The Influence of Climatic Conditions, Demographic Variations, and Water Demand Management Policy on Domestic Per-Capita Water Use in the United States

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Abstract

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Very little is known about how water use differs in various climatic regions. Many studies have been done on the topic of water resources and climate change, but they mainly emphasize on how the changing climate affects water quality. When water quality is decreasing, the quantity of water supply will be affected as well. Balancing water supply and water demand is very critical for sustainable development, because the wellbeing of human lives and sensitive ecosystems depend on reliable water sources.

This paper explores the pattern of domestic per-capita water use in various climatic regions and the influence of climatic conditions, demographic variations, and demand management policies on water use. My research focuses on nine climatic regions across the U.S. I focus my research

around the following questions: 1) how does per-capita domestic water use vary across various climatic regions, 2) how do the various water demand management policies vary across climatic regions, and 3) how do climatic conditions, demographic factors, and water demand management policies relate to domestic per-capita water use?

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Chapter 1. Introduction

1.1 Thesis Statement

Increasing greenhouse gases from anthropogenic activities have contributed to the rise of global temperatures and scientists are strongly convinced that the trend will continue.[1] Shrinking glaciers, rising sea level, and changing weather patterns are observable effects of climate change on the natural environment. The extent on how climate change affects our environment and humans varies by region, and its resilience in adapting to changes. Increasing temperature can provide beneficial impacts in some regions and adverse effects in others. The Intergovernmental Panel on Climate Change states that "If taken as a whole, the published evidence indicates that the net damage costs of climate change are likely to be significant and to increase over time."[2]

Among all the sectors affected by the changing climatic conditions, the impacts on water resources are substantial. Reginal water supply is likely to decrease, while water demand increases as temperature rises. The evaporation rate of water increases as temperature rises, which results in more severe and longer drought seasons. Rising temperatures also causes glaciers to melt faster with potential devastating effects on freshwater storage since glaciers cannot be restored once they melt out. Increasing temperature alters the water cycle. More precipitation occurs as rain rather than snow during winter. Less snowpack results in water shortages during spring and summer times and there would not be enough rainfall to resupply aquifers and reservoirs. Regions relying on glaciers and snowmelt as water sources will experience more frequent and longer water shortages.

[1] NASA, "The Consequences of Climate Change," last updated April 24th, 2017. https://climate.nasa.gov/effects/.
[2] Intergovernmental Panel on Climate Change 2007, "Climate Change 2007: Impacts, Adaptation and Vulnerability." Cambridge University Press, Cambridge, UK, p.17.

Areas affected by water shortages include energy production, agriculture, and human health. Figure 1 illustrates the trends of water withdrawals by water use category from 1950-2010. Thermoelectric power, irrigation, and public supply are the largest categories of water use. In 2010, the water withdrawal for thermoelectric power had decreased drastically in comparison to 2005. Water withdrawal for irrigation has shown a steady decline since 2000, while public supply water use increased. This increasing trend in public supply water use is in agreement with Table 1, which demonstrates the trend of percentage of population getting water from public supply systems. From 1955 to 2010, there was a 16% increase of people served by public supply water systems, while there was a 16 % decrease of people consuming their own water source.

Figure1. Trends in total water withdrawals by water-use category

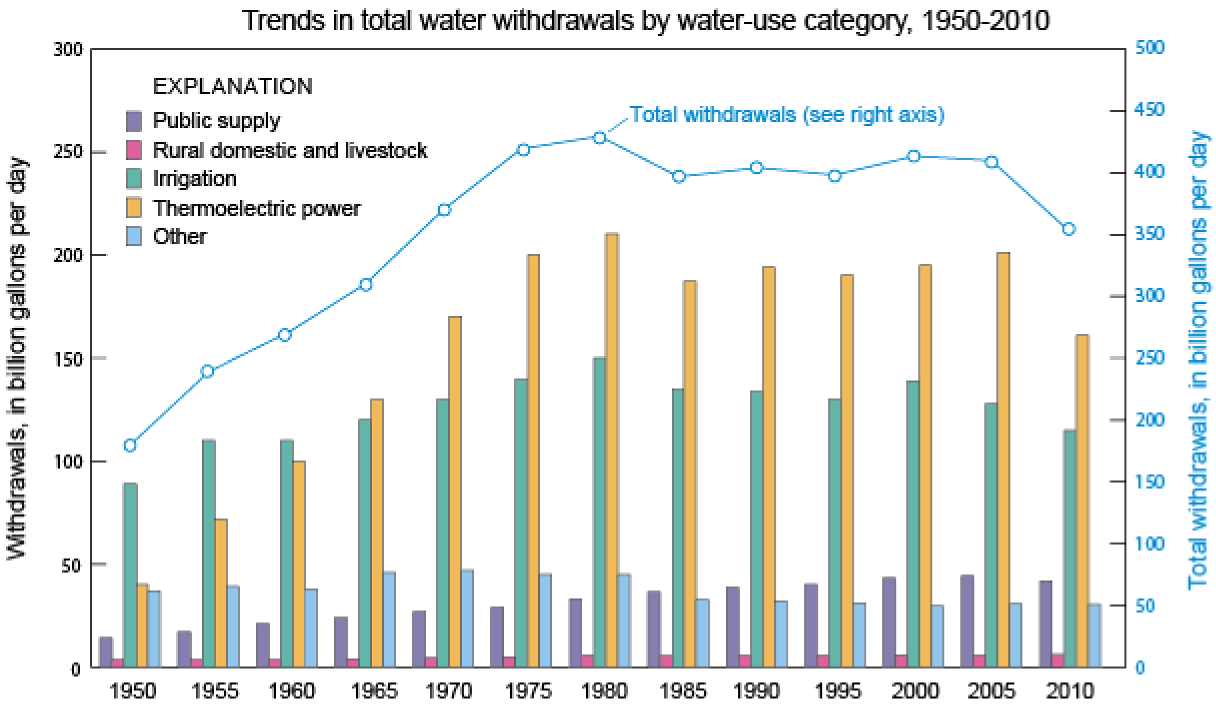

Image Courtesy: USGS, "Trends in total water withdrawals by water-use category," last modified December 9th, 2016. https://water.usgs.gov/watuse/wutrends.html.

Table 1. Public-supplied and self-supplied populations as percent of total population, in the U.S. from 1955-2-10.

	1955	1960	1965	1970	1975	1980	1985	1990	1995	2000	2005	2010
Population	164.0	179.3	193.8	205.9	216.4	229.6	242.4	252.3	267.1	285.3	300.7	313.0
Public supply	70	76	79	80	81	81	83	83	84	84	86	86
Self supply	30	24	21	20	19	19	17	17	16	16	14	14

Image Courtesy: USGS, "Trends in domestic water use, 1955-2010," Las modified December 9th, 2016. https://water.usgs.gov/edu/wudo.html.

As more people move into cities from rural areas, public and private agencies expand their water supply systems to deliver water to a growing population. Early urban water supply systems are managed through supply-side strategy, which focuses on the expansion of water sources and water infrastructure systems to meet the increasing water demand. When water demand exceeds water supply, supply-side management seeks engineering solutions to solve water issues. Supply-side management builds massive water infrastructure to meet growing water demand. For instance, the California State Water Project built complex water delivery systems to distribute water for urban and agricultural uses in Northern California. However, building such massive of an infrastructure has come at irreversible social and environmental costs. As mentioned, water supplies are increasingly stressed due to climate change. Population growth and urbanization places additional burdens on already stressed water supply. With over 50% of renewable and accessible water sources having been exhausted by human,[3] it becomes more and more impractical to acquire new sources for water. Thus, focusing on water demand management becomes a more realistic approach in the light of changing climate and increasing population.

As opposed to the supply-side management, the demand-side management strategy aims to sustain the current water supply. Implementing water conservation plans, promoting water use efficiency, and setting incremental water prices are some of the typical demand-side water management strategies that aim to achieve water savings. However, very little is known on how these strategies actually influence water use. In this study, I explore the patterns of water usage and the strategies for demand-side water management strategies in various climatic regions in the U.S. using data from 45 counties.

1.2 Research Questions

Although the performance of demand-side management strategies is highly unpredictable as consumers in different socioeconomic groups react differently to water use restrictions and price

[3] Gleick, Peter H, and Meena Palaniappan. "Peak Water Limits to Freshwater Withdrawal and Use." *Proceedings of the National Academy of Sciences of the United States of America* 107, no. 25 (2010): 11155-62.

increases, given the time constraint and the availability of data, my research is to study the impact of water demand management policies on domestic water use. The research will address three research questions:

1) How does domestic per-capita water use differ across various climatic regions?

The first question is to determine whether there are differences in water use pattern due to different climatic conditions. I start my research by exploring the domestic water use in various climatic regions to identify a trend of water use in the U.S.

2) How do the implemented water demand management policies vary across climatic regions?

