Brackish Groundwater Desalination:

A Decision Support Tool

By

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Abstract

The purpose of this study is to provide water utility decision makers like city managers, water company managers, city council members, etc. with key questions to consider prior to choosing whether to embark on a brackish groundwater desalination program for their utility. The scholarly literature review indicated five areas of greatest importance for consideration when contemplating a brackish groundwater project. Those topics included power source, source water availability, brine concentrate disposal, support for the program and cost. Twenty initial questions from these five topic areas were created and then posed to twelve subject matter experts, via remote interview, for their comment. Experts interviewed included engineers, water company managers, state association directors, both state and federal agency program administrators, and a retired city manager. With the guidance of these experts, four new "qualifying questions" were created. Six questions were changed extensively. Six questions were modified slightly, and eight questions remained unchanged.

for Steve

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Chapter 1: Introduction

In 2011, the hottest and driest year recorded in Texas, water supplies were at critically low levels. It was the middle of the second worst and second longest multi-year statewide drought dating back to 1895 (Texas Water Development Board, 2017). As General Manager of the Jarrell-Schwertner Water Supply Corporation, it was my responsibility to keep water flowing to approximately 3,000 customers. The water level in one well was one foot or less above the pump and a second well was not much better. The daily and sometimes twice daily well reading was both a source of stress and limited comfort, knowing that the well was not dry yet.

There were a couple of planned emergency interconnections with neighboring water systems, but those other systems were also accessing the Edwards aquifer. If the wells went dry, there was a chance that neighboring systems' wells would be similarly stressed even if they were newer and at deeper depth. The TCEQ requires .6 gallons per minute of well capacity per connection but will allow .35 gpm for each connection in a combined system under emergency conditions (Texas Administrative Code 30 TAC 290), so using the emergency interconnect probably could have worked on a short-term, temporary basis.

Surface water users were in just as bad a situation due to high water use and high levels of evaporation. In addition, every surface water supply within a reasonable distance was already allocated according to Brazos River Authority staff. Everyone was looking for alternative or emergency sources of water just in case it was needed. Fortunately, the Jarrell-Schwertner WSC never had to enact those emergency contingencies. The rains finally came, but the need to prepare for such emergencies is never far from the mind of water providers.

One of the alternative sources or water management strategies referred to in the 2017 State Water Plan is Brackish Groundwater Desalination. It accounts for only 2.1% of the total statewide planned new sources or 70,137 acre-feet (AF) of water per year (22,854,352 kgal), but for those water systems who rely on it even as a backup source, the level of importance is enormous.

Any new source of water takes time to develop. Typically, there are Engineering Feasibility Studies that take a few months, Engineering Plans to be designed, permits from TCEQ to acquire, and financing to secure. Under normal circumstances, it could take a year to several years to bring a new supply online. Therefore, every municipal water provider plans well in advance, to the best of their ability, not for the proverbial rainy day but for the drought.

Brackish groundwater in Texas is a virtually untapped source because it is typically more expensive to produce than the water from freshwater aquifers and lakes (Arroyo, 2012; Bazargan, 2018; Burn, 2015). Eight Regional Water Planning Groups, E, F, H, J, L, M, N, and O included groundwater desalination as a water management strategy in the 2017 State Water Plan (Texas Water Development Board, 2019, April). The 2022 State Water Plan Recommended Water Management Strategies includes the same regions and adds Region G and K. Of those, Regions H, M and N also include Seawater Desalination (Texas Water Development Board, 2022).

There are multiple cost considerations for any water supply. Treatment, transmission lines, water storage, land and water rights are a few. For brackish water desalination, the costs fall in many of the same categories but tend to be several times higher (Ahmed, 2019, Bazargan, 2018). The water must be treated to a higher degree. Energy demands are higher. Disposal of the distillate or brine is expensive as are other costs of environmental / regulatory compliance.

Power Source

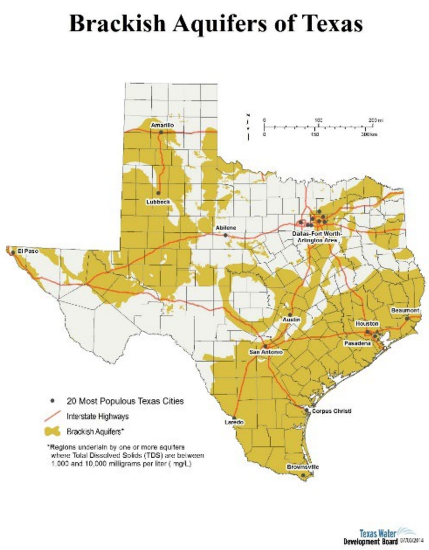
Energy is one of the biggest cost drivers of the ongoing Operating and Maintenance costs of a desalination plant. Electricity alone can be 30 to 50% of Operating costs (Burn, 2015). While energy demand for the high-pressure pumps used in Reverse Osmosis** desalination is significant, Energy Recovery Devices (ERDs) have been employed to reduce some of those costs. Unfortunately, ERDs are not considered economical in small systems due to the considerable upfront cost (Ahmed, 2019).

Source Water

Despite the higher Operating & Maintenance costs, the apparently large and stable quantity of brackish water makes it an attractive option. A US Geologic Survey concluded there is 800 times as much brackish groundwater available as fresh water currently in use in the U.S. (Kucera, 2019, p.13). The question becomes, is it available to your water system? A quick scan of the Brackish Aquifers of Texas map (page 8) shows that roughly 40% of Texas has brackish groundwater under foot.

**There are many desalination technologies currently in use around the world. Reverse Osmosis however is the technology of choice for approximately 80% of all desalination plants currently in operation (Ahmed, 2019). It dominates the market for many reasons. Reverse Osmosis is effective for all levels of salinity according to Burn (2015). It has lower energy requirements than other treatment options (Soliman, 2021); while the operating costs are higher than thermal desalination, the capital costs are lower (Soliman, 2021); the growth of Reverse Osmosis as the technology of choice has opened the desalination market and allowed contractors to purchase the technology without bearing the cost burden of in-house experts (Bazargan, 2018). For these reasons, Reverse Osmosis will be the primary mode of desalination for the foreseeable future (Kucera, 2019) and is the only treatment option discussed in this paper.

The Texas Water Development Board is in the process of determining the locations with the highest probability of being productive sources (Texas Water Development Board, 2019). In those areas where brackish groundwater aquifers do not exist, the produced water byproduct from oil & gas wells is a very tantalizing option (Burnett, 2005). The water-oil ratio, WOR, in Texas is greater than 7 to 1. In other words, for every barrel of oil produced, there are seven barrels of water on average (Burnett, 2005). From a 2002 estimation, “approximately 84% of Texas [oil] production came from the Permian Basin. Since the average well in the Permian Basin produced 7 bbls (barrels) …this represents more than 400 million gallons of water per day” (Burnett, 2005, p.3).



This option could be a win-win for both the oil companies and local water consumers. Hauling produced water off-site is costly to oil companies. Treatment, including desalination, could take place on-site for less money (Burnett, 2005). One of the biggest cost factors that makes desalination of produced water (from oil and gas extraction) interesting from a business perspective, is the fact that contaminants filtered from the brine can be injected back into the well field without requiring additional EPA permits. (Burnett, 2005)

Brine Concentrate Disposal

For everyone who does not have the option of injecting back into the well field, disposal of the concentrate is another substantial ongoing cost in desalination. Fortunately, the US Geologic Survey has just released a Concentrate Management Toolbox (Delagah, 2020). It helps planners determine what type of brine concentrate disposal will work best for their area.

For small cities and stand-alone water systems, processing the brine concentrate through their waste-water treatment plant and then discharging into an evaporation pond or nearest stream may be an option (Mancha, 2020). For larger cities like San Antonio, injecting the concentrate into wells permitted for concentrate discharge is the best option (Shirazi, 2019). The City of El Paso has been able to increase production at the Kay Bailey Hutchison Desalination Plant by almost 10% by partnering with Envirowater Minerals to remove minerals from the brine. Through their patented process, Envirowater Minerals uses the minerals in commercially viable products like High Purity Salt, Agricultural Gypsum, Potash Liquid Fertilizer and Milk of Magnesia (El Paso Water, 2018).

Support

The level of support from local and state government officials can launch or sink a desalination project. The hurdle of permitting a seawater desalination facility in California is so high that planners are considering building a plant in Mexico and piping the water north across the border (Bazargan, 2018). In the case of produced water from oil and gas fields, it is considered Industrial Reclaimed water subject to all relevant regulations (Tx Admin. Code, Chapter 210, Subchapter E, Special Requirements) (Burnett, 2005).

Considering the fact that “water shortages pose systemic risks that cascade through the economy” (Garrick, 2019, p.2), state and local leaders have considerable incentive to help ensure a sustainable water supply. According to the 2017 State Water Plan, Texas must implement the proposed water strategies contained therein or face economic losses in the neighborhood of $73B in 2020 to $151B by 2070.

A considerable and often necessary indication of support is in providing financing. “In the US, the water industry is 2.3 times more capital intensive than the electricity industry in terms of dollars of assets per dollar of annual revenue and 2.4 times more capital intensive than the telecom industry” (Garrick, 2020, p 9). Unfortunately, water infrastructure projects do not offer a high or even moderate return on investment. In addition, there is typically a very long payback, thus it is not attractive to private sector investors (Garrick, 2020). For this reason state support through funding is typically essential.

Cost

The Capital Costs for installing a Desalination Plant ranged from $2.03 to $3.91 / gallon of installed capacity in 2012. Operating and Maintenance costs range from $.53 to $1.16 / kgal of water produced during the same time (Arroyo, 2012). The estimated infrastructure cost alone of the planned Desalination projects in Texas over the next 50 years is $2,287,850,519. (Texas Water Development Board, 2020)

Considering the high investment required, we need all the planning tools we can get to be relatively certain of the decision. Both TWDB and the U.S. Bureau of Reclamation offer an online infrastructure cost estimating tool. The U.S. Bureau of Reclamation additionally offers “WTCost©, a database and computer program with cost algorithms for different types of desalination pretreatment and treatment technologies” (Arroyo, 2012, p.7).

Purpose

Water system administrators and decision makers are under a heavy burden to maintain a reliable water supply season after season. If new water supplies are not explored or brought online in a timely manner, the economic harm to a community could be substantial. The multiple factors to be considered before proceeding with a brackish groundwater desalination program make desalination a more daunting avenue than simple groundwater production or surface water treatment. At the conclusion of this paper, a layman (non-engineer) administrator should have a minimum understanding of the different factors and relevant tools available to have a thoughtful and thorough conversation with the system engineer about moving forward with an engineering feasibility study or looking elsewhere for water.

