AN EXPLORATORY ANALYSIS OF THREE WATER

CONSERVATION ALTERNATIVES FOR

SAN MARCOS, TX

by

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ABSTRACT

The purpose of this study is to analyze three water conservation methods for San Marcos, TX. After reviewing the relevant literature, three popular water conservation alternatives were chosen, case studies from historic conservation initiatives from the San Antonio Water System (SAWS), rainwater harvesting, and graywater reuse. Water savings data were collected; installation and maintenance costs were calculated, and a comparison of the most cost-effective method through price per acre-foot over a 10 year averaged period. All three methods provided sufficient data to provide appropriate, and characteristically consistent numbers for comparison. This study also provided an analytical approach to the economic disparity between water supply issues in central Texas. All three conservation methods ultimately resulted an average savings of about 40,000 gallons of water annually, per household. The averaged total of SAWS' three case studies proved to be the most cost-effective method, followed by graywater reuse doubling in overall cost. By far the most costly approach was rainwater harvesting totaling nearly $20,000 per acre-foot. However, despite variation in overall cost, the alternatives compared did give appropriate insight to the realities of our water situation and the future of water policy for San Marcos and surrounding cities under similar stresses.

CHAPTER I

INTRODUCTION

In recent years drought and urbanization has affected Texas' water availability in many ways. Increased population combined with periodic droughts, groundwater supplies throughout the state are limited and threatened by overuse and surface waters are almost completely allocated. Communities in Hays County, Texas are faced with expensive alternatives for additional supply. The Austin-San Antonio corridor will soon exceed four million, and the smaller cities within the corridor have witnessed the resource and infrastructure stresses found with such rises in population. With a population increase of nearly 5 percent from 2011 to 2012, San Marcos was named the fastest growing city over 50,000 in the nation (USCB 2012a). The city has an average per capita water use of 124 gallons per day (GPCD) and a highly variable precipitation averaging 37.19 inches per year (TWDB 2013) (USNCDC 2013). With such resource pressure, there is a need for a more sustainable water supply. An additional complicating factor is the presence of federally listed threatened and endangered species in the San Marcos River that are dependent upon springflow from the Edwards Aquifer, the traditional water source for the region, which includes the Texas Wild Rice, Texas Blind Salamander, San Marcos Salamander, and the Fountain Darter.

Some costly infrastructure options have been suggested to provide an adequate water supply for the growing population. Among these include a pipeline to bring water from the Carrizo-Wilcox Aquifer (Figure 1). This pipeline will stretch over 40 miles to the Hays Caldwell Public Utility Agency, costing more than $100 million to construct (San Marcos Mercury 2011). Such a pipeline, which represents a costly investment, has the potential to provide adequate water resources to a population for the time being but ignores the ability to develop conservation-oriented solutions.

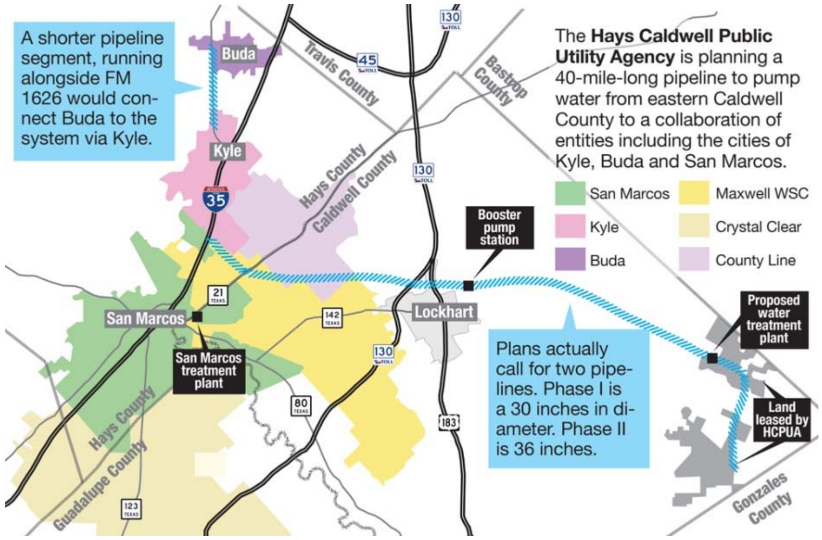

Figure 1. Hays Caldwell Public Utility Agency Pipeline Plan (San Marcos Mercury 2011)

<u>Purpose</u>

The purpose of my thesis will be to evaluate three basic water conservation models in a residential setting. My research question will be; which of these three, water conservation models can provide sustainable contributions to our water supply; (1) historical conservation measures with incentivized and sponsored water-wise practices based on the San Antonio Water Service's (SAWS) case studies; (a) Plumbers-to-People program, (b) Home Check-up program, and (c) Toilet Replacement program; (2) rainwater harvesting for supplemental use inside and outside the home, and (3) graywater reuse for supplemental use inside and outside the home? This analysis will provide the relative amounts that each of those methods can contribute to the reduction of demand on the regional water supply.

CHAPTER II

LITERATURE REVIEW

Background on San Marcos and Hays County

Hays County is one of the fastest growing counties in the Austin-San Antonio Corridor. Water supply in this region traditionally has been provided by the Colorado and the Guadalupe rivers as well as the Edwards Aquifer. The reliability of these sources through precipitation are highly variable with dramatic year to year differences (Figure 2) (Earl, Dixon, and Day 2006). With the rapid increase in population in the region (Figure 3), these sources are at or beyond their sustainable capacity.

