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# Feasibility of Brackish Water Desalination as an Alternative Water Supply in the Barton Springs/ Edwards Aquifer Conservation District

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# Feasibility of Brackish Water Desalination as an Alternative Water Supply in the Barton Springs/ Edwards Aquifer Conservation District

by

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**Thesis**

Presented to the Faculty of the Graduate School of

The University of Texas at Austin

in Partial Fulfillment

of the Requirements

for the Degree of

**Master of Science in Energy and Earth Resources**

**The University of Texas at Austin**

**May 2015**

# Dedication

I would like to dedicate this thesis to my dad, mom, and brother.  Without their support, I would not have been able to overcome the challenges of life and made it this far in my academic endeavors.  I would also like to give a special thank you and dedicate this thesis to Michelle and Ari.  They witnessed, firsthand, my everyday struggles in writing this thesis.  They have stood by me through the good, the bad, and the downright ugly.  Thank you for the support, the laughs, and for keeping me sane.

# Acknowledgements

I would like to give special thanks to Dr. Carey W. King and Dr. Charles W. Kreitler who supported this research and guided me through the entire process. Without their direction, patience, and support, this research would not have been possible. I would also like to thank Dr. Brian Smith of the Barton Springs/ Edwards Aquifer Conservation District. I am extremely grateful for his advice, expertise, and for sharing pertinent information needed for this research with me. I would also like to acknowledge Kevin Morrison and Richard Donat of the San Antonio Water System for their great contribution of information that provided insight to critical portions of this research. I would like to thank staff members of the Texas Water Development Board and the Texas Commission on Environmental Quality for taking the time to speak with me and providing information. And finally, I would like to thank the faculty and staff of the Energy and Earth Resources program at the University of Texas at Austin for providing me the opportunity to expand my knowledge and "Earn My Horns". Hook em!

## Abstract

**Feasibility of Brackish Water Desalination as an Alternative Water Supply in the Barton Springs/ Edwards Aquifer Conservation District**

Alan Barraza, M.S. E.E.R.

The University of Texas at Austin, 2014

Co-Supervisors: Carey W. King and Charles W. Kreitler

Growing demands for water across the State of Texas has prompted many entities to take into consideration alternative means of obtaining water. The Edwards Aquifer within the Barton Springs/Edwards Aquifer Conservation District (BSEACD) has long been an invaluable and reliable resource in providing high quality water at a low cost. The continued population growth within the BSEACD along with continued drought conditions have strained the resource to the point of having restrictions being placed on production. These restrictions are in response to the potential impact of over-pumping water wells, water quality, springflow, and endangered species. At current permitted pumping, even with all curtailments allowed by statutory authority and current rules, the BSEACD cannot meet Desired Future Conditions during an ongoing drought of record. Within the boundaries of the BSEACD, there exist opportunities for groundwater production in the brackish portion of the Edwards and Trinity aquifers. This paper presents the economic feasibility of undertaking a brackish groundwater desalination project in the saline portion of the Edwards aquifer and also considers technical and regulatory obstacles. It is based upon a model that incorporates prevailing market and hydrogeologic conditions within Central Texas and the BSEACD, such as total dissolved solids content, brackish well depth, concentrate well depth, capital and operational costs of desalination facilities, electricity demands and costs, and water costs into its calculation. Results from this study indicate a reverse osmosis desalination project between the modeled range of 1.25 MGD to 12.5 MGD would be economically feasible. At 2.76 MGD the water would cost $748 per acre foot ($2.30 per 1,000 gal) to produce and gradually decreases in cost as the size of the facility increases due to economics of scale. At approximately 10 MGD of desired daily product generation the optimal price of $648 per acre-foot ($1.99 per 1,000 gal) is reached. While a desalination project within the BSEACD may be economically feasible, there are technical and regulatory obstacles that must be overcome before such project can take commence

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# Chapter 1: Introduction

## 1.1 Study Objectives

This study assesses the feasibility of brackish groundwater desalination in the Barton Springs Segment of the Edwards Aquifer for the purpose of reducing pumpage on the fresh water section of the aquifer. This segment is also known as the Austin Section of the Balcones Fault Zone (BFZ) and is managed by the Barton Springs/Edwards Aquifer Conservation District (BSEACD or District). Texas has faced many droughts in its history including the most recent and very severe drought that began in 2011. The drought, coupled with decreasing supplies of fresh groundwater and surface water, stricter drinking water standards, increased cost of water rights, increased competition for surface-water resources, and changes in population/demand centers has prompted regulators and stakeholders to consider alternative solutions to obtaining drinking water (LBG - Guyton Associates, 2003). While several options exist to develop a drinking water resource, many water regulators and providers have begun to seriously consider the development of brackish groundwater, including the BSEACD. This study will clearly identify the potential for developing brackish groundwater through desalination within the BSEACD. The study objectives are to:

- Assess the economic feasibility of brackish groundwater desalination within the BSEACD
- Review the technical feasibility of developing a desalination system within the BSEACD.
- Evaluate current state and district policies to determine potential issues in regards to developing desalination systems within the BSEACD.

### 1.2 Structure of Thesis

The first chapter of this thesis is a brief overview of background information pertinent to the project that will establish a foundation for the remainder of the paper. Chapter 2 discusses regulatory requirements needed to be met to construct and operate a desalination facility. The third chapter concentrates on the water planning structure and current status of water use within Texas and more specifically within the BSEACD. Chapter 4 discusses the geology and hydrogeology within the BSEACD. The fifth chapter discusses the various methods and technologies used in desalination and how they work. The sixth chapter of this thesis is a review on current desalination sites within the state of Texas. Chapter 7 is an overview of the cost of groundwater desalination. Chapter 8 describes the methods used to conduct the economic feasibility study for this thesis. Chapter 9 examines the results and discusses some of the implications these results may have on the BSEACD. In chapter 10, the thesis is concluded with a finalized assessment.

### 1.3 Groundwater Law History in Texas

In Texas, groundwater and surface water are treated completely separate. Surface water is publicly owned and governed by the State of Texas. Without a permit from the Texas Commission on Environmental Quality (TCEQ), landowners may only use surface water for domestic and livestock purposes (Griffin, 2010; Texas Groundwater Protection Committee, n.d.). While surface water is state-owned, groundwater is the private property of the landowner (Griffin, 2010). Texas groundwater is predominantly governed by riparian law otherwise known as the "Rule of Capture" or more commonly known as the "Rule of the Biggest Pump" unless modified by local groundwater conservation districts. Texas groundwater laws were enacted and have been upheld since they were adopted in 1904 in *Houston & T.C. Ry. Co. v East*, 81 S.W. 279 (Texas 1904).

The Rule of the Biggest Pump comes from the idea that a landowner is constrained only by the size of his or her pump (Griffin, 2010). Under this law an owner of land has the right to drill a well of any depth or size on their property and is given the following rights (Barton Springs/Edwards Aquifer Conservation District, 2010b; Griffin, 2010):

- Ownership of the water captured and brought to the surface
- Right to make non-wasteful use of the water
- Right to sell or lease the water
- Right to export water beyond the boundaries of land or the aquifer
- Right to legally reserve the groundwater rights when the land is sold

In a recent court case in 2012, the Texas Supreme Court ruled that landowners own "groundwater in place" underneath their property and not just when it is captured.

In most cases a landowner has the right to pump as much water from his or her well even if it causes his neighbor's well to go dry. There are five situations in which a Texas landowner can take legal action for interference with his groundwater rights. In these cases, Texas courts have made exceptions and ruled that the Rule of Capture does not apply (Griffin, 2010; Texas A&M University, 2014):

- If an adjoining neighbor trespasses on the land to remove water either by drilling a well directly on the landowner's property or by drilling a "slant" well on adjoining property so that it crosses the subterranean property line, the injured landowner can sue for trespass; or

- There is malicious conduct in pumping water for the sole purpose of injuring an adjoining landowner; or
- Landowners waste artesian well water by allowing it to run off their land or to percolate back into the water table; or
- There is contamination of water in a landowner's well. No one is allowed to unlawfully pollute groundwater; or
- Land subsidence and surface injury result from negligent overpumping from adjoining lands.

The Rule of Capture has allowed landowners to manage the groundwater they pump and capture from their property without many stipulations. While the Texas Legislature does acknowledge the private ownership of groundwater, it has established Groundwater Conservation Districts (GCDs) starting in 1949 and again in 1985 (Griffin, 2010; Texas A&M University, 2014). GCDs are the state's preferred method of groundwater management, and they are specifically authorized to modify how the Rule of Capture is to be applied within their boundaries, as part of a comprehensive, approved groundwater management plan (Barton Springs/Edwards Aquifer Conservation District, 2010b). The only other modification to the Rule of Capture occurs for groundwater positioned in the underflow of a river (Griffin, 2010). Texas Water Code, Chapter 36, Subsection 36.101, states that "A district may make and enforce rules, including rules limiting groundwater production based on tract size or the spacing of wells, to provide for conserving, preserving, protecting, and recharging of the groundwater or of a groundwater reservoir or its subdivisions in order to control subsidence, prevent degradation of water quality, or prevent waste of groundwater and to carry out the powers and duties provided by this chapter." By implementing GCDs, the Texas legislature has demonstrated that even though they will uphold the Rule of Capture, it is not without reasonable regulation by the state in order to reduce any waste of the resource.

### 1.4 Aquifers of Texas

The Texas Water Development Board (TWDB) recognizes that there are 9 major aquifers and 31 minor aquifers in Texas underlying approximately 81 percent of the state (Figs. 1.1 & 1.2). A major or minor aquifer is determined by the amount of water they produce. A major aquifer produces a large amount of water over a large area. A minor aquifer produces minor amounts of water over a large area or large amounts of water over a small area (George, Ph, & Mace, 2011).

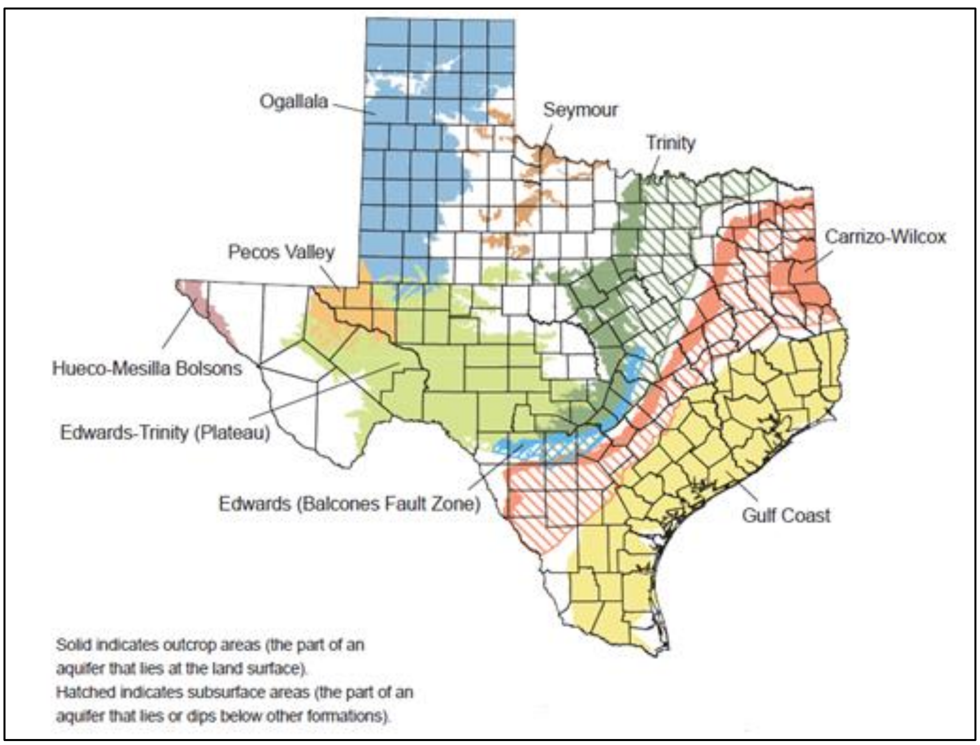



Figure 1.1 – This map displays the major aquifers within Texas (George et al., 2011).

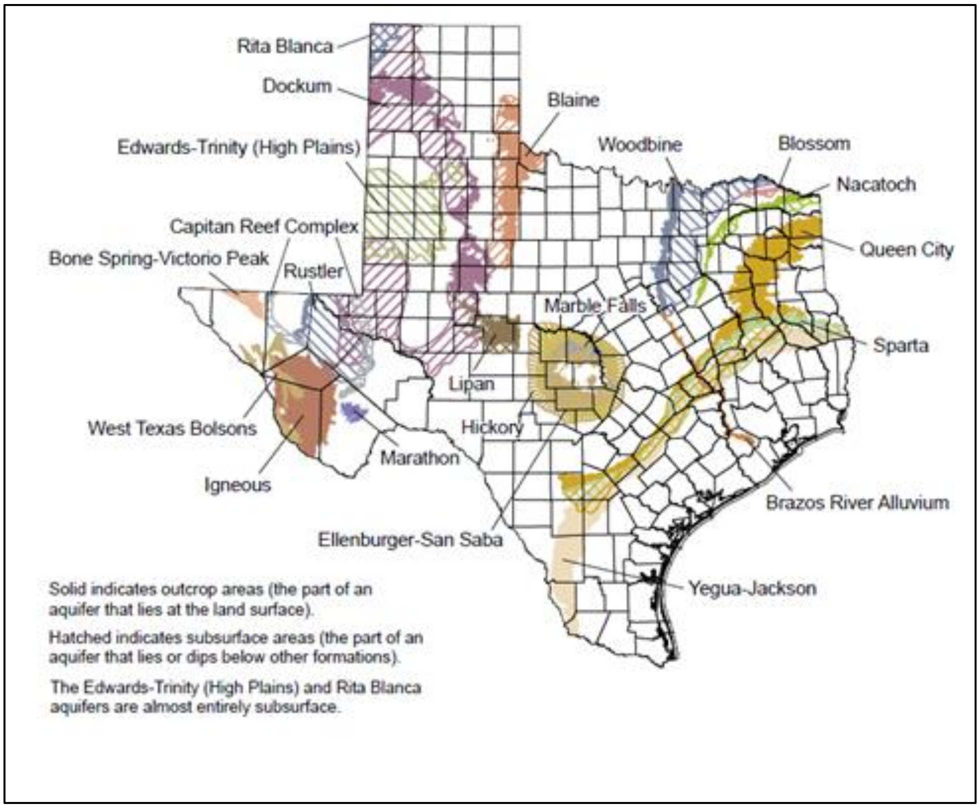



Figure 1.2 – This map displays the minor aquifers within Texas (George et al., 2011)

The aquifers of Texas are crucial to sustaining the state's population, industry, and especially agriculture. In 2003, 59 percent of the 15.6 million acre-feet of water used in the state was supplied by an aquifer. Of that 59 percent, approximately 79 percent was used for irrigation purposes and approximately 36 percent was for municipal use (George et al., 2011). Even with an increased population and ongoing drought, the TWDB reports similar usage percentages but with a higher overall total use. The latest amount reported by the TWDB is 16.1 million acre-feet of water used in the state in 2012.

The ever-growing need for more water in Texas is taking a toll on the state's aquifers. Existing groundwater supply is the amount of groundwater that can be produced with current permits and existing infrastructures on an annual basis and is usually less than the total amount of groundwater that can be produced from an aquifer.

Groundwater availability is the amount of water from an aquifer that is available for use but this amount is in most cases not all of the water in the aquifer. While groundwater supplies are limited by the aquifer's hydrogeology and existing infrastructure, groundwater availability is limited by law, permits, groundwater management goals and rules, and planning group policy (George et al., 2011). Due to a projected decrease of availability in the Dockum, Edwards-Trinity (High Plains), Gulf Coast, Ogallala, and Seymour aquifers, it is expected that the state's water groundwater supplies will decline steadily to 5.8 million acre-feet per year by 2060 (Fig. 1.3). This is in additional to the water level declines that the state's aquifers have already encountered. Aquifer levels across the state have been dropping since the 1950s and range from less than 50 feet to more than 1,000 feet total water level decline (George et al., 2011) (Figure 1.4). The most impacted area for water level declines in the state is the Trinity aquifer of the Dallas-Fort Worth and Waco areas.

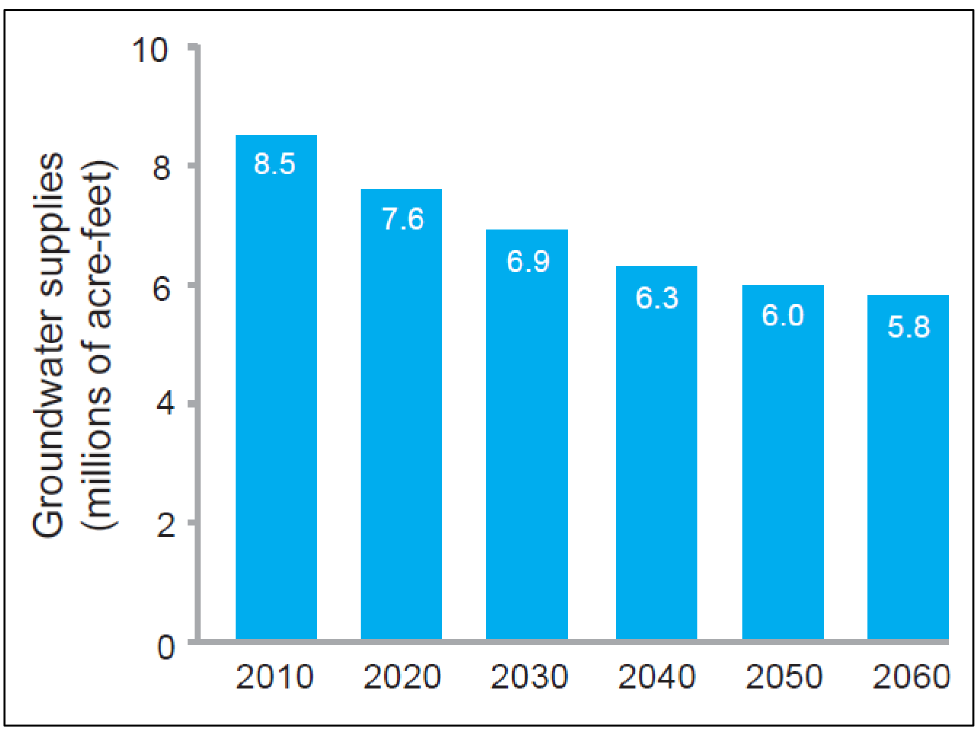



Figure 1.3 – Graph displaying projected groundwater supplies through 2060 (George et al., 2011).

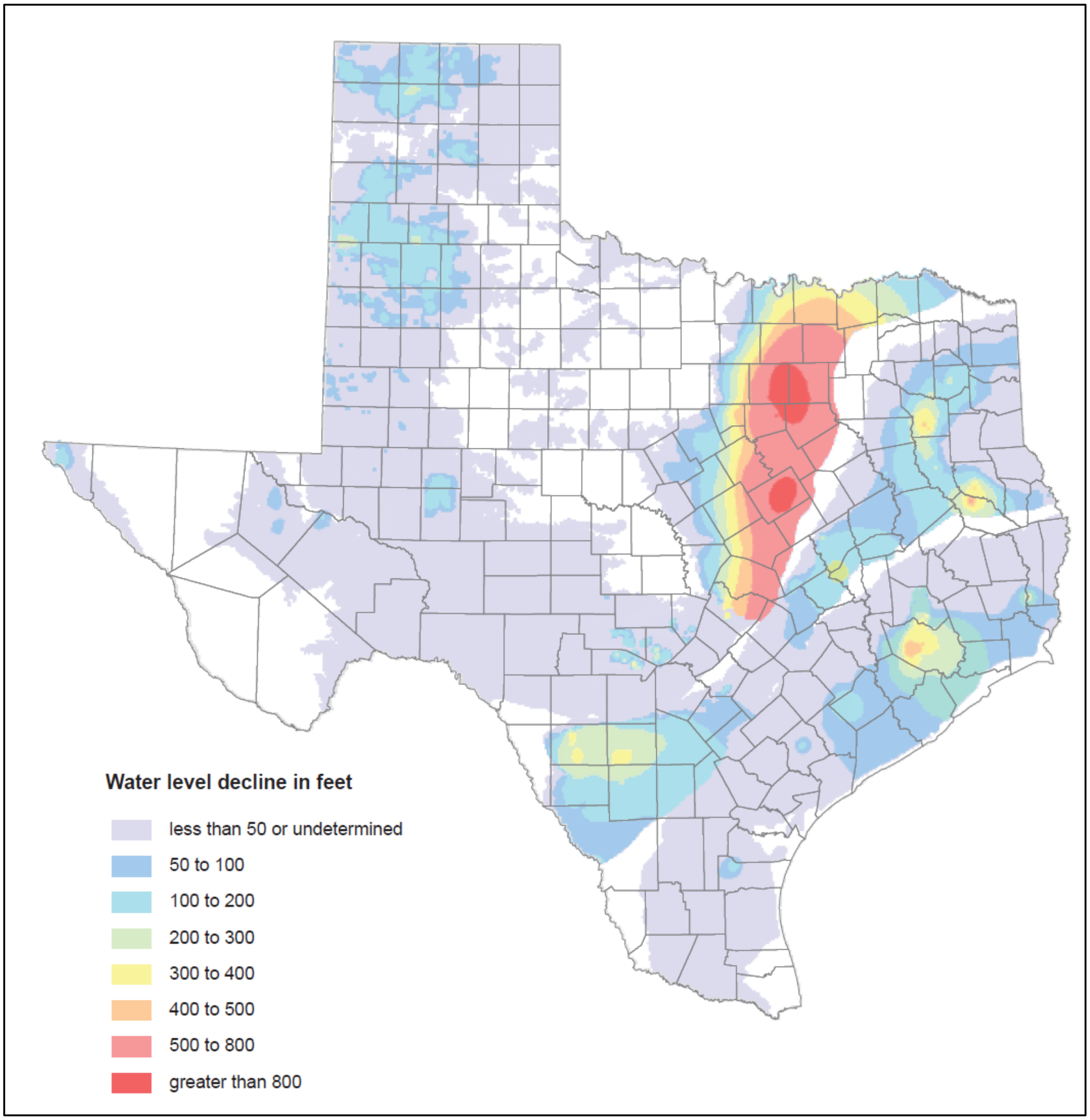



Figure 1.4 – Map of Texas displaying the estimated total water declines in the major aquifers. While most of the state has experienced some level of decline, the most impacted area in the state is in the Trinity aquifer of the Dallas-Fort Worth and Waco areas (George et al., 2011).

## 1.5 Brackish Groundwater in Texas

Most aquifers in Texas, both major and minor, contain brackish water (>1,000 mg/L total dissolved solids). It is estimated that there is approximately 2.5 billion acre feet of brackish groundwater in the state's aquifers and much more if water over 10,000 mg/L total dissolved solids (TDS) is included (LBG - Guyton Associates, 2003). The dissolved constituents (TDS) originate from chemical and biological reactions that occur between the water and soil and rock minerals as it percolates through the subsurface in various geologic formations. As the State of Texas varies greatly on the surface, it also vary varied in the subsurface thus water varies in TDS through the subsurface as a result of the different soil and rock minerals it comes in contact with.

While nearly every geographical region of the state has some brackish water, but west Texas, north-central Texas, central Texas, South Texas, and the Gulf Coast regions have the most significant amounts of brackish water (Kalaswad, Christian, & Petrossian, n.d.). Brackish groundwater is defined as groundwater containing between 1,000 and 10,000 milligrams per liter (mg/L) TDS. TWDB has defined aquifer water quality in terms of TDS and has been classified into 2 categories by the TWDB; slightly-saline (1,000 - 3,000 mg/L) and moderately-saline (3,000 - 10,000 mg/L). Fresh is water with less than 1,000 mg/L TDS, while very-saline water contain 10,000 - 35,000 mg/L TDS (George et al., 2011; LBG - Guyton Associates, 2003).

Even though brackish groundwater cannot be utilized for many uses, there are many wells in place throughout the state taking advantage of the resource. Currently, there are approximately 10,000 wells with a range in TDS of 1,000 to 10,000 mg/L and in depth up to 2,225 m (Figure 1.5) (Clayton, Stillwell, & Webber, 2014; Texas Water Development Board, 2015). Water with total dissolved solids of as much as 1,500 mg/L may be used to irrigate crops, depending on the type of crop and the levels of salt, sodium, carbonate, bicarbonate, nitrogen, and boron. Water with total dissolved solids as high as 3,000 mg/L may still be used for livestock (George et al., 2011). But generally, there is little competition for access to brackish groundwater as it is unusable for most agricultural irrigation and not preferred for livestock use (Clayton et al., 2014).

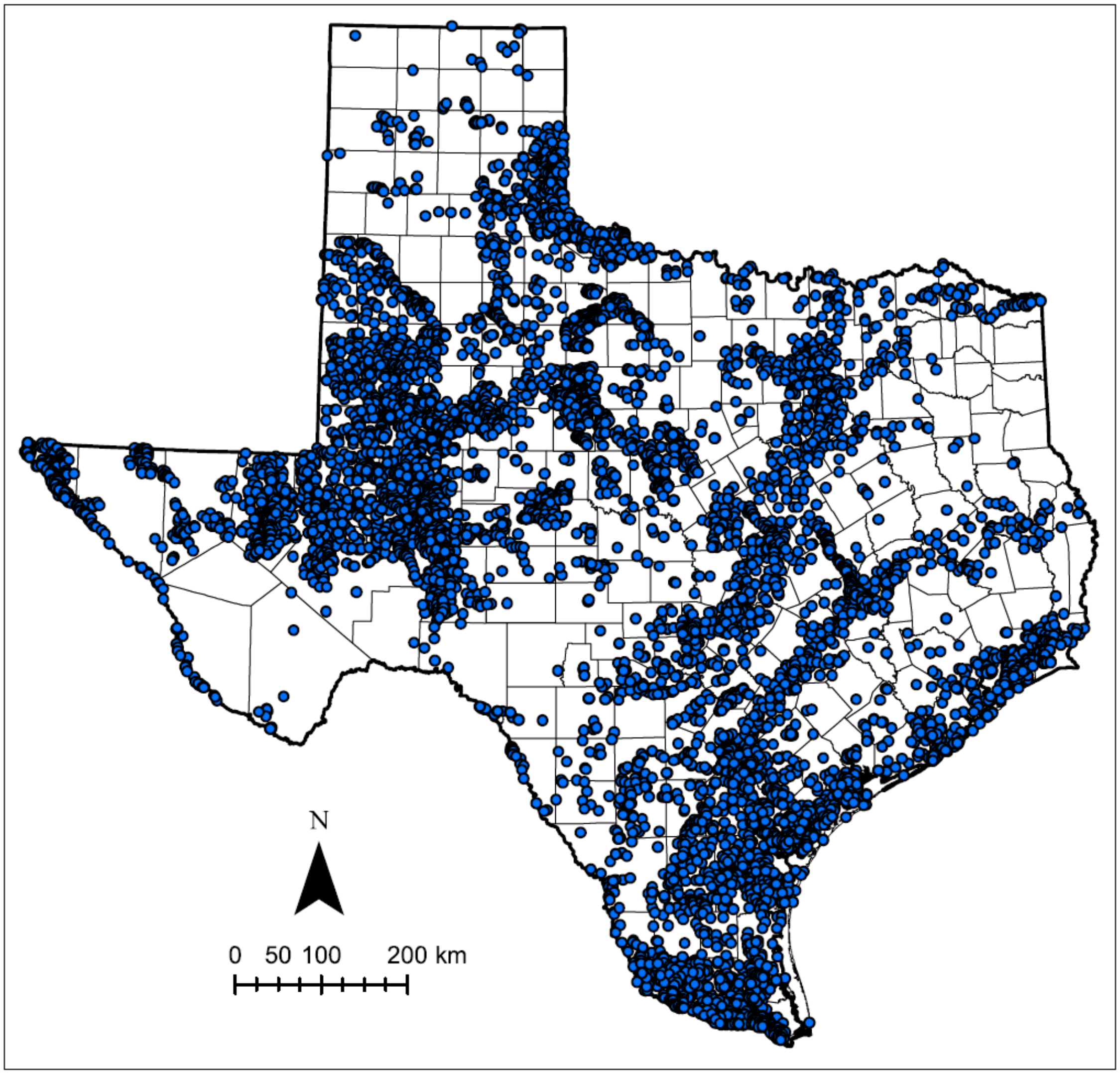



Figure 1.5 – Map of Texas displaying all the brackish (>1,000 mg/L TDS) groundwater wells. Each blue dot indicates a well (Clayton et al., 2014)

## 1.6 Barton Springs/Edwards Aquifer Conservation District

The BSEACD, was created in 1987 by the 70th Texas Legislature under Senate Bill 988 (now codified at Special District Local Laws Code, Chapter 8802) and Chapter 52 (revised to Chapter 36) of the Texas Water Code (TWC) in order to conserve, protect, and enhance the groundwater resources of the Barton Springs segment of the Edwards Aquifer and all other relevant groundwater resources located within the District boundaries. The District has been given the authority to make rules to implement its policies and procedures as well as undertake studies, employ facilities or programs in order to ensure the proper management of the groundwater resources in the area (Barton Springs/Edwards Aquifer Conservation District, 2013).

The BSEACD is located in Central Texas and includes portions of southeast Travis, northeast Hays, and northwest Caldwell Counties. It is bounded on the west by the western edge of the Edwards Aquifer outcrop and on the north by the impounded Colorado River. The eastern and southeastern boundary is generally formed by the easterly service area limits of the Creedmoor-Maha Water Supply Corporation and Goforth Special Utility District, as they existed when the District was formed (Barton Springs/Edwards Aquifer Conservation District, 2013). The District is bordered by several other GCDs including the Hays Trinity GCD, Edwards Aquifer Authority, Plum Creek Conservation District, and Lost Pine GCD (Figure 1.6). The area encompasses approximately 247 square miles in Caldwell, Hays, and Travis Counties. Its land use in 2007 was estimated to be about 29 percent urban/suburban, 51 percent ranchland/farmland, 19 percent open space/conservation land/water, and 1 percent mining/landfill/other land use (Barton Springs/Edwards Aquifer Conservation District, 2010b, 2013). Although, in recent years, growing populations in Texas and especially in and around the Austin area have increased the percent of urban/suburban land use and reduced the ranchland/farmland land use.

