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WATER USE TRENDS AND PATTERNS IN THE RIO GRANDE RIVER BASIN: CASE STUDIES IN TEXAS, NEW MEXICO AND COLORADO

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Abstract

The Rio Grande River Basin spanning over Colorado, New Mexico, Texas, and Mexico presents a big challenge in terms of efficient water management. Water is allocated by a wide range of relatively autonomous water authorities in different regions of the river basin. Moreover, growing population in adjacent cities and the resulting increase in water demand as well as simultaneously shrinking water resources (due to climatic conditions and consumption patterns) create a need for evaluating water use as a sustainability problem described with economic, environmental, and social indicators.

The goal of this study is to evaluate: 1) regional and temporal changes in municipal and total water use across the Rio Grande river counties adjacent to the river, and 2) relationships between socio-economic and environmental sub-indicators and water use in three case study counties: Rio Grande county in Colorado, Bernalillo county in New Mexico, and El Paso county in Texas.

Key findings in this research show that in the majority of analyzed counties there is a strong relationship between water use and per capita personal income as well as public supply population (social sub-indicators). Only in around half of the counties with water rate data was a strong relationship between water use and water rates was found (economic sub-indicators). Moreover, there were few to no relationships detected between water use and temperature, precipitation or stream flow rate (environmental sub-indicators). This shows that social sub-indicators had the strongest relationship patterns where the environmental sub-indicators had the weakest relationship patterns. Water and sustainability managers can use the analysis of correlation significance for

their counties as a basis for further investigation to better understand and design sustainable water management approaches.

Chapter 1: Introduction

1.1 Background information

Fresh water resources have been shrinking both in the United States and around the world (Kundzewicz et al., 2008; Seckler, 1998; Pyne, 1995). Currently, 37 of the world's largest aquifers are being depleted faster than they can recharge (Richey et al., 2015). The southwestern United States in particular is no stranger to water management problems (Seager, et al., 2007; Zekster, et. al., 2005), and the Rio Grande River Basin is a distinct example of the intricacies involved in river water management amid an arid climate (Schmandt, 2002). In recent years, the basin has experienced extreme and exceptional drought, with above average temperatures and below average precipitation (Finnessey and Kosloff, 2017). As freshwater resources continue to be ineffectively managed, the problem continues to build in both complexity and magnitude as some authors claim increase in the Rio Grande's water demand continues due to growing population, as well as economics and environmental policies (Ward, et al., 2001). According to Fort (2002), there are six main issues related to the existing water stress in the west:

(1) An increasing population places a larger demand on water and creates an additional pressure for areas that do not have adequate water resource infrastructure to accommodate this growth;

(2) Most rivers are already fully allocated, making it harder to find necessary water not only for larger populations but also for ecological purposes;

(3) River development occurred without acknowledgement of ecological functions, resulting in ecosystem degradation;

(4) New water sources will be sought after to make up for depleted groundwater supplies;

(5) Water prices typically do not reflect the actual value of water as a resource, while missing societal knowledge of water overuse might lead to unintended environmental impacts; and

(6) Water quality in certain areas is impaired, constraining remaining water uses in some cases.

These underlying issues contribute to water stress in the Rio Grande River Basin and are the basis for the exploratory study presented in this thesis. By analyzing how water use and sustainability variables change over time, patterns are examined to contribute to Rio Grande Basin research with the aim of advancing knowledge of how to efficiently allocate and manage urban water supply.

1.2 Problem Statement

As of 2016, the Rio Grande River is in a state of drought. Regional governments along the river have a variety of water allocation approaches in place depending upon the area of the watershed being examined. As the population continues to grow and the demand for water increases during this time of intense drought, the need for updated, applicable and plausible solutions to water allocation intensifies, both for surface and groundwater. Each state allocates water in different ways, leading to a fragmented regulatory system that impedes holistic river basin water management and coordination. Because of this finding a solution to the allocation problem will require updated interstate and international agreements, political compromise, jurisdictional cooperation and mutual agreements to benefit all societal and sectoral groups in a way that is economically, legally and politically feasible. This research aims at providing knowledge to assist stakeholders in a better understanding of the range of social, environmental and economic issues related to water management and to provide insight into possible trends and patterns in current and future water use in the counties examined.

1.3 Objective and Research Questions

The main objective of this research is to address the specified problems by providing awareness to the many socio-economic and environmental factors potentially impacting water use in counties along the Rio Grande River Basin. As information on this topic is still limited and data are either dispersed, inconsistent at a temporal scale or not easily available, this research aims at synthesizing multiple information and data sets in a coherent way and providing a coherent knowledge basis for decision-making support. This knowledge coherence will depict both a broader picture of water use changes in thirty Rio Grande River counties as well as a detailed picture of relationships between economic, environmental and social sub-indicators and water use in the Rio Grande River Basin, based on the three case study examples in Texas, Colorado, and New Mexico.

This study incorporates three sustainability indicator groups (economic, environmental, and social) (table 1), thus providing a more holistic view for addressing the complex issue of water use and allocation. This set of three sustainability indicator groups is further broken down into sub-indicators, with each sub-indicator placed into the indicator category (group) most appropriate for the study. The terms sub-indicator and variable will be used interchangeably throughout the study.

Table 1: Indicator Categories

Social	**Economic**	**Environmental**
General Total Population	Residential Water Rates	Total Water Withdrawals
Public Water Supply Population	Commercial Water Rates	Temperature Variability
Poverty Estimate	Residential Sewer Rates	Precipitation Variability
Per Capita Personal Income	Commercial Sewer Rates	Streamflow rates
Total Freshwater Withdrawals for Public Supply	Personal Consumption Expenditures (PCE) for Housing and Utilities	
	Per Capita PCE Housing and Utilities	

A selection of one county from each state as a case study example provides additional insights into this complex issue, and depth to this broad study. Looking at three counties in more detail helps with understanding the individualized regulatory nature of counties along the river. Rio Grande County has a slightly larger population than the remaining four Colorado counties in this study yet is still heavily agricultural, which was the main reason for the selection as a case study example as a representative example of the state of Colorado. Bernalillo County in New Mexico and El Paso County in Texas were chosen due to their urban areas and growing populations—the analysis for both counties can provide relevant insights for planning future water demands and urbanization. Using case study examples from different states along the Rio Grande River basin allows for a better understanding of social, economic and environmental changes that occurred in that region over time.

The main research questions addressed with this study are:

1. What are the notable relationships between different social, economic and environmental sub-indicators and water use in Texas, Colorado, and New Mexico counties along the Rio Grande River Basin?
2. Based on the amount of counties with significant relationships, which of the sub-indicator variables from the indicator table has the most significant relationship trends with water use? Are there sub-indicators that lack relationship trends with water use? If so, which variables?

Chapter 2: Literature Review

Stretching from the San Juan Mountains in Colorado all the way to the Gulf of Mexico near Brownsville, Texas and Matamoros, Mexico, the Rio Grande River Basin is the 5th longest river in the United States (Dahm et al., 2005). The Rio Grande supplies municipal and irrigation water for more than 6 million people and 2 million acres of land in the U.S. (U.S. DOI, 2016).

Broadly speaking, the basin can be divided into three subsections: the upper basin, the middle basin and the lower basin. Each of these basin subsections vary greatly in biodiversity, economics, culture and politics. For this review the Upper Basin is considered to start at the headwaters of the Rio Grande and end at the Elephant Butte Reservoir, constructed in 1916 as the river's first key dam. The Middle Basin boundaries are generally considered to start at Elephant Butte Dam and end at the Amistad International Reservoir, near the Terrell, Crockett and Val Verde counties in Texas. From the Amistad Dam, past the Falcon International Reservoir built in 1954, and down to the mouth of the Rio Grande in Brownsville is the area considered to be the Lower Basin. Due to flow characteristics, the river essentially flows as if it is two rivers independent of one another (Rister et al., 2011, p. 368). The upper area uses melted snow flow all the way from Colorado to a controlled general area near Fort Quitman, Texas, due to strict reservoir supervision. The Pecos and Rio Conchos tributaries inflow provide most of the river movement for the rest of the Rio Grande.

Much of this literature review will focus on discussing specifically U.S. water allocation from the Rio Grande since the data collected and analyzed focuses on thirty counties in Texas, New Mexico and Colorado. Despite this restricted focus, the Rio Bravo (the term for the Rio Grande in Mexico) and Mexico's international agreements and transboundary interactions will be occasionally referenced throughout this review and drawn upon to better understand possible allocation solutions to implement in the future for both countries. This inclusion will provide a more comprehensive foundation for the analysis of the U.S. Rio Grande impending water crisis.

To build this foundation, an overview of the historical background of the Rio Grande and the associated surrounding areas is necessary to examine how the water management process has progressed and evolved over time. Initial irrigation and use of the Rio Grande water originated with either Pueblo Indians or their ancestors at an unknown date (Hill, 1974, p. 165). The first recorded history of the Lower Rio Grande Basin, also known as the Rio Grande Valley, began with its discovery by Francisco Vazquez de Coronado in 1540. Spanish colonization during the 17th and 18th centuries in the Middle and Upper Basin subsections brought the first settlers to these areas, along with an initial expansion of irrigation (ibid).

Before the 1850s, the Rio Grande was overall not largely impacted by human development in the area. It was the Treaty of Guadalupe Hidalgo in 1848 and the Gadsden Treaty of 1853 that established joint commissions and have come to be considered the beginning of the eventual establishment of the International Boundary and Water Commission (IBWC) in 1889. The Guadalupe Hidalgo Treaty established the international boundary between Texas and Mexico, and the Gadsden Treaty reestablished the southernmost boundary of New Mexico and Arizona. With established boundaries came an increase in settlement along the Rio Grande's boundaries, which led to increasing use of land for agricultural purposes. This ultimately led to a need for stricter boundary regulations as agriculture grew and settlers encountered the Rio Grande boundaries changing due to the river naturally changing its course and therefore transferring land from one side of the river to the other. This boundary dilemma was addressed in the Convention of 1884, but settler population near the Rio Grande continued to expand quickly along with agricultural production and water use. The 1890's witnessed the first water shortages to occur along the Rio Grande, leading Mexico to file complaints against the United States for diverting the water supposed to be coming from Colorado and New Mexico (ibid). First there was an embargo passed in 1896 by the Secretary of the Interior in the U.S. preventing any further irrigation development to take place in the Rio Grande River Basin in Colorado and New Mexico. Modifications were made to the embargo in 1907, but the overall restriction remained until 1925 when it was removed. The result of this complaint was the Convention between the United States and Mexico: Equitable Distribution of the Waters of the Rio Grande, which produced the Mexican Treaty of 1906 (ibid).

Entering the 20th century, border populations near the Rio Grande continued to expand at a rate that called for water distribution regulations. This call was answered with the first water distribution treaty created between the United States and Mexico, the Mexican Treaty of 1906. This agreement allocated the Rio Grande water from El Paso to Fort Quitman, and apportioned Mexico an annual amount of 60,000 acre-feet of water from the Rio Grande to be delivered on a monthly basis (ibid). To assist with the new delivery system, help farmers receive water faster, increase water storage and protect from flooding the U.S. Bureau of Reclamation built the Elephant Butte Dam on the U.S. territory. The capacity of the reservoir is right around two million acre-feet, with the flood control reservoir Caballo constructed right below Elephant Butte. Even in 1906 when this treaty was made there was a provision included for extraordinary drought or serious accident stating the amount of water delivered to the Mexican Canal will be diminished in the same proportion as the water delivered to lands under the irrigation system in the U.S. that is downstream of the Elephant Butte Dam. While it does not account for prolonged drought or climate change it is the beginning of expressing awareness toward these phenomena (ibid).

The Compact of 1929 was the precursor to the Rio Grande Compact of 1938 and mainly focused on maintaining the “status quo” of the river, meaning that the current conditions of the river when the compact was signed would be preserved. The Compact of 1938 is an extremely important interstate agreement because it defines how much and where Rio Grande water will be allocated, administrative responsibilities, defining special rights of separate states and placing limitations upon each state (ibid). The 1938 Compact is still in place and holds relatively strong authority over how the water is allocated. The agreement called for Colorado to deliver stipulated amounts of water at the New Mexico-Colorado border and for New Mexico to do the same at the Elephant Butte Dam, instead of the New Mexico-Texas border (Durant and Holmes, 1985, p. 824). Two elements in the compact were debated fiercely, the first being if the Rio Grande surface water below Elephant Butte was split between Texas and New Mexico and the second being the question of whether the taking of groundwater led to an unauthorized reallocation of surface waters that had already been allocated by the Compact. Other disputes popped up as well but these two remained the most significant controversies of the Compact for decades after the agreement's inception.

While the Compact of 1938 was an interstate compact between Colorado, New Mexico and Texas, the Mexican-American Treaty of 1944 was an international agreement that aimed to address the bigger water allocation issues present between the United States and Mexico (Hundley, 1967, p. 211). The treaty addressed water rights over the border streams of the Colorado, Tijuana and Rio Grande rivers. For the Rio Grande River Mexico yielded 350,000 acre-feet, which greatly benefitted Texas and promoted the idea of the Good Neighbor policy between Mexico and the U.S. The Good Neighbor policy was a foreign policy developed by the former U.S. President Franklin Roosevelt that encouraged trade and non-aggressive relations between the U.S. and both Mexico and Latin America. The Compact of 1938 and the Treaty of 1944 are two of the main agreements regulating water management of the Rio Grande during this era, and continue to play a factor in today's water distribution in all three of the basin subsections (Rister, 2011).

Beginning with the Upper Rio Grande Basin and concluding with the Lower Basin, an overview of the policies from the 1950s and onward is provided in the following paragraphs to more clearly understand the fragmented governance of water allocation present not only in each area but the entire river.

The problem of water allocation for the Rio Grande includes a variety of factors: continual population increase, increasing water demand, decreasing supply, increasing salinity and a lack of basin-wide stakeholder communication resulting in short-term management plans that to not address the larger water scarcity issue. This research addresses the problem as a basin-wide issue and thus does not focus on the regional fragmentation itself. It rather strives to find a common ground for the analysis of the different management systems and to provide ideas about mutually beneficial water allocation solutions.

The Upper Rio Grande Basin is an area climatologists predict will see a warmer and drier climate as greenhouse gases continue to increase, leading to an even larger increase in already-present water shortages (Bella et al., 1996, p. 248). Problems in Upper Basin water allocation include the absence of agreement on groundwater use and actual water supply, since the demand is expected to go up while the water table is anticipated to go down (Bella et al., 1996, p. 248). Secondly, water quality issues have become apparent as agriculture and irrigation practices expand leading to water contamination. Furthermore, Native American rights have not been quantified and require a resolution to properly manage water resources and rights. These problems all include the ever-present issue of environmental protection that needs to be taken into consideration when attempting to solve any of the aforementioned Upper Basin problems. This section of the river basin supports more than three million people along with extensive agriculture, in addition to the fish and wildlife habitats present. In fall of 2004, water storage in Elephant Butte reservoir was less than 5% of its capacity and water allocations during 2003 were reduced to one-third of full supply conditions (Ward et al., 2007, p. 490). 80% to 90% of water from the Upper Basin is used for irrigated agriculture, with the main crops irrigated being forage, cotton, pecans and vegetables. Consumptive use varies from around 30% in central New Mexico to a high of 70% in southern New Mexico and west Texas, with the remainder of the water constituting an essential source for groundwater recharge, riparian habitat and return flow to users downstream.

Groundwater pumping has previously always been an effective method of keeping up with consumer water demands in the municipal and industrial (M&I) sector, but pumping is not sustainable at current rates let alone increasing rates as demand increases with the population growth. A typical household in the Upper Basin uses water for cooking, washing, cleaning, sanitation, outdoor cleaning and maintaining a domestic landscape setting.

In addition to a demand for pumping groundwater, environmental demands have increased as well (Ward et al., 2007, p. 490). The Rio Grande silvery minnow is an excellent example of the extent of environmental impacts experienced by Rio Grande River Basin ecosystems. It was listed by the U.S. Fish and Wildlife Service as an endangered species in 1994 and associated requirements include minimum river flows to sustain the remaining minnow population even in times of drought.

Existing Rio Grande water supplies are claimed and diverted primarily for irrigation and growing M&I demands, followed by increased protection of in-stream flows and the environment (Booker et al., 2005, p.1). Known as the “Law of the River”, the current policy system for Rio Grande water distribution in the Upper Basin is mandated primarily by the aforementioned 1938 Rio Grande Compact between Texas, Colorado and New Mexico. The most important allocation aspect of this compact is the certain set of supply indices specifying shares of river inflows from one state delivered to the state downstream. Under the operation dictated by the Bureau of Reclamation, New Mexico land receives 57% of annual flows while Texas land receives 43%. The allocation for New Mexico all goes to irrigated agriculture and Texas allocation goes toward both M&I in El Paso and irrigated agriculture in Texas. While legal rules do recognize the impending scarcity of the resource, they do not include significant efforts aimed at water allocation efficiency or conservation.

A study conducted with water utilities in California, Colorado and New Mexico collected information on water use, rate structures, and revenues from selling water and conservation programs with no price from 1980 to mid-1994 (Michelsen et al., 1998). While this study is a little outdated with respect to climate change and recent drought, it is a useful foundation for gaining insight on Upper Basin water use. The cities studied were Los Angeles, San Diego, Broomfield, Denver, Albuquerque, Las Cruces and Santa Fe. From the study, it was found that water’s demand was quite inelastic, meaning that large percentage increases in price are necessary if there is to be any small percentage of decrease in water consumption. This is not the only study showing this result—different studies have continually shown that it will take a significant price increase to motivate people to use even a little less water. The article “Managing Water Demand: Price vs. Non-Price Conversation Programs” by Sheila M. Olmstead and Robert N. Stavins supports the assertion made in the 1998 Michelsen article that price-based approaches, particularly ones with a significant price increase, are much more effective at incentivizing citizens to conserve water than non-price approaches or price-based approaches with only a slight increase in price (Olmstead and Stavins, 2007, p. 2).

A study conducted in 2005 by Booker et al. (2005, p. 6) showed that in the San Luis Valley, Albuquerque, Middle Valley, Mesilla Valley, and El Paso the marginal benefits of pumping groundwater are lower than using surface water because of the costs associated with pumping groundwater. More findings from this study conclude that, as of 2004, El Paso can meet right under half its total water demand from surface water treatment in non-drought situations and a little over half its demand from pumping groundwater in optimal non-drought conditions. As of 2005, Albuquerque met its river demands through pumping groundwater regardless of actual river flow at the time, even though it legally has the water right to meet all its water demands from surface resources. The Middle Rio Grande Conservancy District, which encompasses Cochiti Reservoir down to Elephant Butte Reservoir offers a comprehensive source of information for updates on all aspects of the river in this section.

Referring to the ‘Law of the River’, existing water allocation institutions observe drought impacts concentrated in Colorado agriculture and the Rio Grande River section in New Mexico. Colorado does not have much reservoir storage and instead relies upon groundwater storage. As drought persists shallow groundwater reserves that exist because of irrigation recharge are depleted rapidly, creating economic instability.

Yet Colorado has become fairly successful at suggesting and implementing water conservation measures with the Rio Grande Water Conservation District (RGWCD) recently actively developing measures to regulate water management. These developments are primarily the enhanced communication skills of the water managers in the district and initiatives made to account for drought impact and population growth.

Water allocation in the Middle Rio Grande Basin for close to a century has been regulated by the Pecos River Compact and the Rio Grande Compact at the interstate level (Hogan, 2013, p. 3). The Pecos River Compact asserts that New Mexico is not allowed to deplete the flow from the Pecos River before it has reached the Texas border.

The Rio Grande Compact is the same as the one mentioned for the Upper Basin and provides schedules of deliveries administered by an assignment including three representatives from each Compact state: Colorado, New Mexico and Texas with a fourth non-voting member selected by the President of the U.S. An international treaty signed in 1983 called the La Paz Agreement created regulations to protect and improve the environment along the Mexico-U.S. border (Frisvold and Caswell, 2000). The aim is for both countries to coordinate their efforts with each other all the while conforming to national legislation and any bi-national agreements in effect.

Found within the Rio Grande Compact, the Rio Grande Project deals with reservoir delivery systems in the Middle Basin subsection and was the result of a need for a better irrigation system that would properly sustain New Mexico’s agricultural demand by mandating deliveries to farmers in the Elephant Butte Irrigation District (EBID) and the El Paso County Water Improvement District No.1 (ECPWID). Constructed by the U.S. Bureau of Reclamation in approximately 1916, it was operated as a single irrigation system until the separate districts paid off their federal loans in 1978 (Hogan, 2013). The Rio Grande Compact places the entirety of the Rio Grande Project, even EBID which is located exclusively in New Mexico, under the authority of the Texas Compact Commissioner (King and Maitland, 2003). The diversion structures put in place to help systemize irrigation and provide water to the districts are sustained and operated by the districts under contract to the Bureau of Reclamation, who has overall ownership of the diversion structures. The International Boundary and Water Commission controls much of the river channel in the Middle Basin subsection which includes flood control levies and river modification structures.

Elephant Butte Irrigation District is the upstream district in this basin subsection and was formed when the Elephant Butte Water Users Association and the U.S. created a contract to dissolve the Water Users Association in favor of transferring all the responsibilities, benefits, rights and project revenues exclusively to EBID. It operates under both New Mexico and U.S. rulings and even if the actual irrigated acreage decreases, EBID still holds water rights to irrigate the full 90,640 acres of land it possesses. Farmers living in the EBID supplement their water supply with groundwater retrieved from private wells (King and Maitland, 2003). The district extends from the Elephant Butte Reservoir all the way down to the state line between New Mexico and Texas and is a multi-municipal entity of New Mexico.