The purpose of this research project is to identify those factors of greatest importance in implementing a groundwater desalination program and to create, using the literature and insights from practitioners, a Decision Support Tool for leaders considering adopting this alternative water supply. This tool is intended for those city administrators, small town council members, WSC, SUD and MUD Board members, managers, and anyone else who is considering Brackish Groundwater Desalination for the first time.

Chapter 2: Literature Review

Even though Reverse Osmosis is an established technology, water cost, energy consumption and environmental concerns, among others, are still significant obstacles to establishing a desalination plant (Ibrahim, 2021). In this chapter, the various factors affecting desalination water planning are explored and summarized using insights from researchers as detailed in the available literature.

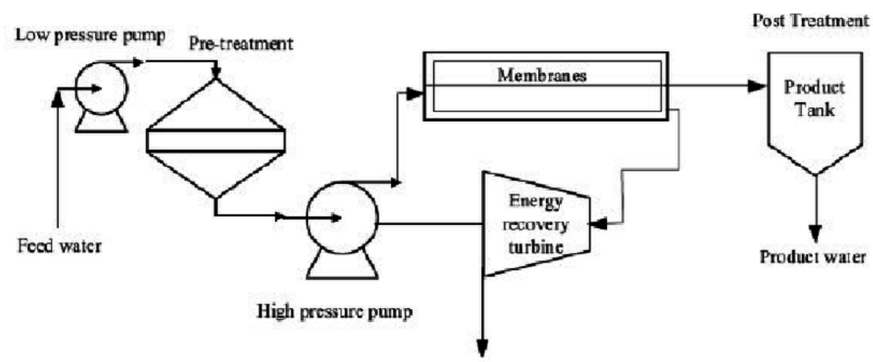
At the end of the chapter the reader will find a table detailing the conceptual framework upon which this paper is structured. First, power source is discussed due to its essential nature throughout the life of a desalination project. Traditional energy sources as well as solar and wind power will be briefly highlighted. Next, source water is broken down into brackish groundwater and produced water from oil and gas production. The third topic is brine concentrate disposal. Options explored in this paper include discharge into a water body, discharge into a sewer system, deep well injection, drying beds, land application and mineral extraction. The often overlooked topic of support is discussed as viewed from the perspective of government regulation and community backing. This chapter will conclude with the topic of cost as it relates to government financing and impact on water rates.

1. Power Source

Energy accounts for up to 50% of the ongoing Operating & Maintenance costs (O&M) of a desalination plant (Burn, 2015; Soliman, 2021), so it stands to reason that it would be one of the most important factors to consider carefully. The largest contributor to that energy consumption in an RO system is the high-pressure pump (Ahmed, 2019), followed by the Reverse Osmosis (RO) membrane and the Energy Recovery Device (ERD) (Chu, 2021).

According to reports, ERDs have recovered as much as 98% of energy spent on pressurizing the feed water (Soliman, 2021). This can be accomplished with a closed concentrate circulation that takes energy from the product water and reroutes it back to the feed water (Song, 2012). The feed water flow rate has a stronger impact on energy consumption than its salinity (Song, 2012). This is noteworthy considering the fact that high salinity seawater desalination can require more than twice the energy that brackish water desalination requires (Soliman, 2021).

Schematic of RO system with High Pressure pump & Energy Recovery Turbine



Renewable Energy Powered Desalination Systems: Technologies and Economics State of the Art

Mohamed Eltawil, Zhengming Zhao and Liqiang Yuan

1.1 Electricity (Traditional Coal & Gas sourced)

Brackish water RO consumes ~1.5kWh/m^3 to 2.5 kWh/m^3 (Soliman, 2021). Since transmission fees are a considerable part of the cost, where possible, desalination plants have been co-located next to electric power stations to decrease that cost.

Table 2.1 Energy Use per Water Volume Equivalents

1.5kWh/m^3	5.69 kWh/ kgal	1,850 kWh/ AF	5,678 kWh/MGD
2.5 kWh/m^3	9.475kWh/ kgal	3,083 kWh/ AF	9,463 kWh/MGD

In the literature and reports, water providers and researchers in Europe and the Middle East measure production in terms of m^3. In the U.S. it is measured in 1000 gallons (kgal) (for smaller water systems) or acre feet and Million Gallons per Day (MGD) for larger water systems. The above equivalents were calculated based on the conversion ratios provided in the Appendix.

The cost of electricity is highly variable. A quick internet search on March 25, 2021 shows the average cost of electricity as $.1319 / kWh while a follow-up inquiry on the same day listed it at $.118 / kWh. A desire for cost savings or energy redundancy, rural location and corresponding distance from an adequate power grid, or climate concerns could all be motivators that point operators to consider alternative sources of power.

1.2 Wind Power

Considering there is strong interest many sectors have shown in moving away from coal and gas sourced power, there is ample research discussing desalination plants powered by wind and solar energy. A study to convert wind power directly to mechanical energy has been underway since 2015 (Burn, 2015). An obvious drawback to utilizing wind turbines to power a desalination plant is the intermittent nature of wind. In order to continue providing water to customers even during times of calm or no winds, water storage tanks can be installed to provide a steady supply of water.

An optimized plant that uses water storage tanks is less expensive and less complicated to operate than a system utilizing batteries, variable feed water pressure or a variable number of RO membranes (Ali, 2021). The lowest cost achieved, using water storage tanks in the Ali, et al study in Saudi Arabia, was $.53/m^3 ($2.01/ kgal). It came with a 43% loss in annual production. The lowest cost using energy storage was $.40/m^3 ($1.52/ kgal); the major drawback was a 10.3% drop in hourly production. When plant operations were optimized to meet the required production rate, the cost was documented to be $7.42 /m^3 ($28.12/ kgal) in the system with water storage tanks. When battery storage was added, the cost increased considerably to $19.7/m^3 ($74.66/ kgal) (Ali, 2021).

The same researcher described a wind-powered RO plant as both complicated and challenging to operate. A hybrid plant, including water storage tanks and a battery bank was even more complicated and expensive to construct. (Ali, 2021). Without back-up systems to keep water continuously flowing however, “membrane deterioration and scaling are bigger problems” (Burn, 2015, p 5).

1.3 Solar Power

There is increasing interest in solar powered desalination plants also, in part, because abundant sunlight goes with water shortage (Ahmed, 2019). Another possible reason for an increase in interest is the fact that photovoltaic modules have experienced an 80% decline in cost in the last decade (Ahmed, 2019). As with wind power, having a back-up plan for those days when the sun is not shining is an important consideration. Lithium Ion batteries plus super capacitors have been used to store excess energy for those cloudy days in order to improve water production (Li, 2021) in lab tests. According to at least one researcher, such "hybrid systems are more economically and environmentally beneficial" (Ahmed, 2019, p 64).

The IRENA Renewable Power Generation Costs in 2019 publication lists Solar Photovoltaic costs as $.068/kWh compared to Fossil Fuel at $.066/kWh and Onshore Wind costs at $.053/kWh. This comparison is on a "global weighted average levelized cost of electricity (LCOE) from utility scale renewable power generation technologies" (Taylor, 2020). Whether or not the cost is comparable on a small scale is not so certain, but costs do continue to drop in the renewable energy sector due to considerable investment and rapid advances in technology.

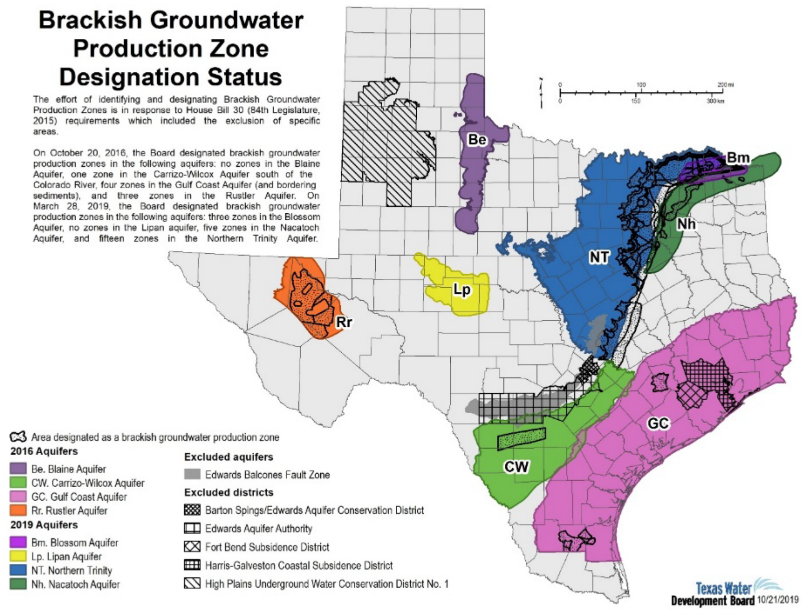
In rural areas where the electric grid is not well equipped to provide the continuous, high power demand of a desalination plant, alternative forms of power may be the right answer. For water systems which are applying for grants favoring or even requiring a green energy approach, alternative forms of power may be the best choice. In the event that community opinion could be swayed by utilizing green energy, it should be carefully considered. Whether a single power source or a hybrid system, decision makers should bear in mind that "future cost of desalination are more sensitive to changes in energy prices" (Cooley, 2006, p 15), thus long-term energy costs must be taken into consideration as much as possible.

2. **Source Water**

The second factor to review is source water. There is ample literature on seawater desalination, and it is readily available along the coast, but higher costs to desalinate and the high cost of transporting it long distances inland make it a more attractive option for coastal water users. One study in South Korea explained that 90% of island desalination plants used brackish groundwater as their source despite being surrounded by seawater (Chu, 2021). While comparisons will be made or details mentioned that relate to seawater desalination, groundwater desalination will be the focus of this paper.

2.1 Brackish Groundwater

Even though brackish water aquifers are found in over 40% of Texas, production zones have only been identified in about a dozen counties thus far. In 2019, the 86th Texas Legislature provided $2 million to the Texas Water Development Board (TWDB) to continue the designation of brackish groundwater production zones in state aquifers and HB 722 established a permitting framework for developing water supplies (TWDB BRACS website).



As previously mentioned, The U.S. Geologic Survey conducted one study which concluded there could be 800 times more brackish groundwater under the U.S. than is currently used on an annual basis. (Drane-Maury, 2017; Kucera, 2019). This same study admitted that data is lacking or is completely absent for depths below 500 ft in many areas of the country. The author's conservative estimate of brackish groundwater available is 35 times our current annual groundwater use. Whether it is 35 years or 800 years-worth of water, researchers are certain brackish groundwater is present throughout the United States, with the exception of New Hampshire and Rhode Island, within 3000 feet of ground level (Drane-Maury, 2017).