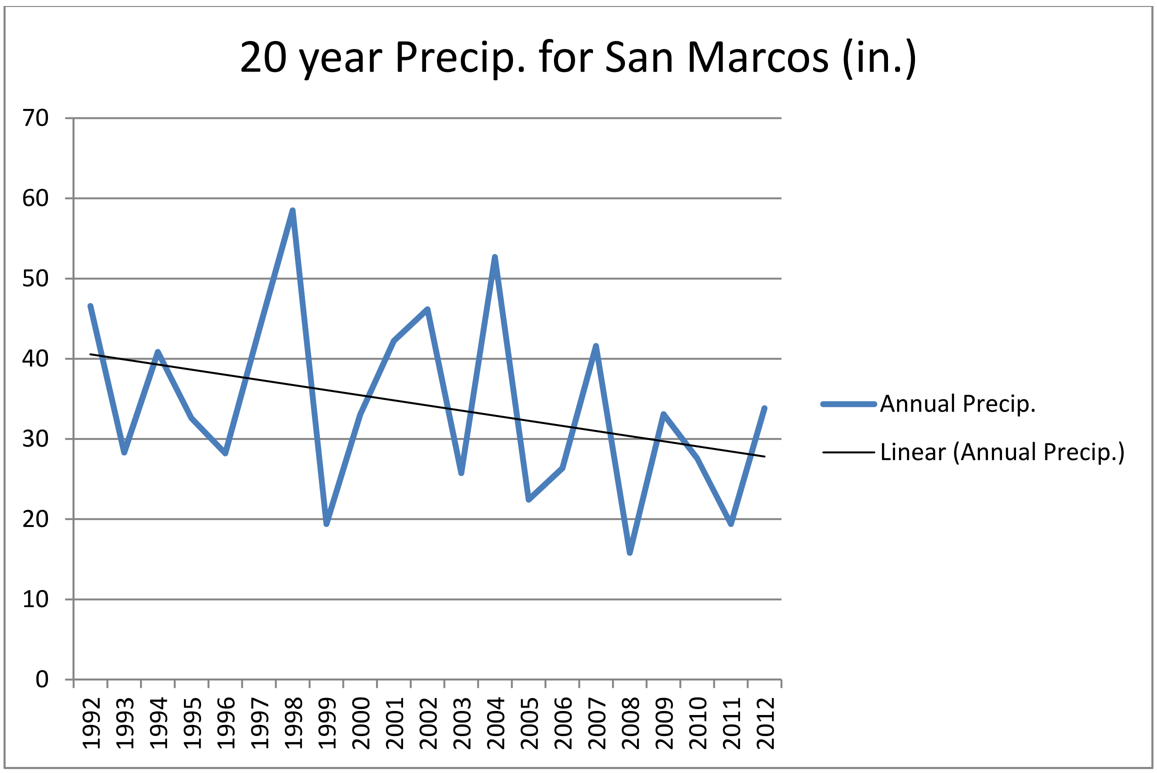

Figure 2. 20 Year Precipitation data for San Marcos, TX (USNCDC 2013)

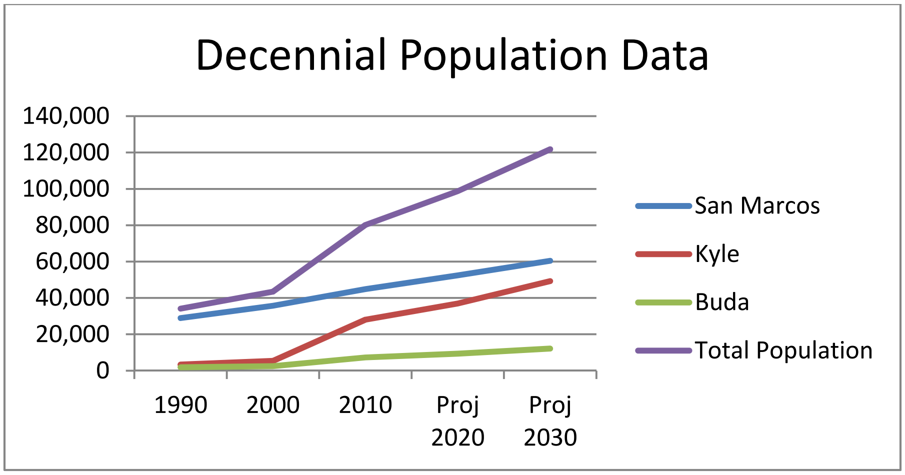

Figure 3. Decennial Population Data for IH-35 Corridor (US Census Bureau 2008)

To adequately provide our growing state's population with water, while maintaining healthy flows in our rivers and springs, various methods of providing sustainable water supply must be investigated outside of what is traditionally used. Unnecessary water shortages threaten Texas' prosperity. Making each individual more responsible for his or her own water use will encourage more efficiency throughout our stressed region.

In the study of sustainable water conservation, the economic viability is as important as the physical availability. Many cities throughout our nation's drier regions have adopted conservation-based approaches. These strategies involve citywide incentives and special programs for educating the public in "water-wise" habits for the household as well as less water demanding appliances.

To appropriately identify the most successful approach, or combination of approaches, to our water crisis, we must see the issue on the demand as well as the supply side of resource acquisition. Currently our modern society is at a crossroads in water availability. Homeowners throughout the country have been able to live their lives as they wish, using water liberally, and without immediate consequence. Now, understanding the state-wide trend of variable precipitation, rising population, and water scarcity, our municipalities are left to decide the best management practice in providing adequate water to their community without continuing down the road of unsustainable use.

Generally, it is accepted that a block payment is the most appropriate way to incentivize conservation-oriented habits within a city. As Table 1 shows, for San Marcos the minimum payment per household is $18.50 per month. This assumes that an average household in San Marcos (2.75 individuals according to US Census Bureau data (2012)) will use no more than approximately 70 gallons of water per person per day. Due to the average per capita water use being well over that amount most households are paying in the 3rd rate tier (9,001-20,000 gallons), resulting in a monthly water bill of approximately $50.

Table 1. San Marcos Municipal Water Rates (City of San Marcos 2013)	
Inside-City Water Rates	
Lifeline Rate	**Rate**
First 6,000 Gallons- Min	18.50
6,001-9,000	5.43
9,001-12,000	6.20
12,001- 20,000	6.98
20,001- 50,000	7.75
Over 50,000 Gallons	9.30

San Marcos represents almost one-third of the total population of Hays County and is growing at an incredible pace. In Table 2 above expected municipal demand is projected into 2030 by the Texas Water Development Board (TWDB). Split between Regional Water Planning Group (RWPG) K and L, which represent the two most populated metropolitan areas in the IH-35 corridor, Travis county (Austin) and Bexar county (San Antonio), Hays county represents an integral part in the future of the area's population distribution and ultimately its water resource demands.

Table 2. Regional Population and Water Demands by County (TWDB 2013)

County	Regional Water Planning Group	Population (2010)	Projected (2030)	Municipal Demands (AF) (2020)	Projected Municipal Demands (AF) (2030)
Travis	K	1,024,266	1,430,000	213,000	241,000
Hays	**K/L**	**157,107**	**290,000**	**32,000**	**41,000**
Bexar	L	1,714,773	2,230,000	299,000	329,000
Comal	L	108,472	180,000	25,000	31,000

Conservation Based Approaches

In order to successfully limit demand throughout a population, a system of well-developed incentives can prove to be an inexpensive way of limiting city-wide water consumption. Texas has a wide range of options for water conservation. Landscape water use is a major component of municipal supply. Annual outdoor water use in Texas ranges from 69 to 414 gallons per capita daily (Hermitte and Mace 2012). This range of use makes it difficult to characterize outdoor watering practices. In summer months alone, outdoor water use averaged 249 gallons per capita daily, that's 729 gallons per household. Ultimately, stretched throughout the year, the figure drops to 124 gallons per capita, resulting in roughly 68 percent of residential water use and 70,000 gallons of water annually per household (Hermitte and Mace 2012).