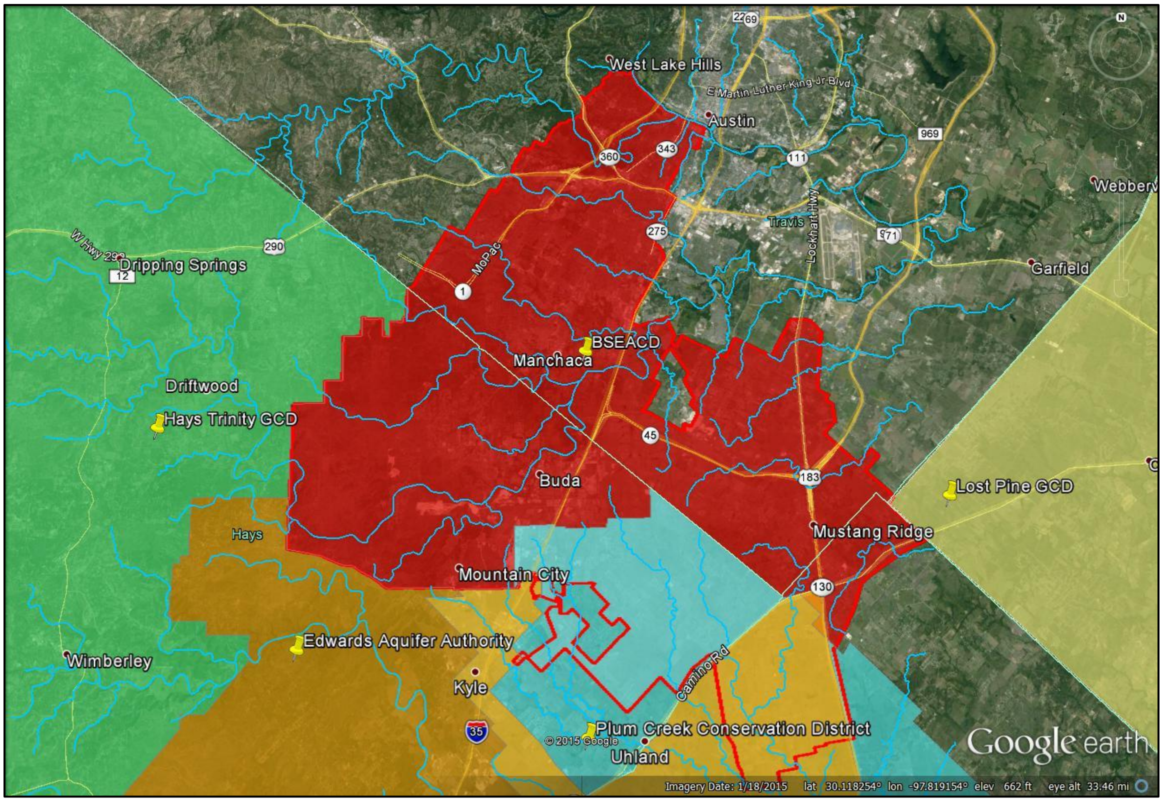



Figure 1.6 – Map displaying the boundaries of the BSEACD and other bordering GCDs. The BSEACD is outlined and filled in red, but as can be noted is overlapped by the Edwards Aquifer Authority and Plum Creek Conservation District (Smith, 2015).

The Edwards Aquifer in the BSEACD is the drinking water source for approximately 70,000 residents and growing. As shown in Figure 1.7, groundwater is primarily utilized for domestic and public water supply purposes. Commercial, irrigation, and industrial pumpage is less than 20% of the total use. Aside from being a water supply source, the Edwards aquifer also provides recreational opportunities and supports 11 threatened or endangered species (Barton Springs/Edwards Aquifer Conservation District, 2013, 2014b). The Barton Springs Pool in Austin's Zilker Park is man-made pool around a natural spring of the Edwards aquifer and hosts over half a million guests annually. The spring provides the habitat for the endangered Barton

Springs salamander, *Eurycea sosorum*; and the Austin blind salamander, *Eurycea waterlooensis*, which will likely be listed as endangered in the near future.

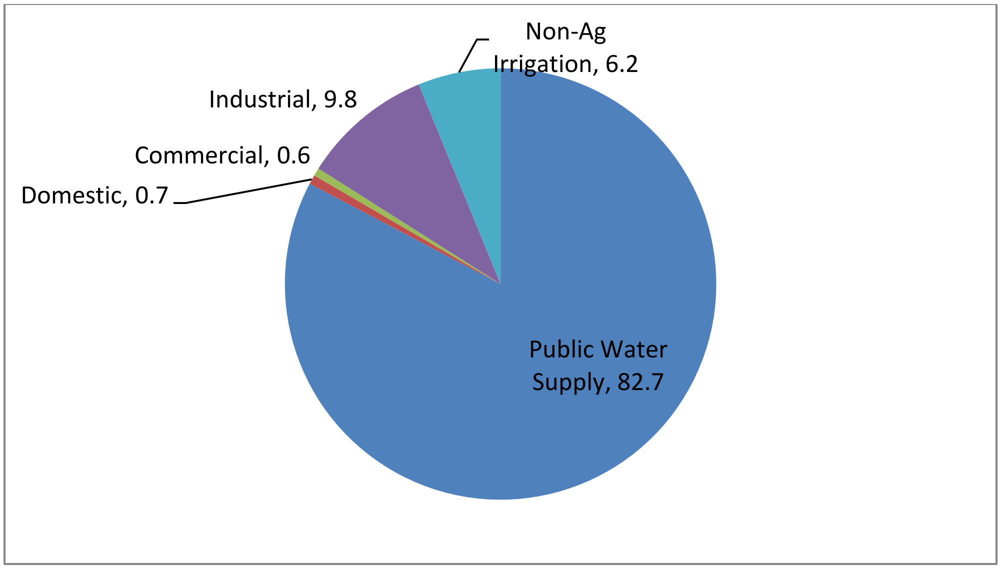
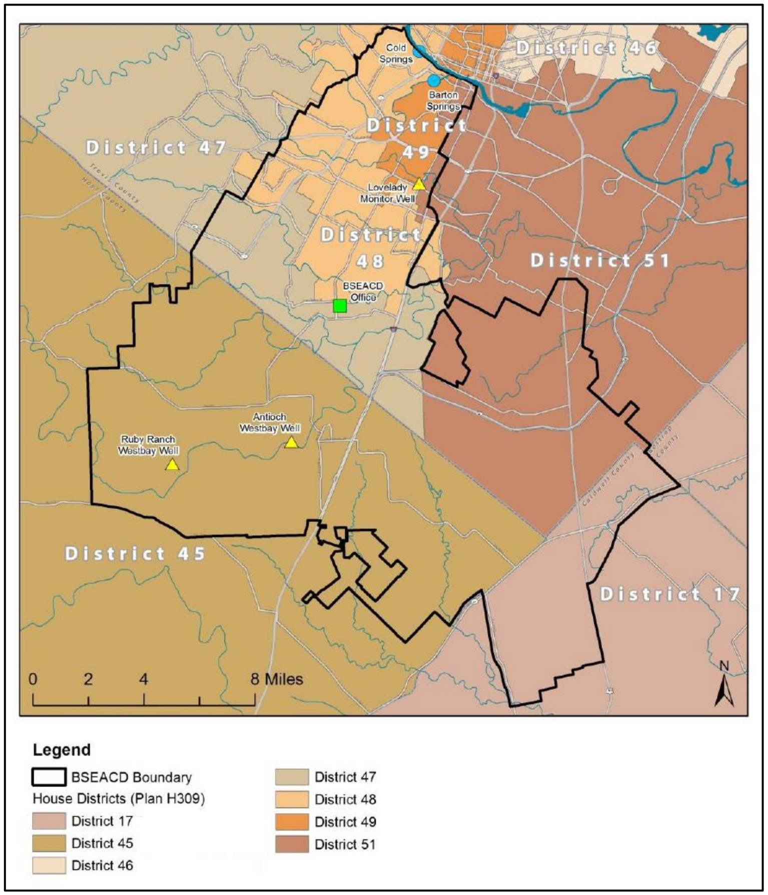



Figure 1.7 – Types of permitted groundwater use within BSEACD (Barton Springs/Edwards Aquifer Conservation District, 2013)

The BSEACD is relatively small in size compared to other districts but sits in a peculiar area that has varied political influence. As shown in Figures 1.8 and 1.9, the district is located within the boundaries of four State Senate Districts and seven State House Districts. Due to this and the varying legislative priorities of the State Senators and State Representatives, it is imperative for the District to maintain working relationships with all the legislators to support groundwater management and future projects. The District also sits lies within two Regional Water Planning Areas overseen by the TWDB and that part of the state's water planning process. Most of the District, including almost all of the freshwater groundwater production area, lies within the Lower Colorado Water Planning Region (Region K). A smaller portion of the District, in the south eastern vicinity, is within the South Central Texas Water Planning Region (Region L) (Figs. 1.10) (Barton Springs/Edwards Aquifer Conservation District, 2013). The district must coordinate with other GCDs to meet regional goals and plan future water strategies to be presented to the TWDB. Fortunately, water strategies in both regions are similar. And, the BSECAD also is within two Groundwater Management Areas (GMA) (Fig 1.11)



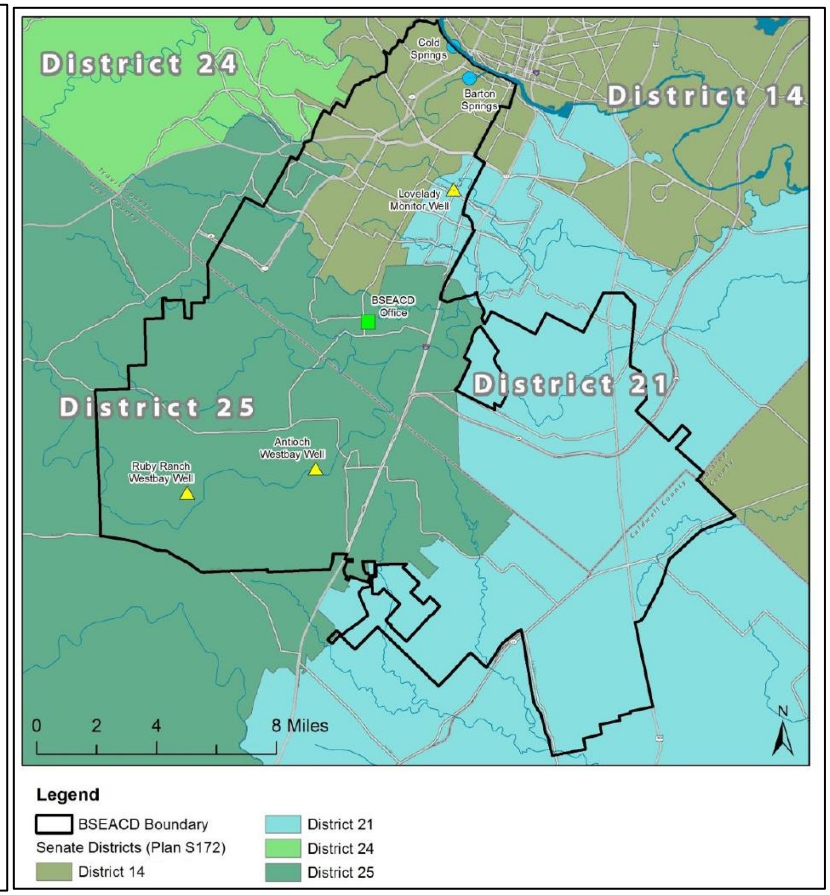
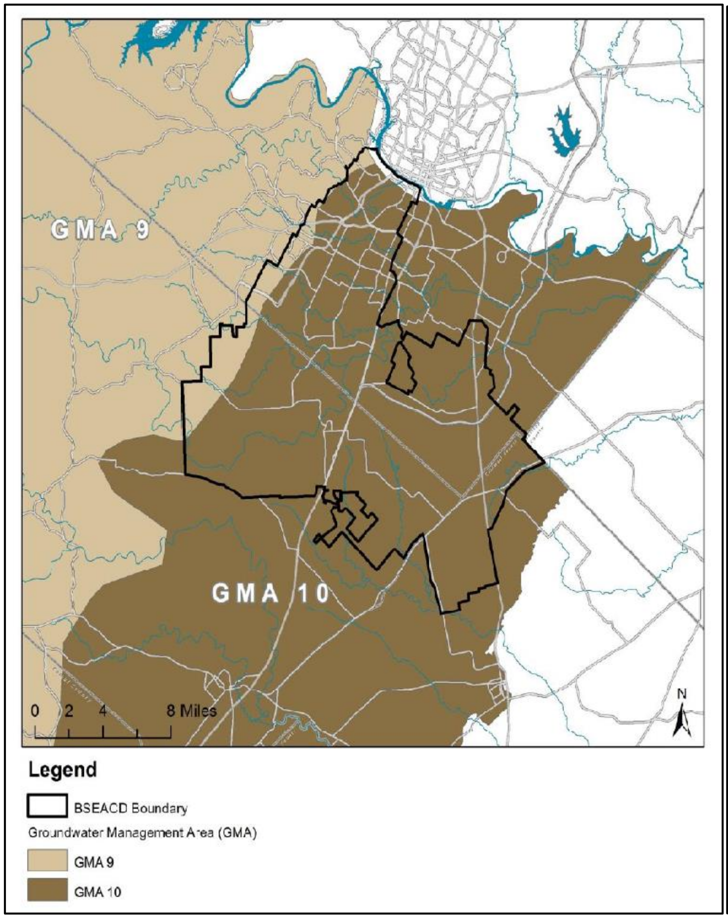




Figure 1.8 – Map of the BSEACD boundaries displaying Texas Senate districts within the District.
Figure 1.9 – Map of the BSEACD boundaries displaying Texas House districts within the District.
(Barton Springs/Edwards Aquifer Conservation District, 2013)



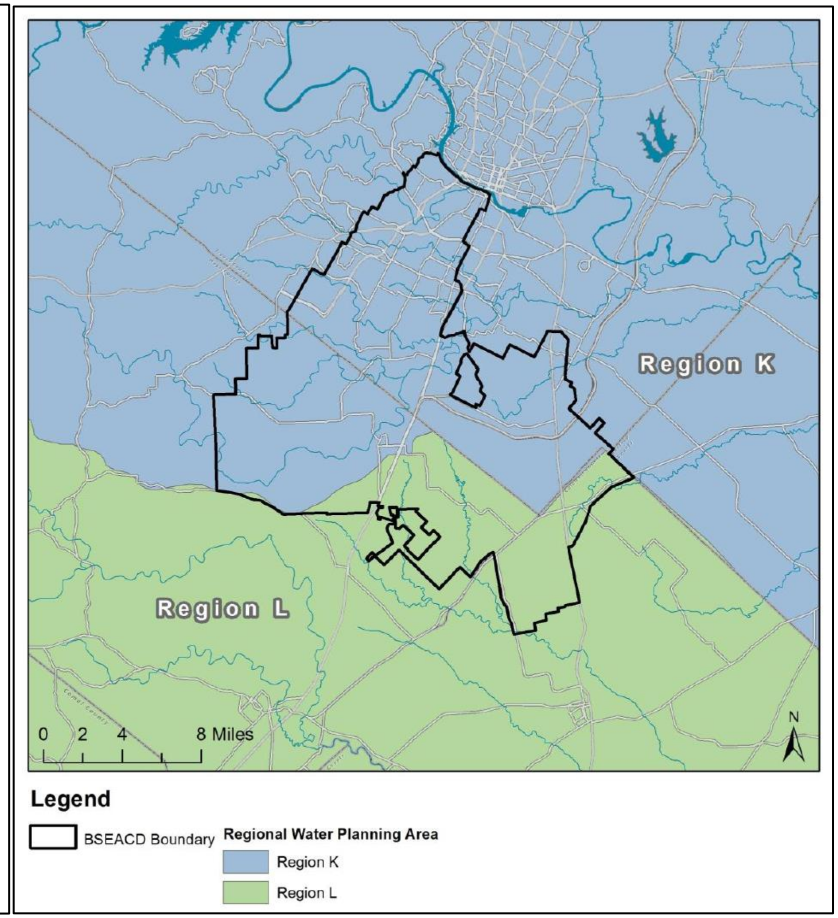




Figure 1.10 – Map of the BSEACD boundaries displaying pertaining Regional Water Planning Areas.
Figure 1.11 – Map of the BSEACD boundaries displaying pertaining Groundwater Management Areas.
(Barton Springs/Edwards Aquifer Conservation District, 2013)

## 1.7 Texas Demographics Outlook

The population in Texas is expected to increase significantly between the years 2010 and 2060, growing from 25.4 million to 46.3 million people or approximately an 82% growth (Texas Water Development Board, 2012b; U.S. Census Bureau, 2014). The latest estimate of population in Texas was in 2014 and at that time it was estimated that 26,956,958 people resided in the state. Of that number, Travis County had a population of 1,120,954 (2013 estimate) with a growth rate of 9.4% and the City of Austin had a population of 885,400 (2013 estimate) with a growth rate of 9.2 percent. This rate was significantly higher than the overall Texas growth rate of 5.4 percent (U.S. Census Bureau, 2014).

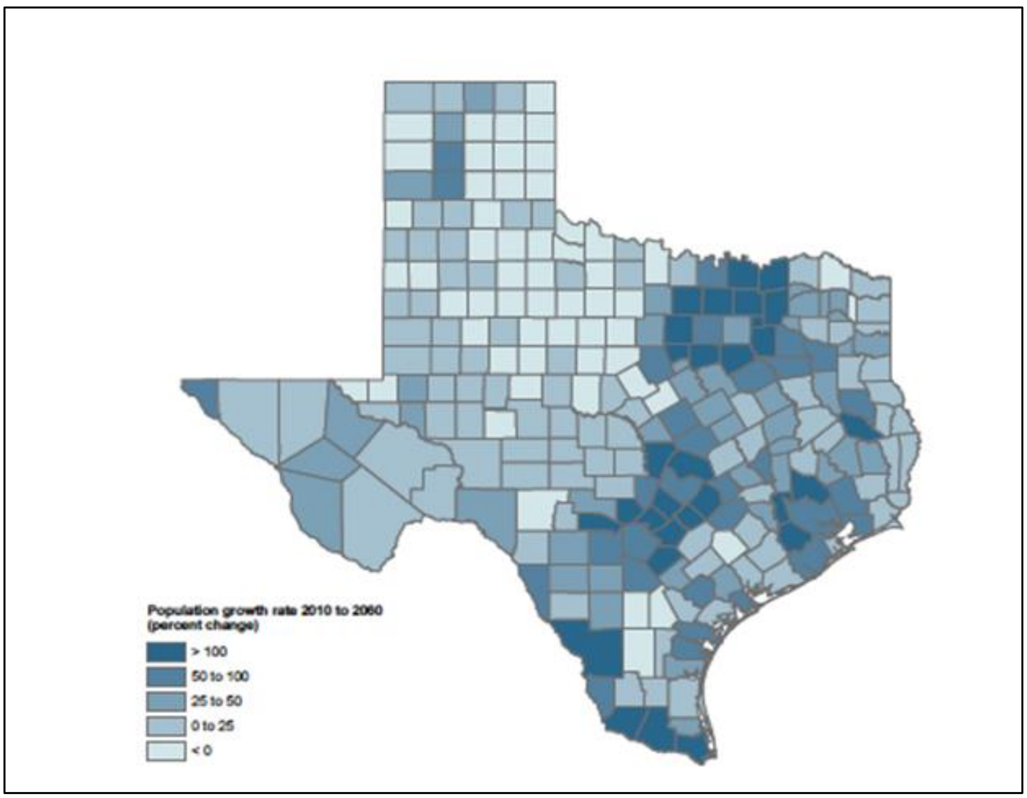



Figure 1.12 – Projected population growth prediction in Texas counties (Texas Water Development Board, 2012b)

The BSEACD area is also currently experiencing a substantial amount of growth and is expected to continue growing in population size just as is the rest of Texas (Fig. 1.12). The City of Austin contributes to the District's growth substantially as the city expands southerly further into the District's boundaries. As Austin continues to grow, so do the surrounding cities. The City of Buda has experienced a phenomenal growth rate of 39 percent while the City of Kyle has expanded at a rate of 13.4 percent (U.S. Census Bureau, 2014). Texas, central Texas, and the BSEACD are all experiencing population booms and will need to develop proper water management strategies in order to serve the changing and growing populations.

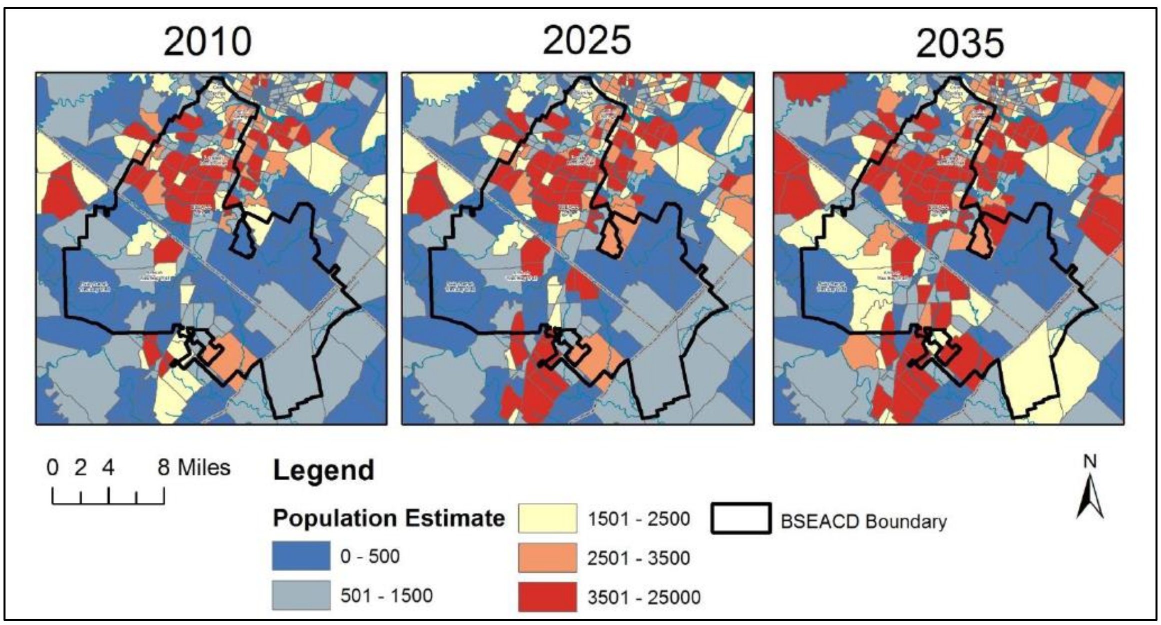


Figure 1.13 – Population Growth Predication for the BSEACD (Barton Springs/Edwards Aquifer Conservation District, 2013)

# Chapter 2: Regulatory Requirements

## 2.1 Desalination Regulation Background

The desalination of brackish groundwater requires interested parties to adhere to several Federal and State regulations. These regulations stem from two issues related to the planning and implementation of desalination plants. The issues relating to desalination are the actual development of the water source and the disposal or management of the concentrate created by the plant (Younos, 2009). Both these issues must be addressed on the Federal and/or state level in order to even commence construction of a desalination plant. While these two issues are highly regulated, once a desalination plant has been constructed, the regulation of the actual desalination process is almost absent (Younos, 2009).

## 2.2 Federal Regulations

There are several Federal laws that are relevant to desalination. The Federal Agencies responsible for implementing and enforcing that statues set forth by the U.S. Congress are the U.S. Environmental Protection Agency (USEPA), the U.S. Army Corps of Engineers (USACE), the U.S. Fish and Wildlife Service (USFWS), the National Marine Fisheries Service (NMFS), the U.S. Coast Guard (USCG), the U.S. Bureau of Reclamation (USBR), and the U.S. Bureau of Ocean Energy Management (US BOEM) for issues related to the Gulf of Mexico's Outer Continental Shelf.

| Table 1.1: An Overview of Federal Regulations and their Application to Desalination | | | |
|---|---|---|---|
| **Federal Regulation** | **Enacted** | **Purpose** | **Application to Desalination** |
| Clean Water Act (CWA) | Originally in 1948 as Federal Water Pollution Control Act; reorganized and expanded in 1972 | Basis for regulating discharges of pollutants into waters of the United States (National Pollution Discharge Elimination System (NPDES)) and regulating quality standards for surface water. | Brine and concentrate disposal are regulated as a point source of pollution through the NPDES Permit Program. Section 404 of the CWA authorizes the USACE to issue permits regarding disposal of dredge or fill materials to US navigable waters. Sections 316(a) and 316(b) require a desalination operator to reduce any impacts that may occur due to the discharge of heated water to receiving waters and reduce the effects of entrainment and impingement on marine life. |
| Safe Drinking Water Act (SDWA) | Originally in 1974; amended in 1986 and 1996 | Main federal law that ensures the quality of drinking water. Under SDWA, EPA sets standards for drinking water quality and oversees states, localities, and water suppliers. | The SDWA tasks the USEPA with protecting drinking water sources, protecting wells and collection systems, making sure water is treated by qualified operators, ensuring the integrity of distribution systems, and informing the public on the quality of their drinking water. Any desalination facility that provides water for public consumption must adhere to the SDWA. Also of concern is desalination facilities that are injecting concentrate into wells. They must not put potential public drinking water at risk. |
| Resource Conservation and Recovery Act (RCRA) | Originally in 1976; also includes the Federal Hazardous and Solid Waste Amendments of 1984 | Gives USEPA the authority to control hazardous waste from the "cradle-to-grave." This includes the generation, transportation, treatment, storage, and disposal of hazardous waste. RCRA also set forth a framework for the management of non-hazardous solid wastes. | RCRA applies to the disposal of the concentrate discharge to receiving waters. |

| Table 1.1 (cont.): An Overview of Federal Regulations and their Application to Desalination | | | |
|---|---|---|---|
| Superfund Amendments and Reauthorization Act (SARA) | A 1986 amendment of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) | Created a tax on the chemical and petroleum industries and provided broad Federal authority to respond directly to releases or threatened releases of hazardous substances that may endanger public health or the environment. | Only applies to desalination facilities if the discharge contains any substances on the Extremely Hazardous Substances list described in Section 313 of SARA |
| Endangered Species Act | 1973 | Provides a program for the conservation of threatened and endangered plants and animals and the habitats in which they are found. The program is primarily lead by the USFWS. | The USFWS can require a desalination facility to prepare a formal biological report if the possibility of affecting an endangered species exists or potentially exists. |
| Water Desalination Act | 1996 and reauthorized in 2011 | Perform research on desalination, conduct development and demonstration activities to test technological advancements, confirm economics, and gain public acceptance, and support operation and maintenance at the Brackish Groundwater National Desalination Research Facility | Desalination facilities could be involved with the USBR through a variety of grants and contracts |

(US Environmental Protection Agency, n.d.; Younos, 2009)

## 2.3 Texas Regulations

Texas requires a variety of permits to be issued to interested parties before construction commences in order to ensure proper design and authorizations. The TWDB in conjunction with a contracted consulting firm have developed a guidance manual to use in the planning process of a desalination facility. This guidance manual also includes a Permit Decision Model that facilitates permit requirements through a simple decision tree analysis (Younos, 2009). Desalination permits are reviewed and approved by a variety of state agencies but is mostly done by the TCEQ. Other agencies involved in the permitting process include the TWDB, the Texas General Land Office (GLO), the Texas Department of Transportation (TXDOT), the Railroad Commission of Texas (RRC), the Texas Department of Licensing and Regulation (TDLR), and the Texas Historical Commission (THC). Additionally, other requirements may be required by local communities, groundwater conservation districts, utilities, and fire marshalls. (Younos, 2009).

Permitting for a desalination facility is divided into three major categories: facility construction, feedwater (including water rights), and residual management (Younos, 2009). For most of Texas this is the case, and a desalination facility can be put into operation after going through all the permitting requirements. Currently, the BSEACD does not have that option when it comes to disposing of the concentrate. Underground injection of desalination concentrate is the most feasible and long-term cost effective method of disposing of the concentrate. The Texas Supreme Court has described the Edwards Aquifer as "a unique underground system of water-bearing formations in Central Texas." (*Barshop v. Medina*, 1996). Because of the status of the Edwards aquifer, Texas Water Code §27.051(i) has prohibited the TCEQ from authorizing by rule or permit an injection well transecting or terminating in the Edwards aquifer unless the injection was of: (1) groundwater withdrawn from the aquifer; or (2) storm water, flood water, or groundwater through improved sinkholes or caves located in karst topographic areas (Brown, 2013).