2.2 Produced Water

For water providers who are in those parts of Texas where there are no known brackish aquifers, produced water from oil and gas production could be a very real consideration. Recent legislation makes the ownership of produced water confusing (Hosey, 2021), but it belongs to someone and may soon be viewed as a valuable resource instead of a costly liability. The

Department of Energy labeled produced water "an important co-product" (Dept. of Energy, Sept. 2, 2020) of oil and gas production.

Texas A&M team field trials and laboratory studies show that pretreatment or conditioning is the most significant difference between desalination of produced water and brackish ground water (Burnett, 2005). Granted, produced water may contain acids, waxes, mineral oils, inorganic metals, and heavy metals (Dept. of Energy, 2020). Produced water is more saline than sea water (Veil, 2004) and the amount of water that can be produced "varies depending on region, geologic setting, and maturity of reservoir" (Dept. of Energy, 2020, p 1). However, there is an abundance of water in question in arid regions where it is greatly needed. In the Delaware Basin, we produced approximately 2 times more water than what was needed for hydraulic fracturing. When subtracting the Hydraulic Fracturing volume from the volume of water produced, there was still 23 million AF of water left over (Scanlon, 2021). Possible beneficial uses of produced water are crop irrigation, municipal use, surface water discharge, groundwater recharge and industrial use (Scanlon, 2021). Even if it was only used for irrigation, a substantial amount of fresh water would be freed for residential use (Scanlan, 2020).

After confirming there is either brackish groundwater or produced water relatively close by, the water system manager, board member or city council member will need to turn their attention to disposal of the concentrate.

3. **Brine Concentrate Disposal**

Once moved offsite, the concentrated brine is considered hazardous (Mace, 2020). Concentrate can be highly turbid and exit the desalination plant at elevated temperatures in addition to containing chemical additives like polymers/coagulants, acids, biocides and corrosion inhibitors or cleaners (Kucera, 2019). Soliman details several approaches to disposal such as deep well injection, sewer discharge, discharge into surface water, evaporation tanks and land usage (Soliman, 2021). The chemical components added during pre-treatment can impact the environment no matter which application is used (Soliman, 2021), thus it is imperative the options are carefully considered, and utmost care is taken. Discharge to surface water is the most commonly utilized disposal method, followed in decreasing order by "discharge to sewer, deep well injection, land application and discharge to evaporation ponds" (Kucera, 2019, p 38). As previously mentioned, the U.S. Bureau of Reclamation has created a concentrate management toolbox that gives decision makers a platform on which to compare brine concentrate disposal technologies (Delagah, 2020).

3.1 Discharge into water body

Disposal of concentrate into surface water may mean discharging into a river or the ocean. This option is only acceptable when the composition of the residual brine matches so closely, due to treatment, that it does not interfere with the natural balance of the flora and fauna of the water body (Soliman, 2021).

3.2 Discharge into sewer system

Disposal into the sewer system to be included in the community's wastewater treatment is more applicable for small scale plants. There is the potential of negative effects on the plant operation (Chang, 2015). Disposal cost using wastewater treatment has been calculated at $.32/m^3 ($1.21/kgal) to $.66/m^3 ($2.50/kgal) (Ziolkowska, 2017).

3.3 Deep Well Injection

Injection into wells is a method of brine concentrate disposal utilized by desalination plants of all sizes. Deep well injection is regulated by a Class I underground injection control General Discharge Permit issued in Texas by the Texas Commission on Environmental Quality (TCEQ) (Shirazi, 2019). The injection wells are typically 500 to 1500 m deep (1640 ft to 4921 ft) (Angelo Basile, 2011). Groundwater surveys are essential to assure brine does not end up in freshwater wells (Cooley, 2006) contaminating the supply, considering the fact that Total Dissolved Solid (TDS) of the brine is typically 9,000 to 15,000 mg/L (Shirazi, 2019). Perhaps surprising to some, capital costs of deep well injection are higher than both surface water and sewer discharge (Panagopolos, 2019).

3.4 Drying Beds, Evaporation Ponds, Land Application

In drying beds, the brine evaporates slowly by direct sunlight. Salt crystals are gathered and disposed off-site. The calculated cost, according to one study, is \$3.28/m^3 (\$12.43/kgal) to \$10.04/m^3 (\$38.05/ kgal) of brine (Soliman, 2021). This approach is designed to reduce groundwater pollution. Land application involves using the brine to irrigate grass and plants that are salt tolerant. This approach is typically only useful for low volumes of brine. The cost is estimated at \$.74/m^3 (\$2.80/ kgal) to \$1.95/m^3 (\$7.39/ kgal) (Soliman, 2021). The brine can be used in some agricultural irrigation, but heavy metals must be removed and the TDS should be low. (Soliman, 2021).

3.5 Mineral Extraction

Mineral extraction does not eliminate the brine concentrate but it can help reduce the volume. The El Paso Water system was able to increase production at the Kay Bailey Hutchison

Desalination Plant by more than 2 MGD at full capacity (27.5 MGD) through mineral extraction (El Paso Water website, 2018). In addition to the agricultural gypsum, potash liquid fertilizer and milk of magnesia beneficial products mentioned earlier, the high purity salt extracted can be used for curing, dying and deicing (Soliman, 2021). El Paso Water's partnership with Envirominerals for mineral extraction reduces overall costs for disposal by reducing the volume left.

Table 2.2 Comparison between different brine disposal techniques (Islam et al, 2018)

Disposal Technique	**Advantages**	**Disadvantages**	**Cost**
Surface Water Discharge	Very economical for Med and large plants Can handle large Brine volume	Can adversely affect Marine environment	$.05-.30/m^3$ ($.19-$1.14/ kgal) Of brine
Sewer Discharge	Very economical Easy to implement	Overloading capacity Of wastewater treatment plant	$.32-.66/m^3$ ($1.21-$2.50/ kgal) Of brine
Deep Well Injection	Brine pretreatment not required before disposal Appropriate for inland plants	Increased capital cost	$.54-2.65/m^3$ ($2.05-$10.04/ kgal) Of brine

Evaporation Ponds	Construction is easy No impact on marine life	Increased capital cost Large area needed	\$3.28-10.04/m^3 (\$12.43-\$38.05/ kgal) Of brine
Land Application	Construction is easy No impact on marine life	Increased capital cost Can affect vegetation	\$.74-1.95/m^3 (\$2.80-7.39/ kgal) Of brine

The ultimate cost savings and environmentally friendly answer could be zero liquid discharge (ZLD). Technology is pushing forward with this as its goal. The term and goal have been around since at least 2004 (National Research Council). According to Soliman, the challenges of implementing ZLD include:

- Creating a system with a > 95% recovery rate
- Capital & Operating Costs
- Chemical composition of the brine
- Material compatibility

Costly and time-consuming environmental regulations regarding brine disposal are the main reason ZLD is receiving an increasing amount of attention and funding (Soliman, 2021). In the Eastern Mediterranean one recent study found energy consumption associated with ZLD to be 9.48 kWh/m^3 (35.92 kWh/kgal). This translated to a cost of \$.84/m^3 (\$3.18/kgal) (Panagopoulos, 2021). The same study claimed ZLD could be “3.18 times cheaper than evaporation ponds” and the “same cost as land application and deep well injection” (Panagopoulos, 2021). Because ZLD is still something of an emerging approach and because it requires a combination of desalination technologies to accomplish, it is not one of the major brine disposal methods that is discussed as part of this Decision Support Tool.

4. **Support**

To move a desalination plant project from idea to completion requires support from two very different groups. Government regulators and political leaders can create obstacles so great as to be insurmountable or can guide applicants through the regulatory process with success as the end goal. Community members, likewise, can stand in opposition physically, mentally, and legally if they do not perceive the outcome as predominantly beneficial to the community or themselves individually. The socio-political factors receive less attention than the “technical, economic and environmental factors, despite the fact that they were mainly behind the success or failure of a significant number of desalination projects worldwide” (Ibrahim, 2021).

4.1 Government Regulations

Few would disagree that regulations must be appropriate to protect the environment, but how strict those regulations should be will likely always be a matter of contention between environmental groups and those working to meet the water needs of a growing community. “Desalination should not be hindered by inappropriate regulations nor accelerated by regulatory exemptions” (Cooley, 2006, p 18). Unfortunately, the current state of permitting and oversight is frequently unclear and occasionally contradictory (Cooley, 2006).

Permitting hurdles and legal entanglements have a direct impact on the levelized water cost (LWC) of a desalination project. More permits or permit delays or higher legal costs result in an increased cost of development and thus higher cost of water to the end customer (Ibrahim, 2021, p 15). A perfect example of this is in Carlsbad, CA. A desalination plant to serve San Diego Co. proposed in 1998 and hindered by more than 20 different permits was finally commissioned in 2015. In that time, the estimated cost of water rose from $.65/m^3 to $1.51/m^3 ($2.46/ kgal to $5.72/ kgal) (Ibrahim, 2021).

A more recent and closer to home example is the Port of Corpus Christi seawater desalination permit application. The permit application was referred to the State Office of Administrative Hearings (SOAH) in November 2019 (Cargo, 2021). As of September 2021, not only had the state permit not been approved, but the EPA chose to "revoke the waiver for permit review" creating yet another roadblock for the water community" (Denny Clow, 2021). As the Port of Corpus Christi Executive Director said, "in the absence of a permit, there's not much to talk about" (Denny Clow, 2021).

4.2 Community Perception

Public backing of a desalination plant cannot be underestimated nor taken for granted. All aspects of the development of a desalination facility, from siting to operation, can be impacted negatively if public sentiment is not in favor of the project (Cooley, 2006). Cooley suggests public administrators practice the utmost of transparency and consensus building by sharing draft plans and contracts with the public from the very beginning of a project. (Cooley, 2006). Water infrastructure is constructed for the benefit of the public, so it stands to reason that public participation and support would be important components of the project (Ibrahim, 2021).

Importing water from neighboring communities (or countries) is economically costly and possibly politically risky (Ibrahim, 2021). Decentralization, or generating freshwater locally on a small scale, can lower costs by eliminating the need for miles of pipeline and the associated pumps required to push the water through. Just as importantly, it can eliminate reliance on neighboring political bodies (Ibrahim, 2021).

In Africa, importing water from a neighboring territory or country may create a potential threat to national sovereignty. In the U.S., Texas specifically, the use of desalination for blending with fresh water to increase volume has relieved the strain of relying on Mexico to honor treaties regarding the Rio Grande River (Sanchez, 2020).

Globally, private, small scale decentralized desalination units have seen an enormous growth in popularity. Many tourist destinations in the Middle East have adopted this technology to meet their growing demands. There were 56 units in 1999 and by 2019, there were 893 (Ibrahim, 2021). Small and fast installation of desalination units have been accomplished in areas experiencing water shortage. One company providing a pre-packaged desalination solution is NIROBOX (Fluence Co). Their desalination unit, contained within a shipping container, has produced 100 m^3/day to 15,000 m^3/day (26.4 kgal/day to 3,958 kgal/day) (Ibrahim, 2021).

