VIABILITY OF RAINWATER CATCHMENT SYSTEMS: ESTIMATES FOR THE SAN ANTONIO, TEXAS WATER SYSTEMS

THESIS

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Page

CHAPTER I

THE PROBLEM AND ITS SETTING

San Antonio is the largest city in the United States to historically rely upon a sole groundwater source for all of its water resource needs (Grubb n.d.). However, with a projected doubling of their population by 2050 (TWDB 2002) and restrictions on pumping from the Edwards Aquifer, as mandated by the State of Texas, San Antonio water purveyors must seek additional water resources for the first time. The projected plans of San Antonio Water Systems (SAWS) include inter-basin transfers from the Lower Colorado River Authority (LCRA) and the Guadalupe-Blanco River Authority (GBRA), leasing of Edwards Aquifer water rights from agriculture communities, desalination and importation from coastal Texas, as well as several other strategies (SAWS 2004). Conversely, SAWS plans are likely to be challenged through protests and legal actions from their targeted source regions (Grubb n.d., 6).

Because of San Antonio's long reliance on a single source of water, an integrated approach to water resources will present a new challenge. An integrated approach to water resources is usually defined by water resource engineers as a combined system of ground and surface water for an urban central water supply system. Typically a centralized system includes a complex network of underground pipes leading to and from structures for pre and post treatments. Stormwater infrastructure is a separate complex network of pipes designed to carry, quickly and efficiently, the heaviest load of stormwater runoff from streets to rivers.

The conceptual framework of this paper looks to Coombes'and Kuczera's (2002) integration of a decentralized water cycle management approach into current centralized urban water resources systems. Integrated urban water cycle management involves employment of conservation, graywater reuse, rainwater catchment systems (RCS), and other techniques that utilize the present water cycle within the urban setting (Coombes and Kuczera 2002). This paper will work within the scope of Coombes' and Kuczera's conceptual framework and estimate through computational modeling the potential environmental viability of rooftop RCS. It will assess whether the water resources caught can be used to meet a significant percentage of the daily indoor household demand for the customers of San Antonio Water Systems.

Challenges for San Antonio and its Water Resources

Precipitation Characteristics of San Antonio, Texas

San Antonio is part of the South Central Texas Water Resource Planning Region L (Texas Water Development Board 2002). Its humid subtropical climate has a wide range of monthly precipitation, from 0 inches to a maximum of 18.07 inches. The maximum annual precipitation of 52.28 inches was recorded in 1973 while the minimum measured only 10.11 inches in 1917 (National Oceanic and Atmospheric Association 2005). The unpredictable precipitation in south central Texas often comes in sudden downpours, causing natural flooding events, which are, in turn, exacerbated by impervious cover in the urban areas. In south central Texas, it is not uncommon to get the monthly rainfall in one or two days, leaving the region dry for the remaining time. Figure 1 shows the 10th percentile, mean, and 90th percentile of precipitation based on the period of record for San Antonio. The National Weather Service provides the precipitation data from years 1871-2004, however, years 1876, 1883, and 1884 have been excluded due to missing data.

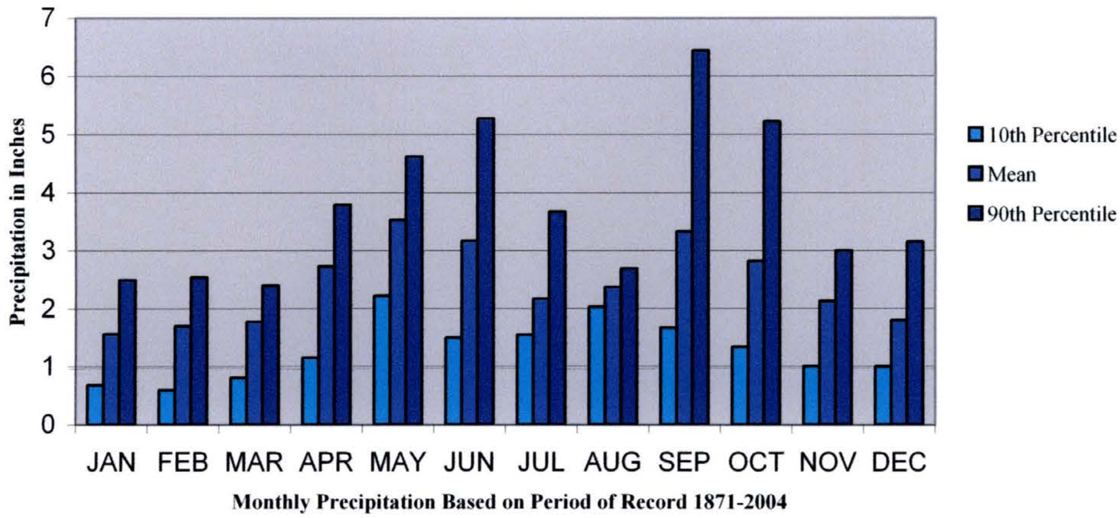


Figure 1. 10th Percentile, Mean, and 90th Percentile of Precipitation for San Antonio, TX: 1871-2004

Projected Water Resource Demands

The Texas Water Development Board (TWDB) is commissioned to plan for the future water need based on projected demand and demand location, focusing on drought-of-record conditions. Urban water resource demand is directly correlated to population growth rates; as the Texas population is projected to grow, so too must the available water resources. Currently in Texas both population and water demand are growing at unprecedented rates. Based on US census data and Texas population trends, that Texas' population is projected to nearly double by 2050 (TWDB 2002, 26). TWDB states in their *Water for Texas-2002* publication "seven percent of municipal demand would not be met by existing sources if a drought were to occur now" (TWDB 2002, 2). TWDB further states, "…if a drought occurs in 2050, almost half (43 percent) of the municipal demand could not be satisfied by current sources" (TWDB 2002, 2). The total water needs for all user groups in south central Texas by 2050 is projected at 786,000 acre-feet per year (TWDB 2002, 108). Of the user groups, thirty-seven percent of urban municipal groups will remain in need in south central Texas (TWDB 2002, 109). New water strategies for water purveyors in south central Texas, including new inter-basin transfers, new groundwater mining, and new surface water will cost an estimated $4.72 billion (TWDB 2002, 108).

Further stressing water resource issues related to San Antonio, the U.S. Department of the Interior (DOI) released in May 2003, "Water 2025: Preventing Crises and Conflict in the West." This initiative identifies regions of likely conflict potential, and suggests solutions to the impending water resource problems. "Water 2025" identifies "Five Realities" of water management that are creating the crisis we are beginning to experience in Texas and throughout the west, explosive population growth, existing water shortages, potential for conflict over water shortages, aging water facilities, and ineffective crisis management (DOI 2003). The report suggests that San Antonio will experience substantial conflicts over water resources (DOI 2003).

Edwards Aquifer in South Central Texas

The Edwards Aquifer has historically served as the sole source of water for San Antonio and a prime source of water for surrounding population centers; its springs have served as life-giving magnets for the communities that were built because of them.

Seventy-six percent of the water supply for south central Texas comes from groundwater supplies; of that, forty-six percent of the groundwater is taken from the Edwards Aquifer. The remaining major and minor aquifers, respectively, supplying south central Texas are Carrizo-Wilcox, Trinity, and Gulf Coast; and Queen City and Sparta. Rivers, streams and reservoirs make up the additional water resources for south central Texas. Surface stream reservoirs, however, make poor storage units due to high evaporation losses. For example, the net lake surface evaporation for the San Antonio River Basin is thirty-one inches annually (TWDB 2002).

The Edwards Aquifer is managed through the Edward's Aquifer Authority (EAA) created through Senate Bill 1477 in 1993. The EAA, however, did not become operational until 1996 after legal challenges were defeated (EAA 2002). The Act creating EAA directs the Authority to perform tasks that "sustain the aquifer as a natural resource, sustain the diverse economic and social interests dependent on the aquifer for water supply, protect terrestrial and aquatic life, protect domestic and municipal water supplies, and provide effective control of the Aquifer to protect the operation of existing industries and the economic development of the state" (EAA 2002, 5). In order to perform these tasks in congruence with the growing population, the EAA limits withdrawals to 450,000 acre-feet per year until January 1, 2008, when it will decrease to 400,000. By 2012 SB 1477 requires that "the continuous minimum spring flows of the Comal Springs and San Marcos Springs are to be maintained to protect endangered and threatened species to the extent required by federal law" (TWDB 2002). It is planned that 340,000 acre-feet per year until 2050 will be withdrawn from Edwards Aquifer for all of south central Texas (TWDB 2002). Although these protections are in place, the water resource is over allocated and new wells are continually being drilled by new subdivisions and individual residences.

The city of San Antonio, with 1.1 million people, is the largest population center in south central Texas (TWDB 2002). San Antonio Water System (SAWS) is the city owned water purveyor for most of urban Bexar County and currently serves 306,475 customers (SAWS 2003). In 1998, Bexar County customers of SAWS received 100% of their water from Edwards Aquifer. SAWS' withdrawals from Edwards Aquifer are permitted through the Edwards Aquifer Authority. SAWS withdrew 204,750 acre-feet in 2003, and are permitted to withdraw 208,068 acre-feet in 2004 (SAWS 2005). A study by the TWDB shows that ten to twenty percent (20,800-41,600 acre-feet) of treated water is lost through transmission (TCPS 2000, 14).

