HARRIS-GALVESTON SUBSIDENCE DISTRICT

FORT BEND SUBSIDENCE DISTRICT

2023 Joint Regulatory Plan Review

Alternative Water Supply Availability

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List of Abbreviations

µg/L	micrograms per liter
µS/cm	microSiemens per centimeter
ACU	apparent color units
AF	acre-feet
AFY	acre-feet per year
AOP	advanced oxidation process
ASR	aquifer storage and recovery
AWS	alternative water supply
AWTF	advanced water treatment facility
AMI	advanced metering infrastructure
BAC	biologically activated carbon
BAF	Biologically active filtration
BGD	billion gallons per day
BGS	below ground surface
BMP	best management practice
BRA	Brazos River Authority
BWA	Brazosport Water Authority
CWA	Coastal Water Authority
DM	demand management
DMA	district metered area
DOM	dissolved organic matter
DPR	direct potable reuse
EIS	Environmental Impact Statement
EPWU	El Paso Water Utilities
ETJ	extraterritorial jurisdiction
FBSD	Fort Bend Subsidence District
GAC	granular activated carbon
GCWA	Gulf Coast Water Authority
GLO	Texas General Land Office
GPD	gallons per day
GPM	gallons per minute
GRP	Groundwater Reduction Plan
GWP	groundwater plant
HAGM	Houston Area Groundwater Model
HGSD	Harris-Galveston Subsidence District
IPR	indirect potable reuse

JRPR	Joint Regulatory Plan Review
KIT	KIT Professionals, Inc.
kWh	kiloWatt-hour
LBITP	Luce Bayou Inter-Basin Transfer Project
MAR	managed aquifer recharge
MBR	membrane bioreactor
MCL	Maximum contaminant level
MF	microfiltration
MG	million gallons
MGD	million gallons per day
mg/L	milligrams per liter
MODFLOW	Modular Three-Dimensional Finite-Difference Groundwater Flow Model
MTT	monitoring trigger threshold
MUD	municipal utility district
MWCPT	Municipal Water Conservation Planning Tool
NA	not applicable
NEPA	National Environmental Policy Act
NEWPPE	Northeast Water Purification Plant Expansion
NOM	natural organic matter
NW	new water
O&M	operations and maintenance
OPCC	opinion of probable construction costs
PBI	performance based indicator
RO	reverse osmosis
RW	reclaimed water
RWP	2021 Region H Regional Water Plan
SAWS	San Antonio Water System
SDI	Silt Density Index
SDWA	Safe Drinking Water Act
SJRA	San Jacinto River Authority
SS	storage solution
SWTP	surface water treatment plant
TAC	Texas Administrative Code
TCEQ	Texas Commission on Environmental Quality
TDS	total dissolved solids
THSC	Texas Health and Safety Code
TOC	total organic carbon

TON	threshold odor number
TPDES	Texas Pollutant Discharge Elimination System
TSV	target storage volume
TPWD	Texas Parks and Wildlife Department
TWDB	Texas Water Development Board
UF	ultrafiltration
UOSA	Upper Occoquan Service Authority
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
UV	ultraviolet
WAM	Water availability model
WCID	water control and improvement district
WPP	water purification plant
WRF	Water Research Foundation
WTP	water treatment plant
WWTP	wastewater treatment plant

EXECUTIVE SUMMARY

ES.1 INTRODUCTION

The Harris-Galveston Subsidence District (HGSD) and the Fort Bend Subsidence District (FBSD) were created to develop regulatory policies and plans to address land subsidence from groundwater pumping in Harris, Galveston and Fort Bend counties. The Regulatory Plans for both HGSD and FBSD, last updated in 2013, require all permitted groundwater users to meet designated percentages of their water demands using alternative water supplies (AWSs) per the regulatory area and schedule established by the Districts.

The Joint Regulatory Plan Review (JRPR) seeks to account for future water needs, current and future water supplies, and associated subsidence risk within Harris, Galveston, Fort Bend and adjacent counties. The AWS Availability task sought to a) examine whether adequate AWSs are available to meet future water needs, and b) serve as a roadmap for systems within the District to develop their water portfolio for future needs and meet the regulatory requirements of the JRPR. HGSD retained KIT Professionals, Inc. (KIT) to perform the assessments related to AWS Availability task for this JRPR.

Key objectives of the AWS Availability Study were as follows:

- Compile and evaluate potential AWSs and their availability for use by systems in the regulatory areas for near-term and long-term (up to 2070). Assessment included supplies originating both within (e.g., reclaimed water, brackish groundwater) and outside (e.g., seawater desalination, inter-basin surface water transfers, off-channel reservoirs) the HGSD and FBSD regulatory areas.

- Assess and define the potential magnitude of supplies, implementation timelines, planning level cost estimates, impacts from climate change, permitting and legal considerations, and subsidence impacts for the promising AWSs.

The Districts' regulatory areas are shown in **Figure ES-1** and **Figure ES-2**.

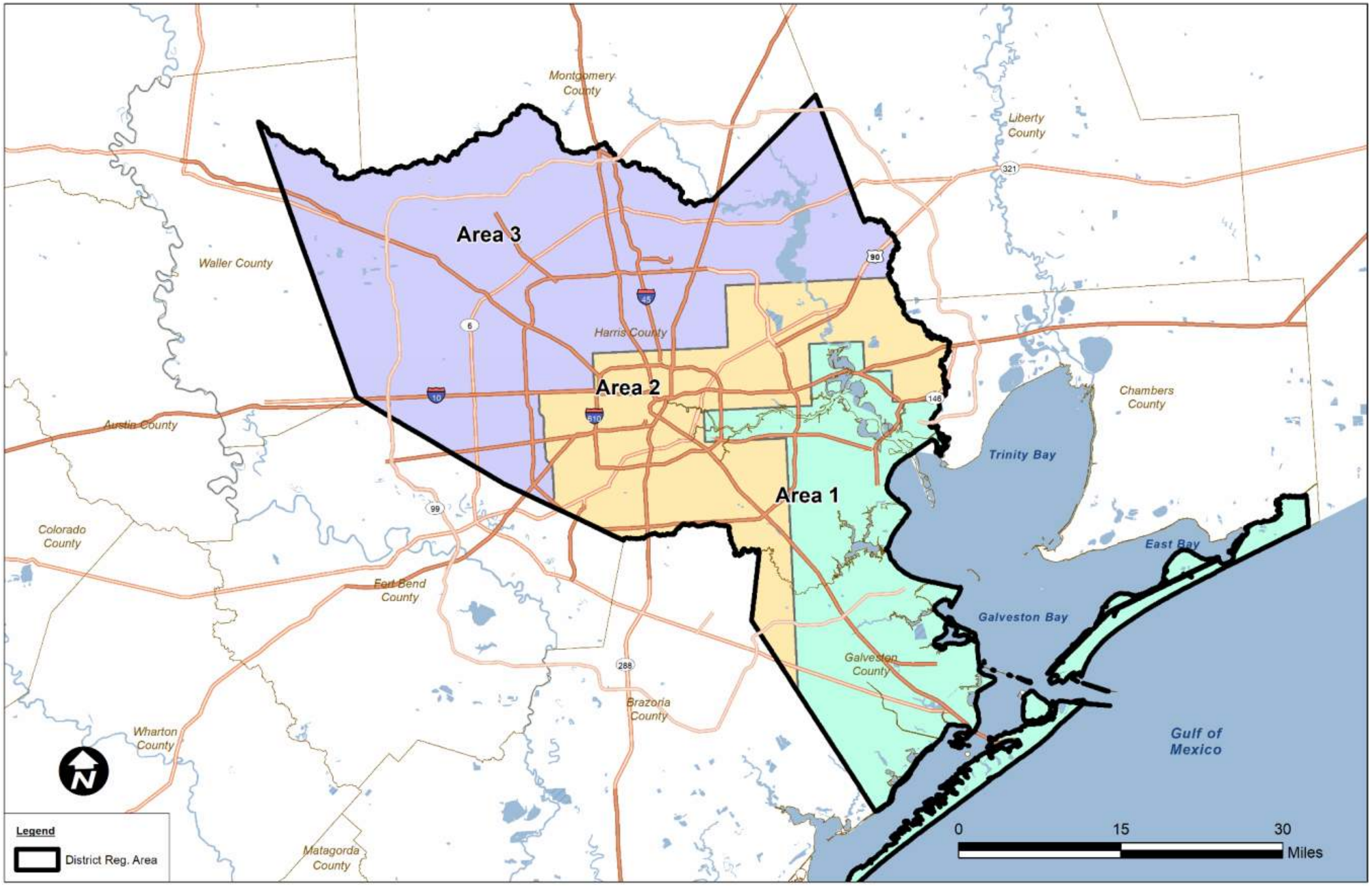

Figure ES-1. HGSD Regulatory Areas

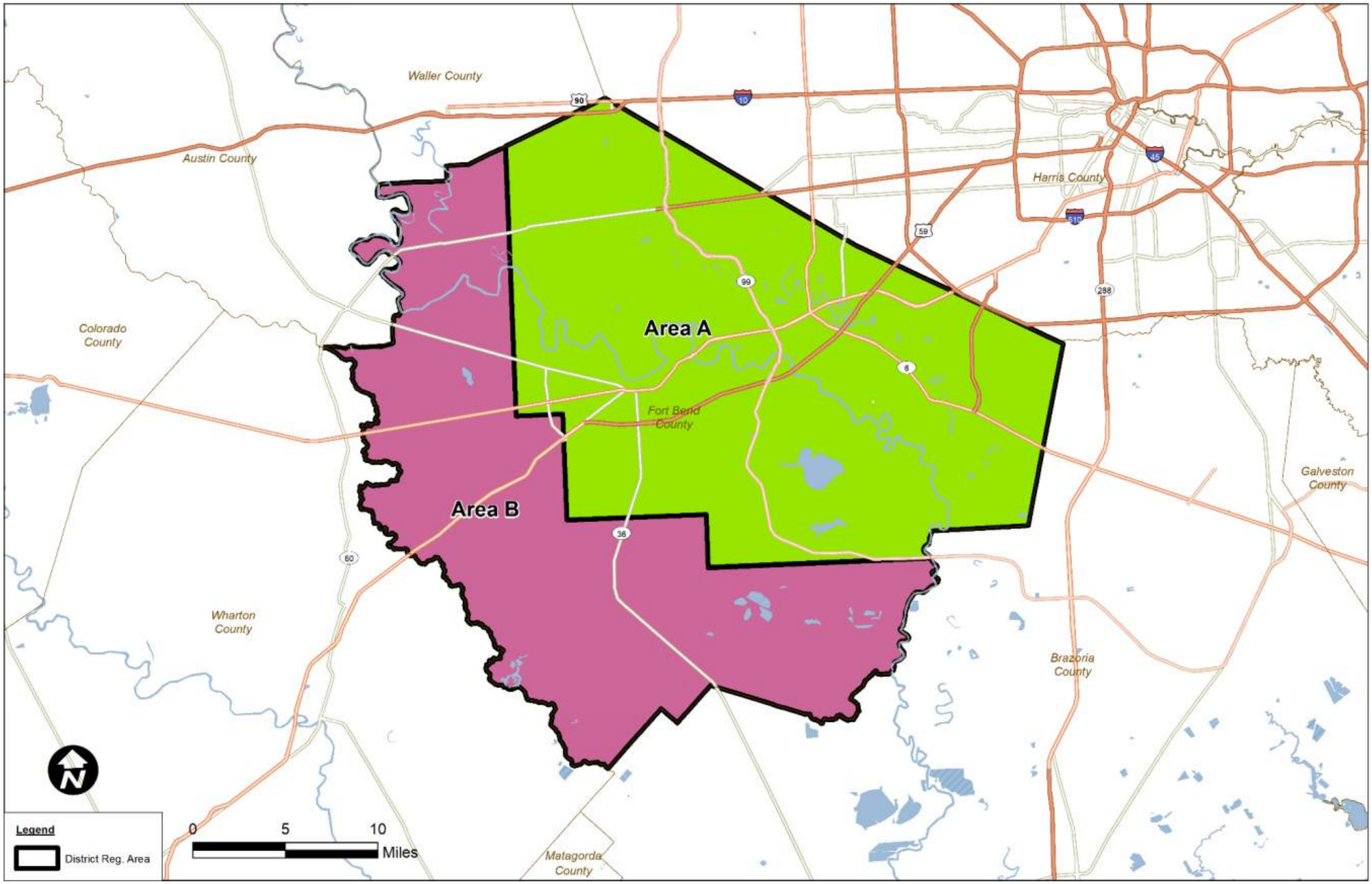

Figure ES-2. FBSD Regulatory Areas

ES.2 EVALUATION CRITERIA AND FINAL SHORTLISTING

More than twenty (20) AWS options/sub-options have been identified and evaluated at a desktop level. The options that were identified included new water supplies (NW), storage solutions (SS), reclaimed water supplies (RS) and demand management (DM) strategies as shown in **Figure ES-3**. These options are presented and described in Section 2 of the study report.

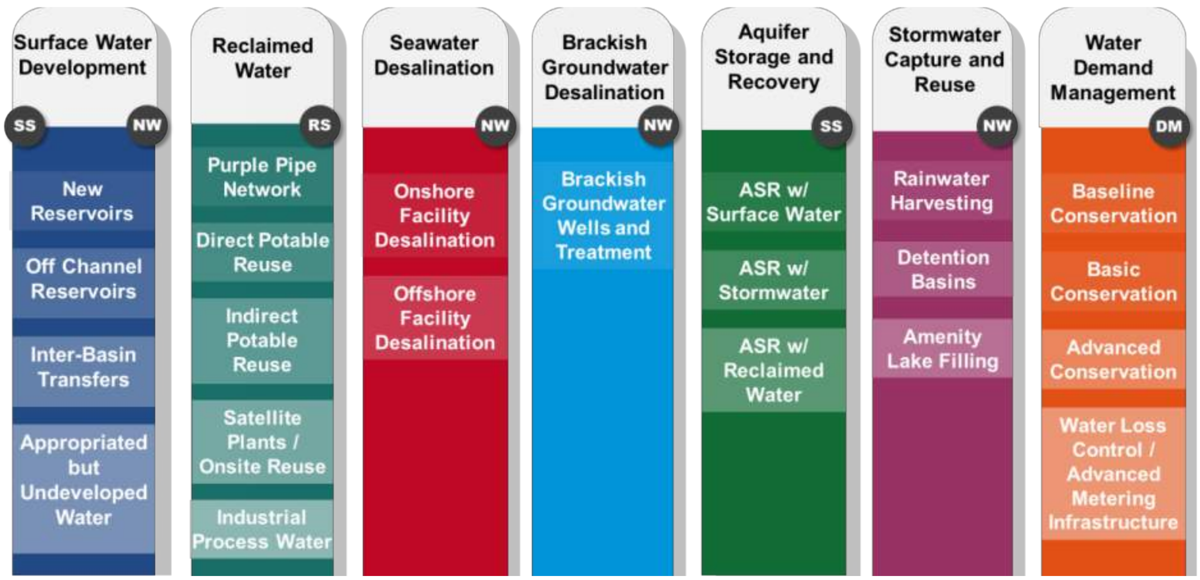

Figure ES-3. Alternative Water Supply Options Identified

Based on a review of prior studies and available information, as well as input from HGSD and FBSD, several AWS sub-options were shortlisted for further evaluation. The shortlisting and aggregation of AWS sub-options was based on a wide variety of considerations, as shown in **Figure ES-4**.