El Paso County Water Improvement District No.1 starts at the New Mexico-Texas state line and ends at the El Paso-Hudspeth county line (Hogan, 2013, p. 4). It is a political subdivision of Texas and includes 69,010 acres with around 10,880 acres in the southern Mesilla Valley and 58,130 acres in the El Paso-Juárez Valley. The City of

El Paso is one of the EPCWID’s biggest water users, which uses surface water to supplement groundwater resources in the area. In a full allocation year El Paso has water rights to around 65,000 acre-feet from the Rio Grande project. With a normal river flow, surface water treatment plants operate during the irrigation season for seven months per year. Currently El Paso Water Utility’s (EPWU) overall water supply strategy is to conjunctively use both surface and groundwater supplies and to pump groundwater more extensively when there is a shortage of surface water. According to EPWU (2011), if Texas went into another drought, the state would face an immediate need for more water supplies, with 8% of that need associated directly with municipal water users. These water needs are projected to increase by 130% between 2010 and 2060. It is municipal water needs that grow 10-fold over the planning period, far exceeding changes in all the other water user categories (ibid.)

Within the Rio Grande Project the Bureau of Reclamation developed regression-based linear relationships to allocate water to the districts between the years of 1979 and 2008. The primary goal was to evaluate a potential decrease in water delivery to the U.S. in times of drought and the efficiency of the delivery system itself. In 2008 EBID and EPCWID signed an Operating Agreement including a new allocation method that appropriated the EPCWID its water share based on operations and delivery efficiency from 1951-1978. EBID’s allocation is now calculated by the “Diversion Ratio” which is estimated by using the ratio of the amount of diversion in a given district to the total discharge from Caballo Reservoir during a particular year (EBID, 2008). Therefore, if the analyzed year’s Diversion Ratio is less than current delivery efficiency expressed, EBID receives reduced water allocation. With this approach, only EBID pays for any amount of water that decreases transport efficiency by receiving decreased allocations. Factors that decrease efficiency include drought, accounting credits and impacts from groundwater pumping on Project surface water provisions (Hogan, 2013, p. 6).

The next county district in this subsection is the Hudspeth County Conservation and Reclamation District No.1 (HCCRD), located in the El-Paso Juarez Valley along the U.S. side of the Rio Grande in the Middle Basin. The district starts at the El Paso-Hudspeth county line and ends around 3 miles upstream of the Rio Grande in Fort Quitman, Texas. It is not a part of the Rio Grande Project and virtually the only flows available to the HCCRD are the flows leaving EPCWID as drainage and operational spills, so the water supply is highly insecure and extremely vulnerable to significant reductions during drought (King and Maitland, 2003).

In parts of both the Lower and Middle Rio Grande, water resources are managed by the Rio Grande Watermaster Program, a division in the Texas Commission on Environmental Quality. This program came into existence in 1971, after the 1950s droughts resulted in the people who owned older water rights at the eastern end of the Rio Grande receiving no water once upstream water rights' owners had already legally diverted their share of the resource. There are 17 counties included in the program which runs from Fort Quitman to the Gulf of Mexico, or Brownsville for U.S. Territory (TCEQ, 2011). Water rights upstream of the Amistad Reservoir have less seniority than downstream, which makes up the Lower Basin subsection.

Since the entire U.S. portion of the Lower Basin is in Texas, Texas surface water law and water rights are an important start to understanding relatively recent water allocation. Instead of analyzing the allocation in each district an overview of allocation regulations for both the state and the subsection are provided here. The regulations stem from a mix of Spanish appropriation rights and English common law, which placed an emphasis on riparian rights (Yoskowitz, 1999, p. 346). Riparian rights allocate water in a systematic fashion to those who own land along the river's path. A court case from 1956 led to judging Texas water rights on a case by case basis as Texas legislature had riparian and appropriation claims merged and created a new procedure to resolve claims. Known as the Texas Water Rights Adjudication Act of 1967, this program also created the Rio Grande Watermaster (RGW) Office which is legally under the Texas Natural Resource and Conservation Committee (TNRCC). The offices of the RGW oversee monitoring use, allocating and enforcing water right laws put in place by both the Hidalgo Treaty and Texas legislature, which handles all individual water rights accounts. According to the Lower Rio Grande Valley Water Case, municipal and domestic users receive top priority, followed by industry and then irrigation, despite this river section having the largest allocation needs among the three subsections. As of 1997 there were 813 active water rights along the Texas portion of the Rio Grande, with 86% of water rights in agriculture, 10% of municipal rights, 1% water rights for the mining industry and 3% for other major participants in the Texas water appropriation market. This breakdown shows how important it is to encourage irrigated agriculture to regulate water use and use it more sustainably.

One major limitation in this study was that institutional and political definitions of basin subsections differ greatly from how researchers define the Upper, Middle and Lower Basin geographic proximities. For this study, the subsections are based upon previous researchers' chosen geographies, which makes the districts mentioned slightly ill-matched definition compared to original basin subsection boundaries. Another limitation is data availability for the past decade—while much of it is from the 1990s or early 2000s, there seems to be a significant dearth in research for the Rio Grande Water Basin starting around 2006. Other limitations include lack of information on water allocation in parts of the Rio Grande controlled and owned by Mexico.

The discussed legal and economic issues in the Rio Grande River basin emphasize the need for sustainable solutions in the respective river sections and throughout the River basin. Several different approaches have been discussed in the literature to improve water management (Tidwell et al., 2004; Schmandt, 2002; Yoskowitz, 1999). They include, among others, reducing physical water loss, properly managing ground and surface water supply concurrently, transferring water over state (and possibly country) borders, enhanced delivery efficiency and agricultural irrigation efficiency, and drawing upon alternative water supplies such as desalinization. While there are regulations in place to determine water transfer and delivery (Rister, 2011), they are vague and unyielding to anomalies in flow pattern, which are occurring more and more as drought and extreme weather events continue to intensify.

Water use and allocation in the Rio Grande River Basin is currently determined by a variety of different regulations and rules in all three areas (sections) of the basin. Many rules and regulations were created in the early 20th century, meaning that they fail in some aspects to account for climate change, drought, an increasing population, and the subsequent increase in water demand for agriculture. Yet there are opportunities for change as districts keep updating legislature and regulations to increase conservation, efficiency and awareness of the water allocation issues in the Rio Grande River Basin.

Even though municipal water use is relatively small compared to agricultural use in the southwest (Gleick, P. H., 2010; Stonestrom, D. A., 1984), understanding current and future trends in water use and associated variables can help stakeholders prepare water resources for a more populated, drought-stricken area. This research aims to contribute additional knowledge and analysis to facilitate and expedite this change.

Chapter 3: Data Collection

3.1 Research design – Sustainability Indicators and Data Sources

The research design is based upon the set of sustainability indicators in table 1, where each sub-indicator (i.e. variable) is placed within either a social, economic or environmental indicator category to account for the three main sustainability pillars. It has also been stated in the literature that solving complex sustainability issues such as water resources would be much more difficult without the holistic view of all three pillars (i.e. indicators) (Moldan et al., 2012). Attempting to solve an issue of sustainability requires a comprehensive understanding of the problem at hand, which requires information from social science, economics, and environmental science, and the ability to compare and evaluate this information (Sandoval-Solis et al., 2010). While there are countless variables related to water resources, the sustainability sub-indicators included for this analysis have been hypothesized and selected as the most relevant and potentially impactful toward water use. They are called sub-indicators because they each belong to one of the three indicator groups (social, economic, environmental), which denote varying levels of the state or condition of the indicators and the entirety of the sustainability problem.

At the same time, it needs to be mentioned that many of the variables fit into multiple indicator categories, meaning they could be either social or economic. In this study, each variable was only mentioned once in the indicator table and therefore placed in the most appropriate category to avoid repetition and overlap in the following analyses.

Regarding the social indicators, general total population was chosen to assess the ways population has changed in the analysis years (2000-2015). For the general total population of each county, the April 1st population dataset was used for the years 2000 and 2010, with the rest of the yearly population estimates originating from estimates gained on the 1st of July. The poverty estimate for each county was collected to observe water use at different poverty levels in the analyzed case study regions. For example, it is possible that high-income households use more water since the owners most likely are able to afford higher utility bills. However, on the other hand, higher water use in lower-income households might also occur since the appliances owned may not be as technologically advanced and therefore not efficient to conserve water. Those and other questions for each indicator will be analyzed with this study.

Per capita personal income adds to the poverty information by supporting any income-based trends. Finally, total freshwater withdrawals for public supply has been assigned to the social category because the measurements are tied to possible trends in the overall demand for water for the population and the public sector supply. The total withdrawals as a sub-indicator was added to the environmental indicator category because it relays all water withdrawn for all industries including public supply, domestic (self-supplied), industrial, irrigation, livestock, aquaculture, mining, thermoelectric, saline and fresh groundwater and surface water. Total water withdrawals can be assumed to have a larger impact on the environment, while public supply withdrawals is a portion of total water withdrawals. It is defined as water withdrawn by public and private water suppliers that deliver water to at least 25 people or have a minimum of 15 water connections (USGS, 2016). For this reason the two sub-indicators were grouped into different indicator categories, even though a case can be made for each sub-indicator to fit into either social or environmental indicator categories. Important environmental water demands, such as ecosystem water use and evapotranspiration, were not mentioned under the total withdrawals statistics and therefore it can be assumed these water use variables were not included when calculating total withdrawals, total in this analysis. When discussing total freshwater withdrawals and total water withdrawals, water withdrawals and water use will be used interchangeably throughout this study.

In the economic indicator category are residential and commercial water and sewer rates since social factors typically do not influence the water rates, but are rather set by local water utilities. Personal Consumption Expenditures from Housing and Utilities and the Per Capita Personal Consumption Expenditures for Housing and Utilities is included in the economic variables as well.

The environmental variables include: total water withdrawals, temperature and precipitation variability, and streamflow rates (expressed in a quantitative way), and endangered and threatened species (discussed in qualitative terms due to a lack of quantitative documentation for this variable).

The water use (total freshwater withdrawals and total water withdrawals), public water supply and the average annual streamflow information were collected from the USGS data base. The data on general population, poverty rates and personal income were obtained from the United States Census Bureau. All personal consumption expenditure data was collected from the Bureau of Economic Analysis, while residential and commercial water and sewer rates were collected from state-level organizations

(Colorado Department of Local Affairs, New Mexico Environment Department, and Texas Municipal League). Temperature and precipitation data was obtained from the PRISM Climate Group from Oregon State University. New Mexico and Texas water rates were collected from the New Mexico Municipal Water and Sewer Rate Survey and the TML's Annual Water and Wastewater Survey, respectively. Since the New Mexico survey determined water rates using per 6000 gallons and the TML survey determined rates using per 5000 gallons, the New Mexico survey rate numbers were converted to per 5000 gallons. These conversions were necessary to compare the two states' water rates. Comparison data between New Mexico and Texas begins primarily at 2002 as the earliest survey information for New Mexico available. There was no cumulative, quantitative water rate data for counties in the state of Colorado.

When looking at the poverty variable, the data for the overall poverty estimate for all ages is the category chosen to represent poverty for each county. Per Capita Personal Income has been collected at both the state and county level. The housing and utilities category of total personal consumption expenditures and the per capita personal consumption expenditures for housing and utilities is state level information since county level information for these categories is not available. The temperature and precipitation is represented as the county level information, while the streamflow data is the average of the yearly data available for each county. The temperature data, while typically measured on a more detailed time scale, was aggregated for this study analysis by county and on an annual level.

The analysis conducted on these variables is quantitative for the most part since the study utilizes secondary data sets. The data included in this analysis spans from

2000 to 2015, depending on data availability for the respective indicators. For the residential and commercial water and sewer rates in New Mexico and Texas, the years span from 2002 to 2014. Also, in for some indicators and years data might be missing because of dispersed and inconsistent sets provided by regional and national statistics or statewide survey data.

3.2 Research Regions and Case Study Counties

To study the Rio Grande River Basin in a conclusive yet succinct format, 30 counties alongside the river were chosen, starting in Colorado and ending in southern Texas. They include:

Counties in Colorado: Alamosa, Conejos, Hinsdale, Mineral, and the Rio Grande,

Counties in New Mexico: Bernalillo, Dona Ana, Los Alamos, Rio Arriba, Sandoval, Santa Fe, Sierra, Socorro, Taos, and Valencia, and

Counties in Texas: Brewster, Cameron, Dimmit, El Paso, Hidalgo, Hudspeth, Jeff Davis, Kinney, Maverick, Presidio, Starr, Terrell, Val Verde, Webb, and Zapata.

Due to the geographic, socio-economic and environmental diversity in each of the counties, data sets show to be variable across those regions. For that reason, the analysis was narrowed down to three selected counties to emphasize those differences and provide a perspective on changes in sustainability indicators over time from a micro scale perspective.

Three counties have been selected for the case study analysis: Rio Grande (CO), Bernalillo (NM), and El Paso (TX).

These case studies will provide a closer look at water use trends and patterns in the region and as a potential information base for future comparisons with other counties and areas.

3.3 Proceeding

The approach to organizing and analyzing the data collected was to first organize them by variable, then by county, and last by year. Counties were chosen instead of cities or specific sites because they provide essential baseline data without encompassing too large or too small of a region. A large number of economic and social datasets has been derived at the county level, making it the most practical regional analysis for this study.

Interpolation was used for the USGS water data to account for missing consistency of the data sets (USGS data is reported only in five year increments, while this analysis focused on annual changes of the analyzed variables). By filling in the numerical gaps, interpolation also allowed for a correlation analysis that will be discussed in more detail in the following paragraphs and chapters.

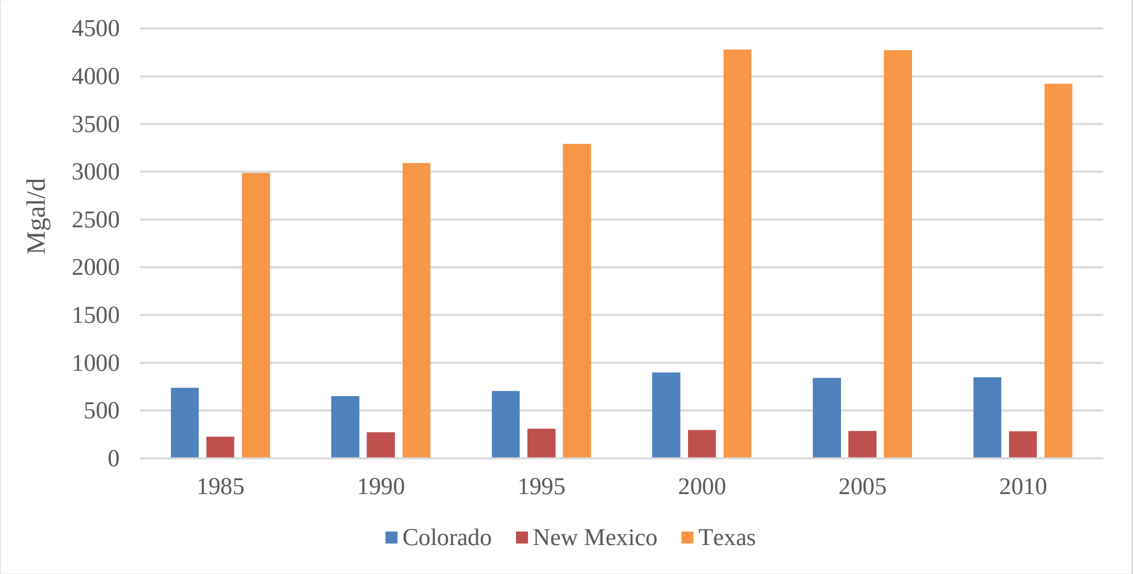
The data was first analyzed for temporal patterns and trends in each Rio Grande state and each case study county. In a next step, a correlation analysis was conducted for sustainability indicators and water use for the three case study counties. The purpose of the correlation analysis was to analyze the relation between one of the two water use datasets and another selected variable at a time from the list of sustainability indicators.

Chapter 4: Trends and Patterns in Socio-economic and Environmental Sub-Indicators in the Rio Grande River Basin

4.1 Water Use in Colorado, New Mexico, and Texas

Water withdrawals for public supply in all three analyzed states: Colorado, New Mexico and Texas have seen an overall increase since 1985, and a slight decrease in 2010 (compared to 2005) (figure 1).

Figure 1: Total withdrawals for public supply (fresh water) in Colorado, New Mexico and Texas

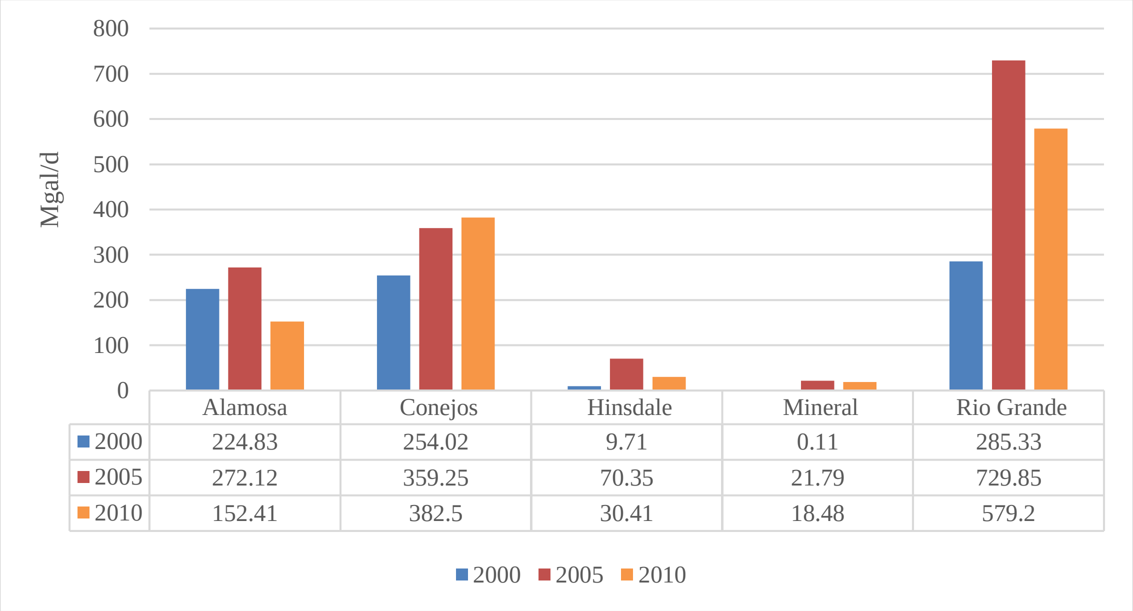


Since World War II, many individuals have relocated from rural areas to urbanized cities, creating more demand for larger water supply systems and more water available for public supply (USGS, 2016). Prior to 1950, the USGS categorized water withdrawn by public and private suppliers that either provide water to a minimum of 25 people or have at least 15 water connections as municipal supply, but since 1955 both approaches have been categorized as public supply. This public supply water is used for domestic, commercial, thermoelectric power generation, industrial and public purposes. It also plays a primary role in observing and tracking urban water use trends. Because of this total public supply of freshwater is considered as the best representation of water use in all three states from 1985 to 2010, and thus was chosen to depict a general picture of water withdrawals in these states over a 25-year time span. The two water use variables utilized for the rest of this study, total freshwater and saline withdrawals and total public supply withdrawals of freshwater were not used to represent state water use because of incomplete data sets for the time span 1985-2010.

Looking specifically at total water withdrawals in each of the three states, a more detailed picture is revealed.

Figure 2 shows that the total withdrawals of both surface and groundwater in the five counties along the Rio Grande River in Colorado has fluctuated from 2000 to 2010.

Figure 2: Total withdrawals in Colorado by county

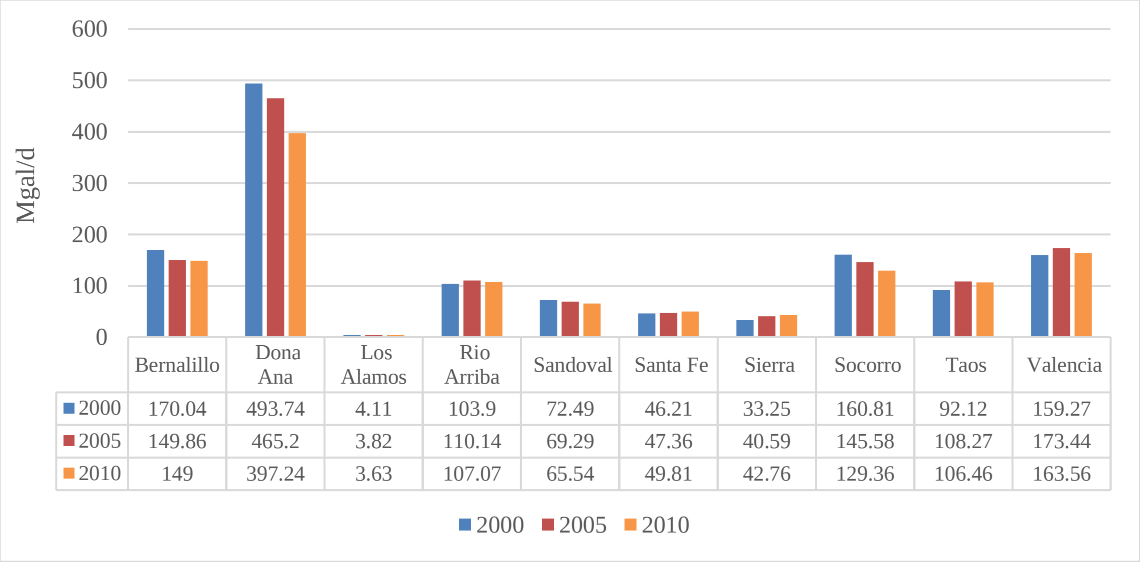


	Alamosa	Conejos	Hinsdale	Mineral	Rio Grande
■ 2000	224.83	254.02	9.71	0.11	285.33
■ 2005	272.12	359.25	70.35	21.79	729.85
■ 2010	152.41	382.5	30.41	18.48	579.2

The total withdrawals include both fresh and saline water withdrawn. In 2005, Alamosa, Hinsdale, Mineral and Rio Grande Counties recorded the highest amount of water withdrawals whereas Conejos had the largest amount of withdrawals in 2010. Rio Grande County, the case study example chosen for Colorado, recorded the highest withdrawals in each of the three years compared to the other counties, with 579.2 million of gallons of water used per day (Mgal/d) in 2010. These large withdrawal amounts relative to the rest of the analyzed counties show the impact this county has on water use and the importance of studying this county in particular. Since water withdrawals are expected to rise as the population increases, minimizing withdrawals in the county with the highest total withdrawals might have a positive effect on water resources and help conserve water – the county with its water management practices could in this way become an example for other counties in the state or other states along the Rio Grande River.