As a result of population growth and demand, the City of San Antonio and SAWS are currently seeking alternative water resources to be brought to the city from long distances. A partnership with the Lower Colorado River Authority is forming to develop a multi-million/multi-year plan to transfer water from the Colorado River to SAWS (SAWS 2003). Additionally, if water providers plan to build any reservoir in the state of Texas, it must store a minimum of 5,000 acre-feet of water (Texas Water Development Board 2002). The City of San Antonio is also researching the possibilities of desalinated water piped in from the Corpus Christi region (SAWS 2003). In any case, alternative water sources must be explored to make up the deficit of water needs of SAWS and other south central Texas water customers.

San Antonio is facing growth beyond its water resources carrying capacity; therefore they must seek water from other viable sources. While SAWS actively seeks new water sources (SAWS 2003), from anywhere but the sky, stakeholders in the targeted source region are becoming concerned. San Antonio has been classified by the Department of Interior as one of the western cities highly likely to have water resource conflicts in the next 20 years (DOI 2003). RCS may delay the need for large-scale engineering projects which in turn may decrease imminent legal actions against San Antonio from source regions and reduce their independence on the Edwards Aquifer.

The purpose of this thesis is to assess how much water can be collected from rooftops from single-family homes in the SAWS customer service area, and how much indoor water saving the rainwater can provide. Subsequently, a direct comparison of volume needed versus saved of SAWS' alternative water source projects can be made. The SAWS customer service area (Appendix A) provides an appropriate study area for this analysis in two respects: the SAWS service area includes most of the urban and suburban area within Bexar County, and direct comparisons between water resource savings and proposed alternative water resource projects can be made. This research is unique in that it will explore the viability of RCS if implemented on a large scale in an urban context. If viable, this decentralized approach utilizing domestic RCS in San Antonio, may lead to regional water security and sustainability, and reduce potential water resource conflicts.

CHAPTER II

RAINWATER CATCHMENT SYSTEMS: OUR FUTURE?

In many parts of the world water resources are in a crisis state. People's most basic need, clean water, is not always being met on a global scale. The quality and availability of water resources have the potential to biologically and politically affect community stability across the globe as water becomes scarce, polluted, and, at times, violently sought after. Current research in, and the return of the ancient practice of rainwater catchment systems (RCS) reflects the needs of humanity for a clean, reliable water source. The main purpose of RCS is simple: to provide clean water directly from the source to meet human needs. RCS, however, involve compounding effects that intertwine environmental, physical, social, population, and political themes. RCS is predominantly a developing world practice that is slowly gaining acceptance as having great potential in the developed world for supplementing current centralized water resource systems. Most importantly, RCS is a practice of human adaptation.

The comprehensive use of rainwater collection systems would have prodigious environmental impacts in urban environments and provides a means to catch water from its source. In terms of the hydrologic cycle, precipitation is our primary source of water. Lakes, rivers, and groundwater aquifers are secondary sources of freshwater that are susceptible to droughts and to contamination due in large part to terrestrial human activities. Due to atmospheric complexities, rainfall is neither consistent nor reliable, and is unpredictable in volume. Global climate regions and geology also factor into the reliability of freshwater resources. RCS bridges the gap in infrastructure for many rural residents in developing and developed countries and provides freshwater as a primary or supplemental source in many different climate settings. In developed urban settings, rainwater harvesting has the potential to decrease the runoff volume and impede the rate of flooding, decrease non-point source pollution, and improve ground infiltration. Overall environmental improvements may include river bank sustainability, aquifer recharge and sustainability, retarding of desertification by a slower release of collected water, and soil sustainability.

Once water is collected from rooftops, the water is stored. There are many types of effective storage units being used in various parts of the world that range in quality, size, structure, materials, and cost. However, the most important factor in storage is preventing any biologic contamination from occurring. Much research has taken place on water quality and filtration systems. There are several methods to ensure water quality that include first flush (discarding the first 1-2 mm of rainfall); cleaning the tank periodically; covering storage tanks to prevent contamination from frogs, lizards, mosquitoes, and other pests; and, covering the tank to reduce evaporation. RCS not only provides a clean, soft source of water, but the systems can help alleviate flooding in urban settings, lower water costs, and provide emergency drinking water in places where environmental factors warrant the need (Coombes 2002; Mitchell, Mein and McMahon 2002; Moddemeyer, Schimek, Fleming and Lilly 2003; Murase 2003).

Urban areas like San Antonio and similar cities in western United States are growing at unprecedented rates, which posses major changes in securing reliable water supplies. Most of these cities are considering costly desalination or importing water over large distances. Water conservation is key to some cities' long-term survival, but conservation of water resources alone can neither keep up with San Antonio's population growth, nor provide a new source of water. Although SAWS has reduced perecapita water use from 213 gallons per day (gpcd) in 1984 to 138 gpcd in 2003 (SAWS 2004), the savings is not sufficient to prevent the need for alternative water sources. Another concern stemming from urban growth is the increase in impermeable surfaces (roads, buildings, concrete parking lots, etc.) that prevents rainwater from infiltrating into the soil, which retards groundwater recharge and often increases flooding.

RCS from rooftops of homes and buildings will potentially provide individuals with a substantial amount of water that can be used solely as a non-potable water resource or a potable water resource after the appropriate filtration. RCS also provide a means to detain some of the rainwater to reduce the volume of flow off surfaces. RCS are not a new technology, but their evolving designs are well suited for meeting some of the many water needs of today's homes. The collection and storage of rainwater from rooftops provide water during dry periods and drought conditions which can be used for lawn irrigation, toilet flushing, and clothes washing with minimal treatment. Collection and storage can also relieve pressure on the exploited natural systems of surface and groundwater resources. RCS have been found to reduce the need for large-scale infrastructure water projects such as reservoir building and importing water over long distances, which alter watershed function and causes stress on neighboring or distant watersheds. RCS also reduce the amount of stored water lost to evaporation, and reduce storm water volume and flooding in urban areas (Coombes 2002; Mitchell, Mein and McMahon 2002; Moddemeyer, Schimek, Fleming and Lilly 2003; Murase 2003)

Some modern cities are considering decentralized water resources management systems that integrate RCS for present and future water resource needs. Because installing RCS is viewed as expensive, some cities that are considering RCS have to provide cost/benefit analyses and pilot programs to test for potential savings compared to other sources, such as imported water. Others simply have little alternative but to support a combined water resources approach due to their environment and lack of ground or surface water resources. There are a variety of ways that cities are promoting RCS by providing incentives for citizens that install RCS themselves.

Rainwater Catchment Systems in the United States: Some Case Studies

Los Angeles

The Tree People's Transagency Resources for Economic and Environmental Sustainability (T.R.E.E.S.) project was initiated in 1997 for Los Angeles, California. Climatically, Los Angeles receives 50% less annual precipitation than San Antonio, Texas; the patterns of drought and flooding, however, make the T.R.E.E.S. project very applicable to this discussion. The project brought together a team of experts in engineering, landscape architecture, building architecture, and urban forestry for four days to develop sustainable urban designs to be implemented in Los Angeles (Tree People, 1997). The primary goal was to demonstrate the benefits of integrating several sustainable features into a pilot project for the overall purpose of recreating a healthy urban micro-watershed. Designs included in-situ rainwater harvesting and xeriscaping for groundwater infiltration, tree planting to slow runoff and reduce peak urban storm flow, and rainwater cisterns to supply residential water for toilet flushing and lawn irrigation. A pilot project was implemented and is being used to showcase the concept of an integrated decentralized water resources system, to reduce demand on imported water, and to reduce the volume and impact of storm water runoff. The T.R.E.E.S. project will also be publishing cost/benefit software package that will aid policy makers and stakeholders to make informed decisions (Tree People, 2004).

Seattle, Washington

Seattle, Washington has become a strong force for the implementation of an integrated decentralized RCS policy and pilot project. In April 2002, The city's legislature adopted Resolution 30454 "…relating to the City of Seattle's interest in the beneficial reuse of wastewater and reclaimed rainwater; setting policies related to wastewater reuse and rainwater reclamation; and calling for the development of pilot projects and the full and careful study of the public health and environmental impacts of wastewater reuse and rainwater reclamation." The resolution further states under Section A. that "the city is committed to wastewater reuse and rainwater reclamation where they can serve as cost-effective and environmentally beneficial sources of water for industrial processes, sanitation and irrigation and thereby increase the security and reliability of the City's and region's drinking water supplies" (Seattle, Washington 2002). Driving this policy is the city's problem with their combined storm and wastewater sewage pipes. In heavy rainfall conditions the two systems overflow and mix resulting in contamination. Additionally, Seattle's summers tend to be mild and dry. By collecting rainfall at the household level, it is projected that water demand in peak seasons could be decreased, while plants reap the benefits of pure, untreated rainwater.