Another type of benefit that creates community support can be seen in Israel. The country's chemically "hard" fresh water supply is mixed with high quality desalinated water. The desalinated water has the effect of softening the water which helps both residential appliances and distribution networks last longer (Ibrahim, 2021). Even at the wastewater plant, the lower concentration of chloride and sodium ions from the addition of desalinated water helps condition the water for use in agricultural applications after treatment (Ibrahim, 2021).

On the other hand, community focus may be on the perceived negatives. For example, the high pressure pumps and other equipment can create noise pollution as high as 100 decibels

(Ibrahim, 2021). As with most all construction projects, construction for desalination plants disrupts the natural habitat and can lead to a change in soil characteristics (Ibrahim, 2021). The value of real estate in the vicinity can be threatened. In the case of seawater desalination, the plant or brine discharge may conflict with or disrupt other activities valued by the community like swimming, fishing, diving, sailing and tourism (Ibrahim, 2021, p 10).

5. **Cost**

As with support, cost has a two-fold meaning and requires consideration from both the government and the end consumer. Because water is 2.3 times more capital intensive than electricity and has a lower rate of return (Garrick, 2020), initial funding almost always comes in whole or in part from the government. Some government funding is provided as grants, however, most of the time the monies come as a loan that must be repaid. The water customer, of course, is the one that pays the bill. Calculating water rates to pay the loan and ongoing operating and maintenance costs is where the rubber meets the road for water system decision makers. How much is too much?

5.1 Government Financing

The U.S Bureau of Reclamation, in addition to its Concentrate Management Toolbox, has a Cost Estimating Tool called WTCost (Arroyo, 2012) that can be used to determine how much money will be needed.

There are several possible approaches to this calculation. "One approach assigns the debt service to the actual production volume" (Arroyo, 2012). "Another alternative is to calculate the debt service load on the basis of a life-cycle analysis and use an efficiency factor [known as a plant operating factor] to estimate actual production volume instead of the design production capacity" (Arroyo, 2012, p 7). Arroyo's paper used Unit Product Cost (UPC) of desalinated water as:

$$UPC = \frac{\text{Annual Debt Service}}{\text{Plant Design Capacity x Plant Operating Factor}} + \frac{\text{Operation \& Maint.}}{\text{Production Volume}}$$

Another similar formula used by Bazargan to calculate the price of desalinated water is:

$$\text{Water Price} = \frac{\text{Amortized Capital Costs + Annual O\&M}}{\text{Annual Water Production Volume}}$$

Bazargan pointed out what is missing from this calculation is the administration and conveyance costs plus profit for private companies if used (Bazargan, 2018).

Experts are divided on whether the cost to desalinate will increase in years to come or decrease. "Despite a drop in cost of desalination in the past decade, costs are projected to rise" (Bazargan, 2018). Some good news all agree on is the idea trends in technology advances will continue and should mean "improving membrane quality and productivity and longer membrane life span" (Bazargan, 2018, p 591) in addition to "significant decrease of energy use by as much as 40 to 50% at Seawater RO plants" (Bazargan, 2018, p 591).

If desalination is part of your local Regional Water Plan, chances of securing a loan from the Texas Water Development Board are favorable. In impoverished areas, funding options through TWDB may be even more generous than a zero or low interest loan. The state agency is aware it is not unusual for a water system to operate at a financial loss and require subsidies to continue supplying water for a community or region (Armondo Garza, 2021). This mirrors the experience reported in the South Korean island study previously mentioned. “All of the islands in the study (incorporating 81 plants), operate at a deficit due to high Operating and Maintenance costs” (Chu, 2021).

5.2 Impact on Water Rates

Capital costs, according to one researcher, range from $2.03 to $3.91/g of installed capacity while O&M costs range from $.53 to $1.16/ kgal (Arroyo, 2012). Ideally, water rates are structured to cover debt service, ongoing O&M costs as well as depreciation cost to fund the replacement of capital equipment as it reaches the end of its useful life.

Unfortunately, most municipalities strive to keep water rates so low they fail to plan for future needs by including capital depreciation in the equation (Garrick, 2020). As anyone who has created or updated water rates knows, the “design of water tariffs requires balancing multiple criteria” (Nauges, 2016). We desire to keep costs low for our clients, yet we as stewards of our precious water resource do not want to encourage waste of the water. Many types of crops could not be grown in parts of Texas without irrigation. Is it reasonable to charge a farmer the same price for his essential water as the residential landowner who chooses to overwater his lawn to keep it green in August?

“The value of water is derived from multiple types of economic benefits; as a result, a single price will be ineffective due to multiple, sometimes competing objectives” (Damania, 2020). Despite our best efforts, "the price of water almost never equals its value and rarely covers its costs" (Garrick, 2020).

Table 2.3 Conceptual Framework Table

Title: Brackish Groundwater Desalination as an alternative water source: A Decision Support Tool *Purpose:* The purpose of this practical ideal type research project is to identify those factors of greatest importance in implementing a groundwater desalination program and create, using the literature and insights from practitioners, a Decision Support Tool for leaders considering adopting this alternative water supply.	
Practical Ideal Type Category	Literature
1.Power 1.1 Electric 1.2 Wind 1.3 Solar	Ahmed (2019); Bazargan (2018); Burn (2015); Chu (2021); Kucera (2019); Soliman (2020); Song (2012); Ali (2021); Li (2021); Taylor (2020); Cooley (2006)

2.Source Water 2.1 Brackish water aquifer 2.2 Oil & Gas Production	Burn (2015); Burnett (2005); Kucera (2019); Hosey (2021); Dept. of Energy (2020); Veil (2004); Scanlon (2020 & 2021); Chu (2021); Drane-Maury (2017); Hightower (2003)
3.Brine Concentrate Disposal 3.1 River 3.2 Wastewater Treatment 3.3 Deep Well Injection 3.4 Drying Beds 3.5 Mineral Extraction	Bazargan (2018); Delagah (2020); Enviro Water Minerals (2014); Kucera (2019); Mancha (2020); Shirazi (2019); Mace (2014); Soliman (2021); (Chang (2015); Ziolkowska (2017); Cooley (2006); Angelo Basile (2011); Panagopolos (2019)
4. Support 4.1 Government Regulation 4.2 Community Perception	Bazargan (2018); Burnett (2005); Garrick (2020); Ibrahim (2021); Cooley (2006); Armondo Garza (2020)
5. Cost 5.1 Government Financing 5.2 Impact on Water Rates	Arroyo (2012); Bazargan (2018); Burn (2015); Garrick (2020); Klawitter (2005) Nauges (2017);

Table 2.4 Operationalization Table

	Title: Desalinated Brackish Groundwater as an Alternative Water Source: A Decision Support Tool *Purpose:* The purpose of this practical ideal type research project is to identify those factors of greatest importance in implementing a groundwater desalination program and create, using the literature and insights from practitioners, a Decision Support Tool for leaders considering adopting this alternative water supply. This tool is intended for those small town council members, WSC Board members, Managers, and anyone else who is considering Brackish Groundwater Desalination for the first time.			
Ideal Type Category	Research Method	Question(s)	Evidence	Source
1. Power				
1.1 Electric	Interview	What types of power do you currently use? Have you considered alternative sources in part or in whole?	Evidence of presence of Electric Grid capable of supporting need	Electric service providers, Water managers, Board members
1.2 Wind	Interview	Is your proposed desal location in a "windy" Corridor?	Evidence of cost/benefit analysis of wind energy	Water managers, Board members, Engineers
1.3 Solar	Interview	Is your proposed desal location in an open space that receives ample sunlight? Is the proposed location large enough	Evidence of cost/benefit analysis of solar energy	Water managers, Board members, Engineers

		for a solar array and battery bank?		

2. Source Water				
2.1 Brackish Water Aquifer	Document Analysis	Are you located in or near a designated Brackish Water Production Zone? To your knowledge is there a brackish water aquifer in your area?	Evidence of presence of Brackish Water	TWDB Brackish Groundwater Production Zone Map & Brackish Aquifer Map
2.2 Oil & Gas Production	Document Analysis	Is there a significant amount of oil & gas production in your area?	Evidence of presence of Produced Water supply	Texas Railroad Commission Maps
3. Brine Concentrate Disposal				
3.1 River Disposal	Interview	Are there rivers near the proposed desal site?	Evidence of availability of River Disposal	Water managers, Board members, Engineers
3.2 Wastewater Treatment	Interview	Does your community have a wastewater treatment plant?	Evidence of availability of Wastewater Treatment facility	Water managers, Board members, Engineers, TCEQ staff

3.3 Deep Well Injection	Interview	Are you familiar with groundwater surveys in your area? Are local well drillers capable of drilling up to 1500 meters (~5000 ft)?	Evidence of availability of Deep Well Injection	Water managers, Board members, Engineers, TCEQ staff
3.4 Drying Beds	Interview	Do you have undeveloped land near the proposed desal site that could be used for drying beds?	Evidence of presence of available land	Water managers, Board members, Engineers
3.5 Mineral Extraction	Interview	If it would increase production or significantly decrease brine volume are you interested in mineral extraction?	Evidence of cost/benefit analysis	Water managers, Board members, Engineers
3.6 Land Application	Interview	Do you know of any property owners with salt tolerant turf or landscaping who are willing to utilize brine?	Evidence of availability of Land Application	Water managers, Board members, TCEQ staff, Engineers
4. Support				

4.1 Government Permitting	Interview	Is Groundwater Desalination part of your current Regional Water Strategy? Have you investigated TCEQ requirements for your area regarding deep well injection or river discharge?	Evidence of availability of government permitting	Water managers, Board members, Engineers, TCEQ staff
4.2 Community Perception	Interview	Has the use of desalinated water ever been discussed with your water customers?	Evidence of support from community	Water managers, Board members
5. Cost				
5.1 Financing	Interview	Would your company be able to take on additional debt with its current debt to equity ratio and water rate structure?	Evidence of availability of funding	Water managers, Board members, TWDB staff
5.2 Impact on Water Rates	Interview	Have you calculated how much acquiring your next source of water will impact water rates?	Evidence of affordability of water rate increase	Water managers, Board members, Water Rate Consultant

Chapter 3: Methods

Purpose

This chapter will describe the methodology used to refine the questions comprising the Decision Support Tool for water administrators and other decision makers. The initial questions were created based on the critical subject areas of power, source water, brine concentrate disposal, support, and cost, found in the literature review. The Decision Support Tool questions were refined by seeking the input and gaining insight from water utility and desalination experts through focused interviews. This chapter includes a table that operationalizes the conceptual framework table presented in chapter 2; describes the experts interviewed and how they were selected; points out some of the strengths and weaknesses of the interview method and provides human subject protection information.