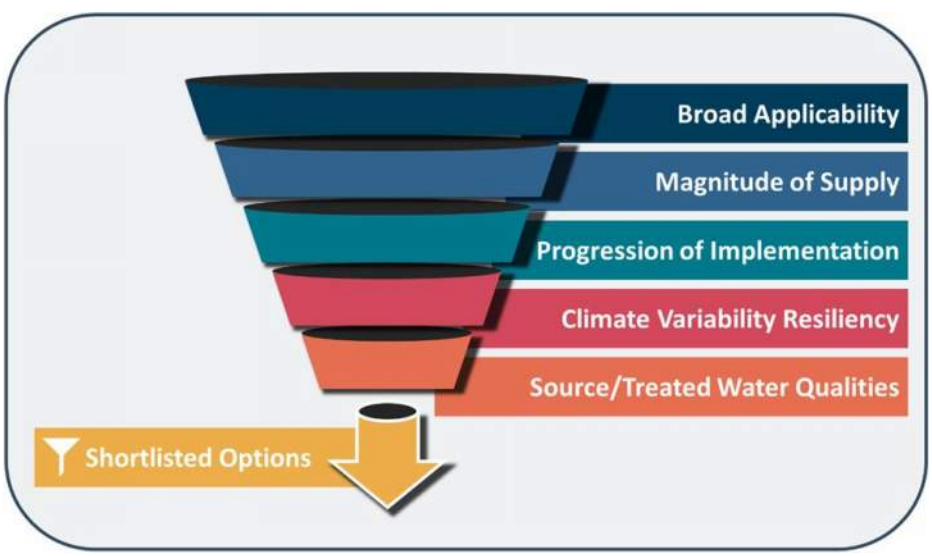

Figure ES-4. Alternative Water Supply Shortlisting Approach

Using this approach, the AWS options were aggregated and shortlisted as shown in **Figure ES-5**.

Figure ES-5. Shortlisted Alternative Water Supply Options

ES.3 AWS OPTION CHARACTERIZATION

After shortlisting, KIT conducted detailed characterizations of each of the seven (7) shortlisted options. For brevity, only brief descriptions of these options are provided herein, and the detailed characterizations of these options are provided in Section 3 of the study report.

Surface Water Development involves construction of new reservoirs, inter-basin transfer of available water supplies, and utilization of appropriated but undeveloped water supplies. Such development requires extensive planning, permitting, inter-agency coordination, and infrastructure construction.

Development of surface water supplies are relatively cost-effective due to their high yields, accessibility, higher water quality and lower treatment costs compared to other alternatives. A major benefit of surface water reservoirs is that they capitalize on existing natural water supplies by storing water and allowing for its use during higher demand periods when natural streamflow may not provide adequate supply.

All surface water supplies are susceptible to impacts from drought and climate change, and are therefore less resilient than several other AWS options.

Seawater Desalination

Seawater Desalination, both onshore and offshore**,** involves treatment of high-salinity water to drinking water quality using energy-intensive membrane processes. Onshore desalination will involve conveyance of seawater from the ocean to a desalination plant and purified through various treatment processes, the main process being reverse osmosis (RO). Offshore desalination requires maintaining offshore desalination plants in the Gulf of Mexico and pumping the treated water to onshore water systems.

The Gulf of Mexico is an effectively unlimited supply, making this option extremely resistant to climate variability. Some implementation challenges include costly treatment, membrane fouling, and environmental consequences from RO brine disposal. These can be mitigated through techniques such as adopting more energy-efficient RO membranes, optimizing pretreatment, and diluting the brine.

Regional cooperation with other public utilities and authorities and partnerships with private entities can further mitigate high development and maintenance costs for seawater desalination. This collaboration will also ensure that a cost-effective plant capacity can be reached. Water trade agreements can provide opportunities for inland communities to participate in the development of seawater supply in coastal communities.

Centralized Reclaimed Water Treatment

Centralized Reclaimed Water is the reuse of treated wastewater treatment plant (WWTP) effluent or raw wastewater for non-potable or potable use. A purple pipe network distributes reclaimed water through a separate recycled water distribution system for non-potable uses such as irrigation of golf courses and green spaces, amenity lake filling and industrial uses.

Potable reuse involves the centralized collection, transport, and treatment of wastewater effluent for drinking water supplies. In Direct Potable Reuse (DPR), the treated wastewater is sent directly to water treatment plants (WTPs) and blended with surface water sources for additional treatment and distribution. In Indirect Potable Reuse (IPR), the wastewater is sent to a surface water or groundwater source to serve as a natural barrier, from which it is extracted for incorporation into potable water treatment and distribution.

Communities that can make the best use of a reclaimed water system are those that have many potential customers that are conveniently located. A major benefit of reclaimed water use is that wastewater is a local, reliable water supply. Given that wastewater collection system flows are reasonably consistent over time, reclaimed water is a highly drought-resistant AWS.

Evaluating the potential for a centralized non-potable reuse system requires thoroughly developing the strategy through demand-side management, mapping out future customers and associated demands to inform where the recycled water distribution should be, and confirm there will be a demand to purchase the supply.

Decentralized Reclaimed Water Treatment

Decentralized Reclaimed Water occurs at a decentralized facility upstream of a WWTP such as a lift station or at the site of wastewater generation. Wastewater satellite treatment, located at lift stations or near end users, allows for reclaimed water conveyance at reduced costs and travel time.

Another type of decentralized reclaimed water treatment is onsite reuse where wastewater is diverted, reclaimed, and applied to end-uses at the site of origin, upstream of the municipal collection system.

Both satellite plants and onsite reuse options require construction of wastewater treatment facilities. Some benefits are that reclaimed water is highly drought-resistant and upstream reuse options reduce flows into a municipal collection system.

Brackish Groundwater Desalination

Brackish Groundwater Desalination is treatment of brackish groundwater to reduce salinity to a range suitable for the intended end use through RO or blending. Brackish groundwater desalination has become a more common water supply strategy in the arid and semi-arid areas of Texas where availability of fresh groundwater resources is limited. The Jasper and Lower Evangeline Aquifers throughout Harris, Galveston, Fort Bend, and surrounding counties, as well as Chicot Aquifer in Brazoria County may be of particular interest for brackish groundwater supplies.

Depending on the hydrogeological conditions and properties of the location, establishing and utilizing a brackish groundwater source may cause varying subsidence consequences depending on well spacing and pumping rates. However, brackish groundwater can be a reliable, lower-cost, drought-protected, and local supply of potable water.

Some implementation challenges are that pre-treatment may be needed if co-contaminants are present and RO brine disposal may be expensive and environmentally detrimental. Techniques such as deep well injection, salt-loop use strategies, and blending with other supplies can be used to mitigate the RO brine disposal challenge. However, as an aquifer-based option, brackish groundwater withdrawal has some inherent subsidence risk.

Aquifer Storage and Recovery (ASR) is the storage of water through recharge into a groundwater formation during low demand time periods and recovery through extraction during high demand periods. This option alone does not provide AWS yield, but rather is used conjunctively with other AWSs to provide storage and a potential shift in the temporal allocation of these other supplies. Three ASR sub-options are considered herein: ASR with surface water, ASR with stormwater, and ASR with reclaimed water. The basic conceptual approach is shared across these sub-options, with the key differences being the source of the injected water and the associated treatment processes required prior to injection.

One of the most commonly referenced benefits is that ASR can provide a drought-resistant water supply when surface water supplies are limited, and it reduces risk from hydrologic variability. Careful data collection, analysis and planning is required to maintain this supply as a subsidence-neutral option.

Water Demand Management includes practices that seek to make a water supply available for alternate or future use. Examples of water demand management practices are various levels of conservation techniques and water loss control / advanced metering infrastructure (AMI). Although the success of conservation programs is dependent on customer participation, a major benefit of water demand management strategies is that they extend the existing water supplies, thereby delaying and/or reducing the need for additional supplies. They also almost always can continuously be improved upon.

AWS Options Characterization Criteria

Each of the seven (7) shortlisted options were characterized in terms of the ten (10) criteria summarized in **Figure ES-6**. Available technical resources such as regional water plans, master water plans, feasibility studies, regulatory codes, and others were used to characterize each AWS option.

Characterization included both specific projects with known supply magnitudes, such as the Luce Bayou Inter-basin Transfer Project (LBITP), as well as assumed projects, such as larger, regional-scale seawater desalination.

When developing budgetary cost estimates, careful consideration was given to project scale to ensure that the costed implementation approaches were feasible while providing sufficient economy of scale to ensure that unit costs were reasonable.

Implementation timelines for the AWS options were characterized using information from local projects, master plans, and other sources. Implementation of each AWS included planning, design, and construction with time buffers to account for any setbacks.

Figure ES-6. AWS Characterization

A summary of characterization findings is presented in the following subsection. However, water providers and planners considering additional AWS to augment their portfolio are encouraged to review Section 3 of the study report for more detailed characterization of these options, including all of the assumptions made when computing supply magnitudes, budgetary costs, and implementation timelines.

ES.4 SUMMARY OF FINDINGS AND CONCLUSIONS

Section 4 includes a summary of the AWSs' characterization findings, information from stakeholder outreach, study conclusions, and recommended next steps. Although detailed characterization of the water options were addressed independently in Section 3, **Figure ES-7** demonstrates that many of the options are interrelated in meeting the potable and non-potable water demands.

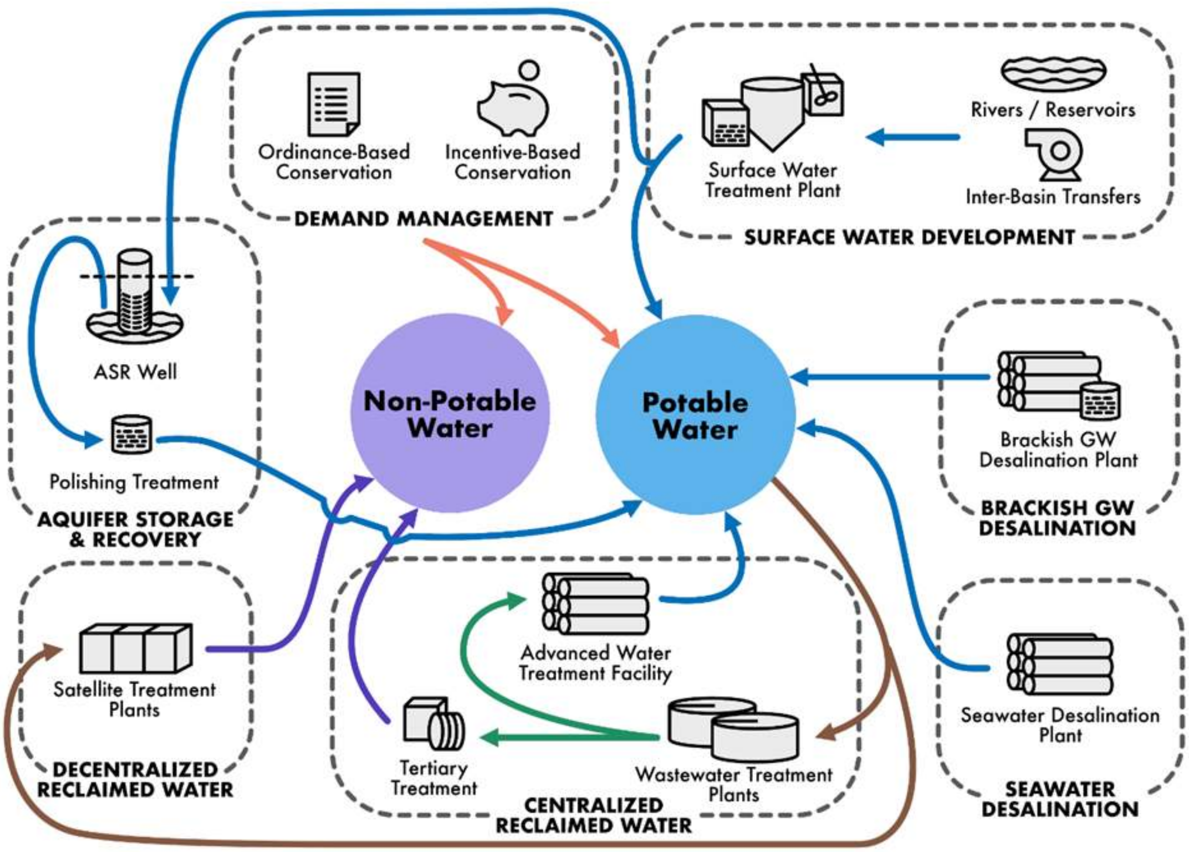

Figure ES-7. AWS Option Interdependencies

Supply Magnitudes

Potential AWS and demand management magnitudes are summarized in **Table ES-1**. As shown in the table, surface water development and centralized reclaimed water treatment for both potable and non-potable uses are considered to have the highest potential supply magnitudes. Note that these are not a reflection of projects that are planned for implementation, but rather an inventory of potential supplies.

