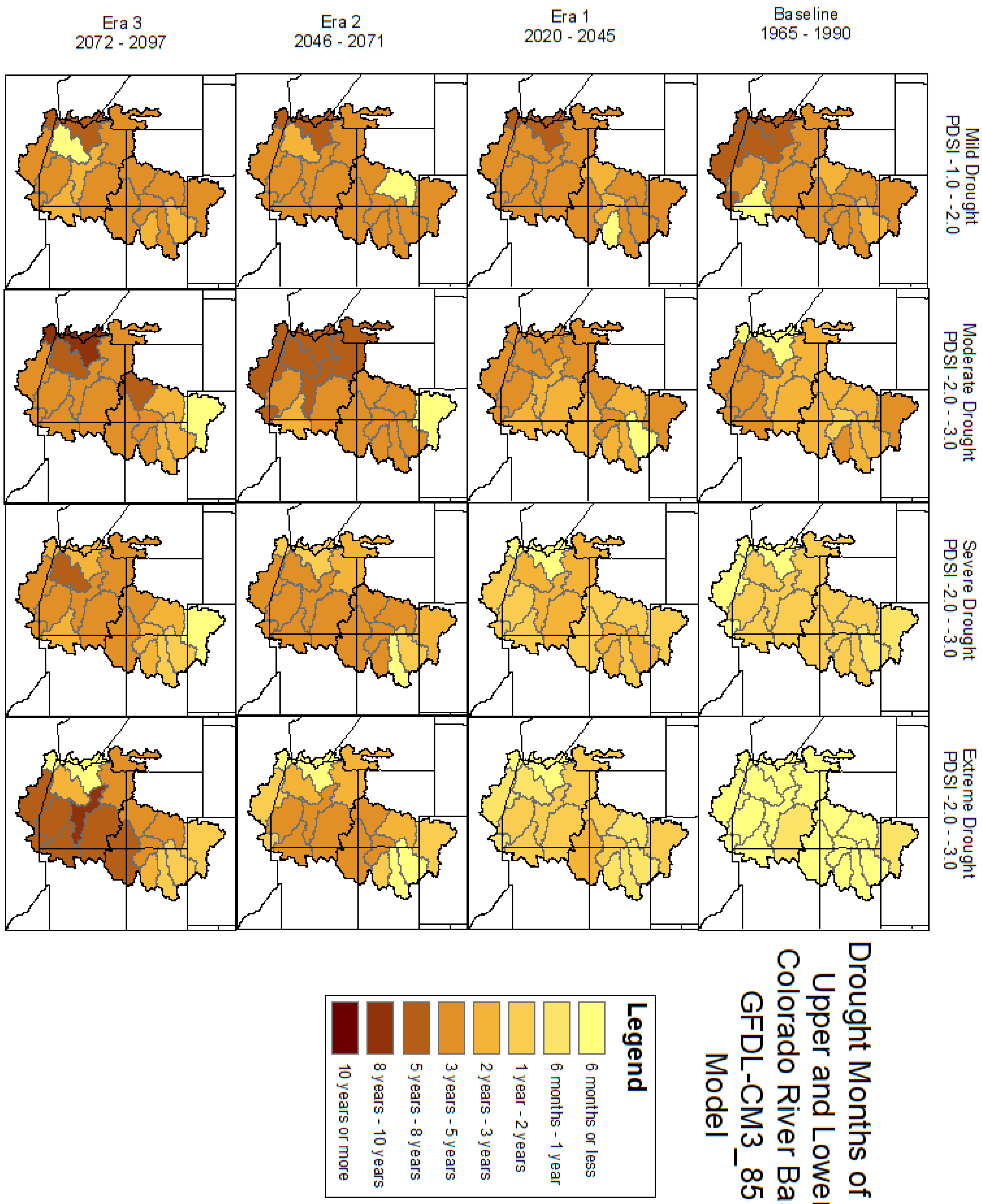

Table 10. Drought Months of the Upper and Lower Colorado River Basin GFDL-CM3_85 Model

The above graph shows the same pattern as the national maps, darker colors later in the century show that extreme drought is likely to be more prevalent later in the century while the continual lightening of the mild drought through the end of the analysis. This model shows that by the end of the century areas of the lower Colorado basin located in Arizona are at increased drought risk due to climate change. Additionally, it is important to note the unevenness of the drought risk. Areas of the headwaters do not reflect the significant increase in extreme drought and instead show relatively consistent between all severity levels and eras. Further analysis would be needed to help quantify different types of drought.

The second model analyzed in the Upper and Lower Colorado River Basins was the MICRO-ESM-CHEM_85 modeled. This model represents an extreme climate scenario. As seen in the tables below, the differences between the era's and the baseline are larger than that of the other model. These results are also mapped on the following page.