After evaluating the domestic water use pattern in various climatic regions, I investigated whether there are differences in demand management policy implementation in various climatic conditions. Thus, I summarize the type and number of policy implemented by each county to seek a trend in demand management adaptation.

3) How do climatic conditions, demographic factors, and water demand management policies relate to domestic per-capita water use?

The last research question seeks to identify whether various factors have significant impacts on water use. Through statistical analysis, I aim to find out how climatic conditions, demographic factors, and demand management policies are related to domestic per-capita water use.

1.3 Thesis Structure

This section summarizes the structure of thesis for the remaining chapters:

Chapter 2 explores the management of water resources, its history, structures, and trends. Furthermore, I introduce some current research by relating climate change to water resource management, and how sustainable management can positively affect urban development.

Chapter 3 discusses the methodology of this research. The overall process of data collection and analysis of this study will be explained in this chapter: how the data are collected from a variety of sources, how the data terms are defined and selected, and how the data and statistical tests are used for analysis.

Chapter 4 presents the analysis and result of the three research questions posted in Chapter 1. Water use data from nine climatic regions are used in this thesis to access the trends and patterns of domestic water use. I summarize the differences of demand policies employed in different climatic regions and perform analysis aiming to understand how these demand policies impact the domestic water use patterns while controlling demographic and climatic factors.

Chapter 5 summarizes and concludes this thesis. This chapter discusses the implication of this study and recommendations for future research. It also discusses the limitations and challenges of this research.

Chapter 2 - Literature Review

2.1 Climate Change

The sun provides energy for life on Earth. The Earth's surface absorbs and radiates heat emitted by the sun. About 90% of the radiated heat is absorbed and re-emitted by the greenhouse gases in the atmosphere, which keeps the average temperature of the Earth at 59 degrees Fahrenheit.[4] Common greenhouse gases that prevent heat from escaping the atmosphere includes water vapor, carbon dioxide, methane, nitrous oxide and chlorofluorocarbons (CFC).

It is unequivocal that the climate system is warming.[5] Between 1906 and 2005, the Earth's surface temperature rose 1.1 to 1.6 degrees Fahrenheit[6]. Although many have argued that warming surface temperature has occurred in the past and that warming is natural, most climate scientists agree that the main cause of the warming temperature since the last century is due to the increase of human induced greenhouse gases in the atmosphere. Variations of climatic impact caused by natural process in the last 2,000 years were much lesser than the increase of greenhouse gases produced by human activities.[7] The burning of fossil fuels since the industrial revolution has produced a variety of greenhouse gases, such as carbon dioxide, methane, and water vapor. Even methane has more greenhouse impact than any other gases, it is typically ignored because it accounts for a much lesser percentage of total emissions.

[4] "A blanket around the Earth." last updated Dec 13th, 2016, http://climate.nasa.gov/causes/.
[5] IPCC Fourth Assessment Report, 2007 Synthesis Report.
[6] "Global Warming." accessed Jan 2nd, 2017, http://earthobservatory.nasa.gov/Features/GlobalWarming/page2.php.
[7] National Research Council (NRC), 2006. Surface Temperature Reconstructions For the Last 2,000 Years. National Academy Press, Washington, DC.

Among all the greenhouse gases, carbon dioxide contributes most to the human induced warming due to the large amount

The Mauna Loa Observatory has been measuring concentration of carbon dioxide in the atmosphere since the mid-20th century and other greenhouses gases have been monitored since 1980.[8] Greenhouse gases concentrations for earlier time are mainly obtained through analyzing air trapped in ice cores in Antarctica and Greenland.

2.2 The Effect of Climate Change on Water Resources

Climate change has shown to have a significant impact on water resources. The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) summarizes with confidence that the effects of climate change on hydrological systems include increasing runoff from earlier discharge of glacier- and snow-melt and warming of lakes, rivers and streams, all of which affects water quality.[9] Due to the warming climate, there will be warmer and shorter winter seasons, and warmer and drier summer seasons.[10] More precipitation will occur as rain, rather than snow during the winter. In addition, snowmelt will occur earlier in the season, which alters the runoff pattern into surface waters. Changing precipitation and runoff patterns implicate changes in the occurrence of floods and in seasonal urban water demands.[11] As all these impacts affect water supply, water management strategists need to adapt to these changes to avoid water shortages.

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[8] National Research Council (NRC), 2006. Surface Temperature Reconstructions for the Last 2,000 Years. National Academy Press, Washington, DC.

[9] IPCC Fourth Assessment Report, 2007 Synthesis Report.

[10] John E. Cronwell, Joel B. Smith, And Robert S. Raucher. "Implications of Cliamte Change in Urban Water Utilities", 2007. Association of Metropolitan Water Agrencies.

[11] O'Hara, Jeffrey, and K. Georgakakos. "Quantifying the Urban Water Supply Impacts of Climate Change." *Water Resources Management* 22, no. 10 (2008): 1477-497.

Moreover, impacts of climate change appear in every region of the U.S. Most of the climatic regions have experienced decreasing snow cover, increasing rainfall, and decreasing water quality due to the warming temperature. Additionally, climate change is likely to have more substantial impacts on water resources in coastal regions due to the combined effect of sea level rise, weather pattern change, and extreme weather event. According to an assessment done by the U.S. Global Change Research Program, climate change is likely to affect water availability and increase demand in the Southwest and Southeast regions due to decreasing annual precipitation.[12] West and northwest regions are expecting more drought and water shortages in spring and summer times due to earlier snowmelt and decreasing snowfall[13]. In addition, due to the warming temperatures, the northeast region has been experiencing heavier raining events in the past 50 years.[14]

2.3 Current Water Management Structure

Water distribution and allocation is complicated in the U.S. because they are governed by international treaties, federal and state laws, and other agreements that are complex and difficult to change.

There are three major federal agencies responsible for water resources development and protection: the US Army Corps of Engineers, the United States Geological Survey, and the Bureau of Reclamation. The US Army Corps of Engineers was established in 1775 with a

[12] Global Change Research Program, "Water Resources Management," Accessed April 30, 2017. http://nca2014.globalchange.gov/report/sectors/water#statement-16606.
[13] B.C. Bates, Z. W. Kundzewicz, S. WU and J. P. Palutikof, "Intergovernmental Panel on Climate Change: Climate Change and Water," edited 2008.
[14] "Water Resources," Global Climate Change Impacts in the United States 2009 Report, accessed April 30, 2017, http://nca2009.globalchange.gov/water-resources/index.html.

mission to eliminate flooding and other navigational hazards.[15] It currently maintains 926 coastal, Great Lakes, and inland harbors as well as providing water supply storage capacity of 329.2 million acre-feet in Corps lakes in the U.S.[16] The United States Geological Survey (USGS) was created in 1879 with a mission to provide scientific information to better understand the Earth.[17] The USGS collects, monitors, and analyzes a wide variety of water resource data to provide scientific understanding on the resource's conditions.[18] Streamflow, groundwater, water quality, water use, and water availability are the primary data that USGS collects and monitors for the nation's water resources.[19] Lastly, the Bureau of Reclamation was found in 1902 and it is the largest water wholesaler in the U.S.[20] Managing, developing, and protecting water resources in an environmentally and economically manner is the mission of the Bureau of Reclamation. Over 600 dams and reservoirs have been constructed by the Bureau of Reclamation.[21] Today, Reclamation's mission focuses on water delivery, water conservation, water recycling and water reuse, which aims at meeting water demand and protecting environment.

Other than federal agencies, water regulations and laws are established at the state level. The most common water-related law in the states are the Riparian Doctrine and Appropriation Doctrine of Water Rights. The Riparian Doctrine is adopted from the early Spanish Law.

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[15] "Mission Overview," US Army Corps of Engineers, accessed March 27th, 2017, http://www.usace.army.mil/Missions/.
[16] "Mission Overview," US Army Corps of Engineers, accessed March 27th, 2017, http://www.usace.army.mil/Missions/.
[17] "Who We Are," United States Geological Survey, accessed March 27th, 2017, https://www.usgs.gov/about/about-us/who-we-are.
[18] "Who We Are," United States Geological Survey, accessed March 27th, 2017, https://www.usgs.gov/about/about-us/who-we-are.
[19] "Mission Areas," United States Geological Survey, accessed March 27th, 2017, https://www.usgs.gov/science/mission-areas/water?qt-mission_areas_l2_landing_page_ta=0#qt-mission_areas_l2_landing_page_ta.
[20] "About Us – Mission/Vision," Reclamation, last modified January 12th, 2016, https://www.usbr.gov/main/about/mission.html.
[21] "About Us – Mission/Vision," Reclamation, last modified January 12th, 2016, https://www.usbr.gov/main/about/mission.html.