Table ES-1. AWS Magnitude of Supplies Summary

Alternative Water Supply	Potential 2070 AWS Magnitude (MGD)
Surface Water Development	~700
Seawater Desalination	100
Centralized Reclaimed Water Treatment	160
Decentralized Reclaimed Water Treatment	13
Brackish Groundwater Desalination	24
Aquifer Storage and Recovery	20[a]
Demand Management through Water Conservation	73[b]

a – ASR requires treated surface water as a supply source. It is assumed that this surface water supply would be derived from interruptible rights that are not reflected in the magnitude of surface water development of this table.

b – Demand management is not a supply option. Rather, the listed magnitude represents a reduction in water demands.

Figure ES-8 summarizes the existing and potential 2070 alternative water supplies and demands to facilitate direct comparison. As shown in the figure, potential supply availability magnitudes exceed projected future demands, suggesting that AWS availability will be sufficient to supply future growth and AWS conversion in the Districts. It is recognized that AWS availability is not spatially uniform, and implementation of these options will be influenced by a host of geographic and provider-specific considerations, as demonstrated in **Figure ES-9**. Several of the highest magnitude AWSs will also require substantial regional coordination among providers to implement at the scales shown herein. Nonetheless, these calculations suggest that there are adequate AWSs to offset future demand growth in the regulatory areas, provided that some of the high-magnitude AWSs can be brought to fruition within the planning horizon. Notably the LBITP, Northeast Water Purification Plant Expansion (NEWPPE), and associated water transmission and distribution projects will develop an additional 320+ MGD of surface water supply within the Districts. Several additional projects will be required to meet projected 2070 AWS demands. Although various combinations of AWSs can be implemented to meet projected demands, it is anticipated that AWS demands would be met primarily through some combination of surface water development (e.g., utilization of allocated but undeveloped supplies), increased reclaimed water utilization, and/or seawater desalination. The timelines for development of future AWSs is dictated by several factors that include population growth and demand projections, reliable geospatial access, evolutions in treatment technologies, climate impacts (e.g., extended droughts), and future policies (e.g., outdoor water use restrictions).

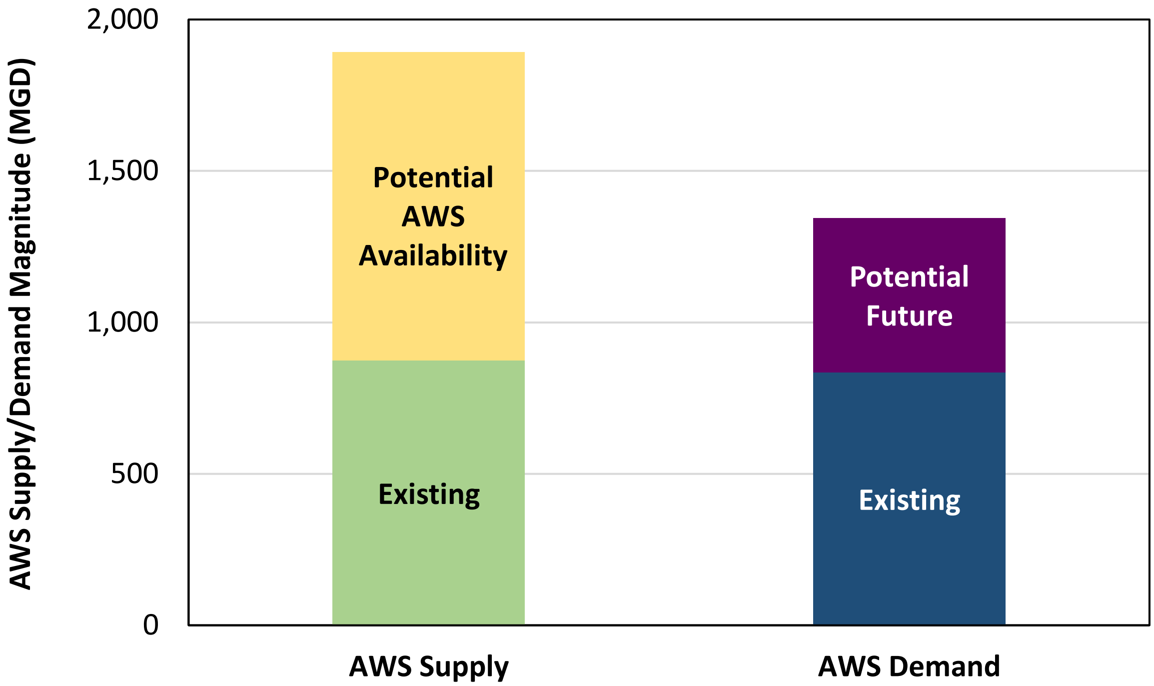

Figure ES-8. Potential 2070 AWS Supply and Demand

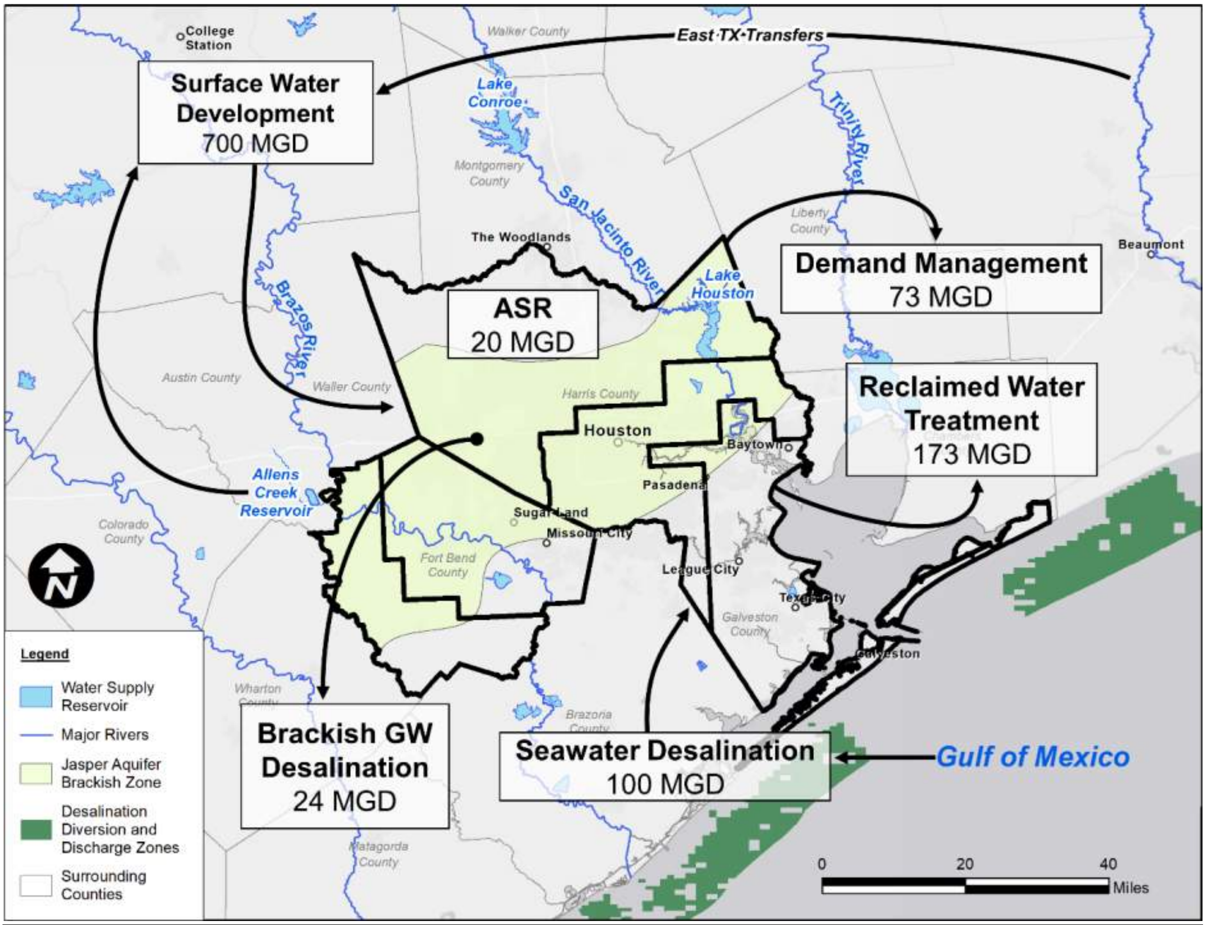

Figure ES-9. Alternative Water Supplies Available Over the Long-term for HGSD/FBSD Regulatory Participants

Costs

The cost summary presented in **Figure ES-10** includes capital, debt service, and annual operations and maintenance costs for each characterized AWS (in $/1,000 gallons). In the figure, markers represent opinion of probable construction cost (OPCCs) for conceptual project implementation, and the whiskers represent a range from -30% to +50% of each OPCC. It is important to note that these costs are based on the assumed implementation magnitudes for each option. In general, total costs on a per-thousand-gallons basis decrease with increasing capacity due to economy-of-scale gains, and this is particularly applicable for projects with advanced treatment technologies (e.g., seawater desalination, potable reclaimed water treatment). Careful consideration was given to assumed implementation capacity to ensure that projects would be reasonably cost-effective.

As with any infrastructure, actual project implementation costs may vary considerably from project to project based on local factors and design choices. The cost opinions for various AWSs were developed applying consistent methodologies and assumptions to enable a comparison of options. Further, these OPCCs were developed in early 2021, and COVID-related supply chain issues and other inflationary pressures may not be fully reflected in these values. Regardless, these costs demonstrate that each of the potential AWSs shown here can be reasonably cost-effective if implemented at an adequate capacity.

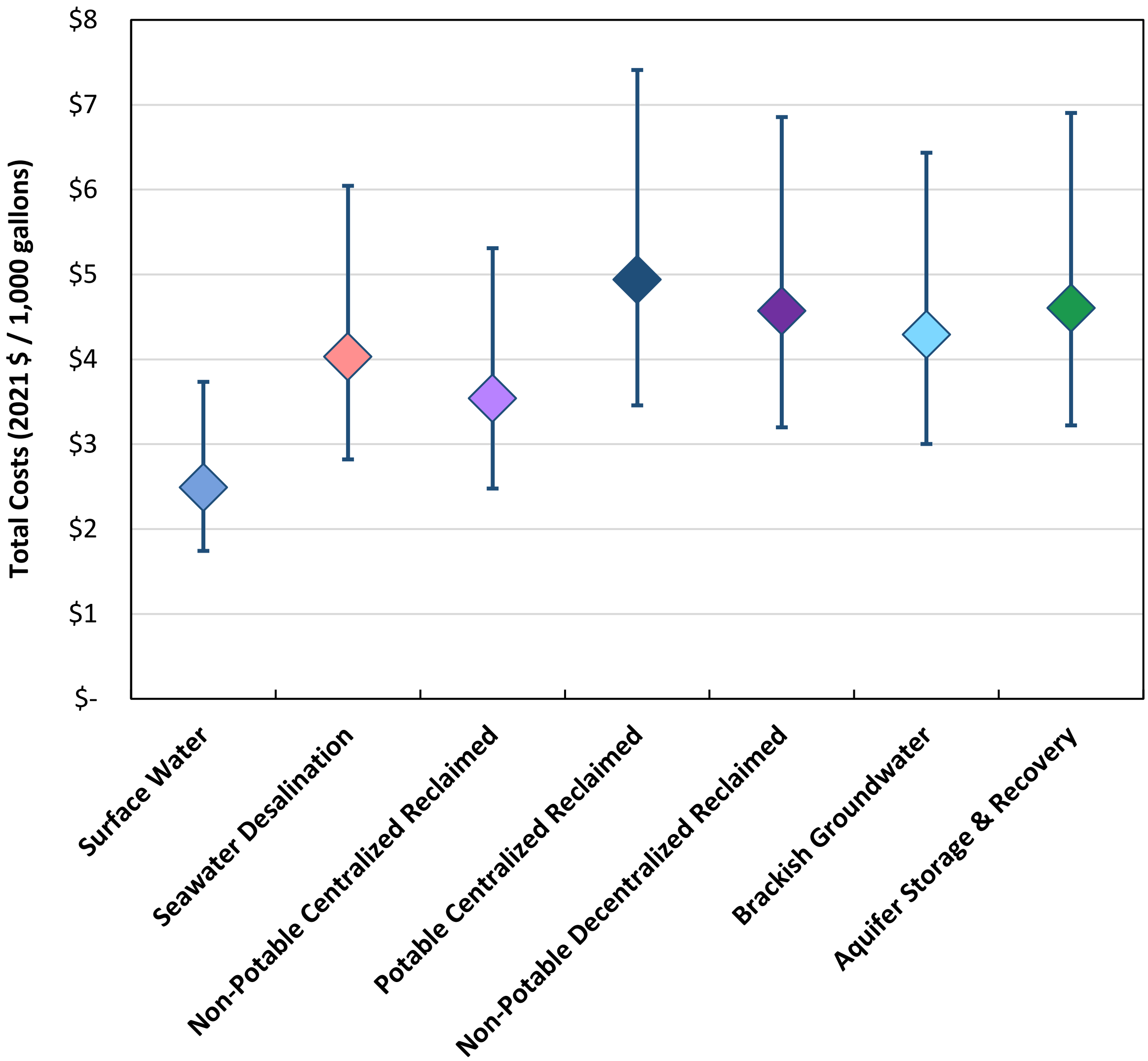

Figure ES-10. AWS Cost per Thousand Gallons

Implementation Timelines

Potential AWS and demand management implementation timelines are summarized in **Figure ES-11**. Given the requisite planning, permitting, design and construction durations, new surface water development, seawater desalination, and centralized potable reclaimed water treatment have the longest anticipated implementation timelines. Thus, entities planning to incorporate one of these options into their AWS portfolio will need to commence feasibility study and planning efforts well in advance of the need for these supplies to meet customer demands. Individual project timelines will vary, but these values demonstrate the relative timelines from concept to full-scale implementation for the various AWSs.