Table 11. Drought Month Results of the Upper Colorado River Basin for Model MICRO-ESM-CHEM_85

MICRO-ESM-CHEM_85 Upper Colorado River Basin PDSI	**Baseline: 1965 -1990**	**Era 1: 2020 - 2045**	**Era 2: 2046 - 2071**	**Era 3: 2072 - 2097**
Severity Level	Number of Months	Change in Number of Months		
(-1) – (-2): mild	409	-60	-105	-260
(-2) – (-3): moderate	294	127	30	-54
(-3) – (-4): severe	159	222	165	114
(-4) >: extreme	66	584	896	1449

Table 12. Drought Month Results of the Lower Colorado River Basin for Model MICRO-ESM-CHEM_85

MICRO-ESM-CHEM_85 Upper Colorado River Basin PDSI	**Baseline: 1965 -1990**	**Era 1: 2020 - 2045**	**Era 2: 2046 - 2071**	**Era 3: 2072 - 2097**
Severity Level	Number of Months	Change in Number of Months		
(-1) – (-2): mild	487	-226	-176	-369
(-2) – (-3): moderate	278	249	179	-40
(-3) – (-4): severe	107	523	376	310
(-4) >: extreme	33	585	874	1579

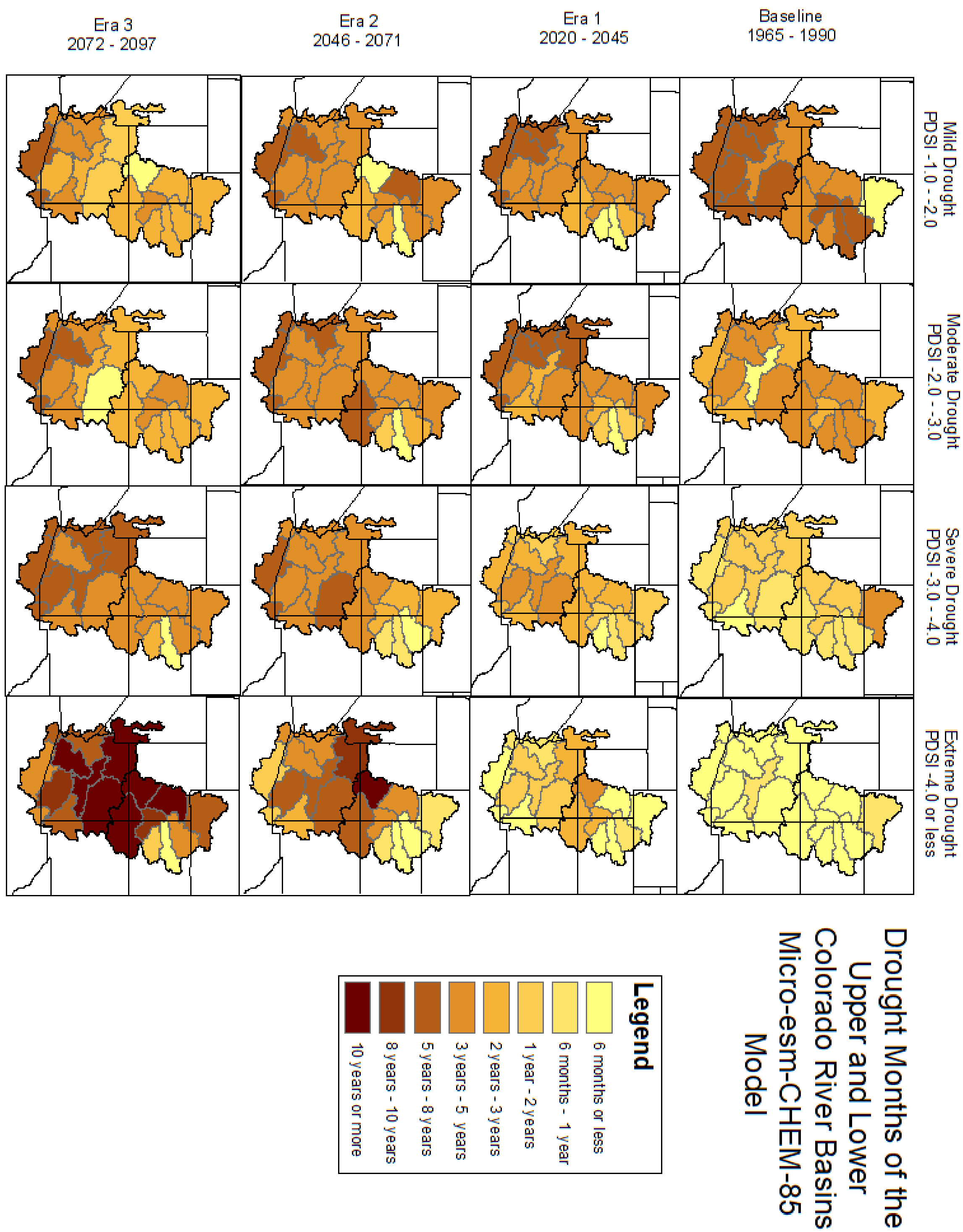

Table 13. Drought Months of the Upper and Lower Colorado River Basins MICRO-ESM-CHEM-85 Model

In the more extreme model, the Colorado River Basins exhibit the trend of decreasing mild drought months and increasing moderate, severe, and extreme drought months. Again, this model is more extreme, and it is just as likely to occur as the moderate model. These maps show increasing drought throughout the middle watersheds of the two basins which could impact water resources significantly because this is where Lake Mead and Lake Powell are located. A significant drought in this region could impact the levels of reservoirs, which would have implications for downstream users. Additionally, the Colorado River basin provides water to a significant amount of water to the desert communities hundreds of miles away from the actual river. Water managers need to consider these types of changing parameters when planning for drought.