Under the Riparian Doctrine, the right to use water is based on property adjacency to a water source. The priority of the right to use water is determined by the date that land or property is separated from federal ownership.[22] In the event of water shortage, all water users curtail their water uses based on the priority of their water right. The Riparian Doctrine only allows water uses at its site, while the Appropriation Doctrine allows water to be transferred to new locations. The priority data for the Appropriation Doctrine water right is determined by the actual date of water being used.[23] Both the Riparian and Appropriation Doctrines of water right apply for surface water in most states and are managed by state agencies. However, these regulations do not apply to groundwater.

2.4 The Need for Sustainable Water Management

Compared to with climate change, population growth has a larger impact on urban water shortage.[24] Water demand is expected to increase with a growing population. According to the population projections from the Bureau of the Census, states including California, New Mexico, Arizona, and Nevada are expected to have more than 50% population growth from 1995 to 2015.[25] The competition for water is likely to grow as the water demand increases and as the amount of available water decreases. Therefore, a sustainable approach is desired in water management to improve food production, reduce poverty, and water-related diseases.[26]

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[22] “Washington State Water Law, A Primer,” Washington State Department of Ecology, last modified July 2006, https://fortress.wa.gov/ecy/publications/documents/98152.pdf.

[23] “Washington State Water Law, A Primer,” Washington State Department of Ecology, last modified July 2006, https://fortress.wa.gov/ecy/publications/documents/98152.pdf.

[24] Mcdonald, Robert I, Pamela Green, Deborah Balk, Balazs M Fekete, Carmen Revenga, Megan Todd, and Mark Montgomery. "Urban Growth, Climate Change, and Freshwater Availability." *Proceedings of the National Academy of Sciences of the United States of America* 108, no. 15 (2011): 6312-7.

[25] General Accounting Office, Washington D.C. 2003, “Freshwater Supply: State’s Views f How Federal Agencies Could Help Them Meet the Challenges of Expected Shortages. http://www.gao.gov/new.items/d03514.pdf.

[26] Russo, Tess, Katherine Alfredo, and Joshua Fisher. "Sustainable Water Management in Urban, Agricultural, and Natural Systems." *Water* 6, no. 12 (2014): 3934-956.

Sustainable water management requires allocating water between competing purposes and users in a manner that meets water demand for current water users without impairing water supply for the future.[27] In developed countries, the objectives of sustainable water management are supporting water demand, improving infrastructure longevity, recycling and reusing water, and protecting the environment.[28]

Balancing supply and demand through acquiring new water sources is a difficult task, mainly due to the increasing financial burden of building and maintaining water infrastructure, and the gradual decrease in water supply due to climate change. The challenge of sustainable water management is to move away from a supply management strategy to a demand management strategy. Water managers have primarily focused on strategies that allows the increase in water supply when the demand increases. For example, the construction of massive infrastructures to transfer water from high supply locations to high demand locations at the costs of likely irreversible social, ecological and environmental impacts.[29] On the other hand, demand management requires water conservation rather than finding new water sources elsewhere. Shifting toward demand management practices is significant in sustainable water managing, because future water resources will be scarce in light of population growth and climate change.[30]

2.5 Moving into Demand Side Management

[27] Mays, Larry W. *Water Resources Sustainability*. 1st ed. New York : Alexandria, Va.: McGraw-Hill ; WEF Press, 2007.
[28] Russo, Tess, Katherine Alfredo, and Joshua Fisher. "Sustainable Water Management in Urban, Agricultural, and Natural Systems." *Water* 6, no. 12 (2014): 3934-956.
[29] Dawadi, and Ahmad. "Evaluating the Impact of Demand-side Management on Water Resources under Changing Climatic Conditions and Increasing Population." *Journal of Environmental Management* 114 (2013): 261-75.
[30] Dawadi, and Ahmad. "Evaluating the Impact of Demand-side Management on Water Resources under Changing Climatic Conditions and Increasing Population." *Journal of Environmental Management* 114 (2013): 261-75.

Population growth, greater per-capita water use, and pollution have caused the decline of water supplies in many areas. An alternative water demand management, is associated with actions that reduce water use or that encourage more efficient water use.[31] There are two types of water demand management policies: non-price policies and price policies. Non-price policies include temporary water restrictions, rebate for water efficient technologies, and conservation education campaigns. On the other hand, examples of price policies are seasonal and block rate pricing. While the adoption of non-price policies is widely spread in many major cities, especially in drought seasons, price policies are starting to gain more attention in water demand management because many studies have shown water is a price elastic commodity.

Many studies that has been performed on residential water demand and rate structures. One of the studies is the Ordinary Least Square Estimation on rate structures and residential water demand in Massachusetts by Stevens and Willis. The estimation illustrates that there are significant differences in water demand between different regions in Massachusetts, but the result is not explained by differences in income, price, climate, or population density.[32]
In addition, a meta-analysis by Dalhuisen et al. investigates the effect of price elasticities on block rate structures from 64 pricing studies between 1963 and 2001. The meta-analysis concludes that under increasing block rate pricing, residential water demand is elastic with regard to price.[33] The most recent study on price elasticities on block rate structures is done by Olmstead et al. The study concludes that there is a significant difference in price elasticity

[31] Russell, Sally, and Kelly Fielding. "Water Demand Management Research: A Psychological Perspective." *Water Resources Research* 46, no. 5 (2010): N/a.
[32] Stevens, T H., Jonathan Miller, and Cleve Willis. "Effect of Price Structure on Residential Water Demand 1." *JAWRA Journal of the American Water Resources Association* 28, no. 4 (1992): 681-85.
[33] Dalhuisen, Jm, Rjgm Florax, HLF De Groot, and P. Nijkamp. "Price and Income Elasticities of Residential Water Demand: A Meta-analysis." *Land Economics* 79, no. 2 (2003): 292-308.

between flat rate (fixed price for all level of water use) and block rate (different prices for different water use level) on price structures, but this study fails to provide an explanation on how consumers respond to the rate structure.[34]

In summary, we see that our understanding of climate change, water resources, and water management strategies are increasing overtime when there are more studies are done. However, these studies focused on climatic impacts on water use as a whole. Leaving open the question of how a specific category of water use is influenced by climatic conditions, demographic variation, and demand management policies, which I will now move to answering (see Chapter 4).

[34] Olmstead, Michael Hanemann, and Stavins. "Water Demand under Alternative Price Structures." *Journal of Environmental Economics and Management* 54, no. 2 (2007): 181-98.

Chapter 3: Methods

This chapter explains the methods I employed to answer the three research questions: 1) How does per-capita domestic water use vary across various climatic regions?; 2) How do the various water demand management policies differ across climatic regions?; and lastly, 3) How do climatic conditions, demographic factors, and demand management polices relate to domestic per-capita water use? I compared the domestic per-capita water use and explored the effect of climatic conditions, demographic factors and demand management strategies implement on domestic per-capita water use in selected counties across various climatic regions in the U.S.

3.1 Scope of Study

My analysis was constructed on forty-five counties from nine climatic regions in the U.S. I closely examined five counties in each of the nine climatic regions. Since water use statistics for the year 2010 is the most current and comprehensive water data, the selection of the counties is also based on the availability of climatic data and population size in 2010. In each climatic region, I selected the five most populous counties in 2010 in each climatic region. By examining these forty-five counties, I determined whether the domestic water use was affected by climatic conditions, demographic variations, and demand management policy. Since each county being studied varies in size (population and acreage), I used the per-capita water use rather than total water use, in each county. A complete list of the forty-five selected counties is shown in Appendix A.

I chose to structure my research at the county level because of the limitation of water use data, as the data is only available at either county level or state level from the USGS. For comparison purposes, I obtained climatic data from weather stations that are within the studied county levels.

Within each county, I explore how the selected characteristics play a role in affecting domestic per-capita water use. The following two sections describe the details of the data collection and analysis procedure.

3.2 Data Collection

For data collection, several types of data have been included in this study. These data include climatic regions data, GIS data, climatic data, water data, demographic data, and demand management policy data. Lastly, the limitation of data selection will also be discussed in this section.

Climatic Regions Data

The National Centers for Environmental Information have classified nine climatic regions in the continental United States. As Table 2[35] demonstrates, each of the climatic regions has been identified as climatically consistent, meaning the climatic conditions and impacts are similar within each region.