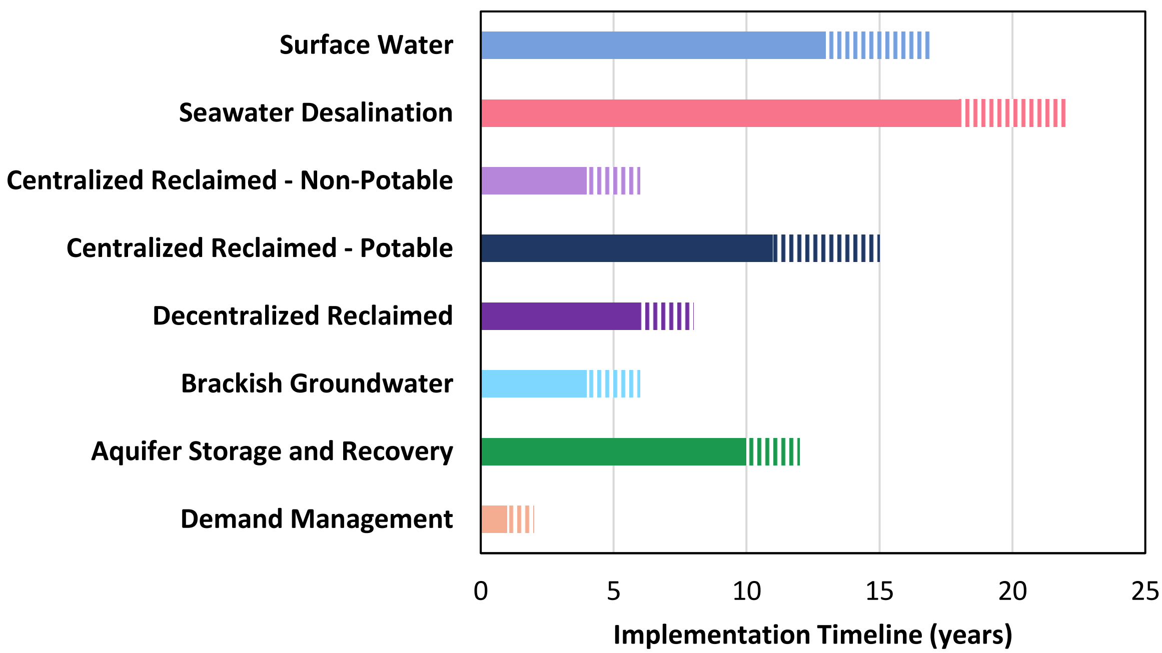

Figure ES-11. Typical Implementation Timelines

Numerous drivers, including population growth, extended droughts, need for diversification of supplies, potential re-development in developed areas and future policies can influence the timing of AWS implementation, and it is recognized that these drivers are not spatially uniform. Implementation of individual AWS projects is therefore subject to local drivers and constraints, and projects are therefore likely to be implemented at varying timelines based on these local considerations. Further, while this study examined the availability of AWSs with respect to anticipated

2070 AWS demands, the phasing of these projects over intervening decades was beyond the study's scope.

Nonetheless, some conclusions can be made regarding future AWS implementation. It is anticipated that surface water will account for the majority of additional AWS implemented by 2070. The majority (320+ MGD) of additional surface water supply will be delivered via the LBITP, NEWPPE, and associated transmission and distribution projects. Given that this infrastructure is already under construction, it is anticipated that the majority of additional AWS demands in HGSD and northern FBSD Area A will be met via these projects in the near- to intermediate-term horizon. In contrast, given the rapid population growth and upcoming regulatory requirements in FBSD, some regulatory participants will need to implement additional supply projects within the next 5-10 years. These projects could include surface water development of existing water rights and increased centralized reclaimed water treatment. In the intermediate- to longer-term horizon, one or more regional-scale AWS projects will likely be required to meet AWS demands in the portion of FBSD Area A not served by the NEWPPE. Potential regional AWSs include the Allens Creek Reservoir and seawater desalination. Regardless of which regional AWSs are implemented and their timing, cooperative planning and coordination among multiple entities will be needed.

Climate Change and Subsidence Considerations

All AWSs were characterized with respect to their vulnerability to climate change and subsidence impacts. As shown in **Table ES-2**, several AWS options were considered resilient to climate change, and five (5) out of seven (7) options have no subsidence impacts. Surface water development, which is currently the predominant AWS in the region, was considered to be the most susceptible to climate change. Diversification of AWSs therefore not only improves climate resilience, but also decreases reliance on groundwater supplies during drought. Most of the evaluated options do not have potential for subsidence impacts. Subsidence impacts for brackish groundwater desalination and ASR are being evaluated as part of the HGSD/FBSD Review.

Table ES-2. Climate Change and Subsidence Considerations

AWS Option	Vulnerability to Climate Change	Subsidence Impacts
Surface Water Development	🔴	None
Seawater Desalination	🟢	None
Centralized Reclaimed Water Supply	🟢	None
Decentralized Reclaimed Water Treatment	🟢	None
Brackish Groundwater Desalination	🟢	Moderate
Aquifer Storage and Recovery with Surface Water	🟠	Moderate
Demand Management – Basic and Advanced Conservation	🟢	None

🔴 – High vulnerability
🟠 – Moderate vulnerability
🟢 – Low vulnerability

Conclusions

Based on this study, potential AWS availability outpaces future demand growth, and there appears to be adequate AWS to meet future needs within the regulatory areas through 2070. However, it is recognized that AWS availability is not spatially uniform, and AWS implementation may be more challenging in some regulatory sub-areas.

It is anticipated that future AWS availability will likely predominantly consist of surface water development and centralized non-potable reclaimed water treatment. Desalination of seawater may also provide substantial contributions to the AWS portfolio.

Proactive planning, as well as regional coordination and partnerships, will be required in the future. In particular, high-capacity projects with supplies originating outside of the regulatory areas (e.g., inter-basin transfers, seawater desalination) will require participation from multiple wholesalers/providers to provide the necessary demands and capital for implementation. Further, seawater desalination may require agreements between coastal and inland entities in which capital contributions are provided in exchange for release of surface water rights, particularly for the Brazos River basin.

SECTION 1 – INTRODUCTION

The Harris-Galveston Subsidence District (HGSD) and the Fort Bend Subsidence District (FBSD) were created to develop and implement regulatory policies and plans to prevent land subsidence from groundwater pumping in Harris, Galveston and Fort Bend counties. The Regulatory Plans for both HGSD and FBSD, last updated in 2013, require all permitted groundwater users to meet designated percentages of their water demands using alternative water supplies (AWSs) per the regulatory area and schedule established by the Districts.

Alternate water supply, as defined in HGSD and FBSD Rules 1.1(b), is metered water from any source that meets regulatory requirements including but not limited to: surface water, reuse water, treated effluent, desalinated seawater, or water from a retail public utility. Water obtained from a supplier in compliance with a Groundwater Reduction Plan (GRP), or groundwater provided as part of a GRP (HGSD, 2019; FBSD, 2016) is considered an alternative water supply. Groundwater withdrawn from any county outside the Districts does not qualify as an alternative water supply unless the permittee can demonstrate that the groundwater withdrawals will not cause groundwater level declines or subsidence within the District.

This AWS availability study considered surface water development, reuse water, treated effluent, and desalinated seawater, as well as water demand management, aquifer storage and recovery (ASR), and other water supply options that may not yet be recognized as an AWS under the HGSD or FBSD rules. This study will also investigate the availability of alternative water supplies; an available AWS, as defined in HGSD Rules 1.1(c), is an AWS that can be utilized with the exercise of reasonable diligence within a reasonable time (HGSD, 2019; FBSD, 2016).

The Joint Regulatory Plan Review (JRPR) seeks to account for the future water needs, current and future water supplies, and associated subsidence risk within the study area. The overall study area for the JRPR includes Harris, Galveston, Fort Bend and adjacent Counties. The JRPR is divided into five distinct but interrelated tasks. The Alternative Water Supply Availability task of the JRPR includes compiling and evaluating the available information on potential alternative source waters for the HGSD and FBSD regulatory areas. However, supplies originating outside of these areas will also be considered. The AWS Availability task will 1) examine whether adequate AWSs are available to meet future water needs, and 2) serve as a roadmap for systems within the District to develop their water portfolio for future needs and meet the regulatory requirements of the Districts' Plans.

1.1 KEY OBJECTIVES

Key objectives of the AWS Availability Study are as follows:

- Compile and evaluate potential AWSs and their availability for use by systems in the regulatory areas for near-term and long-term (up to 2070). Assessment will include supplies originating both within (e.g., reclaimed water, brackish groundwater) and outside (e.g., seawater desalination, inter-basin surface water transfers, off-channel reservoirs) the HGSD and FBSD regulatory areas.
- Assess and define the potential magnitude of supplies, implementation timelines, planning level cost estimates, impacts from climate change, permitting and legal considerations, and subsidence impacts for the promising AWSs.

1.2 REGULATORY AREAS

The Regulatory Plans for both HGSD and FBSD have established regulatory areas that define groundwater conversion requirements and timelines. The 2013 Regulatory Plan for HGSD regulates pumping of groundwater under three regulatory areas: Area 1, Area 2 and Area 3. A map of the HGSD regulatory areas is shown in **Figure 1-1**. The groundwater withdrawal requirement for each regulatory area is shown in **Table 1-1**. The phased AWS requirements for Area 3 with a certified GRP are shown in **Table 1-2**.

Table 1-1. HGSD Regulatory Requirements

Area	Regulatory Requirement
Area 1	Groundwater withdrawal must be no more than 10% of the total water demand
Area 2	Groundwater withdrawal must be no more than 20% of the total water demand
Area 3	Groundwater withdrawal must be no more than 20% of the total water demand*
Note: *Area 3 groundwater reduction requirements for permittees who have certified GRPs have a phased timeline.	

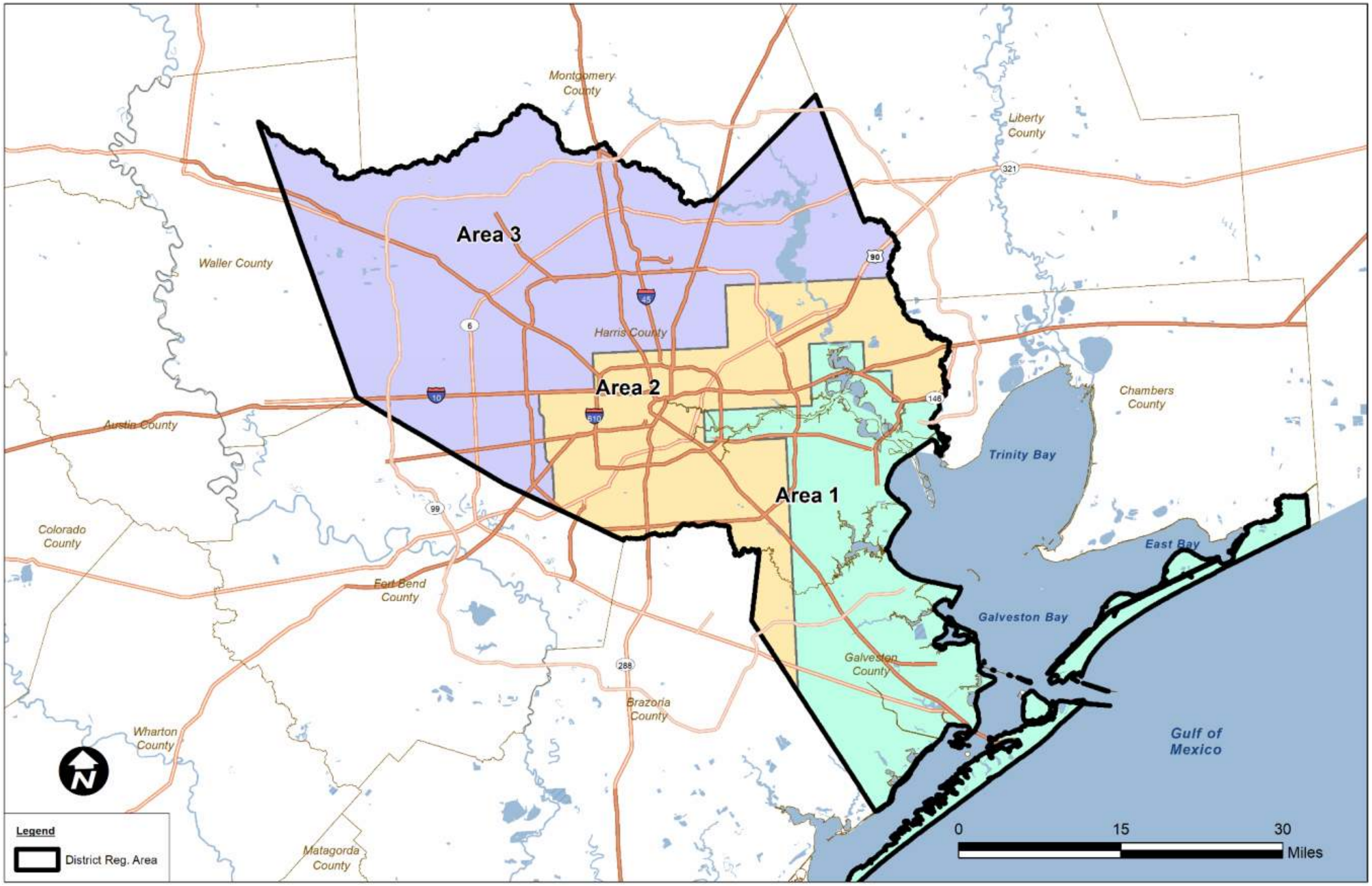

Figure 1-1. HGSD Regulatory Areas

Table 1-2. HGSD Regulatory Requirements for Permittees in Area 3 with GRP

Year	Regulatory Requirement for Systems with a Certified GRP
Current	Groundwater withdrawal must be no more than 70% of the total water demand
2025	Groundwater withdrawal must be no more than 40% of the total water demand
2035	Groundwater withdrawal must be no more than 20% of the total water demand

Area 3 is integrating the Luce Bayou Inter-Basin Transfer Project (LBITP), Northeast Water Purification Plant Expansion (NEWPPE), and water transmission and distribution systems to develop an additional 320 million gallons per day (MGD) of treated surface water. The additional surface water will enable the City of Houston, North Harris County Regional Water Authority, West Harris County Regional Water Authority, North Fort Bend Water Authority and Central Harris County Regional Water Authority to meet the HGSD groundwater reduction mandate for 2025 and beyond.

The 2013 Regulatory Plan for FBSD divides the District into two areas: Area A and Area B. A map of the FBSD regulatory areas is shown in **Figure 1-2**.

The groundwater withdrawal requirement for each regulatory area is shown in **Table 1-3**. Currently, there are no groundwater reduction requirements for Area B. Systems in Area A with a certified GRP can phase in their AWSs as shown in **Table 1-4**.