State Drought Plan Results

The Colorado River basin has increased drought risk due to climate change through the end of the century. An analysis of the state drought plans encompassed within both Colorado River basins was conducted to determine each state's response to the increased drought risk. The figure to the right shows the highlighted river basins for analysis and the surrounding states. The state drought plans of Wyoming and New Mexico were excluded from this analysis due to their minimal use of Colorado River water or small geographical area of the basin.

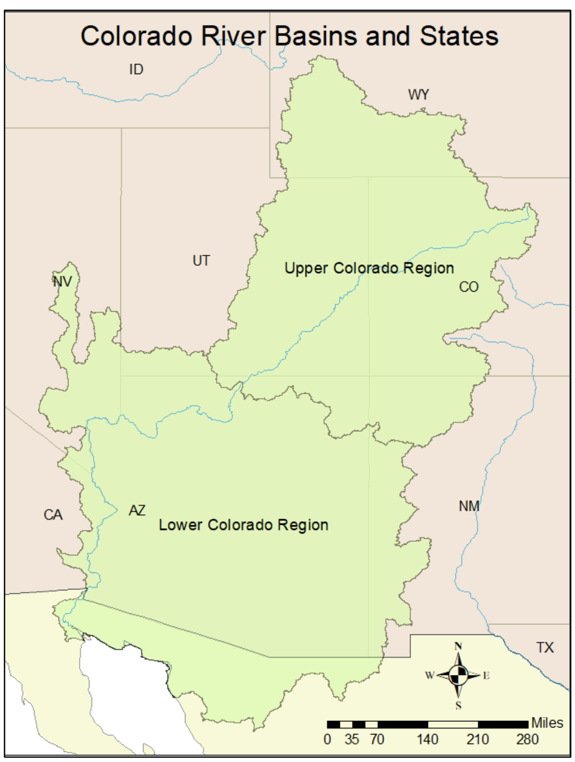

Figure 6. Colorado River Basins

The Colorado River is one of the most contested rivers in history. Its operation is influenced heavily by the Colorado River Compact of 1922. In this compact, the seven states allocated water via an upper basin and lower basin, ignoring Mexico altogether. The compact was formed the instrumental record of the time and guaranteed a ten-year running average of 75,000,000 acre-feet of water annually to each basin. Water was split between the upper basin: Utah, Colorado, Wyoming, New Mexico and the lower basin: California, Arizona and Nevada. The HUC 2 regions reflect this breakdown of upper and lower basin. Only after the signing of the compact did experts begin realizing that the historic flows used to allocate the river in 1922 were some of the highest flow decades on the Colorado River. Since this realization, there has been multiple other treaties including an international agreement with Mexico on how to maintain the best health and beneficial use of the river.

As seen in the climate change analysis, drought is projected to increase in these basins throughout the end of the century. A drought in any part of the river basin could severely affect other areas of the basin. The official state drought plans of Arizona, California, Colorado, Nevada, and Utah were analyzed to determine the awareness of increased risk of drought due to climate change. Plans were assigned levels of maturity based on their ability to answer the prescribed questions as described in the methodology.

State Drought Plan Results

Arizona

Arizona originally adopted their current state drought plan in October 2004. Notably the authors stipulated there would be annual updates to keep Arizona at the forefront of innovative management techniques and drought science. Arizona's drought plan is extensive covering new topics and areas each year.

Question one refers to the ability of a state to recognize the precursors of drought before peak summer season. Arizona has an extensive process to identify and keep track of drought. There are regional monitoring teams that meet monthly to discuss the risk of a drought developing over the varied landscapes of Arizona. Some of the indices tracked include weather outlook, reservoir storage, Palmer Severity Drought Index and many others. Each Monitoring Committee tracks long term changes in climate, provide forecasts, and early warning systems for their regions. Thresholds for moving into a drought are sensitive while thresholds for moving out a drought are conservative.

Arizona has a detailed plan to assess the vulnerabilities of their communities during times of drought. Vulnerability is broken into sectors including energy, health and water quality. These categories encompass impacts such as effects on supply, effects on demand, mental health stress, air pollution, concentration of pollutants, and fires. Vulnerabilities are further identified by workgroups specifically focused on a sectors and areas of the state: commerce, recreation and tourism; environmental health, watershed management, livestock & wildlife; irrigated agriculture; municipal and industrial; tribal. The state plan lists specific mitigation options available for each workgroup.

The Arizona state plan recognizes that Arizona is reliant on precipitation for much their water resources. Because of this constraint, Arizona relies heavily on ground water aquifers. Arizona has multiple committees dedicated to ground water and surface water management techniques that can be applied to increase supply. In the 2007 Drought preparedness update, there is a single paragraph stating that climate change is a reality. The plan emphasizes the state will provide updates on climate change, but the focus of climate adaption and mitigation should be done at a local level.

The state plan states that evapotranspiration is a good proxy for the natural water demand but lacks a statement of how increased temperature effects this process. The 2013 drought plan update includes a recognition that drought can act as a proxy for climate change and a statement about future collaboration with the Center for Integrated Solutions for Climate Change. In the 2015 update there was a single statement regarding the nature of increasing temperatures in the last ten years. No succinct statement was made about the potential impacts of increases sustained heat within the region.

Regarding question five, steps customers can take during a drought, the Arizona state plan has specific action items for the state government, communities and utilities, and individuals for each stage of drought. This action item protocol was listed at the beginning of the main report, for easy access for the officials and citizens who read the drought report.