Table 2. Distribution of Continental States by Climatic Regions

Climatic Region	States
Central	Illinois, Indiana, Kentucky, Missouri, Ohio, Tennessee, West Virginia
East North Central	Iowa, Michigan, Minnesota, Wisconsin
Northeast	Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont
Northwest	Idaho, Oregon, Washington
South	Arkansas, Kansas, Louisiana, Mississippi, Oklahoma, Texas

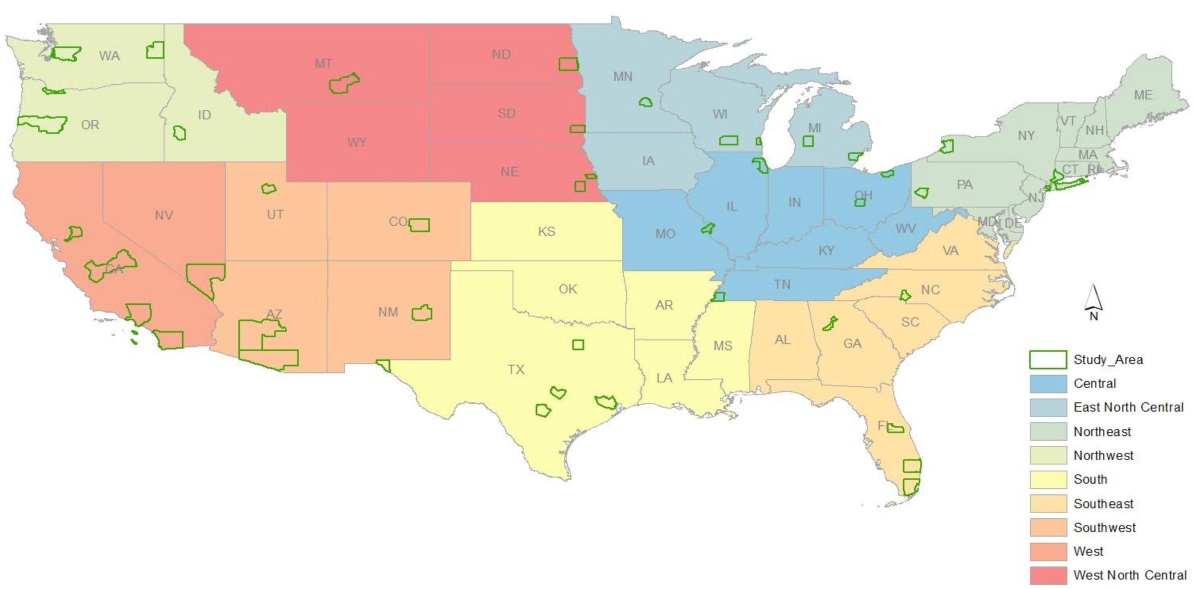
[35] "U.S. Climate Regions," National Centers for Environmental Information, accessed Jan 16th, 2017, https://www.ncdc.noaa.gov/monitoring-references/maps/us-climate-regions.php#references.

Southeast	Alabama, Florida, Georgia, North Carolina, South Carolina, Virginia
Southwest	Arizona, Colorado, New Mexico, Utah
West	California, Nevada
West North Central	Montana, Nebraska, North Dakota, South Dakota, Wyoming

GIS Data

The United States Census Bureau[36] is the primary resource of the GIS data for my mapping illustrations. The layers I collect are within state and county boundaries. County boundaries delineate the borders of the study areas. Figure 2 illustrates the climatic region boundaries and selected studied areas for this study.

Figure 2. Climatic Regions and Study Areas



[36] "Cartographic Boundary Shapefiles," United States Census Bureau, accessed Jan 10th, 2017, https://www.census.gov/geo/maps-data/data/tiger-cart-boundary.html.

Climatic Data

The process of data collection starts with identifying the five most populous counties in each climatic region, and weather stations within these areas. There are several weather stations located in each selected county. They were established by National Centers for Environmental Information from National Oceanic and Atmospheric Administration (NASA). It is a source of historical data and weather station information about the counties throughout the U.S.[37] I analyze every weather station available and make selection based on the availability of data for the total annual precipitation and cooling degree days for 2010.[38] A complete list of selected weather stations and their climatic data is attached in Appendix B.

Table 3. Weather Station Data Terms

Term	Definition
Cooling Degree Day	The total number of degrees that a day's average temperature is above 65 degree Fahrenheit.
Total Annual Precipitation	Total precipitation for a year in inches.

Water Data

For comparison purpose, all data collected for this research were from the year 2010. USGS collects water use data every five years at both county and state levels. I collect public supply domestic water use data from USGS Estimated Use of Water in the United States County-Level Dataset for the Year 2010.[39] This data provides estimations of water use for public supply,

[37] "Local ocal Climatological Data Publication Select State," NASA, accessed Jan 10th, 2017,https://www.ncdc.noaa.gov/IPS/lcd/lcd.html

[38] NOTE: In some rate cases, there are gaps in the archives available. Some weather stations available today have not always been available for publication.

[39] "Estimated Use of Water in the United States County-Level Data for 2010," USGS, accessed Jan 5th, 2017, https://water.usgs.gov/watuse/data/2010/index.html.

domestic, irrigation, livestock, aquaculture, industrial, mining, and thermoelectric power. In this research, I am focusing on domestic water use from public supply water systems.

Table 4. Water Data Terms

Term	Definition
Public-Supply*	Water delivered from public and private water agencies
Domestic Water Use	Total water (self and public supply) used at home
Domestic Per-Capita Water Use	Total gallons of water used per person per year at home

**Water withdrawal for public-supply system is estimated from sales information of private and public agencies, and is calculated using coefficient for per capita use.*

Demographic Data

Demographic data includes population and median per-capita income. Both population[40] and income[41] datasets are collected from the 2006-2010 American Community Survey 5-Year Estimates. A complete list of counties with demographic data is attached in Appendix C.

Table 5. Demographic Data Terms

Term	Definition
Population	The number of people in each county.
Median per-capita income	The amount of income divided by the income into two equal parts with half income above and half income below that amount.

Demand Management Policy Data

[40] "Total Population," American FactFinder, accessed Jan 10th, 2017, https://factfinder.census.gov/faces/nav/jsf/pages/searchresults.xhtml?refresh=t.
[41] "Median income in the past 12 months," American FactFinder, accessed Jan 10th, 2017, https://factfinder.census.gov/faces/nav/jsf/pages/searchresults.xhtml?refresh=t.

For demand management policy, I focus on both pricing and non-pricing policy instruments. In this study, increasing block rate structure (Incremental Pricing) represents the pricing policy instrument. Non-pricing demand management policy instruments includes public education, rebate for installing efficient water use technology, and water use restrictions. These policy instruments have been shown to be effective in reducing water demand in a study of eight California water agencies.[42]

An Internet based data collection method is used in collecting policy data. The collected data are descriptive information, I therefore further categorized these data as the following to help organizing the data for more effective analysis. Incremental pricing policy is broken down to two categories: 0 – No Policy and 1 – Policy Exists. The non-pricing policy instruments are further summarized into three categories: INFO – Public education and conservation campaigns, REBATE – rebate program for low-flow toilet and other efficient water use tools, and RESTRICT – water use restriction schedules and restriction on certain water uses.

Data Limitations

There are several limitations in the collected data. First of all, only one weather station in each county is collected, as a result of the availability of the data; this limited the representative of climatic data and restrict the amount of weather stations that were available for analysis. Secondly, the available water data are estimated by coefficient of per-capita water use; the estimation on water data is based on experience, historic data, and various assumptions, which could lead to inaccuracy if the water use trend changed or invalid assumptions were made.

[42] Renwick, and Green. "Do Residential Water Demand Side Management Policies Measure Up? An Analysis of Eight California Water Agencies." *Journal of Environmental Economics and Management* 40, no. 1 (2000): 37-55.

Lastly, policy data are collected based on online searching; Internet based data collection can be incomplete since there is no standard or requirement on how information should be published online. Some counties might have policy implemented but not published online. Thus, the data collected online may not capture the whole picture of demand management policy implementation in the U.S.

3.3 Procedures for Analyses

There are three analyses that were performed to answer the research questions posted in Chapter 1. The following passage summarizes the procedures of the analyses.

1). There are five observations for each climatic region for a total of nine regions. I perform a One-Way Analysis of Variance (ANOVA) to evaluate whether there is a significant difference for the domestic per-capita water use in the nine climatic regions. The ANOVA analysis allows me to compare the means between three or more groups in a single test. The result of this analysis will not layout where the difference exists and how different they are, but it will tell us whether there is a significant difference in the means of two or more groups.

2). With an assumption that higher domestic per-capita water use regions are more susceptible to climatic change due to higher water demand, I then focus on the analysis of demand management policy implementation in addressing the water scarce issue. In this step of the analysis, I compared the type and number of demand management policy instruments implemented in the nine climatic regions. This analysis provides an understanding of the current stage of demand management policy implemented in various climatic regions, and demonstrates whether higher water use regions have more policy instruments in place.

3). Climatic conditions, demographic factors, and water management policy are factors that influence water demand and water supply. To access how these factors are related to water use, I perform correlation analysis of domestic per-capita water use from public supply with selected climatic conditions, demographic factors, and demand management policies to determine the trends of water usage with various factors.

For climatic conditions, cooling degree days and annual precipitation are two variables used in the analysis to reflect climatic variation. Cooling Degree Days (CDD) represents the annual total number of degrees that daily average temperature is above 65 degree Fahrenheit. Higher CDD value reflects a higher need for water and energy consumption in cooling the built environment. Another climatic variable is annual precipitation. Precipitation influences outdoor water use, for instance, gardening and landscaping. More precipitation results in lower water demand from public- and self-supplies for outdoor use.