Table 1-3. FBSD Regulatory Requirements

Area	Regulatory Requirement
Area A	Groundwater withdrawal must be no more than 40% of the total water demand
Area B	No groundwater reduction mandates

Table 1-4. FBSD Regulatory Requirements for Area A with Groundwater Reduction Plan

Area A	Regulatory Requirement for Systems with a Certified GRP
Current	Groundwater withdrawal must be no more than 70% of the total water demand
2025	Groundwater withdrawal must be no more than 40% of the total water demand

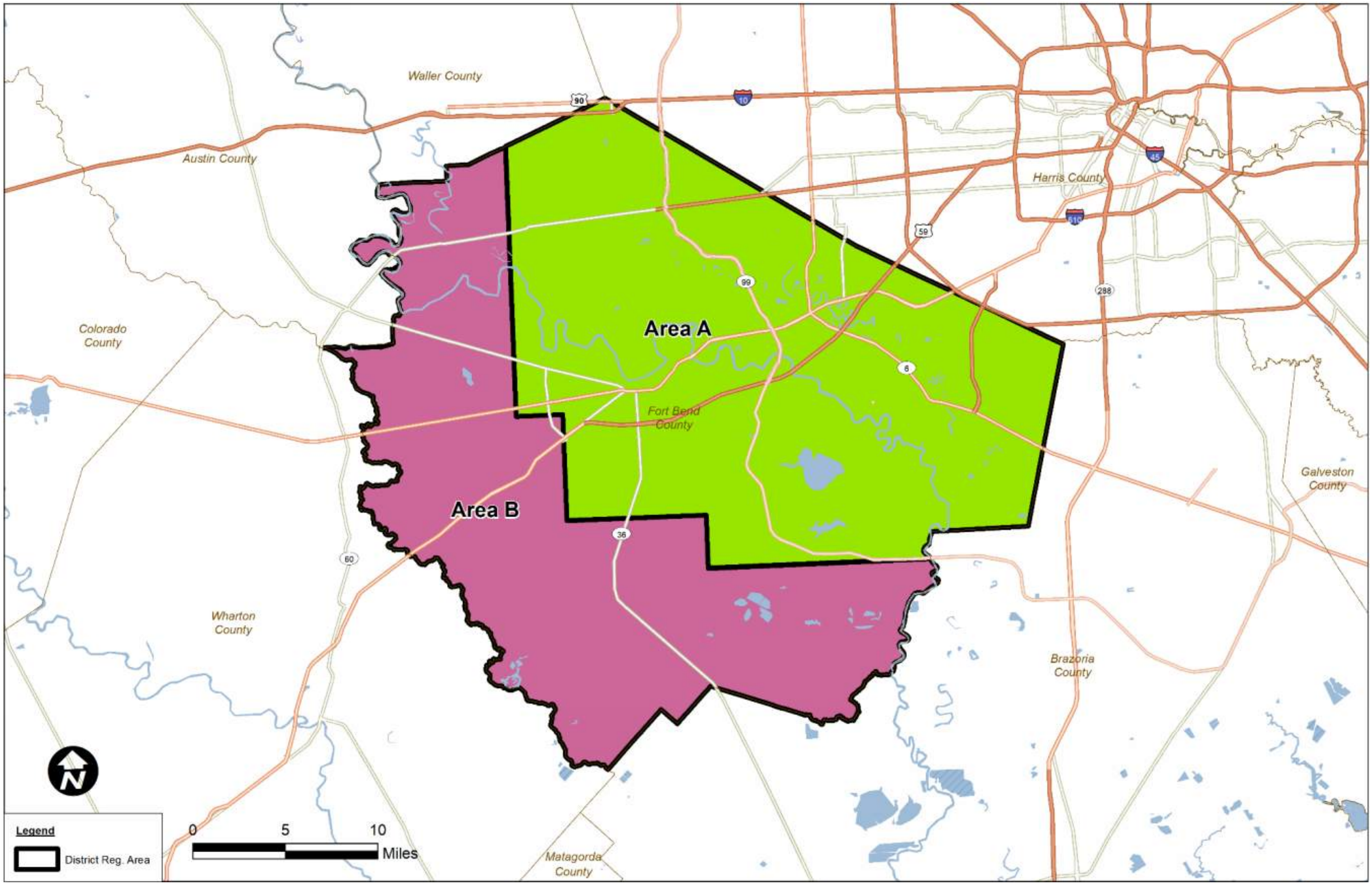

Figure 1-2. FBSD Regulatory Areas

1.3 REPORT ORGANIZATION

Section 2 of this report has a summary of all the options and sub-options that were identified as potential AWSs for the HGSD and FBSD regulatory areas. Based on a review of prior studies and available information, as well as input from HGSD and FBSD, KIT shortlisted several AWS sub-options for further evaluation. Section 3 has the detailed characterization of the shortlisted alternatives. Characterization of the shortlisted AWSs includes narrative descriptions, implementation approach, anticipated yields, budgetary/planning level cost estimate ranges, implementation timelines, vulnerability to climate change, regulatory area(s) served, permitting and legal considerations and subsidence impacts. Section 4 has the key findings, conclusions and suggested next steps.

SECTION 2 – ALTERNATIVE WATER SUPPLY OPTIONS

There are several potential AWS options that water suppliers in the regulated areas could consider and develop as necessary to meet the future water demands and diversify water supplies. **Table 2-1** has a summary of the potential AWS options. This section contains an overview of each of these potential AWS options; a shortlist of the potential AWS options of interest to the HGSD and FBSD will be explored in greater depth in Section 3.

Table 2-1. Potential AWS Options

AWS Options	Sub-Options
Surface Water Development	New Reservoirs
	Off Channel Reservoirs
	Inter-Basin Transfers
	Appropriated but Undeveloped Water
Seawater Desalination	Onshore Desalination
	Offshore (or Platform) Desalination
Reclaimed Water	Centralized – Purple Pipe Network
	Centralized – Direct Potable Reuse
	Centralized – Indirect Potable Reuse
	Decentralized – Satellite Plants/Onsite Reuse
Brackish Groundwater Desalination	Brackish Groundwater Wells and Treatment
Aquifer Storage and Recovery (ASR)	ASR with Surface Water
	ASR with Stormwater
	ASR with Reclaimed Water
Water Demand Management	Baseline Conservation
	Basic Conservation
	Advanced Conservation
	Water Loss Control/Advanced Metering Infrastructure

For these options, KIT collected and reviewed available information through a variety of sources, including, but not limited to, the following:

- Texas Water Development Board's (TWDB) 2017 and 2022 State Water Plans, including the plans for Region H and other regions
- Region H 2021 Regional Water Plan (2021 RWP) (Region H Water Planning Group, 2020)
- Prior studies conducted for HGSD, FBSD and other local agencies
- Publicly available information from databases within the region
- Review of literature regarding efficacy and scale of alternative supply options
- Review of literature regarding innovative supply technologies

Pertinent technical information that was gathered and reviewed for each of the options is discussed below.

2.1 SURFACE WATER DEVELOPMENT

Surface water development involves construction of new reservoirs, inter-basin transfer of available water supplies, and utilization of appropriated but undeveloped water supplies. The use of surface water is the primary source of AWSs for permittees in both HGSD and FBSD.

Currently the majority of surface water that serves the Districts' areas originate from the Brazos, San Jacinto, and Trinity River systems. Major existing water supply reservoirs include Lake Livingston in the Trinity basin, and Lake Conroe and Lake Houston in the San Jacinto basin. Large water providers also serve users within the Districts' areas through run-of-river rights in these basins. Further details on current versus potential future surface water use from these and other sources are discussed in Section 3.1.

New Reservoirs and Off-channel Reservoirs

The construction of new reservoirs and lakes to capture and store natural streamflow is one of several key surface water development strategies. New reservoirs can be utilized for capturing and storing surface water and stormwater runoff. Surface water from the reservoirs is conveyed to end user locations using pump stations, canals and pipelines. For potable uses, surface water is delivered to water treatment plants (WTPs to treat and distribute the treated water.

Reservoirs can be constructed in locations off of, but near natural stream channels. Off-channel reservoirs receive flows diverted from the main river channel, and impounded supplies can either be pumped directly to water users or returned to the main river channel during periods of low flow.

The Allens Creek Reservoir, which is included in the Region H 2021 Regional Water Plan (2021 RWP), is an example of a planned reservoir to increase surface water supply for the region. This project, which impounds Allens Creek in Austin County, receives the majority of its yield from water diverted from the main stem of the Brazos River. The Allens Creek Reservoir is discussed further in Section 3.1.

Inter-basin Transfer of Water

Inter-basin transfer of water involves diverting water from an adjacent or upstream watershed to a recipient watershed by means of pipelines and/or canals, thereby re-distributing any water available to a region deficit in water supplies. The LBITP is one such example, as it moves Trinity River water to Lake Houston to serve Harris and Fort Bend counties through a series of pipelines and pump stations (CWA, 2020).

A potential East Texas Transfer project would transfer water from the Toledo Bend Reservoir and Sabine River to the Trinity River Basin, and possibly even further to the Brazos River Basin. This project has the potential to serve eastern Harris County and possibly even further to Fort Bend County (2021 RWP). This project will also be described in more detail in Section 3 of this report.

Appropriated but Undeveloped Water

Appropriated but undeveloped water refers to water for which rights have been appropriated to a specific water rights holder, but these rights are not currently being used due to lack of infrastructure or insufficient existing demands. In most cases, such rights have been secured to meet projected future demands, and these supplies will be developed as water demands increase. Section 3 has a summary of the appropriated but undeveloped water for Trinity, San Jacinto and Brazos River basins.

2.1.1 TECHNICAL CONSIDERATIONS

As surface water rights approach full allocation in several local river basins, the availability of these supplies is diminishing locally. Development of new surface water supplies (reservoirs, inter-basin transfers, etc.) requires extensive planning and capital investment. One alternative approach for increasing the availability of surface water rights would be for inland water providers to participate financially in a coastal seawater desalination project not to receive desalinated seawater, but rather in exchange for surface water rights held by coastal providers. This approach is discussed further in the context of seawater desalination elsewhere in this report.

Given the relatively large surface areas of reservoirs, securing the necessary land and easements for constructing new reservoirs and pipelines is crucial. Extensive studying and permitting are also necessary, including permits from the U.S. Army Corps of Engineers (USACE) and the Texas Commission on Environmental Quality (TCEQ) (CDM Smith, 2019). For existing reservoirs, transfers of water across basins and, in the case of the Sabine River, across states will require acquisition of water rights and extensive planning, permitting, inter-agency coordination, and infrastructure construction (2021 RWP).

2.1.2 BENEFITS

As compared to other AWSs and despite significant capital costs, surface water supplies are relatively cost-effective due to their high yields, accessibility, higher water quality and lower treatment costs compared to other alternatives. Based on these factors and their relative availability in the past, surface water development options have historically been the preferred AWSs within the HGSD and FBSD regulatory areas.

A major benefit of surface water reservoirs is that they capitalize on existing natural water supplies by storing water and allowing for its use during higher demand periods when natural streamflow may not provide adequate supply. Although reservoirs are subject to climatic and hydrologic variability, impoundment water rights may provide increased resilience as compared to run-of-the-river water rights. By storing water during wet periods and providing supply during dry periods, reservoirs buffer hydrologic variability and increase supply reliability.

2.1.3 IMPLEMENTATION CHALLENGES AND MITIGATION STRATEGIES

Surface water development requires numerous permits and reviews from the federal, state and local governmental agencies, like the USACE and the TCEQ. The regulatory process can be a time-consuming task for water developers to navigate. These barriers can be overcome with careful planning and environmental impact assessment, with the result that new reservoir project implementation is on a decadal (or greater) scale.

Significant ecological and environmental risks can result from the construction of reservoirs and dams by altering habitats and the natural conveyance of streamflow. Adequate impact assessments should be made when considering location and other parameters. If assessments find damages may occur, then mitigation projects for restoration, enhancement, and reestablishment can be implemented to combat the environmental degradation (2021 RWP). Given that they are less disruptive to existing aquatic and riparian habitat, off-channel reservoirs are generally considered more ecologically conscious than reservoirs located on the main stem of a river.

The capital costs for surface water development options can be a barrier for these strategies, particularly as conveyance distances increase. To minimize pumping and conveyance costs, new reservoirs can be strategically located. However, utilization of existing reservoirs via inter-basin transfers may require extensive infrastructure.

All surface water supplies are susceptible to impacts from drought and climate change and may therefore be less resilient than some other AWS options. Although reservoirs are intended to buffer hydrologic variability, they are still susceptible to drought conditions. The vulnerability of surface water supplies to climate is discussed in Section 3.1.9.

2.2 SEAWATER DESALINATION

Seawater has a total dissolved solids (TDS) concentration of greater than 35,000 milligrams per liter (mg/L). Seawater desalination involves treatment of high-salinity water to drinking water quality using energy-intensive membrane processes. Seawater can be desalinated onshore or offshore. The treatment system involves a pre-treatment system to remove sediment, microfiltration (MF) or ultrafiltration (UF) membranes, high-pressure seawater reverse osmosis (RO) membranes and water stabilization. Desalinated water can be brought inland to meet the demands from municipal, industrial, and other uses (Water Research Foundation [WRF], 2019).

Onshore or Coastal Desalination

Onshore desalination will involve conveyance of seawater from the ocean to a desalination plant and purified through various treatment processes, the main process being RO. For regional purposes, seawater will be pumped using an intake structure located close to the Gulf of Mexico. The RO brine or concentrate can then be returned to the Gulf of Mexico with appropriate permitting and approval processes (CDM Smith, 2019).

Offshore Desalination

Offshore desalination is an innovative strategy that would require partnerships between private entities and public utilities. In this option, private entities can maintain offshore desalination plants in the Gulf of Mexico and pump the treated water to onshore water systems. Treatment will require seawater desalination as described above. The brine or concentrate from the desalination process can be discharged back into the ocean with appropriate permitting and approval (2021 RWP).

2.2.1 TECHNICAL CONSIDERATIONS

Seawater desalination has several technical challenges that include permitting, intake location, brine disposal, product water quality and post-treatment. A Texas Parks and Wildlife Department (TPWD) and Texas General Land Office (GLO) study brought light to the importance of evaluating total salt content, ratio of salt-type, adequate circulation for brine dispersal and other factors that need to be considered in brine disposal (TPWD & GLO, 2018). High salinity can compromise marine wildlife; therefore, brine disposal options must be thoroughly evaluated and considered.