Two major conservation strategies have been implemented in cities throughout Texas. The first method involves reducing water use for traditional landscaping through irrigation scheduling and using moisture sensors to prevent irrigation when the soil is moist. The City of San Antonio Water Systems department (SAWS) established a rebate program of a maximum amount of $800 to upgrade inefficient irrigation systems. SAWS also provides a rebate program of a maximum $400 to install a “water-wise” landscape. Xeriscaping, a landscape based on drought tolerant species of plants (xerophytes). Xeriscaping has been of regional importance in maintaining a native landscape. This not only assists in lower outdoor water use but also provides more wildlife habitat for regional fauna. Essentially these approaches can allow outdoor water use to be significantly reduced with very little capital investment (SAWS 2013).

Until more water efficient clothes washers were mandated by the 2005, Energy Management Act, the City of Austin maintained a rebate program for water saving front loading washers that used 30 percent less water compared to older models (Austin Water 2013). Currently, several cities provide free showerheads and faucet aerators to minimize water use indoors. Shower and faucet combined make up 30 percent of indoor water use. These showerheads can save up to 2 gallons per minute and bathroom aerators use 1 gallon per minute and the kitchen aerators use 2.2 gallons per minute (Austin Water 2013). In addition, SAWS’ toilet replacement program where toilets from 1992 or older were replaced by a new, water saving toilet for free (SAWS 2012).

In this study the three most effective conservation programs used by SAWS will be evaluated as appropriate measures for San Marcos. Due to San Antonio’s dependence on the Edwards Aquifer, their determination to limit use acts as an example to the rest of the region, and the country. San Antonio has managed to maintain the same annual withdraws since the mid-1990’s while simultaneously almost doubling in population. This is a great achievement that was possible by the implementation of broad-based conservation measures (SAWS 2012).

First, the Plumbers to People program, a nationally unique conservation program, and the first of SAWS' initiative starting in 1994 provided plumbing assistance to low-income residential customers (SAWS 2012). To qualify for this assistance the customer must own their home, meet Federal Assistance Guidelines, and complete appropriate application process (Ramos 2002).

The 1994 toilet exchange program, or also known as "kick-the-can" began distributing low-flow (1.6 gallons per flush) toilets to single family residential customers. SAWS used a $75 financial incentive to be credited to the customer's water bill for each toilet replaced (3.5-7 gallons per flush). In 2001, SAWS revisited the program with the Residential Toilet Distribution Program, which has distributed low-flow toilets to customers for free. As of 2002, 54,513 toilets were replaced using this conservation initiative and according to SAWS, as of 2012 240,000 toilets have been replaced in commercial and residential settings (Ramos 2002) (SAWS 2012). In a study done in 2002 the overall effectiveness of this program was determined. The author analyzed a total of 550 customers (households) reflecting a 17.3-gallon per person savings per day within a 120 day period (winter months). This conclusion was held up in comparison to earlier studies done by Gregg and Curry (1995) finding average savings being 17.3 gallons (Ramos 2002). Using this average Ramos calculated a total of 4,200 gallons saved per capita annually (2002).

Another productive program the San Antonio Water System implemented in the past twenty years was their Home Check-up program. This program educates residents on how to reduce both indoor and outdoor water use. The primary goals of this program were to identify leaks in plumbing and irrigation systems, recommend changes to plumbing and landscape practices to reduce water demand, and give educational material as well as water efficient shower-heads and faucet aerators (SAWS 2012).

Table 3. SAWS' conservation measures (SAWS 2012) (Ramos 2002)			
Program	Method of Conservation	Customers Assisted	Average Water Savings Per Customer (Gallons Per Year)
Plumbers to People (1994)	Showers/Sinks/Toilets/Water Heaters/Pipes	8,383	59,000
Home Check-up (2000)	Landscape conservation	2,500	67,200
Toilet Rebate Program ("kick-the-can")	Total toilet flush consumption	550*	13,000

*represents study group (Ramos 2002)

Rainwater Harvesting

A method of water conservation that many communities have adopted has been rainwater harvesting. Municipalities have established certain incentives in adding rainwater collection barrels on residential properties as a way to minimize landscape water use (contributing to about 50 to 80 percent of residential water use in summer months (TWDB 2008)). Unfortunately, these incentives have fallen far short of effective water saving alternatives. These incentives have been designed to curve the cost of rain barrels (50 gallon) rather than realistic collection systems needed for areas that experience infrequent and relatively extreme rain events. As stated in the Texas Water

Development Board's (TWDB) *Handbook of Rainwater Harvesting,* home owners who decide on collecting their own rainwater are claiming responsibility of their own water supply system (2005). The maintenance, installation, and general use of the water collected are in the hands of the homeowner and thus require certain levels of responsibility and knowledge of appropriate uses. These maintenance requirements are not unprecedented with many newly constructed homes inside Hays County.

An analysis of rainwater harvesting's (RWH) effectiveness for outdoor landscape watering was done by Kirk Shoppe in 2008. His study demonstrated that RWH could sustain xeriscaping for most years for an average sized suburban residence (Shoppe and Earl 2008). This study provides an example of the flexibility this conservation measure can provide in deciding the best application for various households and budgets.

Between 2004 and 2009, new home construction in Hays County was approximately four times the state average (city-data.com 2013). Many of these homes are required by law to own and maintain septic systems. Some (aerobic) require a maintenance permit by the homeowner or proof of a contracted maintenance provider (TCEQ-Edwards Rules). Thus, implementation of similar requirements for water conservation would be similarly or even less burdensome to overall benefits of such household practices.

Summary of Right-Sized Rainwater Harvesting Facilities

The Meadows Center for Water and the Environment in conjunction with Texas Water Development Board conducted an analysis of rainwater harvesting (RWH) infrastructure for specific model cities as well as a determination of a house-hold "right-sized" harvesting system (Venhuizen 2013). An important variable in the use of rainwater is the ability to determine the smallest RWH system roof-print and cistern capacity to maintain a viable water supply. Successful use of a RWH system requires reducing use during droughts. Failure to do so requires purchasing outside water from private water haulers. If household demand exceeds the possible supply for any given right-sized rainwater harvesting system then cost must reflect the supplemental water provider.