The Arizona State Drought Plan achieved a level one on the maturity model (discussion of drought risk and climate change, more at the leadership high level. Lacking details but starting to set up the process and background to implement the drought and climate change risk). Throughout the entire report and all of the updates there was only one paragraph dedicated to the implications of climate change and its potential impacts on drought. There was a lack of recognition that climate change could increase the risk of drought. The rest of plan meticulously planned but lacks any adaptive measures to combat the increased risk from climate change. Many of the issues brought up by the plan itself are affected by climate change but the State Drought Plan has little to no information addressing this risk.

California

The California State Drought Plan was published in fall 2010 as a supplementary document to the California State Water Plan. The document mentions climate change twenty times and provides a step by step process of responding to drought within the state.

California breaks down their drought identification into state tracks indices and national indices. At a state level, California monitors precipitation, temperature, stream flow, soil moisture, reservoir levels, and snowpack. Additionally, the utilize national resources from the National Integrated Drought Information System (NIDIS) to identify other drought indicators. These include the US Drought Monitor and other season forecasts produced by NIDIS. In the Drought Plan, California plans to implement an online platform for real-time monitoring of drought information. The aim of this portal to allow to instant weather and drought information for free to help water managers and individuals adjust their plans accordingly.

California's Drought Plan makes general statements of sectors and communities that could suffer adverse effects during a drought. The agricultural sector was specifically identified due to high reliance on groundwater, limited delta transfers, increased competition for water and increased pressure due to climate change. The plan also recognizes that drought will disproportionately affect regions in different ways. To determine impacts from drought, California will assign Regional Task Forces to identify impacts during and after drought.

The second section of the drought plan describes the impacts of climate change and its effect on drought. This section states that precipitation patterns are changing which could influence the frequency and intensity of drought. Climate change was also mentioned in the first paragraph of the executive summary and is used primarily as the motivation for preparing a State Drought Plan. This section also answers question four. The plan addresses the fact that increasing temperature increases the demand of water from plants and an overall warming could extend the growing season. Climate change again is used as a main argument for the increasingly stressed water supply of California.

The state of California outlines a local and federal response for each stage of drought. Most actions have implied actions by citizens revolving around increasing water efficiency and increasing conservation throughout the state, but these are never explicitly stated. There are seventeen key strategies for preparing for drought which include: agricultural land stewardship; agricultural water use efficiency; conveyance – delta; conveyance – regional/local; conjunctive management and groundwater storage; desalination- brackish and seas water ; economic incentives; ecosystem restoration; flood risk management; land planning and management; recharge area protection; recycled municipal water; surface storage; system reoperation; urban water efficiency; watershed management; and water transfers. Additional resources and strategies also exist. These are focused on engaging local communities with workshops and streamlining the online portal for maximum efficiency. The state uses policy and regulation as its main tool for aiding drought preparedness.

California's State Drought Plan earns a level three on the maturity model (Mention of drought risk form climate change with a focus on how this will affect other aspects of the drought planning process. Includes ideas of how it could be incorporated into planning but no concrete action). California uses global climate change as one of the main motivators for the development of a state-wide drought plan. Climate change was referred to as one of the major stressors of water resources with or without drought considered. Even though it is one of the main motivators, there is no specific procedure to incorporate climate change into the drought planning process.

The drought plan references the State Climate Change Adaption plan which might include strategies for incorporating climate change into planning activities. Additionally, the State Drought Plan is meant to complement the California Water Plan. This document also may include strategies for incorporating climate change into planning. Overall the plan is comprehensive on reactionary strategies in case of a drought event.

Colorado

The Colorado State Drought Plan was adopted in 2013. The plan updates every five years. In the over 700-page document there are 128 mentions of climate change including an entire Annex section dedicated to the science of climate change strategies for incorporating the results into local drought plans. The plan includes both an actionable response plan and an extensive pre-drought mitigation and preparedness sections.

The state of Colorado monitors drought via six sectors of the state: agriculture, business and industry, energy, fire, plants and wildlife, relief, response, and restrictions, society and public health, tourism and recreation, and water supply and quality. Each sector has multiple indices that are set up in conjunction with trigger points to identify drought events before they become emergencies. In addition to sector specific indices, the state of Colorado uses the US Drought Portal developed by NIDIS to aid in drought designation. The state of Colorado has also developed region specific indices including the

Colorado Modified Palmer Drought Index and the Surface Water Supply Index. Drought task forces meet monthly all year to determine the potential for drought. These meeting increase during times of drought to help provide in depth information to the governor and other stakeholders about the state of the drought.

In addition to being able to recognize and respond to drought's various forms, the state of Colorado conducted a quantitative and qualitative vulnerability analysis of the state. The vulnerability analysis of the state is also an Annex in the back of the main report. Within the main report vulnerabilities are identified based on the six sectors above. In addition to county level drought impacts, the State of Colorado uses historical impacts from the National Drought Impact Reporter in their analysis. Industries such as dryland crops and water for mining are among the most vulnerable during drought. In addition to looking at broad vulnerabilities state wide, the vulnerabilities are aggregated at the county level. Additionally, the state of Colorado has identified and quantified the risk to state owned assets. Many of these risks include structures vulnerable to fire induced by drought conditions.