The selected homes will be retrofitted for the harvested rain to be used for toilet flushing and non-edible landscape irrigation needs. Seattle Public Works will reimburse the project homeowners of all material and installation expenses for the RCS system. At the American Rainwater Catchment Systems Association 2003 Conference, Project Manager, Steve Moddemeyer, and others of the Seattle Public Utilities presented the "Rainwater Harvest Pilot Project." They stated that urban rainwater harvesting in Seattle "shrinks the ecological footprint of those who choose to participate; water they gather will no longer be needlessly mingled with polluted sewage water or polluted stormwater; lowers water treatment costs and less impact on urban lakes and streams; combines the existing centralized and this new decentralized approach will maximize the benefits of both; and promotes greater participation among urban dwellers and promotes greater knowledge of natural systems by urban people" (Moddemeyer et al. 2003).

A preliminary investigation using GIS was conducted through the University of Washington in Seattle to determine priority basins and identify parcels for the installation of rainwater harvesting systems in Seattle. The researchers found that within their identified priority parcels, 8.85 million gallons could be captured for the study year, 1999, through rainwater harvesting systems, and found that the equivalent amount would be taken out of the stormwater runoff (Shandas 2003).

In the Business Case Analysis for the Rainwater Harvest Program, funded by the drainage fund and sewage fund, the project managers of the Seattle Public Utilities estimated the total pilot cost to be $190,500 for 24 home systems. The purpose of the pilot was to determine if developing a decentralized strategy would feasibly complement the existing centralized infrastructure system. For benefits they reported that a centralized storage unit would cost $4.20 per gallon (not including land acquisition costs), reduced operating and maintenance costs of a centralized storage unit, water savings for summer irrigation needs. In contrast, for an individual RCS the costs were estimated at $1.00 per gallon of storage, which included the cistern and installation. They, however, added that the life of the cistern is estimated at 20 years as opposed to the 50 years life cycle of a centralized system. These costs would have to be considered for the long-term viability of the city's adoption. Staff costs for the overall maintenance and inspection was also added into the overall expenses. The homeowner would conduct the maintenance once the City adopted the strategy. They concluded that the pilot should determine the long-range viability of the Rainwater Harvesting Project for the City of Seattle (Moddemeyer 2004).

San Juan Islands, Washington

The San Juan Islands in Washington State have unique conditions that, in some cases, require RCS on homes as their main water source. Engineer, Ronald Mayo (2004), provides water balance equations that homeowners use to calculate their overall collection potential and indoor water needs. Rather than having a back-up system such as a centralized water source, San Juan Islanders must truck water in when RCS are in deficit, which is quite expensive.

Rainwater Catchment Systems: Some International Examples

Germany

Many developed nations are turning to rainwater harvesting and utilization for gaining an additional water resource and reducing urban flooding. Germany has emerged as a leader in RCS technology, incentive programs, and utilization. Germany's interest in RCS began in the late 1980's due to rising water prices and the people's desire to save resources (Turton 2004). As a result of water shortages in the Frankfurt region, and flooding along the Rhine River, the Federal State of Hesse subsidized up to 90% of water saving technologies. Some areas in Germany require RCS for flood mitigation; other areas offer tax incentives to encourage installation of the systems. Approximately 100,000 varying sized units are being installed every year (Turton 2004). The low total dissolved solids in rain contributes to a reduction in the use of detergents and soaps.

Singapore

Singapore is characterized by high-rise apartment buildings reaching 12-16 stories on average. In Singapore, RCS is being considered as a complement to the existing mains. Terry Thomas reports that a study of rooftop RCS in Singapore would supply 18% of toilet flushing needs for the buildings. Although this is a small percentage of water, a study found based on the "interest and capital repayment, the rainwater component would be about 25% cheaper than the mains water it would replace" (Thomas 1998, 100).

Sumida City, Japan

Highly urbanized Japan has become a great proponent of RCS for several factors. Prone to natural disasters such as earthquakes, tsunamis, and flooding, RCS has proven to provide emergency disaster prevention, emergency water during times of shortages, and reduce the volume of water contributing to flooding. Dr. Makoto Murase, Sumida City's Chief of Rainwater Utilization Promoting Section and Vice President of the International Rainwater Catchment Systems Association (IRCSA) reports they have been promoting RCS for the past twenty years. RCS has spread throughout the city but they are currently working toward policy that would implement their best management practices. Murase's goals are to make RCS subsidized and part of the social system, to educated specialist technicians that would encourage the further development of new technologies and their integration into the built society, and to form a network of administrative, technical, architectural professionals including representatives of the general public to create a forum for the advancement of RCS and other methods that help save resources (Murase 2003).

Rainwater Catchment Systems in Australia

Peter Coombes (2002, 1.1-3) recounts a historical summary of RCS in Australia in the 19th Century. Similar to San Antonio, Texas, Sydney, Australia, first attracted settlers because of its spring known as Tank Stream. Unfortunately, Tank Stream was unreliable and responded swiftly to drought conditions by drying up periodically. In the 19th Century, most houses in the Lower Hunter region of New South Wales used collected rainwater as their sole water source. In times of drought or when fires ravaged homesteads, the citizens would call for a reliable source of water. The government's first response was the installation of standpipes (piped water source) located within public areas. The system of RCS with standpipes as a lower quality backup water supply worked well and citizens preferred the system.

In the late 1880's, the Walka water supply was completed and connected to East Maitland, New Castle for a cost of £ 350,000. The annual repayment of £ 18,000 was needed for interest and operational expenses, but citizens refused to connect to the permanent water supply and refused to pay for it. Due to serious debt from the project, the Hunter District Water Supply and Sewerage Act, 1892, required all properties to pay for the mains supply whether connected or not to ensure the government debt was repaid. (Coombes 2002, 1.1-3)

In this case, Coombes writes, "the reluctance of the community to part with their rainwater tanks had threatened the economic viability of the emerging centralized water supply paradigm. The legislated, mandatory fixed charges ensured that citizens used mains water in preference to household rainwater tanks" (Coombes 2002, 1:1-3). Therefore, Coombes suggest that RCS became practically extinct in Australia because of a fee-forced acceptance of the emerging centralized water resource system.

Yet, today, urban Australia has begun to reestablish RCS into their urban housing projects as an integrated decentralized approach to water resources. Through the efforts of local councils, RCS is gaining ground again, and systems are being used by 17 percent of Australians, and 13 percent rely 100 percent on RCS to provide their water needs (Diaper 2004, 1).

Coombes and Kuczera (2002) define the concept of integrating RCS into current centralized urban water resource systems as a decentralized water cycle management approach. Integrated urban water cycle management employs several demand-side reduction methods including conservation, graywater reuse, rainwater catchment systems (RCS), and other techniques that utilize the water cycle within the urban catchment setting (Coombes and Kuczera 2002).

The predominant research into integrated water resource management through RCS and Water Sensitive Urban Design (WSUD) comes from the work of Peter Coombes, Ph.D. from the School of Engineering, University of Newcastle, New South Wales, Australia. Coombes' dissertation, "Rainwater tanks revisited: New opportunities for urban water cycle management" describes two experiments integrating rain tanks at different levels. The Figtree Place experiment, consisting of 27 residential units, utilized WSUD including rain tanks to manage stormwater runoff and provide water for toilet flushing and hot water indoor end uses. Though Coombes reported some institutional resistance, the overall findings showed a significant savings in mains water use. The units were designed in clusters as well as the tanks, 3 of the 4 clusters experienced a 33-44 percent reduction in mains use while the remaining cluster reduced mains by 11 percent, which was found to be a malfunction of the first flush device. A first flush device, also referred to as a roof washer, is a device that directs the first amount of rainwater away from the tank storage to eliminate the majority of contaminants that may have been on the roof (Coombes 2002, 2.1-47).

The second experiment, the Maryville house, retrofitted an old, inner-city house with a RCS to replace mains water for outdoor uses, toilet flushing, and hot water. This experiment, however, was to establish water quality without the use of a first flush device with a rusted galvanized iron roof. The water heater heated the water to 55°C and much of this study looked at the rainwater quality compared to the state guidelines for potable water. A 'trickle top system' method was used for this house. When the tank was low, mains water was used to refill. The results of monitoring the performance showed that the RCS on the Maryville house reduced stormwater volumetric 39 percent and peak discharges by 86 percent, and mains volumetric demand was reduced by 52 percent (Coombes 2002, 3.1-22).

A further study of Coombes and his colleagues (n.d.) estimated water cycle infrastructure savings arising from water sensitive urban design (WSUD) source control measures. In a WSUD, RCS tanks, infiltration trenches, detention basins, and constructed wetlands are used together in housing designs and subdivisions. This report uses findings from a case study on an existing suburban region, Lower Hunter, with a population of 455,000 people. Coombes, et al. state, "Research into WSUD from the urban water cycle management perspective shows that significant economic, social and environmental benefits to the community may be derived from more efficient use of water resources and infrastructure. However, a major impediment to the use of the WSUD approach is a perception that it is expensive to implement and it has limited economic benefits" (Coombes, Kuczera, Argue, and Kalma, n.d.). In this study, they collected demographic data, simulated indoor and outdoor household water demand, compiled regional demand, and modeled the existing headwater and infrastructure systems (reservoirs, rivers, pipelines, and evaporation). Water restriction policies were considered, as well as costs for additional pipeline construction, which was estimated at $103.7 million Australian.

