Sociodemographic and Climatic Factors Shaping the Development of Drought Policies in Major U.S. Cities

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SOCIODEMOGRAPHIC AND CLIMATIC FACTORS SHAPING THE
DEVELOPMENT OF DROUGHT POLICIES IN
MAJOR U.S. CITIES

by

Riana S. Gayle

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Ecology

Approved:

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Logan, Utah

2018
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ABSTRACT

Sociodemographic and Climatic Factors Shaping the Development of Drought Policies in Major U.S. Cities

by

Riana S. Gayle, Master of Science

Utah State University, 2018

Major Professors: Jacopo Baggio and Jordan Smith
Department: Environment and Society

The United States lacks a comprehensive National Drought Policy, though the country has a long history of costly drought incidents. However, many individual cities have been more proactive and developed their own drought-specific water management policies. We examine the sociodemographic and climatic factors shaping the development of these drought-specific water management policies in all U.S. cities with populations greater than 100,000. We systematically identified the presence or absence of drought-specific water management policies through a web-search of each city’s official website. We obtained and compiled sociodemographic and climatic variables from disparate public databases (e.g., the U.S. Census Bureau, PRISM climate data, etc.). These variables included: total population, population growth, age, income, poverty rate, educational attainment, race, deviations of recent precipitation and temperature from historical averages, and historical precipitation and temperature data. We quantified the
effect of these sociodemographic and climatic factors on the adoption of drought specific policies through a series of multiple logistic regression models. Results suggest a city’s poverty rate, income, median age, the deviation of recent precipitation from historical averages, and mean historical temperature are all important factors in affecting whether major cities in the U.S. have adopted drought-specific water management policies. Identifying significant influences on the formation of drought-specific water management policies provides valuable insight into the forces shaping the capacity of cities to adapt to climate change; they can also be used to guide national efforts to establish more drought-resilient cities.

(74 pages)
PUBLIC ABSTRACT

Sociodemographic and Climatic Factors Shaping the Development of Drought Policies in Major U.S. Cities

Riana S. Gayle

In most parts of the world, drought is an inevitable and natural occurrence. However, as the climate continues to warm, and populations grow and expand, the negative impacts of this extreme weather event are predicted to become more pronounced. This leads many communities and stakeholders to question what is being done to prepare society for widespread drought? The following research determines different social and atmospheric characteristics that affect a city’s likelihood of having a drought policy in place. To do this, a thorough search was conducted at the city level to determine where drought policies are currently located in the U.S. The search included all U.S. cities with a population greater than 100,000. Policies and city plans were identified using a list of search terms ranging from “drought” and “water conservation” to “climate mitigation”. By identifying locations where these policies are currently in place this study explores commonalities between cities that have and have not implemented drought management plans.
ACKNOWLEDGMENTS

I wish to thank various people for their involvement in my research and development at Utah State University: Dr. Baggio and Dr. Smith, my academic advisors, for their patience, guidance and constructive suggestions, and Dr. Givens also for her valuable insight and support. Combined, their critiques and expertise helped me develop and gain confidence as a researcher.

Next, a special thanks to my colleagues and lab mates who shared insight both academic and personal throughout my masters. I would not have succeeded if not for their generous donations of time, experience and most often a listening ear. There are too many folks to name and too many adventures to recall, but to everyone with whom I shared a drink or a document and now a memory, thank you.

Lastly, I extend the sincerest of thanks to my parents, Linda and Derrick, my close family and my partner Caleb. Even from great distances, they showered me with ceaseless words of advice and encouragement. I would not have made it into or through this rigorous program without their unwavering support. So, my biggest thank you has to go to those individuals who are my foundation. Much love.

Riana S. Gayle
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CHAPTER I
INTRODUCTION

Drought is an inevitable and natural occurrence. As the global climate continues to warm, hydrologic flows become more variable, making the availability of freshwater resources less predictable and the negative impacts of drought more pronounced (IPCC, 2014; Mishra & Singh, 2010). As a result, many cities have developed adaptation and/or mitigation plans intended to increase their ability to cope with future drought events. Both sociodemographic and climatic characteristics have been found to influence policy adoption (Dean, Fielding, & Newton, 2016; Zahran, Brody, Grover, & Vedlitz, 2006; Zahran, Brody, Vedlitz, Grover, & Miller, 2008; Zahran, Grover, Brody, & Vedlitz, 2008). However, little is known about whether there are specific factors that increase the likelihood of individual cities to create and implement drought-specific water management policies. In this thesis, we determine the significant sociodemographic and climatic factors affecting the likelihood of large U.S. cities adopting drought-specific water management policies.

Assessments of drought-specific water management policies at the city-scale are essential, given the financial costs of drought events are localized (Fu & Tang, 2013) and problems of enforcement often arise when policies are implemented at larger spatial scales, e.g. national, state, and regional (Glickman et al., 2000; Western Governors’ Association, 2004). Plans developed at the national, state, and regional scales involve dozens, if not hundreds, of competing interest groups (Wilhite, Svoboda, & Hayes, 2007). On the other hand, city-scale policies allow water supplies to be more effectively
managed (Fu & Tang, 2013). Additionally, many states realize that state-level polices lack any real regulatory enforcement capabilities, believing instead their primary purpose should be to guide regulatory policies at the local level. For example, Section 6 of the Kentucky State Drought Contingency Plan explicitly reads that the state plan is “intended to help coordinate the actions of state agencies” and that drought response is most effective when managed locally by “government, water suppliers, and individual citizens” (Kentucky Drought Mitigation and Response Plan, pg. 26-27, 2008). While state plans are a positive step towards adaptive management, their lack of specificity can reduce their effectiveness compared to water management plans developed and enforced locally (Mishra & Singh, 2010).

The remainder of the thesis is organized as follows: We first catalog all city-scale drought-specific water management policies present in highly populated cities across the U.S. (i.e., > 100,000). Second, we analyze the relationship between policy adoption and the sociodemographic and climatic characteristics that define each city identified. Lastly, we discuss the implications of our findings and make policy recommendations aimed at spurring the formation of city-scale drought-specific water management policies across the U.S.
CHAPTER II
LITERATURE REVIEW

2.1 U.S. National Drought Policy, from Federal to Local Levels

The U.S. does not have a nation-wide policy in place to address drought events. Various state and city-scale policies have been developed at the discretion of legislators and when prompted by Federal agencies. However, there is little coordination between federal, regional, state and local policies (Wilhite, Sivakumar, & Pulwarty, 2014; Wilhite et al., 2007). For example, the Disaster Mitigation Act of 2000 (DMA 2000 Public Law 106-390), which was issued by the Federal Emergency Management Agency (FEMA) triggered policies at the local level. While the DMA allowed for the creation of new legislation across the country to meet compliance for federal disaster relief following natural disasters, minimal direction was given in how these disasters would be addressed nationally and how responsibilities would be delegated between government entities and the general public. The result is a patchwork of policies across the U.S. which facilitate action at different scales of governance. This system needs more fluidity and oversight to adequately reduce the risk of future drought events (Wilhite et al., 2014).

Table 1 provides a brief timeline of how the nation has progressed towards, but as of yet has failed to implement a national drought policy (Folger, Cody, & Carter, 2013). While the National Drought Policy Act of 1998 established a commission to go so far as to “provide advice and recommendations on the creation of an integrated coordinated Federal Policy”, the Act did not result in the creation of a federal drought response policy (H.Rept. 105-554 - National Drought Policy Act of 1998, 1998). Despite this fact, new
Table 1