When distinguishing between various square foot roof-print on any given structure, the number of inhabitants not only reflects average use but the projected size of the roof-print the family depends. For example, a single story home with 3-4 bedrooms plus a garage would, on average, provide approximately a 3,500 ft^2 roof-print. With a year with average precipitation such a system would provide approximately 70,000 gallons. However, a family of four using 70 gallons per capita daily (GPCD) would be sufficient for only 250 days, which demonstrates the need for supplemental water or means to stretch that water supply. Dramatic decreases in GPCD would reduce this shortfall. Another option would be reusing graywater from the washing machine, showers, and bathroom sinks.

Graywater Reuse

Reusing wastewater from showers, sinks, and washing machines is not a new idea, but many people are hesitant to reuse graywater due to the potential presence of pathogens, and other hazardous chemicals. Wastewater is divided into two categories; graywater and black water. Black water from kitchen sinks and toilets is considered most hazardous due to its higher nutrient, solids, and pathogen content. Graywater is wastewater from showers, bathtubs, washing machines and lavatory sinks (Texas Water Savers 1998). According to Bill Hoffman, chief of the Water Conservation Section of the

Texas Water Development Board (TWDB), graywater volume in the state of Texas is predicted to reach more than 1.3 billion gallons per day in 2050, which works out to approximately 35 GPCD (Texas Water Savers 1998).

In addition to naturally occurring aspects of our waste, harmful cleaning agents can cause issues with our environmental and public health. Commercial products used in the household also contribute to insecurity of graywater reuse. Xenobiotic organic compounds (XOCs) could be expected to be present in graywater due to household use of chemical product in shampoos, perfumes, preservatives, dyes and cleaners. At least 900 different organic chemical substances and compounds can be listed as being likely to exist in domestic graywater (Eriksson 2001). Accepting the risks of such contaminants requires that homeowners accept responsibility for the products they use and dispose of. One unexpected benefit from such water use may simultaneously decrease the demand for such harmful products.

In order to eliminate issues of harmful pollutants, many domestic graywater systems include an on-site filtration system. Whether it is a constructed wetland or an in-home filter system, some of these pollutants can be controlled. Due to safety concerns for reuse of graywater, there has yet to be a documented case in which an individual has suffered from reuse of graywater (Waggett 2004).

According to Chapter 210.81-85 of the TCEQ's description of "Use of Reclaimed Water: Use of Graywater Systems," fecal contaminants must be kept in low to absent concentration for the water to be reused. In order for a system to reuse graywater in irrigation or operation that has a low probability of coming in contact with people, fecal coliforms must be kept at 200-800 colony forming units (CFU) per 100 ml. This contributes to a majority of the suggested reuse of graywater, aside from use in toilet flushing. One study identified storage of the lightly polluted waters increasing its fecal coliform quantity (Liu 2009). In graywater reuse inside the home, like toilet flushing, fecal coliforms must be kept at 20-75 CFU per 100 ml (TCEQ 1997). Such regulations are important in insuring the health and safety of the public. Most graywater has low pathogen levels excluding water used to wash dirty diapers. These potential hazards have been identified and observed on a large scale (Jefferson 2004).

According to Texas Water Code Section (TWC) 26.0311, graywater reuse is a reasonable water conservation method, yet must follow strict guidelines. The proposed amendments to graywater reuse were considered beneficial to the public and water conservation, as well as reduce homeowner's water bills and lower demands on waste water systems (TCEQ 1997). Also, the amendments were found "not subject" to Texas Government Code Sec. 2001.0225, the "Major Environmental Rule," which is, "a rule to protect the environment or reduce risks to human health from environment (TCEQ 1997)." Both the TWC Sec. 26.0311 and Texas Administrative Code (TAC) rule 285.80, clarify the definition of graywater and its appropriate genesis being from parts of the home other than simply clothes-washing machines. The TWC now includes baths, showers, and lavatory sinks as appropriate sources of graywater (TCEQ 1997).

The Texas Health and Safety Code (THSC) Sec 341.039 defines the safety guidelines for installation, maintenance and use of graywater inside and outside the home, specifically placing emphasis on plumbing and domestic safety (TCEQ 1997). According to Chapter 285 of the TAC, "so long as wastewater (black water and graywater) is treated to secondary quality effluent standards," having 200-800 CFUs "it may be used for surface irrigation (TCEQ 1997)." The TCEQ's regulations state that residential laundry washing machines may discharge directly onto the ground surface if the discharge does not create a public health nuisance, the area is supported with plant growth and is limited access, water used in cleaning soiled diapers may not be discharged, water may not pool nor run off, and a lint trap must be installed at the end of the discharge pipe (Texas Water Savers 1998). These standards are concepts needed to protect, not only the owners of the property, but the builders and plumbers installing such systems. Without understanding the codes, these professionals could cause health issues and potentially be prevented from creating a more adaptive, efficient model for future installations.

When discussing design features of a home, builders often offer clients an auxiliary drain line for the washing machine. Charles Hanks, of Premier Custom Homes in San Antonio, stated that about 80 percent of his custom-home clients choose such a feature (Texas Water Savers 1998). This can also include a dual piped system with graywater and air conditioner condensate routed to a storage tank, and black water to the sanitary sewer or septic system. From the storage tank, graywater is pumped to an automated pressurized dosed subsurface drip irrigation system, which waters the lawn or landscape and simultaneously moistens the soil around the foundation to prevent cracking in expansive soils, known as "Grayscaping". This type of graywater reuse system could reduce the homeowner's water costs by about 50 percent (Texas Water Savers 1998). Other proposed actions include a San Diego city councilman's proposal for a "Showers-to-Flower" alternative rather than utilizing a "Toilet to Tap" program that would be very unpopular. Such actions have incentives for graywater systems for both homeowners and developers such as discounted connection fees (Texas Water Savers 1998). These alternatives are intended to limit use of potable water, and the energy and infrastructure required to provide such a resource.

CHAPTER III

METHODOLOGY

The purpose of this thesis will be to conduct an analysis of three basic water conservation models in a residential setting based on their economic feasibility through the cost of installation and maintenance, and benefits of their water conservation effectiveness. My research question will be; which of these three, water conservation methods can enhance the sustainability of our water supply; (1) historical conservation measures with incentivized and sponsored water-wise practices based on the San Antonio Water Service's (SAWS) case studies; (a) Plumbers-to-People program, (b) Home Check-up program, and (c) Toilet Replacement program; (2) rainwater harvesting for supplemental use inside and outside the home, and (3) graywater reuse for supplemental use inside and outside the home? With comparisons between the economic viability of these specific conservation alternatives, a model can postpone the costly water need for supply alternatives and assist in alleviating the depletion of the regional water supply.