Research Participants

Given the researcher's previous experience in water system management, several of the participants are personal acquaintances. Some participants were found in the course of research through contact with state agencies, associations and desalination facilities. The 2021 Texas Desalination Association Online Conference featured several presenters and contributors who were contacted directly or came as referrals from the Association. Others were recommended as subject matter experts by their peers. Thus, a snowball sampling technique was used for a total of 12 interviewees. The subjects vary in their expertise, title, and organization affiliation. Several subjects held more than one qualification. For example, one manager was also an engineer; one administrator was also a lawyer; and several agency administrators were engineers by training. There are two current water system managers, several engineers with significant experience in water infrastructure and desalination, one geologist, one university program director, one national laboratory director, state agency water sector administrators, one federal agency program director, state water association directors and a retired city manager.

Method of Data Collection

Interviews began in July 2021 and were completed in August 2021. An appointment was made with each expert to participate in a Zoom conference for a 30-minute interview. Most interviews, however, lasted closer to an hour. The questions located in the Operationalization Table were posed to the participants. The participants were then asked to evaluate the question's sufficiency in eliciting the type and amount of information that would be needed by a water company decision-maker. The Zoom conference was recorded, and a transcript of the discussion was created.

The process of transcribing took from July through October. Each hour of discussion took approximately eight hours to type due in part to the need to stop frequently and listen carefully to words that were not as clear as initially considered. There was also an issue of whether to record every word spoken or to "clean up the sentence" to more clearly state the meaning within it. For the most part, the interviews were typed in the former manner, with every word spoken written.

Interviewees were both gracious and encouraging. Many seemed hesitant to offer any material criticism of the existing questions. Through probing questions, most experts were willing to give additional detail or suggestions after initially answering "good question" or something similar.

Operationalizing the Conceptual Framework

To create a Decision Support Tool, questions were created addressing the five categories of power, source water, brine concentrate disposal, support, and cost. Interview participants were asked to offer insight based on their expertise, whether the question was useful, focused, or needed to be modified. Based on feedback from the participants, the questions were revised.

Table 3.1 Operationalization Table

	Title: Desalinated Brackish Groundwater as an Alternative Water Source: A Decision Support Tool *Purpose:* The purpose of this practical ideal type research project is to identify those factors of greatest importance in implementing a groundwater desalination program and create, using the literature and insights from practitioners, a Decision Support Tool for leaders considering adopting this alternative water supply. This tool is intended for those small town council members, WSC Board members, Managers and anyone else who is considering Brackish Groundwater Desalination for the first time.			
Ideal Type Category	Research Method	Question(s)	Evidence	Source
1. Power				
1.1 Electric	Interview	What types of power do you currently use? Have you considered alternative sources in part or in whole?	Evidence of presence of Electric Grid capable of supporting need	Electric service providers, Water managers, Board members
1.2 Wind	Interview	Is your proposed desal location in a "windy" Corridor?	Evidence of cost/benefit analysis of wind energy	Water managers, Board members, Engineers

1.3 Solar	Interview	Is your proposed desal location in an open space that receives ample sunlight? Is the proposed location large enough for a solar array and battery bank?	Evidence of cost/benefit analysis of solar energy	Water managers, Board members, Engineers
2. Source Water				
2.1 Brackish Water Aquifer	Document Analysis	Are you located in or near a designated Brackish Water Production Zone? To your knowledge is there a brackish water aquifer in your area?	Evidence of presence of Brackish Water	TWDB Brackish Groundwater Production Zone Map & Brackish Aquifer Map
2.2 Oil & Gas Production	Document Analysis	Is there a significant amount of oil & gas production in your area?	Evidence of presence of Produced Water supply	Texas Railroad Commission Maps
3. Brine Concentrate Disposal				
3.1 River Disposal	Interview	Are there rivers near the proposed desal site?	Evidence of availability of river disposal	Water managers, Board members, Engineers
3.2 Wastewater Treatment	Interview	Does your community have a wastewater treatment plant?	Evidence of availability of wastewater treatment facility	Water managers, Board members, Engineers
3.3 Deep Well Injection	Interview	Are you familiar with groundwater surveys in your area? Are	Evidence of availability Deep Well Injection	Water managers, Board members, Engineers

		local well drillers capable of drilling up to 1500 m (~5000 ft)?		
3.4 Drying Beds	Interview	Do you have undeveloped land near the proposed desal site that could be used for drying beds?	Evidence of presence of available land	Water managers, Board members, Engineers
3.5 Mineral Extraction	Interview	If it would increase production or significantly decrease brine volume, are you interested in mineral extraction?	Evidence of cost / benefit analysis	Water managers, Board members, Engineers, TCEQ staff
3.6 Land Application	Interview	Do you know of any property owners with salt tolerant turf or landscaping who are willing to utilize brine?	Evidence of availability of Land Application area	Water managers, Board members, TCEQ staff, engineers
4. Support				
4.1 Government Regulation	Interview	Is Groundwater Desalination part of your current Regional Water Strategy? Have you investigated TCEQ requirements for your area regarding deep well injection or river discharge?	Evidence of ability to acquire proper permits	Water managers, Board members, Engineers, TCEQ staff

4.2 Community Perception	Interview	Has the use of desalinated water ever been discussed with your water customers?	Evidence of support from community	Water managers, Board members
5. Cost				
5.1 Government Financing	Interview	Would your company/city be able to take on additional debt with its current debt to equity ratio and water rate structure?	Evidence of availability of funding	Water managers, Board members, TWDB staff
5.2 Impact on water rates	Interview	Have you calculated how acquiring your next source of water will impact water rates?	Evidence of affordability of water rate increase	Water managers, Board members, Water rate consultants

Strengths and Weaknesses

Conducting interviews, as a research method, is good for complex topics or processes such as this one (Johnson, 2015). Unstructured or semi-structured interviews can generate rich data because it allows the researcher to veer off-script, to ask for clarification and to probe for more information (Johnson, 2015). Weaknesses of the interview method include the time-consuming nature of conducting each interview and then transcribing and analyzing the discussion (Johnson, 2015). There is also the potential for bias on the part of the researcher. Even though modern technology allowed for 100% remote interviews, any fluctuation in internet service caused communication difficulties. When bandwidth seemed limited, participants turned video feed off so audio could more easily be heard.

During transcription it was necessary to decide whether to type each word uttered or each sound made, even those that are not words. Additionally, some words were not completely clear in the playback. In those moments "(unknown)" was used to indicate that an additional word should be inserted in the transcript but the recording was not clear enough to discern what word was used.

Although the interview was intended to only last 30 minutes, frequently they lasted close to an hour. Experts provided very detailed answers on several questions and diverge off into related areas that were incorporated into new or revised questions for interviewees 6-12 to consider. Also, there was some confusion on the part of the interviewees regarding the type of response that was being asked of them. Several thought they were supposed to answer the question rather than provide feedback about the question itself. It took additional clarification from the researcher and a few early questions for many interviewees to seem comfortable with providing the type of feedback that was sought.

Human Subjects Protection

For the protection of the interviewees, the research project was evaluated and approved by the Institutional Review Board (IRB) of Texas State University (IRB #7891). The IRB considers the content of the questions, how participants are recruited, how information is collected and whether participation could have any detrimental impact on interviewees. IRB approval was granted before any interviews were conducted. The participant's identity will remain confidential. No names or company affiliation will be included in this paper. The interview recordings and transcripts will be stored on a Texas State University Canvas Project site created by the researcher. Only the graduate researcher and advisor will have access to this project site. All data will be stored without any personal identification information of interviewees and this site will be deleted after three years.

Chapter Summary

This chapter reviewed the method of data collection, the method used in selecting participants, the strengths and weaknesses of the method, specific challenges in this study and finally how those subjects would be protected. The next chapter will detail the information gathered from participants regarding the suitability of the questions that will constitute the Decision Support Tool.

Chapter 4: Results

The purpose of the Results chapter is to present how the eventual questionnaire evolved to its final form. This chapter details the expert opinion provided by the twelve interviewees to each of the questions derived from a thorough review of available literature. It gives commentary on changes made to the original questions and explanation behind the creation of four new "qualifying questions". The chapter is divided into six sections based mainly on the conceptual framework found in Chapter 2: Literature Review. The sections are as follows: qualifying questions, power, source water, brine concentrate disposal, support, and cost.

This is an unconventional Applied Research Project. The aim is to develop a query or ideal questionnaire that every key decision maker should review prior to committing to a desalination project.

The first three interviewees were asked the original 20 questions from the five subject areas. Based on feedback received in those early interviews, some questions were changed drastically, and others were modified by adding context. In question three, for example, the following was added: "One large wind turbine produces approximately one to one and a half megawatts of power per day. A city of 50,000 people might need 10 to 12 turbines to power a desalination facility." These examples were provided by the first interviewee, a desalination expert and state laboratory director.

Qualifying Questions

Four additional questions were added through the course of the interviews. These more general questions in nature were not about power, source water, brine concentrate disposal, support, or cost.

They were described to later participants as “qualifying questions.” They include: 1) Are you exploring desalination because you need another water source within the next 5 to 10 years? How urgent is your need? 2) Have you considered partnering with neighboring communities on a regional development? 3) The efficiency of a desalination plant can vary due to a variety of factors, primarily the technology used. Have you considered what level of efficiency you are willing to pay for: 85%, 90%, 95%? 4) Does your engineer have experience with desalination plant design, or have you identified a desalination engineer to consult?

During the third interview, the question about having a qualified engineer was proposed. Interviewee 5 suggested that a question about the urgency of the need be included as well as moving the “qualifying questions” to the top of the list rather than start with the energy specific questions. Interviewee 1 suggested asking what level of efficiency a plant operator/owner has set as a goal. Experts 7,8,11 and 12 all pointed out a flaw in the efficiency question, however. The efficiency will likely be driven by the method of disposal and what permit limits are imposed by TCEQ. Additionally, giving an efficiency percentage to public administrators, who do not know what is involved in reaching that number, is pointless. Therefore, using adjectives like minimum or optimal efficiency was recommended instead.

Some questions received a short, concise “good question” response from most of the experts with little other comment. Some questions, on the other hand, generated lengthy responses and even conflicting answers from the various experts. On a few occasions, the interviewee chose not to comment on the question because it was not their area of expertise.

Power Questions

The first (original) question, regarding power, "What types of power do you currently use?" was rewritten as "Considering the fact that 40% or more of the O&M cost is in power, do you know your least expensive energy option?" It elicited five "good question" affirmations. Two respondents indicated that renewable energy was an up-and-coming option. Interviewee 1 pointed to the design of the plant as a guiding factor in the type of energy that would be most beneficial, "the use of natural gas on sites, specifically if they are doing concentrate recovery management, sometimes they have to use natural gas to get higher temperatures to be able to work on the brine."