The results showed a reduction in piped water needs through the use of collected rainfall for hot water, lawn irrigation, and toilet flushing. With this integrated system, and an annual growth rate in the community of .9%, they could delay construction of new water supplies by up to 34 years (Coombes, Kuczera, Argue, and Kalma, n.d.).

Coombes, Kuczera, Kalma, and Argue (2002) also evaluated the benefits of source control measures at the regional scale in Cessnock, New South Wales, Australia. Cessnock has an environment similar to San Antonio, Texas, it receives 754 mm/yr or 29.7 inches of precipitation per year, and has slightly warmer temperature ranges between 48.2 ^{o} F and 118.4^{o} F with an average temperature of 75 ^{o} F. RCS were estimated to reduce their mains water use by 40.3 percent, reduce stormwater discharge by 59 percent, and reduce peak daily mains water use by 24.3 percent (Coombes et al. 2002).

A hypothetical case study, conducted by Mitchell, Mein, and McMahon (2002), for a suburban residential house block in Australia used simulated water schemes for both traditional mains water and RCS to supply hot and cold water to the bathroom, laundry, hot water to the kitchen and water for toilet flushing and garden watering. Logical tank sizing, a 4kL (1,000 gallon) sized tank was found to reduce potable mains supply by 32 percent. This savings fluctuates as precipitation (yield) and demand (indoor water use) varies (Mitchell, Mein, and McMahon 2002).

Summary

Many modern cities are realizing the benefits of RCS from added water resources and flood mitigation. RCS have been shown by several key Australian researchers to have significant impacts on water resources and stormwater runoff in settings such as

Sydney, Melbourne, Brisbane, and other urban areas in Australia. Reported benefits resulting from the implementation of RCS, as a Water Sensitive Urban Design (WSUD) (Coombes 2002; Coombes et al. n.d.; Coombes and Kuczera 2002), conclude that the collection and storage of rainwater from rooftops provide significant amounts of water throughout the year. Rainwater can be used for hot water, toilet flushing, clothes washing and lawn irrigation, and the collection and storage can relieve pressure on the exploited natural systems of surface and groundwater resources during drought conditions. RCS prolong current systems and/or reduce the need for large-scale infrastructure water projects such as reservoir building and piping water over long distances, which alter watershed function and causes stress on neighboring or distant watersheds. The research of Coombes and other prominent engineering researchers has led to national policy changes and the implementation of water sensitive urban design programs throughout Australia (Coombes 2004).

RCS have been shown by many researchers to provide several benefits to urban settings, which have led, in many cases, to policy changes and incentive marketing for RCS installation. The present research, however, is unique in that it includes a regional study, which considers a total central distribution system's estimated savings for residential units. It is expected that the findings of this research will further support the findings of researchers elsewhere that RCS are viable even in a climate such as San Antonio, and can provide a significant savings of water mains.

CHAPTER III

RESEARCH METHODOLOGY

This study analyzes the potential of RCS to meet some of San Antonio's water needs through an integrated decentralized approach to water resources based on the annual distribution of the region's precipitation. Several calculations are preformed to determine the water mains savings potential of widespread RCS for the SAWS single-family customer distribution. Water savings are estimated for single detached and mobile homes. These structures combined account for approximately 93 percent of the SAWS customer distribution and 53 percent of the total water resource demand (SAWS 2004). In addition annual rainwater collection estimates are made for three annual precipitation scenarios: the mean, 10th percentile, and 90th percentile.

The annual precipitation scenarios were derived from the period of record of precipitation for San Antonio, Texas dating from 1871- 2004, provided online by the National Weather Service (NOAA 2005). The precipitation data from years 1876, 1883, and 1884 was omitted from the study due to unreported data. The period of record was then ranked from lowest to highest annual precipitation. From the 131 years of precipitation data, the mean of the 13 driest years and 13 wettest years were calculated and represent the 10^{th} and 90^{th} percentile precipitation, respectively. The mean precipitation for San Antonio is 29 inches for the period of record, while the averaged 10^{th} and 90^{th} percentile ranked years are 16inches and 45 inches, respectively. By considering the mean, 10th, and 90th percentile precipitation scenarios, the average, worst, and best cases are represented and provide the study with a reasonable account of San Antonio's extreme precipitation variability.

Four main sections below describe the methodology for estimating input into a RCS, output or indoor water demand by sector that rainwater may potentially and reliably replace, overall SAWS potable water savings through RCS, and finally, a comparison of the overall catchment volume and the proposed SAWS water resource development projects will be made.

Rainwater Catchment Systems Input

The "Texas Guide to Rainwater Harvesting" published by the Texas Water Development Board (1997) provides an equation for a monthly balance calculation for roof top RCS. Calculations for the annual mean, 10th percentile, and 90th percentile precipitation data are based on the period of record for San Antonio, Texas provided by the National Weather Service. The roof size is considered an estimated equivalent to the footprint of a house (TWDB 1997, 7 and Banks and Heinichen 2004, 6). The footprint of a house includes the living space and any other roofed areas such as garage and deck. However, for the purpose of this research, it will be assumed that the footprint is the given square footage of living area, as provided by the U.S. Department of Housing and Urban Development (1997). Utilizing the living area for footprint, though these figures only estimate rooftop collection area, may alleviate the discrepancy between 1.5 and 2 story homes, and the lack of roofing area included for overhang, porches, and garages. The formula is described below.

Roof size X 0.8 (collection efficiency rate) X inches of monthly rainfall X 0.623 (conversion to gallons factor) = gallons collected (TWDB 1997)

The American Housing Survey for the San Antonio Metropolitan Area (AHS-SAMA) in 1995, sponsored by the U.S. Department of Housing and Urban Development and conducted by the U.S. Bureau of the Census, provides square footage of single detached and mobile homes, which is divided into square footage categories and used to determine rainwater collection potential. The proportional breakdown of the residential units from the AHS-SAMA of 1995 are maintained and transformed into the 2003 SAWS residential customer distribution (SAWS CD), which total 284,449 customers (SAWS 2004), so to estimate overall square footage of single detached and mobile residential units.

Table 1: Single Detached and Mobile Homes Square Footage for the San Antonio Water Systems Customer Distribution

Homes in Sq Ft	**Cohort of Assumed Roof Area** (ft^2)	**AHS-SAMA**	**Percent of Total**	**SAWS CD**
Less than 500	499.5	4000	1.3	2,844
500 to 749	624.5	15,400	5	14,222
750 to 999	874.5	35,600	11.4	32,712
1000 to 1499	1249.5	100,800	32.3	91,024
1500 to 1999	1749.5	77,600	24.9	71,112
2000 to 2499	2249.5	43,600	14	39,823
2500 to 2999	2749.5	18,600	6	17,067
3000 to 3999	3499.5	10,700	3.4	9,956
4000 or more	4000	5,400	1.7	5,689
Total		**311,800**	**100**	**284,449**
Median	**1500 sq ft**			

Tables 2-4 provide the collection potential in gallons by roof size group for the mean, 90th percentile and 10th percentile precipitation scenarios.

Table 2: Rainwater Collection Potential in Gallons by Roof Size Group:
Estimates Using Mean Precipitation

Month	Mean Monthly Precipitation (Period of Record) in inches	Estimated Rooftop Collection Area by Group in Gallons								
		499.5	624.5	874.5	1249.5	1749.5	2249.5	2749.5	3499.5	4000
Jan	1.56	388	486	680	972	1,360	1,749	2,138	2,721	3,110
Feb	1.70	423	529	741	1,059	1,482	1,906	2,330	2,965	3,389
Mar	1.77	441	551	771	1,102	1,543	1,984	2,426	3,087	3,529
Apr	2.73	680	850	1,190	1,700	2,380	3,061	3,741	4,762	5,443
May	3.53	879	1,099	1,539	2,198	3,078	3,958	4,837	6,157	7,037
Jun	3.17	789	993	1,382	1,974	2,764	3,554	4,344	5,529	6,320
Jul	2.17	540	675	946	2,933	1,892	2,433	2,974	3,785	4,326
Aug	2.37	590	738	1,033	1,476	2,067	2,657	3,248	4,134	4,725
Sep	3.33	829	1,037	1,451	2,074	2,904	3,733	4,563	5,808	6,639
Oct	2.82	702	878	1,229	1,756	2,459	3,162	3,864	4,919	5,622
Nov	2.13	530	663	928	1,326	1,857	2,388	2,919	3,715	4,246
Dec	1.8	448	560	785	1,121	1,570	2,018	2,467	3,140	3,589
Total	**29**	**7,239**	**9,059**	**12,675**	**19,691**	**27,570**	**32,603**	**39,851**	**50,722**	**57,975**

Table 3: Rainwater Collection Potential in Gallons by Roof Size Group:
Estimates Using 90th Percentile Precipitation