The Colorado State Drought Plan has a dedicated Annex to the science of climate change and how to utilize the information for their planning. Throughout the main report there are multiple statements about the uncertainty of water resources. Mountain regions can act as bellwethers for the state of the climate, therefore many of the effects of climate change can be amplify in mountainous regions. One of the biggest impacts of climate change is the changing nature of precipitation in Colorado. The snow packs of Colorado are susceptible to increased temperatures, causing changing patterns of snowmelt and decreased revenues for economies that rely on snowpack.

Due to the conflicting results from climate models on how Colorado precipitation could change, the report focuses on how increased heat will impact Colorado's water resources. Increased temperatures will impact rain vs snow ratios, decrease high elevation snowpack, increase evapotranspiration, move the spring melt earlier, and cause more intense precipitation events. The state of Colorado aims to capture these uncertainties both by projected future climate change using models and analyzing the paleoclimate record. By analyzing a larger historical sample size, the drought risk of an area can be better captured. This combined with climate models provides a wide range of potential drought risk. More extensive drought information can be found in the climate change annex at the end of the Colorado drought plan.

The state of Colorado has identified 78 different mitigation options for the state to investigate within the next six years. They are broken into six board goals with mitigation options ranked as high, medium, and low priority. Colorado takes more of a facilitating approach, with many of their mitigation options aimed at local counties and municipalities to help plan for their drought risk. The State's theory is that droughts are highly localized events, therefore its best to promote planning at the local level. The drought plan provides many quantitative and qualitative comparison tables of counties and their different planning stages throughout the report.

Colorado's State Drought Plan receives a level five on the maturity model (formal plan of how to incorporate drought risk and climate change including addressing what information is needed, how its incorporated into planning and drought monitoring and how it is used to communicate the drought risk and climate change). Colorado achieves a formal plan due to the separate Annex of the plan focused on climate change. The annex provides the science behind the analysis with details on ranges from which counties and other users can incorporate their data into their planning. Additionally, throughout the communication plan there is reference to addressing risk of drought. Overall the plan extensively relies on climate change as both a motivator for the plan and as one of the biggest challenges when facing drought.

Nevada

The state of Nevada state drought plan was published in March of 2012 and severs as a high-level response to drought. The plan is a mere fourteen pages and provides a minimal structure for drought response.

The drought plan of Nevada relies solely on the US Drought Monitor to indicate whether a county has drought occurring. There are three stages of drought: watch stage, alert stage, and emergency stage. While the watch and alert stages are determined by 50% or more of a county in either moderate or severe drought, the emergency stage can only be reached when the drought response committee makes a recommendation based on other recommendations from on the ground teams.

The state recognizes that industries such as tourism, agriculture, and finance can be affected if an emergency stage is reach. The plan lacks specifics on what the actual impacts could be. No vulnerability assessment was performed.

The state plan lacks any statement of the important of precipitation with regard to drought. There is no explanation or recognition of the effect of climate on drought and therefore the plan also does not answer questions three or four. Additionally, there were no specific actions for mitigating the effects of the drought. All the specific actions are to be decided by the Task Forces which are deployed ad hoc by the Drought Response Committee during a time of drought.

The state of Nevada achieved a level zero on the maturity model (No mention of drought risk and climate change coupled together). There was not a single mention of climate change within the state drought plant. The plan lacks specifics of how to respond during a drought and provides no up-front mitigation options.

Utah

The State of Utah developed their drought plan in 2008. Utah's drought plan is a subsidiary of the State Water plan but has can be found as a separate document. The report includes twenty-three mentions of climate change and has chapters dedicated to both historical drought from the instrumental record and historical drought from a paleoclimate perspective and current climate trends.

The state of Utah uses multiple indices to track the develop of drought within Utah. The main indices used are the Palmer Drought Severity Index, Surface Water Supply Index, and the Standard Precipitation Index. These work in conjunction with national combined metrics like the US Drought Monitor and resources developed by NIDIS. Utah uses historical analysis as the basis for drought triggers.

The state of Utah performs a vulnerability analysis based on three main sectors: economic, social, and environmental. Economic impacts include agriculture and livestock, transportation, industry, energy, timber, and tourism/recreation. Social impacts include nutrition, reduced quality of life, health and stress, public safety, increased conflicts, and cultural values/site endangerment. Finally, environmental impacts include wetland impacts, animal and plant disruption, water quality degradation, wind erosion, infestation, and increased wildfire risk. The report calls out water suppliers and agricultural industries as being highly vulnerable to drought. Specifically, non-irrigated agriculture is at high risk during a metrological drought, while irrigated agriculture that relies on aquifers can become vulnerable if a drought progresses to a hydrologic drought. A more comprehensive vulnerability assessment was identified as a mitigation option. The goal of a vulnerability assessment would be to identify the root cause of social vulnerability as a way of reducing overall drought vulnerability.

The state of Utah approached the risk of drought induced climate change differently. First, they dedicated an entire chapter to a review of all historic droughts within the state's instrumental history. This historical account included a back calculation of many drought indices and historical impact analysis. In the next chapter, the state of Utah investigates the paleoclimate record and current climate trends. This two-prong approach helped widen their sample space of potential future drought scenarios. They evaluated the paleoclimate back to 1400 and used 40 climate models to identify the largest range of drought possibilities. Much of this chapter focused on the risk that a changing climate poses to the nature of precipitation within Utah and Colorado. Utah receives a substantial amount of their water from other states and therefore keeps track of water resources outside of their boarder. There is discussion how precipitation, with sustained heat, will transition from snow to rain within the coming century. The State of Utah also recognized that more heat could increase the growing season's length, and increase evapotranspiration, and change the timing of snowmelt within the state.