Among the New Mexico counties, Dona Ana has recorded the highest withdrawals with over 493 Mgal/d in 2000, 465 Mgal/d in 2005 and almost 400 Mgal/d in 2010 (figure 3).

Figure 3: Total withdrawals in New Mexico by county

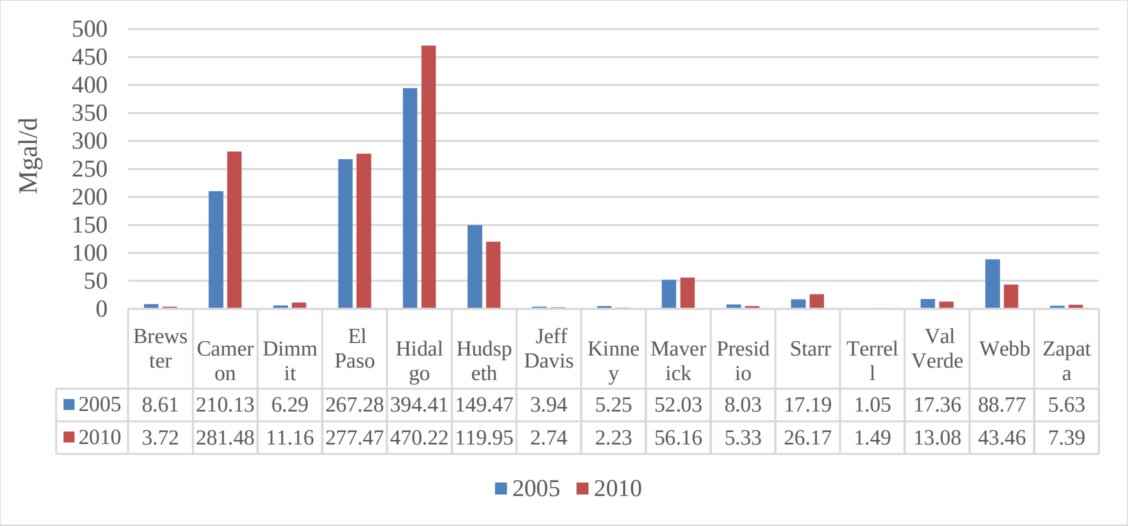


	Bernalillo	Dona Ana	Los Alamos	Rio Arriba	Sandoval	Santa Fe	Sierra	Socorro	Taos	Valencia
🟦 2000	170.04	493.74	4.11	103.9	72.49	46.21	33.25	160.81	92.12	159.27
🟥 2005	149.86	465.2	3.82	110.14	69.29	47.36	40.59	145.58	108.27	173.44
🟧 2010	149	397.24	3.63	107.07	65.54	49.81	42.76	129.36	106.46	163.56

Valencia, Bernalillo and Socorro counties all have the next highest withdrawal amounts, where all withdrawal levels are at a minimum of 129 Mgal/d. The lowest withdrawal levels are in Los Alamos County, with 4.11 Mgal/d in 2000 being the highest withdrawal rate of the three studied years at the same time. The presented fluctuations in total fresh and saline water withdrawn illustrate variations in water supplies in those counties despite their geographic proximity. Bernalillo County has the city (Albuquerque) with the largest population in New Mexico, but Dona Ana is the county with the largest number of farms and ranches (USDA, 2014). This high number of farms in the area could be one of the reasons why Dona Ana's withdrawals are higher than other counties with more populated cities. In Bernalillo County, water withdrawals decreased from 2000 to 2005 by approximately 12%, while the withdrawal level remained relatively unchanged in 2010 (compared to 2005).

A similar variability in total withdrawals among counties has been found in Texas (figure 4).

Figure 4: Total withdrawals in Texas by county



	Brewster	Cameron	Dimmit	El Paso	Hidalgo	Hudspeth	Jeff Davis	Kinney	Maverick	Presidio	Starr	Terrell	Val Verde	Webb	Zapata
🟦 2005	8.61	210.13	6.29	267.28	394.41	149.47	3.94	5.25	52.03	8.03	17.19	1.05	17.36	88.77	5.63
🟥 2010	3.72	281.48	11.16	277.47	470.22	119.95	2.74	2.23	56.16	5.33	26.17	1.49	13.08	43.46	7.39

The total withdrawals in the fifteen selected Texas counties span between a wide range of values over the years 2005 and 2010. Data for total withdrawals from 2000 in these counties was unavailable for the analysis. With the lowest numbers found in the

Terrell County at 1.05 Mgal/d in 2005 and 1.49 Mgal/d in 2010, and the highest numbers found in Hidalgo County at 394.41 Mgal/d in 2005 and 470.22 Mgal/d in 2010, there is a clear variability in withdrawal rates along the Rio Grande River. El Paso County, the case study region for Texas, has the second highest average total withdrawals, although Cameron County had higher withdrawals in 2010 (281.48 Mgal/d). Hypothetical reasons withdrawal rates in some counties could be low are lower population numbers, larger groups of people using their own wells for water supply, or water transfers (water brought in from other areas). El Paso County noted an increase in total withdrawals by around 4% between 2005 and 2010, and was among the seven of the fifteen counties to record a withdrawal increase since 2005.

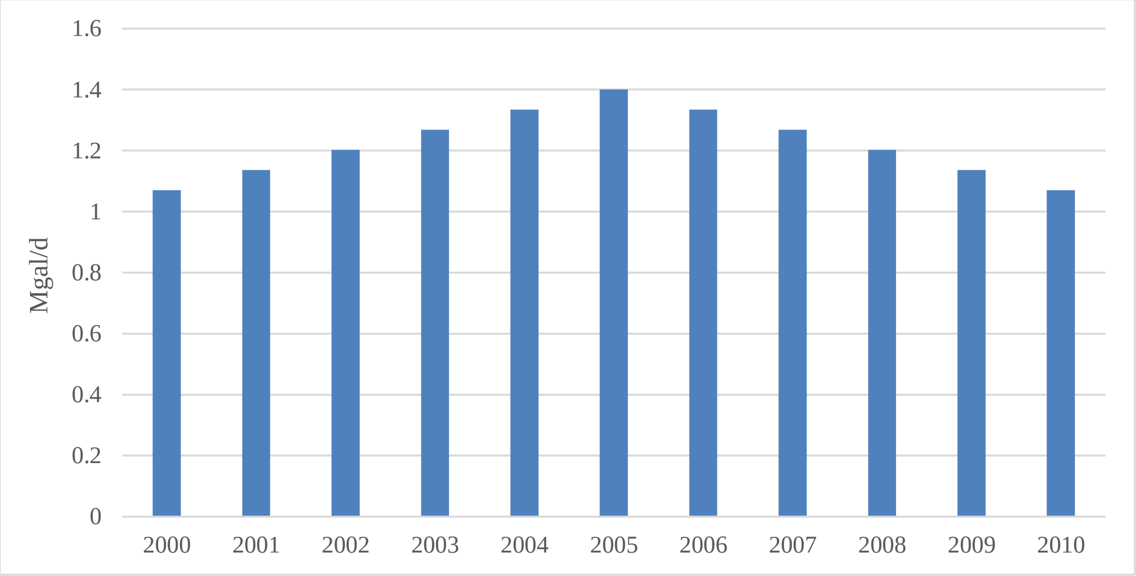
4.2 Water Use in Case Study Counties (Rio Grande, Bernalillo, and El Paso)

4.2.1 Public Supply, Total Withdrawals, Freshwater

This chapter and the following chapters will focus on examining each variable in the selected case study counties rather than using a broad overview of all the counties.

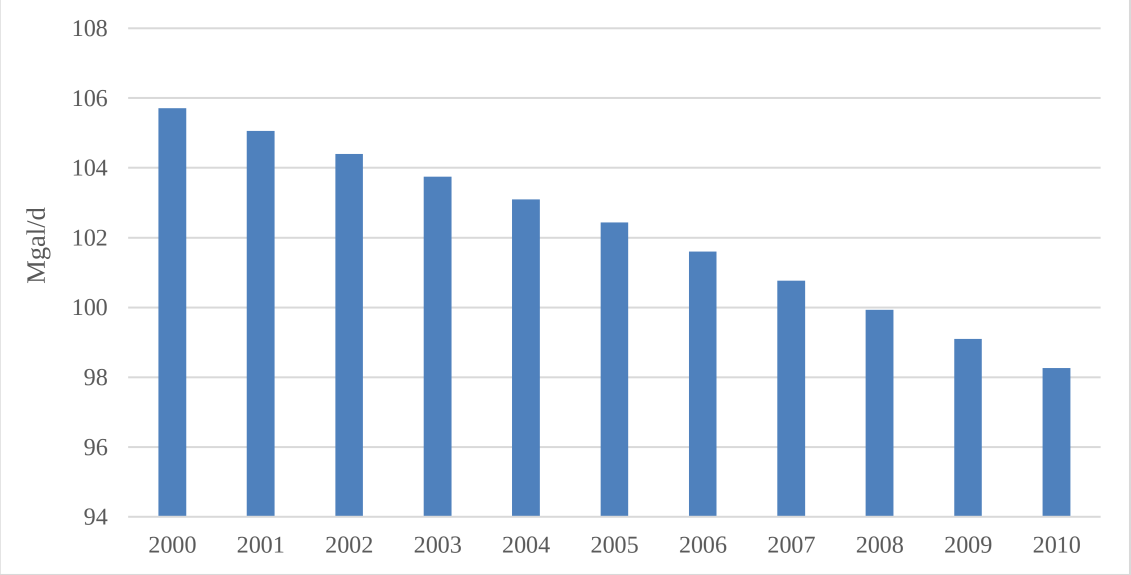
The first of the three case studies is Rio Grande County in Colorado. Figure 5 shows the amount of freshwater total withdrawals in Mgal/d for public supply annually between 2000 and 2010. While the withdrawals showed an initial increase in 2000-2005, they started to steadily decline in 2005, ending up with the same value in 2010 (1.07 Mgal/d) as in 2000.

Figure 5: Public Supply (total withdrawals), fresh water in Rio Grande County, TX



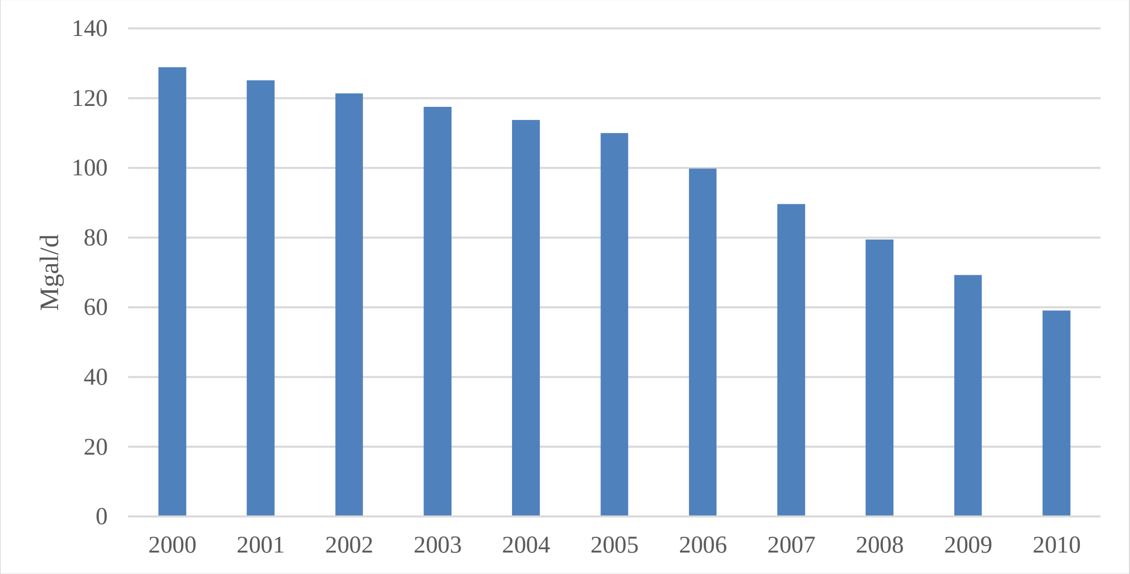
The total freshwater public supply withdrawals were much larger in the New Mexico case study county of Bernalillo compared to withdrawals in Rio Grande County. The highest withdrawals of 105 Mgal/d was recorded in 2000, while the lowest withdrawal amounted to 99 Mgal/d in 2010. The amount of public supply total freshwater withdrawal has decreased steadily since 2000 (figure 6).

Figure 6: Public Supply (total withdrawals), fresh water in Bernalillo County, NM



In the case study county of El Paso in Texas, freshwater withdrawals have also been decreasing since 2000. In 2000, the withdrawal level was at approximately 128 Mgal/d, while it went down to ~59 Mgal/d in 2010 (figure 7). A potential reason for a decrease in withdrawals include, among others, the utilization of desalination plants (Ziolkowska and Reyes, 2016).

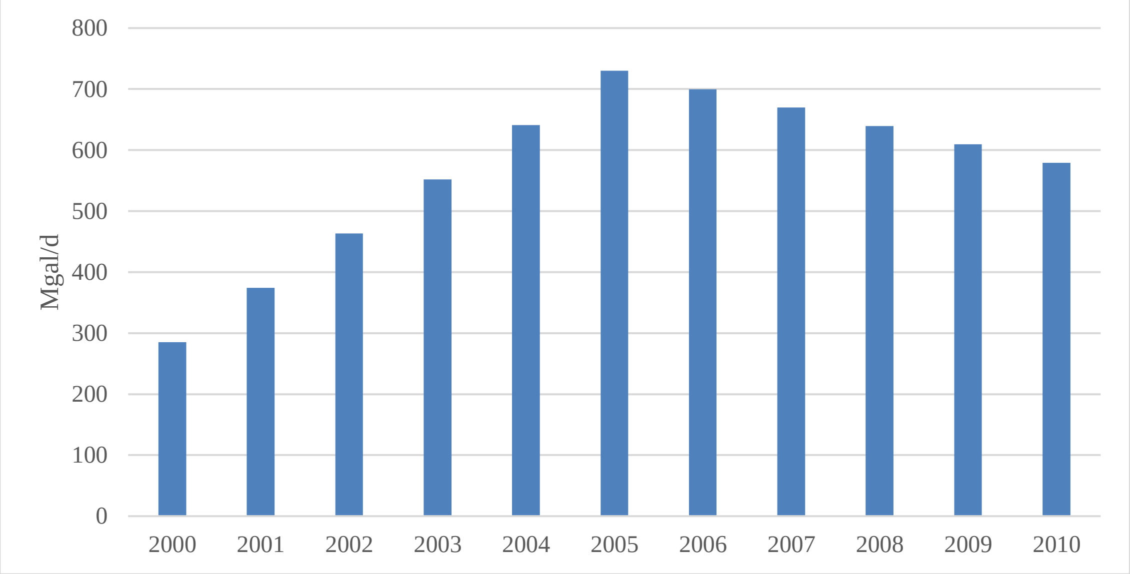
Figure 7: Public Supply (total withdrawals), fresh water in El Paso County, TX



4.2.2 Total Withdrawals

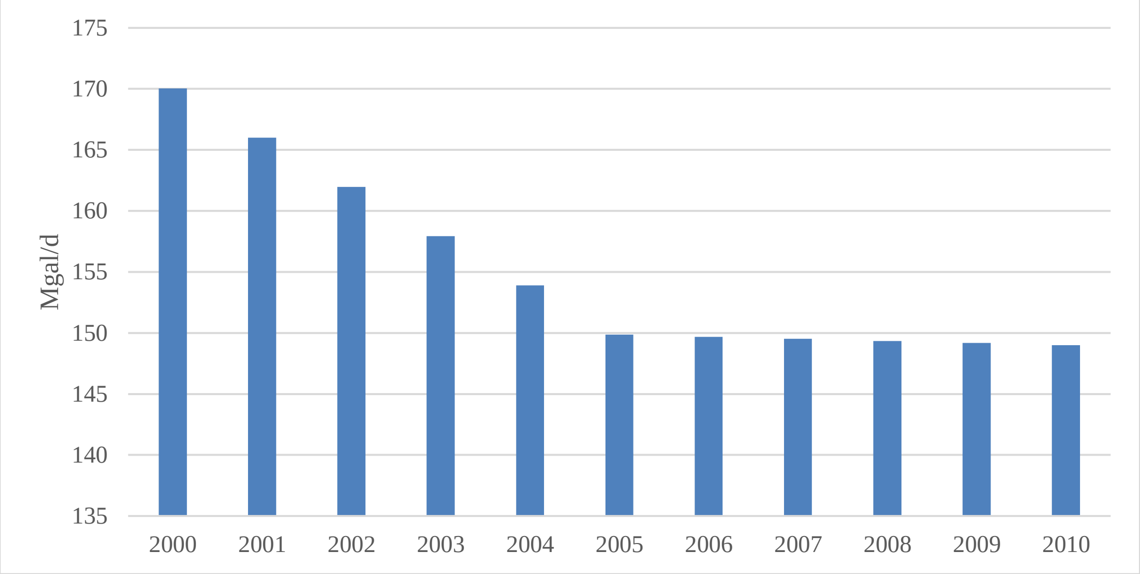
For both saline and freshwater combined, total withdrawals in Rio Grande County indicated a steady increase from 2000 to 2005 of around 90 Mgal/d per year, starting with 285.33 Mgal/d in 2000 and 730 Mgal/d in 2005. From 2005 to 2010 there was a decline in water use, but at a slower rate than the increase in withdrawals observed between 2000 and 2005. With a decline of around 30 Mgal/d per year, the 2010 withdrawal levels amounted to approximately 579 Mgal/d. Even though there has been a decrease in the total withdrawals, in 2010 withdrawals were twice as high as in 2000 (figure 8).

Figure 8: Total withdrawals in Rio Grande County



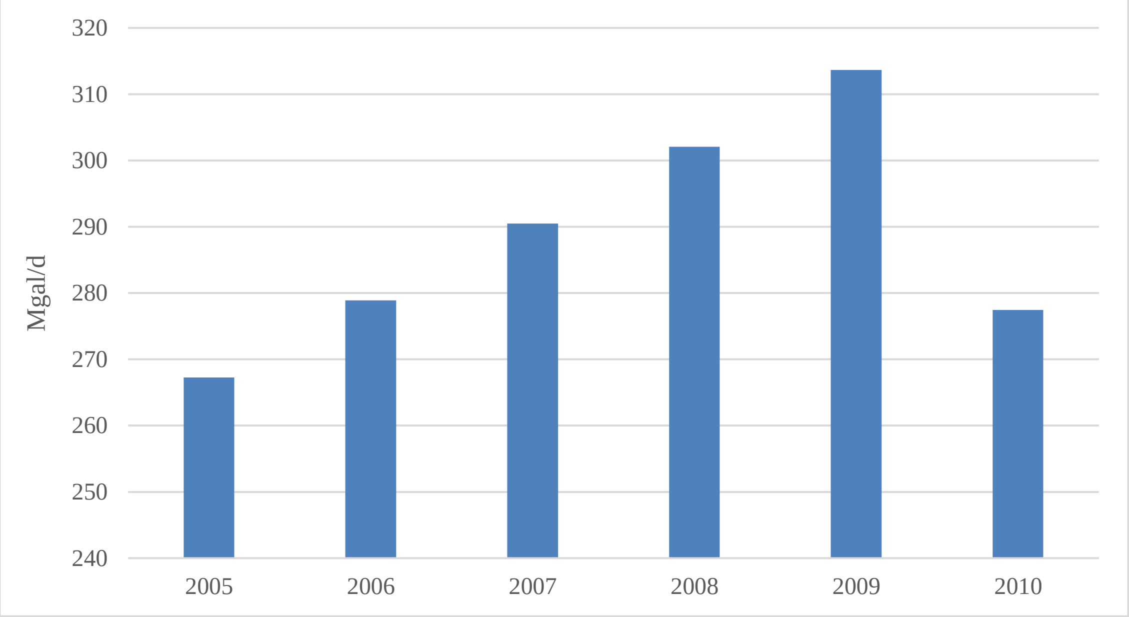
In Bernalillo County, total fresh and saline withdrawals were at the 170 Mgal/d level and decreased steadily by 4 Mgal/d until 2005 when reaching the level of 150 Mgal/d. From 2005 to 2010 there was a minimal change in withdrawal levels, varying marginally and decreasing to 149 Mgal/d by 2010. For overall withdrawals, Bernalillo County has kept a fairly steady withdrawal level since 2005 (figure 9).

Figure 9: Total withdrawals in Bernalillo County



In El Paso County, the total withdrawal levels indicated an increase from 2005 to 2009, and then a fairly dramatic decrease from 2009 to 2010. In 2005, total withdrawals amounted to 267 Mgal/d and increased by around 12 Mgal/d each single year until 2009. From 2009 to 2010 total withdrawals decreased by around 36 Mgal/d, and reaching the lowest level of 277 Mgal/d in leaving 2010 (figure 10).