Month	90th Percentile Monthly Precipitation (Period of Record) in inches	Estimated Rooftop Collection Area by Group in Gallons								
		499.5	624.5	874.5	1249.5	1749.5	2249.5	2749.5	3499.5	4000
Jan	2.49	620	775	1,085	1,551	2,171	2,792	3,412	4,343	4,964
Feb	2.54	632	791	1,107	1,582	2,215	2,848	3,481	4,430	5,064
Mar	2.4	597	747	1,046	1,495	2,093	2,691	3,289	4,186	4,785
Apr	3.79	944	1,180	1,652	2,360	3,305	4,249	5,194	6,610	7,556
May	4.62	1,150	1,438	2,014	2,877	4,028	5,180	6,331	8,058	9,210
Jun	5.27	1,312	1,640	2,297	3,282	4,595	5,908	7,222	9,192	10,506
Jul	3.67	914	1,142	1,600	2,285	3,200	4,115	5,029	6,401	7,317
Aug	2.69	670	837	1,172	1,675	2,346	3,016	3,686	4,692	5,363
Sep	6.44	1,603	2,004	2,807	4,011	5,615	7,220	8,825	11,232	12,839
Oct	5.22	1,300	1,625	2,275	3,251	4,552	5,852	7,153	9,104	10,407
Nov	3	747	934	1,308	1,868	2,616	3,363	4,111	5,232	5,981
Dec	3.15	784	980	1,373	1,962	2,747	3,532	4,317	5,494	6,280
Total	**45.28**	**11,272**	**14,093**	**19,735**	**28,198**	**39,482**	**50,766**	**62,049**	**78,975**	**90,270**

Table 4: Rainwater Collection Potential in Gallons by Roof Size Group:
Estimates Using 10th Percentile Precipitation

Month	10th Percentile Monthly Precipitation (Period of Record) in inches	Estimated Rooftop Collection Area by Group in Gallons								
		499.5	624.5	874.5	1249.5	1749.5	2249.5	2749.5	3499.5	4000
Jan	0.68	169	212	296	423	593	762	932	1,186	1,356
Feb	0.59	147	184	257	367	514	661	809	1,029	1,176
Mar	0.81	202	252	353	504	706	908	1,110	1,413	1,615
Apr	1.15	286	358	501	716	1,003	1,289	1,576	2,006	2,293
May	2.22	553	691	968	1,383	1,936	2,489	3,042	3,872	4,426
Jun	1.5	373	467	654	934	1,308	1,682	2,056	2,616	2,990
Jul	1.55	386	482	676	965	1,352	1,738	2,124	2,703	3,090
Aug	2.03	505	632	885	1,264	1,770	2,276	2,782	3,541	4,047
Sep	1.67	416	520	728	1,040	1,456	1,872	2,288	2,913	3,329
Oct	1.34	334	417	584	834	1,168	1,502	1,836	2,337	2,671
Nov	1.01	251	314	440	629	881	1,132	1,384	1,762	2,014
Dec	1	249	311	436	623	872	1,121	1,370	1,744	1,994
Total	**15.66**	**3,871**	**4,840**	**6,777**	**9,684**	**13,559**	**17,434**	**21,309**	**27,122**	**31,000**

Rainwater Catchment Systems Output

Indoor water use is a function of persons per household (pph) and average water usage in gallons per capita per day (gpcd). Unfiltered rainwater has ostensibly been shown by Coombes (2002) and Mitchell (2002) to have appropriate water quality for use in laundry, toilets, and water heaters. For this study, rainwater is to replace these non-critical indoor water uses such as toilet flushing, laundry, and hot water appliances. Mayer (1999) and Dziegielewski (2000) have found mean indoor end water usage to be 69.3 and 69.2 gpcd respectively. Mayer's study is important in that it encompassed single-family homes in twelve representative North American locations with a large sample size of 1,188 households. Using a conservative rounded figure of 70 gpcd, the approximate indoor water use based on an average of 2.8 persons per household (pph), as reported by the US Census Bureau for San Antonio, 2000, is calculated to be 5880 gallons per household per month.

70 gpcd X 2.8 pph X 30 (days per month) = 5880 gallons per household per month

The non-potable end uses (Figure 2) represent the potential replacement by rainwater and 82% of the total indoor water use based on the findings of DeOreo (1999), Mayer (1999), and Dziegielewski (2000).

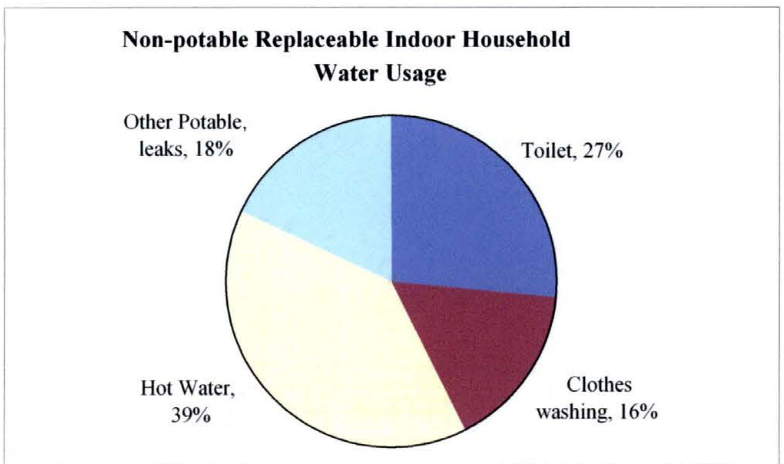


Figure 2. Sources: Mayer, et al. 1999; DeOreo and Mayer, n.d.; Dziegielewski 2000

This study assumes that the indoor monthly water use per household does not fluctuate throughout the year, as opposed to outdoor water use which has pronounced seasonal fluctuations. This study also assumes that the homes are occupied all year with the same number of persons (2.8 on average).

Potential Replacement of Treated Water for Indoor Use

The potential indoor water usage replaced or supplemented by rainwater is calculated using the catchment (input) area and end-use (output) findings, and is reported in percentages. Converting the indoor water demand by end-use into gallons per month demand will allow us to further examine the overall household water balance.

Toilet	27 %	1590 gallons per month demand
Clothes Washing	16 %	940 gallons per month demand
Hot Water	39 %	2290 gallons per month demand

Tables 5-7 demonstrate the feasibility and reliability of rainwater under the three proposed precipitation scenarios for each roof area category. The approximate figures on total water savings for single-family units demonstrate the potential water mains savings that could be incurred by integrating RCS for 52.46% percent of SAWS customer demand. The percent of saving of indoor demand that could be replaced by RCS is based on the monthly collection potential by cohort divided by the constant indoor demand of 5,880 gallons /month for average household size of 2.8 persons per household and multiplied by 100. This was calculated for the mean, 10th percentile and 90th percentile precipitation scenarios. An obvious observation to make is larger roof sizes are able to collect more rain, which can be used to meet greater indoor water demand. Tank or cistern size is an important factor for enabling the highest collection rate of rain. Tanks are sized according to roof area, ground space available, and rainfall patterns. Ideally, the size will accommodate for the more voluminous rainfall events. Actual household size and indoor water demand fluctuates. The more persons/household the more likely water demands increase. Coombes, Frost, Kuczèra, O'Loughlin, and Lees (2002) discuss the trend that wealthier families tend to use more water for more expensive landscaping needs and because they can afford to pay higher bill rates. Likewise, households with lower incomes use less water and cannot afford higher bill rates (Coombes et al 2002).

Table 5: Percentage of savings of indoor demand that could be replaced by rainwater with mean precipitation, based on the collection potential by house-group size and a constant monthly indoor demand of 5880 gallons

Month	**House Group Size and Percentage of Savings of Indoor Water Demand**																	
	499.5	**%**	**624.5**	**%**	**874.5**	**%**	**1249.5**	**%**	**1749.5**	**%**	**2249.5**	**%**	**2749.5**	**%**	**3499.5**	**%**	**4000**	**%**
Jan	388	7	486	8	680	12	972	17	1360	23	1749	30	2138	36	2721	46	3110	53
Feb	423	7	529	9	741	13	1059	18	1482	25	1906	32	2330	40	2965	50	3389	58
Mar	441	8	551	9	771	13	1102	19	1543	26	1984	34	2426	41	3087	53	3529	60
Apr	680	12	850	14	1190	20	1700	29	2380	40	3061	52	3741	64	4762	81	5443	93
May	879	15	1099	19	1539	26	2198	37	3078	52	3958	67	4837	82	6157	105	7037	120
Jun	789	13	993	17	1382	24	1974	34	2764	47	3554	60	4344	74	5529	94	6320	107
Jul	540	9	675	11	946	16	2933	50	1892	32	2433	41	2974	51	3785	64	4326	74
Aug	590	10	738	13	1033	18	1476	25	2067	35	2657	45	3248	55	4134	70	4725	80
Sep	829	14	1037	18	1451	25	2074	35	2904	49	3733	63	4563	78	5808	99	6639	113
Oct	702	12	878	15	1229	21	1756	30	2459	42	3162	54	3864	66	4919	84	5622	96
Nov	530	9	663	11	928	16	1326	23	1857	32	2388	41	2919	50	3715	63	4246	72
Dec	448	8	560	10	785	13	1121	19	1570	27	2018	34	2467	42	3140	53	3589	61
Total/ Avg.	**7,239**	**10**	**9,059**	**13**	**12,675**	**18**	**19,691**	**28**	**27,570**	**36**	**32,603**	**46**	**39,851**	**57**	**50,722**	**72**	**57,975**	**82**