The state of Utah provides a state-wide approach for how to implement mitigation options and increase resiliency. Their mitigation options are focused in two main bins: risk management and response measures. There are eleven main measures of mitigation for the state: water redistribution, conjunctive management, water system interconnection, water development and inter-basin transfers, water metering and leak detection, weather modification, vulnerability assessments, removing water loving invasive species, watershed management and drought forecasting. These focuses on big picture policy measures of how to reduce vulnerability state wide. The plan lacked specific action items for individuals that could reduce their own vulnerability to drought.

The State of Utah received a level four on the maturity model (plan for incorporating drought risk from climate change including addressing information needed, how it will be incorporated and a communication plan). The main report includes extensive descriptions of how risks are quantified and how they could be used within the planning stages for drought. There are detailed descriptions of the current science and how these methods better represent the risk of future droughts. The plan lacks details on how to communicate the risk of drought, but there is a strong suggestion to have water managers consider the findings of the report in their planning process.

Summary

The table below summaries the results of the State Drought Plan analysis.

Table 14. Summary of State Drought Plan Results

	Arizona	California	Colorado	Nevada	Utah
Question 1: Can your institution effectively identify the precursors of drought in your area before the peak warm season?	✓	✓	✓	×	✓
Question 2: What aspects of the community could be susceptible to hardship during a drought?	✓	✓	✓	×	✓
Question 3: Would a change in precipitation pattern highly effect your ability to supply water to your community?	×	✓	✓	×	✓
Question 4: Could increase sustained heat impact your ability to supply water to your community?	×	✓	✓	×	✓
Question 5: What steps are you planning for your customer to take during a drought?	✓	×	×	×	×
Maturity Level	1	3	5	0	4

It is difficult to compare each state drought plan against the other because each state takes a different approach for planning for drought. Additionally, it is difficult to parse out which plans have overall better planning without seeing each plan enacted. In the case of Arizona, their plan had many mitigation options and strategies for preparing the state for drought, but it lacked any information about the changing nature of drought. California relied heavily on climate change as a big stressor for the water resources of the state but lacked many specific mitigation options and incorporation of risk into their plan. Colorado's State drought plan addresses each question at length but question five. It delegates individual actions to local planners rather than providing state wide recommendations.

Nevada's plan was merely an outline of the highest levels of a response plan when considering drought. Finally, Utah's plan provided a in depth discussion of the historic and future drought risk for the state. The plan stopped short of providing a formal plan for integrating climate change into drought planning.

Overall each state's drought plan had to be read in context to determine how clear each question was answered to determine the maturity level of the drought plan. Because the Colorado basin lacks a region wide drought plan it proves difficult to compare different plans across the basin, even though they all share the same water.

Discussion and Conclusions

The State drought plans analyzed in this research provide a breath of strategies for drought planning throughout the United States. Some states, like Nevada, still have highly reactionary or crisis management plans. Others, like Colorado, have extensive risk management plans that include specific sections for addressing the risk of drought due to climate change. Each state in the analysis has room to improve their level of maturity with regard to climate-imposed drought risk. As stated in the literature, moving towards a risk management approach for drought can dramatically reduce a community's vulnerability to its devastating effects.

Arizona

Arizona's State Drought Plan is a risk management focused plan, but it fails to recognize climate change as a major stressor for the state's water resources. As seen in the HUC-4 analysis, drought risk across the state is uneven, partially due to the wide variety of landscapes throughout the state. These differences in drought risk due to climate change are not captured or even addressed in the original state plan or any update thereafter.

In order to move above a level one on the maturity model, Arizona would need to acknowledge climate change as a major risk facing their water resources. A discussion of how climate change will affect the varied environment of Arizona will help the state develop specific region recommendations for addressing climate change. This can be done in multiple ways. One strategy is similar of that to the state of Utah. Arizona can take the approach of relying on the paleoclimate record to reconstruct historical droughts. As stated in the results sections, increasing the range of potential historical droughts helps increase the sample size of drought events from which to plan. It is more politically viable to consult the paleoclimate record than to use climate models. Additionally, because these droughts have historically happened, it is easier to explain to citizens and stakeholders why they are being included in the planning and preparation phase. To reach a higher level, using all available climate science to predict scenarios of future climate and therefore future drought should be applied. These tools help practitioners again widen the sample space of possible drought events that could occur. Both the climate models and paleoclimate record should serve as ways in increase the number of potential scenarios that local water managers can use in their planning sessions.

In addition to incorporating a wider range of historic and potential drought, the state of Arizona needs to also consider ways in which to communicate the increased risk of drought. The state of Arizona did not have a specific communication campaign or goals stated within their state drought plan. One of the best ways to help prepare communities is to give them the information about droughts before they occur or when they are in the early stages. This allows citizens to help adjust their behavior during/before drought occurs making the entire system more resilient to drought.

These few additions to the State Drought Plan of Arizona could improve their plan to a level four on the maturity model. In order to reach a level five, a specific break out section must be written on the science of climate change and how it is being incorporated into planning. These would require additional resources from the state and would have to be updated consistently. Ideally an update on the science and risk in each yearly renewal, would keep Arizona prepared for drought risk due to climate change.