By conducting such an analysis of alternative forms of water conservation the results can open a discussion of a more sustainable approaches to our water issues. Such economic data can shed light on a few of the overlooked conservation methods used amongst water-wise consumers.

The questions I will pursue:

1. In what ways can San Marcos, TX enhance its water supply without having to resort to expensive, non-sustainable alternatives?

2. Are water conservation methods such as, rainwater harvesting or graywater reuse an economically viable alternative compared to current water conservation approaches for municipal supply?
3. How much can, rainwater harvesting and graywater reuse provide a typical residential home?

Comparisons should consider opportunity costs and social benefits that are difficult to accurately measure (Chen 2009). This provides additional reasoning this analysis. Providing a comprehensive analyzed analysis of unforeseen variables for future supply and demand can be analyzed. Additionally, ecological impacts of water use can be implemented in research criteria. To presume such methods can solve the city's water problems would be unrealistic due to the city now growing at such a rapid rate. Instead, common approaches to water supply include a variety of conservation methods. Thus, this analysis will compare residential conservation approaches with the hope that a need for additional supplies may be postponed.

Methodological Design

In order to appropriately provide a community with an adequate water supply, careful calculations must be made using current and past trends. This data will be gathered using federal and state agencies such as The Texas Water Development Board (TWDB), Texas Commission on Environmental Quality (TCEQ), National Climatic Data Center (NCDC), U.S. Geological Survey (USGS), The Environmental Protection Agency (EPA), and The U.S. Census Bureau. Using these public resources an accurate level of water use and distribution can be compiled. Here the level of implementation viability for any one conservation method will be based on its physical and economic constraints in providing a water resource.

This study is subject to several variables in order to assess the most sustainable way of procuring such a resource. These will include regional precipitation rates, fluctuating water consumption habits, current market value for installation and maintenance, and the legal constraints certain methods must adhere to. According to the TWDB (2013) average per capita water use for San Marcos, TX averages 124 gallons of municipally supplied water per day. Cost estimates will be compiled by average market price of various storage, treatment and maintenance methods.

Table 4. San Marcos Housing Data 2008-2012 (US Census Bureau 2012)

Housing units	18,179
Households	16,281
Homeownership rate	27.9 %
Multi-unit housing structures (percent of total)	62.5 %
Single family housing units	6,817
Estimated owner-occupied households in San Marcos	**1,900**

To properly define the households that would potentially participate in one of the potential conservation initiatives analyzed, understanding the percentage of owner-occupied households in San Marcos is important. Due to a high number of transient individuals, mostly students of Texas State University, the estimated number of owner-occupied home is 1,900 (Table 4) (US Census Bureau 2012). This number will be used to estimate the reduction of overall municipal water demand after the variety of methods are assessed.

<u>Definitions and Measurements</u>

Table 5. Measurements of Analysis (Shields 1998)	
BENEFITS:	**MEASURMENTS:**
Direct Benefits	
Reduction in house hold municipal water use	Total per capita water use per day of households within areas with SAWS water conservation approaches, rainwater harvesting, and graywater reuse.
Reduction in utility costs for consumers	Monthly utility costs for different conservation methods
Reduction of need for additional water sources	Subtracts saved water amounts from current and projected water use.
Indirect Benefits	
Increased future water security	Reduction of residential needs from calculations can determine lower future demand.
Costs	

Table 5 Continued.	
Installation costs	Price of materials: storage cost; rain harvesting cisterns/barrels, infrastructure costs, filtration and pumping; graywater reuse storage and treatment for legal residential use based of the whole-life cost model (Memon, 2005).
Maintenance costs	Cost per unit volume
Cost of implementation of newly established water conservation systems	Based on numbers collected from literature and market research
Cost of maintenance for the individual or municipality	a) Basic filtration mechanisms (cost comparisons and frequency of replacements). (b) Water quality data analysis of human proximity to storage and treatment
Physical amount of water conserved in relation to the input required in various conservation method	With appropriate ecological impact presented as non-monetary variable

Methods of Data Collection

Rainwater Harvesting

In order to assess the appropriateness of conservation methods, certain assumptions and measurements must be made. With collecting rainwater from a residential property, the footprint of the building provides the surface area of catchment, rather than the square footage of the roof surface. According to the Chicago Tribune (2012) and TWDB (2005), the average size of an American home is about 2,500 square feet. Assuming, at minimum, homes with installed rainwater harvesting systems have a footprint of 2,500 square feet, the volume of water can be calculated using precipitation data. In San Marcos, average annual precipitation can vary dramatically (Figure 3). I will use the average 37.19 inches of annual precipitation, as well as an estimated drought value of 18.60 inches or half of the yearly average, to accurately predict total catchment potential (NCDC 2013). The drought value used is realistically based upon the recent records of approximately 15 inches in 2008 and 19 inches in 2011 (USNCDC 2014). Using this method I can appropriately adjust water expectations in an almost worst-case scenario.

Once surface area and volume is collected a runoff coefficient of approximately .6, representing an approximate volume of .6 gallons of water per square foot of area per one inch of precipitation, can be applied (TWDB 2005).

$$V_1=V(.6)$$

After a total volume is calculated then a system efficiency of 75 to 90 percent, based on manufacturing and installation quality, can be applied. I will be using an 80 percent efficiency coefficient (TWDB 2005).

$$V_2=V_1(.8)$$

Using this process I can assume water availability in any given month in average rainfall and drought conditions.