Interviewee 8 pointed to funding as a factor in the energy selection, "there is a lot of opportunity in alternative energy sources now, wind power, solar power. You could combine these particularly if you are looking at green grant funds through federal and state grants."

Interviewee 1 not only confirmed that energy is an enormous cost in desalination but claimed a water provider could reduce costs for the entire project by 15 or 20% through innovative energy access. An example of innovation was given in using waste heat from a solar farm to heat the water. "Some of the membranes work better if the temperature of the water is 75-80 even 90 degrees."

The second question also changed after input from a few experts. Considering the renewable energy questions that followed, the original question seemed redundant and was abandoned for one brought up by Expert 2. He touched on the cost savings that could be found in reducing electric transmission costs by co-locating a desalination plant next to a power plant. The original question, "Have you considered alternative sources in part or in whole?" became

“Do you have an electric power or natural gas plant or substation in close proximity to the planned desalination site?”

Again, five experts said the revised wording constituted a “good question.” Two experts mentioned that close proximity might equate to a close relationship with the electric provider, a particular concern in this year of Winter Storm Uri and the unprecedented power outages experienced in Texas.

Question three, “If you are considering alternative sources of energy, like wind power, are you in an area with wind resources and enough land to accommodate multiple wind turbines?” was modified as mentioned before to give it context. It was also reworded to make it more technically correct. Rather than “windy corridor”, the term “wind resources” was used, as recommended by Interviewee 1.

Four of the experts pointed to the intermittent nature of wind generated power as a reason not to pursue it as a main source of power. Two of those also mentioned the additional maintenance requirements having a wind farm would put on water system staff and administrators. Expert 7 summed it up with “Most of the water plants I’ve talked to, they don’t also want to operate a PV system or a wind system. They just want electricity that’s cheap.”

Questions 4 & 5 originally read, “Is your proposed desal location in an open space that receives ample sunlight?” and “Is the proposed location large enough for a solar array and battery bank?” As with a previous question, Expert 1 provided the example that created context. He explained, “It’s about 6 acres per megawatt. That’s in a good resource area. We’re talking Texas so if you want one megawatt, you must have 6 acres which would be a small plant. If your plant requires 15 megawatts of power, you would need 90 acres worth of solar panels. A town of 30,000 people may need 60 acres of solar panel array."

Expert 6 added to that estimation with "The main thing you've got to have is pretty consistent sunshine and not enough vegetation or impeding shadow like in East Texas where you have 100 ft pine trees. You would need a big wide open space, not just 60 acres. You would need a buffer around that, at least a 10 acre strip all around. Instead of 60 acres, it might be closer to 150 acres to get abundant sunshine without shadows. All of that is relevant."

As with wind, Expert 9 voiced the concern of many water providers by saying, "One thing, you end up in the business of is now you're an energy producer and you have to have the expertise to work on the energy products. So that adds a layer of complication later on to operations that a lot of people don't think about. We've never done that specifically because we were a little bit intimidated by dealing with the energy side of it and adding one more thing to maintain and operate".

Question five, "An alternative to building or tying into a local power station is purchasing surplus power from energy merchants. Have you investigated the possibility of purchasing renewable energy from remote venders during off peak hours?" came from a comment made by Expert 1. It was created to replace the original question about solar arrays that was at least partly addressed in the reworded question 4.

None of the other experts seemed to be familiar with the energy merchant's option. Expert 8 wisely advised, "You just need to be careful about your contract that you don't end up paying a premium during peak hours at the same time you're paying low rates in the off peak." Lessons learned during Winter Storm Uri reinforce this idea of being certain that any energy contract includes a caveat to keep the water company from being saddled with unbearable costs during unprecedented events. Expert 7 provided additional insight with the specific example of the City of El Paso. "I think El Paso pays something on the order of $.05 or $.06 per kilowatt hour for when they are in off-peak and it's as much as $.25 in peak. And that's when most water production is being done as well. You might be able to do a desal plant design maybe make more water at night and you have that cheap power but with RO you want it on 24/7."

Source Water Questions

Question six remained unchanged. Ten of the twelve interviewees felt the question was "good". Expert 9 recommended adding a definition of "brackish groundwater production zone" or at least giving the parameters used by TWDB in their assessment. Expert 11 emphasized that it would be paramount for any decision maker to verify the quantity of brackish water available and not just the presence of brackish water. Interviewee 2 shared, "We know it's down there, but we don't know its condition and we don't know how economically it can be brought up. And that's the question that BRACS is trying to answer but they're just getting a small amount of funding. At the rate they're going we're projecting it will take them 100 years at this rate to get enough information to where local communities can get enough information to make a decision."

Question seven, "To your knowledge is there a brackish water aquifer in your area?" was another question that remained the same. All Interviewees agreed, it was a good question. Expert 8 added, "It's a common sense deal." Expert 9 thought it would be helpful for Decision Makers to know the Groundwater Data Viewer on the TWDB website allows a user to enter their address and by turning layers on and off see what information is available for their area including the TDS of groundwater.

Question eight, “Is there a significant amount of oil & gas production in your area?” elicited a variety of input. Expert 2 pointed to the potential for objection from the oil and gas industry, “The farmer / rancher who has the land they are pumping it off of goes from getting a penny per gallon to wanting 50 cents per gallon which runs up the cost. There is always push-back from the oil and gas industry to us exploiting this particular resource.” Expert 7 brought up a concern about the quality, “I mean most of the time, it depends on the kind of water you’re starting with. So if you’re starting with Permian Basin water, you’re not even going to get that down to “Ag” water. It’s just going to take a tremendous amount of energy to get it down to something that farmers would want to use. To be honest with you, farmers want about the same quality of water as we drink. Some people might not want to drink produced water, treated produced water, but the reality is it’s possibly going to be cleaner than something that you’re getting out of a river from a technical perspective.” Experts 9 and 11 brought up the important point that oil and gas production comes and goes. “Yea you do definitely see an increase of when their permits [are] coming through to the Railroad Commission. They say there are spikes when they are really trying to drill and get oil out. So it is sporadic.” (Interviewee 9) Expert 11 added “You’re investing too much of your money at the whim of oil, and you know oil, OPEC and every other thing. They’re going to produce when the price is favorable to them. And when it’s not, they shut it down.”

Brine Concentrate Disposal Questions

Question nine originally read, “Do you have undeveloped land near the proposed desalination sight that could be used for drying beds?” It was modified to provide context after comments by Expert 1. The updated question posed to Interviewees 4-12 reads, “Drying beds or evaporation ponds require approximately 10 acres of undeveloped land per million gallons per day. Do you have enough undeveloped land to accommodate this requirement?" Expert 1 pointed out that a 10 MGD plant would need 100 acres if they used drying beds exclusively. "Once it gets to be that big it looks like a lake. Now you've got water fouling. Now you've got all sorts of issues." Expert 4 mentioned that large drying beds likely would not be approved in urban areas, "We all know that people are pretty picky about what's in their neighborhood." Expert 5 suggested that a city size, based on population, be included in the question to be consistent with other questions. Interviewees 6, 7 and 8 all mentioned that the size of the area would be problematic to control either from a fencing or monitoring standpoint. Experts 7 and 11 calculated that a city the size of El Paso with 3 MGD of concentrate would need 600 acres. In addition to the cost of the land and fencing is the cost of the evaporative membrane or fabric. At a price of $10/ sq foot, it would cost $300 million dollars for the fabric alone. Expert 12 added the issue of rainfall to the discussion, "I think evaporation ponds work great in the west and not so much in the east. I've heard that a general rule of thumb is that if you're east of I-35 chances are you're going to get so much rainfall that even if you had tons of land, your evaporation ponds would probably stay full of water." All the Interviewees seem to support the question, but none viewed Evaporation Ponds alone as a good choice for large water systems. If they are used as part of a diverse concentrate management program, the possibility of success increases.

Question ten originally stated, "Does your community have a wastewater treatment plant?" As with other questions, this also was reworded to include detail after the first three interviews. The revised question was "Is your wastewater treatment plant capable of processing 10 times the volume of your expected brine output?" Nine of the twelve interviewees were quick to name the concentration of the brine and its impact on the wastewater treatment plant's biotic activity as a potential problem. A few experts also suggested that the salt load could violate a plant's TCEQ permit. Expert 8 summed it up best, "It totally depends on how concentrated your brine is. Essentially do you have enough volume to dilute it down to a point that the domestic wastewater plant can discharge it without violating its permit." Expert 11 brought the topic back to the "qualifying question" of how much time is needed, "But it is an important question that has to be asked, answered and approved by the state which takes time." Based on the feedback to the revised question, the question now uses almost the exact wording recommended by Expert 8: "Do you have enough volume in your wastewater treatment plant flow to dilute your brine down to a point that the domestic wastewater plant can discharge it without interfering with the biotic activity and violating its permit?"

Question 11 was another question that was reworded after only a few interviews. The original text, "Are there rivers near the proposed desal site?" was reworked to be more technically pointed. The improved question reads, "Some desalination plants dispose of brine in nearby water bodies under very strict permitting guidelines. The chemistry of the treated brine and the receiving water body must be compatible. Is the flow of your nearby body of water sufficient to dilute your anticipated brine volume without harming the flora and fauna?" Expert 1 said it depends on the "flow and the concentration"; Expert 2 said "it depends on the river and the quality they are putting in there"; Experts 6 and 12 focused the discussion on the river itself, "Each one of these tributaries and basins and stuff they're considering has its own thresholds. So according to how sensitive the vegetation or aquatic life is." (Expert 6) Expert 7 explained that surface water disposal was previously allowed in Colorado and Arizona, but "they hit the limits very quickly so new plants in Colorado and Arizona are not going to be allowed to dispose into that so that's a good question."

Question twelve, "If it would increase production or significantly decrease brine volume, are you interested in mineral extraction?" remained unchanged. All of the experts indicated it was a good question. Comments from Expert 8 and 10 both pointed out that the make-up of the water will be a primary factor in whether mineral extraction is a feasible approach. Experts 9, 10 and 12 explained that a decision maker needs to be certain that there is a strong market for their extracted minerals before investing in the technology to remove it from the concentrate. Expert 9 said, "If you're going to be a water provider you have to make sure you have customers. Like with mineral recovery, before you even embark on wanting to do it, it's almost like you have to make sure you have the buyers there."

Question thirteen originally read: Are you familiar with groundwater surveys in your area? Interviewee 1 explained that "groundwater surveys" was not technically correct. He explained that, "it's not necessarily ground water. It's geologic formations, because the deep well injection has to go down about 3000 feet generally and so you have to have geologic information not necessarily groundwater information." This question was rewritten as, "Deep well injection, is one of the most commonly used brine disposal techniques but also one of the most expensive. Have you investigated geologic formations at and below 2000' in your area to determine if the area is suitable without contaminating fresh water aquifers?"