*U.S. National Drought Policy and Related Actions Timeline*

<table>
<thead>
<tr>
<th>Date</th>
<th>Scale of Government</th>
<th>Action</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>1988</td>
<td>International</td>
<td>The International Drought Information Center founded</td>
<td>To inform and to help reduce social vulnerability to drought (National Drought Mitigation Center, 2017)</td>
</tr>
<tr>
<td>1995</td>
<td>Federal</td>
<td>The National Drought Mitigation Center established.</td>
<td>To inform and to help reduce social vulnerability to drought (National Drought Mitigation Center, 2017)</td>
</tr>
<tr>
<td>1996</td>
<td>Regional</td>
<td>Western Governors’ Association becomes involved with drought initiatives</td>
<td>To improve the way the U.S. prepares for and responds to drought (Western Governors’ Association, 2004)</td>
</tr>
<tr>
<td>1997-1999</td>
<td>Coordinating Federal and State Agencies</td>
<td>The Western Drought Coordination Council is formed</td>
<td>To establish a more comprehensive, integrated response to drought emergencies and cooperatively plan for future droughts (NRCS National Water and Climate Center, n.d.; Wilhite, 1997)</td>
</tr>
<tr>
<td>1998-2000</td>
<td>Federal</td>
<td>The National Drought Policy Commission established pursuant to the National Drought Policy Act (Public Law 105-199)</td>
<td>To provide advice and recommendations on the creation of an integrated, coordinated federal policy (Skeen, 1998)</td>
</tr>
<tr>
<td>2000</td>
<td>Federal</td>
<td>The National Drought Policy Commission’s work is</td>
<td>Presents the argument for national drought</td>
</tr>
<tr>
<td>Year</td>
<td>Type</td>
<td>Action</td>
<td>Goal</td>
</tr>
<tr>
<td>------------</td>
<td>---------------------</td>
<td>------------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------</td>
</tr>
<tr>
<td>2004</td>
<td>Regional</td>
<td>Western Governors’ Association and National Oceanic and Atmospheric Administration produce a report ‘Creating a Drought Early Warning System for the 21st Century’</td>
<td>To introduce the National Integrated Drought Information System and to improve monitoring and compilation of drought indicators and impact. (Western Governors’ Association, 2004)</td>
</tr>
<tr>
<td>2007</td>
<td>Federal</td>
<td>National Integrated Drought Information System launches the portal Drought.gov</td>
<td>To provide coordinated federal drought monitoring and research presence (NIDIS, 2007)</td>
</tr>
<tr>
<td>2012&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Federal</td>
<td>Drought Information Act is introduced - not enacted</td>
<td>To reauthorize National Integrated Drought Information System domain and for other purposes (Pryor, 2012, 2013)</td>
</tr>
<tr>
<td>2014</td>
<td>Federal</td>
<td>National Integrated Drought Information System</td>
<td>To better inform and provide for more timely</td>
</tr>
<tr>
<td>Year</td>
<td>Action</td>
<td>Document</td>
<td>Description</td>
</tr>
<tr>
<td>------</td>
<td>--------</td>
<td>----------</td>
<td>-------------</td>
</tr>
</tbody>
</table>

Note. See also supplementary material for further detail.

a Bill is re-introduced in 2003 and 2005, remains not enacted
b Bill is re-introduced in 2013, remains not enacted

policies and approaches are being developed across the U.S. at more local scales of governance (Krause, 2011).

The evolution of drought-specific water management policies has also seen a change in the language surrounding drought response. In recent decades we have seen the management of drought response shift from one of reactive crisis to one of proactive planning (Wilhite et al., 2007). Examples of this are evident in state plans originating from the 1980s and 1990s which embodied the former approach (Wilhite, Hayes, Knutson, & Smith, 2000) and plans created in late 2000s which transitioned to the latter approach. For example, Utah’s Drought Response Plan created in 1993, frames drought as an emergency to be responded to. Whereas in the neighboring state of Colorado, the 2013 Colorado Drought Mitigation and Response Plan facilitates proactive monitoring and assessment prior to and following drought events (Colorado Water Conservation Board, 2013; Utah Natural Resources, 1993).
2.2 Sociodemographic Variables Driving the Formation of Drought-specific Water-management Policies

Previous research suggests the following sociodemographic characteristics affect the likelihood of a city/state putting in place drought-specific water management policies: population size, population growth, median age, elderly percentage of the population, median income, poverty rate and education level. Each variable was chosen based on their relation to local drought, water, and climate policy adoption.

**Population.** In this research, we explore two distinct measures of population, size and growth rate. Both variables address the expanding infrastructure of urban areas. If not well-planned, rapid expansion of urban areas to accommodate larger populations can inadvertently increase society’s vulnerability to future natural hazards (Berke & Smith, 2009; Comfort et al., 1999; Sanchez, Smith, Terando, Sun, & Meentemeyer, 2018). Previous work suggests that population density and growth positively correlate with the total number of people living under water scarcity conditions in both urban and rural places (i.e., drought conditions) (Güneralp, Güneralp, & Liu, 2015; Smirnov et al., 2016); this has the potential to increase the pressure for the establishment of drought specific policies within a city.

**Age.** Studies show that the elderly population is more sensitive than the general population to certain health impacts and climate stressors like drought (Gamble et al., 2013). An older population, represented as both an elderly population and a rising median age, may be more vulnerable and hence need more intervention in the form of drought-specific water management policies to help them mitigate their social vulnerability to natural hazards (Cutter, Boruff, & Shirley, 2003; Zimmerman, Restrepo, Nagorsky, &
An aging population is also related to increased concern for water scarcity and an increased likelihood of adopting drought-specific water management policies (Bishop, 2013).

**Income and Poverty.** Lower incomes are strongly correlated with a lack of resources and financial capacity, which can contribute to increased social vulnerability of a population to environmental and economic perturbations (Adger, 2000; Cutter et al., 2003; Eriyagama, Smakhtin, & Gamage, 2009). Lack of financial resources as well as infrastructure lead to increased poverty levels that, in turn, reduce the ability of cities to put drought-specific water management policies into place (Berke & Smith, 2009). At the same token, higher income levels are more likely to lead to the development of climate-related risk mitigation and adaptation policies (Cutter et al., 2003; Krause, 2011; Zahran, Brody, et al., 2008).

**Education.** Higher education levels are associated with an improved capacity to combat natural disasters because of increased knowledge, of both mitigation and adaptation practices. Higher education levels have also been associated with increased participation rates in climate related policies and the retention of climate initiatives (Krause, Yi, & Feiock, 2016; Zahran, Brody, et al., 2008; Zahran, Grover, et al., 2008). Further, increased education is also often associated with greater lifetime earnings which may decrease an population’s direct vulnerability to drought (Cutter et al., 2003).
2.3 Climate Variables Driving the Formation of Drought-specific Water-management Policies

Climate change has been linked with increasing frequency and intensity of future extreme weather events, including drought (Easterling & Evans, 2000). Resilience to the negative impacts of these events is not solely determined by atmospheric change but also by the complex interdependencies between human and natural systems (O’Brien, Eriksen, Nygaard, & Schjolden, 2007). Planning and implementation of policies to combat these issues must be adaptive and consider all aspects of the system, because the problems being considered are often “wickedly” evolving (Adger, 2016; Adger et al., 2009; Brown, 2015; DeFries & Nagendra, 2017; O’Brien et al., 2007).

Climate change research suggests that precipitation and temperature are both key variables likely to influence the likelihood of a city adopting a drought-specific water management policy (Baker, Peterson, Brown, & McAlpine, 2012; Zahran, Grover, et al., 2008). Precipitation has a direct impact on the input of water into a system while temperature influences evapotranspiration rates and hence, the ability of a specific place to be more or less susceptible to drought conditions (Eriyagama et al., 2009; IPCC, 2014). In order to assess temperature and precipitation, we calculate deviation of annual precipitation and mean annual temperature from the long term mean (Cai et al., 2014; Yoon et al., 2015). We also calculate the historical average of precipitation and mean temperature (Eriyagama et al., 2009; Mann, Bradley, & Hughes, 1998). Deviation from the long-term mean has been found to influence the adoption of water mitigating policies (Zahran, Grover, et al., 2008). Table 2 summarizes the hypothesized relationship between variables thought to influence likelihood of adopting drought policies.
Table 2

*The Predicted Effect (Disregarding Effect Size) of an Increase in the Independent Variable on the Presence of a Drought Policy in that City*