Table 6: Percentage of savings of indoor demand that could be replaced by rainwater with 90th percentile precipitation, based on the collection potential by house-group size and a constant monthly indoor demand of 5880 gallons

Month	**House Group Size and Percentage of Savings of Indoor Water Demand**																	
	499.5	**%**	**624.5**	**%**	**874.5**	**%**	**1249.5**	**%**	**1749.5**	**%**	**2249.5**	**%**	**2749.5**	**%**	**3499.5**	**%**	**4000**	**%**
Jan	620	11	775	13	1,085	18	1,551	26	2,171	37	2,792	47	3,412	58	4,343	74	4,964	84
Feb	632	11	791	13	1,107	19	1,582	27	2,215	38	2,848	48	3,481	59	4,430	75	5,064	86
Mar	597	10	747	13	1,046	18	1,495	25	2,093	36	2,691	46	3,289	56	4,186	71	4,785	81
Apr	944	16	1,180	20	1,652	28	2,360	40	3,305	56	4,249	72	5,194	88	6,610	112	7,556	128
May	1,150	20	1,438	24	2,014	34	2,877	49	4,028	69	5,180	88	6,331	108	8,058	137	9,210	157
Jun	1,312	22	1,640	28	2,297	39	3,282	56	4,595	78	5,908	100	7,222	123	9,192	156	10,506	179
Jul	914	16	1,142	19	1,600	27	2,285	39	3,200	54	4,115	70	5,029	86	6,401	109	7,317	124
Aug	670	11	837	14	1,172	20	1,675	28	2,346	40	3,016	51	3,686	63	4,692	80	5,363	91
Sep	1,603	27	2,004	34	2,807	48	4,011	68	5,615	95	7,220	123	8,825	150	11,232	191	12,839	218
Oct	1,300	22	1,625	28	2,275	39	3,251	55	4,552	77	5,852	100	7,153	122	9,104	155	10,407	177
Nov	747	13	934	16	1,308	22	1,868	32	2,616	44	3,363	57	4,111	70	5,232	89	5,981	102
Dec	784	13	980	17	1,373	23	1,962	33	2,747	47	3,532	60	4,317	73	5,494	93	6,280	107
Total/ Avg.	**11,272**	**16**	**14,093**	**20**	**19,735**	**28**	**28,198**	**40**	**39,482**	**56**	**50,766**	**72**	**62,049**	**88**	**78,975**	**112**	**90,270**	**128**

Table 7: Percentage of savings of indoor demand that could be replaced by rainwater with 10^{th} percentile precipitation, based on the collection potential by house-group size and a constant monthly indoor demand of 5880 gallons

Month	House Group Size and Percentage of Savings of Indoor Water Demand																	
	499.5	**%**	**624.5**	**%**	**874.5**	**%**	**1249.5**	**%**	**1749.5**	**%**	**2249.5**	**%**	**2749.5**	**%**	**3499.5**	**%**	**4000**	**%**
Jan	169	3	212	4	296	5	423	7	593	10	762	13	932	16	1,186	20	1,356	23
Feb	147	2	184	3	257	4	367	6	514	9	661	11	809	14	1,029	18	1,176	20
Mar	202	3	252	4	353	6	504	9	706	12	908	15	1,110	19	1,413	24	1,615	27
Apr	286	5	358	6	501	9	716	12	1,003	17	1,289	22	1,576	27	2,006	34	2,293	39
May	553	9	691	12	968	16	1,383	24	1,936	33	2,489	42	3,042	52	3,872	66	4,426	75
Jun	373	6	467	8	654	11	934	16	1,308	22	1,682	29	2,056	35	2,616	44	2,990	51
Jul	386	7	482	8	676	11	965	16	1,352	23	1,738	30	2,124	36	2,703	46	3,090	53
Aug	505	9	632	11	885	15	1,264	21	1,770	30	2,276	39	2,782	47	3,541	60	4,047	69
Sep	416	7	520	9	728	12	1,040	18	1,456	25	1,872	32	2,288	39	2,913	50	3,329	57
Oct	334	6	417	7	584	10	834	14	1,168	20	1,502	26	1,836	31	2,337	40	2,671	45
Nov	251	4	314	5	440	7	629	11	881	15	1,132	19	1,384	24	1,762	30	2,014	34
Dec	249	4	311	5	436	7	623	11	872	15	1,121	19	1,370	23	1,744	30	1,994	34
Total/ Avg.	**3,871**	**5**	**4,840**	**7**	**6,777**	**10**	**9,684**	**14**	**13,559**	**19**	**17,434**	**25**	**21,309**	**30**	**27,122**	**38**	**31,000**	**44**

The calculated weighted mean for the percent of total housing units per cohort and the percent indoor water use savings based on the 2.8 persons per household and 5880 gallons per month (Table 8). Mean precipitation provides 35.5 percent savings across all homes in the SAWS customer distribution area, while the 10th percentile rainfall year will meet 20.7 percent of the indoor demand, and 90th percentile rainfall year could meet 47 percent of indoor demand under the same assumptions. Although, the dry year contributes only 20.7 percent of the total indoor demand, RCS can provide a significant reduction in mains use even in the substantially dry years, like those that receive only 17.8 inches of rain. In the wet year, 41 inches, almost 50 percent of the indoor water demand across the SAWS distribution of single-family homes can be met. Clearly, RCS can provide a substantial mains savings in the climate region of San Antonio and south central Texas.

Table 8: Weighted Mean Collection Potential for SAWS Customer Distribution of Single-family Homes

Mean Precipitation			**10th Percentile**			**90th Percentile**		
Cohort of Assumed Roof Area (ft^2)	**Percent of Total**	**Percent Savings**	**Cohort of Assumed Roof Area** (ft^2)	**Percent of Total**	**Percent Savings**	**Cohort of Assumed Roof Area** (ft^2)	**Percent of Total**	**Percent Savings**
499.5	1.3	10	499.5	1.3	5	499.5	1.3	16
624.5	5	13	624.5	5	7	624.5	5	20
874.5	11.4	18	874.5	11.4	10	874.5	11.4	28
1249.5	32.3	28	1249.5	32.3	14	1249.5	32.3	40
1749.5	24.9	36	1749.5	24.9	19	1749.5	24.9	56
2249.5	14	46	2249.5	14	25	2249.5	14	72
2749.5	6	57	2749.5	6	30	2749.5	6	88
3499.5	3.4	72	3499.5	3.4	38	3499.5	3.4	112
4000	1.7	82	4000	1.7	44	4000	1.7	128
	Mean	40		Mean	21		Mean	62
Weighted Mean		**34.5**	**Weighted Mean**		**18.0**	**Weighted Mean**		**53.0**

Potable Water Savings through RCS

Final calculations presented in Tables 9-11 express the total estimated savings per housing cohort combined for the mean, 90th percentile and 10th percentile precipitation years.

Table 9: Total Estimated Savings per Housing Cohort, Mean Year

Home Size Cohort	Mean Year Water Savings	Qty of homes in Size Cohort	Total Gallons per Housing Cohort	Acre Feet Savings
499.5	7,239	2,844	20,587,716	63.2
624.5	9,059	14,222	128,837,098	395.4
874.5	12,675	32,712	414,624,600	1,272.4
1249.5	19,691	91,024	1,792,353,584	5,500.5
1749.5	27,570	71,112	1,960,557,840	6,016.7
2249.5	32,603	39,823	556,435,401	1,707.6
2749.5	39,851	17,067	680,137,017	2,087.3
3499.5	50,722	9,956	504,988,232	1,549.8
4000	57,975	5,689	329,819,775	1,012.2
Total	**257,105**	**284,449**	**6,387,544,943**	**19,602.6**

Table 10: Total Estimated Savings per Housing Cohort, 90th Percentile Year

Home Size Cohort	90th Percentile Year Water Savings	Qty of homes in Size Cohort	Total Gallons per Housing Cohort	Acre Feet Savings
499.5	11,272	2,844	32,057,568	99.4
624.5	14,093	14,222	200,430,646	621.3
874.5	19,735	32,712	645,571,320	2,001.3
1249.5	28,198	91,024	2,566,694,752	7,956.8
1749.5	39,482	71,112	2,807,643,984	8,703.7
2249.5	50,766	39,823	2,021,654,418	6,267.1
2749.5	62,049	17,067	1,058,990,283	3,282.9
3499.5	78,975	9,956	786,275,100	2,437.5
4000	90,270	5,689	513,546,030	1,592.0
Total	**394,840**	**284,449**	**10,632,864,101**	**32,961.9**

Table 11: Total Estimated Savings per Housing Cohort, 10th Percentile Year

Home Size Cohort	10th Percentile Year Water Savings	Qty of homes in Size Cohort	Total Gallons per Housing Cohort	Acre Feet Savings
499.5	3,871	2,844	11,009,124	34.1
624.5	4,840	14,222	68,834,480	213.4
874.5	6,777	32,712	221,689,224	687.2
1249.5	9,684	91,024	881,476,416	2,732.6
1749.5	13,559	71,112	964,207,608	2,989.0
2249.5	17,434	39,823	694,274,182	2,152.2
2749.5	21,309	17,067	363,680,703	1,127.4
3499.5	27,122	9,956	270,026,632	837.1
4000	31,000	5,689	176,359,000	546.7
Total	**135,596**	**284,449**	**3,651,557,369**	**11,319.8**

The mean year, 29 inches of rain, provides a total of 6,387,544,943 gallons among all homes per cohort in the SAWS customer service area. This converts to 19,602.6 acre-feet. During the wet year (the 90th percentile) the 284,449 homes would receive approximately 45 inches of rainfall throughout the year, and potentially produce 10,632,864,101 gallons or 32,961.9 acre-feet. The dry year (10th percentile) would potentially receive approximately 16 inches of rainfall, producing 3,651,557,369 gallons or 11,319.8 acre-feet that year.