Installation/Maintenance

Table 6. Rainwater Harvesting Cistern/Barrel Costs (TWDB 2005)			
	Cost	**Size**	**Comments**
Fiberglass	$0.50–2.00/gallon	500–20,000 gallons	Can last for decades w/out deterioration; easily repaired; can be painted
Concrete	$0.30–1.25/gallon	Usually 10,000 gallons or more	Risks of cracks and leaks but these are easily repaired; immobile; smell and taste of water sometimes affected but the tank can be retrofitted with a plastic liner
Metal	$0.50–1.50/gallon	150–2,500 gallons	Lightweight and easily transported; rusting and leaching of zinc can pose a problem but this can be mitigated with a potable approved liner
Polypropylene	$0.35–1.00/gallon	300–10,000 gallons	Durable and lightweight; black tanks result in warmer water if tank is exposed to sunlight; clear/translucent tanks foster algae growth
Wood	$2.00/gallon	700–50,000 gallons	Aesthetically pleasing, sometimes preferable in public areas and residential neighborhoods
Polyethylene	$0.74–1.67/gallon	300–5,000 gallons	
Welded Steel	$0.80–$4.00/gallon	30,000–1 million gallons	
Rain Barrel	$100	55–100 gallons	Avoid barrels that contain toxic materials; add screens for mosquitoes

Table 7. Gutter Costs (TWDB 2005)		
	Cost	**Comments**
Vinyl	$.30/foot	Easy to install and attach

Table 7 Continued.		
Plastic	$.30/foot	Leaking, warping and breaking are common problems
Aluminum	$3.50-6.25/foot	Must be professionally installed
Galvalume	$9-12/foot	Mixture of aluminum and galvanized steel; must be professionally installed

Table 8. Pump and Pressurization (TWDB 2005)		
	Cost	**Comments**
Grundfos MQ Water Supply System	$385-600	Does not require a separate pressure tank
Shallow Well Jet Pump or Multi-Stage Centrifugal Pump	$300-600	These require a separate pressure tank
Pressure Tank	$200-500	Galvanized tanks are cheaper than bladder tanks but often become waterlogged, which will wear out the pump more rapidly

Table 9. Filters and Disinfectants (TWDB 2005)				
	Cost	**Maintenance**	**Effectiveness**	**Comments**
Cartridge Filter	$20-60	Filter must be changed regularly	Removes particles >3 microns	A disinfection treatment is also recommended
Reverse Osmosis Filter	$400-1500	Change filter when clogged (depends on the turbidity)	Removes particles >0.001 microns	A disinfection treatment is also recommended

Table 9 Continued.				
UV Light Disinfection	$350-1000; $80 to replace UV bulb	Change UV bulb every 10,000 hours or 14 months; the protective cover must be cleaned.	Disinfects filtered water provided there are <1,000 coliforms per 100 milliliter	Water must be filtered prior to exposure for maximum effectiveness
Ozone Disinfection	$700-2600	Effectiveness must be monitored with frequent testing or an in-line monitor ($1,200 or more)	Less effective in high turbidity, can be improved with pre-filtering	Requires a pump to circulate the ozone molecules
Chlorine Disinfection	$1/month manual dose or a $600-$3000 automatic self-dosing system	Monthly dose applied manually	High turbidity requires a higher concentration or prolonged exposure but this can be mitigated by pre-filtering	Excessive chlorination may be linked to negative health

The benefits totals found in the rainwater harvesting (RWH) method were produced by data collected by TWDB, USNCDC, and the US Census Bureau. By calculating the below equations we can project estimated water reduction by the offset harvested with a "Right-Sized" RWH system where; improved GPCD with RWH installation = t; average GPCD = a; number of individuals in household= i; annual household water use = w; and total water harvested in an average year = h.

$$t=((w-h)/365)/i$$

$$w=(i*a)365$$

Table 10. Rain Water Harvesting Supply and Demand		
Roof Footprint	2500 ft^2	3500 ft^2
Precipitation	37.2 in	37.2 in
Drought (50 % reduction)	18.6 in	18.6 in

Table 10 Continued.		
Number of People	2	4
Average Demand	124 GPCD	124 GPCD
Total Annual Demand (per household)	89,800 gal	135,500 gal
Total Harvested in an Average year	46,000 gal	64,500 gal
Total Harvested in a Drought year	23,000 gal	32,500 gal
Improved GPCD with RWH installation (average year)	60 gal*	65 gal*

*see equation

In Table 10 the comparative use an average household would reduce if implementing a RWH system were presented. Assuming average rainfall to be present both households could drastically reduce their per capita water demand. If one can assume certain municipal ordinances or volunteer conservation habits would be implemented in a year of drought, we could potentially see similar demand reductions.

Cost

The most costly investment for a home conservation system would be rainwater harvesting. To adequately use your roof-runoff for any practical purposes a 10,000-gallon rainwater harvesting storage system complete with pumping, sterilization and installation would expect to cost approximately $27,800. This would in effect save each household over 46,000 gallons annually (Table 11).

Table 11. RWH Cost for 2 person home	
Material	Cost
Gutter Costs (Aluminum)	$12,500
Storage Costs (Polyethylene)	$10,000
Pressurization Costs (Grundfos MQ)	$500

Table 11 Continued.	
Maintenance Costs for 10 years (including sterilization)	$4,800
Total	**$27,800**
Total for outdoor use only*	**$23,000**

*no sterilization

Table 11 shows expected costs in installation of a RWH system. Two totals display the reduction of costs if one decides to use collected water for outdoor use only. Outdoor use is one of the most popular applications for this conservation method because it reduces the cost of installation and maintenance as well as provides flexibility for the amount collected.

Additionally, a majority of the costs displayed represent gutter installation. This is not necessary for every household, and would reduce overall costs by almost 50 percent, but the system would still cost more than $10,000.

One method not specifically analyzed in relation to rainwater harvesting is the implementation of small-scale, 50-gallon barrels for residential-outdoor use only. The City of San Marcos does currently provide an incentivized program for these catchment alternatives. This program provides a 50 percent rebate on up to 2 barrels per household. Provided in Table 12 below is the price calculation per acre-foot in an average San Marcos residence.

Table 12. 50-gallon barrel analysis	
Footprint of Home	2,500 ft^2
Days of Precipitation per year with ≥ 0.50 in. (Average year)	22.5 days

Table 12 Continued.	
Total Captured	11,250 gallons
Price Per Acre-foot (incentivized $33.50 per barrel)	$970*

*Price does not include gutter cost

As mentioned earlier, the primary reasoning for not analyzing rain barrels with other conservation alternatives is primarily due to the unrealistic solution it provides. These barrels can provide small amounts of relief in outdoor watering but cannot be fully relied upon in San Marcos and other areas in the region that receive such volatile rain events (Figure 2). In addition, we are particularly looking at how rainwater harvesting can provide a conservation alternative for general household use, not specifically outdoor watering.

Graywater Reuse: Installation/Maintenance

Because reuse of domestic graywater is not supplying additional resources, but maximizing efficiency, a simple estimation of various applications can give an understanding of how viable this model is. For example, since indoor water use is approximately 75 gallons per person per day and toilet flushing is the source of 26.7 percent of that use, toilets use over 20 GPCD (EPA 2008). If proper plumbing is introduced to a household, graywater reuse strictly on toilet flushing can decrease average water requirements by over 15 percent.