Figure 10: Total withdrawals in El Paso County

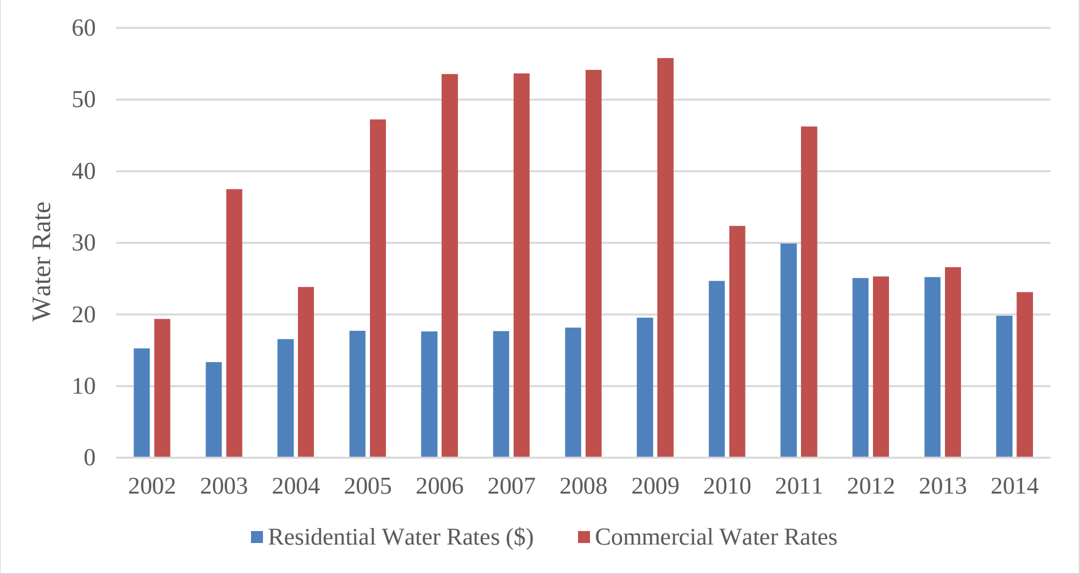


4.3 Residential and Commercial Water Rates

In the context of this analysis it is important to analyze water rates in each county to gain a better understanding of how water is regionally valued and perceived by citizens by using public supply water as an indicator. Analyzing water rates also has the potential to shed light on any relationships between the price of water rates and amount of water withdrawn, and provide utility stakeholders and interested groups with information about correlations between the current water rates and the actual water use.

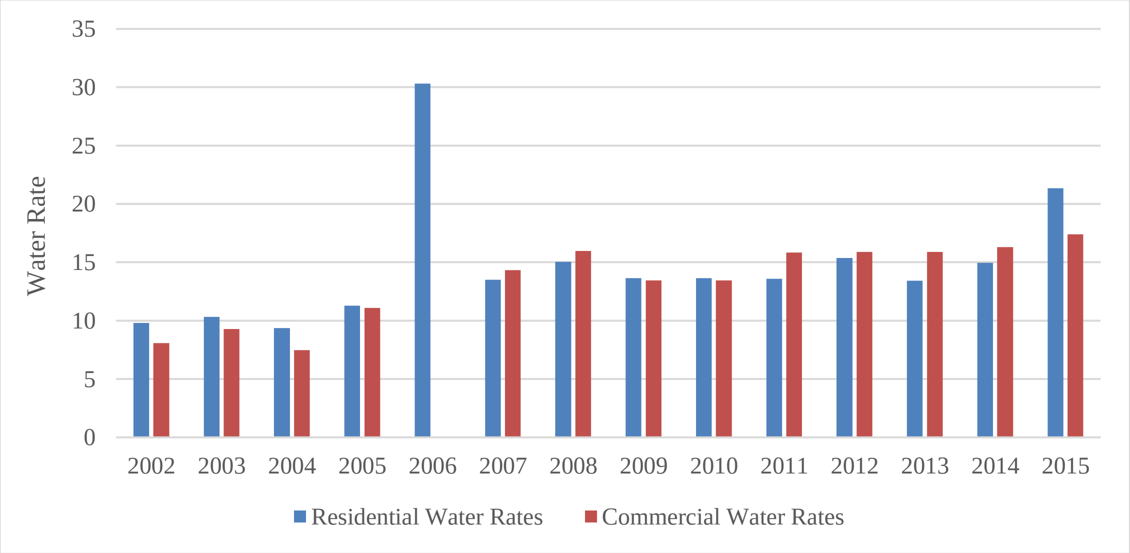
Figure 11 shows the residential and commercial water rates in Bernalillo County between 2002 and 2010, where the blue columns indicate residential water rates and the orange columns indicate commercial water rates. The commercial water rates are consistently higher than the residential water rates, particularly in the year range of 2005-2009. The highest commercial rate was found in 2009 at $56.00 per 5,000 gallons of water. The lowest commercial rate was found in 2002 at $19.00 per 5,000 gallons of water, indicating variability in the commercial water prices. For residential water rates, the highest rate was found in 2011 at around $30.00 per 5,000 gallons of water used, and the lowest rate in 2003 at just around $13.00 per 5,000 gallons of water.

Figure 11: Residential and Commercial Water Rates in Bernalillo County (in $)



A different picture was found for El Paso County (figure 12).

Figure 12: Residential and Commercial Water Rates in El Paso County (in $)



In El Paso County, there was a general increase in the residential and commercial water rates since 2002. In 2002, commercial water rates were around $8.00

per 5,000 gallons and residential rates were around $10.00 per 5,000 gallons. By 2015 the rates increased to $17.00 for commercial rates and $21.00 for residential rates, both more than double compared to 2002. The highest residential water rates were found in 2006 at $30.00 per 5,000 gallons, which is an outlier and indicates a potential error in the survey information. The highest commercial water rates were in 2015.

When analyzing water rates, sewer rates also need to be considered as they denote another indicator of municipal water pricing that has the potential to reflect value of water. Correlating water use to sewer rates can show current relationships and opportunities for changing sewer rate pricing to more accurately value public supply water.

In Bernalillo County, commercial sewer rates were variable in the analyzed time frame, with the lowest rate in 2012 at $15.00 per 5,000 gallons and the highest rate in 2005 at $184.00 per 5,000 gallons (figure 13). The rates fluctuated through the years, with much higher rates in 2003 than in 2002 and 2004. Also, the highest commercial sewer rates were observed in 2005 through 2009. The residential sewer rates remained relatively stable from 2002 to 2015, with the lowest rate in 2006-2009 at $11.00 per 5,000 gallons and the highest rate in 2015 at $18.00 per 5,000 gallons. The residential sewer rates decreased from 2002 to 2009 before steadily increasing from 2010 to 2015.

Figure 13: Residential and Commercial Sewer Rates in Bernalillo County (in $)

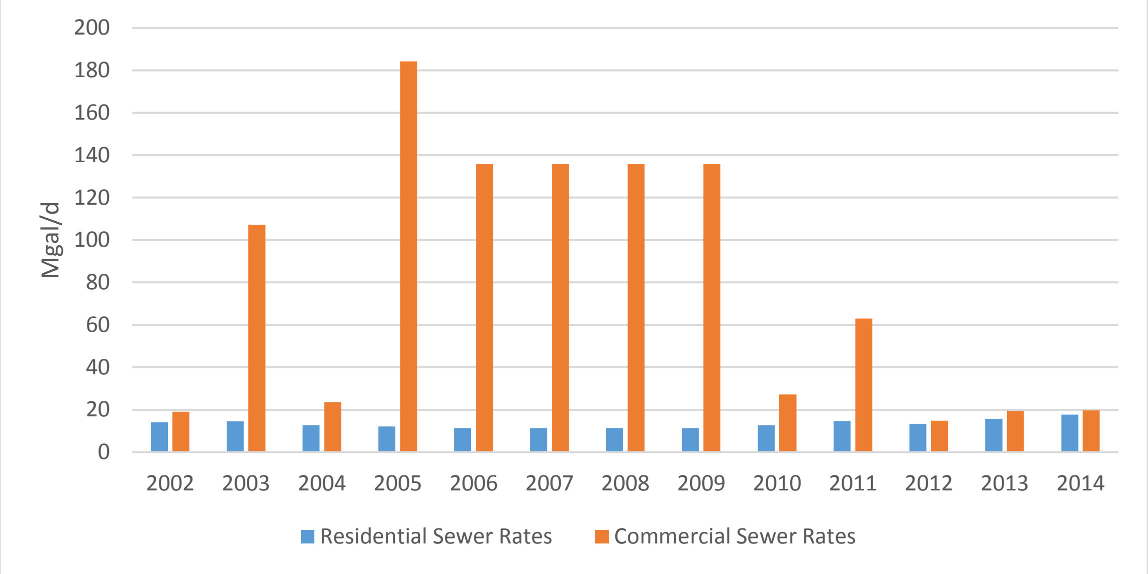
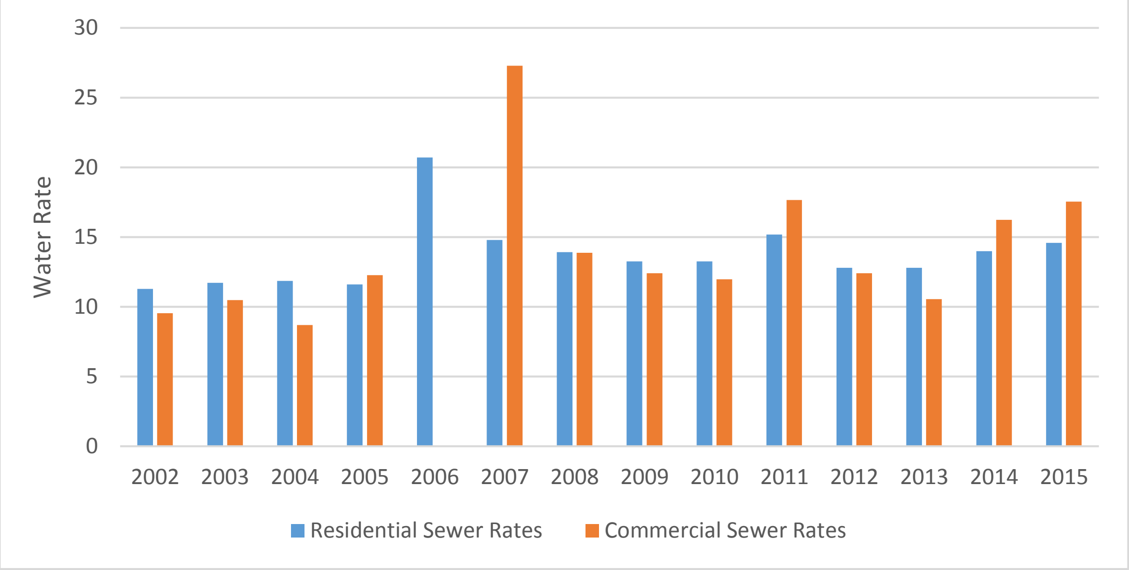


Figure 14 depicts residential and commercial sewer rates in El Paso County. The sewer rates fluctuated between 2002 and 2015. In 2002, the residential sewer rate was $11.00 per 5,000 gallons and the commercial rate amounted to $10.00 per 5,000 gallons. In 2015, the residential sewer rate was $15.00 per 5,000 gallons and the commercial rate was $18.00 per 5,000 gallons. The highest commercial rate was found in 2007 at $27.00 per 5,000 gallons and the lowest rate in 2004 at $9.00 per 5,000 gallons. The highest residential rate was found in 2006 at $21.00 per 5,000 gallons and the lowest rate in 2002 at $11.00 per 5,000 gallons. Residential sewer rates fluctuated throughout the time period but saw an overall increase by 2015 from 2002. For commercial sewer rates the rates fluctuated and the only discernible trend is an overall increase, where the rates remained above $10.00 per 5,000 gallons after 2004.

Figure 14: Residential and Commercial Sewer Rates in El Paso County (in $)



4.4 Personal Consumption Expenditures Housing and Utilities

The Personal Consumption Expenditures on Housing and Utilities in Colorado have steadily increased since 2000, from approximately 23 billion dollars to 41 billion dollars in 2014 (figure 15). Since county data for personal consumption expenditures for Housing and Utilities is unavailable, state data has been used to look at personal consumption expenditure trends. The average personal consumption expenditures for housing and utilities in Colorado over this time span was approximately 32 billion dollars. These values are not adjusted for inflation and represent the absolute dollar values in the respective years.

Figure 15: Personal Consumption Expenditures for Housing and Utilities in Colorado

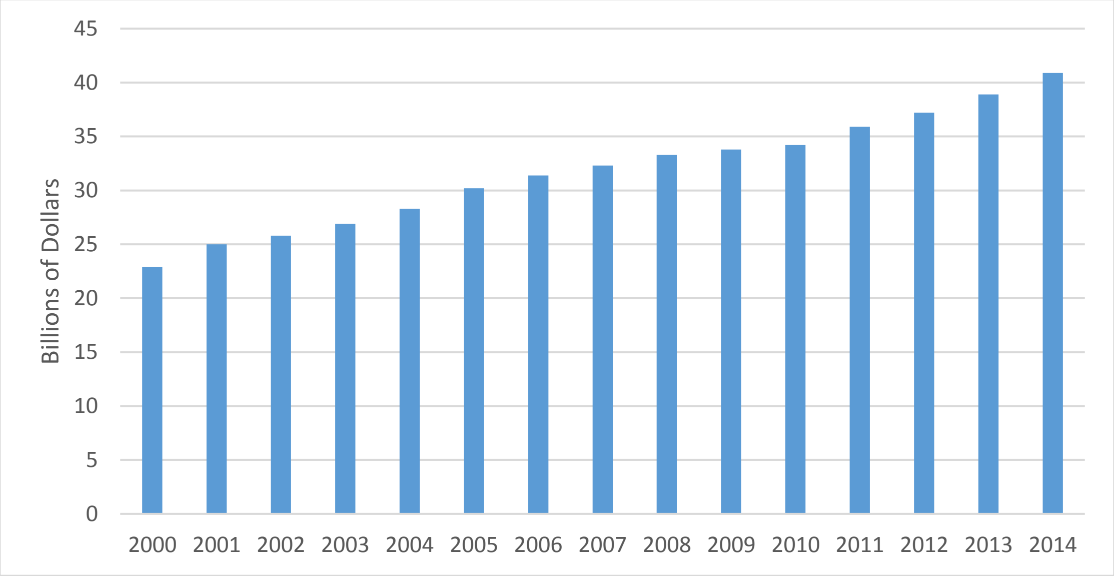


Figure 16 shows Personal Consumption Expenditure Housing and Utilities in New Mexico in the time span from 2000 to 2014 and a steady increase every single year since 2000, with around 6.2 billion dollars spent in 2000 and 11.4 billion dollars in 2014. The average personal consumption expenditures for housing and utilities in New Mexico in 2000-2014 amounted to around 9 billion dollars.

Figure 16: Personal Consumption Expenditures for Housing and Utilities in New Mexico

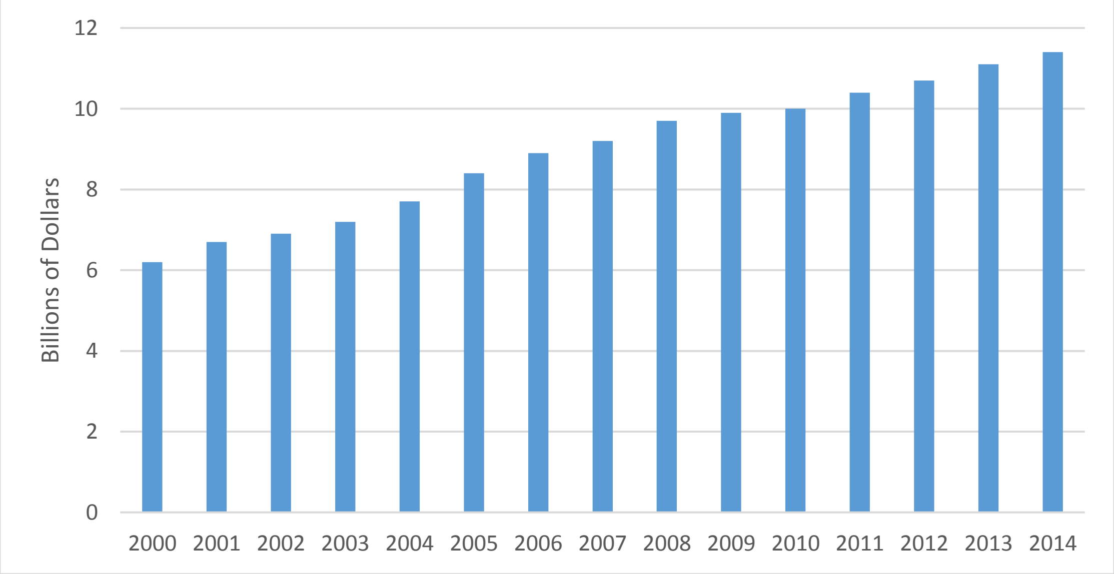
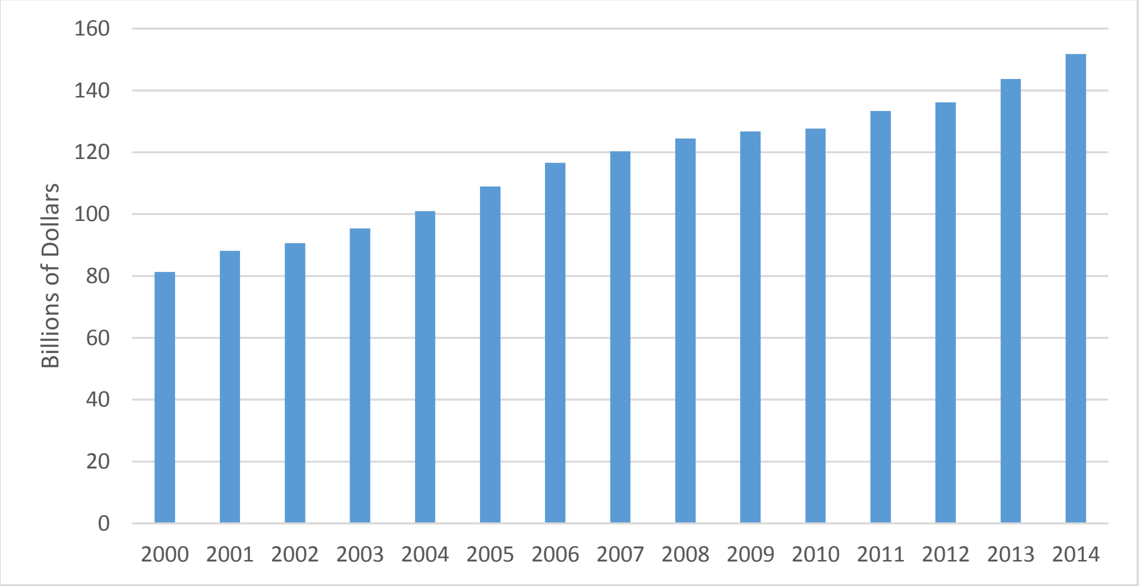


Figure 17 shows Housing and Utility Personal Consumption Expenditures in Texas in 2000-2014 and an increasing trend since 2000, varying from the initial 81 billion dollars to 152 billion dollars in 2014. The average personal consumption expenditures on housing and utilities in Texas between 2000 and 2014 amounted to approximately 116.4 billion dollars.

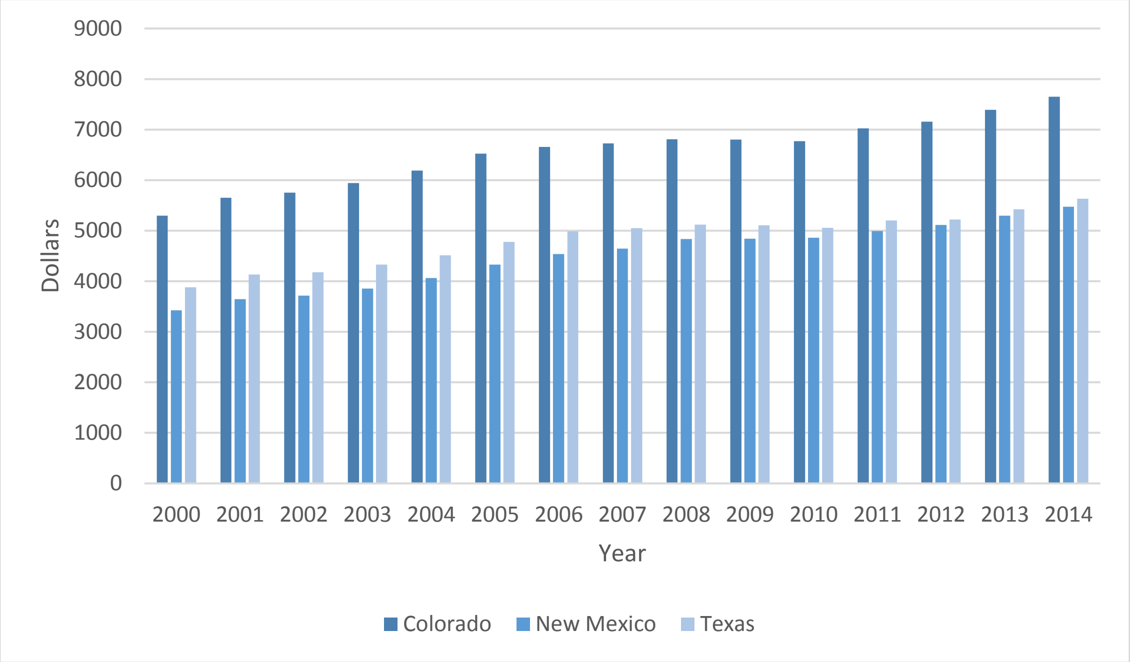
Figure 17: Personal Consumption Expenditures for Housing and Utilities in Texas



4.5 Personal Consumption Expenditures: Per Capita Housing and Utilities

In Colorado, there was an overall increase in the per capita housing and utilities personal consumption expenditures as shown in figure 18. The year 2000 indicated the lowest levels with $5,300, while the highest levels of $7,652 were found in 2014. A dip occurred in 2009 and 2010 where the personal consumption expenditures were lower than in the previous years, but other than these two years there was a steady increase in per capita housing and utilities personal consumption expenditures. The average between 2000 and 2014 amounted to $6,557.

Figure 18: Per Capita Personal Consumption Expenditures for Housing and Utilities in Texas, New Mexico and Colorado



In New Mexico, there was an increase in per capita housing and utility personal consumption expenditures s as well starting in 2000 at $3,425 and ending at $5,476 in 2014. These numbers were also the lowest and highest personal consumption expenditure values throughout the analyzed range of time. The average per capita housing and utility personal consumption expenditure in New Mexico was $4,509 (figure 18).