CHAPTER IV

SAWS NEW WATER PROJECTS AND RCS

This study provided an estimate of water resources that could potentially be created or conserved through rooftop RCS from single-family homes. The analysis is based on San Antonio's precipitation record, housing stock size, and estimated indoor water use per month. Because San Antonio water resources are projected to be in deficit in the near future as populations increase, San Antonio Water Systems (SAWS) is researching several options for new sources of water. The following section describes some of the projects (Figure 3).

Conservation and water resource education through the SAWS Conservation Department remains an important factor in reducing per capita water usage. The successes of the SAWS Conservation Department have been recognized through many awards. For their latest program, *Community Challenge*, customers attempt to meet their stated goals for reducing water consumption. Communities that meet their goals receive funding awards for group projects. This program is projected to save up to 100 million gallons (300 acre-feet) per year (SAWS 2004, 2-14).

The Trinity Aquifer-Oliver Ranch project is an operational 4,000 acre-feet per year water supply for those residing over the Trinity Aquifer. The water from the Trinity Aquifer will be transferred to and stored in a tank at Oliver Ranch. SAWS has also, contracted with the BSR Water Supply Company to receive 1,000 acre-feet per year from public supply wells that are located within the Trinity Aquifer Group. However, BSR has initiated litigation against SAWS and the project cannot move forward until all matters are resolved (SAWS 2004, 2-28).

The under construction Western Canyon Project between SAWS and Guadalupe-Blanco River Authority (GBRA), will supply 8,500 acre-feet per year of water from the Canyon Reservoir to SAWS customers. The Friends of Canyon Lake has brought lawsuits to fight the TCEQ permit, and had delayed this project. So far The Friends of Canyon Lake has lost its lawsuits and appeals (SAWS 2004, 2-30).

The Simsboro Project is a contract between SAWS and ALCOA and City Public Service (CPS) for a combined 55,000 acre-feet per year. These are land/water rights acquisition from ALCOA's Rockdale and CPS's water rights from land in Bastrop County. A feasibility study is being conducted for this project through 2005 (SAWS 2004, 2-32).

The Aquifer Storage and Recovery project involves aquifers located in Southern Bexar County and possibly Wilson and/or Atacosa Counties. This project involves pumping Edwards Aquifer water out in low demand months, then transferring and injecting it into the project aquifers. The water would then be retrieved during the high peak seasonal demand of summer. Phase I of this project is operational and the design for Phase II has been initiated (SAWS 2004, 2-33).

The Lower Guadalupe Water Supply Project is an agreement between SAWS, the San Antonio River Authority, and GBRA to "divert presently under-utilized surface water rights and unappropriated stream flow from the Guadalupe River together with groundwater from the Gulf Coast aquifer," (SAWS 2004, 2-35) providing between

70,000 to 94,500 acre-feet per year for 50 years. A feasibility study is being conducted for this project through 2007.

The Lower Colorado (LCRA)-SAWS Water Project will provide water from water resource Planning Group K. This region, however, is projected to have shortfalls of up to 160,000 acre-feet by 2050, which could cripple the rice production industry downstream. Additionally, rural communities upstream from the Highland Lakes are projected to be short 5,300 acre-feet by 2050. Yet, the LCRA-SAWS project expects to create 333,000 acre-feet per year through conservation and off-channel storage ponds. An expected 150,000 acre-feet per year will be sent to the SAWS customer distribution. A feasibility study is being conducted for this project through 2009 (SAWS 2004, 2-37).

The Carrizo Aquifer (Gonzales County) Project is expected to provide 55,000 acre-feet per year after all phases are complete by 2011, drawing water from the Carrizo-Wilcox Aquifer. So far, SAWS has been able to secure 26,166 acre-feet per year of the project. In addition to other conservation programs, SAWS is looking to coastal and brackish water desalination projects located in Freeport, Corpus Christi, and the Lower Rio Grande Valley. Water would be piped from long distances to the SAWS customer distribution. This study is in the Phase I design stage (SAWS 2004, 2-53).

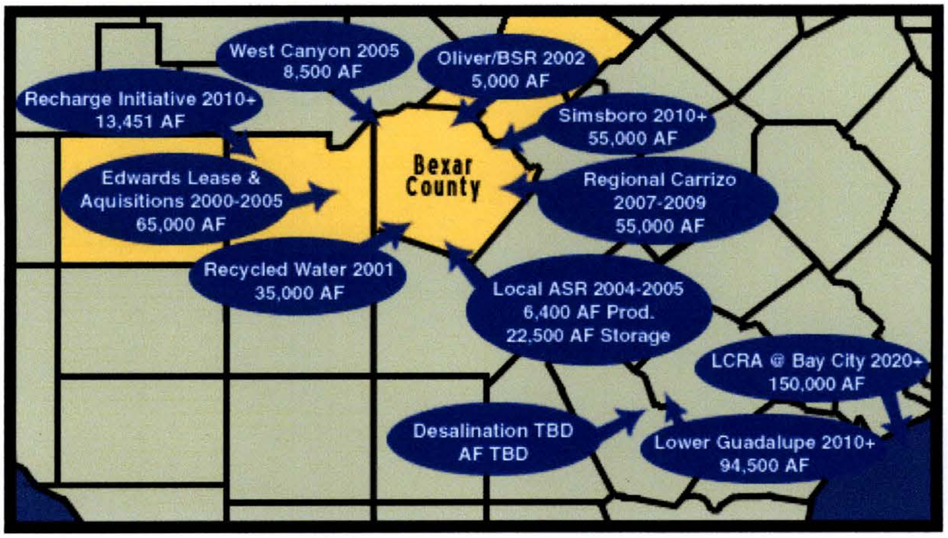


Figure 3: SAWS Projected Source Targets of Water Resources; Source: SAWS. 2005. Available from http://www.saws.org/our_water/waterresources/waterfuture/project_locations.shtml

This thesis research presents three RCS scenarios. Calculations illustrate that between 11,319.8 acre-feet in a dry year, 19,602.6 acre-feet in a mean year, and 32,961.9 acre-feet in a wet year can be collected directly from rooftops of single-family residences in San Antonio, Texas. Although the RCS scenario using mean precipitation would supply only a small portion, 3.4 percent, of the water SAWS is attempting to secure, 570,351 by 2020, it could eliminate one or two of the alternative projects. The potential volume of water collectable could increase with the inclusion of multi-family residences, industries, and all commercial buildings where surplus water could be stored and provided as a community service. Integrating RCS into the mains may demonstrate to neighboring communities a good-faith effort to collect available water resources. Unfortunately, a water resource management plan that integrates RCS may never become a reality in San Antonio if left up to current management.

SAWS Conservation Planners Eddie Wilcut and Janie Guzman conducted "A Cost/Benefit Analysis of Rainwater Harvesting for Water Conservation Planning" and presented their findings during the American Rainwater Catchment Systems Association 2003 Conference (Wilcut and Guzman 2003). Their report is based on determining landscaping needs, the amount of rainfall that could potentially be captured, and the storage size necessary to carry the user through the season of peak demand (July through September). The cost/benefit analysis portion of the study was limited to determining a "cost per gallon for storage capacity and a cost per acre-foot saved based on the price per acre-foot" (Wilcut 2003). Although their calculations found that by the second year of rainfall storage, an adequate sized cistern could provide 91% of the annual deficit, they concluded that the total cost of a system outweighs the benefit of the total cost of the water one would save. Wilcut also stated that SAWS will not give rebates or incentives for RCS to their customers, and that the only value of RCS in cities with established infrastructure is educational (Wilcut, 2004).

In contrast, Peter Coombes and other key researchers in Australia have found, through well-researched, hands-on studies in urban settings, great benefits to integrating RCS into urban areas where infrastructure is preexisting. Their research has led to national policy changes toward integrating RCS in urban settings and implementing water sensitive urban design programs throughout Australia (Coombes 2004).

CHAPTER V

POLICY RECOMMENDATIONS, DISCUSSION AND CONCLUSIONS

This study has found that significant indoor mains water can be saved through rooftop RCS in single-family homes in San Antonio, Texas. Based on the assumptions set for the calculations performed, 20.7% to 47% of the indoor demand among the single-family homes within the SAWS customer service area can be met with RCS. Approximately 11,320 to 32,962 acre-feet a year can be caught and saved from all single–family homes in the study region. While this could reduce the need for a few smaller water source projects, RCS on single-family homes, will only reduce the projected deficit by 3.4 %, a fairly insignificant finding and one that could be matched by repairing leaks within the aged infrastructure. On the regional scale, RCS may be difficult to justify, however, on the household scale, RCS can provide a substantial savings of potable mains water within the climate region of San Antonio.