Recent additions the Texas Water Code have made it easier for desalination plants to operate within the Edwards aquifer, particularly within the BSEACD. The introduction of Senate Bill 1532 amending Subchapter D, Chapter 27 of the Texas Water Code states that the TCEQ by rule may authorize an injection well that transects and isolates the saline portion of the Edwards aquifer and terminates in a lower aquifer for the purpose of injecting concentrate from a desalination facility or freshwater for aquifer storage and recovery (ASR). The new statue also authorizes an injection well that terminates in that part of the saline portion of the Edwards aquifer that has a total dissolved solids concentration of more than 10,000 milligrams per liter for the purpose of injecting concentrate from a desalination facility or freshwater from ASR into the saline portion of the Edwards aquifer provided that the injection well must be at least three miles from the closest outlet of Barton Springs (Zaffirini, 2013). The bill also allows for injections used for: (a) aquifer remediation; (b) nontoxic tracer dyes used for a hydrological study; or (c) "another beneficial activity that is designed and undertaken for the purpose of increasing protection of an underground source of drinking water from pollution or other deleterious effects" (Brown, 2013)

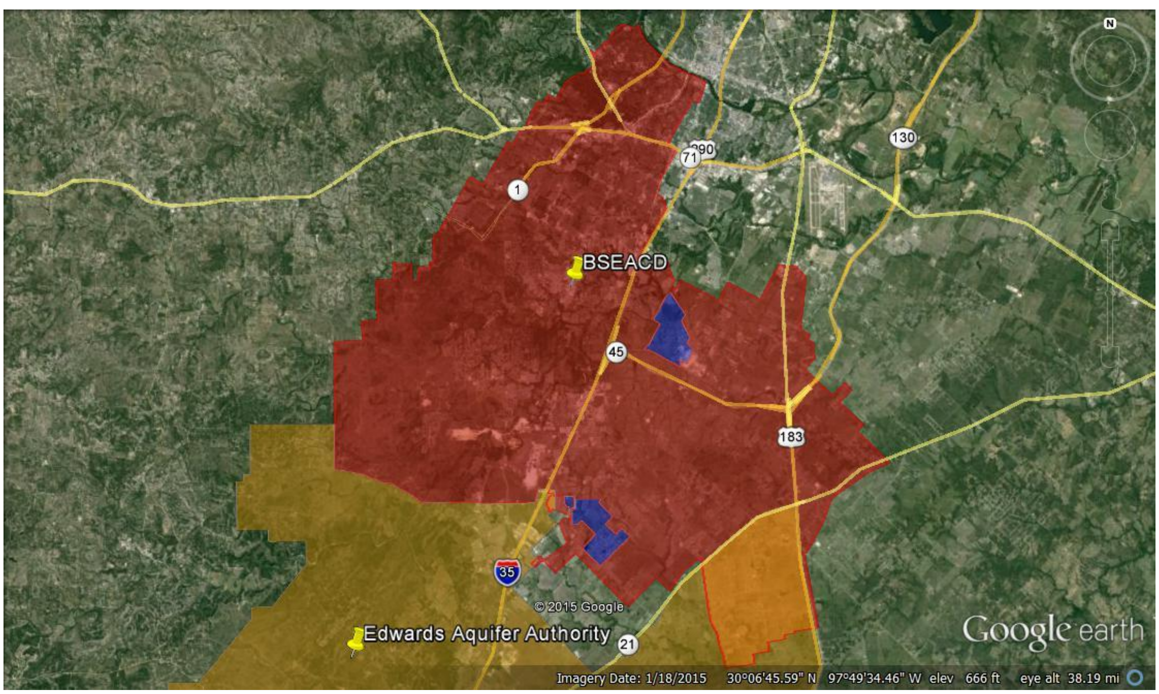



Figure 2.1 – Map of the BSEACD displaying the areas allowing injection as per SB 1532. The map also displays overlapping areas between the BSEACD and the Edwards Aquifer Authority (Smith, 2015).

While the bill does not allow widespread implementation of desalination facilities within the District, it does provide for a start point to desalination research within the portion of the Edwards Aquifer that is within the geographic area circumscribed by the external boundaries of the BSEACD but is not in that district's territory or the territory of the Edwards Aquifer Authority (Fig. 2.1) (Zaffirini, 2013). TCEQ can only grant permits for injection wells initially associated with "a small-scale research project" designed to evaluate the long-term feasibility and safety of injections of desalination concentrate. As defined in the bill, small-scale research project means "one production well and one injection well that are operated on a limited scale to provide requisite scientific and engineering information". The project findings must be shared with TCEQ and Texas State University-San Marcos. To issue a permit for the injections, TCEQ must: (a) hold a public meeting; (b) require monitoring of the injection well; and (c) ensure that the injections do not result in the waste or pollution of fresh water (Brown, 2013)

Currently, the only project that would fit the bill is a desalination pilot project slated for Texas Disposal Systems in Creedmoor in southern Travis County. The project would be a part of an ongoing effort by the BSEACD to bring desalination into the district. While the bill allows for few locations where the facility can be located, it does provide some important benefits. First, it could open the door to research injection wells that eventually become commercial injection wells. Second, through "small-scale research" and through the more broadly authorized use of remediation and other "beneficial" activities, it could help to generate data and encourage the use of groundwater desalination or aquifer storage and recovery within the BSEACD (Brown, 2013).

# Chapter 3: Overview of Water Use and Planning in Texas

### 3.1 State of Water Use in Texas

The seven year drought of record that occurred in the 1950s brought on the development of the TWDB in 1957 by act and by amendment of the state constitution. The TWDB is charged with, “leadership, planning, financial assistance, information, and education for the conservation and responsible development of water for Texas,” according to its mission statement. The board has recently become more visible to the public due to an ongoing drought in Texas that began in 2011 when approximately 88% of the state was in a state of exceptional drought (National Oceanic and Atmospheric Administration, 2015). While the severity of the drought has lessened in more recent years, it is still ongoing through many parts of the state and impacting the population (Figs. 3.1 and 3.2). Part of their mission includes issuing state water plans. The 2012 State Water Plan is Texas’ ninth water plan and the third to be developed through the regional water planning process, initiated by the Texas Legislature in 1997 (Texas Water Development Board, 2012b).

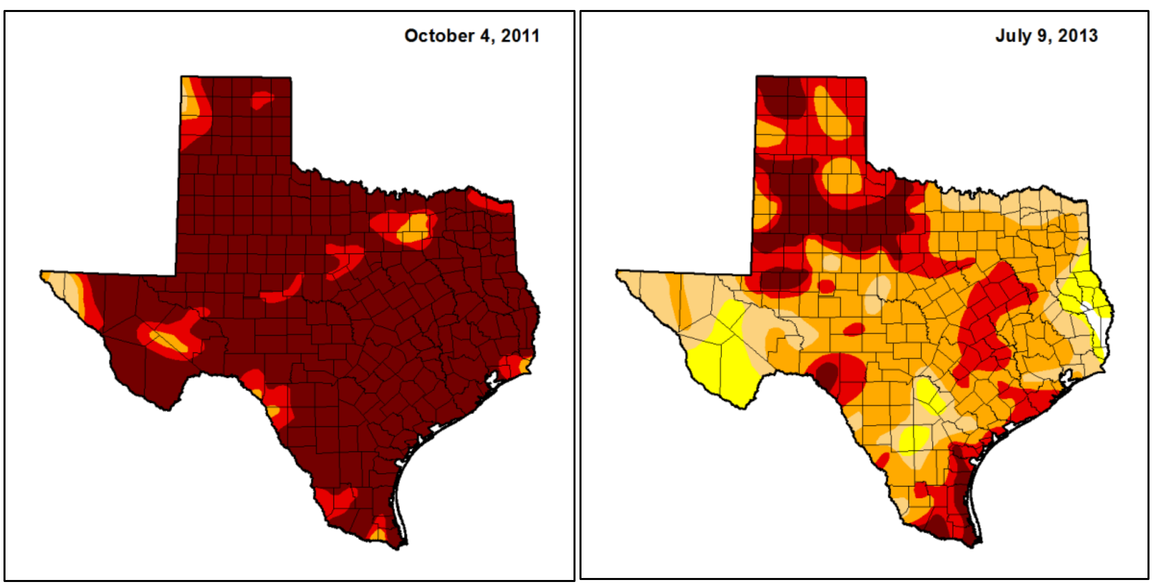



Figure 3.1 – Figure displaying the progression of drought conditions from their worst in 2011 to severe conditions in 2013 (National Oceanic and Atmospheric Administration, 2015)

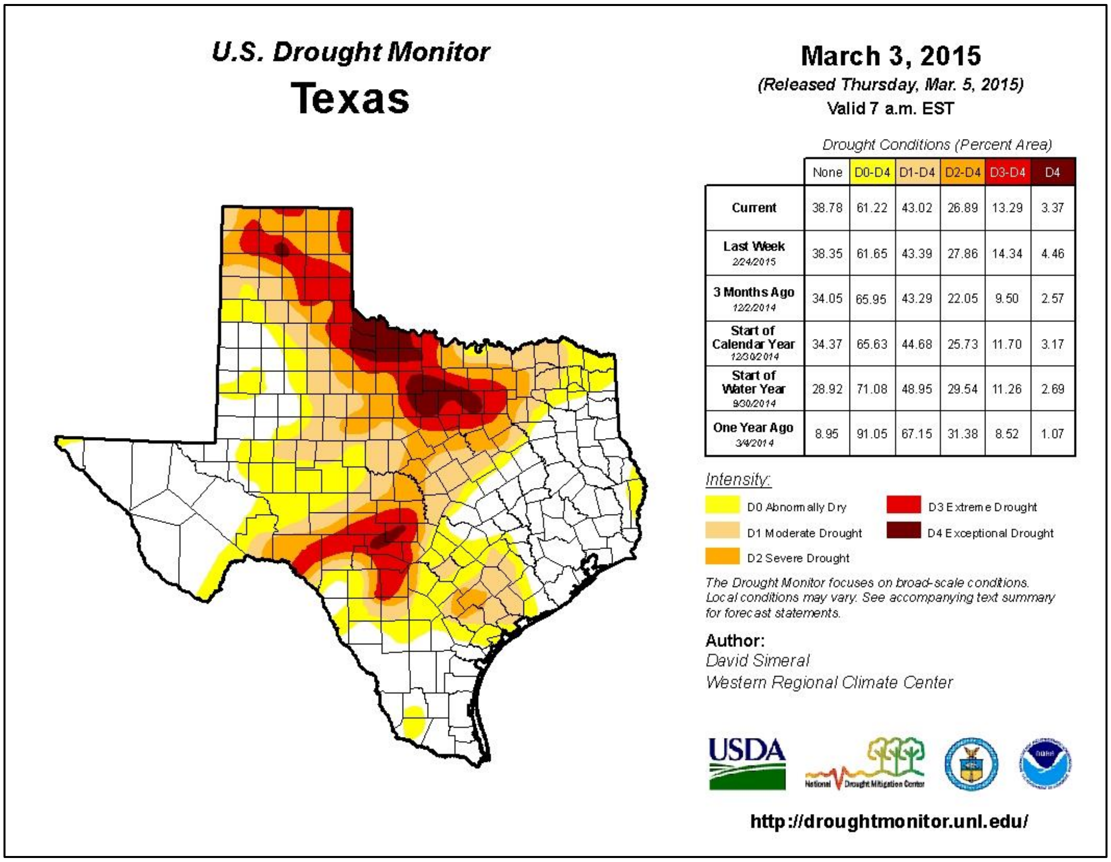



Figure 3.2 – Snapshot of the most current drought conditions across Texas. The Severity of the drought has lessened in many parts of the state, but some areas still remain under exceptional drought (National Oceanic and Atmospheric Administration, 2015).

The population in Texas is expected to increase significantly between the years 2010 and 2060, growing from 25.4 million to 46.3 million people or approximately an 82% growth (Texas Water Development Board, 2012b). The increase in population is expected to increase the water demand in Texas by 22%, from about 18 million acre-feet per year in 2010 to 22 million acre feet per year in 2060 (Texas Water Development Board, 2012b). This projected increase is causing many entities throughout the state to look into alternative means of supplying water to their communities.

There exist several different water users by sector within Texas, including: municipal, manufacturing, mining, steam-electric, livestock, and irrigation. Municipal users are defined as residential, commercial, and institutional users in cities with more than 500 residents, non-city utilities that provide more than 280 acre-feet per year (250,000 gallons per day), or a combined water user grouping of each county's remaining rural areas (Texas Water Development Board, 2012b). Out of all the groups, municipal is expected to have the largest increase in demand as more of the population is living in urban areas as compared to rural areas the TWDB began creating its State Water Plan. Municipal demand will grow by approximately 73% from the current use of 4,851,201 acre-feet per year in 2010 to 8,414,492 acre-feet per year in 2060 (Fig. 3.3). Texans leaving the rural parts of the state will result in a decline in the irrigation sector of the State Water Plan; the only sector to have a decrease. Irrigation demand will decrease by approximately 17% from 10,079,215 acre-feet per year in 2010 to 8,370,554 acre-feet per year in 2060 (Fig. 3.3). Overall, Texas is experiencing unprecedented growth in population and economic opportunities, but without appropriate water resource planning this growth could be hindered by the dwindling developed water supplies the state has relative to the water demands (Texas Water Development Board, 2012a).

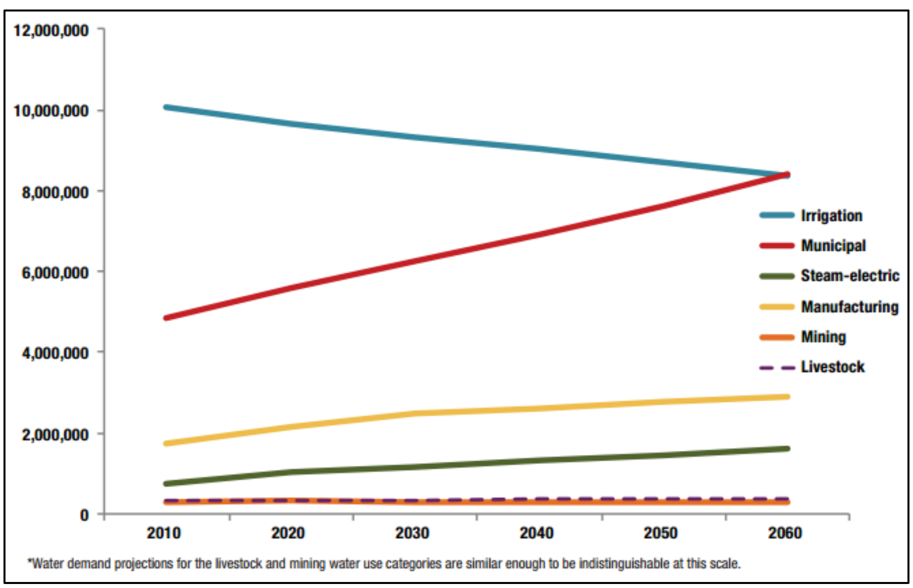



Figure 3.3 – Water demand projections by use category (acre-feet per year)

### 3.2 Overview of Texas Water Management Strategy

Water use in Texas is based on the concept of entities regulating and planning for Texas water needs. Water planning in Texas is complex and requires coordination and collaboration between local, regional, and state entities. Groundwater regulating entities will be the focus of this analysis due to the focus of the paper being on brackish groundwater desalination and the BSEACD, a groundwater regulating entity. Texas groundwater law is based on the “rule of capture” or “law of the biggest pump,” implying that a person owns an unlimited amount of groundwater that can be drilled within their property boundaries. While there are some constraints to the law such as GCD regulation and not wasting the water maliciously, the laws are there to protect the basic groundwater rights of all Texans and have consistently withstood several court rulings (Steinbach & Turner Jones, 2012).

As previously stated, the TWDB is charged with, “leadership, planning, financial assistance, information, and education for the conservation and responsible development of water for Texas.” The TWDB partially fulfills its mission by promoting water development projects to supply the water needs of the state over time (Texas Water Development Board, 2012b). It also provides loans and funding for state water projects (Steinbach & Turner Jones, 2012). The agency constantly collects information about water use throughout the state and produces a state water plan every five years with solutions to the water issues in different regions of the state based upon an analysis of their water use and how it is used. Local entities provide their management plans and modeling to the TWDB that then approves or further assists them in developing them. The TWDB assists each region in modeling for (Steinbach & Turner Jones, 2012):

- Groundwater Availability Models (GAMs)

- Modeled Available Groundwater (MAG), or the amount of water that may be produced on an average annual basis to achieve a desired future condition (DFC)
- Groundwater quality monitoring
- Groundwater level monitoring

In 2005, the Texas Legislature passed HB 1763 implementing a joint-groundwater planning process. HB 1763 requires that GCDs with common area in a GMA jointly make policy decisions that determine the volume of groundwater pumpage available for permitting. The TWDB provides assistance to the various entities in an effort to facilitate the joint planning process and develop the best regional water plan possible (Steinbach & Turner Jones, 2012).

In Texas, groundwater is primarily managed through the use of permitting, which is based from the MAG (Barton Springs/Edwards Aquifer Conservation District, 2010a; French, 2012). Accuracy of the MAG is vital to producing a water plan for the upcoming fifty years, thus the TWDB works closely with local and regional entities in producing their DFCs. DFCs are updated at least every five years for "relevant" aquifers. These are nine major aquifers and twenty-one minor aquifers that have current groundwater production and are managed by local water regulators (French, 2012). GAMs are scientific approximations of the reality with the objective to define groundwater availability (French, 2012). GAMS can include information on each aquifer, such as recharge (amount of water entering the aquifer); geology and how that conveys into the framework of the model; rivers, lakes, and springs; water levels; aquifer properties; and pumping. By working together, the TWDB and entities across the state can develop a MAG and subsequently implement a water management plan (Fig. 3.4).

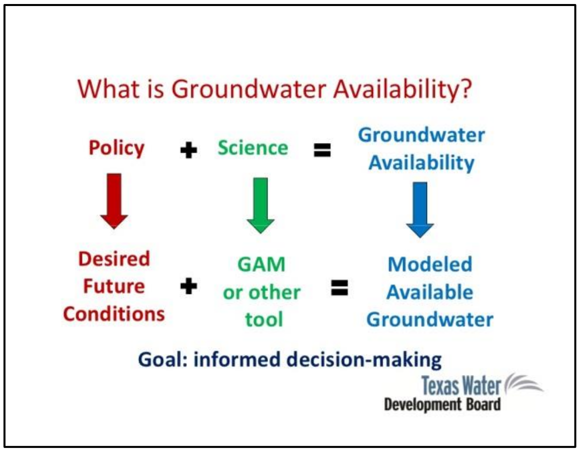



Figure 3.4 – Simple diagram displaying the integral parts of policy and science used to develop a groundwater availability amount that is used in developing a water management plan (French, 2012).

There are sixteen different regions of water planning that the TWDB assesses and gathers data from in the years prior to releasing a state water plan (Fig. 3.5). The BSEACD is located within Region K or the Lower Colorado Region. Within each region there exists GMAs and GCDs to regulate water on a regional and local scale.

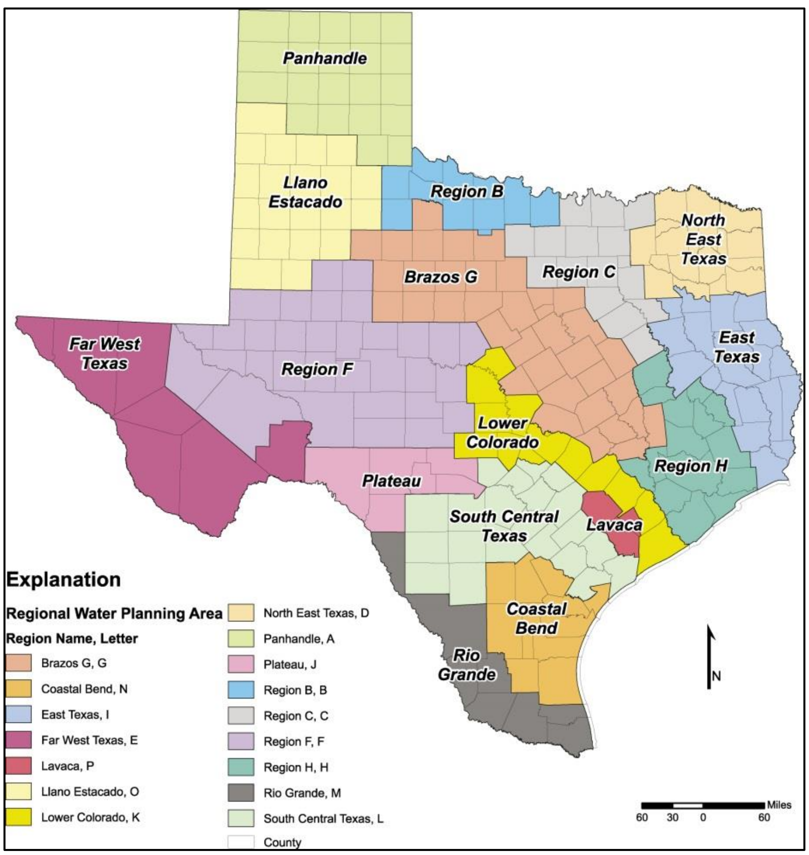



Figure 3.5 – Map of Regional Water Planning Areas in Texas

On a state wide basis, groundwater withdrawals are managed by the TWDB and TCEQ, but on a more local level GCDs manage withdrawals within their areas (Fig. 3.6). In 1997, Senate Bill 1 deemed GCDs are Texas's "preferred method of groundwater management". A GCD is "granted specific legal authority related to the management of groundwater and may regulate things like well spacing and groundwater production," as well as protecting and balancing private property interests (Steinbach & Turner Jones, 2012). A GCD does not own any groundwater but does have some tax authority on a local level and is created by either the TCEQ or the Texas Legislature to plan and regulate groundwater use within a locality (Steinbach & Turner Jones, 2012).

When planning, GCDs must consider aquifer uses and conditions, state water planning, hydrological conditions, private property rights, impacts on subsidence, socioeconomic impacts, environmental impacts, feasibility to achieve DFCs, and any other relevant information that is occurring that could impact long term groundwater use (Steinbach, 2013b). A GCD can regulate groundwater usage within its boundaries by issuing permits for (Steinbach & Turner Jones, 2012):

- Water well spacing
- Acreage-based regulation
- Use-based regulation

The primary purpose of issuing permits is to manage total groundwater production on a long-term basis to achieve a DFC. While achieving a DFC is important, a GCD must also take into consideration (Steinbach & Turner Jones, 2012):

- The MAG
- Exempt use estimates

- Previously (not permitted) authorized withdrawals
- Actual production estimates
- Yearly precipitation
- Production patterns

Due the high demand for water across the state, many GCDs have found themselves in a difficult situation. The high demand across Texas calls for the highest possible level of groundwater production possible in many GCDs. But, at the same time, GCDs are charged with conservation, protection, recharging, prevention of waste of groundwater, and control of subsidence within their districts. In a perfect situation, the demand and production would be balanced by the recharge and preservation and meet the DFC. The latest Texas State Plan recommends several strategies to meet DFCs (Table 3.1). From the several strategies, it is expected that groundwater desalination projects will add approximately 125,000 acre-feet of water by the year 2060 to the 2010 volume.

**Table 3.1 - Recommended Water Management Strategy Supply Volumes By Type of Strategy (acre-feet per year)**

| Types of Water Management Strategy | 2010 | 2020 | 2030 | 2040 | 2050 | 2060 |
|---|---|---|---|---|---|---|
| Municipal Conservation | 137,847 | 264,885 | 353,620 | 436,632 | 538,997 | 647,361 |
| Irrigation Conservation | 624,151 | 1,125,494 | 1,351,175 | 1,415,814 | 1,463,846 | 1,505,465 |
| Other Conservation | 4,660 | 9,242 | 15,977 | 18,469 | 21,371 | 23,432 |
| New Major Reservoir | 19,672 | 432,391 | 918,391 | 948,355 | 1,230,573 | 1,499,671 |
| Other Surface Water | 742,447 | 1,510,997 | 1,815,624 | 2,031,532 | 2,700,690 | 3,050,049 |
| Groundwater | 254,057 | 443,614 | 599,151 | 668,690 | 738,484 | 800,795 |
| Reuse | 100,592 | 428,263 | 487,795 | 637,089 | 766,402 | 915,598 |
| Groundwater Desalination | 56,553 | 81,156 | 103,435 | 133,278 | 163,083 | 181,568 |
| Conjunctive Use | 26,505 | 88,001 | 87,496 | 113,035 | 136,351 | 135,846 |
| Aquifer Storage and Recovery | 22,181 | 61,743 | 61,743 | 72,243 | 72,243 | 80,869 |
| Weather Modification | 0 | 15,206 | 15,206 | 15,206 | 15,206 | 15,206 |
| Drought Management | 41,701 | 461 | 461 | 461 | 461 | 1,912 |
| Brush Control | 18,862 | 18,862 | 18,862 | 18,862 | 18,862 | 18,862 |
| Seawater Desalination | 125 | 125 | 143 | 6,049 | 40,021 | 125,514 |
| Surface Water Desalination | 0 | 2,700 | 2,700 | 2,700 | 2,700 | 2,700 |
| **Total Supply Volumes** | **2,049,353** | **4,483,040** | **5,831,779** | **6,518,415** | **7,909,290** | **9,004,839** |

(Texas Water Development Board, 2012b)

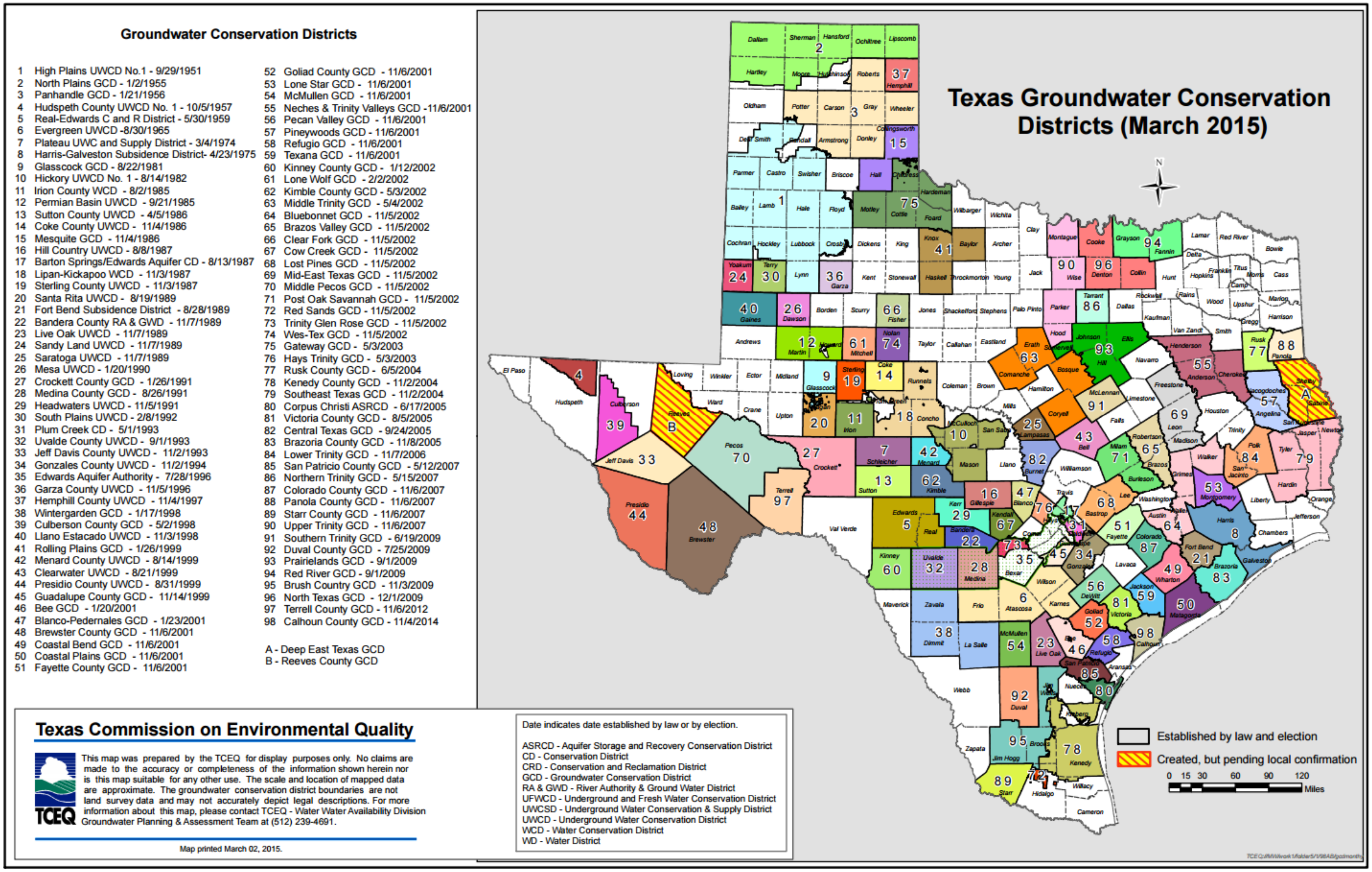



Figure 3.6 – Map of Groundwater Conservation Districts in Texas

### 3.3 Desalination Use in Texas

Water management strategies recommended by regional water planning groups include conservation, drought management, reservoirs, wells, water reuse, desalination plants, and others and if implemented can add 9.0 million acre-feet per year in additional water supplies by 2060 (Texas Water Development Board, 2012b). Desalination as described by the TWDB is the process of removing salt from seawater or brackish water. Recent improvements in membrane technology, new variations on evaporative-condensation techniques, and other more recent changes have made desalination more cost-competitive than ever before. The average cost of desalinating brackish groundwater in Texas ranges from \$357 to \$782 per acre-foot (Arroyo, Shirazi, Innovative Water Technologies, & Texas Water Development Board, 2012).