In Texas, the per capita personal consumption expenditures for housing and utilities in 2000-2014 rose initially, and then experienced a dip in 2009 and 2010 before continuing to increase until 2014 (figure 18). The lowest per capita personal consumption expenditures value for Texas was at $3,882 in 2000 and the highest value was $5,631 in 2014 The overall average for Texas per capita housing and utility expenditures in the analyzed time period was $4,840.

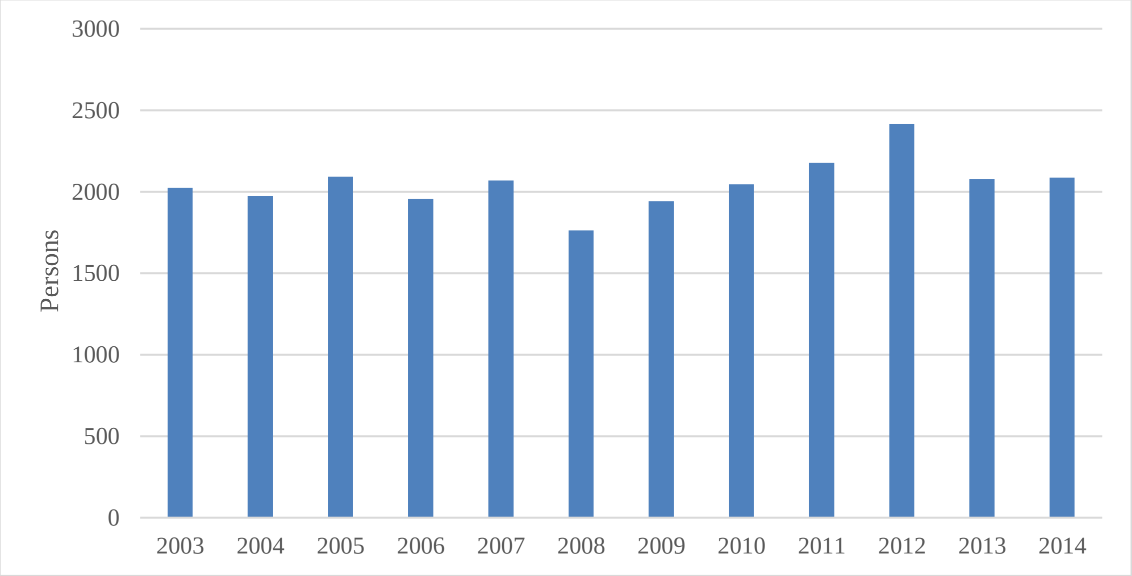
The dip in 2009 and 2010 both in Colorado and Texas could potentially be explained by the national economic recession at the time. New Mexico avoided a dip but still saw a slower rate of increasing expenditures for 2009 and 2010.

4.6 Poverty Estimates and per Capita Personal Income

Poverty is one of the social indicators included in this analysis that depicts the number of people who cannot meet their basic financial needs. The poverty indicator is normally used to describe income ‘below the poverty line’, where the ‘poverty line’ is set at $12,060 for individuals as of April 2017 (Health and Human Services Department, 2017).

As displayed in figure 19, the poverty level between 2003 and 2014 has fluctuated, with the lowest poverty rate found in 2008 at 1,763 people below the poverty line and the highest rate in 2012 at 2,416 people below the poverty line.

Figure 19: Poverty Estimate in Rio Grande County



The poverty estimate is grouped with per capita personal income because the higher the per capita personal income in a region, the lower the number of people living under the poverty line. Looking at the relationship between per capita personal income and water use can help determine how income could impact water use, and this information could further lead water managers to adjust prices according to withdrawal amounts and even to income levels. Looking at the poverty estimate for each case study county shows if poverty levels have increased or decreased, which could be a factor in the amount of water families use.

Figure 20: Per Capita Personal Income for Rio Grande, Bernalillo and El Paso Counties

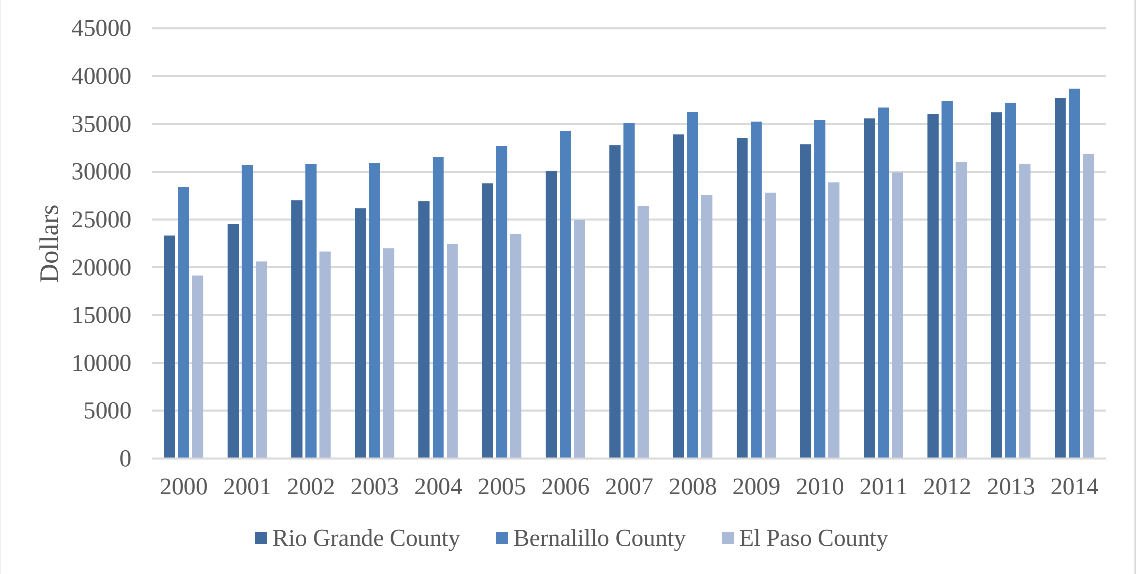
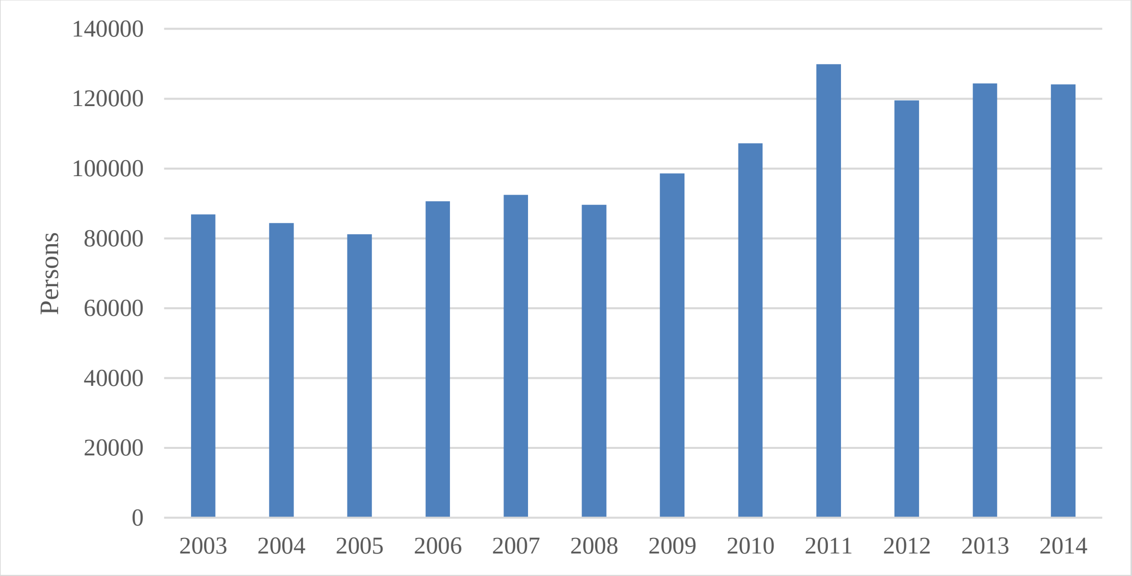


Figure 20 shows that per capita personal income in Rio Grande County has increased in the analyzed time frame, from $23,311 in 2000 up to $37,721 in 2014. In 2003, 2009 and 2010 small one-year declines were recorded where the per capita personal income was less than the previous year on record. These decreases in per capita personal income could point to a county struggling to combat the 2009 recession, and the 2003 dip could potentially be an indirect result of the 2002-2003 drought in Colorado (Pielke et al., 2005). Per capita personal income is important to include because it provides insight on the wealth of the citizens of a county, which plays a role in water use and can be important when looking to understand how a community operates.

A similar trend was observed in Bernalillo County with poverty levels at 86,837 people in 2003 and 124,091 people in 2014 (figure 20). The lowest poverty estimate was in 2005 at 81,184 people, while the highest estimate was found in 2011 at 129,882 people. This means that there have been slight fluctuations in the number of people under the poverty line over time, which might have resulted from economic changes and unemployment level fluctuations. However, the general trend shows an increase in the poverty indicator, thus indicating growing social pressures and potential impacts on resource use as the county must figure out how to provide for a growing number of citizens who cannot financially meet their basic needs.

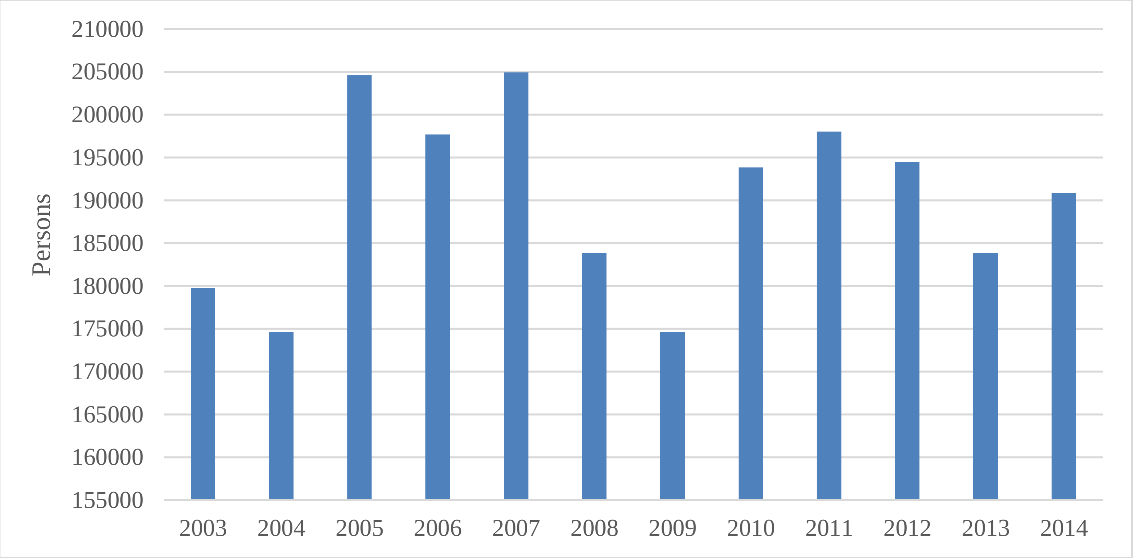
Figure 21: Poverty Estimate in Bernalillo County



At the same time, the per capita personal income in Bernalillo County increased from $28,407 in 2000 to $38,690 in 2014 (figure 20). The poverty estimate (figure 21) rose every single year by more than $10,000 since 2000, and there were only two dips in the entire timeline in 2009 and 2010.

El Paso County's poverty estimate had no determinable pattern in 2003-2014 and reached the lows of 174,591 people in 2004 and 174,651 people in 2009, while it reached the highs in 2005 and 2007 at 204,588 people and 204,927 people, respectively (figure 22). Comparing the beginning years of the analysis (2003), the poverty estimate was much lower (179,739 people) than in 2014 (190,846 people).

Figure 22: Poverty Estimate for All Ages in El Paso County



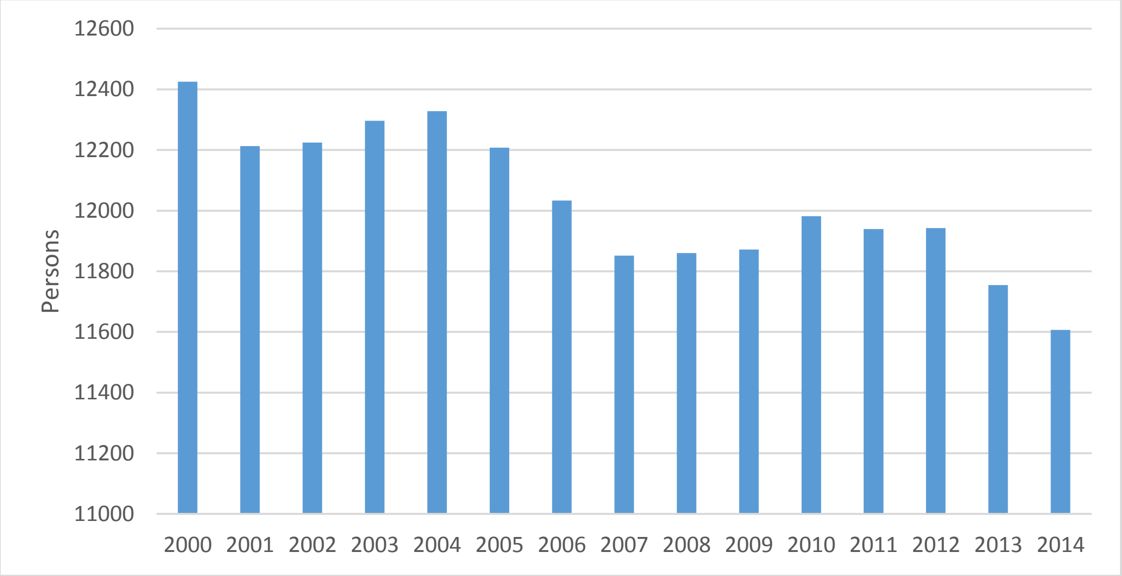
Simultaneously, a visible increasing trend in per capita personal income in El Paso County has been recorded. It increased steadily from $19,151 in 2000 up to $31,816 in 2014. Only one insignificant dip in the trend has been recorded in 2013 (figure 20).

4.7 General Total Population and Public Supply Population

Analyzing population changes in any region affected by water scarcity is crucial because population fluctuation is directly related to the amount of water used and withdrawn, since the demand for water will increase as a population increases or decrease if people move away from the area. This is especially true in the Rio Grande River Basin as large cities like Albuquerque in New Mexico and El Paso City in Texas continue to receive large influxes of people, and the population continues to grow in the basin. This chapter addresses both the total population and the public supply population defined as the estimated number of people in the county who receive water from the public supply.

Figure 23 shows the general population decline in Rio Grande County between 2000 and 2015 by 818 people, from 12,425 people down to 11,607 people, respectively. There were two significant population changes in the county in the analyzed time frame: 1) 212 people from 2000 to 2001, and 2) around 4,000 people between 2004 and 2007.

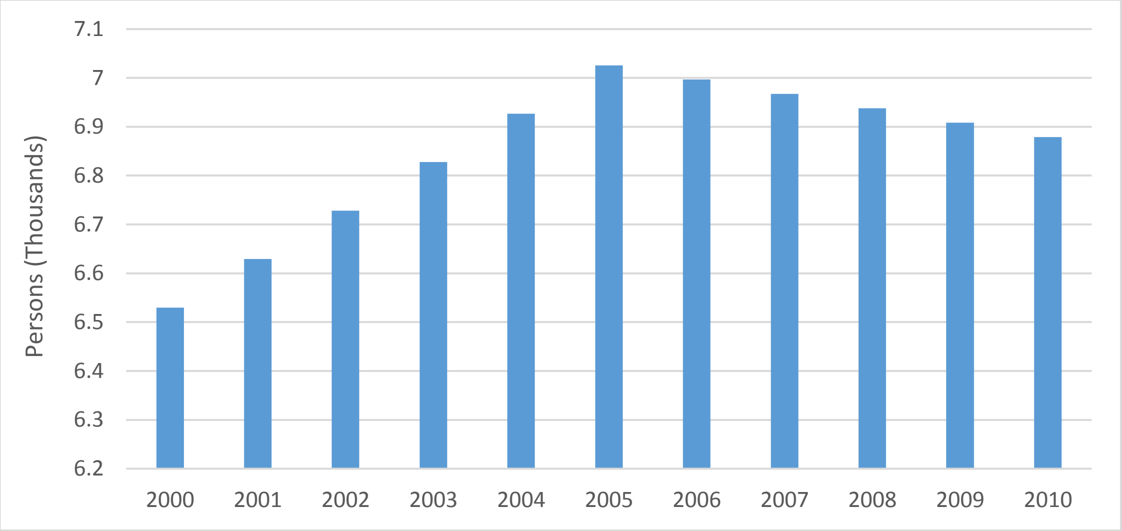
Figure 23: Total Population in Rio Grande County



The changes in the number of people receiving water from the public supply in Rio Grande County increased from 6,530 people in 2000 up to 6,879 people in 2010 (figure 24). There was also a visible peak in the population numbers in 2005 (at the level of

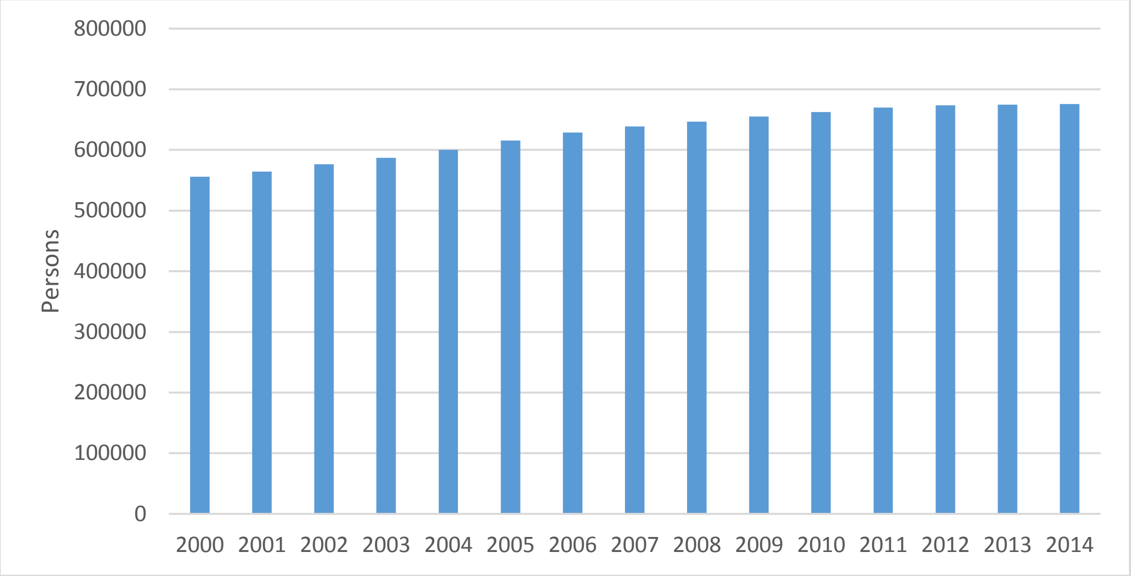
7,026 people in that year), followed by a slight decline. This trend can be explained with the theory of rural flight that people are moving to urban areas instead of staying in more rural areas (Davis, 1965). The increase in population in both Bernalillo and El Paso Counties testifies to this idea, since both are large metropolitans containing big cities like Albuquerque and El Paso City.

Figure 24: Public Supply Population in Rio Grande County



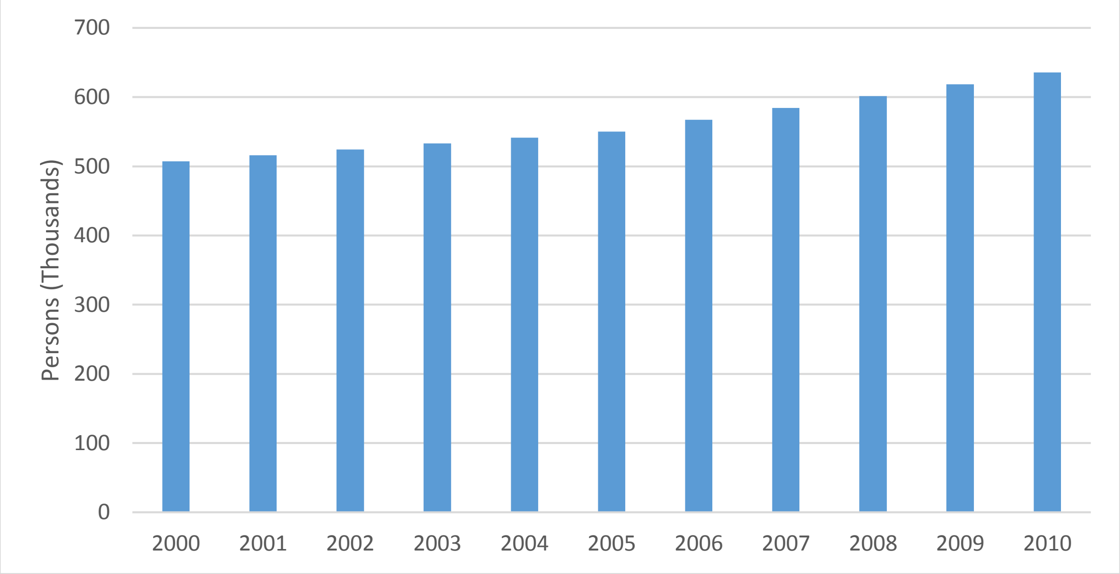
The trend in the total population in Bernalillo County indicated a slight increase from 556,120 people in 2000 up to 675,551 people in 2014 (figure 25). This indicates an increasing need to create more efficient water management and monitor water use for an increasing population in a relatively arid part of the southwest United States.