The use of RCS is listed among best management practices to address nonpoint source pollution (TCEQ 2004); however, cities and water providers minimally promote the practice through policy, rebates, and incentive programs. In the United States RCS has never been seriously considered as a stand-alone or an integrated water source. Reasons for ignoring RCS in the modern urban setting, may involve attitudes of engineers and water purveyors, availability of surface and ground water resources, resistance or lack of knowledge from the citizens, or the overall costs of systems. In traditional water resource management practices, projections of demand are made and compiled through population surveys, evaluations of irrigation needs for farming, and of industrial needs. Surface and ground water resources are surveyed, and construction plans for surface collection basins implemented. Projects, such as a dam and reservoir system, are constructed and/or groundwater wells are tapped and the resources are sold to user groups. Importing water from one catchment basin to another is now common practice; nevertheless, it disrupts the natural ecosystem and flows of surface and ground water.

Social barriers to alternative approaches of water supply such as RCS should be explored through surveys and research. The barriers are likely to encompass cultural attitudes about individual rights to free water resources. An informal, verbal survey conducted with San Antonio residences found that fears of quantity, lower water quality, and control of a life essential resource also shape individual resistance to RCS (Brunet 2003). As the population increases, especially in water-short regions, it is imperative that people be educated and participate in optimizing local water resources. RCS education, directed toward urban and suburban residences, businesses, and developers will reduce the fears and prejudices of people detached from their water sources. Changes in attitudes may help to decrease the overall reliance on large-scale projects, and bring some of the responsibility of water resource management to the household level.

The cost of tanks or cisterns may concern those who investigate RCS as a water resource option and may be a deterrent for those connected to the reticulated systems. RCS can be expensive at the individual level depending on the sophistication of the system and level of filtration installed. This will remain so until RCS are more commonly used, which will drive the overall costs down through increased innovation and competition. Coombes and Mitchell have demonstrated that the non-critical indoor water use of rainwater for toilet flushing, laundry, and hot water needs only a first flush device to meet Australian health standards. This can dramatically reduce the overall cost of a RCS at the household level. Cistern material is the driving force behind the expense, and includes ferro-cement, metal with liner, polypropylene, and fiberglass. The costs of these materials vary greatly and can run from $0.35 - $1.50 per gallon of storage (Banks and Heinichen 2004).

RCS should be considered as new water resources and micro flood control devices. Although analyzing the flood control benefits of RCS was beyond the scope of this thesis, several other researchers have found significant improvement in runoff, especially when coupled with WSUD (Coombes 2002; Coombes, Peter J., and George Kuczera 2002; Coombes, Peter J., George Kuczera, J. Kalma, J. Argue 2002; Coombes, Peter J., Andrew Frost, George Kuczera, Geoff O'Loughlin, and Stephen Lees 2002; Coombes, Peter J., and George Kuczera 2003; Mitchell, V. Grace, R. G. Mein, and T. A. McMahon. 2002; and Moddemeyer, Steve, Gary Schimek, Paul Fleming, Dick Lilly. 2003). A full study on WSUD that incorporates RCS could be conducted to evaluate storm water runoff reductions. Carefully planned pilot studies set in residential areas of San Antonio could confirm the findings presented in this thesis, and evaluate source control measures designed to reduce storm water runoff.

Conservation education, toilet replacement, lawn irrigation scheduling, and showerhead replacement should continue as important components of savings programs of water utilities providers, especially in drier climates. Widespread residential, agricultural, and industrial methods of conservation are of great cost benefit for cities and water providers. Conservation campaigns in San Antonio have helped lower overall demand that had been projected for 2000. However, conservation alone cannot keep up with the growing population.

For most cities the impact of RCS on the current centralized system will have to be established through a comprehensive cost/benefit analysis as a new water resource and flood control measure as performed in Seattle. An appropriate approach to reaching an accurate cost/benefit analysis of RCS for a large scale application should include the cost to explore, pay a consultant firm, and build a new reservoir (including land, labor and equipment, environmental costs, social cost); the cost for building the infrastructure (pipes, equipment, labor, environmental costs, social costs); the costs of water treatment to meet EPA drinking water standards for the amount RCS could replace; the costs of drainage and sewage treatment, and building of new facilities to accommodate new neighborhoods; and the costs of retention facilities. Additionally, the cost/benefit analysis should consider the costs of depleting natural resources; the costs of preventing species losses; and the costs of flooding damage preventable by RCS. Some of these costs are, unfortunately, difficult to quantify. However, an increasing number of urban communities around the world are attempting to substantiate the benefits of widespread RCS programs for sustainable water supply.

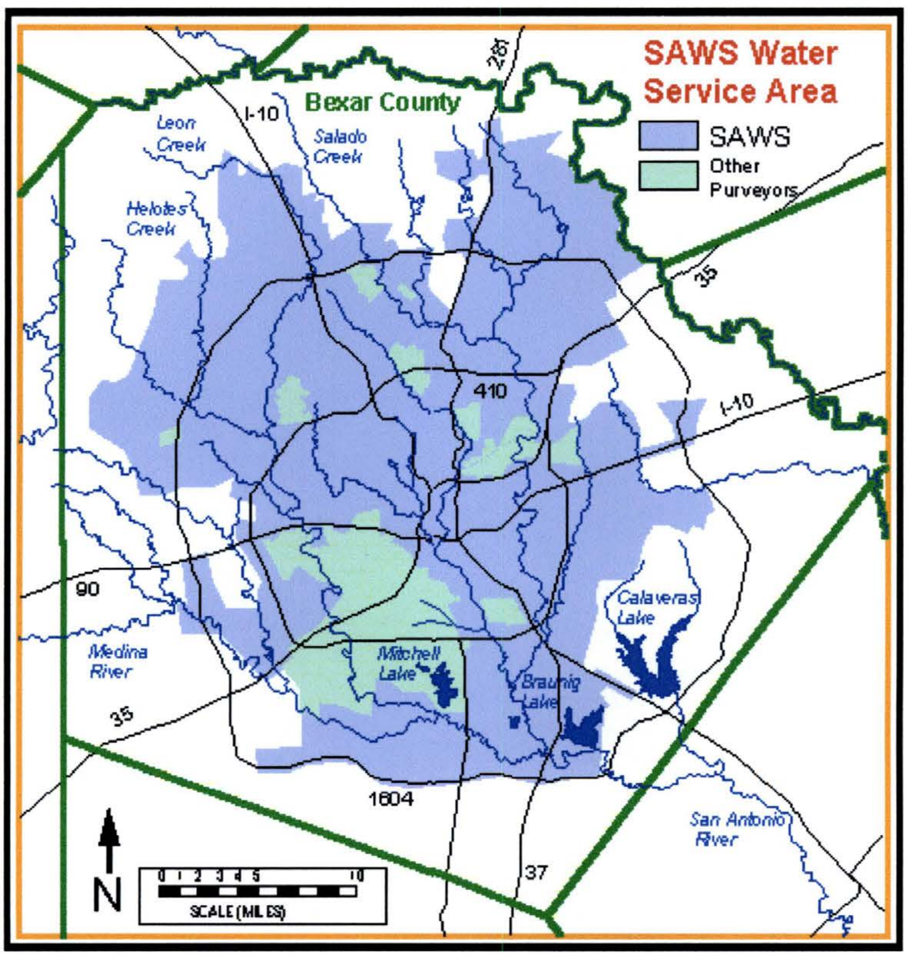
The implementation of RCS presents many relevant research opportunities to geographers. It is the perfect synthesis of many of the themes of geography. Patricia Gober, past president of the American Association of geographers, stressed the need to balance the perspective of geography "comes from the need to marry more closely our personal research agendas with the needs of the society for which we work." (Gober

2000, 10). RCS research brings together climate, environment, population studies, social science, political science, computer technologies, architecture, and engineering; and demonstrates how these combine to influence humans' greatest trait: adaptation. RCS research allows the geographer to get involved in action-oriented research and real world problem solving. Political leaders, now better understanding that exploitation of resources can lead to devastating environmental changes, are calling for solutions to the problems that many of their policies have permitted. Access to and battle over water resources has paradoxically become a political issue because societies have come to depend on governments for meeting their basic needs. Integrating rainwater harvesting promotes some degree of independence from political control. So the very answer politicians seek is perhaps how to make societies more self sufficient, self reliant, and sustainable. Geographers, with their emphasis on synthesis, are well qualified to integrate the various issues associated with RCS.

This study has revealed the extent to which the decentralized approach of household RCS integrated into a centralized urban water distribution system could lessen the need of external water sources for the City of San Antonio, Texas. The greater implication may be that cities, suburbs, and new housing developments encouraging the use of RCS could be able to reduce the need of large-scale projects, and reduce the impeding legal difficulties originating from targeted source regions.

APPENDIX A:

San Antonio Water Systems Service Area



SOURCE: San Antonio Water System. Who We Are: Service Areas. Online; accessed December 22, 2004; available at http://www.saws.org/who_we_are/service.shtml.

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