Population and median per-capita income are the two variables selected to represent the demographic variation. The population variable is used as an indicator for urban/rural distinction. The income variable is also included in this analysis, because some studies suggest that domestic water demand is income elastic, meaning that the demand of water changes as income changes.

Finally, both pricing and non-pricing demand management policy instruments are selected for the correlation analysis. Given that the increasing trend of the implementation of demand management policies in water management agencies, I am interested in how demand management policy instruments are related to domestic per-capita water use. These policy instruments were selected for a couple reasons, including various effects on water demand and control levels (direct or voluntary). Pricing increment policy is widely used to encourage water conservation, because neoclassical economic theory on supply and demand suggests that consumers would adjust their water use behavior according to price change.

The selected non-pricing policy instruments are INFO, REBATE, and RESTRICT. Water conservation and education campaign (INFO) are commonly implemented as part of the water demand management policy instrument because of the ease of educational program reaching out to the people at all ages and it helps people develop critical thinking in understanding complex resource concepts. In addition, providing financial rebates (REBATE) for more efficient toilets and technologies aims to achieve water conservation and to motivate water efficient usage. Finally, restricting certain water use and assigning water restriction schedules (RESTRICT) have immediate effects on water savings because they strictly regulate water use during dry seasons and regulate watering during times of high evaporation rate. All these non-pricing policy instruments are means to reduce water usage, which decreases water demand.

The purpose of performing these correlation analyses is to evaluate the relation between water use and other variables, as well as ~~to~~ determining the strength of such relation. This evaluation provides information for future water management policy planning and background information for further study.

Chapter 4. Analysis and Result

Chapter 4 describes the analyses perform in this study: analysis of domestic per-capita water use by climatic regions, of demand management policy by climatic regions, and of domestic per-capita water use with selected demographic, climatic and policy variables. These analyses help investigate the three research questions in Chapter 1.

There are several constraints I encounter as conducting these analyses. As mentioned in Chapter 3, these constraints include:

- Limited weather stations at county level
- Constrained/uncompleted data at certain weather stations
- Data constraints in demand management policy collection method

Thus, I specifically selected the weather stations that provide complete data for my purpose. Based on the availability of weather stations, the number of weather stations used for the analysis is one per county. Furthermore, I examined local demand management policies that were accessible online. When the county website did not publish any information regarding the selected demand management policy, I considered there is not policy in place.

4.1 Analysis of Domestic Per-Capita Water Use in Various Climatic Regions

One-way Analysis of Variance (ANOVA) was used to determine whether there is a significant difference in domestic per-capita water use from public supply across different climatic regions. There are five observations for each climatic region with a total of nine regions. The domestic per-capita water use is set as the dependent variable, which is explained by the independent variable, climatic region.

Table 6.1 shows the statistics of per-capita water use and Table 6.2 shows the result of the ANOVA test. First, I look at the summary statistics of per-capita water delivered from public supply in the climatic regions. Table 6.1 includes the mean and standard deviation of water delivered to each climatic region from public supply in 2010. There is a significant variability in the average per-capita water delivered across climatic regions, ranging from approximately 26,769 gallons per person per year in the East North Central Region to 52,355 gallons per person per year in the West Region. This variability is presumably due to the differences in water sources and climatic conditions. Given the fact that only public supply water data is used in this study, the difference in water delivered suggested that the West climatic region relies more on public water supply while East North Central climatic region uses more self-supplied water. Looking at the standard deviations (Table 6.1), the result shows that Central, Northwest, South, and West climatic regions have much larger standard deviations than any other regions. The larger standard deviation-reflects larger degree of variation of per-capita water use within these regions. These variations can be caused by outliner observations or other factors that require further investigation.

Next, we look at the result of the ANOVA test (Table 6.2)[43]. This test evaluates both variances of the average domestic water use between climatic regions and within climatic region. The test statistic, F, is the ratio of the estimate variances among climatic regions and within each climatic region. The result $F(8, 36) = 1.04$, $p > 0.05$, indicates that there is no statistically significant difference among the means of domestic water use in various climatic regions.

This insignificant difference shown in the F test can be caused by the large variation of data within each region, which is also presented in the standard deviation. However, it is difficult to

[43] The completed analysis result can be found in Appendix D-1.

estimate the difference among the group means, as the observations within each group are widely distributed.

Table 6. Summary of ANOVA Test on
Per-Capita Water Use and Climatic Regions

Table 6.1 Summary of the Statistics of Per Capita Water Use

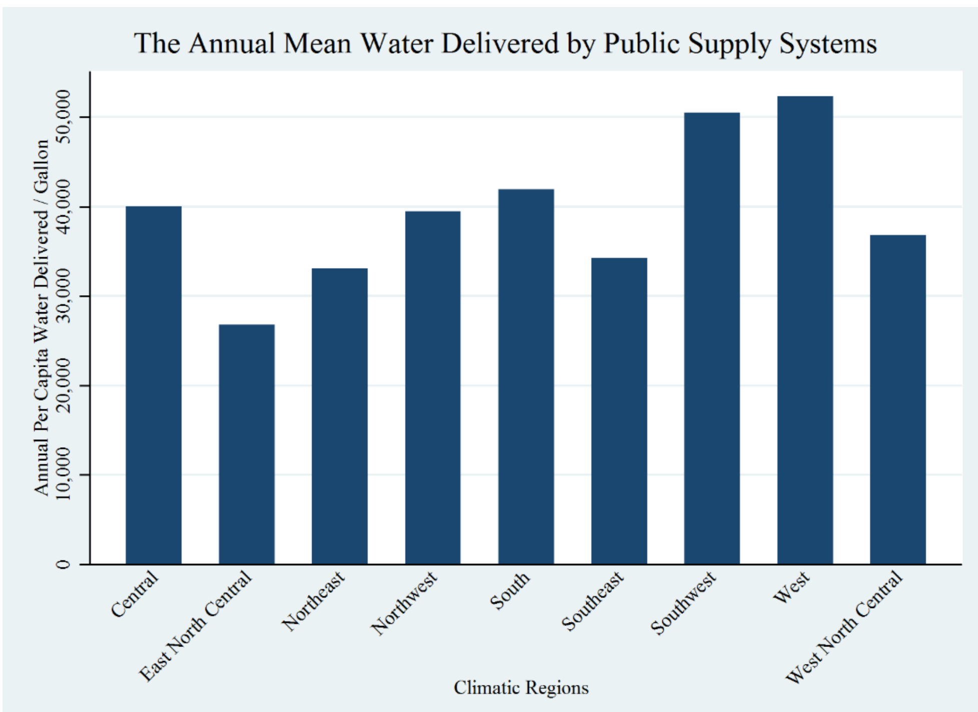
Climatic Region	Mean	Standard Deviation	Frequency
Central	40072.77	28423.87	5
East North Central	26796.48	2771.32	5
Northeast	33121.86	9185.38	5
Northwest	39461.14	28427.19	5
South	41929.19	23355.94	5
Southeast	34257.20	4845.00	5
Southwest	50551.92	11686.29	5
West	52355.43	21172.26	5
West North Central	36820.14	4390.49	5
Total	**39485.12**	**17948.46**	**45**

Table 6.2 Summary of ANOVA Test

Source	Sum of Squares	Degree of Freedom	Mean of Squares	F	Significant Level
Between groups	2.6518e+09	8	331477663	1.04	0.4282
Within groups	1.1523e+10	36	320073571		

The ANOVA test suggests no significant difference in water delivered from public supply systems to various climatic regions. Figure 3 shows the mean of water delivered to the 9 climatic regions in 2010. As shown, the West and Southwest climatic regions had more water delivered from public supply systems than any other regions. Increasing temperature along with more frequent and longer dry season could increase water use in households, especially for landscape irrigation. This result is consistent with the facts of warmer temperatures and reduced snowpack storage observed in these regions in recent decades.[44] On the other hand, East North Central has the lowest water use. While this region also experiences warmer temperature, there is an increasing amount of rainfall observed. The heavier rainfall could decrease the amount of water use in landscaping and gardening, which could result in lower amount of domestic water use.

Figure 3. The Means of Domestic Per-Capita Water Use by Climatic Region



4.2 Analysis on Demand Management Policy by Various Climatic Regions

In this section of the analysis, I summarize the demand management policy collected from the studied areas. There are two categories of policy: non-pricing and pricing. Non-pricing policy

[44] "Climate Impacts in the Southwest," United States Environmental Protection Agency," accessed April 10th, 2017, https://www.epa.gov/climate-impacts/climate-impacts-southwest.

does not affect the price of water, but it influences water demand by changing water use behavior and adopting water efficient fixtures. On the other hand, pricing policy is an economic approach to reduce water demand by increasing water price. Both categories of policy are widely implemented by water planning managers and policy makers, thus accounting for the influence of both non-pricing and pricing policies helps determine the total potential performance of demand management approaches for water management.