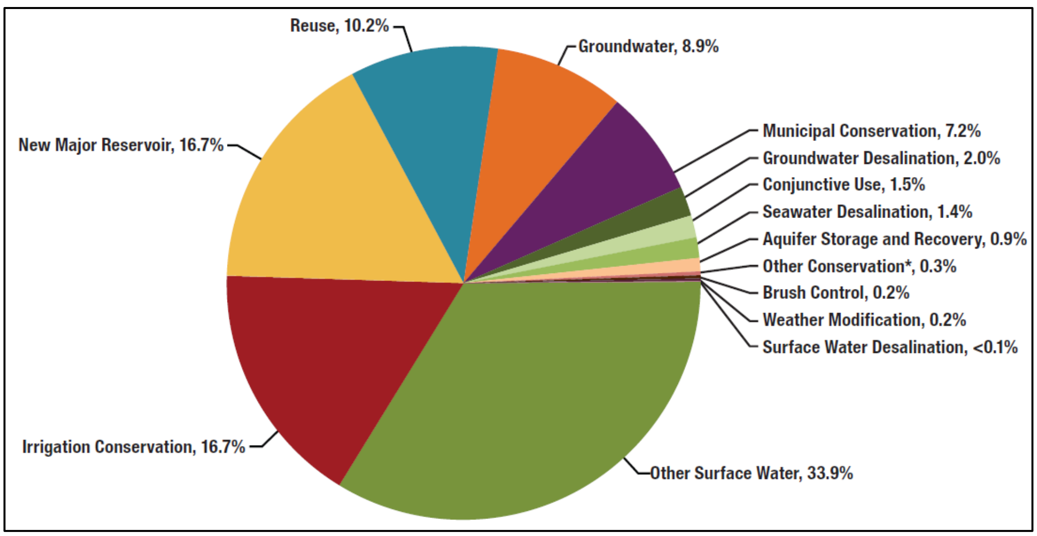



Figure 3.7 – Relative volumes of recommended water management strategies in 2060 (Texas Water Development Board, 2012b)

Desalination is included in the Groundwater Strategies of the 2012 State Water Plan. The Water Management Strategy recommended 181,568 acre-feet per year volume to be in place by 2060 up from 56,553 acre-feet per year in 2010 (Texas Water Development Board, 2012b). While the increase is substantial, the total output from groundwater desalination in 2060 will only be about 2 percent of the total supply of water across the state (Fig. 3.7). To put this into perspective, the average household uses approximately 400 gallons per day or nearly 0.45 acre-feet per year (US Environmental Protection Agency, 2008). By 2060, the supply from groundwater desalination will have the capacity to serve nearly 2.5 million people or the population of the Dallas-Fort Worth Metroplex including Arlington.

Even though groundwater desalination only accounts for 2 percent of the total water supply across the state in 2060, it is highly important to some regions of the state. Region E or Far West Texas is expected to supply the region's water needs with approximately 21 percent coming from groundwater desalination. Other regions such as the Rio Grande Region (L), Region F, and the South Central Texas Region (L) will be also be counting on groundwater desalination with overall uses of 13.7 percent, 6.8 percent, and 5.5 percent, respectively. Even though producing desalinated groundwater is historically more expensive due to the high energy demand, in many parts of the state where water is scarce it will become cost effective as compared to obtaining other sources of water such as those brought in from outside a region.

### 3.4 Water Use and Planning in the Barton Springs/Edwards Aquifer Conservation District (BSEACD)

As previously described, GMA's must update their DFCs to determine their MAG at least every five years. The BSEACD last adopted DFCs in 2010. Through a joint planning process with the northern subdivision of GMA Region 10 the following DFCs for the district were adopted (Barton Springs/Edwards Aquifer Conservation District, 2013):

- Edwards Balcones Fault Zone (Freshwater) DFC dated August 24, 2010
    - Springflow of Barton Springs during average recharge conditions shall be no less than 49.7 cubic feet per second (cfs) averaged over an 84-month (seven-year) period;
    - During extreme drought conditions, including those as severe as a recurrence of the 1950s drought of record, springflow of Barton Springs shall be no less than 6.5 cubic feet per second (cfs), averaged on a monthly basis.
- Saline Edwards Aquifer DFC adopted August 4, 2010
    - Well drawdown at the saline-freshwater interface (the so called Edwards "bad water line") in the northern subdivision of GMA 10 that averages no more than 5 feet and does not exceed a maximum of 25 feet at any one point on the interface.
- Trinity Aquifer DFC adopted August 23, 2010 (for the entire GMA 10)
    - 1) Except as otherwise provided herein: regional average well drawdown during average recharge conditions that does not exceed 25 feet (including exempt and non-exempt well use); 2) within the jurisdiction of the Hays-Trinity GCD: regional average well drawdown during average recharge conditions of zero (0) feet (including exempt and non-exempt well use); 3) in the Uvalde County part of GMA 10: regional average well drawdown during average recharge conditions of no more than twenty (20) feet (including exempt and non-exempt well use); 4) declare the Trinity

Aquifer in part of GMA 10 that is in the Trinity-Glen Rose GCD as a non-relevant aquifer.

After submitting the DFCs, the TWDB determined the MAG available to the District. These MAGS are in line with the amount of water the available from the aquifer in order to preserve the DFCs. The MAGs for the District as developed by the TWDB are as follows:

**Table 3.2 – Summary of MAGs**

| Aquifer | MAG (acre-ft/yr) | MAG(cfs) | TWDB GAM Report Citation |
|---|---|---|---|
| Edwards (freshwater) | | | (Hutchison & Oliver, 2011) |
| Average Conditions | 11,528 | 16 | |
| Drought Conditions | 3,756 | 5.2 | |
| Edwards (saline) | 523 | 0.72 | (Bradley, 2011) |
| Trinity aquifer | 1,288 | 1.78 | (Thorkildsend & Backhouse, 2011) |

(Barton Springs/Edwards Aquifer Conservation District, 2013)

Previous studies by Smith and Hunt in 2004 and Hunt in 2011 have supported that there is an approximate one-to-one relationship between springflow and pumping under low-flow conditions. Due to these studies, the BSEACD has implemented a drought MAG in order to maintain springflow. Springflow has been deemed important by the District in order to preserve endangered species populations at Barton Springs. The District's desire to maintain springflow during drought in order to preserve the habitat has been drafted into the Habitat Conservation Plan (HCP). The requirements of the HCP have been used to establish the DFCs for Edwards (Freshwater) aquifer segment and in turn the MAG (Barton Springs/Edwards Aquifer Conservation District, 2013).

The District has set a limit of 5.2 cfs groundwater withdrawals from the Edwards (Freshwater) aquifer during a recurrence of the drought of record (DOR) in order to comply with the DFC. This is achieved by utilizing a groundwater management regulatory program. This limitation is the Edwards (Freshwater) drought MAG and is nearly equivalent to the District's Extreme Drought Withdrawal Limitation (EDWL) that was developed as a key output of the HCP. The EDWL maximizes, within current statutory authority and current rules, the amount of springflow during the worst part of a drought similar to the DOR (Barton Springs/Edwards Aquifer Conservation District, 2013). EDWL pumping needs to be reduced by a further 1.5 cfs to equal the drought MAG (Fig 3.8). The District is continually researching and working with its groundwater users in order to meet the 1.5 cfs reduction goal.

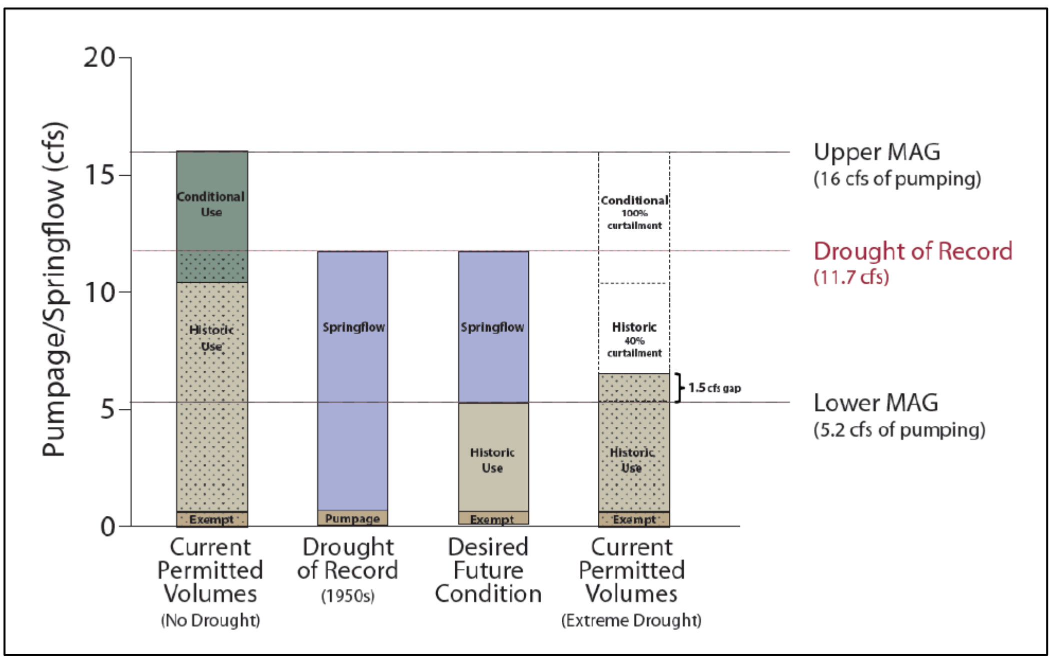



Figure 3.8 – Diagram of the District's MAG and the equivalent extreme drought withdrawal limitation formulation for the Edwards (freshwater) aquifer (Barton Springs/Edwards Aquifer Conservation District, 2013)

# Chapter 4: Geology

### 4.1 Geology of the Edwards Aquifer

Geologic processes over several millions of years such as deposition, tectonism, erosion, and diagenesis has created the Edwards Aquifer that we are familiar with today (Smith & Hunt, 2004). In general, the aquifer consists of highly faulted, cavernous, highly transmissive Cretaceous-age limestones (LBG - Guyton Associates, 2003).

Today, the Edwards Aquifer outcrop spans 1,560 square miles ($mi^2$) while the area in the subsurface spans 2,314 $mi^2$ (George et al., 2011) The aquifer is present in twelve counties in central Texas spanning approximately 250 miles beginning in Kinney County, west of San Antonio, and terminating in Bell County, north of Austin (Fig. 4.1). The Edwards Aquifer system also supports 11 threatened or endangered species, aquatic habitats in rivers of the Gulf Coastal Plain, and coastal bays and estuaries (Barton Springs/Edwards Aquifer Conservation District, 2014b). The Edwards Aquifer is hydrologically separated into three segments. North of the Colorado River is the Northern segment, south of the southern hydrologic divide near the City of Kyle is the San Antonio segment, and in between is the Barton Springs segment.

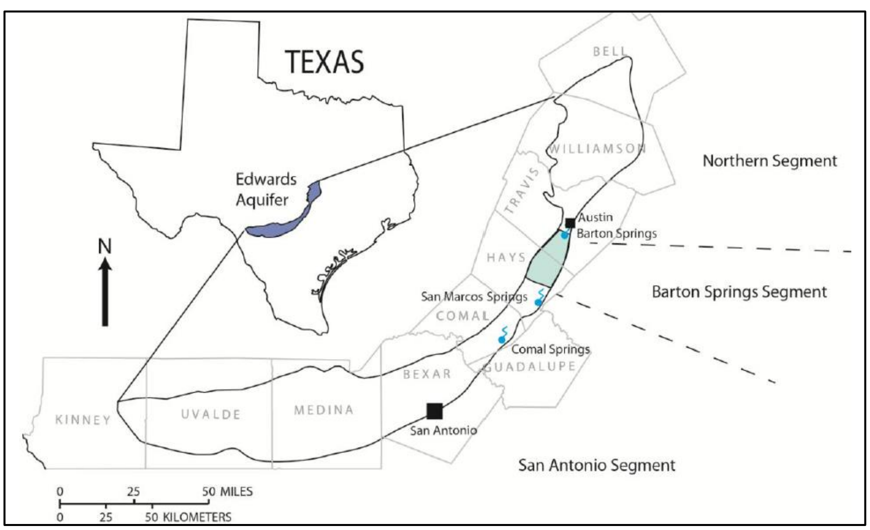


Figure 4.1 – Location map of the Edwards aquifer and its segments. The study is focused in the BSEACD which in the Barton Springs Segment (Barton Springs/Edwards Aquifer Conservation District, 2014b).

The Edwards Aquifer is composed of the Cretaceous-age Edwards Group (Kainer and Person Formations) and the Georgetown Formation (Smith & Hunt, 2004). Deposition of the Edwards Group occurred on the Comanche Shelf as shallow marine, intertidal, and supratidal deposits. The Georgetown Formation was deposited in a more shallow marine environment and disconformably overlays the Edwards Group.(Rose, 1972). Original sediments composed of aragonite, calcite, dolomite, and gypsum have been mostly replaced by calcite and are in the process of forming a highly porous and strongly heterogeneous limestone rock (Susan D. Hovorka J. P. Nicot, Adrien Lindley, 2004). Overall the thickness of the aquifer ranges from 200 to 600 feet, and freshwater saturated thickness averages 560 feet in the southern portion of the aquifer (George et al., 2011; LBG - Guyton Associates, 2003).

### 4.2 Fresh Water – Brackish Water Interface

The fresh water – brackish water interface, also known as the bad water line, runs east of Interstate 35 until it reaches the South Austin area where it crosses under Interstate 35 and begins to veer west (Fig. 4.2 and 4.3). The interface is a hydrochemical boundary where two distinctively different waters are separated within the Edwards Aquifer (Clement & Sharp, n.d.). To the west of the bad water line is the fresh water Edwards with a TDS concentration of generally less than 500 mg/L. In contrast, to the west of the bad water line is the saline Edwards with TDS concentrations ranging from 1,000 to 10,000 mg/L (Clement & Sharp, n.d.). Other than having varying salinities, the lithologies of the Edwards units to the east and west of the bad water line are essentially the same.

There are two main factors that contribute to the differences in salinity between the two sides: the extent of dissolution of the rocks and faulting that has offset the units by tens to hundreds of feet (Smith, Dupnik, Holland, & Hunt, 2012). On the west side of the fault between the recharge zone and Barton Springs, there is a high level of percolation of fresh water through the aquifer. The water is slightly acidic and has dissolved large amounts of the limestone and dolomite throughout geologic time. In contrast, fresh water on the east side of the fault percolates very slowly through the aquifer. The water is of similar acidity, but due to its slower rate of flow, it has not dissolved nearly as much rock. With not as much minerals being flushed out of the system, the water on the east side has higher concentrations of dissolved minerals and thus is considered brackish. The offset of the units also contributes to the east side of the fault being brackish. The offset has caused the east side to be isolated from the west and this limits the flow of fresh water creating a buildup of salinity (Fig 4.4) (Smith et al., 2012).

In the fresh water zone of the Edwards aquifer, transmissivities are commonly in millions of gallons per day per foot (gpd/ft) and porosities are typically in the 5% to 15% range (LBG - Guyton Associates, 2003). Due to this high productivity, the aquifer has been highly produced for many years for both irrigation and industrial and municipal uses.

The saline portion of the Edwards aquifer is still currently mostly undeveloped. With very few wells in place, the characteristics of the saline portion of the aquifer are not completely understood. With what information is available, the saline portion of the aquifer is generally considered to have a lower transmissivity, ranging between 5,000 to 100,000 gpd/ft and a storage coefficient of $1 \times 10^{-4}$ (LBG - Guyton Associates, 2003).

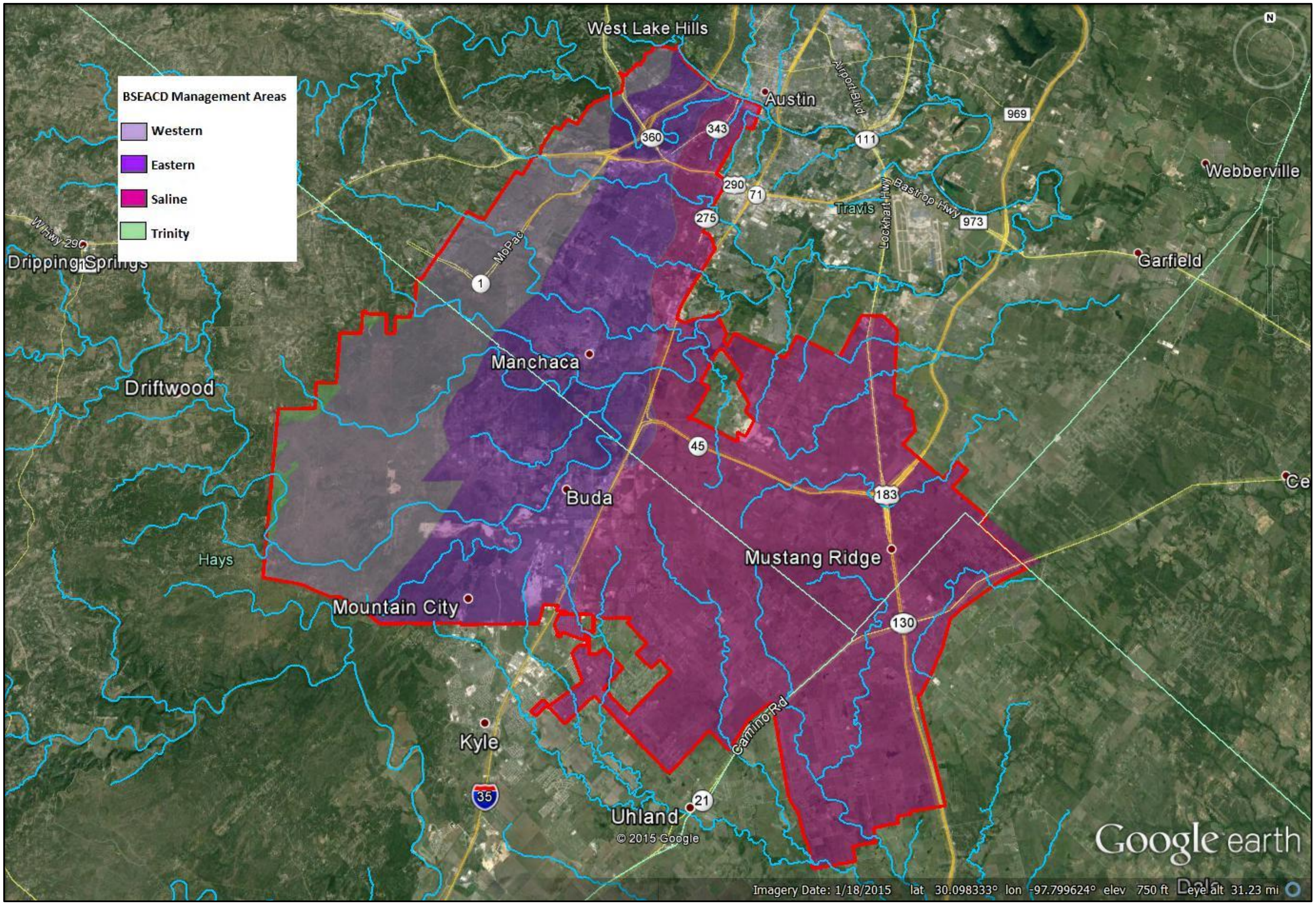



Figure 4.2 – Groundwater management areas in the Barton Springs/Edwards Aquifer Conservation District (Smith, 2015)

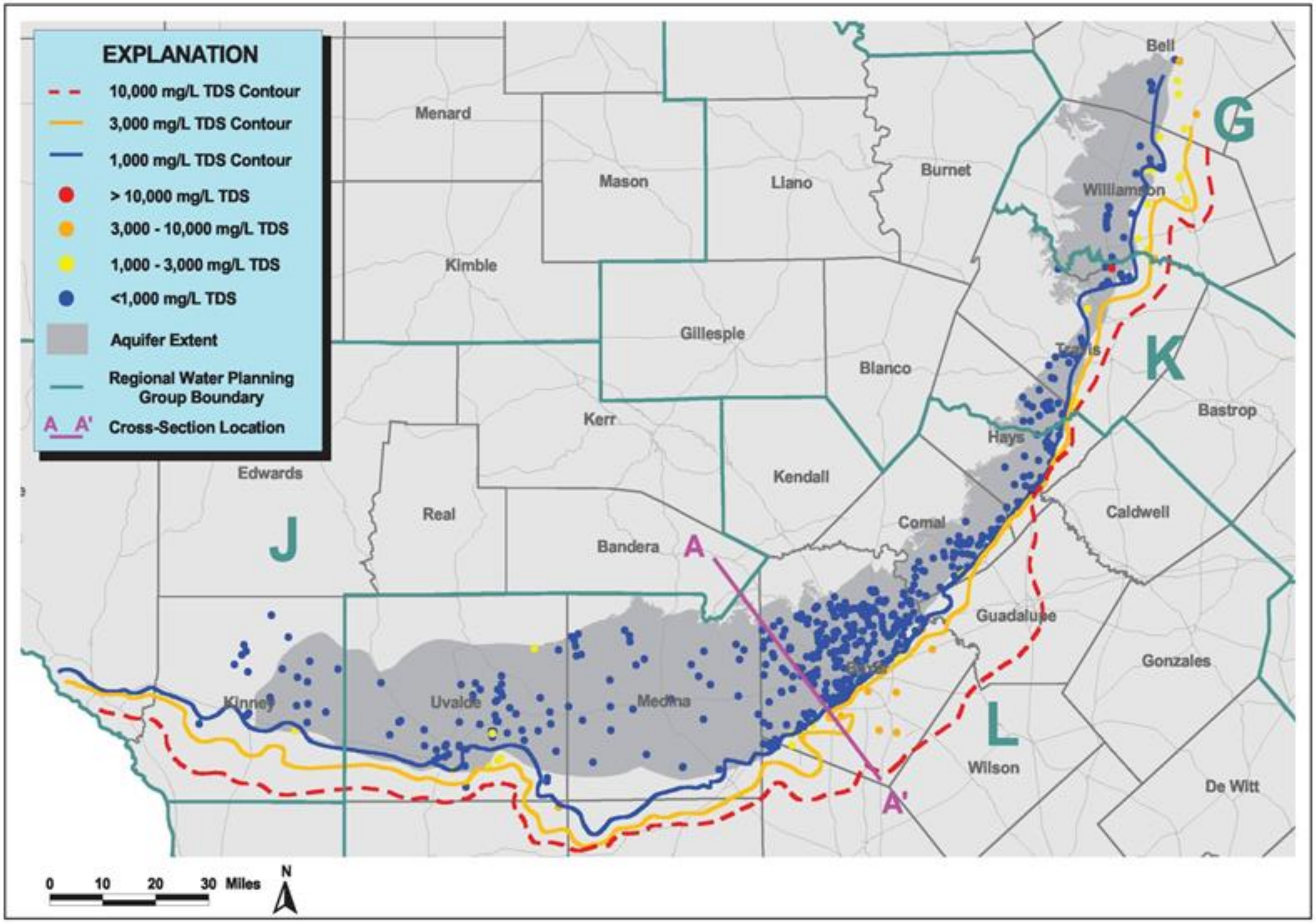



Figure 4.3 – Groundwater quality in the Edwards (Balcones Fault Zone) aquifer
(LBG - Guyton Associates, 2003)

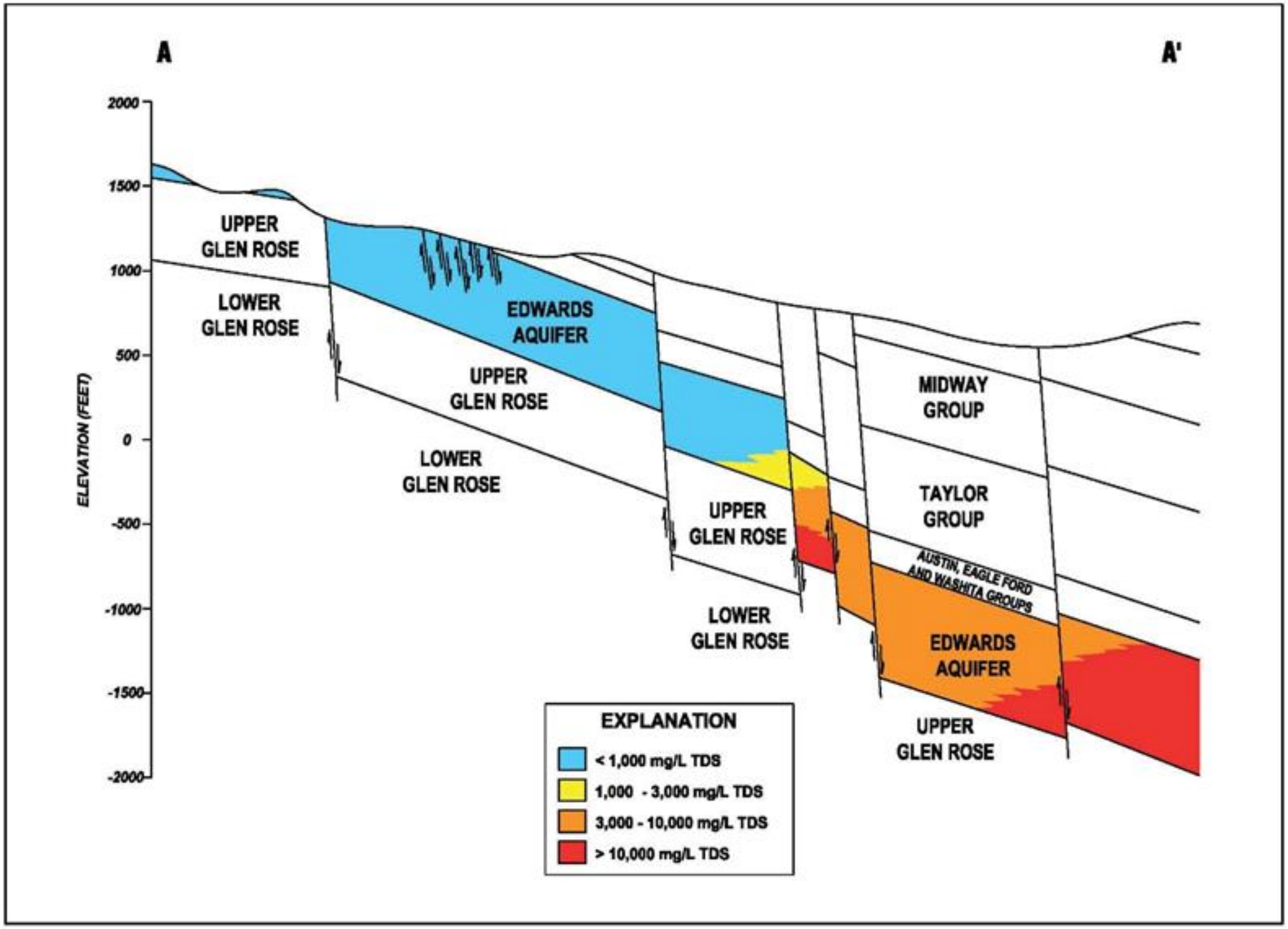



Figure 4.4 – Simplified cross-section of the Edwards (Balcones Fault Zone) aquifer with generalized water quality ranges (LBG - Guyton Associates, 2003)

## Chapter 5: Technology Description

## 5.1 Desalination

Desalination can be defined as any process that removes salts from water for the purpose of municipal, industrial, or commercial applications (Krishna, 2004). The process also removes unwanted bacteria, viruses, metals, as well as dissolved solids, Desalination is used to treat brackish water with TDS between 1,000 and 10,000 mg/L to a primary public use standard concentration of 500 mg/L TDS and a secondary standard of 1000 mg/L TDS set by the TCEQ (Clayton et al., 2014). A desalination process essentially separates saline water into two parts - one that has a low concentration of salt (treated water, permeate or product water), and the other with a much higher concentration than the original feed water, usually referred to as brine concentrate or simply as ‘concentrate’ (Krishna, 2004).

There are two basic categories of water purification technologies that are used for desalination: membrane technologies (pressure driven and electro-potential driven) and evaporation-based technologies (multistage flash or multiple-effect distillation). Desalination can also occur through a chemical approach but it is not widely used (J. Nicot, 2005; Younos & Tulou, 2005).

By using any form of desalination to produce fresh water from saline sources, concentrates are created and need to be disposed of appropriately. The amount of concentrate as a percentage of feedwater varies according to desalination method, percent recovery, and chemical additives (J. Nicot, 2005).

| Table 5.1 – Characteristics of Major Desalination Technologies | | | | |
|---|---|---|---|---|
| **Characteristics** | **Reverse Osmosis** | **Electrodialysis reversal** | **Multistage flash** | **Multiple-effect distillation** |
| Energy Cost | Moderate | High | High | Very High |
| Energy/Salinity | Increases with salinity | Increases fast with salinity | Independent of salinity | Independent of salinity |
| Applicable to | All water types | Brackish | Seawater - brine | Seawater – brine |
| Plant size | Modular | Modular | Large | Large |
| Bacterial Contamination | Possible | Post-treatment always needed | Unlikely | Unlikely |
| Final product salinity | On demand | On demand | Can be <10 mg/L TDS | Can be <10 mg/L TDS |
| Complexity | Easy to operate; small footprint | Easy to operate; small footprint | Only large complex plants | Only large complex plants |
| Susceptibility to scaling | High | Low | Low | Low |
| Recovery | 30-50% (seawater) up to 90% for brackish water | High | Poor (10-20%) | Low but better than Multistage flash |

(J. Nicot, 2005)

## 5.2 Membrane Technologies

The most commonly used technique in the United States is membrane technology and in particular, reverse osmosis is the most predominantly used technology in Texas (Texas Water Development Board, 2012b; Younos & Tulou, 2005). Membranes emerged as a viable means of water purification in the 1960s with the development of high performance synthetic membranes and have continually advanced using more advanced membranes from new materials and employing them in new configuration (Sagle & Freeman, 2004). Membrane treatment processes use either pressure-driven or electrical-driven technologies. Of the available technologies, reverse osmosis, nanofiltration, ultrafiltration, and microfiltration, utilize pressure driven mechanisms to function. The difference in these technologies is the pore size in the membrane. Of the four technologies, microfiltration has the largest pore size of 10-0.05 μm only capable of blocking bacteria and suspended particles. Ultrafiltration is capable of blocking colloids and macromolecules with a pore size between 0.05–0.005 μm. Nanofiltration blocks solutes as small as organic molecules and divalent ions with a pore size of 0.005–0.0005 μm while RO is effectively non porous with pore size of 0.001–0.0001 μm and capable of blocking particles as small as monovalent ions (J. Nicot, 2005). Only reverse osmosis, and in some cases nanofiltration, is effective in removing salts from brackish water (Younos & Tulou, 2005).