Integration of desalinated sea water into potable water systems will require careful consideration of blending, compatibility with existing supplies and distribution system impacts. While desalinated sea water is low in TDS, it is highly corrosive and will require additional water quality stabilization. Post-treatment would be needed to safeguard human health and the integrity of the distribution system. This could include remineralization and corrosion control, among other solutions (WRF, 2009).

2.2.2 BENEFITS

The Gulf of Mexico is an effectively unlimited water supply, making this option extremely resistant to climate variability. Seawater could therefore serve as a drought-proof water supply for HGSD and FBSD regulatory participants, particularly those closest to the coast (e.g., HGSD Regulatory Area 1). Development of seawater supply will require significant cooperation and coordination at a regional level possibly through formation of a consortium. This consortium will include coastal and inland communities that would together pay for development of the supply. Under this arrangement, coastal water systems served by a desalinated seawater supply can trade their surface water rights with upstream entities in regulatory areas further inland who share the cost for developing the seawater supply. Coastal communities will benefit directly from the supply while the inland communities will in return receive additional surface water rights. Seawater supply can also provide environmental benefits to freshwater sources by offsetting reliance on them, and there is a greater degree of public acceptance for this option in comparison to other alternative water sources.

2.2.3 IMPLEMENTATION CHALLENGES AND MITIGATION STRATEGIES

The treatment process and extensive pumping of seawater desalination is energy-intensive, has a bigger environmental footprint, and therefore, cost-intensive. Further, if powered by non-renewal energy sources, desalination can have a considerable environmental footprint. Water and energy systems are interdependent, with water used in energy production and energy used in water production. Thus, energy-intensive water production (or water-intensive energy production) result in positive feedback that increases the net demand for both water and energy. These impacts can be offset by using low-cost renewable energy sources for power supply. Acquiring the most cost-effective and clean energy sources can reduce operation costs, reduce carbon emissions, and potentially increase public acceptance. There is also significant progress being made in the development of more energy-efficient RO membranes (WRF, 2019).

There are some long-term environmental consequences to ocean intakes and the discharge of RO concentrate into ocean. Different management techniques for brine discharge to ocean can be employed, such as dilution and using discharge pipes with diffusers to minimize environmental impacts. Dilution of brine can be accomplished with natural freshwater, wastewater effluent discharge, or seawater from the intake pump.

Desalination requires a lot of energy for sea water conveyance, membrane treatment, brine disposal and desalinated water conveyance. There is an intricate linkage of water and energy in every step of sea water desalination. If renewable energy sources are not integrated into the desalination process, it can cause an increase in greenhouse gas emissions and exacerbate climate change impacts.

Another potential challenge is underutilized infrastructure due to desalination plants only being used during times of drought and higher demands. When weather is wetter, water supplies are switched to cheaper, less energy-intensive options. As a result, desalination plants remain in care and maintenance mode for an extended period of time and are not consistently used. This inconsistent use of desalination operations can have financial impacts. One solution can be to implement desalination at a smaller scale for regular operations so that the plant will not be shut down for long periods (WRF, 2019).

2.3 RECLAIMED WATER

Reclaimed, or recycled, water is provided through the reuse of treated wastewater treatment plant (WWTP) effluent or raw wastewater for non-potable or potable use. Major non-potable end uses for reclaimed water can include irrigation, amenity lake filling, urban green spaces, golf courses, and industrial uses such as cooling towers or tanker trucks distribution.

A non-potable reclaimed water system treating WWTP effluent is expected to include additional filtration or similar polishing treatment, additional storage and pumping facilities at the WWTPs, and additional reclaimed water piping to connect new customers to the system (CDM Smith, 2019; WRF, 2019). Reclamation of raw wastewater would require additional wastewater treatment facilities to treat the wastewater to a quality suitable for reuse applications. Water reclamation for potable uses would require additional treatment steps before reclaimed water could be introduced into a potable drinking water system.

In addition to end use, reclaimed water treatment can also be categorized by treatment facility location. Centralized reclaimed water treatment is defined herein as water reclamation treatment at a WWTP for potable or non-potable end uses. Decentralized reclaimed water treatment is defined as reclamation that occurs at a decentralized facility upstream of a WWTP. A decentralized facility could be located in the collection system (e.g., a lift station facility) or at the site of wastewater generation.

Decentralized reclaimed water is typically intended for non-potable uses, although potable use is being explored in water constrained regions.

Centralized Non-Potable – Purple Pipe Network

A purple pipe network is a pipeline network that distributes reclaimed water for non-potable uses. It is operated and distributed through a separate recycled water distribution system, with the purple color of the pipes used to distinguish from drinking water pipelines. System size for a purple pipe network is driven by demands which can range from a single-user to a city or agency. Water quality standards are set by the TCEQ and also depend on the intended end-use.

Centralized Potable – Direct Potable Reuse and Indirect Potable Reuse

Potable reuse involves the centralized collection, transport, and treatment of wastewater effluent for drinking water supplies. There are two types of potable reuse: direct potable reuse (DPR) and indirect potable reuse (IPR). In DPR, treated wastewater will be sent directly to WTPs to be blended with other water sources for treatment and distribution. In IPR, treated wastewater will be sent to a surface water or groundwater source, from which it will later be extracted for incorporation into potable water treatment and distribution. Potable water reuse can be a strategy for augmenting groundwater, surface water, raw water, or treated water supplies, depending on the point of the wastewater's incorporation. Each method will require proper management of resulting waste streams and may require the construction of an advanced water treatment facility (AWTF) for treating the initial wastewater (CDM Smith, 2019; INTERA, 2019).

Decentralized Non-Potable – Satellite Plants/Onsite Reuse Plants

Although there are numerous configurations of decentralized reclaimed water treatment that could be explored, one of the most straightforward approaches is wastewater satellite treatment. In this strategy, raw wastewater is diverted from the collection system upstream of WWTPs for water reclamation at smaller-scale facilities. These facilities are located at lift stations near the end-users of the reclaimed water, ideally high-volume users of non-potable water (i.e., golf courses, parks, amenity lakes, industries with cooling towers, etc.). Close proximity to lift stations and end users reduce pumping and conveyance costs, and locating a satellite plant upstream of a WWTP reduces travel time, flow, and odor issues in wastewater collection system (Striano et al., 2010; CDM Smith, 2019; WRF, 2019).

Another type of decentralized reclaimed water treatment is onsite reuse. Onsite reuse systems function similarly to satellite systems, except that wastewater is diverted, reclaimed, and applied to end-uses at the site of origin, upstream of the municipal collection system. Such systems capture wastewater (graywater and/or blackwater) from around a property or building and treat the water onsite for non-potable uses at the same site. Because of property requirements and economy of scale, this strategy tends to be utilized at commercial and industrial facilities with higher wastewater production and non-potable demands. On-site reuse facilities typically have four major components: (1) an alternative water collection system; (2) an on-site treatment system; (3) non-potable water storage; and (4) a non-potable water distribution system.

Both satellite plants and onsite reuse options require construction of wastewater treatment facilities. Although several treatment technologies are available, one established approach is the use of membrane bioreactor (MBR) technology, which provides a compact, modular, and automated process. Suspended solids and pathogens are retained by the MF/UF membranes, resulting in high quality reclaimed water (WRF, 2019). Per TCEQ regulations, solids removed from wastewater at satellite facilities are returned to the municipal collection system for treatment at the downstream WWTP.

2.3.1 TECHNICAL CONSIDERATIONS

Larger reclaimed water systems benefit from economies of scale and are generally more efficient. The tradeoff is that they require more infrastructure and often more pumping for the collected wastewater and the treated water being distributed. These tradeoffs should be thoroughly analyzed and depend on a multitude of site-specific factors such as land use, water demands, and topography. There is also increasing popularity for recycled water as a sustainable solution for industrial processes. Establishing industrial customers can serve as a dependable, year-round demand for recycled water, but purchase agreements should be established so that constant demand remains even as management changes.

Communities that can make the best use of a reclaimed water system are those that have many potential customers that are conveniently located. Given that non-potable reuse options require the construction of a separate, dedicated distribution system, the closer in proximity customers can be to a centralized water reclamation facility or existing distribution system the easier and more cost-effective it is to serve reclaimed water.

Onsite reuse and satellite plants are often preferred options for dense urban developments or communities with difficult topographies that make developing centralized infrastructure less cost-effective. Users with larger buildings can take advantage of economies of scale for onsite reuse also (Striano et al., 2010; WRF, 2019).

2.3.2 BENEFITS

A major benefit of reclaimed water use is that wastewater is a local, reliable water supply. Given that wastewater collection system flows are reasonably consistent over time, reclaimed water is a highly drought-resistant AWS. It is also easy to argue for the dual benefit of addressing supply challenges and environmental concerns, including groundwater subsidence, through augmentation of groundwater with renewable water supplies. It can also build upon existing WWTP infrastructure and does not generate additional waste streams that need to be separately managed (CDM Smith, 2019).

Advancements in scientific research and technologies have made the effective and safe treatment of wastewater for potable reuse implementation, and ongoing research continues to support the IPR and DPR options. Additionally, potable reuse leverages already existing water distribution infrastructure and augments potable water supply. Environmental benefits include the diversion of wastewater discharge to receiving water bodies, reducing pollutants and nutrient loading.

A strength of upstream reuse options, such as satellite plants and onsite reuse facilities, is that they reduce flows into a municipal collection system and can offset or delay the need for future WWTP expansions, thus relieving stress on the system and avoiding potentially costly expansions (WRF, 2019).

2.3.3 IMPLEMENTATION CHALLENGES AND MITIGATION STRATEGIES

Evaluating the potential for a centralized non-potable reuse system requires thoroughly developing the strategy through demand-side management, mapping out future customers and associated demands to inform where the recycled water distribution should be and confirm there will be a demand to purchase the supply. During design, it is also important to accommodate for shifts in demands and water use efficiencies. The additional challenge of implementing new infrastructure for wastewater collection and pumping can be combated by encouraging new construction to include dual-plumbing in recycled water service areas.

The disposal of concentrate from IPR and DPR is another factor to consider, and some communities may lack access to cost-effective management strategies for waste streams. Innovative advanced treatment solutions can be considered to mitigate this issue and to drive down energy and costs.

A major consideration regarding potable reuse options is the public perception and potential pushback towards drinking water originating from wastewater. To combat this, it is necessary to conduct outreach early on to overcome these barriers through community engagement and partnering with local environmental organizations (WRF, 2019).

2.4 BRACKISH GROUNDWATER DESALINATION

Brackish groundwater desalination is treatment of brackish groundwater to reduce salinity to a range suitable for the intended end use. The TWDB defines brackish groundwater as groundwater with a salinity concentration range from 1,000 to 10,000 mg/L of total dissolved solids. The salinity in brackish groundwater can be removed through RO treatment.

Brackish Groundwater Wells and Treatment

The above-ground treatment for brackish groundwater includes cartridge filtration, RO membrane treatment, chemical disinfection, and water quality stabilization. This process generates residual streams of different types of waste, each of which must be appropriately managed. Spent backwash water from filter cartridges can be recycled and re-treated. The RO brine can be discharged to natural streams or disposed via deep well injection with appropriate permitting and approval (WRF, 2019).

Brackish groundwater has become a more common water management strategy in the arid and semi-arid areas of west Texas where availability of fresh groundwater resources is limited. Interest in brackish groundwater has also grown in the Gulf region due to the significant sources in the Gulf Coast Aquifer System across the southeastern portion of the state. There are currently five brackish wells in HGSD; however, these wells are not in operation and their proposed use was for oil and gas recovery. There is an existing Jasper brackish well in the Fort Bend district, located in Cinco Municipal Utility District (MUD) 1. More information about the Cinco MUD 1 well is discussed in Section 3.

Brackish resources exist within the Gulf Coast Aquifer system, with groundwater transitioning from fresh to brackish with increased depth in the aquifer and/or closer proximity to the Gulf of Mexico. Additionally, localized areas of brackish groundwater can exist near buried salt deposits that exist throughout the region. More information on the occurrence of brackish groundwater within the Districts can be found in a prior report (INTERA et al., 2018).

2.4.1 TECHNICAL CONSIDERATIONS

Depending on the hydrogeological conditions and properties of the location, establishing and utilizing a brackish groundwater source may still have subsidence consequences. In 2018, a study was completed by the HGSD and FBSD to assess the hydrogeologic characteristics and potential subsidence risk associated with development of brackish groundwater in the Jasper Aquifer portion of the Gulf Coast Aquifer System. This included development of a MODFLOW numerical model to simulate potential compaction and subsidence that would result from brackish development of the Jasper Aquifer. Subsidence risk scores were assigned based on the modeling results and showed the potential for land subsidence due to brackish groundwater development generally increases to the northeast (updip) as the Jasper Aquifer becomes shallower (INTERA et al., 2018).

2.4.2 BENEFITS

Brackish groundwater can be a reliable local supply of potable water, especially in areas that do not have access to surface water supplies. Brackish groundwater can also be a lower-cost drought protected water source in comparison to seawater desalination due to its lower treatment costs and potential shorter conveyance distances. Brackish groundwater may therefore serve as a viable AWS in areas where supplies cannot be fully met via other AWS options (e.g., lack of viable surface water supply or access to seawater).

2.4.3 IMPLEMENTATION CHALLENGES AND MITIGATION STRATEGIES

The potential occurrence of co-contaminants in brackish groundwater such as iron, manganese, arsenic, radionuclides, sulfide, or methane can impact treatment processes, footprint, and costs. If co-contaminants are present in brackish water supplies, then additional pre-treatment processes prior to RO treatment would be necessary.

The disposal of RO brine can be challenging, and in some cases, as expensive as the RO treatment cost itself. Techniques such as deep well injection, evaporation ponds, zero liquid discharge, sewer disposal and disposal to natural streams are all possible options depending on the individual project, proximity to discharge locations, and applicable laws and regulations. For example, discharge to a surface water body, such as the Willow Fork of Buffalo Bayou, can be a potential solution for regional purposes, but this requires a permit. RO brine discharges to natural streams are constrained by TCEQ's Surface Water Quality Standards, which limit the receiving stream's TDS concentration. Salt-loop use strategies in which brine can be used for salt products, and thus create a waste stream disposal, can also be evaluated. This can have a symbiotic impact for local businesses (WRF, 2019; 2021 RWP).