Design criteria of implementing graywater systems must then be categorized by level of use. Installation and maintenance costs will increase as reuse is implemented.

Thus, the analysis for graywater must be based on the extensiveness of its design (Memon, 2005).

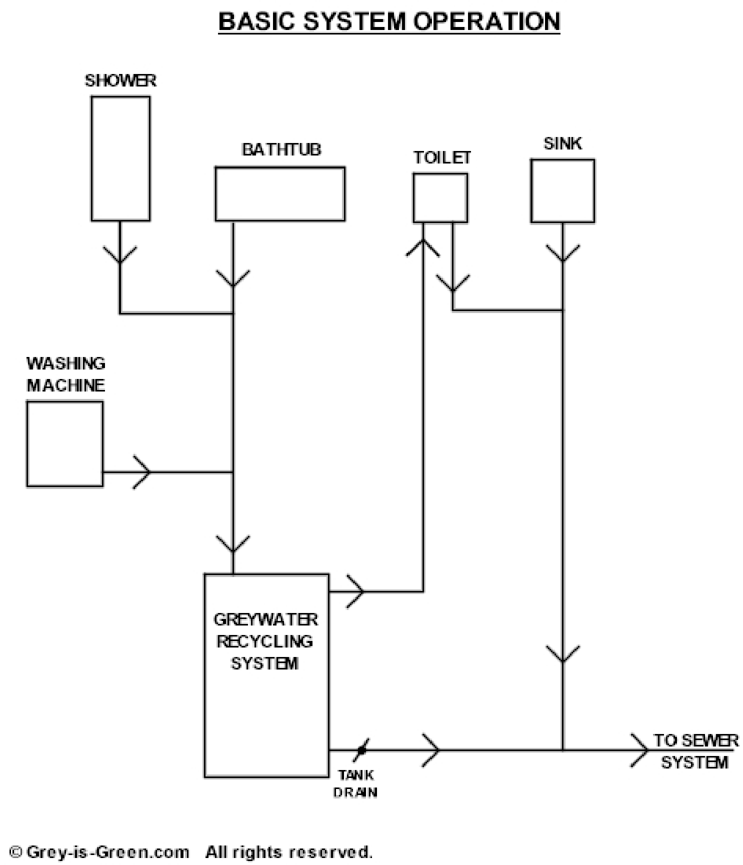

Figure 4: Basic in-house system operation (Grey-is-Green.com 2014)

Table 13. Whole-Life Cost Modules (Memon 2005)			
Module	**Reasoning**	**Measurement**	**Scale**
Input Module	Necessary for defining scale of reuse	Single, Medium, and Large household scale	Scale is based on the assumed average number of residents.
Water Flow Module	Generates a input cost calculation and quantifies water saving potential	1.$T_{bv}=b_vDF_bN_r$ 2.$T_{sv}=S_vDF_sN_r$ 3.$T_{hv}=h_vDF_hN_r$ 4.$TGW_v=(T_{bv}+T_{sv}+T_{hv})/1000$ 5.$TWC_v=(WC_vDF_{wc}N_r)/1000$ 6.$W_s=TWC_vE_r$	Volume sources are measured by bathing, showering and hand washing only.

Table 13 Continued.			
Cost Quantification Module	Net cost of a graywater reuse system	1. $C=C_{cons}+C_{energy}+C_{aim}$ 2. $C_{cons}=C_{ch}(1+i_{ch}t)W_s$ 3. $C_{energy}=C_{en}(1+i_c t)W_s$ 4. $C_{aim}=\beta n t_{aim}$ 5. $S=(w_p+s_{wp})W_s$	Capital cost, regular and unplanned maintenance, operation costs

T_{bv} is the total bath volume (g/day); T_{sv} is the total shower volume (g/day); T_{hv} is the total hand washing volume (g/day). b_v is the bath volume (g/use); S_v is the shower volume (g/use); h_v is the hand washing volume (g/use). F_b is the frequency of baths (uses/person/day); F_s is the frequency of showers (uses/person/day); F_h is the frequency of hand washing (uses/person/day). N_r is the number of residents and D is the average number of days per year when graywater is produced (Memon, 2005).

TGW_v is the total graywater quantity required for toilet flushing; WC_v flush volume and F_{wc} is frequency of use. W_s is the net volume of water saved. E_r is the coefficient indicating the effectiveness of a graywater reuse system (where 1 is working perfectly and 0 is not at all) (Memon, 2005).

C_{cons} is the total consumables (disinfectants, filters cost ($/year); C_{energy} is the total energy cost ($/year);$C_{aim}$ is the initial consumable s cost at t=0; C_{en} is the initial energy cost at t=0; i_{ch} is the percentage increase in consumable cost per year (%); i_e is the percentage increase in energy cost per year (%); β is the inspection/ maintenance personnel charges ($/hour); n is the number of maintenance sessions per year; and t_{aim} is the duration of each maintenance session (Memon, 2005).

S is the volume of water saved and is calculated as a function of water price (w_p) and S_{wp} is reduction in wastewater disposal (Memon, 2005).

Treated graywater for toilet flushing and or outdoor landscape use is a considerable water saving technique (Memon 2005). A main reason for lack of adoption is the perception of high cost/benefit ratio. The following model assesses the cost of graywater reuse using the whole-life cost (WLC) financial technique, arguably the most representative technique for graywater reuse (Memon 2005). The total was found by the equation below where improved GPCD with RWH installation is t; average GPCD is a; number of individuals in household is I; annual household water use is w; total harvested in an average year is h.

$$t=((w-h)/365)/i$$

$$w=(i*a)365$$

Table 14. Graywater Cost Calculator (Gray-is-Green.com 2014)		
Input Module	Medium (2-3 individuals)	Large (4+ individuals)
Water Flow Module (48.3%) E_r=.8	(2) 35,000 gal annually	(4) 70,000
Cost Quantification Module (maintenance) over 10 years	$250	$500
Construction Cost	$350	$350
Improved GPCD with GW reuse installation	75 gal*	

*see equation

With implementation of a graywater reuse system in a municipal household, we can expect a 35,000-gallon savings annually. If such a system were established, the cost would be approximately $850 (depending on system demand).

CHAPTER IV

RESULTS AND DISCUSSION

This study provides useful information for future decision making on providing appropriate water resource infrastructure. In incorporating a more sustainable public policy on the municipal level, cities can retroactively prepare for rises in population and extreme weather patterns. For San Marcos, a decision on proper water distribution is of utmost importance.