Table 7 provides a summary of key demand management policies implemented by each county. The most popular type of demand management policy implemented in the studied areas is water conservation education and information campaigns (INFO). Education and information campaigns provide information on means to reduce water usage. For instance, providing information on how to fix leaking pipes and recommending watering schedules to avoid excessive loss to evaporation. Effective information campaigns can shift the water demand curve by motivating water conservation behaviors. Additionally, providing financial subsidies (REBATE) to encourage using water efficient technologies is another mean to shift the water demand curve. For example, providing financial assistance for shifting to low-flow toilets is the most common rebate program for improving the efficiency of water-using fixtures.

These two types of non-pricing policy instruments are voluntary, the efficiency varies depending on the effectiveness of the outreach. The third type of non-pricing policy is applying mandatory restrictions on water use (RESTRICT). Water use restrictions place controls on what water use practices are not allowed, such as prohibition on hosing down sidewalks and watering lawn/landscape during high evaporation hours. Mandatory restrictions can effectively shift the water demand curve when penalties are imposed to control domestic water use.

Table 7. Summary of Demand Management Policy by Climatic Regions

Climatic Region	County	Non-Princing			Pricing
		INFO	REBATE	RESTRICT	INCREMENT
Central	Cuyahoga				x
	Franklin	x			
	Cook	x		x	x
	St. Louis	x			
	Shelby				
East North Central	Wayne	x			x
	Hennepin	x			
	Kent	x			
	Milwaukee	x			x
	Dane				x
Northeast	Erie	x			x
	Allegheny	x			x
	Queens	x	x		x
	Suffolk	x	x		
	Fairfield	x			
Northwest	Ada				
	Spokane	x			x
	Lane	x	x		x
	Multnomah	x	x		
	King	x	x		x
South	El Paso	x		x	x
	Travis	x	x	x	x
	Dallas	x	x	x	x
	Bexar	x	x	x	x
	Harris	x			x
Southeast	Mecklenburg				x
	Orange	x		x	x
	Fulton	x			
	Palm Beach	x	x		x
	Miami-Dade	x	x	x	x
Southwest	Bernalillo	x		x	
	Maricopa	x			x
	El Paso	x	x	x	x
	Pima	x	x		x
	Salt Lake	x	x		
West	Clark	x	x	x	x
	San Diego	x	x	x	x
	Fresno	x	x	x	
	Los Angeles	x	x	x	x
	Sacramento	x	x	x	
West North Central	Yellowstone				x
	Cass	x		x	
	Lancaster	x		x	x
	Douglas	x			x
	Minnehaha				x

Incremental pricing block rate is another type of demand management policy instrument (INCREMENT). Figure 4 shows an example on how the per unit water price changes as the quantity of water used increases. Water users have the lowest rate in the first block of consumption. Then they are required to pay a higher price in the next block and so on until they reach the highest block of consumption. In the studied areas, the incremental pricing block rate is the second most popular demand management policy implemented. The idea of the incremental pricing block is that from an economic standpoint, people would adjust their water usage behavior if the price increases, which can further reduce the water demand.

Figure 4. Incremental Pricing Block Rate Structure

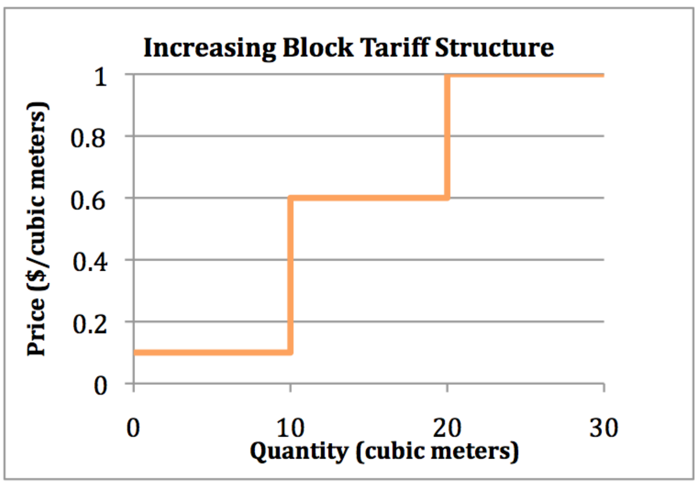
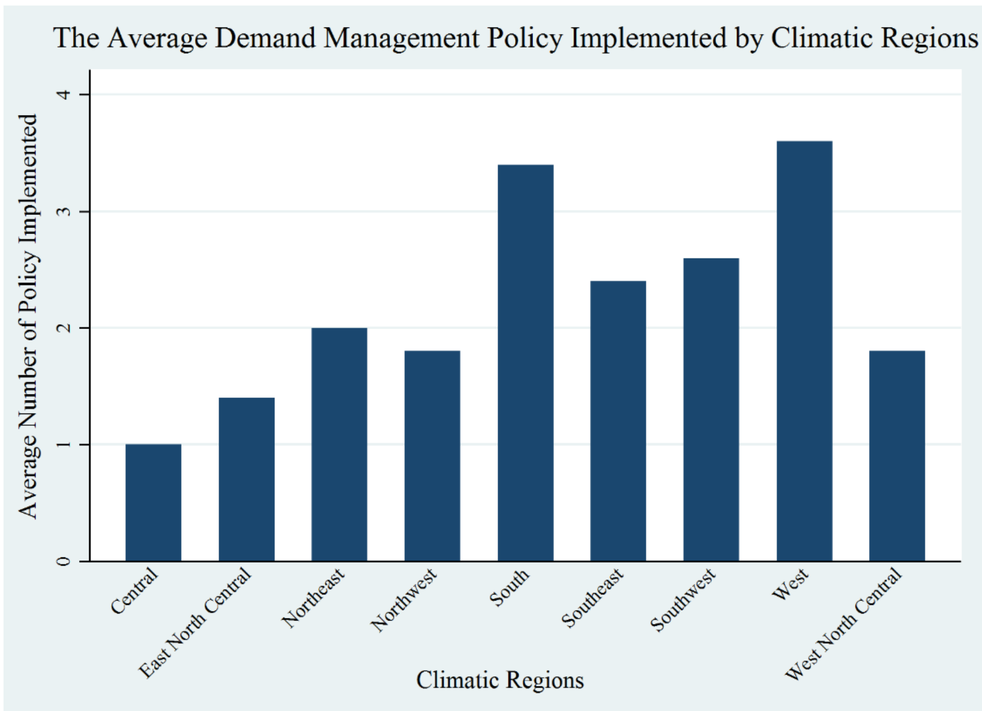


Image Courtesy: Whittington, Dale. "Pricing Water and Sanitation Services." HDOCPA-2006-18 (2006).

Next, I discuss the analyses on the demand management policy across the nine climatic regions. In the first step, the ANOVA test shows no significant difference in the average domestic water use among climatic regions. And this insignificance is probably due to the heterogeneity of data within each climatic region. Next, Figure 4 demonstrates the average demand management policy implemented by climatic regions. With a total of four possible demand management policies implemented, the graph shows that the West and South regions have an average of more than three policies implemented. And, the Central region has only one policy implemented on average.

Figure 5. The Means of Demand Management Policy Implemented by Climatic Region



To see whether there is difference among the number of demand management policy implement across various climatic regions, an ANOVA test was performed. Table 8 shows the result of the ANOVA test, F (8, 36) =4.59, p<0.01, indicating that there is a significant statistical difference among the means of the number of demand management policy implemented in the climatic regions.[45]

[45] The completed analysis result can be found in Appendix D-2.

Table 8. Summary of ANOVA Test on Implemented Demand Management Policy and Climatic Regions

Source	Sum of Squares	Degree of Freedom	Mean of Squares	F	Significant Level
Between groups	30.1777778	8	3.77222222	4.59	0.0006
Within groups	29.6	36	0.82222222		

This analysis shows that the implementation of demand management policy is significantly different across climatic regions. Based on the data, this difference can be caused by demographic factors or climatic conditions. But, it could be political or cultural reasons. For example, people in the western and eastern regions are fonder of outdoor and water recreational activities, thus they are more concern about water conservation. The observations selected for this study are based on population size. Four out of five observations from the South Region and three out of five observations from the West Region had a population size over one million people. Larger population size indicates higher water demand, so implementing more demand management policies could move the water demand curve. Also, both climatic regions had experienced longer and more frequent drought events. Shifting toward a demand focused water management strategy could alleviate the burden on water supply by implementing more demand management policies.

4.3 Correlation Analysis

The last two sections aim to evaluate whether there is significant difference in domestic per-capita water use and the number of demand management policy in various climatic regions. In this last part of the analysis, I evaluate the nature of the relation between domestic per-capita water use and water demand management policies, demographic factors and climatic conditions.