<table>
<thead>
<tr>
<th>An increase in this variable...</th>
<th>...Will result in an increased (+) or decreased (-) chance of adopting policy</th>
<th>Literature citing why this variable is influential on drought</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population Size</td>
<td>+</td>
<td>Smirnov et al., 2016; Güneralp, Güneralp, &amp; Liu, 2015</td>
</tr>
<tr>
<td>Population Growth</td>
<td>+</td>
<td>Smirnov et al., 2016; Güneralp, Güneralp, &amp; Liu, 2015; Cutter et al., 2003</td>
</tr>
<tr>
<td>Median Age</td>
<td>+</td>
<td>Gamble et al., 2013; Cutter et al., 2003; Zimmerman et al., 2009; Bishop, 2013</td>
</tr>
<tr>
<td>Elderly Age</td>
<td>+</td>
<td>Gamble et al., 2013; Cutter et al., 2003; Zimmerman et al., 2009; Bishop, 2013; Ngo, 2001; Morrow, 1999</td>
</tr>
<tr>
<td>Median Income</td>
<td>+</td>
<td>Adger, 2000; Cutter et al., 2003; Zahran et al., 2006; Zahran, Brody, et al., 2008</td>
</tr>
<tr>
<td>Poverty Rate</td>
<td>-</td>
<td>World Meteorological Organization, 2011; Cutter et al., 2003; Morrow, 1999</td>
</tr>
<tr>
<td>Educational Attainment</td>
<td>+</td>
<td>Striessnig et al., 2013; Cutter et al., 2003; Morrow, 1999; Zahran, Brody, et al., 2008</td>
</tr>
<tr>
<td>Deviation from long-term mean annual Precipitation</td>
<td>+</td>
<td>IPCC, 2014; Eriyagama et al., 2009; Zahran, Grover et al., 2008, Baker et al., 2012</td>
</tr>
<tr>
<td>Deviation from long-term annual Max Temperature</td>
<td>+</td>
<td>IPCC, 2014; Baker et al., 2012</td>
</tr>
<tr>
<td>Deviation from long-term annual Mean Temperature</td>
<td>+</td>
<td>IPCC, 2014; Eriyagama et al., 2009; Baker et al., 2012</td>
</tr>
<tr>
<td>Long-term annual Mean Temperature</td>
<td>+</td>
<td>Eriyagama et al., 2009; Baker et al., 2012</td>
</tr>
</tbody>
</table>

*Note.* Race/Ethnicity was considered, but ultimately excluded from our study due to changing definitions of racial groups as reported by the census from 1950-present day.
CHAPTER III

METHODS

3.1 Sampling Frame

Policy is defined as an actionable plan shaped by popular social, political, and economic factors (Birkland, 2014). Public policy, as it occurs in the public sector, is achieved through a process in which decision makers choose to address or disregard specific aspects of a complex problem (Hill & Varone, 2014) such as the interaction between social and ecological systems (Orach & Schlüter, 2016). By studying when and where drought-specific water management policies are established, one can gain a better understanding of what social and environmental factors trigger or influence their formation. In this study, we focused on places with a population of 100,000 individuals or more. To collect place names, we used the U.S. Census Bureau website. Rather than search by city name, which can exclude some of the towns and municipalities with populations of 100,000 persons or more, the geographic type known as place was specified in the search. The term place references all towns, cities, villages, neighborhoods, and so on with either a population of 5,000 or more people, or 5,000 or more jobs (U.S. Census Bureau, 2012).

To find the most recent population estimates, we used the 2015 American Community Survey (ACS) database with 5-year estimates. These surveys, as opposed to the Decennial Census which is run only once every 10 years, are updated every 1 to 5 years. We chose to utilize the 2015 ACS with 5-year estimates, over the 2016 1-year estimate, because a 5-year estimate better represents a city’s population, reducing short-
term variability and increasing confidence in population estimates. As of late 2016, there were 308 places with a population of greater than 100,000 (Figure 1). Five states (Delaware, Maine, Vermont, West Virginia, and Wyoming) do not have a place with more than 100,000 residents.

![Number of Cities With Drought Policy](image1)

Figure 1. Map of U.S. cities with a population of 100,000 or more persons (right) and proportion of cities by state with a drought policy present (left).

### 3.2 Variable Selection

#### 3.2.1 Policy Identification

To identify all relevant drought-specific water management policies at the city level we systematically searched official city websites. Each city website was searched on Google between April and August 2017. Once we identified an official city website, we searched that website for the following terms:
• “drought” or “sustainability” and plan;
• “drought” or “sustainability” and policy;
• “climate adaptation” or “climate mitigation” and plan;
• “climate adaptation” or “climate mitigation” and policy;
• “water conservation” and plan; and
• “water conservation” and policy

We downloaded documents related to the searched terms (if found) and compiled them in a database. We further refined the search by differentiating within our newly created database between general and drought specific plans and policies (see also supplementary material), removing reports and other documents that were not drought-specific water management policies.

3.2.2 Sociodemographic Variables

We collected all sociodemographic data from the U.S. Decennial Census’ prior to the policy adoption date for each individual city. We calculated the 5-year deviation in climatic conditions dating back from the policy adoption date, to better characterize conditions that may explain the relationship between policy adoption (or lack thereof) and specific sociodemographic and climatic variables. Figure 2 provides an example of this data collection process. For states having multiple policies, we choose to analyze the first policy adopted by that city (see Figure 2).

The sociodemographic variables we collected included:

• Population. We derived two independent variables from the population data, total population size and population growth rate; the former variable is self-
Figure 2. Sample of policies identified in the Alabama cities of Birmingham, Huntsville, Mobile, and Montgomery. Dark gray indicates variable year differences between the census data and date of policy adoption. Light gray indicates the 5-year short-term climate, which is in our study compared against historic 1901-2015 trends.

explanatory, and the latter was calculated as a city’s growth rate over the last decade preceding policy adoption. For example, if a policy was adopted in 1994, we calculated the growth rate as: \( \frac{\text{pop}_{1990} - \text{pop}_{1980}}{\text{pop}_{1980}} \). For cities without a drought-specific water management policy, the growth rate refers to recent growth: \( \frac{\text{pop}_{2015} - \text{pop}_{2005}}{\text{pop}_{2005}} \).

- **Age.** We recorded age as two distinct variables median age and the percentage of the population which is elderly (> 65 years). An increase in the median age alludes to a changing age distribution in the local population, while an increase in the elderly percentage represents an aging population.

- **Median household income.** We recorded median household income rather than the ‘family’ or ‘individual’ income because a Census designated
‘household’ captures more of the population, including persons living alone, multiple unrelated individuals, and families living together.

- **Poverty.** We recorded poverty rates, which represent the percentage of people whose income fell below the respective poverty threshold. Thresholds are defined federally and updated annually, so there is no geographic variation in this variable. Poverty rates were not recorded for plans developed in the 1950s because the current official poverty measure was not developed until the mid-1960s and adopted in the late 1960s.

- **Educational attainment.** We include educational attainment and report it as the percentage of individuals, aged 25 years old and up, that have completed 4 or more years of college.

### 3.2.3 Climate Variables

We collected all climate data from the Parameter elevation Regression on Independent Slopes Model (PRISM). Due to the spatial and temporal scale of the study, and to determine if short-term variability in precipitation and temperature influence the presence of a drought policy, we report climate values from 1901 to 2015. Except for four cities: Huntsville, AL; Hollywood, FL; Miramar, FL; and Broken Arrow, OK. Each of these cities have adopted a policy in either 2016 or 2017, warranting the use of climate data past 2015. We collected climate data from the PRISM Climate Group (prism.oregonstate.edu), downloading time series values for each city. PRISM uses high resolution grid estimates of daily and monthly data to estimate annual averages measured at scale of 4 km. Annual values from 1901–2015 were collected for three climate
variables: total precipitation \((precipitation)\), mean temperature and maximum temperature. Annual mean temperatures and annual maximum temperatures were averaged from the years 1901–2015 to create historical averages over this period. We subsequently refer to these historical averages as \(mean\ temperature\ HA\) and \(max.\ temperature\ HA\).

To assess how the variability in recent climatic conditions relative to historical averages may have influenced policy adoption, we calculated short-term deviation from long term averages for all three climate variables. Analyzing the variability of annual precipitation and temperature values against long-term trends is considered appropriate for assessing climatic variance of this spatial scale (Cai et al. 2014, Yoon et al., 2015). We used 5-year annual averages to calculate the short-term climatic conditions, while historical climatic conditions are defined in our study as the averages taken from 1901–2015. For example, if a drought plan was adopted in the year 2011, we used climate data from 2007 to 2011 to calculate the variability in recent climatic conditions relative to historical averages. This resulted in the creation of three new variables: recent precipitation deviation from historical average \((precipitation\ DHA)\), recent mean temperature deviation from historical average \((mean\ temperature\ DHA)\), and recent maximum temperature deviation from historical average \((max.\ temperature\ DHA)\). More precisely, the deviation measure was calculated as:

\[
D(clim) = 1 - \frac{(clim_{y1-y2})}{(clim_{y0-yT})}.
\]
Where clim = climatic variable (precipitation, mean temperature, or maximum temperature), \( y_1 \) and \( y_2 \) represent the 5-year interval closest to the policy implementation, \( y_0 = 1901 \) and \( y_t = 2015 \). For cities that were reported as having no policy present, the short-term climatic conditions from 2010–2015 were taken and compared with historical averages.