California

The California State Drought Plan focuses on procedures and policies related to the preparing and reacting to a drought event. It uses climate change as a one of the main drivers for the plan but fails to provide in-depth information on the subject. Therefore, they reached a level three on the analysis.

In order to improve the state of California's maturity level, they should include a detailed section on how climate change will affect the water resources of the state. While they make a lot of sweeping generalizations on how climate will affect the state, the state is a very large with lots of different climates that will each react differently to a changing climate. Moreover, California receives a good portion of their water from outside its borders via water transfers. It is imperative that California also considers the effect of climate change on basins they rely on outside of their boarders. This can be accomplished by looking at the paleoclimate records and by studying the results of the climate models. Both the state of Colorado and the state of Utah provide good templates in which California could choose to model their analysis on.

Along with a directed section on climate change's effect on water resources, California should consider adopting a more extensive communication plan. This will help the state inform its residences before, during and after a drought occurs. A well thought out and executed communication plan can provide the much-needed buffer between crisis and simply water restrictions.

Colorado

The State of Colorado has the most extensive drought plan of any of the states analyzed receiving a level five on the maturity model. Colorado should sever as the basis for other states that aim to quantify the risk of drought due to climate change and as a template for developing an extensive drought state plan. The state of Colorado made a planning document to help aid local municipalities and counties to prepare for drought with the state, but this document could also be used as a guide for state agencies that would like to have a more comprehensive state drought plan.

Even though the plan has specific formalized sections for how to quantify the risk of drought with regard to climate change, there are still aspects in which the state could improve. It would be beneficial for the state to help provide options that individuals and industries can take during and before droughts. This would centralize all the information one could need to complete a comprehensive drought plan. Additionally, the state of Colorado could improve its communication plan and provide examples of information campaigns that would help increase drought education throughout the state. Since good communication campaigns can be difficult to compose, and since many municipalities and counties lack the resources to develop these on their own, the state could provide some options that have proven to be effective, decreasing the burden on these smaller governmental agencies.

Nevada

The state of Nevada received a level zero for their state drought plan. Their drought plan was by far the most reactionary and least detailed of any of the plans analyzed. The plan lacked any sort of risk management techniques and relied solely on a crisis management framework, where much of the reaction to the drought would occur in the moment with minimal planning. Therefore, the basic recommendation for the state of Nevada would be to form a risk management focused state drought plan. This would require resources and potentially hiring an outside consulting firm to ensure a comprehensive plan for droughts.

When considering what to include within a state drought plan, Nevada should take into consideration the planning document made by the state of Colorado. This plan includes eight main sections: Stakeholders, Objectives and Principals; Historical Drought and Impact Assessment; Drought Vulnerability Assessment; Drought Mitigation and Response Strategies; Drought Stages, Trigger Points, and Response Targets; Stages Drought Response Program; Implementation and Monitoring; and Formal Plan Approval and Updates. These categories should be used as the board outline of a state drought plan for Nevada. In the historical drought an impact assessment section, specific sections should be dedicated to the discussion of climate change and how it effects the water resources of Nevada. Again, this can be done by analyzing the paleoclimate and climate models which help widen the range of potential drought scenarios to plan for.

It is imperative for Nevada to plan for drought at a state-wide basis because as seen in the climate change analysis, areas of Nevada are highly susceptible to droughts going forward. Additionally, southern Nevada, especially the area around Las Vegas relies solely on water from Lake Mead as their water supply. This water resource is one of the most vulnerable to climate change going forward and the state should come up with an action plan on how to best deal with potential water scarcity state wide.

Utah

The state of Utah received a level four on the maturity model for their state drought plan. Unlike Colorado, Utah chose to address the risk of drought due to climate change mainly by focusing on the historical paleoclimate record. This record was used to reconstruct historic drought conditions going back to 1400. These conditions were then used in the rest of the planning exercise and helped inform the different strategies for preparing for drought.

While the analysis of climate change was very extensive, it focused mainly on the historic record with only a minimal mention of the climate models used. In order to decrease confusion around how climate models can be used for planning, one recommendation would be to increase the explanation of the science of climate models and how they were used in the planning process. Additionally, in order to move up to a level five, Utah would simply need to provide an appendix or separate section on what is climate change, how does it affect water resources, how is it being accounted for in the planning process and how should local counties and municipalities take these results and incorporate them into their planning. Many of these pieces exist already in the Utah state drought plan and would simply need to be put in one central location.

Finally, much like all of the other states, Utah should also consider improving their communication plan to incorporate aspects of climate change. This might be less politically feasible in this state, but it is important that water managers receive a full range of potential future droughts to plan around or otherwise risk a highly impactful drought events.

State Plan Discussions

Each one of these states have semi -arid or arid climates within their boundaries. This makes these states more aware of the dangers of drought. While drought can occur in every climate zone, many associate droughts with arid climates. This potentially leaves wetter climates more vulnerable to drought, especially if their state governments have not planned for it. Therefore, it is in everyone's best interest for all states to have a drought plan. It may be sufficient for states with wetter climates to have a less robust plan than states with arid climates, but if the state relies heavily on water for their economy, such as a farming state, they are just as at risk from drought as a semi-arid/arid region.