The phenomenon of water flowing from a low concentration solution to a more concentrated solution through a membrane is known as osmosis while water flowing from the more concentrated side the diluted side using and applied pressure is known as reverse osmosis (Fig. 5.1) (Pabalan, Daruwalla, & Green, 2003). Reverse osmosis is an effective means of treating brackish groundwater as it does not allow for salts to penetrate through the membrane resulting in nearly pure water.

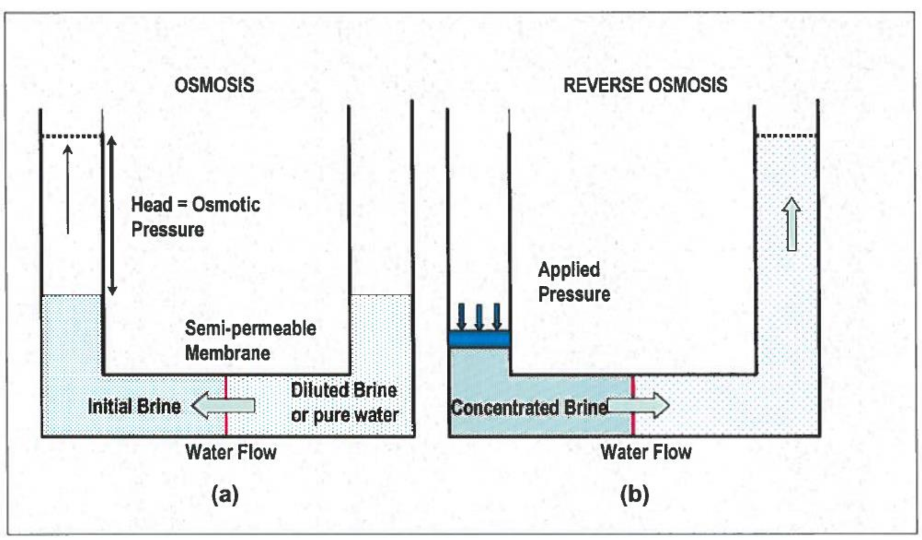


Figure 5.1 – Schematic of osmosis and reverse osmosis (Pabalan et al., 2003).

There are five integral parts to a RO desalination facility: (1) an intake to provide a consistent supply of feedwater; (2) a pretreatment system to properly condition the feedwater, (3) a high-pressure pumping system to provide the energy necessary for fresh water to pass the membrane; (4) a membrane assembly performing the desalination process by rejecting the passage of salts; and (5) a post-treatment system before being transferred into the distribution system (Fig 5.2) (Pabalan et al., 2003; Pankratz, 2004).

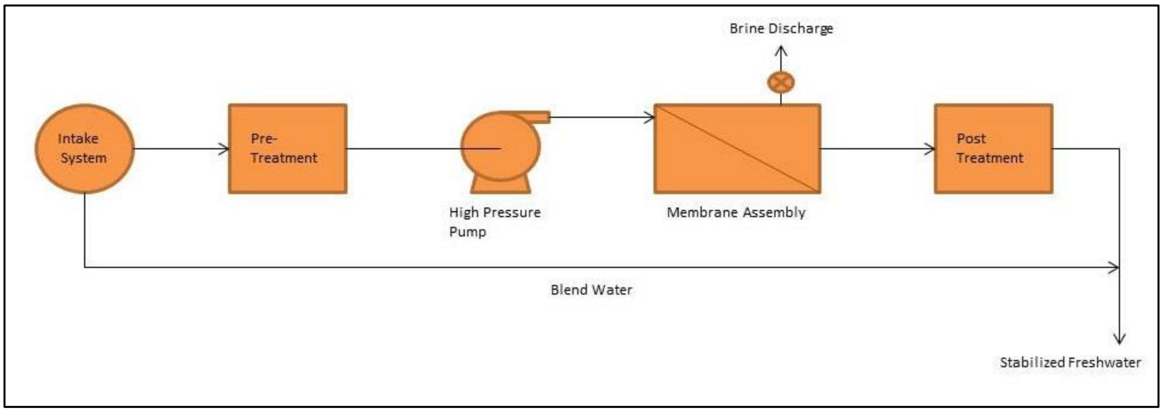



Figure 5.2 - Flow diagram of a RO system (modified from Pabalan et al., 2003).

**5.3 Evaporation-based Technologies**

Evaporation-based technologies are those that involve heating of saline water and collecting condensed vapor to produce pure water. Evaporation-based technologies are more commonly used in seawater applications but there are instances when it could be economical to produce fresh water from brackish groundwater using the technology. While there are a variety of technologies that exist, two main technologies that are commonly used are Multi-Stage Flash Distillation (MSF), Multi-Effect Distillation (MED).

The MSF process uses several (multi-stage) chambers that operate at progressively lower pressures as the distillation progresses. The feedwater is initially heated under high pressure. It is then transferred into the first 'flash chamber' where the pressure is released causing the water to boil rapidly and thus creating a sudden evaporation or 'flashing'. This 'flashing' of a portion of the feedwater continues in each consecutive chamber. The vapor generated by the flashing is converted into fresh water by being condensed on heat exchanger tubing that run through each stage. (Krishna, 2004)

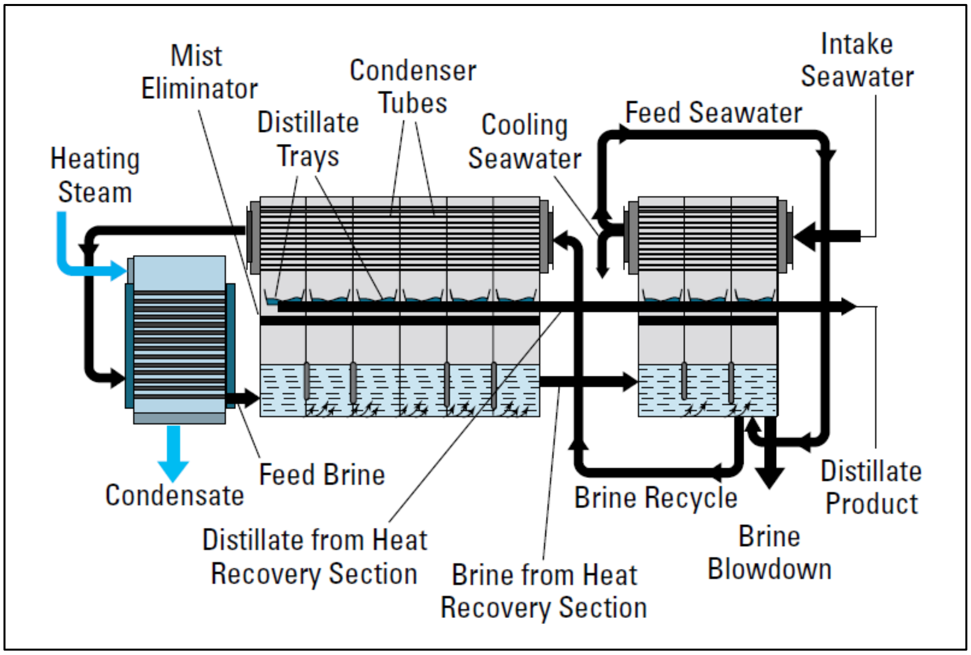



Figure 5.3 – Schematic of a multi-stage flash distillation system (Ettouney, El-Dessouky, Faibish, & Gowin, 2002)

All evaporation-based technologies for desalinating water produce a high purity distillate product with a salinity of usually less than 10mg/L TDS (Ettouney et al., 2002). While these levels are fine for human consumption, it is usually blended with treated water of higher TDS to satisfy consumer preference in odor, taste, and color. While evaporation-based technologies are highly effective, they have higher energy requirements than any other type of system. These systems consume heating steam to drive the flashing and evaporation processes and also use a considerable amount of energy to drive pumps (Ettouney et al., 2002)

### 5.4 Concentrate Disposal

Desalination concentrate consists of dissolved compounds that have been rejected by the reverse osmosis membranes. The concentration of dissolved compounds in the concentrate is dependent upon the quality of the source water. The concentrate requires proper disposal that meets the regulatory requirements set forth by local, State, and Federal authorities. Compared to seawater desalination where the concentrate can be disposed of back into the sea, it is not possible to dispose of the concentrate from brackish water directly back to the source (Brady, Kottenstette, Mayer, & Hightower, 2009). The concentrate volume ranges from 10 to 25 percent of the feedwater flow for brackish water thus can be a significant amount to dispose of (Pabalan et al., 2003).

There exists a variety of methods to dispose of the concentrate. There exists three major factors when selecting a disposal method: location, cost, and the ability to meet regulatory requirements. Currently, the most common methods for concentrate disposal are: discharge to a surface water body, discharge to a wastewater treatment facility, discharge with stormwater, land application, deep injection well, and evaporation by either thermal of solar application (Pabalan et al., 2003). Each method has its own unique benefits but also pose different challenges.

In Texas, where there is plenty of land but nearby surface water resources and infrastructure may be difficult to reach, inland desalination facilities can use deep well injection or evaporation methods. Deep water injection involves pumping concentrate deep into the earth into geologic units that contain water that is of lesser quality than that of the concentrate and is separated from aquifers that have the potential to be drinking water sources by low permeability zones (Pabalan et al., 2003). Deep injection wells have a high upfront cost and must be undergo a thorough geologic evaluation before they are put to use. Areas that have plentiful land can possibly use evaporation methods to handle the concentrate disposal needs. Upfront cost may be moderate to high depending on the cost of the land needed to set up the ponds. Along with a requirement for sufficient land, evaporation systems also require high evaporation rates, low precipitation rates, low concentrate discharge volumes (<0.01 MGD), and adequate pond lining material. The concentrate solids also must be disposed of properly on an ongoing basis for the life of the facility.

# Chapter 6:  Desalination Sites in Texas

## 6.1 Overview of Desalination Facilities in Texas

Recently, Texas has had a renewed interest in desalination to the growing fear of running out of water as a result of ongoing drought and population increases. A report by the Bureau of Economic Geology prepared for the TWDB (J. Nicot, 2005), focused on determining how many desalination facilities existed in Texas. While the study obtained a rough estimate of industrial and non-public water supply (PWS) systems across the state, the main focus was on PWS systems with a desalination design capacity of greater than 0.025 MGD. With California, Florida, and Texas hosting most of the U.S. desalination capacity, it was deemed important to create a database for Texas with publicly available information beyond what was basic information and already easily obtainable.

At the time of the study in 2005, Texas had 38 PWS facilities utilizing desalination with a design capacity greater than 0.025 MGD. The total design capacity for all the facilities at the time was 52 MGD. Since 2005, the amount of desalination facilities has grown and thus has the desalination capacity. Online reporting by the TWDB (Texas Water Development Board, n.d.) is currently reporting 46 desalination facilities in Texas with a design capacity greater than 0.025 MGD and a total cumulative capacity of approximately 86 MGD (Table 6.1).

**Table 6.1 - Summary of Texas desalination facilities with capacity ≥0.025 MGD**

| Plant Name | County | Startup Year | Design Capacity (MGD) | Use | Source | Process | Blending ? | Disposal Method |
|---|---|---|---|---|---|---|---|---|
| Sportsman World MUD | Palo Pinto | 1984 | 0.083 | DW | SW | RO | No | SW |
| City of Granbury | Hood | 1985 | 0.35 | DW | SW | EDR | Yes | WWTP |
| River Oaks Ranch | Hays | 1987 | 0.1152 | DW | GW | RO | No | EP |
| Esperanza Fresh Water Supply | Hudspeth | 1990 | 0.023 | DW | GW | RO | Yes | |

| Table 6.1(cont.) - Summary of Texas desalination facilities with capacity ≥0.025 MGD | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Plant Name** | **County** | **Startup Year** | **Design Capacity (MGD)** | **Use** | **Source** | **Process** | **Blending ?** | **Disposal Method** |
| Longhorn Ranch Motel | Brewster | 1990 | 0.023 | DW/ IRG | GW | RO | No | LA/IRG |
| City of Bardwell | Ellis | 1990 | 0.036 | DW | GW | RO | Yes | WWTP |
| City of Bayside | Refugio | 1990 | 0.29 | DW | GW | RO | No | EP |
| Oak Trail Shores | Hood | 1990 | 0.79 | DW | SW | EDR | Yes | SW |
| The Cliffs | Palo Pinto | 1991 | 0.2 | DW | SW | RO | No | SW |
| City of Los Ybanez | Dawson | 1991 | | DW | GW | RO | Yes | |
| Big Bend Motor Inn | Brewster | 1992 | 0.072 | DW | GW | RO | No | EP |
| Veolia Water Treatment Plant | Jefferson | 1992 | 0.245 | DW | SW | RO | No | ND |
| City of Sherman | Grayson | 1993 | 7.5 | DW | SW | EDR | Yes | WWTP |
| City of Robinson Reverse Osmosis Plant | McLennan | 1994 | 1.6 | DW | SW | RO | Yes | SW |
| City of Kenedy | Karnes | 1995 | 0.72 | DW | GW | RO | Yes | SW |
| Dell City | Hudspeth | 1996 | 0.1 | DW | GW | EDR | No | LA/IRG |
| City of Fort Stockton Osmosis/ Desalination Facility | Pecos | 1996 | 6.5 | DW | GW | RO | Yes | WWTP |
| DS Waters of America, LP | Waller | 1997 | 0.9 | DW | GW | RO | No | WWTP |
| City of Laredo Santa Isabel R.O. | Webb | 1998 | 0.1 | DW | GW | RO | No | WWTP |
| Holiday Beach WSC | Aransas | 1998 | 0.15 | DW | GW | RO | Yes | SW |
| City of Seadrift | Calhoun | 1998 | 0.52 | DW | GW | RO | Yes | SW |
| City of Tatum | Rusk | 1999 | 0.29 | DW | GW | RO | Yes | WWTP |
| Study Butte Terlingua Water System | Brewster | 2000 | 0.144 | DW | GW | RO | No | SW |
| Valley MUD #2 | Cameron | 2000 | 0.5 | DW | GW | RO | Yes | SW/LA |
| City of Seymour | Baylor | 2000 | 3 | DW | GW | RO | Yes | SW |
| Water Runner, Inc | Midland | 2001 | 2.16 | DW/ IRG | GW | RO | No | LA/IRG |
| Horizon Regional M.U.D. RO Plant | El Paso | 2001 | 3.3 | DW | GW | RO | Yes | LA/IRG/ EP |

| Table 6.1(cont.) - Summary of Texas desalination facilities with capacity ≥0.025 MGD | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Plant Name** | **County** | **Startup Year** | **Design Capacity (MGD)** | **Use** | **Source** | **Process** | **Blending ?** | **Disposal Method** |
| City of Hubbard | Hill | 2002 | 0.432 | DW | GW | RO | Yes | WWTP |
| Possum Kingdom WSC | Palo Pinto | 2003 | 1 | DW | SW | RO | Yes | SW |
| Windermere Water System | Travis | 2003 | 1 | DW | GW | RO | Yes | WWTP |
| Lake Granbury Surface Water Advanced Treatment System | Hood | 2003 | 7.5 | DW | SW | RO | Yes | SW |
| Midland Country Club - fairways & greens | Midland | 2004 | 0.11 | DW/ IRG | GW | RO | No | EP |
| City of Beckville | Panola | 2004 | 0.216 | DW | GW | RO | No | WWTP |
| City of Abilene (Hargesheimer Treatment Plant) | Taylor | 2004 | 3 | DW | SW | RO | No | EP |
| Southmost Regional Water Authority | Cameron | 2004 | 6 | DW | GW | RO | Yes | SW |
| North Alamo Water Supply Corporation (Lasara) | Willacy | 2005 | 1 | DW | GW | RO | Yes | |
| City of Brady | McCulloch | 2005 | 1.5 | DW | GW | RO | Yes | EP |
| North Cameron/Hidalgo WA | Cameron | 2005 | 2 | DW | GW | RO | Yes | SW |
| City of Clarksville City | Gregg | 2006 | 0.288 | DW | GW | RO | Yes | WWTP |
| Kay Bailey Hutchison Desalination Plant | El Paso | 2007 | 15 | DW | GW | RO | Yes | IW |
| North Alamo Water Supply Corporation (Owassa) | Hidalgo | 2008 | 2 | DW | GW | RO | Yes | |
| North Alamo Water Supply Corporation (Doolittle) | Hidalgo | 2008 | 3 | DW | GW | RO | Yes | |

| Table 6.1(cont.) - Summary of Texas desalination facilities with capacity ≥0.025 MGD | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Plant Name** | **County** | **Startup Year** | **Design Capacity (MGD)** | **Use** | **Source** | **Process** | **Blending ?** | **Disposal Method** |
| Cypress Water Treatment Plant | Wichita | 2008 | 10 | DW | SW | RO | No | SW |
| City of Evant | Coryell | 2010 | 0.08 | DW | GW | RO | Yes | WWTP |
| Fort Hancock RO Plant 1 | Hudspeth | 2012 | 0.43 | DW | GW | RO | No | EP |
| Victoria Road RO Plant | Hidalgo | 2012 | 2 | DW | GW | RO | Yes | |

DW: Drinking Water IND: Industrial GW: Groundwater SW: Surface Water RO: Reverse Osmosis
EDR: Electrodialysis Reversal EP: Evaporation Pond IRG: Irrigation LA: Land Application
SW: Discharge to Surface Water WWTP: Wastewater Treatment Plant IW: Injection Well
(J.-P. Nicot & Scanlon, 2012; Texas Water Development Board, n.d.)

In the last decade the desalination design capacity at Texas facilities has greatly increased while total facilities in Texas has continually increased at a steady rate (Fig. 6.1). This can be mostly attributed to newly built facilities being much larger than they have been in the past and also in part older facilities have upgraded to process more water to better serve their growing communities.

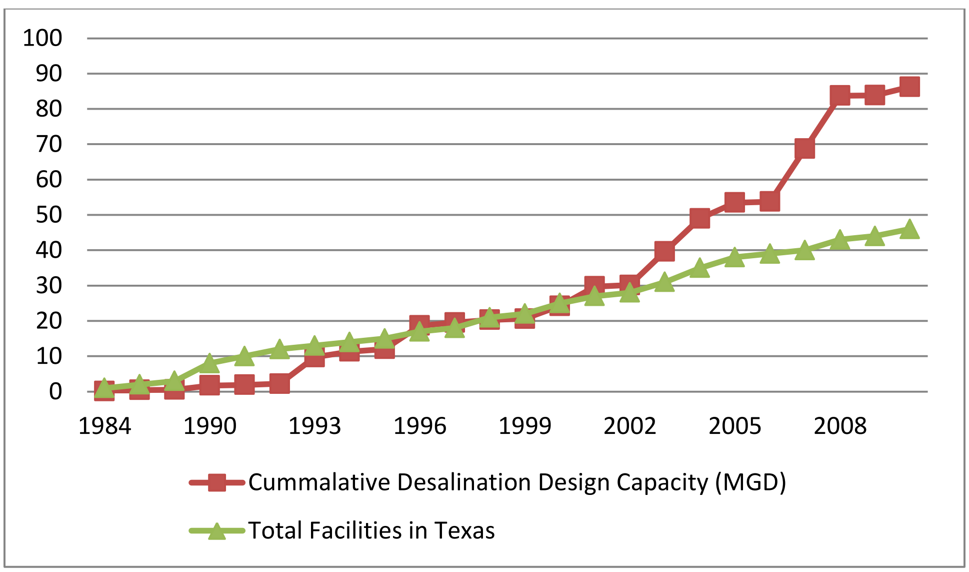



Figure 6.1 – Time-cumulative total facilities and design capacity at facilities in Texas

### 6.2 Kay Bailey Hutchison Desalination Plant (El Paso, TX)

El Paso, TX, located in the most western part of the state, lies in the middle of the Chihuahuan Desert. Being in the desert, the city receives approximately 302 days of sunshine annually and an average of 8.8 inches per rain per year (Archuleta, n.d.). The heaviest rains are usually experienced in July and August during the monsoon season.

The City of El Paso is strategically located on a busy trade corridor between the United States and Mexico. It is also in close proximity to two other cities, Las Cruces, NM and Ciudad Juarez, Chihuahua, making it one of the largest bi-national metropolitan areas in the world. The most current population estimate, as of July 1, 2013, for El Paso is 674,433 residents making it the 19th largest city in the United States (U.S. Census Bureau, 2014). And, an additional 153,285 residents live within El Paso County. El Paso Water Utilities (EPWU) serves approximately 95 percent of El Paso County through either wholesale or on a retail basis (Archuleta, n.d.). Las Cruces, NM had a population estimate of 101,324 residents as of July 1, 2013 making it the second largest city in New Mexico (U.S. Census Bureau, 2014). As of 2010, the population of Ciudad Juarez, Chihuahua was 1,332,131 (Instituto Nacional De Estadistica y Geografia, 2011). With nearly 2.5 million residents currently living in the region and growing, water resources must be managed carefully to ensure sufficient water for the increased population.

Historically, since the beginning of the 20th century, El Paso has relied on both surface and groundwater for their municipal needs (El Paso Water Utilities, 2007) . El Paso obtains its surface water from the Rio Grande, which originates as snowmelt in southern Colorado, and groundwater is obtained from either the Mesilla Bolson or the Hueco Bolson (Fig. 6.2). Both of the aquifers are Quaternary to Tertiary age basin-fill type aquifers, and are separated by the Franklin Mountains (Fig 6.3) (LBG - Guyton

Associates, 2003). Since the early 1990's, EPWU has been interested in and began assessing the feasibility of using brackish groundwater from the Hueco Bolson as an alternative water resource. At the time, the capital costs of desalination and its operating costs were too high compared to other sources. Along with the costs, there also existed the issue of dealing with the disposal of concentrate. (Archuleta, n.d.)

After a detailed analysis by the U.S. Geological Survey (USGS) mapping out fresh and brackish water within the Hueco Bolson and its flow patterns, EPWU began the planning phase of a 20 million gallons per day (MGD) desalination facility near the El Paso International Airport. Coincidently, the U.S. Army installation, Fort Bliss, which is located in El Paso was also considering constructing a 7.5 MGD desalination facility to supply the military installation and meet its future needs. The two entities formed a partnership to construct a desalination facility that would meet Fort Bliss' current and future demands as well as provide a valuable resource to EPWU for its own needs. (Archuleta, n.d.)

The Army and EPWU each had a role in the desalination project. The Army conducted an environmental impact study to determine the best site for the proposed project and subsequently leased that land for constructing and operating the plant and its infrastructure. It also underwrote the cost of investigating the deep-well injection of the concentrate and provided brackish wells for blending. EPWU agreed to design, build, operate and maintain the plant and supporting facilities, as well as conduct any related engineering studies. (Archuleta, n.d.) On August 8, 2007, the world's largest inland desalination facility opened, providing water to the city and the Fort Bliss Army Base. Construction began on August 1, 2005 and cost the city approximately $87 million to construct (Texas Water Development Board, 2014). The project includes the rehabilitation of 15 existing wells plus three new source wells, 16 blend wells, a 27.5 MGD plant, concentrate disposal facilities, and pipelines for collection, transmission, and concentrate disposal (Archuleta, n.d.).

The facility withdraws from the saline portion of the Hueco Bolson at a maximum operating capacity of 27.5 MGD (15.0 MGD permeate and 12.5 MGD blend) (Texas Water Development Board, 2014). The concentrate flow is pumped from a concentrate pump station to a surface injection facility and disposed via deep well injection into the Fusselman and Montoya formations approximately 22 miles northeast of the plant site, near the Texas-New Mexico state line.

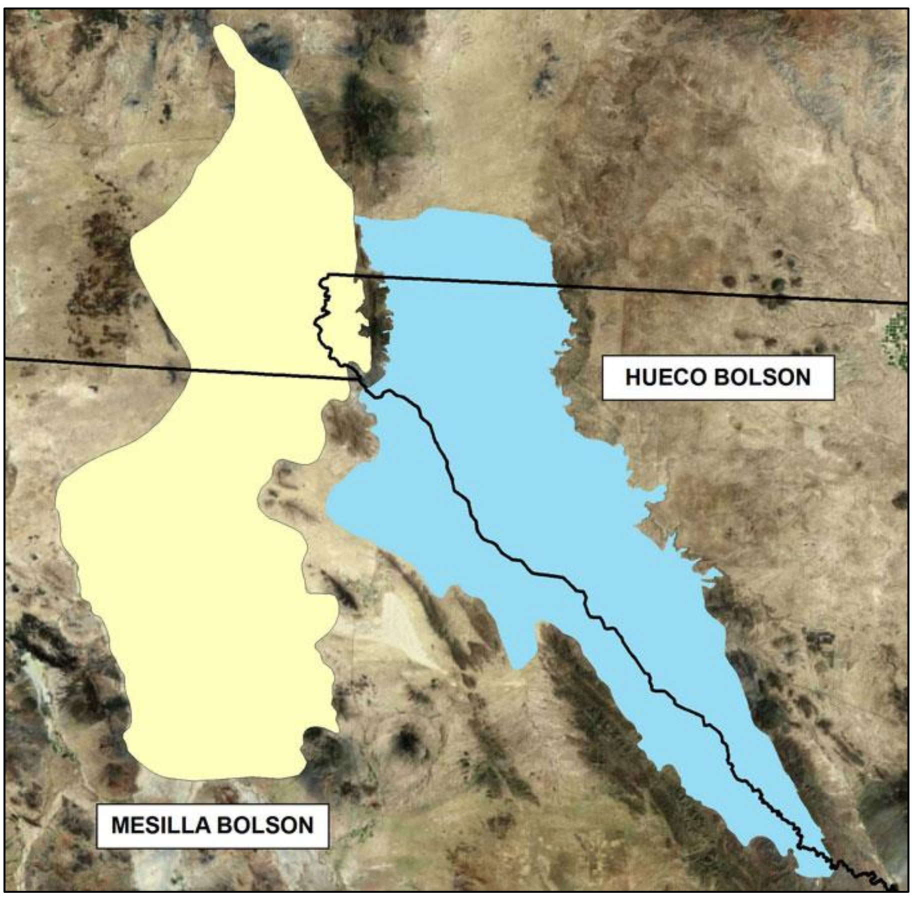


Figure 6.2 – Map of the Hueco and Mesilla Bolsons in West Texas (El Paso Water Utilities, 2007).

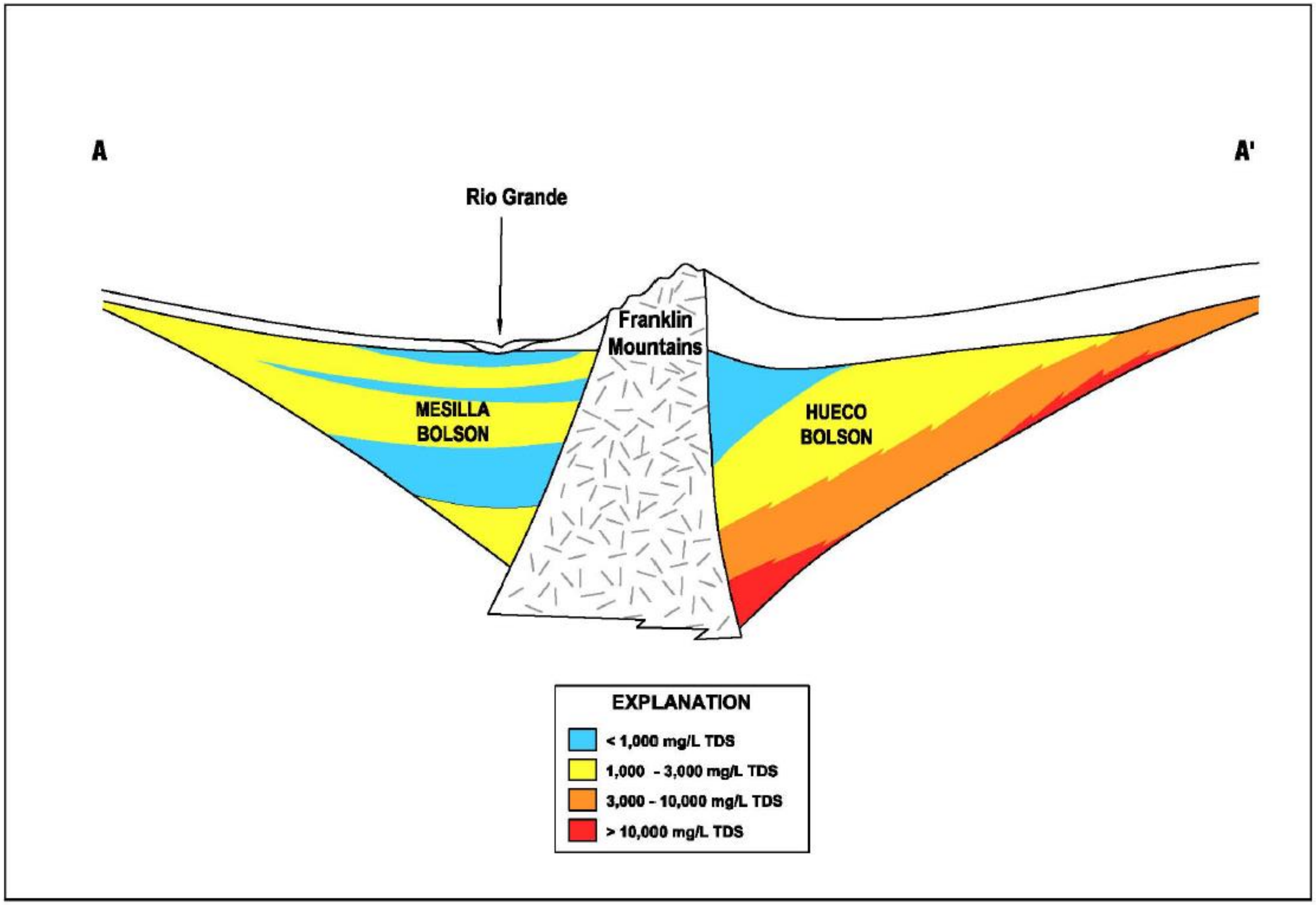



Figure 6.3 – Cross-section of the Hueco and Mesilla Bolsons transected by the Franklin Mountains. TDS distribution in the bolsons is also displayed (LBG - Guyton Associates, 2003)

### 6.3 San Antonio Water System Desalination Plant Program

In 2012, the City of San Antonio updated its Water Management Plan to better serve the community's needs. The previous update was in 2009, but due to environmental, regulatory, technical political, and demographic changes in the city, the plan was updated before its normal five year cycle (San Antonio Water System, 2012). The Water Management Plan is designed to meet the city's water needs over the next 50 years while reducing dependence on the Edwards aquifer.