### 3.3 Analysis

Descriptive statistics for both the dependent and independent variables above are provided in Table 3. To meet the assumptions of a logistic regression model, variables with substantial amounts of skewness or containing outliers were transformed. Table 3 also presents revised descriptive statistics for the variables used. Figure 3 also shows the distribution of independent variables before and after transformation. High skewness is classified as a value less than -1 or greater than +1 and moderate skewness is a value between -1 and -1/2 or +1 and +1/2. Variables are approximately symmetric when skewness values are between -1/2 and +1/2 (Bulmer, 1979). We used these definitions to transform 5 out of the 13 variables that exceeded high skewness boundaries of -1 and +1. Log and square root transformations were used where appropriate. The following variables were normally distributed without transformation: median age, median household income, poverty and all the climate variables except for maximum temperature HA.

Although the dataset includes 308 places across 9 climatic regions, four out of the five climate variables (precipitation DHA, max. temperature DHA, mean temperature...
Table 3

Descriptive Statistics for Independent Variables

<table>
<thead>
<tr>
<th>Type</th>
<th>Variable</th>
<th>N</th>
<th>Mean</th>
<th>Median</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Skewness</th>
<th>Kurtosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dependent</td>
<td>Is there a policy present</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>No (%)</td>
<td></td>
<td>109 (35.4%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Yes (%)</td>
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<td>199 (64.6%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Socio-Demographic</td>
<td>Pop$^1$</td>
<td></td>
<td>306 2</td>
<td>2.62E+05</td>
<td>1.38E+05</td>
<td>1.85E+03</td>
<td>8.01E+06</td>
<td>1.01E+01</td>
</tr>
<tr>
<td></td>
<td>Pop_Log</td>
<td></td>
<td>306 2</td>
<td>5.20</td>
<td>5.14</td>
<td>3.27</td>
<td>6.90</td>
<td>-0.34</td>
</tr>
<tr>
<td></td>
<td>PopGrowth$^2$</td>
<td></td>
<td>301 7</td>
<td>16.02</td>
<td>11.23</td>
<td>-13.03</td>
<td>91.92</td>
<td>1.59</td>
</tr>
<tr>
<td></td>
<td>PopGrowth_Sqrt</td>
<td></td>
<td>264 44</td>
<td>3.96</td>
<td>3.71</td>
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<td>9.59</td>
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<tr>
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<td>Age</td>
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<td>306 2</td>
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<td>32.7</td>
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<td>50.70</td>
<td>0.19</td>
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<tr>
<td></td>
<td>Elderly$^3$</td>
<td></td>
<td>306 2</td>
<td>11.02</td>
<td>10.9</td>
<td>3.10</td>
<td>31.60</td>
<td>1.39</td>
</tr>
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<td></td>
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<td>306 2</td>
<td>1.02</td>
<td>1.04</td>
<td>0.49</td>
<td>1.50</td>
<td>-0.51</td>
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<tr>
<td></td>
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<td>306 2</td>
<td>43.02</td>
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<td>1.60</td>
<td>109.92</td>
<td>0.66</td>
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<tr>
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<td>Poverty</td>
<td></td>
<td>300 8</td>
<td>16.35</td>
<td>15.8</td>
<td>3.10</td>
<td>37.40</td>
<td>0.40</td>
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<tr>
<td></td>
<td>Edu$^4$</td>
<td></td>
<td>295 13</td>
<td>27.72</td>
<td>25.6</td>
<td>6.10</td>
<td>72.90</td>
<td>1.17</td>
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<td></td>
<td>Edu_Log</td>
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<td>295 13</td>
<td>1.40</td>
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<td>1.86</td>
<td>-0.12</td>
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<tr>
<td>Climate</td>
<td>Precipitation DHA</td>
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<td>304 4</td>
<td>-0.01</td>
<td>-0.03</td>
<td>-0.60</td>
<td>0.49</td>
<td>0.32</td>
</tr>
<tr>
<td></td>
<td>Max. Temperature DHA</td>
<td></td>
<td>304 4</td>
<td>-0.01</td>
<td>0.00</td>
<td>-0.04</td>
<td>0.03</td>
<td>-0.27</td>
</tr>
<tr>
<td></td>
<td>Mean Temperature DHA</td>
<td></td>
<td>304 4</td>
<td>-0.01</td>
<td>-0.01</td>
<td>-0.05</td>
<td>0.02</td>
<td>-0.07</td>
</tr>
<tr>
<td></td>
<td>Max. Temperature HA$^5$</td>
<td></td>
<td>306 2</td>
<td>70.81</td>
<td>71.46</td>
<td>6.48</td>
<td>86.32</td>
<td>-1.20</td>
</tr>
<tr>
<td></td>
<td>Max. Temperature HA_Sqrt</td>
<td></td>
<td>306 2</td>
<td>3.89</td>
<td>3.98</td>
<td>1.00</td>
<td>8.99</td>
<td>-0.14</td>
</tr>
<tr>
<td></td>
<td>Mean Temperature HA</td>
<td></td>
<td>306 2</td>
<td>59.94</td>
<td>60.65</td>
<td>41.25</td>
<td>75.93</td>
<td>0.03</td>
</tr>
</tbody>
</table>
1 We use a log transformation on total population. New variable name is Pop_Log.
2 We use a square root transformation on population growth. New variable name PopGrowth_Sqrt.
3 We use a log transformation on the percent of the population which is elderly. New variable name is Elderly_Log.
4 We use a log transformation on education, the percent of population with a bachelor’s degree or higher. New variable name is Edu_Log.
5 We use a reverse square root transformation on the Max. Temperature HA. New variable name Max. Temperature HA_Sqrt.
Figure 3. Distributions of the independent variables with transformations
DHA and mean temperature HA exhibited normal distributions. These findings were not surprising considering values represent annual averages, which minimizes the effects of daily fluctuations. In addition, although the effects would not be large on a dataset of this size, climate data for two of the outstanding places identified by this study, Honolulu, HI and Anchorage, AK, were not included due to missing data.

Some variables such as total population and population growth varied highly amongst cities. The high skewness values are not surprising considering the broad range of populations of the 308 cities. Other variables such as median household income and median age are less variable.

After checking each of the independent variables for normality, we examined a correlation matrix of all the variables (sociodemographic and climatic) to check for high correlations ($r > |0.70|$) and ensure that we were able to meet the assumption of independence and avoid multicollinearity. The correlation matrix is provided in Table 4. Using Pearson’s correlation, the following highly correlating variables were:

- Max. temperature HA and mean temperature HA ($r = 0.902$). Theory does not support one climate variable over the other in relation to policy adoption. However initial analysis shows that mean temperature is a slightly stronger predictor and so we removed maximum temperature HA.

- Max. temperature DHA and mean temperature DHA ($r = 0.719$). Here again, theory does not support one climate variable over the other in relation to policy adoption, however due to high correlation. We removed the max. temperature DHA variable.
Table 4

Correlation Matrix of the Independent Variables

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Pop_Log</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>(2) PopGrowth_Sqrt</td>
<td>-.322*</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(3) Age</td>
<td>0.067</td>
<td>-.239*</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(4) Elderly_Log</td>
<td>0.093</td>
<td>-.372*</td>
<td>.672*</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(5) Income</td>
<td>0.093</td>
<td>-0.121</td>
<td>.420*</td>
<td>0.003</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(6) Poverty</td>
<td>.269*</td>
<td>-.348*</td>
<td>-.120*</td>
<td>.173*</td>
<td>-.412*</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(7) Edu_Log</td>
<td>0.104</td>
<td>-.012</td>
<td>.218*</td>
<td>0.042</td>
<td>.495*</td>
<td>-.231*</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(8) Precipitation DHA</td>
<td>-.132*</td>
<td>0.111</td>
<td>-.039</td>
<td>-.0098</td>
<td>0.083</td>
<td>-.235*</td>
<td>-.180*</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(9) Max. Temperature DHA</td>
<td>-0.083</td>
<td>.211*</td>
<td>0.00</td>
<td>-.0005</td>
<td>-.130*</td>
<td>-.125*</td>
<td>0.041</td>
<td>-.150*</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(10) Mean Temperature DHA</td>
<td>-0.074</td>
<td>.144*</td>
<td>-.160*</td>
<td>-.008</td>
<td>-.373*</td>
<td>0.001</td>
<td>.130*</td>
<td>-.281*</td>
<td>.719*</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(11) Max. Temperature HA_Sqrt</td>
<td>0.109</td>
<td>-.427*</td>
<td>-.001</td>
<td>0.079</td>
<td>0.043</td>
<td>.174*</td>
<td>.181*</td>
<td>-.336*</td>
<td>-.089</td>
<td>0.048</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>(12) Mean Temperature HA</td>
<td>-0.065</td>
<td>.349*</td>
<td>0.037</td>
<td>-.06</td>
<td>-.068</td>
<td>-.120*</td>
<td>-.178*</td>
<td>.336*</td>
<td>.116*</td>
<td>.038</td>
<td>-.933*</td>
<td>1</td>
</tr>
</tbody>
</table>

* Correlation is significant at the 0.05 level (2-tailed).
• Age and Elderly_Log ($r = 0.672$). While this correlation remains below the generally accepted level of 0.7, both variables represent an aging of a population. Previous studies suggest that an elderly population may have a stronger interest in supporting mitigative policies. However initial analysis suggests that median age is a slightly stronger predictor of policy adoption (see Ranks in Table 5), thus the Elderly_Log variable was removed.