Figure 25: General Total Population in Bernalillo County



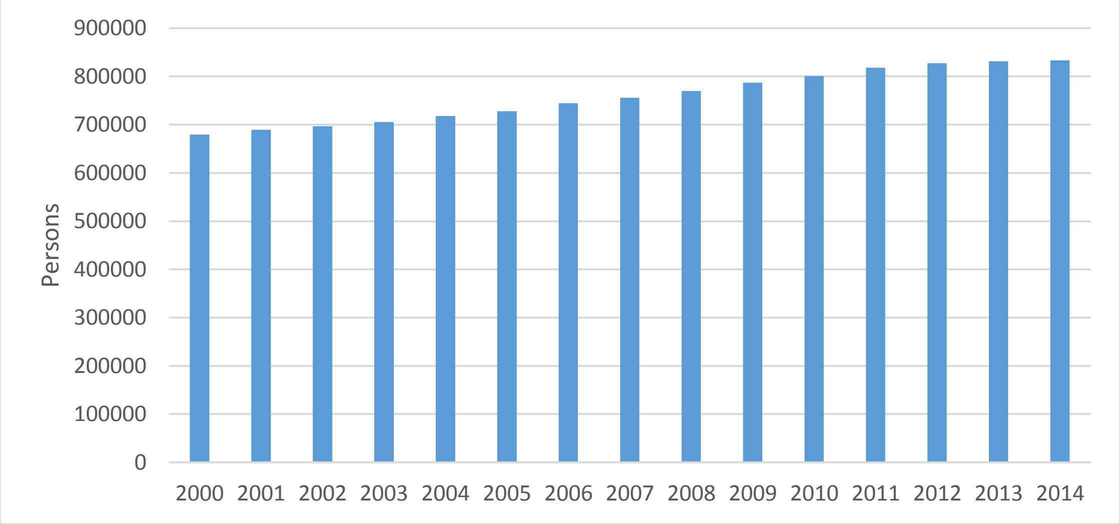
In Bernalillo County, the total population receiving water from the public supply has been increasing from 2000 to 2010. In 2000, approximately 507,000 people were provided with public water supply, while it was approximately 637,000 people in 2010 (figure 26). There is a trend of increasing dependence on public supply water, either due to a growing overall population or a decreasing supply from private sources (wells). Comparing the total population and the public water supply in Bernalillo County shows an overall increase in population in the area, where the number of people using water from the public supply remains consistently proportionate to the overall population. This indicates future withdrawals for citizens using public supply will also increase consistently with the population.

Figure 26: Public Supply Population in Bernalillo County



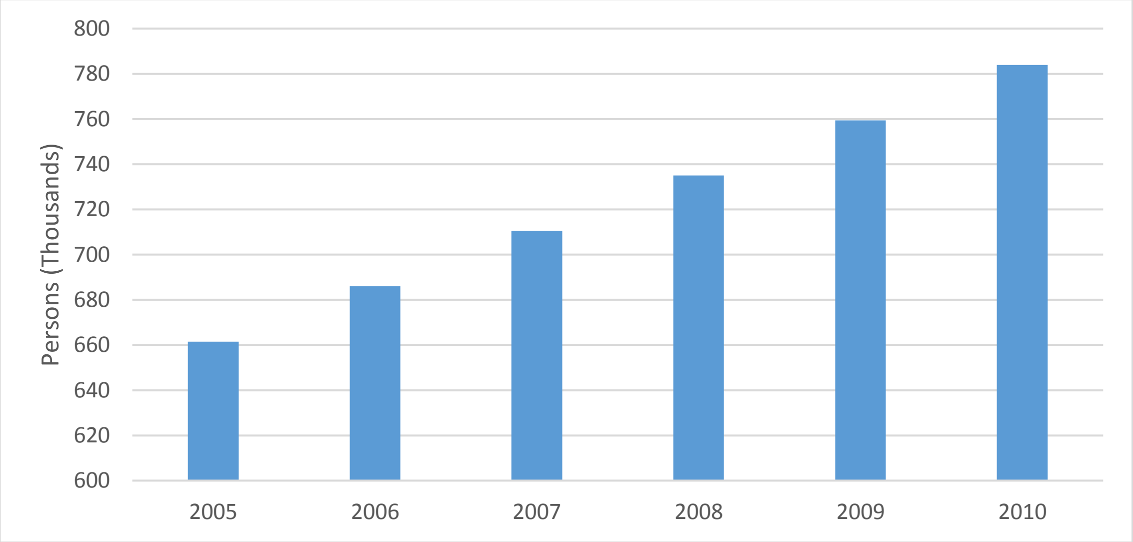
A continuously increasing total population has also been recorded in El Paso County in 2000-2015 with the lowest level of 679,568 people in 2000 and the highest level of 833,487 people in 2014 (figure 27).

Figure 27: Total Population in El Paso County



The same increasing trend has been noticed in El Paso County public supply population between 2005 and 2010. While the population receiving water from the public supply amounted to 662,000 people in 2005, it has grown to around 784,000 people in 2010 (figure 28). This increase makes for over 100,000 people in a span of only five years, and indicates a significant change when considering water withdrawals and use.

Figure 28: Public Supply Population in El Paso County



Comparing all three case study regions in terms of population changes and public water supply, a clear trend exists for El Paso and Bernalillo Counties where both population data sets are increasing. There is a decreasing population trend for Rio Grande County, which again points to the concept of rural flight as Bernalillo and El Paso Counties are both more urban than Rio Grande County.

4.8 Temperature and Precipitation

Analyzing changes in temperature and precipitation allows us to understand impacts in water use and withdrawals from natural weather conditions. Both variables count as environmental variables that are more difficult to quantify, either due to data scarcity or to varying specificity of measurements.

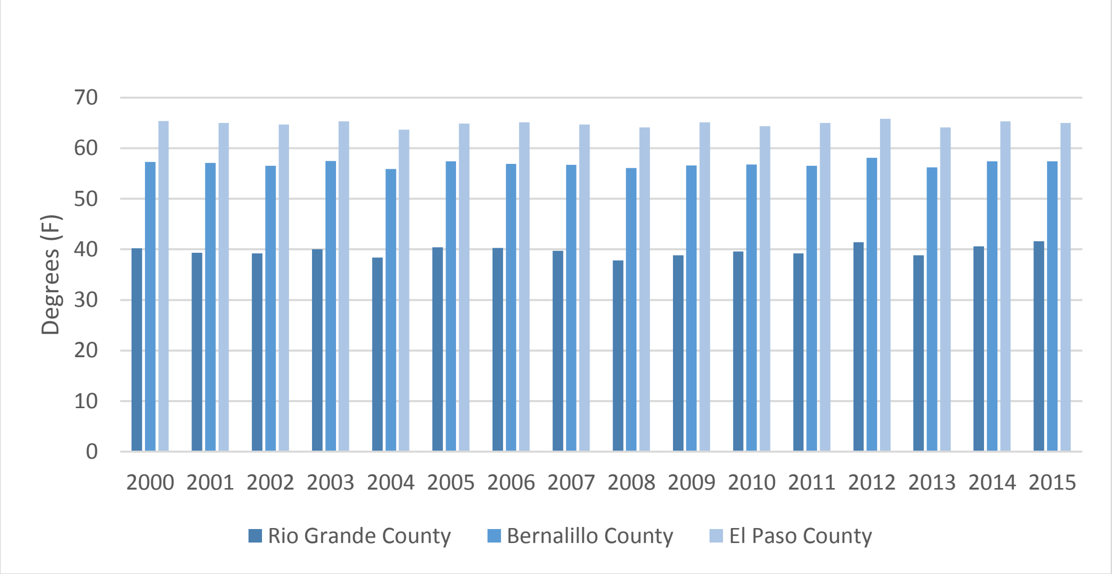
Climate change might make temperature and precipitation variability more extreme in the future, so analyzing current weather patterns helps determine current changes and prepare for future, more extreme changes. While temperature and precipitation data is usually collected on a minute or daily basis, for the purpose of this study it has been aggregated to annual values to correlate to the other county data.

The average annual temperatures in Rio Grande County have significantly fluctuated between 2000 and 2015, with the lowest temperature of 37.8 degrees Fahrenheit in 2008 and the highest temperature reaching 41.6 degrees in 2015. There appears to be a trend of a low average temperature every four or five years before rising back to higher temperatures. The average temperature for the entire time span of the analysis is approximately 39.7 degrees F.

In Bernalillo County, the average annual temperatures ranged from a low average of 55.9 degrees Fahrenheit in 2004 to a high average of 58.1 F in 2012. This temperature fluctuation range is slightly smaller than the range seen in Rio Grande County. The overall average annual temperature for 2000-2015 is around 60 degrees F.

In El Paso County, temperature levels fell to 63.7 degrees Fahrenheit in 2004 and rose to a high of 65.8 degrees in 2012. The county has the smallest fluctuation ranges in the analyzed time period compared to the other case study counties. The overall average temperature for 2000-2015 was around 64.9 degrees F (figure 29).

Figure 29: Average Annual Temperature in Rio Grande, Bernalillo and El Paso Counties

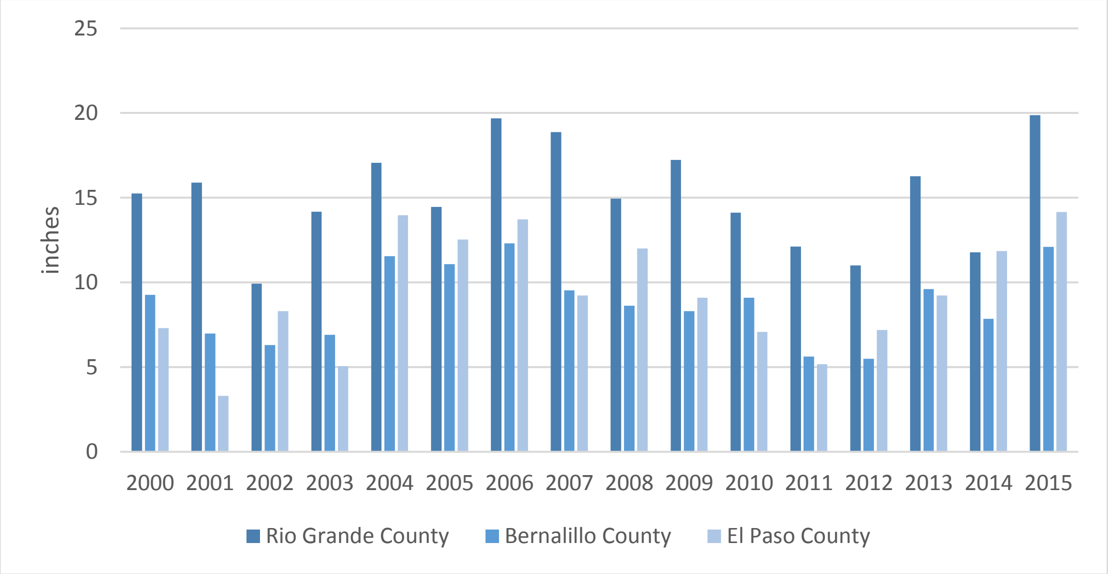


Another environmental indicator analyzed in this context is annual precipitation. In Rio Grande County, the average annual precipitation ranged between a low of 9.92 inches in 2002 and a high of 19.88 inches in 2015. Both the highest temperature and highest precipitation values for Rio Grande County were found in 2015. The overall average precipitation level in the entire timespan of the analysis amounted to around 15 inches.

The average annual precipitation levels in Bernalillo County ranged from a low value of 5.5 inches in 2012 and a high of 12.3 inches in 2006, with the average annual precipitation of 8.8 inches in 2000-2015.

Similarly, there were large fluctuations in the average annual precipitation in El Paso County, ranging from 3.3 inches in 2001 to 14.15 inches in 2015. This is the largest range of precipitation out of the three case studies, where in 2015 recorded precipitation levels were more than four times the amount of rainfall in 2001. The overall average annual precipitation in 2000-2010 amounted to around 9.3 inches (figure 30).

Figure 30: Average Annual Precipitation in Rio Grande, Bernalillo and El Paso Counties



When comparing the three case study counties in terms of temperature and precipitation it can be stated that 2012 was the hottest year for Bernalillo and El Paso Counties, and the second hottest year for Rio Grande County (2015 was the hottest). The years 2006 and 2015 had the highest precipitation rates for Rio Grande and Bernalillo Counties, and the third and first highest precipitation levels for El Paso County, where 2004 saw the second highest rate of precipitation. This indicates a heatwave around 2012, where temperatures were especially high and precipitation low relative to the data in the graphs. One notable trend for all three counties is that temperatures increased for three or four years at a time before dropping, where this cycle then begins again. This trend in temperature change can help water managers prepare for increasing temperatures and for an incoming low temperature year.

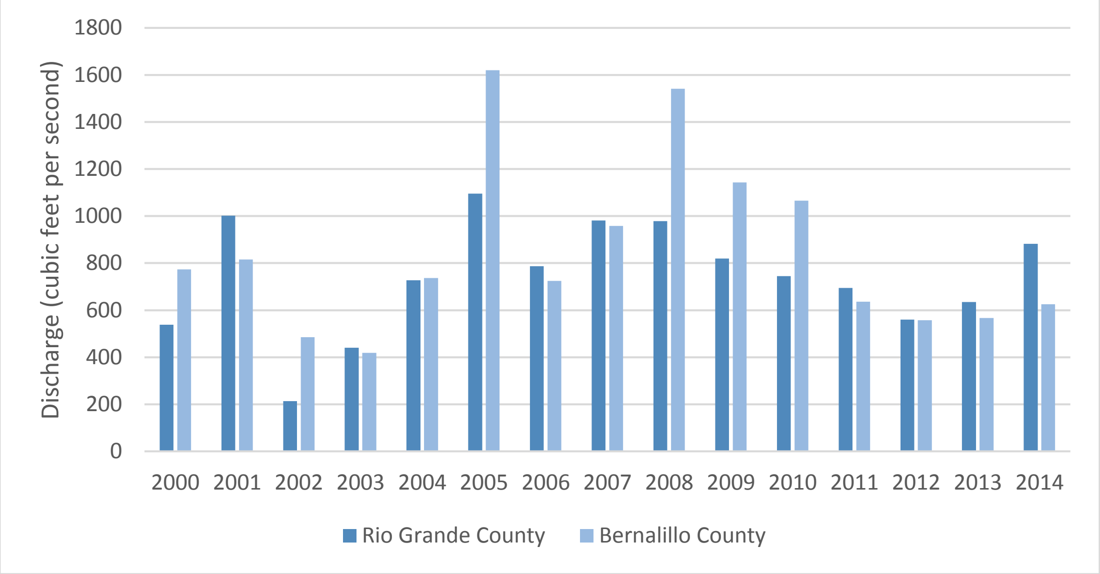
4.9 Streamflow Rate

Looking at the average annual streamflow rate creates a better understanding of current streamflow variability and environmental stability. Streamflow variability may increase as water continues to be withdrawn and climate change occurs. More extreme weather from climate change may increase the amount of runoff from snowmelt, evaporation, or transpiration from vegetation which all impact streamflow rates. There are natural factors that create variability, but human-induced factors like surface-water withdrawals and diversions accelerate this change. Even though streamflow is constantly changing, the average annual streamflow rate was collected to correlate with the other variables. Unfortunately, there was no cohesive, comprehensive average annual streamflow rate data for El Paso County, so the focus is on Rio Grande and Bernalillo Counties.

The average annual streamflow rate in Rio Grande County spans from a low rate of 213 cubic feet per second in 2002 to a high rate of 1,096 cubic feet per second in 2005. The overall average streamflow rate in 2000-2014 is approximately 740 cubic feet per second.

In Bernalillo County, the average annual streamflow rates ranged from a low rate of 418.3 cubic feet per second in 2003 to a high rate of 1,620 cubic feet per second in 2005.The overall average streamflow rate in the analyzed time frame was around 844.4 cubic feet per second (figure 31).

Figure 31: Average Annual Streamflow Rate in Rio Grande and Bernalillo Counties



For Bernalillo and Rio Grande Counties, the highest average annual streamflow rate was in 2005, and the lowest in 2002 for Rio Grande County and 2003 for Bernalillo County. The year 2012 had relatively low streamflow rates for both counties, which could be tied to the high temperature levels.

Chapter 5: Methods and Results

5.1 Correlation Analysis

Correlations were used to analyze socio-economic and environmental impact factors (represented with the sustainability indicators in table 1) on water withdrawals and public water supply in the analyzed counties along the Rio Grande River, and especially in the case study regions. Correlation analysis was applied to calculate relationships between either the total withdrawals or the public supply freshwater withdrawals, and one of the remaining sustainability indicators (general total population, poverty estimate, per capita personal income, total freshwater withdrawals for the public supply, residential and commercial water rates, residential and commercial sewer rates, personal consumption expenditures for housing and utilities, per capita personal consumption expenditures for housing and utilities, temperature and precipitation variability, and streamflow rates).

Correlation reveals the strength and direction of a linear relationship between two selected variables by means of the correlation coefficient.

The correlations were calculated in Microsoft Excel 2013 with the CORREL function, which returns the correlation coefficient of the Array 1 (a cell range of values) and Array 2 (a second cell range of values) cell ranges. If an array contains any empty cells due to missing or unavailable data, those values are ignored. However cells with the value zero are included. If Array 1 and 2 have a different amount of data points then CORREL results will be a #N/A error value. Therefore all correlations were calculated for the same number of years (and unavailable data in between the time frame was not included in the correlation).

$$Correl(X,Y) = \frac{\sum (x-\overline{x})(y-\overline{y})}{\sqrt{\sum (x-\overline{x})^2 \sum (y-\overline{y})^2}}$$

(Eq. 1)

Equation 1 was used to calculate correlation coefficients in Excel, where $\overline{x}$ and $\overline{y}$ are the sample means of AVERAGE (array 1) and AVERAGE (array2).

The strength of a relationship between two variables is described with the values of the correlation coefficient ranging between 0 (no correlation) and 1 (perfect correlation). The direction of a relationship between two variables is described by the sign of the correlation coefficient, where a positive correlation coefficient indicates that as variable A increases, variable B increases as well. On the contrary, a negative correlation occurs when variable A increases, variable B decreases.

If the correlation coefficient is at least +0.5 or -0.5, statistical significance is given. Despite this significance, correlation does not provide an answer about which variable influenced the other variable and what other external variables (and to what extent) influenced the two studied variables. Thus, it is necessary to remember that correlation provides information about relationships between variables, but it does not imply causation in any regard.

5.2 Social Indicators

5.2.1 Poverty Estimate and Per Capita Personal Income

5.2.1.1 Total Withdrawals

Table 2 displays correlation Coefficient 1 as the poverty estimate correlated with total water withdrawals, and correlation Coefficient 2 for the poverty estimate correlated with public supply withdrawals. Per capita personal income is correlated with both sets of water withdrawal data with total withdrawals as Coefficient 3 and public supply withdrawals as Coefficient 4. Finally, the last four coefficients are for general total population (Coefficients 5 and 6) and public supply population (7 and 8). Due to the lack of total withdrawals data, New Mexico and Colorado numbers only reflect the years 2003-2010, while Texas numbers cover the years 2005-2010.

The correlation coefficients for Bernalillo County are both negative, but only the correlation for per capita personal income is statistically significant at -.90. This means that as water withdrawals increased, per capita personal income decreased. The reason for this trend could be an increase in technology in higher per capita personal income areas.

Table 2: Social Indicator Correlations

State	County	Coefficient 1	Coefficient 2	Coefficient 3	Coefficient 4	Coefficient 5	Coefficient 6	Coefficient 7	Coefficient 8
NM	Bernalillo	-0.44	-0.86	-0.90	-0.95	-0.93	-0.99	-0.82	-0.99
NM	Dona Ana	-0.73	0.63	-0.97	0.94	-0.99	0.89	-0.99	0.88
NM	Los Alamos	0.44	0.44	-0.86	-0.86	0.14	0.14	0.40	0.40
NM	Rio Arriba	0.41	-0.06	0.60	0.51	-0.81	-0.16	0.09	0.88
NM	Sandoval	-0.76	0.77	-0.94	0.93	-0.99	0.99	-0.99	0.99
NM	Santa Fe	0.71	0.21	0.86	-0.78	0.97	-0.75	0.99	-0.58
NM	Sierra	0.29	0.06	0.90	-0.85	-0.98	0.49	-0.85	0.92
NM	Socorro	-0.16	-0.02	-0.99	-0.90	0.05	0.19	-0.92	-0.99
NM	Taos	-0.13	-0.25	0.94	0.60	0.92	0.53	0.62	0.04
NM	Valencia	-0.46	0.62	0.68	0.84	0.58	0.94	0.45	0.99
TX	Brewster	0.75	0.45	-0.95	-0.91	-0.88	-0.53	0.99	0.99
TX	Cameron	-0.42	-0.37	0.97	-0.77	0.97	-0.71	0.97	-0.99
TX	Dimmit	-0.59	-0.39	0.40	-0.08	-0.90	0.37	-0.48	-0.99
TX	El Paso	-0.83	0.00	0.58	-0.98	0.51	-0.99	0.52	-0.99
TX	Hidalgo	-0.20	0.88	0.98	0.87	0.99	0.89	0.99	-0.99
TX	Hudspeth	0.58	0.00	-0.96	0.84	-0.15	0.52	-0.99	0.99
TX	Jeff Davis	0.52	-0.18	-0.68	0.74	-0.99	0.93	0.99	-0.99
TX	Kinney	-0.09	-0.28	-0.94	-0.67	-0.92	-0.50	-0.99	0.99
TX	Maverick	-0.49	-0.43	0.45	-0.04	0.37	0.01	0.42	-0.99
TX	Presidio	0.72	0.54	-0.99	-0.78	-0.23	-0.90	-0.99	-0.99
TX	Starr	-0.50	-0.31	0.50	-0.09	0.45	-0.38	0.48	0.99
TX	Terrell	-0.94	-0.53	-0.53	-0.45	0.78	0.76	-0.65	-0.99
TX	Val Verde	-0.64	-0.28	0.31	-0.80	0.17	-0.75	-0.27	0.99
TX	Webb	-0.60	-0.43	-0.08	-0.83	-0.21	-0.83	-0.24	0.99
TX	Zapata	0.23	0.28	0.51	0.96	0.61	0.99	0.65	0.99
CO	Alamosa	-0.38	-0.21	-0.69	-0.22	-0.55	-0.07	0.87	0.48
CO	Conejos	0.48	0.09	0.94	0.90	-0.80	-0.82	-0.89	-0.97
CO	Hinsdale	-0.55	0.30	0.35	0.92	-0.02	0.61	0.94	0.34
CO	Mineral	0.45	0.22	0.64	0.30	-0.35	0.03	-0.32	-0.67
CO	Rio Grande	0.11	0.25	0.69	0.03	-0.55	0.07	0.99	0.68

Legend: Total Withdrawals and Poverty Estimate (Coefficient 1), Public Supply Withdrawals and Poverty Estimate (Coefficient 2), Total Withdrawals and Per Capita Personal Income (Coefficient 3), Public Supply Withdrawals and Per Capita Personal Income (Coefficient 4), Total Withdrawals and General Total Population (Coefficient 5), Public Supply Withdrawals and General Total Population (Coefficient 6), Total Withdrawals and Public Supply Population (Coefficient 7), and Public Supply Withdrawals and Public Supply Population (Coefficient 8).