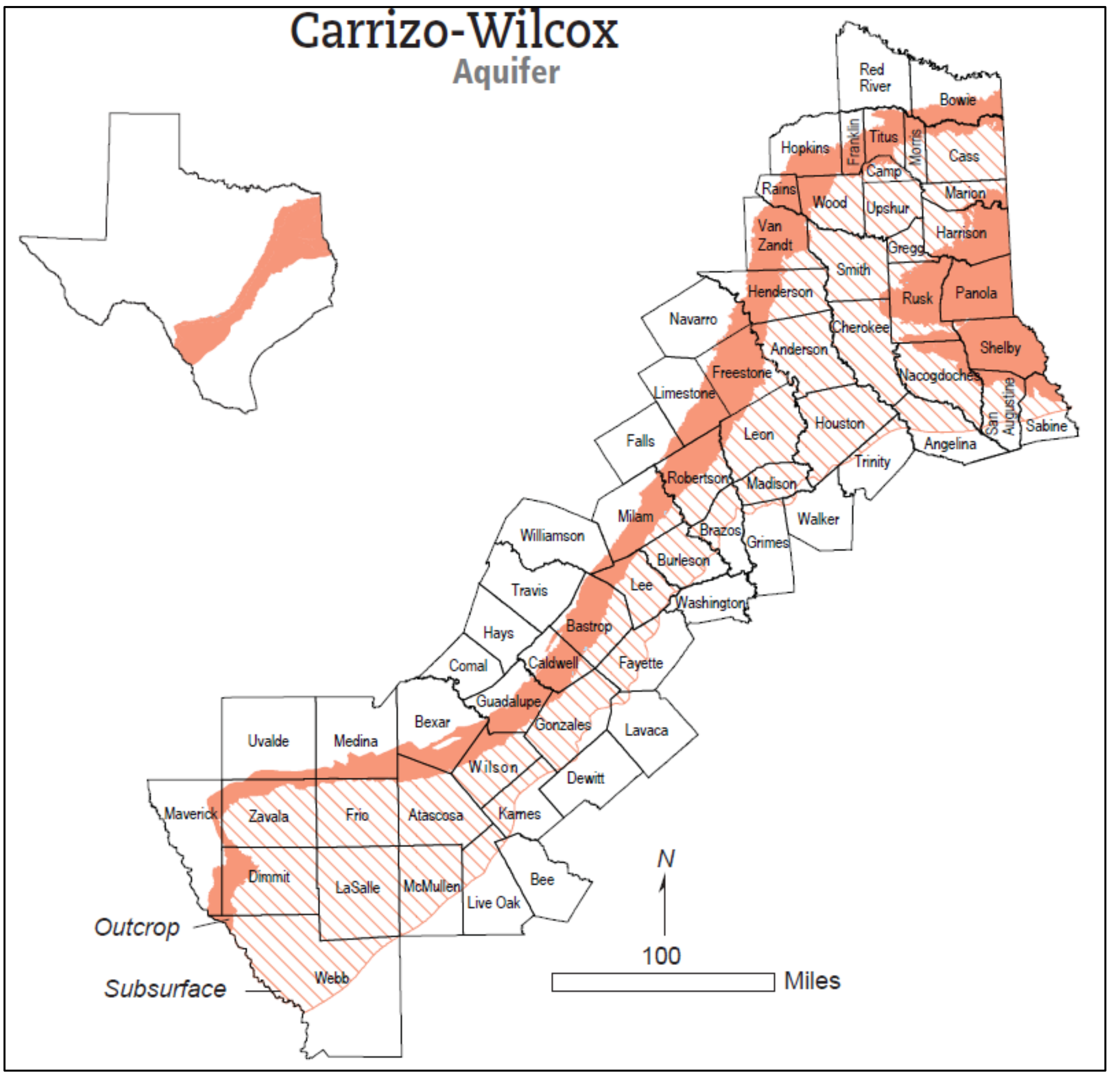



Figure 6.4 - Location map of the Carrizo-Wilcox aquifer (George et al., 2011)

On August 2, 2011, the SAWS Board of Trustees approved of a project to study the feasibility of adding water from the Wilcox aquifer (Figure 6.4) into the city's water system through the use of a desalination facility. At that point, the Board recognized a water resource existed within close proximity to San Antonio that had the possibility of diversifying SAWS water resource portfolio with an available, sustainable, drought-proof supply and without directly competing for access to freshwater resources with neighboring water users (San Antonio Water System, 2012).

The San Antonio Water System (SAWS) is currently constructing the desalination facility to produce brackish water from the lower Wilcox formation (Fig. 6.6) in southern Bexar County. The site is located in the existing SAWS Twin Oaks Aquifer Storage and Recovery site (Fig. 6.5) and is expected to have twelve wells extracting the brackish water from approximately 1,500 feet deep when the project is completed.

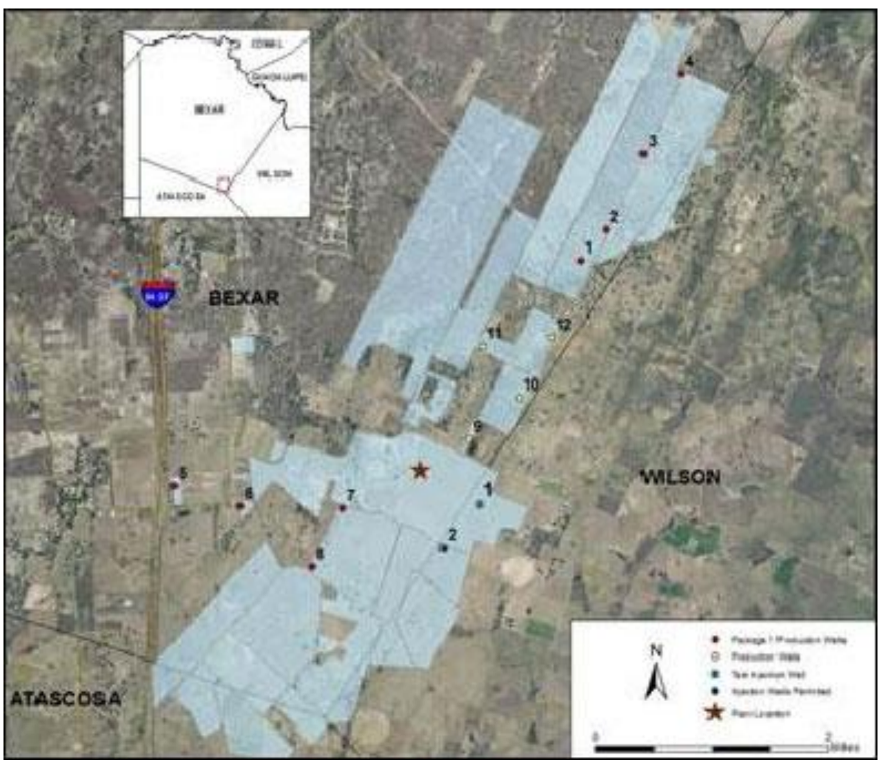


Figure 6.5 – Map of the SAWS Twin Oaks Facility in Bexar County, Texas

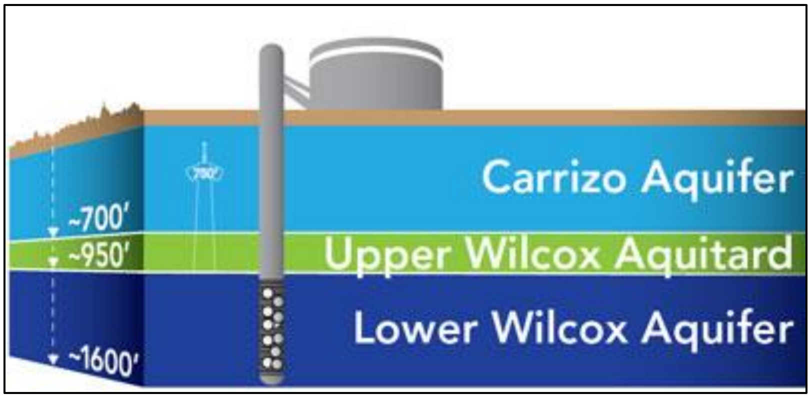


Figure 6.6 - Generalized cross-section of the Carrizo-Wilcox aquifer. SAWS will be operating their desalination facility withdrawing water from the lower Wilcox at a depth of approximately 1,600 feet (San Antonio Water System, 2015).

The first phase of the project has an expected completion date of 2016 and will produce approximately 12 MGD. Phase II and III will be completed in 2021 and 2026, respectively, and will supply the city with approximately 25 MGD in total (San Antonio Water System, 2012). The project consists of the following to the water system (San Antonio Water System, 2007):

- Well field and well field collection system: It is estimated that approximately 24 production and 2 backup wells will be required to produce the source water supply. Initially, only 12 wells will be drilled in Phase I. In addition, a total of approximately 6-8 Wilcox monitor wells will be required to with monitoring aquifer.

- Transmission pipelines: The transmission pipe system will consist of a main line from the well field collection system to the plant, a finished water transmission line to from the R.O. treatment plant to SAWS distribution system, and a concentrate disposal line from the R.O. plant to the disposal site.

- Reverse osmosis treatment plant, pre-treatment and post-treatment facilities: The final goal is to construct a reverse osmosis ("RO") treatment plant capable of treating 30 MGD. The treatment facilities will include pre-treatment for incoming raw water, the RO plant, post-treatment facilities, and ground storage facilities. Based on available raw water quality data, pre-treatment may be required to remove iron, manganese and other chemical constituents prior to introduction into the RO system. Post-treatment such as blending will be required to adjust water chemistry prior to introduction to the SAWS distribution system.

- Concentrate management and disposal facilities: SAWS will be using deep well injection for their concentrate disposal at the desalination facility. Based on raw water quality and desired plant production rates, it is estimated that approximately 5 MGD of concentrate will be generated at approximately 7,000 to 10,000 mg/L TDS.

- Integration system improvements: Desalinated groundwater will need to be integrated into the current SAWS distribution system. Four potential SAWS pump stations located in the southwest and west side of San Antonio have been identified to receive upgrades in order to take on the additional water supply.

- Power generation system improvements: The electrical system infrastructure in the vicinity of both the well field and the proposed locations for the treatment plant will require upgrades. SAWS has supported electric power improvements necessary for the well field and treatment plant facilities

The project in currently on schedule to be completed in 2016 and will put SAWS ahead of schedule on their implementation of their 50-year Water Management Plan. The second phase, projected to come on line in 2021, will bring another 10 million gallons per day to San Antonio, and the final phase in 2026 will provide an additional 5 million gallons per day – for a grand total of 25 million gallons per day. The SAWS desalination program is one of several programs in place that SAWS has commissioned in order to supply the growing city with a sustainable water supply while lessening their reliance on the Edward's aquifer. By 2030, SAWS expects to reduce their reliance on the Edwards aquifer to approximately 32.3% of their total supply; down from 70 percent in 2000 and 46% in 2012. Of the total water supply in 2030, the desalination program will supply approximately 5.8 percent (Fig 6.7).

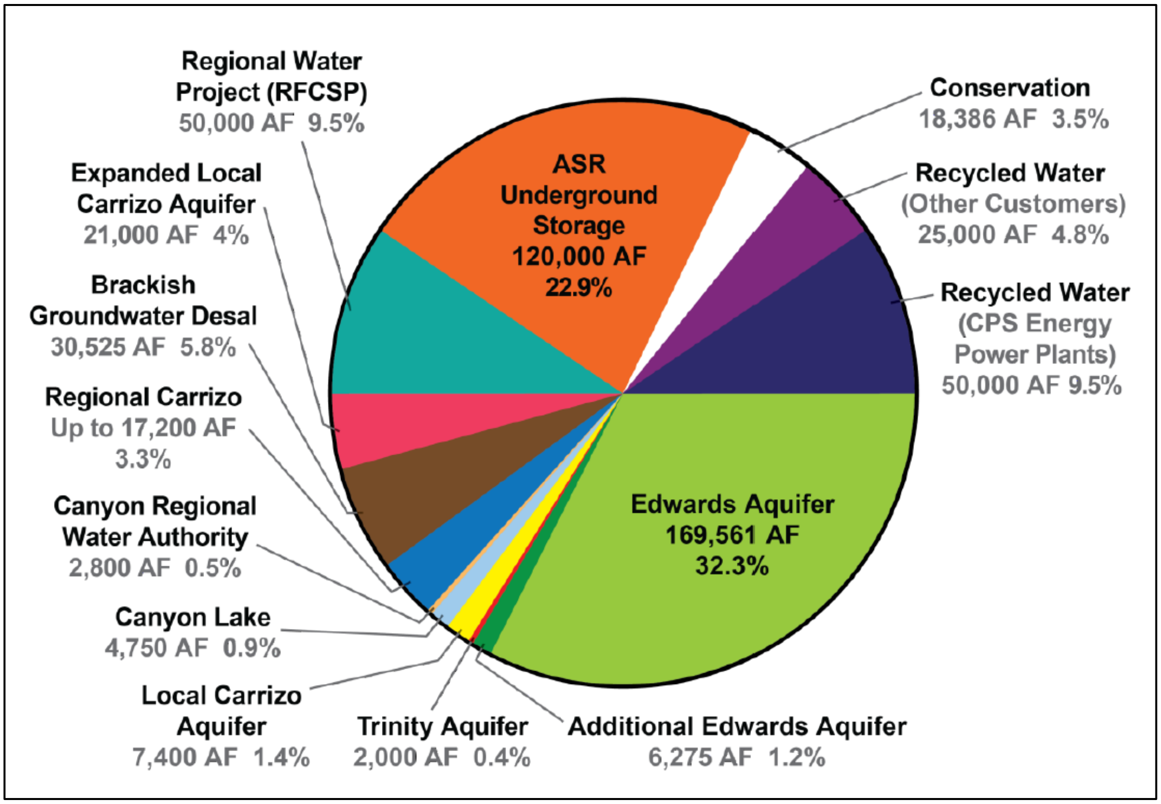


Figure 6.7 – SAWS water supplies in drought conditions by 2030 (San Antonio Water System, 2007).

# Chapter 7: Cost of Groundwater Desalination

### 7.1 Background

The use of desalination has spread across the globe not only due to an increase in water demand but largely due to advances in the technologies that have consequently reduced costs. This reduction in costs has made desalinated water cost competitive with obtaining other new sources of fresh water. Currently and as the technology evolves even more, desalination will have great development potential on a global scale (Ettouney et al., 2002; Ghaffour, Missimer, & Amy, 2013). This is due to the fact that out of 71 of the largest cities that do not have access to a new fresh water source, 42 are located along coasts (Ghaffour, 2009). With approximately 40% of the Earth's total population living within 100 km from a coast (Center for International Earth Science Information Network at Columbia University & United Nations Environment Programme, n.d.), desalination may be the only viable option to supply to these densely populated cities with ever increasing water needs. Looking into the future, populations in semi-arid and arid parts of the world have been steadily growing and become more urban (Population Association of America/Association of Population Centers, n.d.). While semi-arid and arid cities may not be as densely populated as coastal cities, the demand for water supplies is just as present. Fresh water supplies may be difficult to attain or cost prohibitive thus desalination is a viable option. Already, desalination use is increasing worldwide and is expected to have an expected market of $31 billion by this year, 2015 (Ghaffour et al., 2013)

The costs for a desalination facility primary are generated by the capital cost and annual operation and maintenance costs. These costs can vary significantly depending on the size and type of the desalination plant, the source and quality of incoming feed water, the plant location, site conditions, qualified labor, energy costs and plant lifetime (Zhou

& Tol, 2005). Of all the factors, as seen in Figure 7.1, the size of the facility and the quality of the incoming feedwater has the largest impact on the final unit cost of water. Because of economies of scale a larger facility's capacity reduces the unit cost of water. The incoming feedwater quality is directly correlated with lower-energy costs and thus reduce unit product water cost.

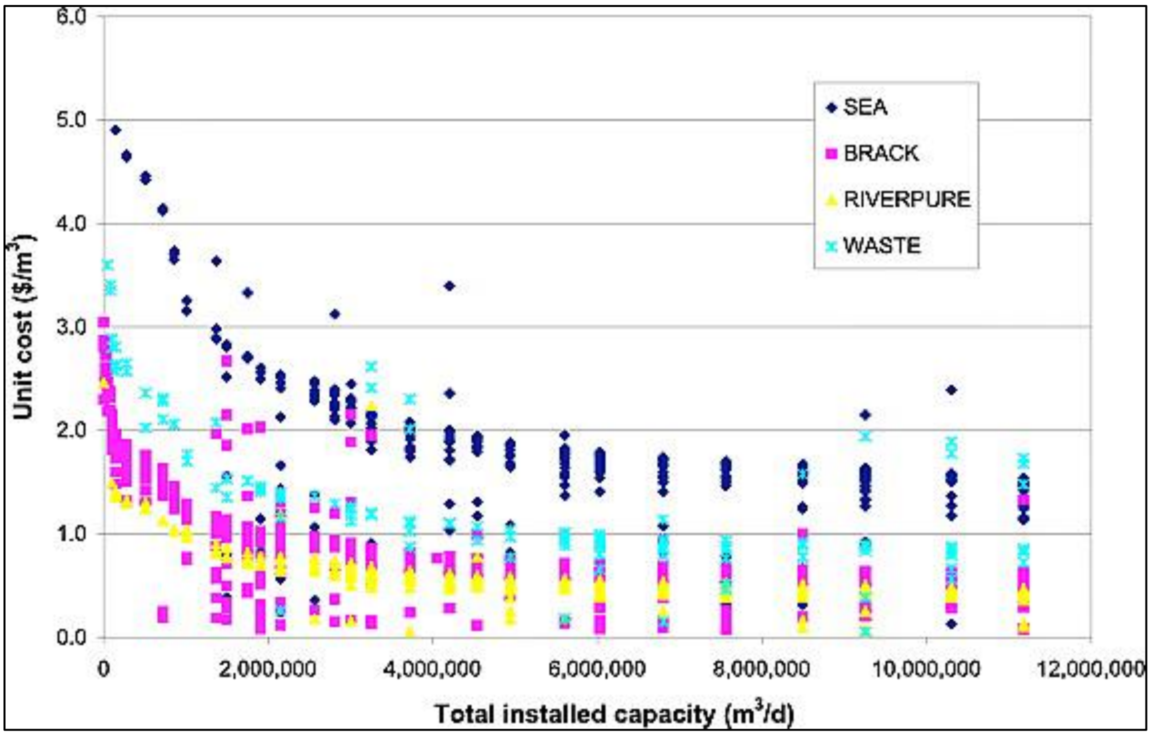


Figure 7.1 - Unit cost versus total installed capacity by the RO process (Zhou & Tol, 2005).

### 7.2 Factors Affecting Desalination Costs

Capital costs in building a desalination facility are very site specific due to several factors that can have a substantial impact on the overall cost. A recent study by Arroyo concluded capital costs range from \$2.03 to \$3.91 per gallon of installed capacity after examining six brackish groundwater desalination facilities completed within the last decade (Arroyo et al., 2012). Of all the common cost factors for a desalination facility (Table 7.1), the following factors have the largest impact on capital cost (Younos, 2005):

- **Feedwater Quality:** In general, water with a lower TDS concentration cost less to treat than that of a higher TDS concentration due to the higher energy demand needed to treat more saline water. Another factor to consider with feedwater quality is anti-scaling chemicals. Lower TDS waters require less treatment for scaling thus reducing costs. Some waters may also require pretreatment or post-treatment depending on contaminants present in the feedwater. This is especially true of tidal waters. Feedwater with higher TDS levels will also require more costly concentrate disposal solutions.
- **Plant Capacity:** Long-term planning is required in order to select the economically optimal size plant for the operation. A large desalination facility will require a larger capital investment but the unit production cost can be lower due to the economy of scale.
- **Site Characteristics:** Costs can vary depending on where the facility location. Infrastructure to deliver feedwater to the facility and concentrate away from the facility
- **Construction Costs:** Construction costs include both direct and indirect capital costs. Direct capital costs include set costs such as land, production wells, pipeline infrastructure, the process equipment, and the actual buildings. The indirect capital cost is usually estimated as percentages of the total direct capital cost. These include freight and insurance, construction overhead, owner's cost (engineering design, contract administration, administrative expenses, commissioning and/or startup costs, and legal fees), and contingency cost.
- **Regulatory Requirements:** There are costs related with obtaining and upkeeping state and local permits and regulatory requirements.

Operation and maintenance cost consists of fixed and variable costs (Table 7.1). Usually, a desalination facility will have fixed insurance costs of approximately 0.05 percent of the total capital cost (Younos, 2005). Variable costs will vary from plant to plant and can have a large impact on overall cost depending on individual situations. Factors usually considered a variable cost at a desalination facility include energy costs, chemicals, maintenance, age of the plant, and the localized cost of labor. Source water quality can alter costs as well. Higher TDS operations will require more maintenance, more frequent membrane replacements, and more chemical use (Younos, 2005). Overall, operation and maintenance costs range from \$0.53 to \$1.16 per 1,000 gallons of water produced (Arroyo et al., 2012).

| Capital Cost | | | | Operation & Maintenance Cost |
|---|---|---|---|---|
| **Direct capital costs** | | | | **Fixed operation & maintenance cost** |
| Installed membrane equipment | | | | Labor |
| Additional process items | | | | Administrative |
| Building & structures | | | | Equipment and membrane replacement |
| Electric utilities & switchgear | Water treatment plant construction cost | | | |
| Finished water storage | | | | **Variable operation & maintenance cost** |
| High service pumping | | Total project construction cost | | Power |
| Site development | | | | Chemicals |
| Miscelleneous plant items | | | | Other costs (such as cartrdge filters) |
| Supply intake/wells | | | Total capital cost | |
| Raw water pipelines | | | | |
| Finished water pipelines | | | | |
| Waste concentrate/residual disposal | | | | |
| Land | | | | |
| **Indirect capital costs** | | | | |
| Legal, administrative | | | | |
| Interest | | | | |
| Contingency | | | | |

Table 7.1 - Key factors for capital and operation and maintenance costs of a desalination facility (Arroyo et al., 2012)

# Chapter 8: Economic Feasibility Study

## 8.1 Sources of Information

The first step in data collection was conducting a literature review on desalination costs. Several previously conducted studies have reviewed and included average costs of desalination. The studies had a variety of focuses but none were specifically to the Central Texas area. At best, the studies reviewed cost information as an average across the state and could be compared to studies of specific sites throughout Texas that were presented in other studies.

For the quantitative analysis, the bulk of data for this study was extracted from personal contact with SAWS and the TWDB. Both entities were extremely helpful in providing the most up to date cost information they had available. In the case of SAWS, their costing information is the most recent in the state as they are currently in the process of constructing their facility. SAWS was able to provide several pricing spreadsheets as well as vendor contracts detailing costs and plans. This information is available to the public through a Public Information Request. The TWDB provided several useful studies and also a variety of helpful links to their website including their Water Management Unified Costing Model ("UCM"). The cost model is readily accessible to the regulated community as well as the general public through the TWDB website (http://www.twdb.texas.gov/waterplanning/rwp/planningdocu/2016/current_docs.asp).

The data gathered from literature review, SAWS costing spreadsheets and contracts, and the UCM was entered into a Microsoft Excel spreadsheet. The cost of the information available was compared against each other and a low, high, and most likely range was created. The spreadsheet was developed using Palisade @RISK software coding so that it could be further analyzed. @RISK software can be purchased through the Palisade website but offers free trials and substantial discounts to students and universities.

### 8.2 Texas Water Development Board Water Management Unified Costing Model

The TWDB undertook the project of developing the UCM completed in 2013 in order to assist regional water planning groups and their consultants in developing consistent cost estimates across the State of Texas for the development of a desalination facility (Texas Water Development Board, HDR Engineering Inc., & Freese and Nichols Inc., 2013). The TWD consistently compiles pricing and usage information on a variety of projects from the 16 regions across the state in order to develop the State Water Plan. Before the UCM was developed, there was no standardized model to estimate the cost of developing a desalination facility across the state. Only individualized costs from regions that had submitted cost information existed.

The goal of the UCM was to develop a model that was relatively intuitive, with individual component modules that feed information to a line item costing form, automatically when possible (Texas Water Development Board et al., 2013). The UCM was developed on a Microsoft Excel platform thus is easily accessible to majority of users. Within the UCM model there exists 10 costing models, some of which are optional, that are linked to each other to create a cost estimate based on user inputted data and standardized information already in place in the model. A Reference Flow Chart is also included to facilitate moving through the UCM and to assist users in learning the model (Fig. 8.1). The model uses the following costing models to estimate the cost of a desalination facility:

1. Project Information and Assumptions

2. Simplified Hydraulics

3. Advanced Hydraulics

4. Well Field

5. Embankment Calculations

6. Land Acquisition

7. Costing Form

8. Cost Summary

9. Conservation

10. Drought Management Risk Factor

The costing models are meant to assist users in developing cost estimates for the most common types of water management strategies in regional water planning but there can always exists parameters beyond the ability of the model for special circumstances unique to individual facilities (Texas Water Development Board et al., 2013).

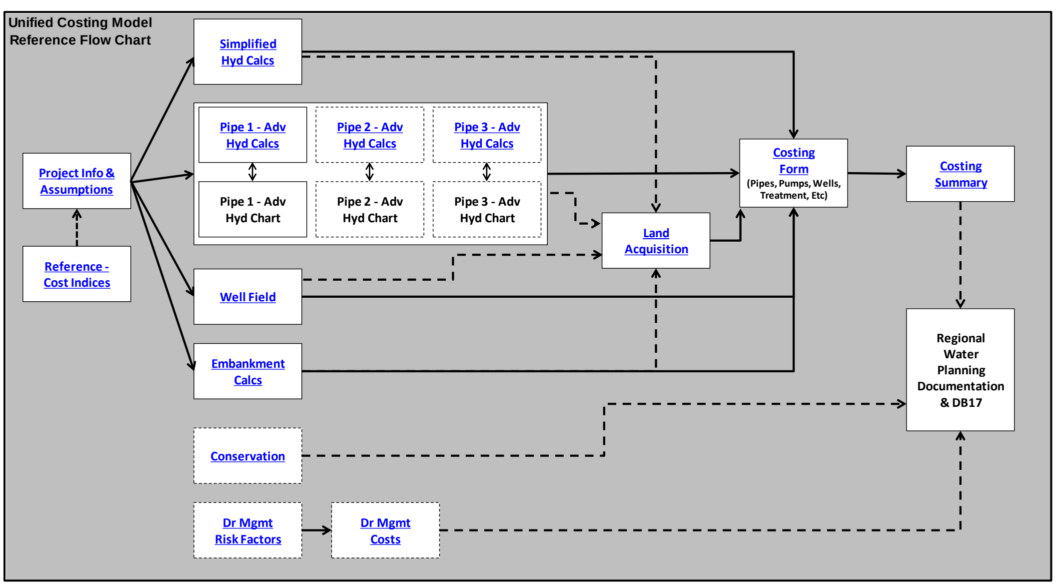



Figure 8.1 – Screenshot of UCM Reference Flow Chart

## 8.3 Palisade @RISK Analysis Tool

@RISK is a software program built specifically to run risk analysis (predicted variability). The software has many applications such as analyzing the risk of making or losing money, the probability of finding oil and gas and in what amounts, forecasting production costs, forecasting construction and labor costs, determining if the level of benefits will be what is projected, along with many more. @RISK is a very versatile program to determine risk levels that can be implemented into many applications through very commonly used Microsoft Excel spreadsheets. By using Monte Carlo simulations, @RISK mathematically and objectively computes and tracks many different possible future scenarios, and then outputs probabilities and risks associated with each different one onto a spreadsheet. By providing a range of data instead of point data to the program, it becomes easier to assess which risks to take and which to avoid.