In addition to the correlation matrix, individual logistic regressions were run to assess the influence of each independent variable on the probability of a city adopting a drought-specific water management policy. Results from these models can be seen in Table 5. Highly correlated variables and non-significant variables were removed from the model. These included: Elderly_Log, Max. Temperature DHA and Max. Temperature HA_Sqrt. A final multiple logistic regression was created by introducing independent variables in order of their predictive power on policy adoption. This was done by entering first the most explanatory variables and then variables with decreasing R-square values. The final model is expressed as:

\[
P(Y = 1) = F(\beta_0 + \beta_1 \text{poverty} + \beta_2 \text{popgrowth}_{sqr} + \beta_3 \text{age} + \beta_4 \text{income} \\
+ \beta_5 \text{meantempDHA} + \beta_6 \text{meantempHA} + \beta_7 \text{precipitationDHA} \\
+ \beta_8 \text{popLog} + \beta_9 \text{eduLog} + \varepsilon)
\]

Where \(F(z) = \frac{e^z}{1 + e^z}\) is the cumulative logistic distribution.
Table 5

Results of Each Independent Variable Run Through Logistic Regression with the Dependent Variable

<table>
<thead>
<tr>
<th>Rank</th>
<th>Variable</th>
<th>R-Square</th>
<th>B</th>
<th>S.E.</th>
<th>Wald</th>
<th>df</th>
<th>Sig.</th>
<th>Exp(B)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Poverty</td>
<td>0.220</td>
<td>-0.128</td>
<td>0.020</td>
<td>42.282</td>
<td>1</td>
<td>0.000</td>
<td>0.880</td>
</tr>
<tr>
<td>2</td>
<td>PopGrowth_Sqr</td>
<td>0.113</td>
<td>0.396</td>
<td>0.091</td>
<td>18.886</td>
<td>1</td>
<td>0.000</td>
<td>1.485</td>
</tr>
<tr>
<td>3</td>
<td>Age</td>
<td>0.108</td>
<td>-0.153</td>
<td>0.033</td>
<td>21.273</td>
<td>1</td>
<td>0.000</td>
<td>0.858</td>
</tr>
<tr>
<td>4</td>
<td>Income</td>
<td>0.089</td>
<td>-0.032</td>
<td>0.008</td>
<td>17.945</td>
<td>1</td>
<td>0.000</td>
<td>0.968</td>
</tr>
<tr>
<td>5</td>
<td>Mean Temperature DHA</td>
<td>0.048</td>
<td>29.891</td>
<td>9.309</td>
<td>10.311</td>
<td>1</td>
<td>0.001</td>
<td>9.58E+12</td>
</tr>
<tr>
<td>6</td>
<td>Mean Temperature HA</td>
<td>0.045</td>
<td>0.050</td>
<td>0.016</td>
<td>9.835</td>
<td>1</td>
<td>0.002</td>
<td>1.051</td>
</tr>
<tr>
<td>7</td>
<td>Precipitation DHA</td>
<td>0.043</td>
<td>2.490</td>
<td>0.827</td>
<td>9.059</td>
<td>1</td>
<td>0.003</td>
<td>12.061</td>
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<tr>
<td>8</td>
<td>Pop_Log</td>
<td>0.033</td>
<td>-0.848</td>
<td>0.325</td>
<td>6.824</td>
<td>1</td>
<td>0.009</td>
<td>0.428</td>
</tr>
<tr>
<td>9</td>
<td>Edu_Log</td>
<td>0.008</td>
<td>-0.815</td>
<td>0.640</td>
<td>1.625</td>
<td>1</td>
<td>0.202</td>
<td>0.442</td>
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</table>
CHAPTER IV
RESULTS

Results from each iteration of the logistic regression model, adding additional independent variables in decreasing order of their predictive power, are shown in Table 6. Our model shows consistent trends in significance and directionality of all but one of the variables, population growth, across model iterations and so we interpret only the final model. The population growth variable loses significance in the second iteration and changes sign as other independent variables are added, suggesting that there may be a window of opportunity while a society is growing to better develop and adopt certain mitigation policies.

All the estimated coefficients shown in Table 6 are presented as log-odds; they should be interpreted as the change in the log-odds of a city adopting a drought-specific water management policy given a 1%-unit change in any given independent variable, holding other independent variables constant.

The final iteration of the model indicates that select sociodemographic and climate variables including: poverty, age, income, mean temperature HA, and precipitation DHA significantly affect the adoption of a drought-specific water management policy across large U.S. cities. Our model predicts the outcome moderately well, accounting for 74.4% of the variability in the response data. A city’s poverty rate had the largest effect on the adoption of a drought-specific water management policy. Specifically, a 1% increase in the poverty rate resulted in a .583% decrease in the log-odds of adopting a policy ($\beta = -.582, p < 0.000$).
Table 6

*Multiple Logistic Regression Model*

<table>
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<tr>
<th>Model Iterations</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
<th>(6)</th>
<th>(7)</th>
<th>(8)</th>
<th>(9)</th>
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<tbody>
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<td>-.148**</td>
<td>-.132**</td>
<td>-.208**</td>
<td>-.530**</td>
<td>-.535**</td>
<td>-.548**</td>
<td>-.550**</td>
<td>-.550**</td>
<td>-.583**</td>
</tr>
<tr>
<td></td>
<td>(0.024)</td>
<td>(.024)</td>
<td>(.03)</td>
<td>(.075)</td>
<td>(.076)</td>
<td>(.078)</td>
<td>(.081)</td>
<td>(.082)</td>
<td>(.088)</td>
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<tr>
<td>PopGrowth_Sqrt</td>
<td>.278**</td>
<td>.150</td>
<td>-.081</td>
<td>-.104</td>
<td>-.262</td>
<td>-.266</td>
<td>-.267</td>
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<tr>
<td></td>
<td>(.107)</td>
<td>(.115)</td>
<td>(.135)</td>
<td>(.137)</td>
<td>(.153)</td>
<td>(.156)</td>
<td>(.158)</td>
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<td>-.453**</td>
<td>-.447**</td>
<td>-.447**</td>
<td>-.465**</td>
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<tr>
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<td>(.052)</td>
<td>(.071)</td>
<td>(.073)</td>
<td>(.077)</td>
<td>(.079)</td>
<td>(.079)</td>
<td>(.082)</td>
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<td>-.171**</td>
<td>-.161**</td>
<td>-.170**</td>
<td>-.170**</td>
<td>-.201**</td>
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<tr>
<td></td>
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<td>(.032)</td>
<td>(.032)</td>
<td>(.035)</td>
<td>(.035)</td>
<td>(.041)</td>
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<td></td>
<td></td>
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<tr>
<td>DHA</td>
<td>26.098</td>
<td>32.582</td>
<td>49.080*</td>
<td>49.211*</td>
<td>35.955</td>
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</tr>
<tr>
<td>Mean Temperature</td>
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<td>HA</td>
<td>.099**</td>
<td>.072*</td>
<td>.072*</td>
<td>.075*</td>
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<td></td>
<td>(.032)</td>
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<tr>
<td>Precipitation</td>
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<td>3.545*</td>
<td>4.259*</td>
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<tr>
<td>DHA</td>
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<td>(1.763)</td>
<td>(1.859)</td>
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<td>Pop_Log</td>
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<td></td>
<td>(0.635)</td>
<td>(0.648)</td>
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<td>Edu_Log</td>
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<td>2.741</td>
<td>(1.559)</td>
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<tr>
<td>Constant</td>
<td>3.016**</td>
<td>1.751**</td>
<td>13.463**</td>
<td>31.353**</td>
<td>32.301**</td>
<td>28.401**</td>
<td>30.630**</td>
<td>30.775**</td>
<td>29.734**</td>
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<td></td>
<td>(0.429)</td>
<td>(.625)</td>
<td>(2.182)</td>
<td>(4.730)</td>
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<td>(4.783)</td>
<td>(5.258)</td>
<td>(6.205)</td>
<td>(6.363)</td>
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<td>R-Squared</td>
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<td>.286</td>
<td>.455</td>
<td>.691</td>
<td>.698</td>
<td>.725</td>
<td>.736</td>
<td>.736</td>
<td>.744</td>
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</table>

*Significance at .05 level; **Significance at .01 level*
Of the remaining sociodemographic variables, a city’s median age ($\beta = -0.465, p < 0.000$) and median household income ($\beta = -0.201, p < 0.000$) were significantly and negatively related to probability of it having adopted a drought-specific water management policy. A 1% increase in the median age of a city was associated with a 0.465% decrease in the log-odds of having a drought-specific water management policy. Similarly, a 1% increase in a city’s median household income was associated with a 0.201% decrease in the log-odds of having a drought-specific water management policy.