Operations and maintenance (O&M) costs for RO treatment are energy-intensive and therefore costly, but lost-cost renewable energy sources, such as solar, are potential options to mitigate this. Renewable energy sources can also reduce environmental impacts.

Unlike other AWS options, brackish water supplies are still groundwater supplies and therefore have some inherent subsidence risks. Proper design and implementation (locations, production rates, etc.) must be carefully considered to minimize these risks when developing brackish groundwater supplies and issuing permits. Section 3 has more details on the areas wherein brackish water supply is a potential option.

2.5 AQUIFER STORAGE AND RECOVERY

ASR is the storage of water through recharge into a groundwater formation during low demand time periods and recovery through extraction during high demand periods. Because the recharge water mixes with native groundwater, one typically needs to initially recharge approximately twice the project storage volume to ensure stability in terms of water quality since the mixing of recharge water and native groundwater can cause geochemical reactions. This combined volume is referred to as the target storage volume (TSV) and also as the "bubble" in the literature.

ASR has similar benefits to reservoirs or lakes by utilizing underground storage. Key elements of an ASR project include injection and extraction wells, pre- and post-recovery treatment, and transmission piping. In most ASR projects, recharge and production occur from the same well; however, some systems may use an aquifer storage transfer and recovery system (or hybrid system) and maintain separate injection and extraction wells. ASR is currently being used by three cities in Texas: San Antonio, Kerrville and El Paso.

Unlike most other AWSs, this option alone does not provide AWS yield, but rather is used conjunctively with other AWSs to provide storage and a potential shift in the temporal allocation of the water supplies. A key advantage of ASR is a transfer of supply from periods of surplus to periods of deficit, which increases resiliency during periods where adequate surface water may not be available.

Three ASR sub-options are considered herein: ASR with surface water, ASR with stormwater, and ASR with reclaimed water. The basic conceptual approach is shared across these sub-options, with the key differences being the source of the injected water and the associated treatment processes required prior to injection. A few specific considerations are discussed below.

ASR with Surface Water

Due to the relatively higher levels of turbidity/solids in surface water relative to groundwater, treatment would be required to remove particulates from surface water prior to injection to avoid clogging well screens and/or aquifer pore spaces. Consideration would also need to be given to surface water quality to ensure that detrimental impacts to the receiving aquifer (e.g., contamination or clogging of the pore space) as a result of mixing with the native groundwater are mitigated.

ASR with Stormwater

ASR injection using stormwater shares many of the same water quality concerns as with other surface water sources, but perhaps to an even greater degree. Stormwater commonly has high levels of suspended solids that would require settling or removal prior to injection. Stormwater may also be less preferable due to low alkalinity, elevated nutrient levels, and the potential of other contaminants, both natural and anthropogenic. One benefit of stormwater is that it can be captured and stored when water is more plentiful. However, this source is more transient and may require development or repurposing of stormwater storage since it may only be available during short time windows.

ASR with Reclaimed Water

Although reclaimed water meeting TCEQ criteria has relatively low solids content, additional treatment would likely be required prior to injection. Regardless, injection of reclaimed water into a freshwater aquifer increases the risk of contaminating the existing groundwater supply and would likely face strong permitting hurdles to demonstrate adequate control of the injected bubble. An advantage of reclaimed water is that it is a highly renewable, drought-proof source of water for ASR injection.

2.5.1 TECHNICAL CONSIDERATIONS

Recoverability of stored volume depends on factors such as operational details, aquifer stratification, native groundwater quality, regional groundwater flow patterns, and regulatory requirements (Smith et al., 2017; WRF, 2019). The additional constraint of being subsidence neutral will also impact an ASR project's recoverability (INTERA et al., 2019). It is essential to adequately characterize the hydraulic and water quality properties of the potential ASR project through data collection, scientific assessments, modeling, and pilot testing before implementing the project at scale. Because of the variety of hydrogeologic, geochemical, and mineralogic factors involved in ASR, projects are very site-specific and require careful analysis. These details are discussed further in Section 3.6.

2.5.2 BENEFITS

One of the most commonly referenced benefits is that ASR can provide a drought-resistant water supply when surface water supplies are limited, thus reducing risk from hydrologic variability. Since water is stored until required, this also allows for fuller utilization of surface water contracts. Another major benefit of this option is that it reduces water loss due to evaporation that can result from storing water in traditional above-ground reservoirs. ASR may also delay the need for additional treatment and distribution infrastructure required to meet peak summer demands (INTERA et al., 2019; WRF, 2019).

2.5.3 IMPLEMENTATION CHALLENGES AND MITIGATION STRATEGIES

Careful data collection, analysis, planning, and monitoring is needed to maintain ASR as a subsidence-neutral supply strategy. For example, a study completed in 2019 found that a summer peaking operational scheme resulted in less compaction over time than a drought of record operational scheme. An ASR facility designed for seasonal operations can likely supply water with less land subsidence than traditional groundwater production (INTERA et al., 2019).

2.6 WATER DEMAND MANAGEMENT

The HGSD and FBSD rules define water conservation as "a measure that seeks to make a water supply available for alternative or future use. The term includes best management practices (BMPs), improved efficiency or accountability, recycling, reuse, pollution prevention, and reduction in consumption, loss, or waste." While water conservation and demand management are not considered a potential AWS since neither option increases the overall AWS yield, water conservation and water demand management are two of the most important tactics for preserving water resources for future use. Thus, it was important for the discussion of AWSs to include these options.

Baseline or Passive Conservation

Water conservation is a strategy based on the management of water demands through policies, practices, and measures that contribute to quantifiable supply savings. However, some water demand reductions occur passively without the participation of a water provider in a demand management strategy. Innovation by plumbing and appliance manufacturers has increased the availability of high-efficiency washers, low-flow toilets, faucets, and shower-heads, smart irrigation systems, and other fixtures that use less water than their older counterparts. As communities age and the plumbing codes update to favor the new, water-efficient fixtures, home and business owners will replace their legacy fixtures; over time, the replacement of older fixtures and appliances and the continued innovation by the product manufacturers can generate a considerable reduction in water demand. The water demand reductions from baseline conservation are already being incorporated into water demand projections being developed as part of the larger 2023 JRPR efforts. Thus, while baseline conservation is anticipated to play an important role in long-term regional water demands, it was not considered as a shortlisted strategy in this study.

Basic Conservation

Water providers can increase their savings by actively encouraging water-saving behaviors in their customers through policies and education and incentive-based programs. The success of conservation programs relies on customer participation. Conservation efforts can be short- (emergency drought response) or long-term for future sustainability. Basic conservation, as defined herein, is incentive focused, while advanced conservation requires the implementation of ordinances for reducing water use (CDM Smith, 2019; 2021 RWP).

Basic conservation can involve offering rebates for adopting water-saving practices and technologies and education and outreach programs. One example, the WaterWise program, initiated by the Districts, distributes WaterWise kits to children in schools that contain items that will improve conservation practices in their homes all while educating children, and as a result, their families about the importance of water supplies. Other examples include rebate programs for adopting water-efficient appliances and free residential and non-residential irrigation system evaluations. Additional details on incentive-based water conservation programs and how they are being developed and applied in Harris, Galveston and Fort Bend counties are described in Sections 3 and 4.

Advanced Conservation

Advanced conservation practices include the implementation of ordinances that restrict water use for specific municipal water user groups or water-use categories. Outdoor water use is often a target of advanced conservation ordinances; common examples of these restrictions include twice-a-week watering schedules, ordinances prohibiting the waste of water, and landscape transformation ordinances encouraging the use of native and drought-tolerant plants (HGSD, 2020). Although adoption of watering restrictions is likely to vary considerably between water providers, it is anticipated to become a component of AWS portfolios for some entities.

Water Loss Control/Advanced Metering Infrastructure

Water loss can be classified in two types: real and apparent. Real water loss relates to leaks and unmetered water use. Apparent loss is typically due to meter and billing inaccuracies. The issue of water loss is not always prioritized due to the lack of proper audits and precise quantification of social and economic impacts that result from it. However, it remains a pressing issue that can be tackled regardless of the water supply and demand since all water utilities experience some form of loss. The simplest form of accounting for water losses is to perform a water audit. Controlling real water losses can require a strategic plan for detecting leaks, rapid response to the leaks, pressure management, and pipeline and asset management selection, installation, maintenance, and replacement (CDM Smith, 2019; WRF, 2019).

Advanced metering infrastructure (AMI) is an integrated system of customer water meters, communication networks, and data management systems that provides real time water use information to the water utility and its residents. In this way, it couples well with water loss control measures by improving efficiency and helping conserve water. There are three main components to AMI: systems that measure, systems that collect and communicate the measured data, and systems that analyze the data. AMI technology can connect every part of a water utility and use the resulting data to optimize operations, administration, and infrastructure (McHenry, 2013; CDM Smith, 2019).

2.6.1 TECHNICAL CONSIDERATIONS

Conservation benefits are gradual and become recognizable only in the long term, however, they can have significant yields. Conservation is also a continuous process, as opposed to a one-time infrastructure investment. Once goals that are more “low-hanging” are achieved, strategies can be re-evaluated and adapted to the changing scenario. Incentive programs may require a larger investment over time to see additional water savings benefits.

Participation is critical to the success of a conservation program. Thus, marketing and outreach are crucial for a basic conservation program. Advanced conservation ordinances require an administrative investment for program oversight and management (CDM Smith, 2019; WRF, 2019; 2021 RWP).

When assessing the potential fit for AMI, rigorous and comprehensive evaluation must be done to determine design capacity of equipment, costs, and benefits. To realize the full-potential of water loss savings from AMI, utilities would need to create district metered areas (DMAs). DMAs are discrete zones of 1,000 to 3,000 customer connections that have a separate master meter for the entire DMA service area (McHenry, 2013).

2.6.2 BENEFITS

A major strength of water demand management strategies is that they extend the existing water supplies, thereby delaying and/or reducing the need for additional supplies. Most conservation strategies do not require the construction of new infrastructure, but rather rely on changes to consumer demands, either through passive efficiency gains, incentive-based programs, or usage restrictions. There are also many opportunities for cost savings to be realized through reduction of operations costs for water and wastewater pumping (WRF, 2019).

AMI offers multiple benefits including: more informed customers who adjust usage behaviors based upon the data, a more informed utility to make data-driven decisions, and improved main break response time. Implementation of AMI reduces water losses in the distribution system, unauthorized consumption, data transfer/archive errors, data billing errors, and customer-side leaks by identifying uncharacteristic water use. What used to be a tedious, manual process that could allow a leak go undetected for up to years, now make it possible for a whole distribution network to be monitored at hourly intervals (McHenry, 2013).

2.6.3 IMPLEMENTATION CHALLENGES AND MITIGATION STRATEGIES

Since the success of conservation programs is dependent on customer participation, there is a potential risk of customer participation shortfalls. Mitigation of this risk requires investment in outreach to water users up front. Further some users may actively oppose the more restrictive advance conservation measures. Without a continual commitment to outreach or enforcement, the water-savings from conservation measures can decay over time.

Another potential challenge is the reduced revenue as a result of effective water conservation. This challenge is especially acute in areas that have recently invested in infrastructure to meet increased water demands and/or AWS conversion requirements. One approach to demand management is the creation of a block rate structure that involves a higher rate for water consumed above a set amount (WRF, 2019).

AMI can be technically ambitious. The selection of certain types of technologies poses their own risks and consumers may or may not receive the full benefit of AMI investments. Because of this, thorough investigation and cost-benefit analysis into the technological specifics of the AMI being considered is necessary (McHenry, 2013).

2.7 OTHER AWS APPROACHES

Although Sections 2.1 through 2.5 provide a reasonably comprehensive overview of the AWS options that are expected to account for the majority of providers' AWS portfolios in coming decades, it is recognized that this discussion is not exhaustive and that some water providers may implement and/or benefit from approaches or technologies beyond those listed in this report.

One novel approach being considered is the withdrawal of groundwater from the Carrizo – Wilcox aquifer beneath more inland counties and using bed and banks permits to convey this water to utilities and industries in HGSD and/or FBSD regulatory areas through public watercourses (e.g., the Brazos River).

Another novel approach being considered by systems in arid and semi-arid regions of the country (e.g., the Mountain West and Southwestern United States, including west Texas) include rainwater harvesting and onsite graywater reuse. Rainwater harvesting is a form of onsite reuse wherein rainwater that falls upon roof surface(s) is collected, stored and used for non-potable applications such as irrigation of green spaces. This is typically accomplished on an individual facility or building basis. Graywater includes water from bathroom sinks, showers and bathtubs and clothes washers that is collected, filtered and used for non-potable purposes.

A few small systems in Harris and Fort Bend counties have been using amenity lakes and detention ponds to store stormwater and using the stored water to irrigate greenspaces. Water that is being pumped for reuse is metered and documented as an AWS. Stormwater capture and reuse is a unique AWS that can be adopted at a smaller scale in the future.

These and other innovative AWS approaches may form components of future water supply portfolios for some municipal and industrial water providers. However, as discussed in Section 2.8, this study sought to catalogue the most broadly applicable AWS options for the districts' regulatory areas.

2.8 AWS OPTIONS SHORTLISTING

More than 20 AWS options/sub-options have been identified and evaluated at a desktop level. The options that were identified included new water supplies (NW), storage solutions (SS), reclaimed water suppliers (RS) and demand management (DM) strategies as shown in **Figure 2-1**. A summary of these options, their technical considerations, implementation challenges, mitigation strategies and benefits are in **Table 2-2**.