I therefore perform a pairwise correlation analysis across the 45 observations from 9 climatic regions in 2010.

The correlation analysis does not reveal a causative relationship between two variables, but it does show the strength and direction of the relationship. The goal of the correlation analysis is to understand whether, and to what degree water delivered from public supply for domestic per-capita use relates to demographic factors (population size and median per-capita income), climatic conditions (precipitation and cooling degree days), and demand management policies (incremental pricing, information campaigns, rebate programs, and water use restrictions).

Table 9 provides the results of the correlation analysis between domestic per-capita water use and selected variables, the completed analysis result can be found in Appendix D-3. The analysis shows that precipitation and water delivered from public supply have a moderate negative relationship with a significance at the 0.01 level; median per-capita income and water delivered from public supply have a weak positive relationship with a significance at 0.05 level; and lastly, the demand management policy instrument RESTRICT and water delivered from public supply have a weak positive relationship with a significance at 0.05 level.

Table 9. Result of the Pairwise Correlation Analysis

	Annual Domestic Per-Capita Water Use
Population	-0.0414 0.7870
Median Per Capita Income	0.3203 0.0320*
Annual Precipitation	-0.5037 0.0004**
Annual Cooling Degree Days	0.1928 0.2046
Increment Pricing	0.0389 0.7999
INFO	0.0070 0.9638
REBATE	0.2127 0.1607
RESTRICT	0.3186 0.0329*

**Significant at the 0.05 level.*
***Significant at the 0.01 level.*

The result of the correlation analysis indicates that when there is a decrease in precipitation, we will expect an increase in water delivered from public supply for the domestic per-capita use. When precipitation decreases, there is more need of outdoor water use for landscaping and gardening. And, an increase in median per-capita income is correlated with more domestic per-capita water use. A positive relation between per-capita water use and per-capita income could imply less concerned about the cost of using more water for high income population, thus using more water usage. Another interpretation is that the high-income population is more likely to pursue more water related fixtures, such as home swimming pools. Lastly, the implementation of water use restriction is positively correlated with water use. This finding indicates that when domestic per-capita water use increases, more water use restrictions are implemented to control water demand. The sign of the estimated coefficient is consistent with the expectation. The results of correlation estimations show that only water use restriction (RESTRICT) has a significant positive correlation with domestic per-capita water use. This can be rationalized given the fact that water use restrictions are more likely to be implemented as water use increases due to the direct control on the level of water use.

4.4 Summary

The ANOVA analyses performed in this chapter show that as of 2010, the amount of domestic per-capita water use did not significantly differ in various climatic regions, but the number of demand management policies implemented were significantly different across regions. The results indicate that there are factors influencing the amount of domestic per-capita water use other than climatic regions. The insignificance of domestic per-capita water use across regions could imply that the amount of water use by each person is similar regardless of where they live. The demand management policy implementation is influenced by climatic regions can be rationalized with the regional effects climate change has on water resources. Also, population size could be a reason of the variation in demand management policy implementation. The demographic data show that there is more policy implemented in regions that have higher population. This explanation indicates that the implementation of demand management policy is based on total water demand rather than per-capita water demand.

Lastly, the correlation analysis demonstrates significant relationships of domestic per-capita water use with precipitation, median per-capita income, and water use restriction. Although the direction and strength of the relationship vary, this result highlights the importance of accounting for the influence of demographic factors, climatic conditions, and demand management policy when analyzing domestic water use.

Chapter 5 Conclusions

There is growing evidence indicates the effect of climate change on water resources. Increasing water demand and shrinking water supply create challenges for water managers to balance the required water for growing populations, ecosystems, farming and energy production. In some areas, drought and water shortage becomes more frequent due to the change in climate. These effects are problematic for people because hour health depends on reliable and clean water. Thus, demand management is being recognized as an influential to control of consumer demand for water resources.

To study the influence of demand management policies on water use, a quantitative analysis was performed in this thesis to identitfy relationship between water use and demand management policies, climatic and demographic variables. The primary goals of this thesis are to investigate whether domestic per-capita water use and the implementation of demand management policy vary in different climatic regions and how does water use correlate with the selected variables.

The results of these statistical analyses reveal three findings. First, the average domestic per-capita water use in the western climatic regions appear higher than in the eastern climatic regions. But this finding is not consistent with the ANOVA test, which revealed no significant difference among the means of water use across various climatic regions. The lack of statistical significance can be rationalized by the large variance among observations within each climatic region. Second, there is significant difference in the means of the number of demand management policy implemented in various climatic regions, which indicates a regional difference in the number of implemented demand management policies. Finally, the correlation analysis result supports the intuition that domestic per-capita water use: it is related to demand management policies, climatic conditions, and demographic factors. Specifically, domestic per-capita water use is positively related to water use restrictions and median per-capita, but it is negatively related to precipitation.

5.1 Limitations and Recommendations

Previous research on water resources mainly focuses on how climate change influences the quality of water supply. Given the fact that increasing pollution on water resources will further effect the quantity of water supply available for human use, demand management is will be playing an important role in water resource management. This thesis was conducted with the goals of studying how domestic per-capita water use and water demand management policies differ in various climatic regions; moreover, this research investigated how various factors are related to water use. While this thesis present evidences of domestic per-capita water use relating to three variables, more analyses with different data sets, for instance data for commercial and industrial sectors, are needed for further study.

There are several limitations and recommendations that should be considered in conducting future research. The lack of data causes problems in variables establishment and analysis. Limited access to data is a major constraint for a thorough analysis of the topic. Especially the unavailability of data limits the scope of variables one can consider in the analysis. In my analysis, weather stations provide limited climatic data, which constrains the representativeness of the data in the study area. Also, in this thesis, for the ease of data analysis and the limited reliable resource available, I assumed change of more efficient water technologies used at homes, such as landscape irrigation controllers and high efficiency plumbing fixtures to be invariant. In reality, repairing leaks and using water saving technologies can also make a big difference in decreasing water demand. Moreover, the studied areas of this thesis spanned the U.S., establishing highly controlled variables is challenging. Thus, future research is suggested to narrow down the selected areas, which would allow more comprehensive and representative data sets. As far as I am concerned, comparative case study in this case is more effective in selecting comparable study areas and it can yield new insights by comparing two similar areas. With a more flexible time frame, a comparative case study in one area from different time frame can be conducted. For instance, to study the impact of water demand management policies on water use, analysis on the water use data before and after the implementation of the policies can be performed.

Despites the limitations encountered of the study, this thesis provides useful insight on the domestic per-capita water use pattern in various climatic regions. The example of correlation analysis between water use and various variables can be improved by analyzing different communities in one county. This thesis aims to study the influence of demand management policies on domestic per-capita water use. The type of demand management policies may have little impact on domestic water demand, while the pricing structure (decreasing rate, flat rate, and increasing rate) might have great influence on how much water is being used. Future study can emphasize on how a single demand management policy affects water demand.

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Appendix A: Study Area

Climate Region	State	County
Central	Illinois	Cook
Central	Tennessee	Shelby
Central	Missouri	St. Louis
Central	Ohio	Franklin
Central	Ohio	Cuyahoga
East North Central	Wisconsin	Dane
East North Central	Michigan	Kent
East North Central	Wisconsin	Milwaukee
East North Central	Minnesota	Hennepin
East North Central	Michigan	Wayne
Northeast	Connecticut	Fairfield
Northeast	New York	Erie
Northeast	New York	Suffolk
Northeast	Pennsylvania	Allegheny
Northeast	New York	Queens
Northwest	Oregon	Multnomah
Northwest	Idaho	Ada
Northwest	Oregon	Lane
Northwest	Washington	Spokane
Northwest	Washington	King
South	Texas	El Paso
South	Texas	Travis
South	Texas	Bexar
South	Texas	Dallas
South	Texas	Harris
Southeast	North Carolina	Mecklenburg
Southeast	Georgia	Fulton
Southeast	Florida	Orange
Southeast	Florida	Palm Beach
Southeast	Florida	Miami-Dade
Southwest	New Mexico	Bernalillo
Southwest	Arizona	Maricopa
Southwest	Arizona	Pima
Southwest	Utah	Salt Lake
Southwest	Colorado	El Paso
West	California	Los Angeles
West	California	San Diego
West	California	Sacramento
West	California	Fresno
West	Nevada	Clark
West North Central	Montana	Yellowstone
West North Central	South Dakota	Minnehaha
West North Central	North Dakota	Cass
West North Central	Nebraska	Lancaster
West North Central	Nebraska	Douglas

Appendix B: Weather Stations and Climatic Data

Central Climiatic Region			
County	**Weather Station**	**Cooling Degree Day**	**Annual Precipitation**
Cook	Chicago, Illinois	1181	37.61
Cuyahoga	Cleveland, Ohio	1168	35.4
Franklin	Columbus, Ohio	1331	36.26
Shelby	Memphis, Tennessee	2837	47.9
St. Louis	St Louis, Missouri	2083	39.07