The total population of a city ($\beta = -0.138, p = 0.832$) as well as the proportion of a city’s adult population with at least a 4-year college degree ($\text{Edu}_{\log}, \beta = 2.741, p < 0.079$) were not significantly related to probability of a city having adopted a drought-specific water management policy. Excluding the nonsignificant variables, total population ($\text{Pop}_{\log}$) and education ($\text{Edu}_{\log}$), the sociodemographic variables show a consistent and negative association with the adoption of a drought-specific water management policy. An increase in a city’s poverty rate, median age, and median household income are all associated with a decreased probability of that city adopting a drought-specific water management policy.

Results from the climate variables are also shown in Table 6. The deviation of recent mean temperatures from the historical average ($\text{Mean Temperature DHA}, \beta = 35.955, p = 0.094$) had no effect on the probability of a city adopting a drought-specific water management policy. However, both the historical average of mean temperatures ($\text{Mean Temperature HA}, \beta = 0.075, p = 0.036$) and the deviation of recent precipitation from the historical average ($\text{Precipitation DHA}, \beta = 4.249, p = 0.022$) were significantly and positively related to the probability of a city adopting a drought-specific water management policy. In contrast to what we
had expected to see, a 1% increase in the deviation of recent precipitation from the historical average was associated with a 4.25% increase in the log-odds of a city adopting a drought-specific water management policy. Additionally, a 1% increase in the historical average of mean temperatures was associated with a .075% increase in the log-odds of adopting a policy. Collectively the climate variables, except for the deviation of mean temperatures from the historical average, were positively associated with the probability of a city adopting a drought-specific water management policy.
Drought policy has become increasingly important for mitigating the negative impacts that drought can have on social and ecological systems (Wilhite, 2012; Wilhite et al., 2014). Drought conditions are expected to increase in both intensity and frequency over the coming decades as average air temperatures rise and precipitation becomes more variable (Bates, Kundzewicz, Wu, & Palutikof, 2008; IPCC, 2014). Populations exposed to drought conditions are simultaneously expected to increase as population growth intensifies in cities (Schewe et al., 2014; Smirnov et al., 2016). Drought-specific water management policies are one key way that cities can decrease the vulnerability of their inhabitants and ultimately, create a more resilient governance structure. Understanding the factors that significantly increase the likelihood of cities adopting drought-specific water management policies allows us to inform cities, states and the federal government about where policy development efforts need to be focused in the years to come.

In this study, we have assessed the underlying factors that may increase or decrease the ability of large U.S. cities to adopt policies related to drought mitigation, adaptation and management. Our findings revealed that poverty, median household income and median age are the sociodemographic factors that significantly affect the likelihood of a city to adopt drought related policies. Meanwhile population size and growth, as well as education do not. Previous social science literature suggests sociodemographic factors shape the capacity of large urban populations to adapt to climate change (Cutter et al., 2003; Güneralp et al., 2015; Ivey, Smithers, Loë, &
Kreutzwiser, 2004). Our findings also revealed that cities that have experienced larger variations in precipitation over the 5 years before a drought policy was adopted are more likely to have adopted drought-specific water management policies. Similarly, cities in warmer climatic zones are more likely to have adopted drought-specific water management policies. Previous literature suggests that climatic factors, like recent deviations in precipitation and historical temperatures, are important factors affecting the likelihood of cities to adopt climate policies (Baker et al., 2012; Zahran, Brody, et al., 2008) We discuss each of the sociodemographic and climatic factors found to be significantly related to the probability a city had adopted a drought-specific water management policy.

5.1 Sociodemographic Variable Findings

We found poverty to be the most influential factor influencing the probability that a city had adopted a drought-specific water management policy. This finding confirms previous studies which have demonstrated increases in poverty rates are negatively related to city’s ability to implement climate related policies (Krause, 2011; Zahran, Brody, Grover, & Vedlitz, 2006). The significant relationship between poverty and drought policy underscores the importance of a population’s financial well-being and their capacity to adapt to climate change (Cutter et al., 2003). Poverty is a complex phenomenon that is highly correlated with a variety of economic growth well-being issues such as insufficient transportation and the lack of adequate health and education services (Morrow, 1999). Consequently, it is highly likely that populations living in cities with higher poverty levels are not only exposed to more climatic risks by not having a
drought-specific water management policy in place, but also because they lack the adequate infrastructure and social services necessary to adapt.

We also found a significant relationship between income and the probability that a city had adopted a drought-specific water management policy. Unexpectedly however, our findings suggest that cities with higher median household incomes, as opposed to lower, are less likely to adopt policies that target the negative impacts of drought. While this does not meet initial expectations based on previous literature (Cutter et al., 2003; Zahran, Brody, et al., 2008) this relationship may be indicative of higher-earning households having less perceived risk/social vulnerability to hazard events (Çarkoğlu & Kentmen-Çın, 2015; Pattanayak & Kramer, 2001). Thus, it is possible that policy adoption is of less concern to cities with higher-earning households despite the fact that they have larger financial capacity to adopt drought policy. Further analysis is needed to assess if factors outside of the scope of this study influence income and the likelihood of policy adoption. Nevertheless, previous literatures suggests that economic development activities, such as poverty reduction programs as well as efforts to increase the median income within a city via housing and transportation development, job stability and social welfare plans (Cutter, Mitchell, & Scott, 2000; Morrow, 1999) likely have the greatest influence on improving societal capacity to address the negative consequences of drought.

We also found median age to be a significant factor in determining cities’ likelihood for adopting drought-specific water management policies. Cities that have a younger population are more likely to adopt drought-specific water management policies. This finding contradicts previous studies suggesting cities with large elderly populations
are more likely to adopt climate related policies (Bishop, 2013). This is unexpected given older individuals are more vulnerable to the negative consequences of drought events (Cutter et al., 2003; Gamble et al., 2013; Zimmerman et al., 2009). Our analysis suggests that greater proportions of younger individuals are more likely to have the social and political capacity to introduce and adopt drought-specific water management policies (Peek, 2008). These findings support previous work suggesting younger populations are more directly engaged with climate change-related policy while elderly populations face social and political barriers (Hamilton, 2011; Ngo, 2001).

Finally, we found that population size, population growth rate and education do not affect the likelihood of a city adopting a drought-specific water management policy. These results are somewhat unexpected, as previous studies related to both population size and population growth rate highlight the importance of these factors in increasing/decreasing social vulnerability to natural hazards (Güneralp et al., 2015; Vörösmarty, Green, Salisbury, & Lammers, 2000). Cities with larger populations as well as cities that are growing at a more rapid rate, have more individuals exposed to variable climate and increasing drought conditions (Smirnov et al., 2016). However, similar to increased poverty rates, increases in population size and population growth rate may reduce the ability of cities to allocate resources to drought policies as other priorities, such as infrastructure development and health and education spending, take precedent (Brown, 2015). Our finding of no significant relationship between education and policy adoption is also unexpected as previous studies indicated higher levels of education to increase engagement in the policy process, as well as awareness of climate change and
the importance of adaptation and mitigation to climatic changes (Krause, 2011; Morrow, 1999; Striessnig, Lutz, & Patt, 2013; Zahran, Grover, et al., 2008).

Taken together, these findings suggest that cities making notable headway to alleviate poverty and attract younger in-migrants are the most likely to develop and adopt drought-specific water management policies in the future, and consequently reduce their social vulnerability to natural hazards (Güneralp et al., 2015; Morrow, 1999). More generally, these findings demonstrate that the sociodemographic and economic composition of a city plays a significant role in whether or not a city will be likely to set in place drought policies and management frameworks that reduce the vulnerability of its inhabitants to the negative consequences of climate change.