One aspect not discussed in this research is that many states are developing state-wide water plans. These water plans can be seen as the master plan for how a state wants to develop or use its water resources in the future. Drought should be included in these plans, but it does not negate the need for a separate document for a drought response. The state water plans were not analyzed in this research and likely these reports contain answers to many of the questions posed by this research. While this is great news if the water plan answers the questions, it is helpful to have all the information in a single document for easy access by the public and water managers.

While planning at a local level is helpful, especially for times of crisis, larger drought coordination should be considered to avoid significant conflict. Ideally drought plans should be developed around water basins because water is recycled and used throughout the basin until it terminates in an ocean or final location. By planning at the basin scale, conflicts can be resolved before they occur. Basin wide planning would allow for states to learn from their neighbors and work together in planning how water will be allocated during times of drought. In the Colorado basin there exists contingency plans for times in which Lake Mead reaches below a certain elevation. This approach, while a step in the right direction, relies solely on the reactionary/crisis management frame. This is a good place to start because deciding what to do in a crisis is important if they were ever to reach that level. The next step would be to move towards a risk management framework that encompasses the entire basin. This process would take significant time, effort and corporation by all parties involved. The Colorado river basin, having been one of the most litigated in history, may have an upper hand in being able to start these types of talks. Extensive network building across the basin has led to partnerships that have resulted in other beneficial uses to the river, such as the pulse of Colorado River water to the Gulf of Mexico a few years back. This work required lots of negotiation and relies heavily on preexisting network to help develop a basin wide drought plan.

Limitations

There are a few major limitations of this study. The first major limitation of this study is that only one drought index was used for the analysis. As already stated, the Palmer Drought Severity Index (PDSI) was developed in 1965 and incorporated temperature and precipitation into a calculation of soil moisture to determine drought severity levels. Although this is a widely used index throughout the literature it does not provide a complete picture of drought risk into the future. The PDSI does not consider snowpack in its calculation and does not perform well in areas of dramatic topographic relief. To have a complete picture of drought risk into the future, other indices such the Standard Precipitation Index (SPI) or the Effective Drought Index. Working with multiple drought indices would increase the robustness of the overall analysis.

The second major limitation of this study is that it only considers state drought plans. As seen in the analysis, drought is a highly localized event. For this reason, many local municipalities and counties conduct their own specific drought analysis and subsequent planning. These types of local plans, such as drought plans from Denver Water or the Las Vegas Valley Water District, potentially have extensive drought plans. In addition to neglecting local water plans, this analysis also does not consider federal agencies' drought plans. The Bureau of Reclamation is a major stakeholder in the Colorado River Basin. They operate Lake Mead and provide information about drought to lower half of the Colorado River Basin. These institutions along with other Federal agencies that provide information on drought were not considered in this analysis.

Finally, the last limitation of this study was the consideration that all global circulation models (GMCs) had equal weight within the drought and climate change analysis. While it is true that the future is uncertain, and each model provides a different parameterization of variables, some GMCs can model the baseline historic period more accurately than other models. For this reason, it has been argued that the models that can model the historical period with greater accuracy should receive greater weight in an analysis using all twenty-one models. In this analysis there was no consideration of preferential models.

Future Research

This research can serve as the backbone for a variety of future research projects. A next step to build directly on this research would be to analyze the meeting notes for the meeting of the Colorado River Basin to see what action is being done regarding drought planning. There are many organizations that sever as mediators between the Colorado River basin states including the Upper Colorado River Commission, the Colorado Basin Roundtable and the Lower Colorado River Basin. More research would be needed to identify the key stakeholders and decision makers at this level of discussion.

Another area of future research would be to perform an in-depth climate analysis and scenario planning for a specific region of the US that has little to no development regarding drought. This would be both an exercise in performing a climate analysis that is useful for practitioners and that can help a region of the US develop a comprehensive plan for drought emergencies.

Finally, another area of future research would be to expand the scope to an international stage and look at either national drought policy in conjunction with increased drought risk. This would require a larger climate study including possibly delineating watersheds internationally and would require access to drought/emergency planning documents from countries or cities within the study area which could prove difficult.

Conclusions

In conclusion, through the end of the century, the US has a wide range of drought risk. Climate change will cause the southwest to be at elevated drought risk while the mid-west has slightly increased risk. These changes in climate should be considered when preparing for the next century. The abundance or scarcity of water could be a contributing stressor for the US throughout the end of the century. As stated, drought risk has the potential to interrupt the economy, case hardship to effected, and threaten the well-being of natural assets and human structures. While drought planning has steadily moved from a crisis management approach to a risk management approach, many places are still failing to recognize the risk of drought to due to climate change. This leave many states underestimating the effects of drought through the end of the century.

Although some states fail to recognize climate change as a major stressor for their water resources, other states have implemented policies that quantify the risk due to climate change and provide strategies for incorporating climate information into drought planning. This process helps prepare states for a wider range of potential droughts, thereby lessening the overall impacts of drought events. Out of the five state plans studied, two states provided extensive risk assessment that incorporates the risk of drought due to climate change, two states acknowledge climate change as a stressor of water resources and one state failed to recognize climate change at all. These differences between state drought plans has the potential of causing conflict if a drought is severe enough and effects a large enough area.

In order to better prepare the US for drought in the future it is imperative that states, and the nation at large considers the changing climatic environment. Climate change will affect the nature of drought into the future and will determine how water resources are utilized throughout the end of the century. Preparing for this now at a state, basin, and national level will help communities to continue to prosper for years to come.

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