East North Central Climatic Region			
County	**Weather Station**	**Cooling Degree Days**	**Annual Precipitation**
Dane	Madison, Wisconsin	829	37.86
Hennepin	Minneapolis, Minnesota	1000	32.89
Kent	Grand Rapids, Michigan	964	35.87
Milwaukee	Milwaukee, Wisconsin	944	35.98
Wayne	Detroit, Michigan	1103	32.28

Northeast Climatic Region			
County	**Weather Station**	**Cooling Degree Days**	**Annual Precipitation**
Allegheny	Pittsburgh, Pennsylvania	1029	37.85
Erie	Buffalo, New York	744	36.72
Fairfield	Bridgeport, Connecticut	1159	45.94
Suffolk	Islip, New York	1127	43.07
Queens	New York, JFK International Airport	1406	42.47

Northwest Climatic Region			
County	**Weather Station**	**Cooling Degree Days**	**Annual Precipitation**
Ada	Boise, Idaho	914	14.98
King	Seattle, Washington	162	46.99
Lane	Eugene, Oregon	225	45.59
Multnomah	Portland, Oregon	314	46.18
Spokane	Spokane, Washington	380	19.03

South Climatic Region			
County	**Weather Station**	**Cooling Degree Days**	**Annual Precipitation**
Bexar	San Antonio, Texas	3121	37.39
Dallas	Dallas, Texas	3360	34.33
El Paso	El Paso, Texas	2738	6.67
Harris	Houston, Texas	3417	42.72
Travis	Austin, Texas	3017	28.42

Southeast Climatic Region			
County	**Weather Station**	**Cooling Degree Days**	**Annual Precipitation**
Fulton	Atlanta, Georgia	2425	48.15
Mecklenburg	Charlotte, North Carolina	2130	36.4
Miami-Dade	Miami, Florida	4448	65.1
Orange	Orlando, Florida	3361	45.72
Palm Beach	West Palm Beach, Florida	4044	53.39

Southwest Climatic Region			
County	**Weather Station**	**Cooling Degree Days**	**Annual Precipitation**
Bernalillo	Albuquerque, New Mexico	1634	8.96
El Paso	Colorado Springs, Colorado	742	9.38
Maricopa	Phoenix, Arizona	4628	9.14
Pima	Tucson, Arizona	3077	11.13
Salt Lake	Salt Lake City, Utah	1142	18.69

West Climatic Region			
County	**Weather Station**	**Cooling Degree Days**	**Annual Precipitation**
Clark	Las Vegas, Nevada	3648	5.9
Fresno	Fresno, California	2031	16.51
Los Angeles	Los Angeles, International Airport	348	20.05
Sacramento	Sacramento, California	1079	22.84
San Diego	San Diego, California	464	16.26

West North Central Climatic Region			
County	**Weather Station**	**Cooling Degree Days**	**Annual Precipitation**
Cass	Fargo, North Dakota	611	29.48
Douglas	Omaha, Nebraska	1388	34.99
Lancaser	Lincoln, Nebraska	1306	34.42
Minnehaha	Sioux Falls, South Dakota	729	38.26
Yellowstone	Billings, Montana	525	18.75

Appendix C: Demographic and Water Use Data[46]

[46] Water data are measured in gallons/person/year.

Climatic Region	State	County	2010 Population	2010 Median Per-Capita Income	Water Delivered by Public Supply Systems
Central	Illinois	Cook	5,194,675	$29,678	32,849.70
Central	Ohio	Cuyahoga	1,280,122	$40,470	26,394.00
Central	Ohio	Franklin	1,163,414	$27,058	22,930.20
Central	Tennessee	Shelby	927,644	$26,252	27,671.80
Central	Missouri	St. Louis	998,954	$28,098	90,518.10
East North Central	Wisconsin	Dane	488,073	$30,097	24,267.10
East North Central	Minnesota	Hennepin	1,152,425	$26,189	26,666.10
East North Central	Michigan	Kent	602,622	$29,706	27,381.60
East North Central	Wisconsin	Milwaukee	947,735	$29,247	24,531.40
East North Central	Michigan	Wayne	1,820,584	$27,927	31,136.20
Northeast	Pennsylvania	Allegheny	1,223,348	$26,057	20,585.60
Northeast	New York	Erie	919,040	$32,010	43,946.80
Northeast	Connecticut	Fairfield	916,829	$27,729	27,371.70
Northeast	New York	Queens	2,230,722	$27,526	37,216.40
Northeast	New York	Suffolk	1,493,350	$26,856	36,488.80
Northwest	Idaho	Ada	392,365	$31,766	52,690.80
Northwest	Washington	King	1,931,249	$31,282	31,301.80
Northwest	Oregon	Lane	351,715	$29,406	35,255.90
Northwest	Oregon	Multnomah	735,334	$23,868	474.95
Northwest	Washington	Spokane	471,221	$29,087	77,582.20
South	Texas	Bexar	1,714,773	$23,241	47,743.70
South	Texas	Dallas	2,368,139	$26,694	57,628.60
South	Texas	El Paso	800,647	$29,666	54,734.60
South	Texas	Harris	4,092,459	$26,397	802.53
South	Texas	Travis	1,024,266	$38,569	48,736.50
Southeast	Georgia	Fulton	920,581	$32,566	28,509.40
Southeast	North Carolina	Mecklenburg	919,628	$31,834	29,491.50
Southeast	Florida	Miami-Dade	2,496,435	$26,647	38,106.20
Southeast	Florida	Orange	1,145,956	$28,749	36,839.50
Southeast	Florida	Palm Beach	1,320,134	$30,104	38,339.40
Southwest	New Mexico	Bernalillo	662,564	$32,342	36,715.00
Southwest	Colorado	El Paso	622,263	$35,589	66,530.80
Southwest	Arizona	Maricopa	3,817,117	$39,866	55,172.30
Southwest	Arizona	Pima	980,263	$28,281	41,913.40
Southwest	Utah	Salt Lake	1,029,655	$30,442	52,428.10
West	Nevada	Clark	1,951,269	$32,166	70,698.60
West	California	Fresno	930,450	$35,403	78,808.30
West	California	Los Angeles	9,818,605	$31,854	44,504.00
West	California	Sacramento	1,418,788	$20,624	36,406.40
West	California	San Diego	3,095,313	$27,772	31,359.80
West North Central	North Dakota	Cass	149,778	$28,874	32,586.20
West North Central	Nebraska	Douglas	517,110	$25,466	36,544.70
West North Central	Nebraska	Lancaster	285,407	$27,353	39,310.90
West North Central	South Dakota	Minnehaha	169,468	$30,356	32,786.60
West North Central	Montana	Yellowstone	147,972	$31,273	42,872.40

Appendix D: Results of Analyses

D-1 Analysis of Variance for Domestic Per-Capita Water

Analysis of Variance

Source	SS	df	MS	F	Prob > F
Between groups	2.6518e+09	8	331477663	1.04	0.4282
Within groups	1.1523e+10	36	320073571		
Total	1.4174e+10	44	322147043		

Bartlett's test for equal variances: chi2(8) = 31.5621 Prob>chi2 = 0.000

D-2 Analysis of Variance for Implemented Demand Management Policy

Analysis of Variance

Source	SS	df	MS	F	Prob > F
Between groups	30.1777778	8	3.77222222	4.59	0.0006
Within groups	29.6	36	.822222222		
Total	59.7777778	44	1.35858586		

Bartlett's test for equal variances: chi2(8) = 6.2863 Prob>chi2 = 0.615

D-3 Correlation Analysis between Water Delivered by Public Supply and Selected Variables

	Water_~d	Popula~n	Income	Precip~n	CDD	INCREM~T	INFO
Water_Deli~d	1.0000						
Population	-0.0414	1.0000					
	0.7870						
Income	0.3202	0.0605	1.0000				
	0.0320	0.6930					
Precipitat~n	-0.5037	-0.0514	-0.3627	1.0000			
	0.0004	0.7376	0.0144				
CDD	0.1928	0.1175	0.1067	0.0692	1.0000		
	0.2046	0.4420	0.4853	0.6515			
INCREMENT	0.0389	0.2614	0.1961	-0.0197	0.1865	1.0000	
	0.7999	0.0829	0.1966	0.8976	0.2200		
INFO	0.0070	0.2573	-0.2106	0.0334	0.1948	-0.0822	1.0000
	0.9638	0.0879	0.1650	0.8276	0.1998	0.5914	
REBATE	0.2127	0.2350	-0.0767	-0.0443	0.1211	0.0962	0.3797
	0.1607	0.1203	0.6167	0.7727	0.4282	0.5295	0.0101
RESTRICT	0.3186	0.2738	0.0173	-0.3155	0.2285	0.1313	0.3454
	0.0329	0.0687	0.9102	0.0348	0.1312	0.3899	0.0201