5.2 Climatic Variable Findings

While sociodemographic factors are key factors influencing a city’s capacity to adopt drought-specific policies, our analysis also revealed that climatic factors play a significant role. More precisely, cities which have recent precipitation rates that deviate substantially from the historical average as well as cities in warmer climates, are more likely to have adopted a drought-specific water management policy. Previous research suggests that cities in warmer climates, as well as those which have more variable annual precipitation patterns are more likely to adopt climate change-related policies (Eriyagama et al., 2009; Howe, Markowitz, Lee, Ko, & Leiserowitz, 2012).

Regarding the finding of a significant relationship between recent deviation in precipitation from the historical average and drought-specific water policy adoption, it is possible that because more variable patterns in recent precipitation are a clear sign of a
more “risky” climate, people living in the cities experiencing these conditions may be acting through the policy process to avoid expected future risks (Kahneman & Tversky, 2012; Rabin, 2003). The adoption of drought-specific policy potentially lessens risk of variable precipitation by mitigating the impact of costly drought to communities and economies (Kasprzyk, Reed, Kirsch, & Characklis, 2009). The risk-drought policy adoption relationship is also highlighted by the significant relationship between cities with warmer climates and drought-specific water policy adoption. Such relationship is related to the fact that increased average temperatures contribute to increased drought occurrence (Dai, 2013; Dai, Trenberth, & Qian, 2004; Vicente-Serrano, Beguería, & López- Moreno, 2009).

Changes in climate exacerbate the frequency and intensity of drought by creating a feedback loop for drought conditions (Carpenter & Brock, 2008; Easterling & Evans, 2000). While our findings suggest that greater variability in recent precipitation as well as warmer climates will increase the probability of a drought-specific water management policy being adopted, climate predictions across the contiguous U.S. remain variable and uncertain (IPCC, 2014; Schewe et al., 2014) making it difficult to apply our findings of climate characteristics to probabilistic forecasting of policy adoption. Future studies might reconsider the relationship between seasonal climate and policy adoption with respect to spatial distribution across the U.S.
5.3 Policy Implications

5.3.1 National and City Level Policy Recommendations

The fact that we are able to analyze the creation of over 150 drought-specific water management policies across 308 U.S. cities highlights the progress that major urban areas in the U.S. have made in adopting proactive strategies despite absent and insufficient state and national legislation. We have discovered significant factors that can be incorporated into more proactive drought planning, future drought policy monitoring, risk and impact assessments, and responses to drought events (Wilhite et al., 2000).

These findings build on previous literature suggesting that efforts to decrease society’s vulnerability to future drought will need to apply holistic policy frameworks (Dascher, Kang, & Hustvedt, 2014; Hurlbert & Gupta, 2016; Orach & Schlüter, 2016; Wilhite et al., 2007). The findings presented here establish that targeting specific sociodemographic and climatic factors can significantly influence the likelihood of cities to adopt a drought-specific water management policy.

Through this study, we recognize the potential of city level drought-specific policies to fuel bottom-up policy reactions in the U.S. (L. C. Botterill, 2013; Sabatier, 1986). Given that city-level policy is often effective, but limited in its ability to work across large spatial scales and competing interest groups, drought policy planning, monitoring and response should be coordinated across city, state and national levels (Wilhite, 1991, 2014; Wilhite et al., 2007). Previous literature suggests city-level policies focusing on community-based management can galvanize change through stakeholder involvement and network expansion (Tompkins & Adger, 2004). For example, in the
case of Georgia, it was the engagement and input of 100 local stakeholders that enabled the state to create its first statewide drought plan (Steinemann & Cavalcanti, 2006). Important drought indicators and monitoring methodology from local drought plans were used to inform the development of Georgia's drought plan. Drought plans, and plans related to reducing the impact of natural hazards more generally, should be considered “nested”, that is local plans should be considered within regional and federal plans so as to correctly address different segments of the population and economic sector at the appropriate scale (Cutter et al., 2003; Krause, 2011; Wilhite et al., 2014).

The adoption of a national drought policy in the U.S. would create a much needed framework for state and local governments to monitor, mitigate and respond to drought events (Wilhite, 2014). As well, it would help shift the framing of drought events from that of reactive crisis management to a more proactive management approach (Wilhite et al., 2000). Examples of successful national drought policy adoption have been noted in countries such as Australia where drought conditions are comparable to the U.S. (Wilhite, 1986). Australia’s approach to a national drought policy focuses on preparedness and risk management across states and agencies while the U.S. approach still relies heavily on post-disaster assistance and heterogeneous state and local policies (Botterill, 2003; Botterill & Hayes, 2012). Despite our findings, which support that local-level drought policies are present even under the absence of a national drought policy, the need for a national framework in the U.S. is evident due to increasing amounts of social vulnerability directly correlating to increasing population sizes and changing climatic conditions. Over the course of 15 years, from 2000 to 2015, 63 cities have grown to a population of 100,000 or more persons. Totaled with the existing 245 cities at this
population threshold, this number results in the 308 places included in our study. Consequently, over 25% of the cities we assessed had populations reach 100,000 only in the last 15 years. In another 15 years, this number could again drastically increase, heightening the urgency of adaptation and mitigation policies to naturally occurring events such as drought. The current incremental policy approach utilized to address drought policies in the U.S., while it has generated useful drought monitoring tools, has also proven less effective than Australia’s top-down policy approach (Botterill, 2013; Lindblom, 1979). To effectively address societal capacity and other factors influencing the likelihood of cities to create and adopt drought specific policies, the U.S. needs a national drought policy in place.

5.3.2 Targeting Specific Policy Implementation Strategies

Poverty Reduction. Our research builds upon previous literature highlighting the relationship between poverty and vulnerability. More precisely, during times following a natural hazard (e.g., a drought), there is a clear risk of falling into a poverty trap (Carpenter & Brock, 2008). In this case, the poverty trap relates to the fact that drought hits more vulnerable communities harder given vulnerable communities are often poor and lack financial and human resources to adapt and mitigate drought effects. At the same time, drought effects can exacerbate the lack of finances and human resources, weakening the existing infrastructure, and forming a continuous cycle in which poverty augments the effects of natural hazards, and natural hazards increase poverty. As such, long-term investments in poverty alleviation are needed. Poverty reduction programs following natural hazards are often focused on short-term solutions. For example,
housing incentives following a natural hazard keep low-income households in vulnerable locations despite the risk, while higher-earning households use financial capacity to relocate to less vulnerable locations (McCaughey, Daly, Mundir, Mahdi, & Patt, 2018). Also ineffective are crisis assistance programs that dissuade the adoption of mitigation or adaptation strategies to future vulnerability by focusing on immediate economic infusion (Comfort et al., 1999; Martine & Guzman, 2002). Moving forward, enabling long-term strategies that are able to improve economic development, and thus reduce poverty and increase median income, will increase the ability of communities to mitigate or adapt to future natural hazards (i.e., droughts) (Brooks, Grist, & Brown, 2009; Kreimer & Arnold, 2000).

In addition to poverty reduction, our research builds upon previous literature highlighting the relationship between increasingly variable annual precipitation and vulnerability. Similar to poverty, there is a clear risk of falling into a “trap” created by a deviation in precipitation from historical averages (Carpenter & Brock, 2008). In this case, the trap refers to the effect of unpredictable rainfall patterns on drought conditions in maladapted communities and ecosystems. Globally, interannual precipitation variability has been connected to increasing incidents of high rainfall events and a decrease in the total number of rain days in a year (Batisani & Yarnal, 2010; Donat et al., 2013). Thus, despite increases in cumulative annual rainfall, social and ecological systems can be stressed similarly to the way in which they would be under drought conditions. Variability in precipitation patterns contribute to unexpected water shortages and economic stress on industries such as agriculture and energy (Dijk et al., 2013; Narisma, Foley, Licker, & Ramankutty, 2007). Moving forward, while policies cannot be
directly enacted to mitigate deviations of precipitation from historical norms, drought policies that address the drivers/impacts of climate change and water scarcity measures will increase the ability of communities to respond to future incidents of drought.

5.4 Limitations

Our research assumes a very broad definition of drought. Previous studies have found that type of drought may influence the type of policy response adopted (Fu & Tang, 2013; Huang et al., 2017; Medd & Chappells, 2007). Therefore, significance of factors identified in this study may be affected by drought type.

Additionally, methodology in this study assumed all city-level drought-specific water management plans are publicly available. This has the potential to overlook drought-specific water management strategies implemented by non-governmental organizations, non-profit agencies and other public-private partnerships. Further development of the database might address this by including a more extensive search of local agencies. Following this, research might then compare the diverse types of plans collected. Understanding the differences between an explicit drought plan against a general plan that includes only a drought clause or chapter could prove to be pertinent in drawing any conclusions on how drought is being managed not only by specific cities, but also the larger geopolitical contexts in which they operate (Glickman et al., 2000).