To categorize the most appropriate water conservation method, a comparison of cost per acre-foot (AF) averaged over the 10-year period, described earlier, will be used. By compiling the estimated costs per customer for implementation and maintenance over the life of the application, a total cost can be projected per generic unit of water resource measurement. Below is the equation used to find our estimated cost per AF averaged over 10 years. Where estimated cost per AF averaged over 10 years is T; projected cost per customer (household) is P; water saved per customer per year is W; and water saved over the projected 10 year period is W_1.

$$W_1 = (W*10)/325,850$$

$$T = P/W_1$$

Table 15: Analysis (SAWS 2012) (Ramos 2002) (TWDB 2005)				
Conservation Method-Low Cost	**Projected Cost per Customer**	**Water Saved Per Customer Per Year**	**Water Saved over a 10 years**	**Estimated cost per AF Averaged over 10 years**
Plumbers to People	$480	59,000 gal	1.8 AF	$250
Home Check-up	$110	67,200 gal	2 AF	$55
Toilet Replacement	$340*	13,000 gal	0.4 AF	$850
Water Conservation Average	$310	46,400 gal	1.4 AF	$220
Rainwater Harvesting	$27,800	46,000	1.4 AF	$19,000
Graywater Reuse**	$600	35,000	1.1 AF	$550

*average customer replaced 1.9 toilets (Ramos 2002)

**Based on 2 individual household

We can observe a relatively consistent level of water projected to be saved over the life of the systems proposed, but a drastic contrast in level of financial investment. Comparisons between the three systems leave the average of the SAWS water conservation methods the most cost-effective method in a residential setting. Graywater reuse, though not the most cost-effective, does promote satisfactory results in reducing overall use and managing waste more sustainably, while rainwater harvesting is found far too expensive yet provides the most benefit and autonomy within the home. This is found by not solely encouraging conservation and reducing demand, but also providing an independent supply of water.

The following conclusions from the results define appropriate policy implementation for San Marcos, TX and the future of their water conservation endeavors.

1. In what ways can San Marcos, TX enhance it's water supply without having to resort to expensive, non-sustainable alternatives?

The most cost-effective method would be to initiate water conservation alternatives based on example used by the San Antonio Water System (SAWS). Their progressive initiatives have proven to be some of the most effective ways in reducing overall municipal demand and giving any stressed region a path to more sustainable water use.

2. Are water conservation models such as, rainwater harvesting or graywater reuse, an economically viable alternative compared to current water conservation approaches for municipal supply?

Whole home rainwater harvesting is not an economically viable alternative to traditional water supply infrastructure. However, rain barrels can provide a relatively cost effective supplemental landscaping water supply if the home already has rain gutters. Graywater reuse has costs comparable to other water conservation options and is viable when compared to new water sources.

3. How much can, rainwater harvesting and graywater reuse provide a typical residential home?

In an average residential household in San Marcos, installation of a rainwater harvesting system has the potential to save over 45,000 gallons annually while reuse of graywater can save an estimated 35,000 gallons annually. More importantly, these methods could reduce overall residential demand by almost half (Table 10 and 14).

It is important to consider the price averaged over our 10-year return on investment and how it compares between all three methods. It would be safe to assume installation of a large-scale rainwater harvesting system would be expected to last 10 years without major repairs, but it would be appropriate, as discussed below, to expect additional investment necessary in implementing programs similar to those SAWS has successfully implemented.

Future Research

Future study recommendations would include an analysis of longevity of various systems. This study's 10-year period for averaging cost over the life of the system reflected a confidence in homeownership duration. It would be necessary for future research to be done to provide data for specific program longevity. For example, one can safely assume that the life of a plumbing program may differ in longevity compared to a rainwater harvesting system.

Additionally, a more powerful discussion using a cost-benefit analysis may be appropriate. By averaging over a 10-year period we did not take into account a discount rate nor did we run life-cycle costing. Using both of these methods could provide a more accurate understand of true costs over the life of the system. In considering such a method one could take into account the purpose of the study at hand as a comparative analysis and not a public financial report. The primary purpose is to specifically understand the best conservation alternative for San Marcos, TX. Further financial analysis would be most appropriate to decide implementation of a chosen program among the three analyzed in this study.

CHAPTER V

POLICY RECOMMENDATIONS AND CONCLUSION

For this study in particular, the analysis was designed to reflect the most cost effective conservation method for the City of San Marcos residents. Yet, it is worth pursuing the potential for an integrated approach to these independently successful conservation methods on new construction and even renovated housing.

In order to properly identify the most sustainable approach to provide a reliable, and cost effective water resource to households, in any city, careful analysis of multiple variables are required. For sustainability purposes one must distinguish between what is generally accepted as necessary costs, and what costs are beyond reasonable calculation. Essentially, individuals must ask how much water they are willing to take out of the system. Whether surface or groundwater the influences may be more costly than predicted. In approaching public policy with a sustainability approach to any necessary natural resource our modern society depends upon, the question of self-sufficiency should be discussed.

This study primarily focused on in-house water supply and did not analyze the water savings that could be achieved through landscape water conservation measures. Most cities in the region have active landscape conservation programs that involve replacing water demanding traditional landscape plants with less water demanding dry-region plants (xeriscaping). Most cities have ordinances that restrict the time of day and day of the week that landscaping can be watered. Finally, some cities have requirements that all irrigation systems must be provided with moisture or rain sensors that override the automatic system when irrigation is not necessary.

Perceiving the home as an independent unit, providing many of the resources our municipal infrastructure provides, we could bridge the gap between conservation as a habitual hurdle for residents to adopt, to a physical necessity. In addition, the apprehension towards mandated conservation measures, which consumes the majority of the debate against universal policy adoption, could be inadvertently eliminated through simple supply issues. If a household was unable to produce or reuse enough water to sustain a landscape of their choice, then that resident would be inclined to install more drought tolerant vegetation on their property or abandon a landscaping option.

Traditionally, some of the more progressive conservation methods have seen opposition by a variety of institutions. Specifically, Home Owners Associations (HOA's) have long opposed alternative supplies and, most definitely, reuse of water by imposing aesthetic guidelines that neighborhood residences must follow. The level of power HOAs wield on homeowners is substantial but have seen some recent reforms through court rulings.

Furthermore, the implications of wise municipal planning can move wiser use of regional water supplies to a more sustainable level. Generally Texas is seeing staggering projections for future water shortages. Nowhere has more to lose than the IH-35 corridor. These rapidly growing cities of our state are fighting the policy battles of providing a cheap, reliable source of water to rising populations, while simultaneously attempting to mitigate the impact of that use on our natural systems.

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