The revised question was posed to Interviewees 4-12. All experts agreed the question was "good" or "relevant". Among the comments that were added were two reminders (Expert 10 and 11) to take into consideration seismic activity or seismicity studies in the area. Experts 7, 11 and 12 countered that the cost of deep well injection may be a more economical option than evaporation ponds for a large desalination plant. Expert 11 also mentioned that there would be a big difference in what is considered affordable depending on the size of the water plant, "if you're a small system, when we're talking small, we're talking 100 gpm source water and 10 gpm of concentrate, a small system, an injection well for that disposal, that is expensive. It's cost prohibitive for the small system but if you're a large system like El Paso then injection wells are something you need to analyze." He also mentioned that injection wells are legal in Texas and not legal in Arizona.

Question fourteen originally read, "Are local well drillers capable of drilling up to 1500 m (~5000 ft)?" It was rewritten after Expert 2 stated, "Well actually there's only a few people, only a few companies that are capable of doing that especially when you are drilling for municipal water. There are very specific regulations as you can imagine and there is only a couple of drillers in the state that are capable of doing that." The revised question posed during interviews 4-12 reads: "Have you identified or contacted well drillers who are capable of drilling up to 5000 feet?" With the exception of two experts who offered no comment, all others identified it as a valid question for decision makers to consider.

Question fifteen: "Do you know of any property owners with salt tolerant turf or landscaping who are willing to utilize brine?" was modified slightly. The phrases, "or aquaculture industry" and "and if so, what volume are they able to accept?" was added after Interview 8. The expert mentioned, "Yea you can, but you'll end up ruining the turf no matter what. Because when you keep applying salt to the soil it just keeps building up. If you don't have enough rain to keep flushing it out and that salt ends up running off when you do have rain events into the local estuaries and everything else." Expert 1 shared, "we're seeing most of people who have done land application have had a lot of problem with it. They're really moving away. I think Arkansas is even eliminating that. It just is not something people are moving toward at all. But it's worthwhile asking." Expert 2 was more optimistic in his assessment, "Typically, you can use it on golf courses or public parks is where they mostly use it now and it's not typically, well obviously depends on the condition of the water. The other thing you can use it for is for cattle up to a certain level obviously, but cattle will drink it. So ranchers, so yea that's a legitimate question."

Expert 6 pointed to Dell City, Tx as an example of a community that has been using land application for years. He said, "They've been doing desal for over 35 years. They've been taking water coming out of the ground at 3000 parts salt, dropping it down to 600-700 parts salt. They sell the main stream of water treated for household use only and the other water they send out in a separate distribution line for all outside watering. All of the trees out there and all the houses it splatters water on are white because it's got salt all over it." Expert 7 suggested adding aquaculture to the list of possible applications, "Add aquaculture in there because sometimes they can go up to 4000 TDS for any kind of salt tolerant plant. They might take up to 20,000 TDS if they are growing algae or salt water shrimp or something of that sort." Expert 11 cited an example of one small community in west Texas that has sprayed their brine concentrate on crops of alfalfa.

Support Questions

Question sixteen "Is Groundwater Desalination part of your current Regional Water Strategy?" remained unchanged but the conversation around it became more focused. Experts 8 & 9 explained that the individual entity should have desalination in their plan rather than some other water purveyor in the region. "If you don't have specific projects in the state water plan, you're not eligible for the state revolving fund money. You can still get DWSRF money through Texas Water Development Board because that's coming down from the feds and that's not tied to the state water plan." (Expert 8) Expert 9 provided the following detail: "You qualify especially for the state, the SWIFT funding, the State Water Implementation Fund for Texas. One of the requirements is that your project has to be in the state water plan. If it's not it doesn't qualify but depending on if desal was an alternative plan they are able to make some major and minor amendments [to the State Water Plan]." Expert 11 tied this topic back to the 'qualifying question' of timing when he said, "This ought to be one of the very first things that any municipality does is putting this concept 10 years out or whatever into the state water plan. Then they could start getting funding."

Question seventeen was broadened in scope slightly. The original wording, "Have you investigated TCEQ requirements for your area regarding deep well injection or river discharge?" was changed to "have you investigated TCEQ permitting requirements for your area regarding brine disposal options?" This change was made at the suggestion of Experts 5 and 9 to broaden the scope to include other brine disposal options that must be permitted by TCEQ. Experts 10 and 11 advised decision makers to be in touch with TCEQ early in the investigation process. "So, I think the earlier you can bring the regulatory entities onto your project, the better off you might be. So, identifying at what point it makes sense to start bringing your regulatory entities onto your project I think is key. It might not be at the very beginning, but you can't wait until you are so far along that you've already spent all of this money and it ain't going to happen because you're not going to get a permit." (Expert 10) Expert 12 added that water systems need to explore the approval process for the drinking water at the same time they are investigating the permitting process for disposal of the concentrate.

Question eighteen, "Has the use of desalinated water ever been discussed with your water customers?" remained unchanged. Each of the experts determined it to be a "good" question. Several of the experts felt the public would want to be informed early because of the higher costs that would mean higher water bills. Two experts thought the public might have questions or concerns around the potential for environmental impact. One expert said she would not notify the public until the time that she was instructed to do so by TCEQ to avoid premature or even unnecessary drama prior to a decision being made.

Cost Questions

Question nineteen and twenty remained consistent throughout the interviews. Experts responded with "good question", "great question", "excellent question" and "important question". Expert 6 expounded on the idea of question 20 with this, "They should investigate all aspects of water and stuff before they make a decision on which. I tell people they are doing an error to their customers and to themselves if they don't investigate all options going in. If they fail to investigate the other fresh groundwater supply, if they close their mind to purchasing bulk water from another entity, wholesale water from another entity… that's got to be an option and desal and stuff goes in there and even surface water and stuff out there if there are sources that have water available, they need to consider that. The other thing is any partnering to make it work. I think they are missing the ball if they don't ask all these questions and spend a little time digging and doing research on those things"

The following table summarizes the revised questionnaire. Of the original set of 20 questions 6 were rewritten completely, 6 were altered somewhat, 8 remained unchanged and 4 new questions were created.

New “Qualifying Questions”

1. Are you exploring desalination because you need another water source within the next 5 to 10 years? How urgent is your need?
2. Have you considered partnering with neighboring communities on a regional development?
3. The efficiency of a desalination plant can vary due to a variety of factors, the primary one being the technology used. If state brine disposal permits allow, what level of efficiency are you are willing to pay for, basic, advanced or optimized?
4. Does your engineer have experience with desalination plant design or have you identified a desalination engineer to consult?

Table 4.1 Modified Original Questions

	Small Water System		Large Water System	
1.1 Electric	5. Considering the fact that 40% or more of the O&M cost is in power, do you know your least expensive energy option?” 6. Do you have an electric power or natural gas plant or substation in close proximity to the planned desalination site?”		5. Considering the fact that 40% or more of the O&M cost is in power, do you know your least expensive energy option?” 6. Do you have an electric power or natural gas plant or substation in close proximity to the planned desalination site?”	

1.2 Wind	7. If you are considering alternative sources of energy, like wind power, are you in an area with wind resources and enough land to accommodate multiple wind turbines?”	One large wind turbine produces approximately one to one and a half megawatts of power per day. .A city of 5,000 people might need 1 or 2 turbines (for redundancy) to power a desalination facility.	7. If you are considering alternative sources of energy, like wind power, are you in an area with wind resources and enough land to accommodate multiple wind turbines?”	One large wind turbine produces approximately one to one and a half megawatts of power per day. A city of 50,000 people might need 10 to 12 turbines to power a desalination facility.
1.3 Solar	8. If you are considering solar power, do you have enough land to accommodate 6 acres of solar panels per megawatt	A desal plant for a city of 5,000 people might need 6 acres of land or more	8. If you are considering solar power, do you have enough land to accommodate 6 acres of solar panels per megawatt	A desal plant for a city of 50,000 people might need 60 acres of land or more
1.4 Other	9. Have you investigated the possibility of purchasing renewable energy from remote venders during off peak hours?		9. Have you investigated the possibility of purchasing renewable energy from remote venders during off peak hours?	
2. Source Water				
2.1 Brackish Water Aquifer	10. Are you located in or near a designated		10. Are you located in or near a designated	

	brackish water production zone? 11. Do you know if there is a brackish water aquifer in your area?		brackish water production zone? 11. Do you know if there is a brackish water aquifer in your area?	
2.2 Oil & Gas Production	12. Is there a significant amount of oil & gas production in your area?		12. Is there a significant amount of oil & gas production in your area?	
3. Brine Concentrate Disposal				
3.1 Drying Beds	13 Do you have undeveloped land near the proposed desal sight that could be used for drying beds?	A 1 MGD plant would need 10 acres of drying ponds	13 Do you have undeveloped land near the proposed desal sight that could be used for drying beds?	A 10 MGD plant would need 100 acres worth of drying ponds
3.2 Wastewater Treatment	14 Do you have enough volume in your wastewater treatment plant flow to dilute your brine down to a point that the domestic wastewater plant can discharge it without interfering with the biotic activity		14 Do you have enough volume in your wastewater treatment plant flow to dilute your brine down to a point that the domestic wastewater plant can discharge it without interfering with the biotic activity	

	and violating its permit?”		and violating its permit?”	
3.3 River Disposal	15 Is the flow of your nearby body of water sufficient to dilute your anticipated brine volume without harming the flora and fauna?”		15 Is the flow of your nearby body of water sufficient to dilute your anticipated brine volume without harming the flora and fauna?”	
3.4 Mineral Extraction	16 If it would increase production or significantly decrease brine volume, are you interested in mineral extraction		16 If it would increase production or significantly decrease brine volume, are you interested in mineral extraction	
3.5 Deep Well Injection	17 Have you investigated geologic formations at and below 2000’ in your area to determine if the area is suitable without contaminating fresh water aquifers? 18 Have you identified or contacted well drillers who are capable of drilling up to 5000 feet?		17 Have you investigated geologic formations at and below 2000’ in your area to determine if the area is suitable without contaminating fresh water aquifers? 18 Have you identified or contacted well drillers who are capable of drilling up to 5000 feet?	
3.6 Land Application	19 Do you know of any property owners		19 Do you know of any property owners	

	with salt tolerant turf or landscaping or local aquaculture industry who are willing to utilize brine and if so what volume are they able to accept?		with salt tolerant turf or landscaping or local aquaculture industry who are willing to utilize brine and if so what volume are they able to accept?	
4. Support				
4.1 Government Permitting	20 Is Groundwater Desalination part of your current Regional Water Strategy? 21 Have you investigated TCEQ permitting requirements for your area regarding brine disposal options?		20 Is Groundwater Desalination part of your current Regional Water Strategy? 21 Have you investigated TCEQ permitting requirements for your area regarding brine disposal options?	
4.2 Community Perception	22 Has the use of desalinated water ever been discussed with your water customers?		22 Has the use of desalinated water ever been discussed with your water customers?	
5. Cost				
5.1 Financing	23 Would your company, city or district be able to take on additional debt with its current debt to equity ratio and water rate structure?		23 Would your company, city or district be able to take on additional debt with its current debt to equity ratio and water rate structure?	