The @RISK program completes its risk analysis by running a Monte Carlo simulation. Monte Carlo sampling refers to the traditional technique for using random or pseudo-random numbers to sample from a probability distribution (Palisade Corporation, 2010). The principle behind Monte Carlo simulation is that the behavior of a statistic in random samples can be analyzed by simply producing lots of random samples and observing their behavior (Mooney, 1997). Mooney describes creating an artificial "world," or pseudopopulation, which resembles the real world in respect to what is relevant in the study. Mathematical equations are then used to generate sets of numbers from the pseudopopulation to resemble actual data collected from a true population. The pseudopopulation is then used to conduct multiple trials to investigate how a procedure behaves across samples. When done on a computer, a spreadsheet is recalculated over and over, using randomly selected sets of values for the probability distributions that are set by the user. The computer tries as many possible combinations as possible simulating many outcomes and thus producing a frequency distribution curve. This is the same as if the user manually entered hundreds or thousands "what-if" scenarios into their spreadsheet and calculated each one individually. The Monte Carlo simulation is very simple concept as it can be clearly visualized from what a sampling distribution is (Mooney, 1997). The most difficult part of the simulation is actually creating the code but @RISK has been specifically built for that purpose and only requires minimal user input and ingenuity. @RISK also facilitates the creation of a variety of graphs to better enable the user to understand risks associated with the project. One important and informative graph that at @RISK can create is a "tornado graph". A tornado graph is a bar chart in which the data is place horizontally displaying the largest bar at the top of the chart, and subsequently smaller bars below it. The wider the bar, then the wider the variability of the selected parameter possibly affecting cost. Tornado graphs are used in sensitivity analysis in which the relative importance of variables is compared. By analyzing the variables that contribute the most to the variability of the outcome

**8.4 Energy Requirements Analysis**

A substantial portion of calculating capital and operation cost is derived from the power requirement of the desalination facility. More water demand out a system requires larger infrastructure thus requires a larger power supply to pump the water from the aquifer, into the pipelines, and through the desalination facility. The energy requirements for the BSEACD desalination facility were estimated as follows (Clayton et al., 2014):

Total power requirements ($P$, in kW) were estimated to determine final capital and operational costs. Power is required for pumping water from the aquifer and in pipelines ($P_P$, in kW), for brackish groundwater desalination ($P_D$, in kW), and for pumping water from the facility through the pipelines into a deep injection well ($P_C$, in kW), as defined in Equation (1):

$$P = P_P + P_D + P_C \quad (kW) \tag{1}$$

The Darcy-Weisbach equation for head loss in pipes was considered in the calculation of $P_P$ and is dependent on the flow rate into the facility ($q$, in units of cubic meters per second, see Equation (3)), the desalination capacity factor ($CF_D$, a dimensionless ratio of the actual output of the facility over a period of time to the potential output of the facility operating at full capacity; assumed to be 95% in this study to account for maintenance downtime), depth to aquifer ($z$, in meters), the distribution pipe length ($l$, in meters), and other standard parameters (summarized in Table 8.1), as defined in Equation (2):

$$P_P = \frac{\rho g q}{1000 \eta_P CF_D} \left( \frac{\left(\frac{4q}{\pi(d)}\right)^2}{2g} \frac{f}{d} (z + l) \right) \quad (kW) \tag{2}$$

The flow rate into the facility ($q$, in cubic meters per second) depends on the desired daily product water generation ($G_D$, in cubic meters of treated water per day) and the RO recovery rate ($R_D$), which is the ratio of product water flow to incoming flow, as defined in Equation (3) (including a conversion from day to seconds):

$$q = \frac{1}{86{,}400} \times \frac{G_D}{R_D} \quad \left(\frac{m^3}{s}\right) \tag{3}$$

The calculation of $P_C$ is the same as that of $P_P$ with only a few factors modified. $P_C$ is dependent on the flow rate out the facility ($q$, in units of cubic meters per second, see Equation (5)), $CF_D$, depth to aquifer at the injection well ($z_B$, in meters), the distribution pipe length ($l_B$, in meters), and other standard parameters (summarized in Table 8.1), as defined in Equation (4):

$$P_C = \frac{\rho_B g q}{1000\eta_P CF_D}\left(\frac{\left(\frac{4q}{\pi(d)}\right)^2}{2g}\frac{f}{d}(z_B + l_B)\right) \quad (kW) \tag{4}$$

The flow rate out of the facility ($q_D$, in cubic meters per second) depends on the daily wastewater generation calculated from the desired daily product water generation ($G_D$, in cubic meters of treated water per day) and the RO recovery rate ($R_D$), as defined in Equation (5) (including a conversion from day to seconds):

$$q_D = \frac{1}{86{,}400} \times \left(\frac{G_D}{R_D} - G_D\right) \quad \left(\frac{m^3}{s}\right) \tag{5}$$

| Factor | Description | Units | Value |
|---|---|---|---|
| $\rho$ | Density of water | kg/m$^3$ | 1,000 |
| $\rho_B$ | Density of concentrate | kg/m$^3$ | 1,570 |
| $g$ | Acceleration due to gravity | m/s$^2$ | 9.81 |
| $\eta_P$ | Pump efficiency | -- | 0.85 |
| $d$ | Pipe diameter | m | 0.30 |
| $f$ | Friction factor | -- | 0.0162 |

**Table 8.1.** Standard parameters used in the calculation of the power requirement needed for pumping brackish groundwater into the system and pumping concentrate out of the system into an injection well (Clayton et al., 2014)..

The power requirement for desalination ($P_D$, in units of kW) is a function of $q$, $CF_D$, and the energy intensity of desalination ($EI_D$, in units of kWh per cubic meter), as defined in Equation (6):

$$P_D = \frac{3600\ EI_D q}{CF_D} \quad (kW) \tag{6}$$

$EI_D$ is function of the TDS of the source water and the desalination technology. The national average electricity use for brackish groundwater treatment is 1.0 to 2.6 kWh/m$^3$ (Clayton et al., 2014). While the model incorporates a range of possible TDS levels, it is modeled to output nearer to 3,500 mg/L TDS as the most likely value. This value falls within the average range for $EI_D$. For the BSEACD desalination feasibility study a range in project parameters—$R_D$, $z$, $z_B$, $l$, $l_B$, and $EI_D$—from favorable (requiring less power) to unfavorable (requiring more power) are considered in the calculation of the project capacities and generations, as given in Table 8.2.

| Factor | Parameter | Units | Favorable | Average | Unfavorable |
|---|---|---|---|---|---|
| $R_D$ | Desalination Recovery | -- | -- | 0.8 | -- |
| $z$ | Depth to aquifer | m | 500 | 525 | 550 |
| $z_B$ | Depth of injection aquifer | m | 625 | 600 | 575 |
| $l$ | Distribution pipe length | m | 1,000 | 8,000 | 16,000 |
| $l_B$ | Disposal pipe length | m | 7,000 | 18,000 | 22,000 |
| $EI_D$ | Energy intensity of desalination | kWh/m$^3$ | 1.0 | 1.8 | 2.6 |

**Table 8.2.** Ranges in desalination parameters within the BSEACD considered in the calculation of the project capacities and generations (Clayton et al., 2014)

| Calculations | |
|---|---|
| P (Power requirements of the RO desalination facility (kW)) | 6606 |
| Pp (Power required for pumping water from the aquifer and in pipelines (kW)) | 1349 |
| PD (Power required for brackish groundwater desalination (kW)) | 4670 |
| Pc (Power required for pumping brine from the facility into the aquifer(kW)) | 588 |

$$P = P_P + P_D \ (kW)$$

$$P_P = \frac{\rho g q}{1000\eta_P CF_D}\left(z[m] + \frac{\left(\frac{4q}{\pi(d)^2}\right)^2}{2g}\frac{f}{d}(z+l)\right) \ (kW)$$

$$P_D = \frac{3600\ EI_D q}{CF_D} \ (kW)$$

$$P_C = \frac{\rho_B g q}{1000\eta_P CF_D}\left(\frac{\left(\frac{4q}{\pi(d)}\right)^2}{2g}\frac{f}{d}(z_B + l_B)\right) \ (kW)$$

| Variables | |
|---|---|
| q - flow rate in units of cubic meters per second | 0.684572443 |
| qD - flow rate in units of cubic meters per second for injection | 0.136914489 |
| CFD - desalination capacity factor (a dimensionless ratio) | 0.95 |
| z - depth to aquifer in meters | 525 |
| l - the distribution pipe length in meters | 8000 |
| p - density of water (kg/m3) | 1000 |
| g - acceleration due to gravity (m/s2) | 9.81 |
| nP - pump efficiency | 0.85 |
| d - pump diameter (m) | 0.65 |
| f - friction factor | 0.0162 |
| EID - energy intensity of desalination (kWh/m3) | 1.8 |
| RD - RO recovery | 0.8 |
| GD - desired daily product water generation in m3 of treated water per day | 47318 |
| pB - density of brine (kg/m3) | 1570 |
| zB - depth to aquifer in meters to injection well | 575 |
| lB - the disposal pipe length in meters | 18000 |

$$q = \frac{1}{86{,}400} \times \frac{G_D}{R_D} \ \left(\frac{m^3}{s}\right)$$

$$q_D = \frac{1}{86{,}400} \times \left(\frac{G_D}{R_D} - G_D\right) \ \left(\frac{m^3}{s}\right)$$

Figure 8.2 – Screenshot of energy analysis model.

### 8.5 Model Assumptions

As previously mentioned cost figures were gathered from a variety of sources and compared to each other to validate the cost or derive an average appropriate for the Central Texas area. Sources of information are listed below in Tables 8.3 and 8.4, but overall were gathered through literature research, the TWDB UCM, and through communication with SAWS. The following is an expanded description of what is included in each parameter:

- **Building & Site Construction:** Construction cost of structures such as control room, laboratory, workshops, offices, and site-specific buildings (Younos, 2005). This cost also includes the cost of parking structures and perimeter security.
- **Electrical:** Cost of electrical wiring for all facilities throughout the site including buildings, the well field, water treatment plant, and other site-specific buildings.

- **Pipeline:** Construction and purchase costs related to the installation of pipes from production wells and to disposal wells.
- **Water Treatment Plant:** Costs related to the purchase and installation of water treatment units, instrumentation and controls (SCADA), pre- and post-treatment units and cleaning systems (Younos, 2005). For this model, the cost is based upon total plant capacity.
- **Well Field:** The costs related to the purchase and installation of wells, storage tanks, generators, transformers, pumps, valves (Younos, 2005).
- **Production Well Drilling:** The cost of production well construction based upon total depth.
- **Injection Well Drilling:** The cost of injection well construction based upon total depth.
- **Permitting:** Cost related to obtaining construction and operating permits through local, state, and federal entities.
- **Electrical Service:** Cost related to upgrading the surrounding utility service in order to provide adequate reliable power to the facility.
- **Contingency:** Cost added for possible additional services. For the purpose of this study, contingency costs were calculated to be between 2 to 4 percent of the total direct capital costs.
- **Contractor Fee:** Common general contractor fees calculated at a constant 4.0 percent of the total capital costs.

- **Bonds and Insurance:** Insurance and bonds during construction phase calculated to be between 1.5 to 2.0 percent of the total capital cost.

| **Table 8.3 – Capital cost range per MGD** | | | | |
|---|---|---|---|---|
| **Capital Costs** | **Low** | **Mid** | **High** | **Reference** |
| Building & Site Construction | $166,500 | $185,000 | $203,500 | (Donat, 2015; Morrison, 2015; Sturdivant et al., 2009) |
| Electrical | $639,000 | $710,000 | $781,000 | (Donat, 2015; Morrison, 2015; Sturdivant et al., 2009) |
| Pipeline | $720,000 | $800,000 | $880,000 | (Donat, 2015; Morrison, 2015; Smith et al., 2012; Sturdivant et al., 2009; Texas Water Development Board, 2013) |
| Water Treatment Plant | $1,500,000 | $1,750,000 | $2,500,000 | (Donat, 2015; Ettouney et al., 2002; Morrison, 2015; Sturdivant et al., 2009; Texas Water Development Board, 2013) |
| Well Field | $972,000 | $1,080,000 | $1,188,000 | (Donat, 2015; Morrison, 2015; Smith et al., 2012; Sturdivant et al., 2009; Texas Water Development Board, 2013) |
| Production Well Drilling | $162,000 | $180,000 | $198,000 | (Donat, 2015; Ettouney et al., 2002; LBG - Guyton Associates, 2003; Morrison, 2015; Texas Water Development Board, 2013) |
| Injection Well Drilling | $103,500 | $115,000 | $126,500 | (Donat, 2015; Ettouney et al., 2002; LBG - Guyton Associates, 2003; Morrison, 2015; Texas Water Development Board, 2013) |
| Permitting | $40,500 | $45,000 | $49,500 | (Donat, 2015; Morrison, 2015) |
| Electrical Service | $43,200 | $48,000 | $52,800 | (Donat, 2015; Ettouney et al., 2002; Morrison, 2015) |
| Contingency | $86,934 | $98,260 | $119,586 | (Donat, 2015; Ettouney et al., 2002; Morrison, 2015) |
| Contractor Fee | $177,345 | $200,450 | $243,955 | (Donat, 2015; Ettouney et al., 2002; Morrison, 2015) |
| Bonds and Insurance | $69,165 | $91,205 | $126,857 | (Donat, 2015; Morrison, 2015) |
| **TOTAL** | **$4,680,144** | **$5,302,915** | **$6,469,698** | (Arroyo et al., 2012; Donat, 2015; Mancha, 2015; Morrison, 2015; Smith et al., 2012; Sturdivant et al., 2009; Texas Water Development Board, 2013; Younos, 2005) |

- **Administrative Overhead:** Expenses related to the administration and general operations of the business wages for general secretaries, accountants, receptionists and other office workers, and management salaries. Administrative costs are calculated based upon total plant capacity.
- **Chemical:** Cost of chemicals frequently used to clean and maintain the water treatment plant. Total cost is dependent upon the total plant capacity.
- **Insurance:** Annual fixed cost of insurance calculated at 0.5 percent of the total capital cost. For the purpose of this paper, a cost curve was used to calculate the total labor cost and is dependent upon total plant capacity.
- **Labor:** Plant operation and maintenance technicians, and plant management.
- **Replacement Equipment:** Cost of replacing membranes and pumps based upon the total plant capacity.
- **Consumables:** Annual cost of lab consumables, lubricants, tools, safety, lab costs, landscaping, SCADA maintenance, security, office equipment, uniforms, phones and radios, and vehicle related costs. Consumables are calculated based upon total plant capacity.
- **Electrical Power:** Cost of providing electricity to the facility. Energy needs were calculated through an Energy Requirements Analysis (Chapter 8.4). The cost of electricity was modeled between \$0.04 to \$0.09 per kilowatt hour.

| Table 8.4 – Yearly Operational cost range per MGD | | | | |
|---|---|---|---|---|
| **Operational Cost Drivers** | **Low** | **Mid** | **High** | **Reference** |
| Administrative Overhead* | $45295, | $106,058 | $116,664 | (Donat, 2015; Morrison, 2015; Sturdivant et al., 2009) |
| Chemical | $18,404 | $19,372 | $20,341 | (Donat, 2015; Ettouney et al., 2002; Morrison, 2015; Sturdivant et al., 2009) |
| Insurance* | $23,863 | $26,515 | $29,166 | (Donat, 2015; Ettouney et al., 2002; Morrison, 2015) |
| Labor | $222,875 | $247,638 | $272,402 | (Donat, 2015; Morrison, 2015; Sturdivant et al., 2009) |
| Replacement Equipment | $19,930 | $22,145 | $24,359 | (Donat, 2015; Ettouney et al., 2002; Morrison, 2015; Sturdivant et al., 2009) |
| Consumables | $127,347 | $141,497 | $155,646 | (Donat, 2015; Ettouney et al., 2002; Morrison, 2015; Sturdivant et al., 2009) |
| Electrical Power ** | $135,222 | $236,639 | $304,250 | (Ettouney et al., 2002; Texas Water Development Board, 2013) |
| **TOTAL** | **$643,093** | **$799,864** | **$922,829** | |

* cost is a percentage of total capital cost
** cost is based upon energy requirement calculations discussed in Chapter 8.4

As can be seen in Figure 8.3, the largest portion of average capital cost per MGD is the water treatment plant followed by the well field. Together they account for 53 percent of the total average capital cost per MGD. The largest portion of operational costs is overwhelmingly the costs associated with electrical power (Fig. 8.4).

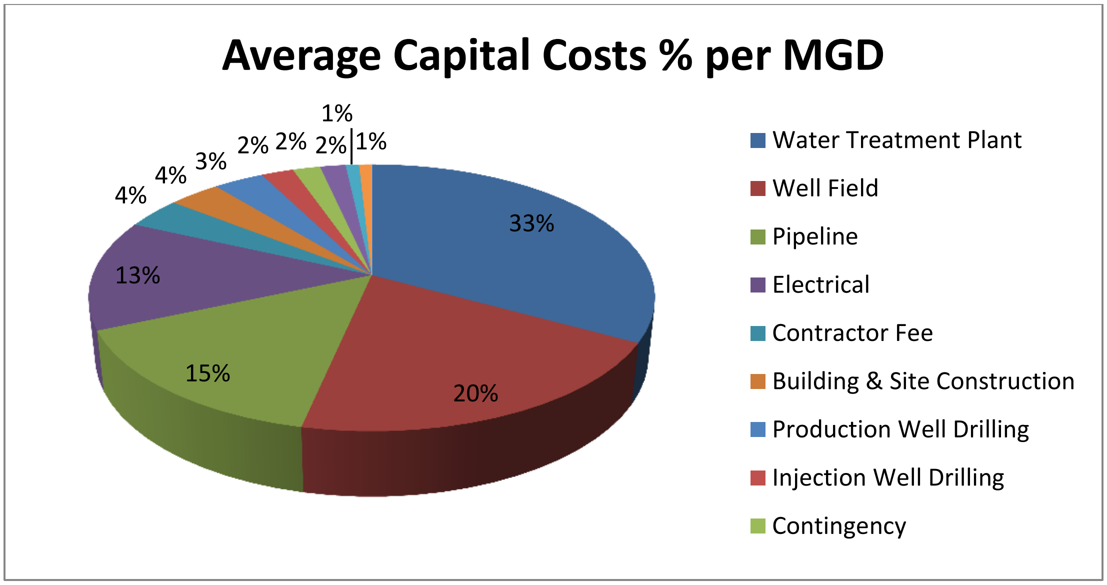



Figure 8.3 – Graph displaying percentage of each capital cost parameter.

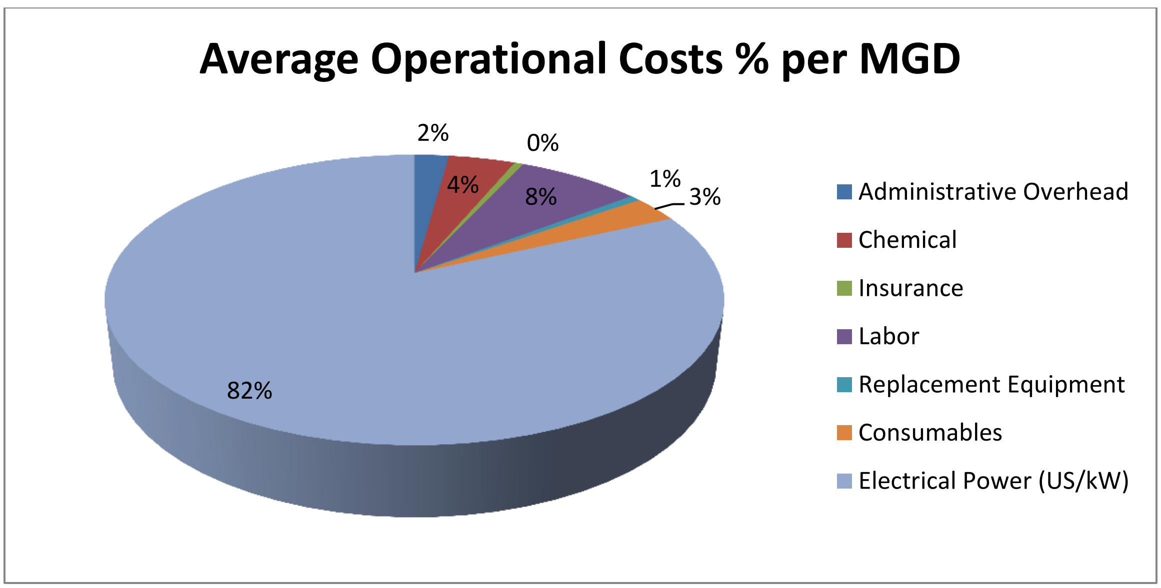



Figure 8.4 – Graph displaying percentage of each operational cost parameter.

# Chapter 9: Results and Discussion

## 9.1 Quantitative Analysis

Using the Palisade @RISK Analysis Tool, a model was developed using with varying parameters to calculate the economic feasibility of varying sizes of desalination projects. All the parameters described in Chapter 8 (Tables 8.2, 8.3, and 8.4) with a range of distribution were modeled in @RISK using a triangular distribution. A triangular distribution was used to avoid unwanted extreme high and low values and because means and standard deviations were unknown. Desired daily product generation ($G_D$) was the sole parameter with a uniform distribution so that all values would be as equally likely to be observed. $G_D$ is the governing parameter driving all functions throughout the model.

The simulation was set to run twenty repetitions of 10,000 iterations each for a total of 200,000 possible outcomes. Separate simulations of eighty repetitions of 1,000 iterations each were run to determine the desired daily product generation that would produce a Net Present Value (NPV) of zero dollars and the price of water that would be profitable. NPV is defined as the difference between the present value of cash inflows and the present value of cash outflows. Due to the time value of money, a dollar earned in the future won't be worth as much as one earned today. By using a discount rate in calculating an NPV, the time value of money can be accounted for and the value of a project can ultimately be determined. In the case of a BSEACD desalination project, a desired daily product generation below 2.76 MGD (~8,361 $m^3$) would generate a negative NPV and would not be a desirable project to pursue (i.e. the operator/investor loses money). The initial desire of the BSEACD was to have a desalination facility with a desired daily product generation between 1.25 to 12.5 MGD within the District. The price of produced water that would make the project profitable is as follows:

| Table 9.1 – Price of water for profitability | |
|---|---|
| Price of Water [$/MMGal] | 3000 |
| Price of Water [$/m3] | 0.79 |
| Price of Water [$/Ac-Ft] | 980 |
| Price of Water [$/1,000 gal] | 3.01 |

The minimal cost of water and maximum desired daily product generation were calculated through @RISK simulations with capital cost and operation/maintenance cost ranges manually entered into the model. Costs were simulated between the ranges of 1.25 to 12.5 MGD. Total capital costs for a facility within the desired production ranges ranged from a minimum of $5,850,180 to a maximum of $80,871,225. The cost of the treatment plant is the most sensitive to creating changes in the NPV (Fig. 9.1). A large price increase for the water treatment plant could easily result in a negative NPV. A cost increase in the electrical system, pipelines, and well field could also make an impact on the NPV but not as drastically as would the water treatment plant. Just as an increase in price would create a negative impact on NPV, a price decrease would create a positive impact. These effects can be noted in Figure 9.2. The figure displays the percentage change from the base value and its effect on the NPV. As previously noted, the NPV will be significantly affected by deviating from the base value for the water treatment plant. This is more so when increasing the cost as compared to decreasing it.

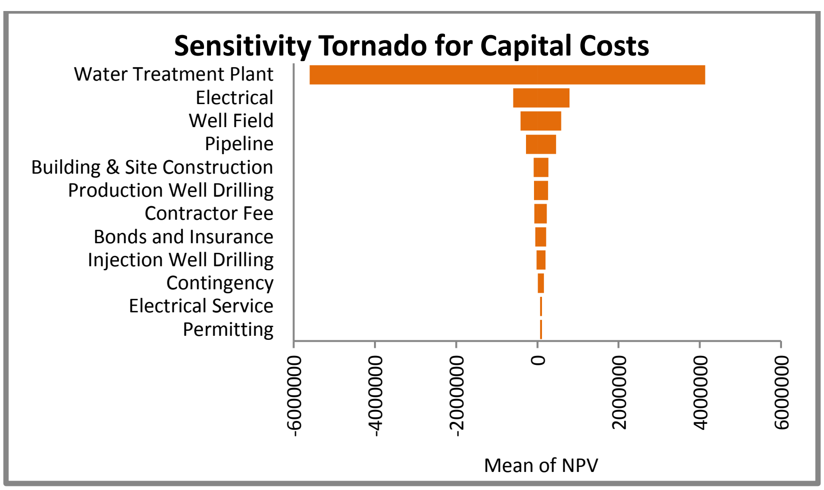



Figure 9.1 – Tornado graph displaying sensitivity of capital cost parameters to the NPV.

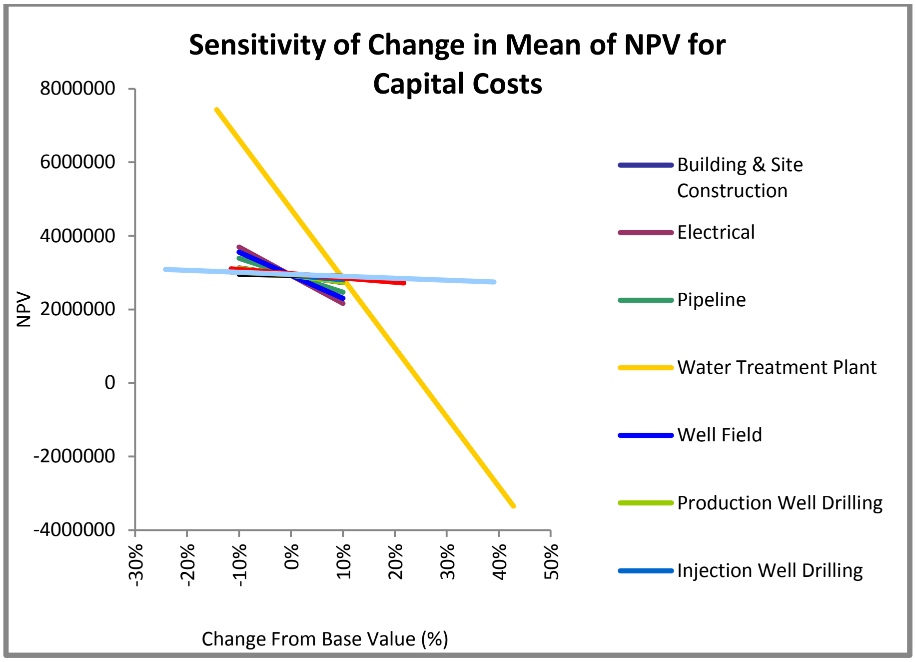



Figure 9.2 – Graph displaying the sensitivity of change in the mean of NPV values for capital costs when parameters are changed from their base value. The "water treatment plant" line is offset from the other lines due to its significant contribution to total capital costs and wider range of possible cost.

Operational costs were also included in the model. Total operational costs for a facility within the desired production ranges ranged from a minimum of $1,104,947 to a maximum of $17,428,262 annually. The cost electrical power is also the most sensitive to creating changes in the NPV (Fig. 9.3). An increase of as little as two cents per kilowatt hour could easily result in a negative NPV (Fig 9.4). If the desalination project could secure a long term contract with an electric utility provider for lower cost electricity (even one cent), the NPV would have a large positive improvement. Utilization factor and operational efficiency also make an impact on the NPV. Equipment must be maintained to run at maximum efficiency and the plant must minimize down-time in order to avoid the possibility of going into negative NPVs.

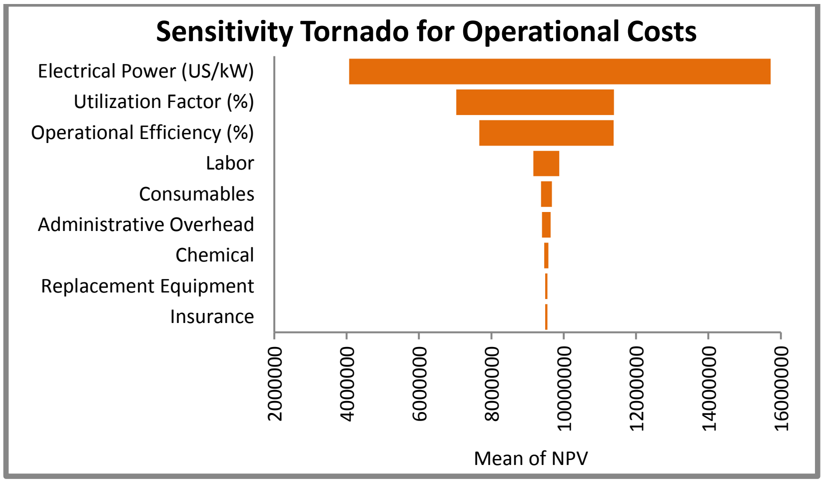



Figure 9.3 – Tornado graph displaying sensitivity of operational cost parameters to the NPV.

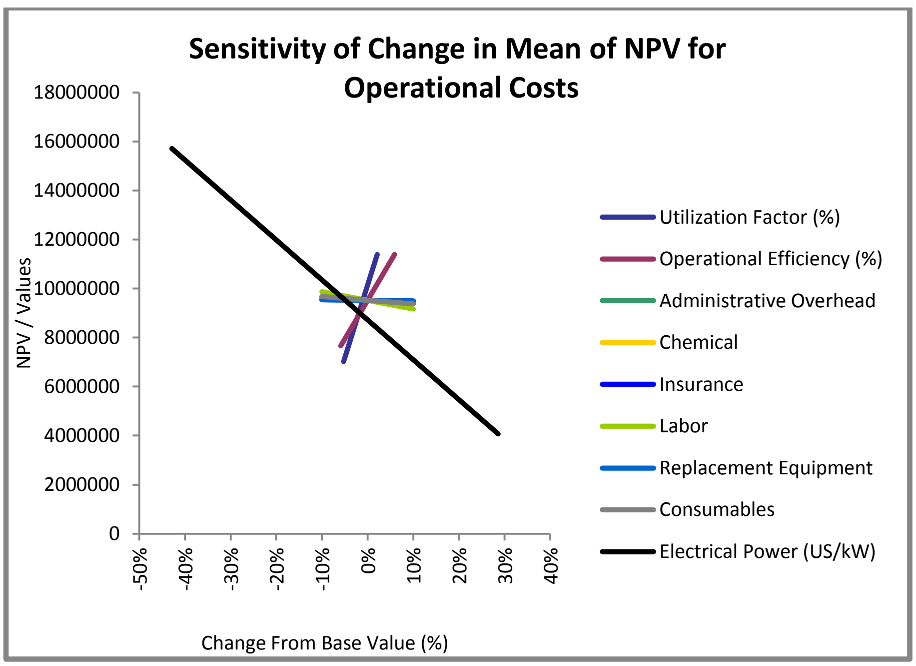



Figure 9.4 – Graph displaying the sensitivity of change in the mean of NPV values for operational cost when parameters are changed from their base value.