Finally, with respect to temperature and precipitation, our analysis did not take into account seasonal variability. Precipitation was collected as a cumulative annual value, while temperature was collected as an annual average value, which may obscure month-to-month fluctuations. Previous studies address the importance of interannual
variation in temperature and precipitation variables on understanding and predicting future drought events (Dai, 2013; Dai et al., 2004; Eriyagama et al., 2009; IPCC, 2014). Further study should address the relationship between interannual climatic change and drought-specific policy adoption as it may differ from this study.
CHAPTER VI

CONCLUSION

Drought is a unique hazard affecting much of the world’s inhabitants. Previous studies have stated that the best approach for mitigating the negative effects of future drought conditions are through the adoption of proactive policies (Wilhite, 1991; Wilhite et al., 2014). In this research, we have identified select sociodemographic and climate factors significantly increasing a city’s likelihood for adopting proactive drought-specific policy; these factors include poverty, income, age, deviation of recent precipitation levels from historical averages and long-term mean temperature averages. We have found these factors to significantly shape major U.S. cities’ capacity for decreasing social vulnerability to drought through the adoption of drought-specific water management policies.
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APPENDICES
APPENDIX A

U.S. DROUGHT POLICY HISTORY DETAILS (SECTION 2.1, TABLE 1)

- **1988 – 2002** The International Drought Information Center (IDIC) founded in the former Department of Agricultural Meteorology at the University of Nebraska-Lincoln.

- **1995** The National Drought Mitigation Center (NDMC) established at the University of Nebraska-Lincoln to help reduce social vulnerability to drought, succeeds the IDIC.

- **1997 – 1999** The Itern Drought Coordination Council (WDCC) is formed. Numerous state and federal agencies sign the Memorandum of Understanding (MOU) to formally establish a more comprehensive, integrated response to drought emergencies and cooperatively plan for future droughts (in particular respect to the landscape of the Ist). To date, a work plan for the Council has been developed, a steering body has been formed and 4 working groups established. The council is co-chaired by the governor of New Mexico and the Secretary of Agriculture. The work group co-chair selections were limited to those agencies (state, federal, tribal) that signed the original MOU. The 4 working groups include;
  
  - Preparedness and Mitigation Working Group
  - The Monitoring, Assessment and Prediction Working Group
  - The Response Working Group
  - The Communications Working Group
• **1998** The National Drought Policy Act of 1998 is enacted following recommendations from the Itern Governors’ Association (Public Law 105-199). The bill passed by Congress recognizes that the “United States often suffers serious economic and environmental losses from severe droughts and there is no coordinated Federal strategy to respond to such emergencies” [P.L. 105-199 (105th Congress)]


• **1998 - 2000** Through the creation of the National Drought Policy Act of 1998, The National Drought Policy Commission (NDPC) is established. In accordance with Public Law 105-199 the commission is composed of 15 members, representative of all levels of government and other drought impacted groups, and is charged by Congress to provide advice and recommendations on the creation of an integrated, coordinated Federal policy designed to prepare for and respond to serious drought emergencies.


• **2002** A bill to establish a National Drought Preparedness Act is introduced in the U.S. Congress. The purpose of this bill is to “improve national drought preparedness, mitigation, and response efforts”. **The bill was not enacted** (National Drought Preparedness Act of 2002 [S.2528 (107th Congress)])
• **2003** A bill to establish a National Drought Preparedness Act is re-introduced in the U.S. Congress. The bill was not enacted (National Drought Preparedness Act of 2003 [S.1454 (108th Congress)])

• **2005** A bill to establish a National Drought Preparedness Act is re-introduced in the U.S. Congress. The bill proposes to establish a National Drought council within the Department of Agriculture and to “improve national drought preparedness, mitigation, and response efforts, and for other purposes”. The bill was not enacted (National Drought Preparedness Act of 2005 [S.802, H.R.1386 (109th Congress)]);

• **2006** National Integrated Drought Information System (NIDIS) Act is enacted by the U.S. Congress (Public Law 109-430). NIDIS and its implementation embark under the leadership of the National Oceanic and Atmospheric Administration (NOAA) in collaboration with other federal partners, national and regional organizations, and states. Their mission is to enhance observation networks, monitoring, prediction and information delivery of drought information. Authorization expires in 2012. [P.L. 109-430 (109th Congress)]

• **2007** NIDIS launches the online portal Drought.gov to provide coordinated federal drought monitoring and research presence

• **2012** Drought Information Act is introduced in the U.S. Congress to reauthorize the NIDIS, and for other purposes. The bill was not enacted. (Drought Information Act of 2013 [S.3584 (112th Congress)])

• **2013** Drought Information Act is re-introduced in the U.S. Congress to reauthorize the NIDIS, and for other purposes. Amends the NIDIS Act of
2006 to specify that; (1) the Under Secretary of Commerce for Oceans and Atmosphere shall continue to support the NIDIS program and (2) the program’s purpose shall be to better inform and provide for more timely decision making to reduce drought related impacts and costs. **The bill was not enacted, but provisions of the bill were incorporated into other bills which were enacted.** (Drought Information Act of 2013 [S.376 (113th Congress)]

- **2013** The National Drought Resilience Partnership (NDRP) is established as part of President Obama’s Climate Action Plan to build national capabilities for long-term drought resilience. The lead agencies involved include:
  - United States Department of Agriculture (USDA)
  - National Oceanic and Atmospheric Administration (NOAA)
  - Department of the Interior (DOI)
  - Assistant Secretary of the Army for Civil Works (Army Corps of Engineers)
  - The Federal Emergency Management Agency (FEMA)
  - The Environmental Protection Agency (EPA)
  - U.S. Department of Energy (DOE)

- **2014** NIDIS Reauthorization Act of 2014 enacted after being signed by the President in March 2014 (Public Law 113-86). Allows provisions from the Drought Information Act of 2013 and amends the NIDIS Act of 2006 to specify that the NIDIS programs’ purpose shall be to better inform and
provide for more timely decision making to reduce drought related impacts and costs. (National Integrated Drought Information System Reauthorization Act of 2014 [H.R. 2431 (113th Congress)])

- **2016** Presidential Memorandum signed, tasking the National Drought Resilience Partnership (NDRP) to work collaboratively to deliver on a Federal Action Plan, to help communities manage the impact of drought by linking information, such as forecasts and early warning, with drought preparedness strategies in critical sectors like agriculture, municipal water systems, tourism and transportation.
APPENDIX B

POLICY IDENTIFICATION (SECTION 3.2.1)

Drought specific plans that address adaptation strategies in the face of limited water resources in the United States.

1. Presence of a search term. We use quotations (“”) on the search terms and conjunction words ‘and’ and ‘or’ to limit search results to documents where search words appear next to one another. For example, the phrase “drought” or “sustainability” and plan will search for ‘drought and plan’ and ‘sustainability and plan’ respectively. The terms ‘plan’ and ‘policy’ are excluded from quotations because they are not all-encompassing terms for policy documents, which can also be filed as ordinances, resolutions and other city specific titles.
   a. Drought
   b. Sustainability
   c. Climate Adaptation
   d. Climate Mitigation
   e. Water Conservation

In a few select cases, no city official website was available. Absence of an official website typically indicated that the city is labeled as a Census-Designated Place (CDP), an area with a settled concentration of population used for Census purposes, but not legally incorporated as place under the laws of the state in which they are located (U.S. Census Bureau, 2012).
2. Document inclusion/exclusion
   a. Documents included when they appear on the first page of search term results. Documents not pulled up in this first page were often found in subsequent searches under other included search terms.
   b. Documents excluded when use of the search term in the document is in a different context from that intended by the study.
   c. Documents excluded when the resulting document is a report, slideshow, program or other informal exchange between individuals (i.e. not an official or enforceable document).

4. Redundancy
   a. If multiple chapters appear under the same plan, attach the complete plan and not links to all subsequent chapters.

5. Policy Adoption Year
   a. The years mentioned in the title of the document may not match up with the actual publication date of the document.
   b. Record original adoption date of the document. If newer versions of the same policy exist, keep the latest version and include both the dates of the earlier version and later version.
      1. E.g., Torrance, California has a 2010 and 2015 Urban Water Management Plan. List the earlier date, 2010, as the adoption date and the later date, 2015, as the most recent update. Link the 2015 plan.