5.2 Impact on water rates	24 Have you calculated how acquiring your next source of water will impact water rates?		24 Have you calculated how acquiring your next source of water will impact water rates?	

Chapter 5: Conclusion

This research project was designed to create and evaluate a Decision Support Tool for water system administrators, city managers, board members, city council members and anyone else who is considering utilizing brackish groundwater desalination as a water resource for their community. Twenty questions were developed based on a review of literature. Twelve experts in the areas of desalination, water system management, Engineering and state or federal agency regulation were interviewed via Zoom meeting and asked to evaluate each question based upon their understanding of the topic. Some interviewees provided feedback on a technical level, some on understandability to a layman and some on how to make the questions more useful for decision makers. Based on the input from the experts, six questions were revised extensively, six questions were revised slightly, eight questions remained the same and four additional questions, termed "qualifying questions," were added.

This chapter will touch on the reason for and possible benefits of this study. Next, the revised Decision Support Tool questions are presented. Thirdly, the most important findings and recommendations for water system decision makers will be detailed. The chapter will conclude with the limitations of the study as well as recommendations for future researchers.

Possible Benefits

Possible benefits of this study include helping public administrators make the best decision possible, prior to expending large amounts of public money, on whether to add brackish groundwater desalination to their portfolio of water sources. The Decision Support Tool is intended to give decision makers specific questions to consider or research. It focuses on areas of greatest importance due to the time, cost, or difficulty in completing to bring a desalination plant from idea to commissioning. Some questions may be answered in a few moments of research or from studies that have already been completed. Other questions may take weeks or months to answer due to the need for expert input from engineers, state regulators, geologists, environmental consultants, etc. Decision makers are encouraged to review both the Literature Review and Results chapters to see pros and cons of some of the possible choices they must make. While the Literature Review chapter broaches emerging technology, the Results chapter provides commentary from statewide experts on what is and what is not a good idea for the average community to implement.

Based on input from the experts, certain questions are followed by some context regarding system size and capacity needs. The first four "qualifying questions" are being added at the beginning of the Decision Support Tool because they describe a need or question that must be considered no matter how many customers will be served.

Decision Support Tool (Questions)

Qualifying Questions

1. Are you exploring desalination because you need another water source within the next 5 to 10 years? How urgent is your need?
2. Have you considered partnering with neighboring communities on a regional development?
3. The efficiency of a desalination plant can vary due to a variety of factors the primary one being the technology used. If state brine disposal permits allow, what level of efficiency are you are willing to pay for, basic, advanced, or optimized?

4. Does your engineer have experience with desalination plant design, or have you identified a desalination engineer to consult?

Power Questions

5. Considering the fact that 40% or more of the O&M cost is in power, do you know your least expensive energy option?
6. Do you have an electric power or natural gas plant or substation in close proximity to the planned desalination site?
7. If you are considering alternative sources of energy, like wind power, are you in an area with wind resources and enough land to accommodate multiple wind turbines?
8. If you are considering solar power, do you have enough land to accommodate 6 acres of solar panels per megawatt needed?
9. Have you investigated the possibility of purchasing renewable energy from remote venders during off peak hours?

Source Water Questions

10. Are you located in or near a designated brackish water production zone?
11. Do you know if there is a brackish water aquifer in your area?
12. Is there a significant amount of oil & gas production in your area?

Disposal of Concentrate Questions

13. Drying beds or evaporation ponds require approximately 10 acres of undeveloped land per million gallons per day. Do you have enough undeveloped land to accommodate this requirement?

14. Do you have enough volume in your wastewater treatment plant flow to dilute your brine down to a point that the domestic wastewater plant can discharge it without interfering with the treatment plant's biotic activity or violating its permit?
15. Is the flow of your nearby body of water sufficient to dilute your anticipated brine volume without harming the flora and fauna?
16. If it would increase production or significantly decrease brine volume, are you interested in mineral extraction?
17. Have you investigated geologic formations at and below 2000' in your area to determine if the area is suitable for deep well injection without contaminating fresh water aquifers?
18. Have you identified or contacted well drillers who are capable of drilling up to 5000 feet?
19. Do you know of any property owners with salt tolerant turf or landscaping or local aquaculturists who are willing to utilize brine and if so what volume are they able to accept?

Support Questions

20. Is Groundwater Desalination part of your current Regional Water Strategy?
21. Have you investigated TCEQ permitting requirements for your area regarding brine disposal options?
22. Has the use of desalinated water ever been discussed with your water customers?

Cost Questions

23. Would your company, city or district be able to take on additional debt with its current debt to equity ratio and water rate structure?
24. Have you calculated how acquiring your next source of water will impact water rates?

Important Findings and Recommendations

Based on the literature review in part but more so on the input of experts, the most important findings and recommendations are in the areas of quality of source water, lead time, diverse approaches to brine disposal and alternative energy limitations. The quality of source water impacts most of the decisions that have to be made. Will you include mineral extraction as a brine disposal option? It depends on what is in the source water. Would there be a market in which to sell it? Which desalination technique will you use (there are others besides RO)? It depends in large part on the source water. Some desalination options require more energy than others. How will you dispose of the brine concentrate? The options may be limited by the TDS of the water you start with.

Lead time is a huge consideration. First, to even hope for state funding participation, the water system needs to have a desalination project in the State Water Plan. If the project is not included during the 5-year update cycle, it could possibly be added as an amendment, but that takes time. Next, a preliminary discussion with the TCEQ regarding brine disposal permitting options will be the guide in making the brine specific decisions. A thorough discussion though will likely require an environmental impact study. That takes time.

If the water need is for a small community, a prepackaged plant, discussed in the literature review chapter, may be sufficient. Securing permits, studying the source water, establishing power access and obtaining the prepackaged plant itself could take five years. A large desalination plant with its large capacity brine disposal demands and energy needs could take 10 to 15 years. If there is significant community opposition including legal action, that time line could expand out to 20 years.

Just as water systems are encouraged to have a diverse portfolio of water resources, so they can and arguably should have a diverse portfolio of brine disposal methods. Larger systems like El Paso's Kay Baily Hutchison Desalination plant use multiple brine disposal techniques simultaneously. Which technique to use is based on permits, land availability, and cost. Deep well injection would be an expensive option for a small community but it is a very affordable choice for a large community when compared to the cost of 300 acres of drying beds with its pricey fabric.

Renewable energy, like wind and solar power, are attractive from a funding perspective because there may be more grants available for infrastructure projects that have a "green" component. The drawbacks however need to be carefully considered. Both wind and solar power are intermittent by their nature. Thus, the water system would need to have a back-up energy source. If battery banks were successfully utilized to store the power, the water system would still be taking on the additional responsibilities of maintaining the "power plant" and all that goes with it.

Study Limitations

Limitations to this study include the lack of a cost analysis of the various components of a desalination plant and their impact on water rates. The study would be stronger with more concise differences between the needs of a large water system and a small community water system. More representation from smaller and/or rural areas in different regions would give a clearer picture of the obstacles faced state-wide. Topics like prepackaged desalination plants and the TWDB brackish groundwater production zones were mentioned briefly but could be described in detail.

Groundwater Conservation Districts (GCD) play an important oversite role in today's water environment. Despite attempts to contact three GCDs, no comment was received regarding whether they would view a brackish groundwater permit differently from a freshwater aquifer permit. The final limitation that will be mentioned in this section is the likelihood that the author failed to record in this paper important or more useful details shared by the expert interviewees. The reason all of the expert commentary was not shared is for the sake of brevity or to fit in the predetermined scope of the paper or through accidental omission.

Future Research

Future research in this area could be focused on several of the above limitations like a detailed breakdown of the costs or differences between the needs of large and small water systems. Future studies could focus on energy options including contracting with energy merchants, briefly mentioned in the results chapter. The viability and cost of utilizing a prepackaged unit for a small community is a study this author would like to read. The attitude toward alternative energy among water purveyors was a topic mentioned by three contributors as an area of interest. How the questionnaire might be used by different regions was an additional idea posed as a potential topic of study.

In summation, this chapter has presented possible contributions of this research; the most important findings and recommendations, limitations of the study, suggestions for future research, and the final 24 questions that comprise the Brackish Groundwater Desalination Decision Support Tool intended for public administrators considering utilizing brackish groundwater desalination, to supply or partially supply the water needs of their community.

Ideally, the Decision Support Tool will be useful in guiding decision makers to ask the right questions, consider options they had not previously considered, take steps in the most efficient order possible for the greatest cost and time savings possible, and ultimately to make the best decision for the good of their community.

In her paper titled, "Desalination, with a grain of salt: A California Perspective," Heather Cooley, et al said, "In the end, decisions about desalination developments will revolve around complex evaluations of local circumstances and needs, economics, financing, environmental and social impacts and available alternatives." (Cooley, 2006, p 4) She also said, "Is desalination the ultimate solution to our water problems? No. Is it likely to be a piece of our water management puzzle? Yes" (Cooley, 2006, p 4). This author agrees.

Appendix

Abbreviations Used

AF	Acre Feet
DWSRF	Drinking Water State Revolving Fund
EPA	Environmental Protection Agency
ERD	Energy Recovery Device
Gpm	Gallons per minute
HB	House Bill
IRB	Institutional Review Board
Kgal	1000 gallons
kWh	kilowatt hours
LWC	Levelized Water Cost
MGD	Million Gallons per Day
MUD	Municipal Utility District
O&M	Operating and Maintenance
OPEC	Organization of the Petroleum Exporting Countries
RO	Reverse Osmosis
SUD	Special Utility District
SWIFT	State Water Implementation Fund for Texas
TDS	Total Dissolved Solids
TCEQ	Texas Commission on Environmental Quality
TWDB	Texas Water Development Board
WOR	Water-Oil Ratio
WSC	Water Supply Corporation
ZLD	Zero Liquid Discharge

Helpful Conversions (Cooley, 2006, p 10)

1 cubic meter m^3 = 264 gallons = .0008 acre feet

1000 gallons = 3.79 m^3

1 million gallons = 3,785m^3

1 AF = 325,853 gallons = 1,233m^3

1 m^3 / day = 264 gallons /day = .3 AF / year

1 MGD = 3,785 m^3 / day = 1,120 AF / year (AFY)

$1 per thousand gallons = $.26 / m^3 = $325.85 / AF

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