Finance drivers (Table 9.2) remained constant through the model as they are fairly standard financing variables and were determined based upon the assumption that investment of this magnitude would be largely financed through a business or investors. The BSEACD currently operates on a very small budget as they do not currently sell any water nor do they have any plans to enter the water supply business. The District encourages development of the saline Edwards and is consistently looking for more information to present to interested parties who may be interested in constructing a desalination facility. For ease of display the following Tables and Figures are displayed assuming the desired daily product generation is 2.76 MGD making the NPV equal $0 (Fig 9.5). At NPV equaling $0, the Internal Rate of Return (IRR) equaled 4.59 percent. IRR is defined as the internal rate of return on an investment or project that makes the NPV of all cash flows (both positive and negative) equal to zero. The higher a project's internal rate of return, the more desirable it is to undertake the project. As the desired daily product generation increase so did the NPC and IRR. All the capital and operation cost parameters were assigned a range for the model to provide the most possible scenarios and ultimately obtain the most likely values.

| **Table 9.2 - Finance Drivers** | **Value** |
|---|---|
| Depreciation [years] | 15 |
| Debt/Value [%] (20 year) | 95% |
| Tax | 30% |
| Cost of Debt | 5.0% |
| Annual Payment | $1,097,650 |

Figure 9.5 displays the water yield from the range that was found to be economically feasible within the District based on having a positive NPV. The cost of the water is based of operational costs and the yearly cost to repay the debt. The BSEACD could possibly add up to 13,776 acre feet per year of usable, available water. Adding this much water starts at a cost of $748 per acre foot ($2.30 per 1,000 gal) for a small project and gradually decreases in cost as the size of the facility increases (Fig 9.5). Due to economics of scale, the price of producing water decreases as the facility grows in size. At approximately 10 MGD of desired daily product generation the optimal price of $648 per acre-foot ($1.99 per 1,000 gal) is reached.

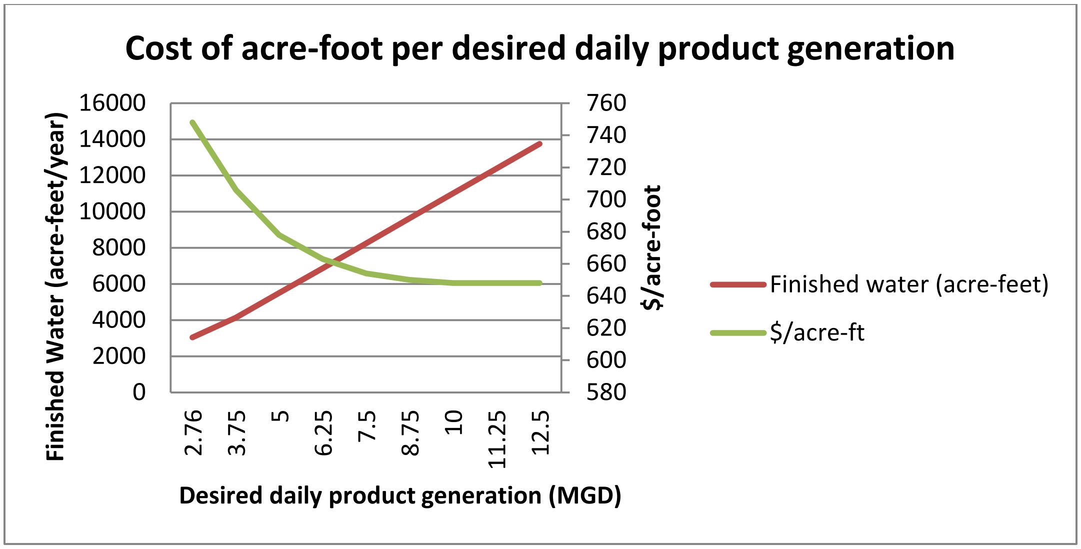



Figure 9.5 – Graph displaying the cost of an acre-foot per desired daily product generation. As desired daily product generation increases, so does the amount of finished water, but the cost of the finished water gradually decreases down to $648 per acre-foot.

The @RISK model was developed to evaluate a variety of possibilities in both capital and operational costs. These cost variabilities were analyzed by the @RISK software and distribution graphs were created to better evaluate possible risks with undertaking a desalination project. Overall, undertaking a desalination project within the BSEACD is an economically sound project based on the following distributions:

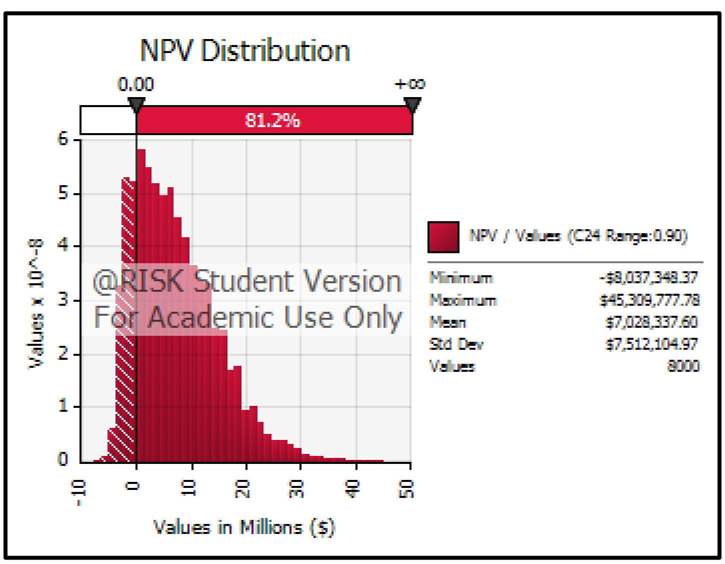



Figure 9.6 – The NPV distribution displays 81.2 percent of all possible outcomes have an NPV of greater than $0. The mean NPV is approximately $7 million dollars making the project economically viable and a sound investment.

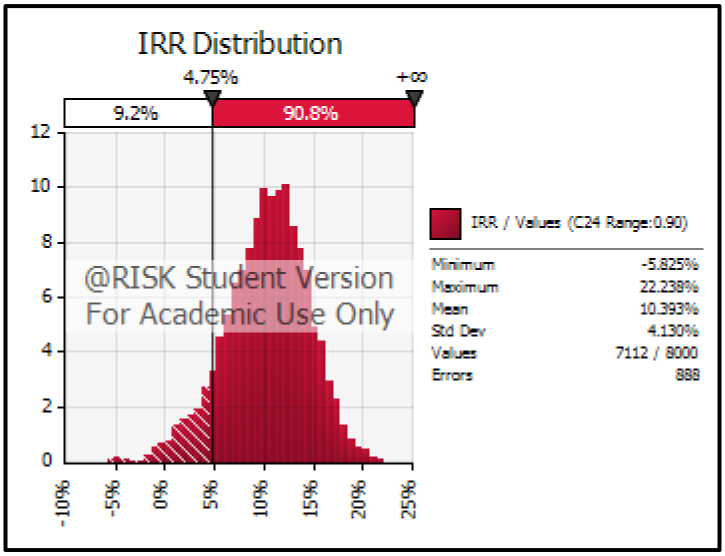



Figure 9.7 – The IRR distribution displays 90.8 percent of all possible outcomes have an IRR of greater than 4.75 percent. As previously stated, a higher IRR makes a project more desirable for possible investors. Additionally, 98.9 percent of all possible IRR for the desalination project are about 0 making it unlikely that an investor would have a negative return.

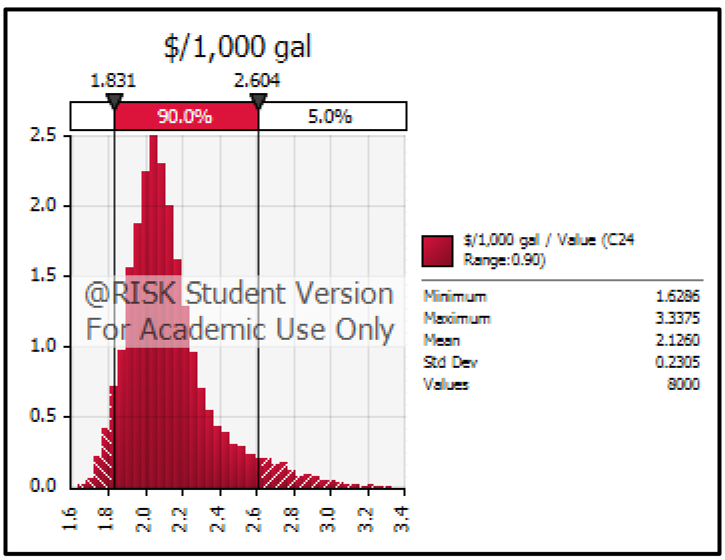



Figure 9.8 – The price to produce desalinated water per 1,000 gallons with a 90 percent confidence level is between $1.83 and $2.60 with a mean value of $2.12.

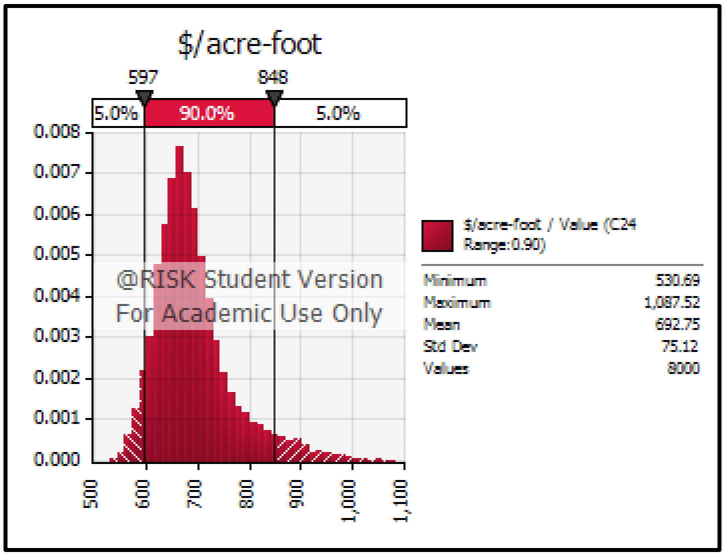



Figure 9.9 - The price to produce desalinated water per acre-foot with a 90 percent confidence level is between $597 and $848 with a mean value of $692.

The cost of producing groundwater through desalination in the BSEACD falls within the expected range of $357 to $782 per acre-foot ($1.09 to $2.40 per 1,000 gallon) published by the TWDB (Arroyo et al., 2012; Wythe, 2014). As explained in Section 3.4, the District is continually researching and working with its groundwater users in order to meet the 1.5 cfs reduction goal for its Extreme Drought Withdrawal Limitation (EDWL). The BSEACD needs approximately 1 MGD to cover this deficit. Even through the reductions allowed by law, the District cannot currently meet its EDWL. Constructing a desalination facility to supplement current supplies only during a drought was considered in this study but was found to be economically unfeasible. Utilizing a facility less the 80 percent of the time does not create enough revenue to cover the operating costs and debt payment (Fig. 9.10). A desalination facility within the BSEACD would have to be utilized as a constant source of water to be economically feasible. Consistent utilization would offset the deficit if a drought occurs and reduce hardships on current permitted users as they would not be subject to as drastic curtailment of their permitted water allowance.

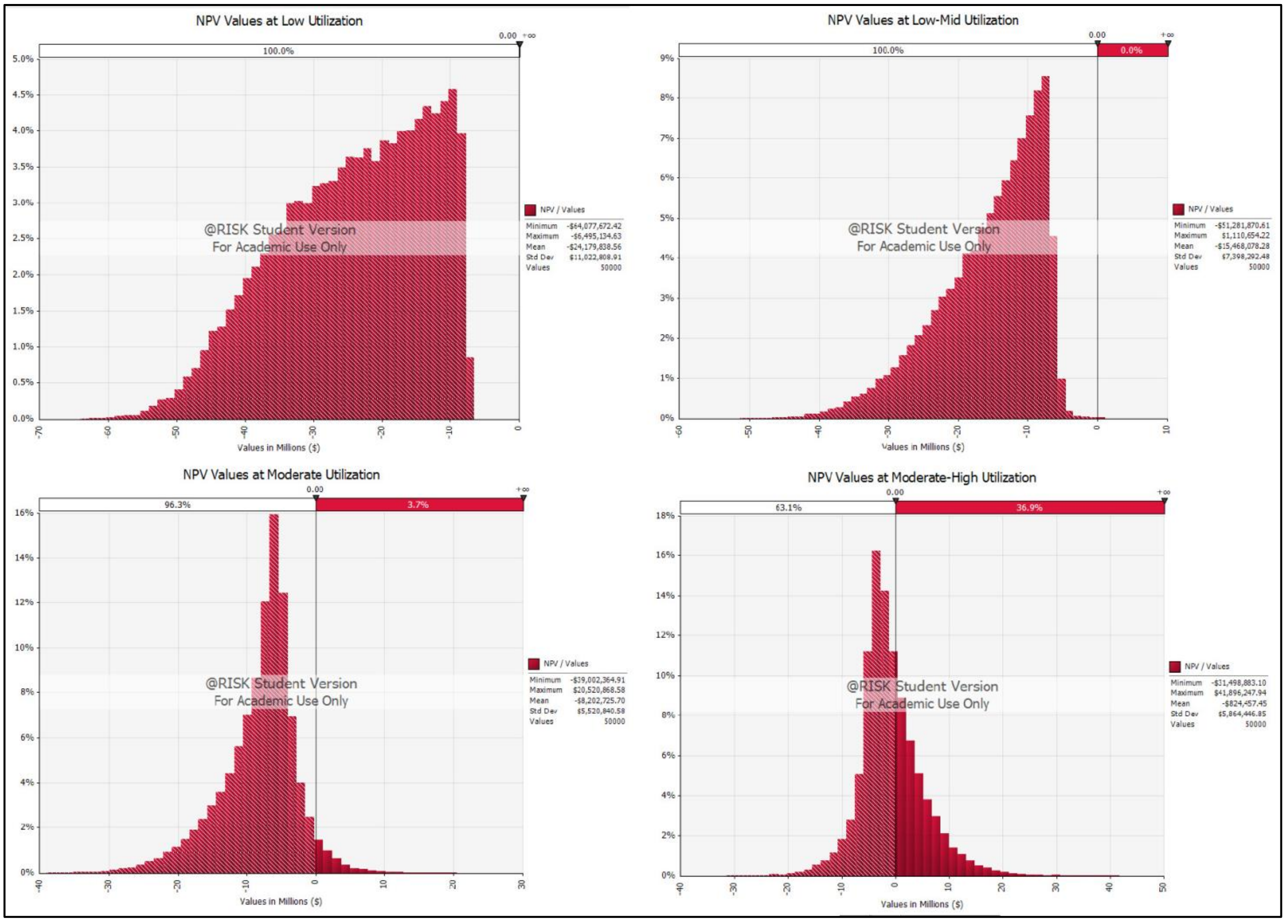



Figure 9.10 – Graphs displaying NPV distributions for varying utilization factors (Low: 2 – 10%; Low-Mid: 20 – 40%; Moderate: 40 – 60%; Moderate-High: 60-80%). Utilization under 40 percent creates negative NPV values no matter how much the desired daily product generation is. As utilization nears 80 percent, positive NPV values can be observed.

## 9.2 Regulations Overview

The most significant regulatory hurdle for alternative-supply development involves restrictions on injection wells that transect or terminate in the Edwards Aquifer (Smith et al., 2012). Even though SB 1532 has opened the door to some desalination within the confines of the District, the majority of the BSEACD still falls under Section 27.051(i) of the TWC. This section specifically states "The commission may not authorize by rule or permit an injection well that transects or terminates in the Edwards Aquifer." The only exception this section allows is for injection of "groundwater withdrawn from the Edwards Aquifer, or injections of storm water, flood water, or groundwater through improved sinkholes or caves located in karst topographic areas." The TCEQ defines "groundwater withdrawn from the Edwards" as groundwater that has not been "physically, chemically, or biologically altered". The provision also does not distinguish between fresh and saline zones of the Edwards aquifer.

Under Section 27.051(i) of the TWC, desalination in the District would not be possible unless the concentrate is disposed of in another method other than injection. While other methods of disposal are available (Fig. 9.11), they affect the economic viability of saline Edwards aquifer desalination projects as deep well injection is one of the more conventional and economical disposal methods for concentrate. (Smith et al., 2012). The other option for deep well injection exists in Bastrop and Caldwell counties. The provisions of Section 27.051(i) of the TWC do not apply to the Edwards aquifer as they do in Hays and Travis counties. While this option is available to the District, it complicates the process as wastewater would be crossing boundaries and the distance could make the effort economically unfeasible.

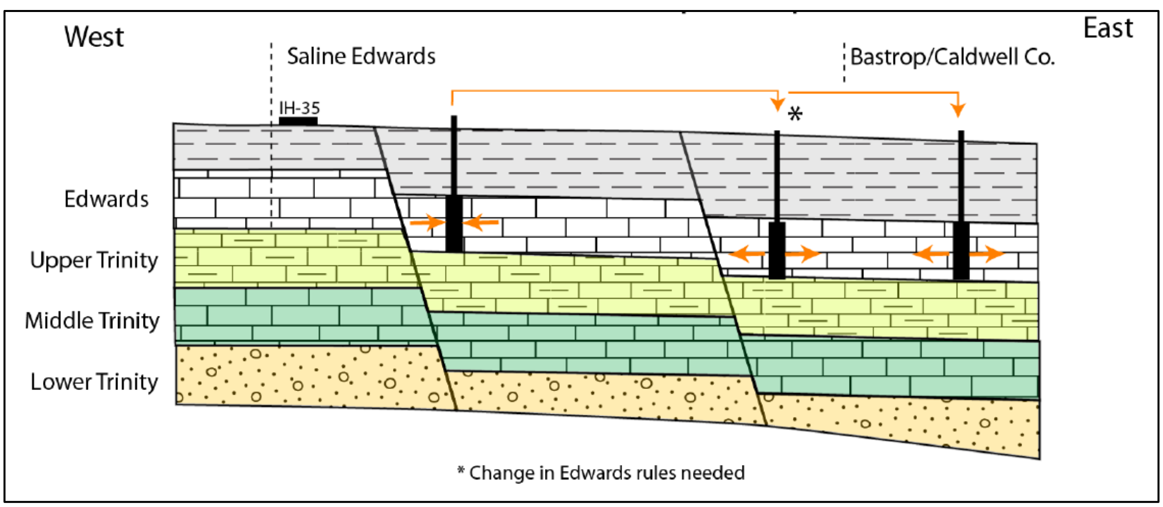



Figure 9.11 – Disposal options within the saline Edwards aquifer (Smith et al., 2012).

Currently the TCEQ's underground injection rules implement the federal Underground Injection Control (UIC) Program put into effect by the EPA. The federal regulations for the UIC Program are found in Title 40 of the Code of Federal Regulations. The requirements and provisions for the UIC Program are established through the SDWA. TCEQ follows the federal definition of Underground Source of Drinking Water (USDW) to be water that is less than 10,000 mg/L TDS. Due to the TCEQ's adoption of this program, there is currently a state-wide prohibition on injection of essentially anything other than native water, or water meeting drinking water standards, into or above such aquifers, including concentrate or other residuals from a desalination facility (Smith et al., 2012). While there are zones in the saline Edwards aquifer that are very saline with TDS above 10,000 mg/L and would not be considered a USDW, it could have a slight impact on the overall capital cost to deliver the concentrate to these areas. The cost of pipeline infrastructure is not a high sensitivity item to the overall capital cost as can be noted in Figure 9.4. The challenge arises in running the pipeline from the western part of the saline Edwards to the eastern side where TDS values tend to be higher. Obtaining local community permits and authorizations to construct a pipeline near existing infrastructure could face challenge and be time-consuming. Even then, this would only be possible if local regulations previously discussed are removed.

### 9.3 Technical Feasibility

Improvement in desalination technologies alongside increasing demands for new water supplies has facilitated the significant growth and interest in desalination projects on a global scale (Clayton et al., 2014). Locally, the ongoing drought and continuing population growth has sparked an interest in the technology as water supplies dwindle and the cost of obtaining a new water supply continues to grow. As desalination technologies improve and become more commonplace, costs will gradually decrease all while the cost of obtaining a new freshwater supply is gradually increasing due to limited availability and higher demand.

Much of the area managed by the BSEACD lies to the west of the "bad water line" and thus overlies and uses fresh water. But, as can be noted in Figure 9.6, the area east of the "bad water line" also managed by the BSEACD is saline and remains mostly undeveloped. Currently there are no large permitted wells and only a handful of small private wells in the saline Edwards. In contrast, there are numerous mid-size to very large permitted wells and conditionally permitted wells in freshwater zone of the Edwards aquifer. The potential for constructing a large well within the eastern sections of the district exists due to the availability of a permit within the area as long as economic feasibility and regulatory requirements are met.

Generally speaking, the saline Edwards aquifer is a relatively shallow water source that could be potentially developed. The aquifer can be reached at 500 feet in some areas and is about 500 to 700 feet in thickness. It can be expected that most wells will not surpass 800 feet in depth. This is advantageous to potential desalination as deeper wells increase costs significantly and has higher potential of have problems arise from unknown factors underground.

Electrical costs for a desalination facility are the largest continual operation cost. Electrical costs are directly correlated to the TDS of the incoming feedwater. Saline water in the Edwards aquifer ranges from 1,000 to greater than 10,000 TDS. While desalination of high TDS water is technically possible with today's technologies, it is usually not economically viable. The cost of desalinating high TDS water would greatly increase the operation costs and thus increase the final price of the produced water.

Desalinated water costs more than many other sources of fresh water but there is a limit to how much many communities are willing to pay for the product. The saline zone concentrations are not well known in the BSEACD as there are currently very few wells in the saline area. Test wells would need to be installed in order for a potential; desalination project to place the production wells in the most economically feasible location possible

In evaluating whether a desalination facility would be technically feasible within the saline portion of the Edwards aquifer, it also must be determined whether there is sufficient water to supply the demand of a desalination facility. Previous studies described in Pabalan (2003) estimate the well yield potential discharge to be between 860 to 2,575 gallons per minute (gpm) with an average of 1,547 gpm. These yield potentials equal out to approximately 1.2 MGD up to 3.7 MGD from a single well. From these studies, just south of the BSEACD in San Marcos and New Braunfels, the potential well yield discharge indicates that there is sufficient water and high enough hydraulic conductivity to support a desalination facility of up to several MGD. A concern of the BSEACD and current users of the Edwards aquifer is that of the saline water boundary moving due to the potential development of the saline Edwards. Currently, there is very little information on this potential problem but research at the BSEACD has been funded in order to better understand the interactions occurring at the boundary and to implement any rules such as buffer zone in order to avoid potential problems arising from the boundary line moving.

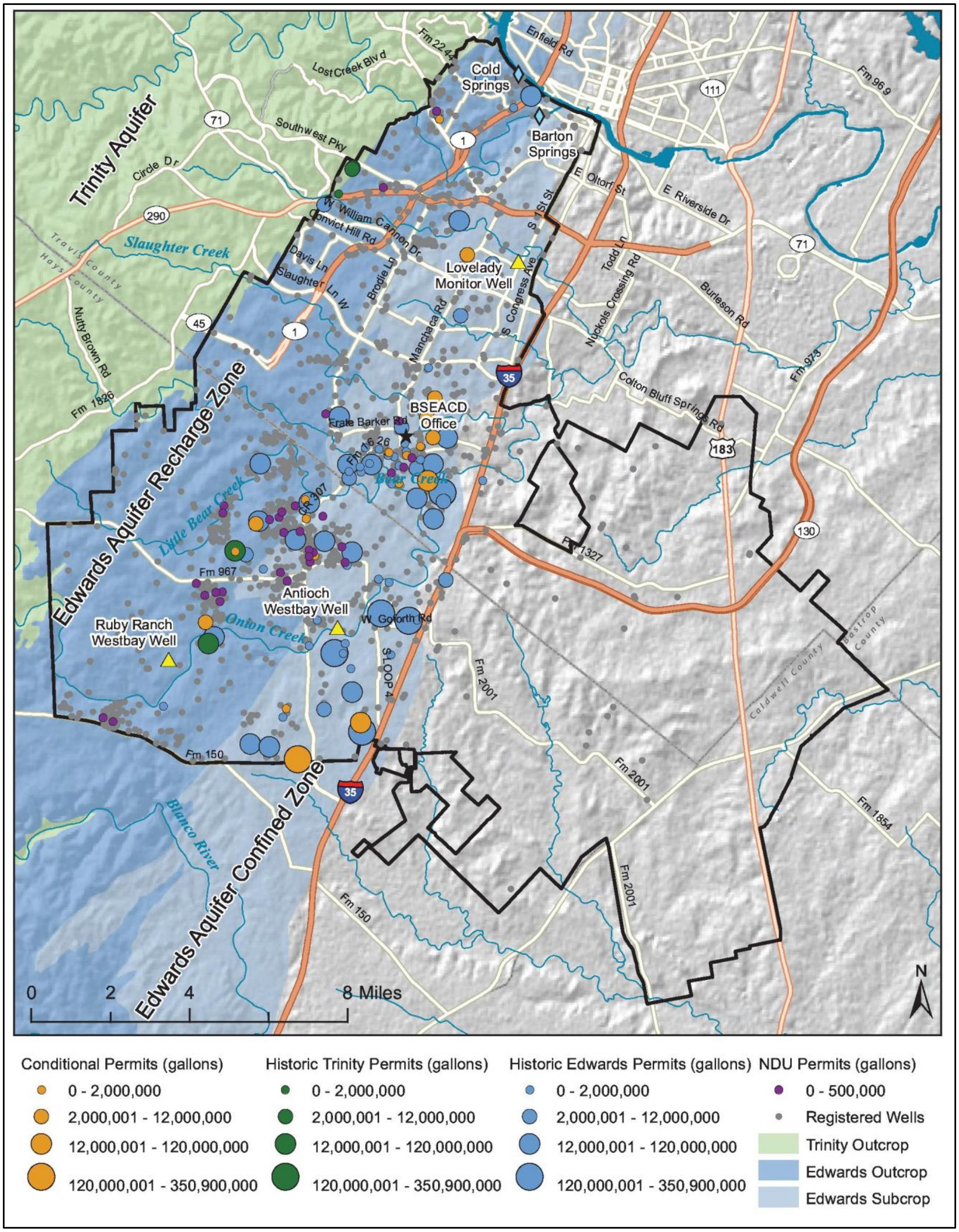



Figure 9.12 - Representative permitted volumes shown by approximate location within the District. Monitoring wells (triangles), major spring discharges, and office location are shown (Barton Springs/Edwards Aquifer Conservation District, 2014a)

# Chapter 10: Conclusions

## 10.1 Conclusion

This paper presents a method for estimating the total cost and feasibility of brackish groundwater desalination and feasibility of doing so within a preset range for a desalination project within the BSEACD. The model was developed using cost information that is readily available to the industry and the public through the TWDB, literature research on desalination costs, and cost information obtained through personal communication with relative entities.

In conclusion, a desalination project within the BSEACD within the desired ranges of 1.25 to 12.5 MGD would be economically feasible above 2.76 MGD when operated at a 95% desalination capacity factor. At this capacity, the facility would be operated constantly except when shut down for maintenance needs. As the project nears upper boundary of the desired daily product generation the NPV and IRR continue to increase and the cost of producing the desalinated water gradually decreases down to $648 per acre-foot ($1.99 per 1,000 gal). A facility producing less than 2.76 MGD creates a negative NPV and thus the project is not economically viable. Also, for projects near 2.76 MGD, an increase on construction cost, an electricity rate hike, or even extended periods on not operating the facility could easily bring the NPV of the project into negatives. As with all desalination facilities, electrical demand is a major cost contributor. Creating long-term contracts with electric utility providers for lower rates could increase the total water produced, increase the NPV, or decrease the overall cost of producing the water making it available for a cheaper price or creating a larger profit margin.

While a desalination project in the BSEACD is economically feasible if enough water is produced, there are regulatory and technical obstacles that must be overcome first before such a large capital investment can be put into place. Section 27.051(i) of the TWC was developed without regard to differentiating between the fresh water and saline water portions of the Edwards aquifer. The original intention of the regulation was to prevent the potential contamination of the fresh water in the Edwards aquifer. The saline portion was not considered nor where the possibilities of using the saline portion as the regulation was developed when there was no interest or forethought that the saline Edwards aquifer would eventually become a developable water source. In order to encourage saline Edwards desalination as a cost-effective water supply, the intent of this restriction needs to be recognized as unnecessary in the saline Edwards and then modified through legislation to allow for the development of desalination. S.B. 1532 opens up the possibility of desalination within the District, but is still too confined to produce enough outside interest. The confines of the bill are very narrow and are aimed at allowing Texas Disposal Systems to develop a small-scale desalination project that could be also used for research. Research could possibly open the opportunities for a larger scale desalination project within the confines of SB 1532 or possibly through a change in regulation.

As previously described in Chapter 3.4, the District is continually researching and working with its users in order to meet the 1.5 cfs reduction goal in order to meet the Extreme Drought Withdrawal Limitation. The District would need to obtain approximately 1 MGD or 1,120 acre feet in order to meet this goal during a severe drought. The goal could easily be achieved through a desalination project. The District could meet DFC without making extreme reductions to historical users and possibly some conditional users. This would only be possible with the facility being operated consistently and only down periodically for maintenance. While operating the facility intermittently could provide the water needed to cover the current deficit, it would not be economically viable. Utilizing the facility below 80 percent does not create sufficient income to cover the cost of desalinating groundwater (operating costs plus debt payment).

Further research is needed to better understand the saline Edwards aquifer and its dynamics. Currently, not much is known about the aquifer due to a very limited number of wells drilled into it and monitored. Better understanding the aquifer and it's salinity distribution will make desalination projects more economically feasible as less TDS requires less electrical demand. Research is also needed to better understand the saline boundary line. Production in the fresh water Edwards is still and will continue to be highly important to the region. It is important to understand if production from the saline Edwards will affect the saline boundary line and how it will affect it

Further research within the interests of the BSEACD area could consider optimizing the operation profile to maximize revenues, evaluating different forms of desalination in the same manner as has been done in this paper, or continue working towards RO desalination but consider alternate forms of disposal. Other options to consider are integrating renewable energy into the system and evaluate the cost benefits.

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## Vita

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