For El Paso County, both correlations are significant, but poverty estimates and withdrawals have a strong negative relationship of -0.83, while per capita personal income has a significant positive relationship with the level of water withdrawals (correlation coefficient equals 0.58). This indicates a strong correlation between the poverty levels and total water withdrawals, and a significant correlation between per capita personal income and withdrawals.

For Rio Grande County, there were no significant relationships between the poverty estimates and total water withdrawals found, with a correlation coefficient of 0.11. At the same time, a significant positive relationship between per capita personal income and water withdrawals was detected with a correlation of 0.69. Overall, there were nine negative significant correlations and five positive significant correlations for poverty estimates and total water withdrawals. For per capita personal income and withdrawals, there were twelve significant negative correlations and thirteen significant positive relationships.

These results indicate that poverty estimates are more likely to have a negative relationship with total withdrawals, which could be due to more impoverished people unable to buy materials or goods that use and require water, which could lower withdrawal rates. Per capita personal income had a similar amount of positive and negative relationships, but there is a strong trend of significant relationships. This means that in most counties observed, including all three case study counties, per capita personal income and total withdrawals have relatively strong influences on each other.

5.2.1.2 Public Supply, Total Withdrawals, Fresh Water

Another correlation analysis assessed public supply of freshwater withdrawals vs. poverty estimates (the second correlation coefficient) and per capita personal income (the fourth correlation coefficient) for the time frame 2003-2010 for all three analysis states (table 2).

Both correlations for Bernalillo County data show significant negative relationships between public supply withdrawals and poverty estimates and between public supply withdrawals and per capita personal income. El Paso County shows a different outcome, with poverty estimates and public supply withdrawals yielding no relationship, yet per capita personal income and withdrawals having a strong negative relationship. These findings support the trend noted with these coefficients and total withdrawals—the per capita personal income variable has a strong relationship with water withdrawals.
Rio Grande County also yielded no significant relationships between total water withdrawals and either the poverty estimates or per capita personal income. Rio Grande County is one of seven out of thirty counties to not have a significant relationship between total withdrawals and per capita personal income.

Overall, there were two negative significant relationships and five positive relationships for public supply withdrawals and poverty estimates. Even though the amount of overall significant relationships between public supply withdrawals and poverty estimates is low, there is a trend of positive relationships. This differs from the trend found with these coefficients and total withdrawals, and three of the five are found in New Mexico, while the other two positive relationships are from counties in Texas. This could indicate a growing need for water to supply to a growing population that current infrastructure may not be equipped to handle.

For public supply withdrawals and per capita personal income, there were twelve negative significant relationships and eleven positive significant relationships. These findings match the trend found with total withdrawals, supporting the idea that per capita personal income and water withdrawals influence one another and impact each other relatively frequently.

5.2.2 General Total Population and Public Supply

5.2.2.1 Total Withdrawals

The next variables correlated with total withdrawals are the total population in each county and population receiving public supply water (Coefficients 5 and 7). Due to missing data, the analysis for Texas was conducted on a data set for the timespan 2005-2010, while in the case of New Mexico and Colorado data sets for 2000-2010 time frame were considered (table 2).

For Bernalillo County in New Mexico, both population datasets correlated with total withdrawals yielded strong negative relationships. Practically, this means that as the populations increased, withdrawals decreased. This goes against the initial theory that withdrawals would increase alongside population increase and indicates the importance of studying a variety of variables to get a more holistic picture of water use in the Rio Grande River Basin. Withdrawals could be decreasing if Bernalillo has invested in utility infrastructure and decreased the amount of water waste, leaks, and inefficiency to prepare for a growing urban population.

For El Paso County in Texas, both population data sets correlated with total withdrawals yielded significant positive relationships. The results for Rio Grande County in Colorado show that total county population yielded a significant negative relationship with total water withdrawals, but the population using water from the public supply yielded an extremely strong positive relationship with total withdrawals. Thus, El Paso is experiencing a trend that aligns with the initial theory of increasing water withdrawals alongside an increasing population size, although the correlations were just barely significant with Coefficient 5 at 0.51 and Coefficient 7 at 0.52. Rio Grande County has a unique case where as the total county population declines, withdrawals increased but as the public supply population increases so does the amount of total withdrawals. This points to the idea that the people staying in Rio Grande County rely primarily on public supply water and that the remainder of people in the county might be investing more heavily in agriculture which requires larger amounts of withdrawals.

Comparing all analysis counties, for total water withdrawals and total population twelve significant negative correlations and eight significant positive correlations were found. For total withdrawals and public supply population, ten negative correlations were significant and eleven positive correlations were significant. The main trend here is that for total water withdrawals and total county population there are more negative significant trends, confirming that there are other variables influencing withdrawals, despite the fact that twenty out of thirty counties have a significant relationship between the two variables.

5.2.2.2 Public Supply, Total Withdrawals, Fresh Water

Using the same population variables seen in table 2, correlations for counties from Texas, New Mexico and Colorado for public supply withdrawals and total county population and public supply withdrawals and public supply population in 2000-2010 were calculated (Coefficients 6 and 8).

The results for Bernalillo County and El Paso County show extremely strong negative correlations for both population variables. No significant relationship was found between general total population and public supply withdrawals for Rio Grande County, but there was a significant positive relationship between public supply population and public supply withdrawals of 0.68. Overall, there were ten significant negative relationships and ten positive significant relationships for total general population and public supply withdrawals. For public supply population and water withdrawals, there were thirteen significant negative correlations and thirteen significant positive correlations. All the negative correlations that occurred were significant for public supply population and withdrawals.

These findings indicate a couple of different ideas. First, for Bernalillo and El Paso Counties this indicates that as the population is increasing, the counties are finding other ways to supply water to their citizens with techniques like desalinization, or they are using more efficient infrastructure to decrease water use despite an increasing population and demand for public supply water. Then Rio Grande County experienced a positive significant correlation between public supply population and public supply withdrawals, which means the public supply population has a direct impact on public supply withdrawals in this county. Both total general population and public supply population yielded a majority of significant correlations (20 and 26, respectively), meaning that population fluctuations do have an impact on public supply withdrawals most of the time, and population patterns are an important factor in studying water use.

5.3 Economic Indicators

5.3.1 Residential and Commercial Water Rate Correlations

5.3.1.1 Total Withdrawals

Table 3 summarizes correlation coefficients for the amount of total (saline and freshwater) withdrawals and both residential water rates (Coefficient 1) and commercial water rates (Coefficient 3) in the New Mexico counties between 2002 and 2010. Exceptions were made in case of missing or inconsistent data sets from the NM survey, while correlations for the Texas counties were analyzed between 2005 and 2010 due to missing USGS data for total withdrawals.

Table 3: Economic Indicator Correlations, Part 1

State	County	Coefficient 1	Coefficient 2	Coefficient 3	Coefficient 4	Coefficient 5	Coefficient 6
NM	Bernalillo	-0.68	-0.87	-0.74	-0.53	0.88	0.65
NM	Dona Ana	-0.93	0.75	-0.76	0.97	-0.88	0.96
NM	Los Alamos	0.57	0.57	0.01	0.01	0.02	0.02
NM	Rio Arriba	-0.01	0.78	-0.08	0.56	0.14	0.56
NM	Sandoval	-0.31	0.3	-0.52	0.52	-0.16	0.14
NM	Santa Fe	0.52	-0.79	0.09	-0.69	0.79	-0.51
NM	Sierra	0.73	-0.89	0.77	-0.54	0.75	-0.48
NM	Socorro	-0.74	-0.81	0.27	0.05	-0.33	-0.43
NM	Taos	0.41	-0.34	0.52	0.01	-0.32	-0.44
NM	Valencia	0.27	0.91	0.27	0.91	0.34	0.83
TX	Brewster	-0.08	-0.37	-0.9	-0.94		-0.71
TX	Cameron	0.93	-0.65	0.59	-0.62	0.89	-0.7
TX	Dimmit	0.63	0.67	0.9	0.14	0.62	0.49
TX	El Paso	-0.15	-0.21	0.64	-0.81	-0.08	-0.23
TX	Hidalgo	0.33	0.77	0.32	0.5	0.82	0.71
TX	Hudspeth	0.12	0.12	-0.81	0.29	-0.83	0.35
TX	Jeff Davis						
TX	Kinney						
TX	Maverick	0.99	0.03	0.87	-0.09	0.99	-0.23
TX	Presidio	-0.96	-0.68	-0.88	-0.8	-0.96	-0.71
TX	Starr	-0.33	0.52	-0.79	-0.21	0.49	0.15
TX	Terrell						
TX	Val Verde		-0.68	0.97	-0.81	-0.22	-0.2
TX	Webb	0.94	-0.5	0.98	-0.29	0.68	-0.17
TX	Zapata						
CO	Alamosa						
CO	Conejos						
CO	Hinsdale						
CO	Mineral						
CO	Rio Grande						

Legend: Total Withdrawals and Residential Water Rates (Coefficient 1), Public Supply Withdrawals and Residential Water Rates (Coefficient 2), Total Withdrawals and Commercial Water Rates (Coefficient 3), Public Supply Withdrawals and Commercial Water Rates (Coefficient 4), Total Withdrawals and Residential Sewer Rates (Coefficient 5), and Public Supply Withdrawals and Residential Sewer Rates (Coefficient 6).

The case study county Bernalillo has a negative correlation to both residential and commercial water rates, with correlation coefficients of -0.68 and -.74, respectively. This indicates a statistically significant relationship between total withdrawals and water rates, meaning that as one variable increased the other decreased in the analyzed time span. Thus, as total water withdrawals dropped over time, water rates tended to increase (or when total withdrawals increased, then the water rates decreased). This result is rather counterintuitive and requires more investigation of other interconnected variables. For example, water withdrawals might have dropped because of the public becoming more educated and aware of their water use and how water is a stressed resource, but the rates are determined by utility companies and generally do not reflect the amount of withdrawals for a given year. So even if people are using less water, rates might become higher due to utility companies needing more money for more employees, maintenance or equipment to support a growing population.

El Paso County denoted a slightly different outcome, where the residential water rates had a correlation coefficient of -0.15 and the commercial rates a coefficient of 0.64. This indicates a weak negative correlation between residential rates and total water withdrawals, but a statistically significant positive correlation between commercial rates and total water withdrawals. This positive correlation indicates that total water withdrawals increased as commercial water rates increased. For residential water rates in both New Mexico and Texas, there are four statistically significant negative correlation coefficients, and seven statistically significant positive correlation coefficients. Commercial water rates have seven statistically significant negative correlation coefficients, and eight statistically significant positive correlation coefficients. With more positive correlation coefficients overall, counties along the Rio Grande in Texas and New Mexico tend to indicate a trend of total water withdrawal increasing alongside water rate increases.

Those opposite trends can be explained by weather conditions (intensifying droughts) and growing population occurring at the same time (just to mention the most plausible variables of this direction of change). Increasing water withdrawals due to the aforementioned factors might overlap with increasing water prices as municipalities try to limit water use in counties where water rates are dictated by the regional utilities. Missing values of the correlation coefficients in the table result from missing data to conduct a correlation analysis.

5.3.1.2 Public Supply, Total Withdrawals, Fresh Water

Table 3 displays residential water rates and commercial water rates as correlation coefficients 1 and 2 for the total freshwater withdrawals for public supply in 2002-2010 in New Mexico and Texas counties.

For the case study county Bernalillo both correlation coefficients are negative and equal to -.87 and -.53, respectively. This indicates that both types of water rates have statistically significant relationships with public supply freshwater withdrawals, although residential water rates (Coefficient 2) had a stronger correlation than commercial water rates (Coefficient 4). For the case study El Paso County, commercial water rates and public supply freshwater withdrawals have a statistically significant relationship with a correlation coefficient of -.81, while residential water rates have a correlation coefficient of -.21 and do not have a statistically significant relationship.

These findings are similar to the total withdrawal findings in that the negative relationship most likely stems from water rates not being connected to amount of withdrawals. Knowing that withdrawal levels are not a major factor in determining water rates can help policy makers look for a way to change prices to help conserve water or at least accurately reflect the amount of water being withdrawn.

Table 4: Economic Indicator Correlations, Part 2

State	County	Coefficient 7	Coefficient 8	Coefficient 9	Coefficient 10	Coefficient 11	Coefficient 12
NM	Bernalillo	-0.54	-0.18	-0.92	-0.99	-0.93	-0.98
NM	Dona Ana	-0.33	0.77	-0.96	0.94	-0.94	0.95
NM	Los Alamo	0.02	0.02	-0.99	-0.99	-0.99	-0.99
NM	Rio Arriba	-0.36	0.76	0.59	0.51	0.63	0.46
NM	Sandoval	-0.73	0.72	-0.99	0.99	-0.98	0.97
NM	Santa Fe	0.63	0.11	0.97	-0.74	0.95	-0.77
NM	Sierra	0.66	-0.56	0.97	-0.74	0.98	-0.7
NM	Socorro	-0.01	-0.12	-0.99	-0.91	-0.98	-0.88
NM	Taos	0.15	0.44	0.86	0.4	0.88	0.45
NM	Valencia	0.42	0.19	0.64	0.87	0.66	0.84
TX	Brewster		-0.7	-0.96	-0.92	-0.77	-0.85
TX	Cameron	0.82	-0.67	0.98	-0.68	0.86	-0.56
TX	Dimmit	-0.06	0.54	0.64	-0.32	0.78	-0.44
TX	El Paso	0.06	-0.28	0.67	-0.94	0.8	-0.88
TX	Hidalgo	0.3	0.66	0.94	0.91	0.74	0.95
TX	Hudspeth	-0.81	0.36	-0.96	0.75	-0.77	0.64
TX	Jeff Davis			-0.96	0.81	-0.77	0.71
TX	Kinney			-0.96	-0.78	-0.77	-0.85
TX	Maverick	0.99	-0.35	0.59	0.18	0.75	0.31
TX	Presidio	-0.87	-0.68	-0.96	-0.97	-0.77	-0.98
TX	Starr	0.09	0.23	0.64	-0.27	0.78	-0.4
TX	Terrell			0.47	-0.44	0.15	-0.55
TX	Val Verde		-0.35	0.46	-0.75	0.65	-0.65
TX	Webb	0.68	-0.03	-0.03	-0.85	0.27	-0.91
TX	Zapata			0.47	0.95	0.15	0.89
CO	Alamosa			-0.55	-0.03	-0.41	0.13
CO	Conejos			0.98	0.86	0.99	0.77
CO	Hinsdale			0.48	0.98	0.61	0.99
CO	Mineral			0.88	0.62	0.94	0.73
CO	Rio Grande			0.78	0.12	0.86	0.27

Legend: Total Withdrawals and Commercial Sewer Rates (Coefficient 7), Public Supply Withdrawals and Commercial Sewer Rates (Coefficient 8), Total Withdrawals and Personal Consumption Expenditures for Housing and Utilities (Coefficient 9), Public Supply Withdrawals and Personal Consumption Expenditures for Housing and Utilities (Coefficient 10), Total Withdrawals and Per Capita Housing and Utilities (Coefficient 11), and Public Supply Withdrawals and Per Capita Housing and Utilities (Coefficient 12).

5.3.2 Residential and Commercial Sewer Rate Correlations

5.3.2.1 Total Withdrawals

Tables 3 and 4 display correlations between residential and commercial sewer rates and total saline and freshwater withdrawals (Coefficients 5 and 7) in the analysis timeframe 2002-2010 for New Mexico, and 2005-2010 for Texas. The difference in the time series analysis was determined by data availability.

The case study county Bernalillo indicates a correlation coefficient of .88 for residential sewer rates and -.54 for commercial sewer rates vs total water withdrawals. This means that there was a positive relationship between total withdrawals and residential sewer rates, as both variables tended to increase or decrease, respectively when the other variable increased (or decreased). For commercial sewer rates, there was only a slight negative relationship between water rates and total withdrawals. For El Paso County, both correlation coefficients were insignificant meaning that there was no discernible relationship between the two variables.

When analyzing all counties included in this study, the counties with the most significant positive relationships between total water withdrawals and residential sewer rates were Maverick, Cameron, Bernalillo, Hidalgo and Santa Fe. The counties with the most significant negative relationships between total water withdrawals and residential sewer rates were Presidio, Dona Ana, and Hudspeth. For total withdrawals and commercial sewer rates, the counties with the most significant positive relationships were Maverick, Cameron and Webb. The counties with the most significant negative relationships were Presidio, Hudspeth and Sandoval. Overall, there were eight positive significant relationships for withdrawals and residential sewer rates and three negative significant relationships. For withdrawals and commercial sewer rates, there were five positive relationships and four negative relationships.

Bernalillo County yielded significant results and indicated that there could be more of a direct relationship between residential sewer rates and total withdrawals than with commercial sewer rates and total withdrawals, meaning that the county is already portraying a fairly accurate correlation between withdrawals and sewer rate pricing to its citizens.

5.3.2.2 Public Supply, Total Withdrawals, Fresh Water

Tables 3 and 4 shows the relationships between residential and commercial sewer rates and total freshwater withdrawals (Coefficients 6 and 8) for the public supply in 2002- 2010. Although additional sewer rate information is available for the years 2002 through 2014, the USGS data ended in 2010 so the correlations cover only this time period.

For Bernalillo County, a significant positive relationship between public supply withdrawals and residential sewer rates was found, while there was an insignificant relationship between public supply withdrawals and commercial sewer rates. For El Paso County on the other hand, insignificant results for both residential and commercial sewer rates were detected.

For residential sewer rates from all counties, there was a positive relationship between withdrawals and sewer rates in six counties and a negative relationship in four counties. With commercial sewer rates and public supply withdrawals, there were five statistically significant positive relationships and four negative relationships. When looking at Bernalillo County, the results are similar to total withdrawals in that residential sewer rates tend to increase when withdrawals increase, even though commercial sewer rates and both of El Paso County's rates show no significant relationship. Overall, the amount of positive and negative relationships is similar and there appears to be no strong trend or pattern between public supply withdrawals and residential and commercial sewer rates.

5.3.3 Personal Consumption Expenditures—Housing and Utilities

5.3.3.1 Total withdrawals

Table 4 shows correlations between personal consumption expenditures and total water withdrawals (Coefficients 9 and 11) for all counties analyzed in this study. Correlation coefficients were calculated for New Mexico and Colorado for the time frame 2000-2010, while for Texas counties the analysis encompassed the years 2005-2010.

For Bernalillo County, both housing and utility personal consumption expenditures and per capita housing and utility personal consumption expenditures were both statistically significant with a strong negative correlation. This means that as water withdrawals increased, personal consumption expenditures for housing and utilities and per capita housing and utilities decreased. Since this is total withdrawals, some of the water withdrawn could have gone to agriculture or other industries and not greatly impacted expenditures on utilities. Total withdrawals could be increasing because of drought or increased urbanization in a relatively arid area.

For El Paso County, both correlation coefficients for personal consumption expenditures have a significant positive relationship with total water withdrawals. In other words, water withdrawals increased alongside both personal consumption expenditure sub-indicators. This points to a utility system that is more directly influenced by withdrawals and water usage. It could also mean the city anticipates increases in withdrawals and adjusts utility bills to accommodate these withdrawals.

For Rio Grande County, both correlations are statistically significant and positive as well. Out of all the correlation coefficients for the counties listed for personal consumption expenditures for housing and utilities and water withdrawals, there are 11 significant negative correlations and 14 significant positive correlations. For per capita personal consumption expenditures for housing and utilities and water withdrawals, there are 10 significant negative correlations and 15 significant positive correlations. Values were not adjusted for inflation and are expressed in current dollars.

Overall, there are more positive correlations, indicating that as total withdrawals increase, rates increase as well. There is a positive correlation pattern in total withdrawals and both personal consumption expenditure sub-indicators, meaning that minimizing withdrawals and conserving water could indirectly lead to lower utility bills for citizens. Lowering these bills would in turn be a great incentive for citizens to conserve water to keep the utility bills lower. Even though correlation does not equate to causation, inferring potential trends and future outcomes can help prevent water stress for the Rio Grande Basin in the future.

5.3.3.2 Public Supply, Total Withdrawals, Fresh Water

Analyzing total freshwater withdrawals for public supply and personals (Coefficients 10 and 12), similar time periods are used as with the previous table depicting total withdrawals, except now the time range for all three states is 2000-2010 because data for Texas is available.

For the case study Bernalillo County, both correlation coefficients for personal consumption expenditures were statistically significant with negative relationships. This is similar to Coefficients 9 and 11 from Table 4, with correlation coefficients for total water withdrawals. Correlation coefficients 10 and 12 for El Paso County are different than Coefficients 9 and 11, with Coefficients 10 and 12 both indicating significant negative relationships. For Rio Grande County, no statistically significant relationships between personal consumption expenditures and public supply freshwater withdrawals were found. Overall, for correlation coefficient 1 (Personal Consumption Expenditures for Housing and Utilities) there are 12 negative significant relationships and 11 positive significant relationships. For per capita housing and utilities and withdrawals, there were 13 negative significant relationships and 10 positive significant relationships.

These results differ greatly from the total withdrawals results, except for Bernalillo County which had strong negative correlations for both total withdrawals and public supply freshwater withdrawals (Coefficients 9, 10, 11 and 12). In table 4, El Paso has negative significant correlations as well while Rio Grande has no significant relationships, which could indicate that housing and utility expenditures in more urban areas have more of an impact on water withdrawals.

5.4 Environmental Indicators

5.4.1. Temperature and Precipitation

5.4.1.1 Total Withdrawals

Table 5 displays temperature and precipitation values correlated with total water withdrawals (Coefficients 1 and 3) for the time periods 2000-2010 for New Mexico and Colorado counties, and for 2005-2010 for Texas counties.

Table 5: Environmental Indicator Correlations

State	County	Coefficient 1	Coefficient 2	Coefficient 3	Coefficient 4	Coefficient 5	Coefficient 6
NM	Bernalillo	0.35	0.37	-0.48	-0.23	-0.54	-0.54
NM	Dona Ana	0.63	-0.54	-0.19	0.38		
NM	Los Alamos	0.29	0.29	-0.72	-0.72		
NM	Rio Arriba	-0.28	-0.46	0.58	0.07	0.16	0.43
NM	Sandoval	0.41	-0.41	-0.56	0.55	-0.24	0.25
NM	Santa Fe	-0.4	0.22	0.38	-0.41	0.4	-0.19
NM	Sierra	0.07	0.09	0.31	-0.2	-0.23	-0.3
NM	Socorro	-0.02	-0.09	0.14	0.29	-0.32	-0.16
NM	Taos	-0.44	-0.25	0.72	0.77	0.58	0.38
NM	Valencia	-0.46	-0.26	-0.01	-0.41		
TX	Brewster	0.43	0.3	-0.25	-0.15		
TX	Cameron	-0.57	0.43	0.68	-0.46		
TX	Dimmit	-0.01	-0.01	0.02	-0.02	-0.04	-0.2
TX	El Paso	-0.08	0.31	-0.25	-0.2		
TX	Hidalgo	-0.25	-0.29	0.66	0.46		
TX	Hudspeth	0.3	-0.16	0.18	0.06		
TX	Jeff Davis	0.12	-0.26	-0.7	0.15		
TX	Kinney	0.4	0.11	0.01	-0.03	0.14	0.03
TX	Maverick	-0.05	0.12	-0.07	0.21		
TX	Presidio	0.35	0.66	-0.17	-0.32		
TX	Starr	0.42	0.28	0.63	-0.22		
TX	Terrell	-0.37	0.19	0.62	-0.31	-0.12	-0.14
TX	Val Verde	0.11	0.22	-0.24	0.06		
TX	Webb	0.38	0.06	-0.26	-0.21	-0.31	0.2
TX	Zapata	-0.77	-0.32	0.51	0.12		
CO	Alamosa	0.47	0.15	0.31	0.17		
CO	Conejos	-0.58	-0.55	-0.15	-0.58	0.61	0.38
CO	Hinsdale	0.27	0.4	0.41	0.49		
CO	Mineral	0.41	0.33	0.45	0.45		
CO	Rio Grande	-0.08	0.17	0.39	0.25	0.46	0.24

Legend: Total Withdrawals and Temperature (Coefficient 1), Public Supply Withdrawals and Temperature (Coefficient 2), Total Withdrawals and Precipitation (Coefficient 3), Public Supply Withdrawals and Precipitation (Coefficient 4), Total Withdrawals and Average Annual Streamflow Rate (Coefficient 5), and Public Supply Withdrawals and Average Annual Streamflow Rate (Coefficient 6).

For Bernalillo County, total withdrawals correlated with both temperature and precipitation yielded no significant relationships. For El Paso and Rio Grande Counties there were no significant relationships either. Overall, Dona Ana County is the only county with a positive significant relationship between temperature and total water withdrawals at 0.63. This means that as temperature increased so did water withdrawals. Cameron County, Zapata County, and Conejos County are the only counties with a negative significant relationship between temperature levels and total withdrawals. This means that as temperatures decreased, water withdrawals increased.

For precipitation and total withdrawal correlations, there were seven significant positive relationships and three significant negative relationships, meaning that more counties experienced increases in water withdrawals as there were increases in precipitation.

These findings indicate that neither precipitation nor temperature (as the most relevant environmental indicators) seem to be strongly correlated with water withdrawals.

5.4.1.2 Public Supply, Total Withdrawals, Fresh Water

A similar pattern as in the previous section was found the public supply withdrawals and both temperature and precipitation, respectively in 2000-2010 (Coefficients 2 and 4).

For the three case study counties, there were no significant positive or negative correlations between either public supply withdrawals and temperature or public supply withdrawals and precipitation. Overall, Dona Ana County and Conejos County were the only two counties with significant negative correlations for public supply withdrawals and temperature. Presidio County in Texas was the only county indicating a significant positive relationship between public supply withdrawals and temperature. For public supply withdrawals and precipitation, Los Alamos County in New Mexico and Conejos County in Colorado were the only two counties with significant negative correlations, while Sandoval and Taos counties in New Mexico were the only counties with significant positive correlations.

Public supply water withdrawals correlated with temperature and precipitation yielded even less significant results than total withdrawals, indicating that in the ten year time period analyzed these variables do not strongly impact withdrawals.

5.4.2 Streamflow

Streamflow rate is another significant environmental variable that was correlated here with total withdrawals in the time period 2000 through 2010 in New Mexico and Colorado, while it was analyzed for 2005- 2010 in Texas due to data paucity (Coefficients 5 and 6). Average annual streamflow data correlated with freshwater public supply withdrawals was for the years 2000 through 2010.

The counties that had sufficient streamflow data for the correlation analysis with total withdrawals were Bernalillo, Rio Arriba, Sandoval, Santa Fe, Sierra, Socorro, Taos, Dimmit, Kinney, Terrell, Webb, Conejos, and Rio Grande Counties. Out of the available counties, Bernalillo is the only one with a significant negative correlation between the average annual streamflow and total water withdrawals. Taos and Conejos Counties are the only counties with available data that indicated a significant positive correlation between streamflow rates and water withdrawals. Missing data led to gaps in the correlation coefficients, while overall the correlation coefficients are low with only three out of thirteen showing a significant relationship. The correlation relationships vary, with a low positive relationship in the Kinney County in Texas at 0.14 and a high positive relation of 0.61 in the Conejos County in Colorado. Negative relationships ranged from -0.04 in Dimmit County to a high of -0.54 in Bernalillo County. This finding indicates a weak relationship between total water withdrawals and freshwater resources such as rivers.

Furthermore, counties with sufficient streamflow data to correlate to public supply withdrawals were as follows: Bernalillo, Rio Arriba, Sandoval, Santa Fe, Sierra, Socorro, Taos, Dimmit, Kinney, Terrell, Webb, Conejos and Rio Grande Counties. Out of the counties with available data, Bernalillo County is the only county with a significant negative relationship and there are no counties with available data that indicate significant positive relationships. Moreover, the correlation coefficients are very low, regardless of the sign, indicating a weak relationship between public water supply withdrawals and streamflow rates. Bernalillo County indicated the strongest correlation of -0.54, while other correlation coefficients vary significantly—positive relations range between 0.03 for the Kinney County in Texas and 0.43 for the Rio Arriba County in New Mexico. Negative relations range from -0.14 for the Terrell County in Texas and -0.54 for Bernalillo County in New Mexico.

Chapter 6: Discussion and Conclusions

6.1 Discussion

This study aimed at understanding underlying trends and patterns within the studied variables from thirty counties in the Rio Grande River Basin, with a focus on Bernalillo, El Paso and Rio Grande Counties. The main goal was to conduct a correlation analysis to detect these trends and see which sub-indicators had stronger relationships with total and public supply water withdrawals, which will then help water managers decide which variables to prioritize when looking to manage water resources in the future. The study results are variable in terms of the range of correlation coefficients in the analyzed Rio Grande River counties and states, meaning that the coefficients ranged from 0 to .99.

When analyzing residential and commercial water rate correlations, Bernalillo County shows significant negative relationships with both commercial and residential water rates and total withdrawals, total and public supply total freshwater withdrawals. At the same time, El Paso County indicated a significant positive relationship between commercial water rates and total withdrawals and a significant negative relationship with between commercial water rates and public supply withdrawals. The presented case studies indicate that there are strong negative relationships between water use and commercial water rates, and significant positive relationships between total water use and residential water rates.

Overall there were more significant negative relationships than positive relationships between water rates and total withdrawals in the analyzed counties, which reinforces the case study findings of a lack of positive relationships between water rates and withdrawals. Significant positive relationships would more accurately reflect the water supply, which could be particularly helpful during drought. If there was a stronger positive relationship between withdrawals, then water rates would be more likely to increase as water withdrawals increase, which could incentivize citizens to minimize excess water use.

Residential and commercial sewer rates correlated with total withdrawals generated similar results as the water rates correlated with total withdrawals analyzed above. Thus, relationships between the variables in Bernalillo County and El Paso County were negative and there were more significant negative correlations than significant positive correlations. This pattern is understandable since sewer rates are typically handled by the same office as water rates, thus there is room to improve on making sewer rates correspond closer to the fluctuations in withdrawals.

Public supply water rates and the sewer rate correlations yielded vastly different correlations with a positive significant correlation for Bernalillo County (and residential sewer rates), while Bernalillo County commercial sewer rates and El Paso County residential and commercial rates yielding insignificant results. This indicates a different relationship between total withdrawals and public supply withdrawals, and that Bernalillo’s sewer rates are potentially closer to representing an accurate reflection of water value for the public supply.

When analyzing housing and utility personal consumption expenditures and associated per capita expenditures, correlations for Bernalillo County for housing and utility and per capita for both total withdrawals and public supply withdrawals were significant negative relationships. This indicates that housing and utility expenditures and the expenditures per capita are connected to withdrawals and need to be considered for examining future water use. These utilities tie into water rates and could also be utilized to better reflect the value of water to help citizens understand the importance of preserving water in Bernalillo County. The correlation between personal consumption expenditures for housing and utilities and total withdrawals for El Paso County had significant positive coefficients, but public supply withdrawal correlations both had negative significant correlations. This shows that personal consumption expenditures for housing and utilities could be linked closer to overall withdrawals than just the public supply. Total withdrawals in Rio Grande County correlated with the two personal consumption expenditure sub-indicators were both positive and significant, but when correlated with public supply they yielded no significance, leading to a similar pattern as the one in El Paso County.

Considering correlations between poverty and per capita personal income and the total withdrawals and public supply, there were many more significant correlation relationships between per capita personal income and total or public supply withdrawals than between poverty estimates and either of the water withdrawals. Rio Grande County yielded one significant positive per capita personal income correlation. Bernalillo and El Paso Counties both denoted strong negative relationships between per capita personal income and total water withdrawals. Also, there were twice as many significant correlations for per capita personal income and withdrawals than correlations for poverty and total water withdrawals. This pattern indicates that per capita personal income could be a sub-indicator that plays a more important role for withdrawal levels than poverty estimates. The level of income acquired could be linked to water trading, which links to withdrawal levels, particularly for the public supply. It can be concluded that poverty estimates are less correlated with withdrawals than per capita personal income.

Analyzing further the two different population samples (total population and the public supply population) all three case study counties yielded significant relationships for both types of population samples. An exception is a correlation in Rio Grande County between public supply withdrawals and total population which yielded insignificant results. Bernalillo County indicated significant negative correlations for both withdrawal sub-indicators (total withdrawals and public supply withdrawals) correlated against both population samples (total population and public supply population). At the same time, El Paso County denoted significant positive correlations between both population samples and total withdrawals as well as significant negative correlations between both population samples and public supply withdrawals. Rio Grande County yielded mixed results, with the general total population and total withdrawals indicating a significant negative relationship, while the public supply population yielding strong significant positive correlations. Total withdrawals and public supply withdrawals correlated with the public supply population variable yielded the highest number of significant results. This means that the population sample that receives water from public supply is more likely to have a more direct connection to total and public supply withdrawals than the total population (not using public supply water).

Temperature and precipitation correlated with total and public supply withdrawals yielded the most surprising results. All three case study counties indicated insignificant correlations between both temperature and precipitation and total withdrawal rates. Temperature and precipitation are potential indicators of drought or water availability; thus, the anticipation of this study was that many significant positive relationships between these environmental variables and water withdrawals will be found. For total withdrawals, Dona Ana was the only county with a positive significant relationship (between water withdrawals and temperature), while Cameron, Zapata and Conejos Counties had a negative significant relationship. Precipitation yielded ten significant relationships, seven positive and three negative correlation coefficients. Dona Ana and Conejos counties showed significant negative relationships between public supply withdrawals and temperature, while for Presidio County a positive significant relationship was found. Los Alamos and Conejos counties had significant negative relationships, while Sandoval and Taos counties indicated significant positive relationships between total withdrawals and precipitation.

Overall, precipitation yielded more significant correlations than temperature for this set of counties, but even this number of significant correlations is relatively small compared to the other analyzed variables. These findings indicate that temperature and precipitation are not as strongly correlated with water withdrawal levels as previously anticipated and hypothesized with this study.

Since streamflow rates were missing seventeen out of thirty county data sets, there is a less holistic view of the represented counties in terms of correlations involving this variable. Yet one of the case study counties, Bernalillo, was the only county with significant negative relationships between both total withdrawals and public supply withdrawals. The only other significant positive relationships between total withdrawals and streamflow rates were found in the Taos and Conejos counties. This signifies that streamflow is an important variable for Bernalillo County but may not be of such an importance to other counties along the Rio Grande River. Streamflow data could play a key role in understanding future withdrawal levels, while monitoring streamflow levels could help Bernalillo County with a more efficient water management.

To summarize the results for the three case study counties, it needs to be stated that withdrawal levels in Bernalillo County seemed to be determined by the most variables specified in the sustainability table (table 1), while Rio Grande County was the least affected. Bernalillo County is the most populous county in New Mexico and is home to the most populous city in New Mexico, Albuquerque. As it continues to grow, water resource vulnerability will most likely grow as well. The results for El Paso County were more diverse and variable, which makes it more difficult to detect any clear trends or patterns. At the same time, Bernalillo County has strong relationships between the analyzed variables. Per capita personal income seemed to have the most significant importance in regard to both types of water withdrawals. Future research is needed to continue analyses of this kind as well.

6.2 Conclusions

There are a few different, important conclusions to be drawn from this study. For starters, it becomes apparent that urbanized areas such as Bernalillo and El Paso Counties are most likely beginning to find their freshwater from other sources than the Rio Grande River. El Paso utilizes desalinization to contribute to their water demands. Other sources is a viable explanation for why the population is increasing but withdrawal rates are decreasing or only increasing slightly. Another explanation is the amount of marketing, advertising and education about water conservation may be paying off in the form of decreased withdrawals despite growing populations. As larger cities and metropolitan areas see an increase in population and anticipate increases in water demands, water conservation education is publicly marketed to help raise awareness of the water stress the city may be facing currently or in the near future.

Looking at the different relationships between the sub-indicators and water use, it should be noted that the sub-indicators within the social category yielded the most consistently strong relationships with water use, while sub-indicators within the environmental category yielded the least consistently strong relationships with water use. From this study, the social science aspect of analyzing water use yields the strongest relationships and therefore could be the driving force behind managing water use. Utilizing the population in the county and understanding their water use patterns alongside the general demographics can help stakeholders adapt a more sustainable way of managing water by educating the population on water conservation and providing incentives to adjust water use behavior. The strong relationships found with per capita personal income and water use were relatively unexpected, but can be used by water managers to understand their audience. For lower income areas, provide water conservation education, particularly in schools. For higher income areas, market new technology that might increase water efficiency in a residence or business. Per capita personal income has not been mentioned in the literature as linked with water use, so future research is needed to solidify these conclusions.

Another notable relationship was the somewhat unremarkable amount of significant relationships between water/sewer rates and water use. It is unremarkable because water pricing is a tool managers can utilize to help preserve water, but is often underutilized or not utilized at all. Even though water rates are not typically based upon withdrawals, a significant relationship between the amount withdrawn and rates persists in some counties, such as Bernalillo. This indicates there are other factors at play, and that there is an opportunity here to change how water rate prices are determined to better reflect the amount of total water withdrawals. By analyzing water rates in relation to total water withdrawals, particularly public supply withdrawals, consumers can gain a more accurate understanding of the value of water.

Finally, the lack of relationship trends within the environmental indicator category was relatively surprising based on the literature, but makes sense when thinking about the social sciences at play. Even in drought, citizens unaware of water stress will expect to use the same amount of water they always use, if not more (lawn-care, hydration, etc.). If there is no incentive to use less water, and there is no knowledge of any future water stress, citizens are unlikely to change their behavior despite environmental changes. The precipitation, temperature and streamflow results were initially surprising, but after reevaluation and consideration, these findings support the notion that the social indicator category is just as important, if not more important, to utilize in water management than environmental or economic indicators.

Chapter 7: Recommendations, Future Research, and Limitations

Based on the literature and the outcome of this research, municipal water managers could consider evaluating their county's relationship between water or sewer rates and water withdrawals. Recognizing the relations and their strengths might provide a valuable basis for designing schemes for more efficient water conservation practices, for examples pricing water according to withdrawal levels and the amount of water available for the city/county to utilize. Raising the rates of water slightly, particularly during drought, could help increase societal awareness on the value of water and serve as an approach for creating change in water use behavior (Hilaire et al., 2008; Campbell et al., 2004; Brookshire et al., 2002).

There are a few main limitations to this study where further research is needed. The first is the lack of data for a longer time period. The correlations represent trends in either five or ten year increments - trends may have been exaggerated or missed altogether due to a lack of data over a lengthier period of time. Future research could focus on collecting further data for these variables to add to the current knowledge.

In addition to expanding data sets over a longer range of years, more variables can be analyzed to further contribute to the Rio Grande River basin socio-economic and environmental analysis. A larger number of social, environmental and economic variables could provide a more holistic representation of the Rio Grande River Basin for stakeholders and water managers for them to better understand the full complexity of this basin's water management.

Providing additional environmental indicators to future water use studies would be beneficial and provide an even more holistic picture of how to address sustainable issues like managing water use in water-stressed regions. This study did not include all potential environmental sub-indicators, such as water quality or ecosystem services, mainly due to the complex nature of quantifying these variables and data paucity. Future research can benefit from analyzing water quality, endangered species, ecosystem services, and recharge rates to the environmental indicator category.

Another important limitation is the water use and water rate information. The water use information was obtained from the USGS and was only available in five year increments, with 2010 being the most recent dataset available. The commercial and residential water and sewer rates were both obtained from Texas and New Mexico survey data. This data was based upon generic surveys distributed to water utilities throughout each state, and a lot of the survey questions were not filled out or left room in the questions for unintended but potential multiple interpretations to take place. There was also no available quantitative survey data for Colorado water rates. This lack of definitive recorded change in water rates over a certain time period (in this case, 2002-2014 for New Mexico and 2002-2015 for Texas) and the number of years missing from the datasets leaves a lot of room for additional data to be collected as it becomes available in the course of time. Water rate data collected directly from the source instead of survey data would provide more precise numbers, albeit it is much more difficult to find it on a county level and standardize it to future studies.

Another limitation for this study was the lack of sub-indicators depicting policy or regulations in the river basin. Regulations and policies in place play an important role for determining withdrawals. While quantifying these sub-indicators may prove challenging, future research including those variables would provide new knowledge and foster improved social awareness about the importance of policy regulations in different regions of the Rio Grande for sustainable water management.

Remembering that correlations do not equate to causations is an important factor in this study because in addition to the two variables correlated, there are a variety of other factors at play when analyzing the interrelationships between two variables. This study assessed trends between two variables, but it is not meant to provide definitive conclusions on whether one variable is the only determinant of correlation changes.

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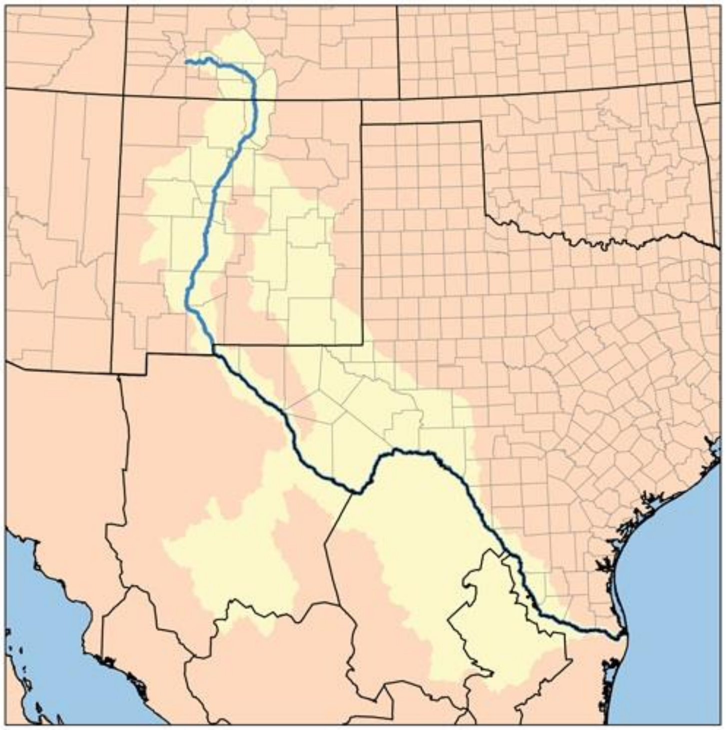
Appendix



Colorado
- Hinsdale County
- Rio Grande County
- Alamosa County
- Conejos County
- Mineral County

New Mexico
- Taos County
- Santa Fe County
- Rio Arriba County
- Los Alamos County
- Sandoval County
- Bernalillo County
- Valencia County
- Socorro County
- Sierra County
- Dona Ana County

Texas
- El Paso County
- Hudspeth County
- Jeff Davis County
- Presidio County
- Brewster County
- Terrell County
- Val Verde County
- Kinney County
- Maverick County
- Dimmit County
- Webb County
- Zapata County
- Starr County
- Hidalgo County
- Cameron County

Total Counties: 30