Figure 2-1. Alternative Water Supply Options Identified

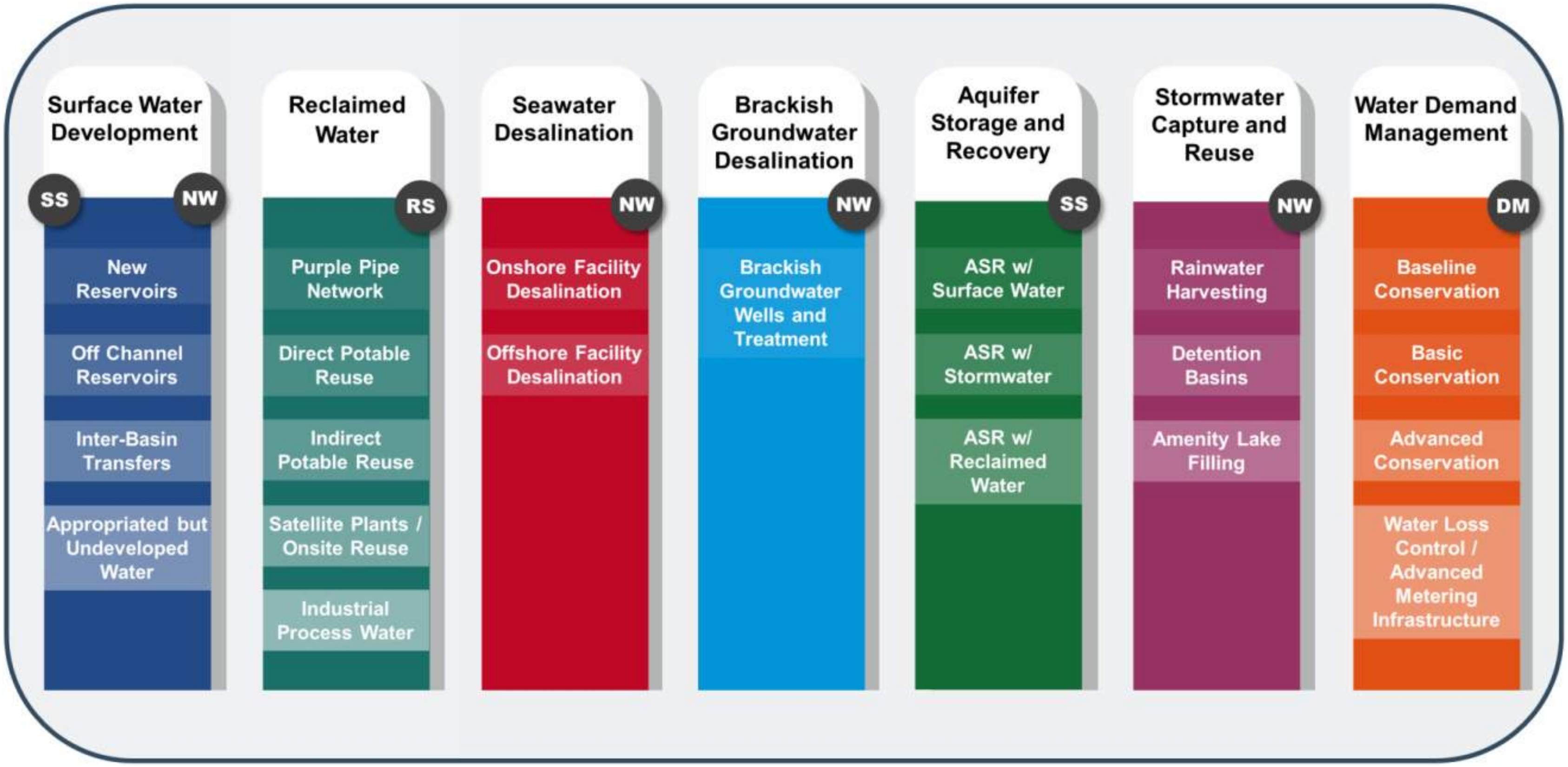

Table 2-2. Summary of Identified Alternative Water Supply Options

AWS Options	Sub-Options	Technical Considerations	Implementation Challenges	Mitigation Strategies	Benefits	Included in Detailed Characterization?
Surface Water Development	New Reservoirs	• Location of new reservoirs to capture and store natural streamflow • Securing land and easements for construction • Extensive planning and capital investment • Permitting	• Numerous permits and reviews from many agencies • Significant environmental risks • Susceptible to impacts from drought and climate change	• Careful planning • Environmental impact assessment and mitigation projects for restoration, enhancement, etc. • Strategic operation of surface water facilities	• Cost effective due to high supply	✓
	Off Channel Reservoirs	• Location of off channel reservoirs to capture and store natural streamflow • Securing land and easements for construction • Extensive planning and capital investment • Permitting	• Numerous permits and reviews from many agencies • Significant environmental risks • Susceptible to impacts from drought and climate change	• Careful planning • Environmental impact assessment and mitigation projects for restoration, enhancement, etc. • Strategic operation of surface water facilities	• Cost effective due to high supply	✓
	Inter-Basin Transfers	• Securing land and easements for construction of pipelines • Extensive planning and capital investment • Permitting	• Numerous permits and reviews from many agencies • Significant environmental risks • Susceptible to impacts from drought and climate change • Capital costs for increasing conveyance distances	• Careful planning • Environmental impact assessment and mitigation projects for restoration, enhancement, etc. • Strategic operation of surface water facilities • Intensive infrastructure	• Cost effective due to high supply	✓
	Appropriated but Undeveloped Water	• Extensive planning and capital investment • Permitting	• Numerous permits and reviews from many agencies • Significant environmental risks • Susceptible to impacts from drought and climate change	• Careful planning • Environmental impact assessment and mitigation projects for restoration, enhancement, etc. • Strategic operation of surface water facilities	• Cost effective due to high supply	✓

AWS Options	Sub-Options	Technical Considerations	Implementation Challenges	Mitigation Strategies	Benefits	Included in Detailed Characterization?
Seawater Desalination	Onshore Desalination	• Water demands study for project feasibility	• Treatments and extensive pumping is energy and cost intensive • RO Brine discharge • Potential underutilization of infrastructure due to shifts in demand	• Using renewable energy source for power supply • Significant development of more efficient RO membranes. • Diluting the brine or using discharge pipes with diffusers • Implementing desalination at a smaller scale	• Unlimited supply • Drought Resistant • No impacts to subsidence	✓
	Offshore (or Platform) Desalination	• Water demand study for project feasibility	• Treatments and extensive pumping is energy and cost intensive • RO Brine discharge • Potential underutilization of infrastructure due to shifts in demand	• Using renewable energy source for power supply • Significant development of more efficient RO membranes. • Diluting the brine or using discharge pipes with diffusers • Implementing desalination at a smaller scale	• Unlimited supply • Drought Resistant • No impacts to subsidence	✓
Reclaimed Water	Centralized – Purple Pipe Network	• Land Use • Water demand study for project feasibility • Requires the construction of a separate, dedicated distribution system • Permitting	• Shifts in demands and water use efficiencies • Implementing new infrastructure for wastewater collection and pumping • Public perception and potential push back	• Scenario based planning processes and demand-side management • Encouraging new construction to include dual pumping in recycled water • Conduct early outreach and community engagement	• Drought Resistant • No impact to subsidence	✓
	Centralized – Direct Potable Reuse	• Land Use • Water demand study for project feasibility • Requires the construction of a separate, dedicated distribution system • Permitting	• Disposal of concentrate from DPR • Public perception and potential push back	• Consider Innovative advanced treatment solutions • Conduct early outreach and community engagement	• Drought Resistant • No impact to subsidence	✓

AWS Options	Sub-Options	Technical Considerations	Implementation Challenges	Mitigation Strategies	Benefits	Included in Detailed Characterization?
	Centralized – Indirect Potable Reuse	• Land Use • Water demand study for project feasibility • Requires construction of a separate, dedicated distribution system • Permitting	• Disposal of concentrate from IPR • Public perception and potential push back	• Innovative advanced treatment solutions • Conduct early outreach and community engagement	• Drought Resistant • No impact to subsidence	✓
	Decentralized – Satellite Plants/Onsite Reuse	• Land Use • Water demand study for project feasibility • Establishing purchase agreements • Permitting	• Implementing new infrastructure for wastewater collection and pumping • Public perception and potential push back	• Encouraging new construction to include dual pumping in recycled water • Conduct early outreach and community engagement r	• Drought Resistant • No impact to groundwater subsidence • Reduce flows into municipal collection systems	✓
Brackish Groundwater Desalination	Brackish Groundwater Wells and Treatment	• Possible Subsidence consequences when establishing and utilizing source • Permit issuance	• Potential occurrence of co-contaminants • Disposal of RO Brine • Inherent subsidence risks	• Additional pre-treatment processes would be necessary • Utilizing alternate techniques such as deep-well injection, evaporation ponds, etc. • Consider proper design, location, and production rates of the wells	• Drought Resistant • Reliable local supply of potable water • Lower treatment costs and potential shorter conveyance distances	✓
Aquifer Storage and Recovery (ASR)	ASR with Surface Water	• Aquifer stratification • Native groundwater quality • Regional groundwater flow patterns • Regulatory requirements	• Subsidence can possibly occur • Higher levels of turbidity/ solids in surface water	• Careful data collection, analysis, and planning • Treatment required to remove particulates prior to injection	• Drought Resistant • Reduces risk from hydrologic variability • Reduces water loss due to evaporation	✓
	ASR with Stormwater	• Aquifer stratification • Native groundwater quality • Regional groundwater flow patterns • Regulatory requirements	• Subsidence can possibly occur • Greater degree of water quality concerns (high levels of suspended solids) • More transient and less predictable	• Careful data collection, analysis, and planning	• Can be captured and stored when water is more plentiful	×
	ASR with Reclaimed Water	• Aquifer stratification • Native groundwater quality • Regional groundwater flow patterns • Regulatory requirements	• Subsidence can possibly occur • Risks of contamination • Permitting hurdles	• Careful data collection, analysis, and planning • Additional treatment likely needed prior to injection	• Drought Resistant	×

AWS Options	Sub-Options	Technical Considerations	Implementation Challenges	Mitigation Strategies	Benefits	Included in Detailed Characterization?
Water Demand Management	Baseline Conservation	• Conservation benefits are recognizable in the long term	• Aging communities and plumbing code updates	• Replacement of older fixtures and appliances	• Extend existing water supplies • Does not require construction of new infrastructure	×
	Basic Conservation	• Conservation benefits are recognizable in the long term • Marketing and outreach	• Customer participation shortfalls • Potential reduced revenue as a result of effective water conservation	• Investment in outreach to water users • Creation and utilization of a block rate structure	• Extend existing water supplies • Does not require construction of new infrastructure	✓
	Advanced Conservation	• Conservation benefits are recognizable in the long term • Administrative investment for program oversight and management	• Users may actively oppose restrictive advanced conservation measures • Potential reduced revenue as a result of effective water conservation	• Continual commitment to outreach or enforcement • Creation and utilization of a block rate structure	• Extend existing water supplies • Does not require construction of new infrastructure	✓
	Water Loss Control/Advanced Metering Infrastructure	• Conservation benefits are recognizable in the long term • Marketing and outreach • Comprehensive evaluation and creating of district meter areas (DMAs)	• Potential reduced revenue as a result of effective water conservation • Types of technologies have risks and customers may not receive the full benefit of AMI investments	• Creation and utilization of a block rate structure • Conduct thorough investigation and cost-benefit analysis of the technology	• Extend existing water supplies • Does not require construction of new infrastructure • More informed customers and utility providers	×

Based on a review of prior studies and available information, as well as input from HGSD and FBSD, several AWS sub-options were shortlisted for further evaluation. The winnowing and aggregation of AWS sub-options was based on a wide variety of considerations, as shown in **Figure 2-2**, including broad applicability, technical feasibility based on best available technology, expected supply availability, ability to supply areas where surface water may not be available, logical progression of implementation (i.e., "low-hanging fruit" options), climate variability resilience, anticipated source and treated water qualities, end user requirements, among other factors. In several cases, the shortlisted AWS options comprise multiple sub-options where the sub-options were sufficiently similar for detailed characterization. The shortlisted AWS options are presented in **Figure 2-3**. Detailed characterization of these options is provided in Section 3.

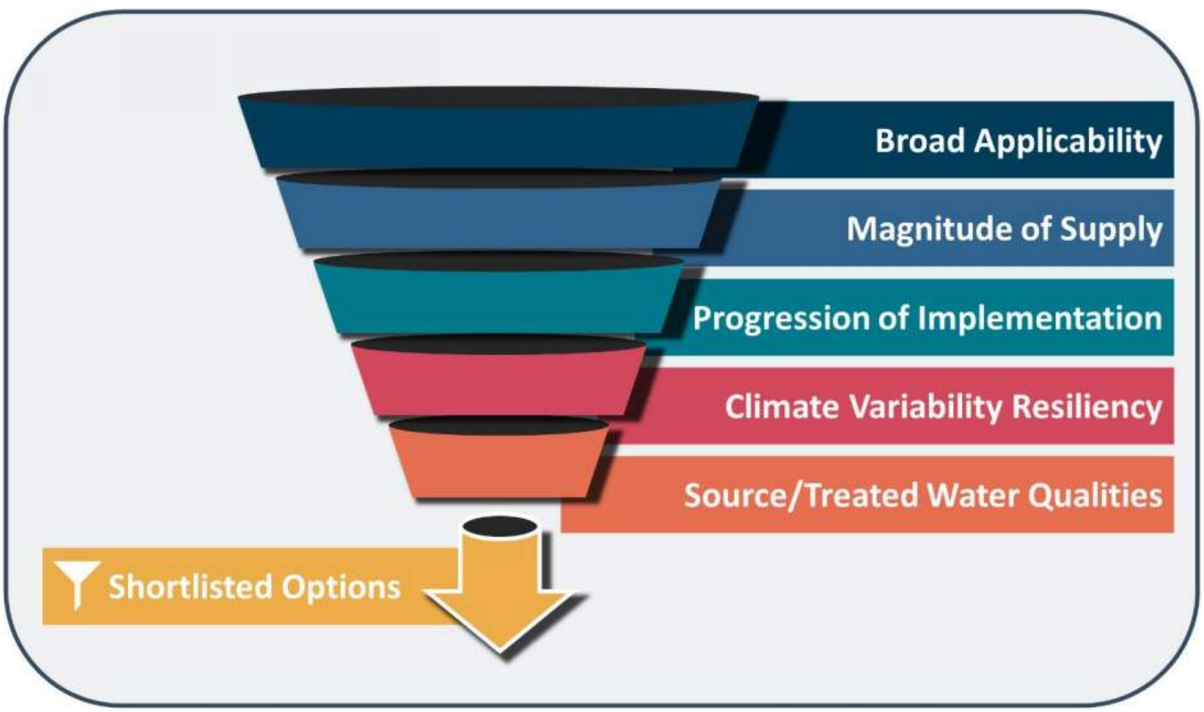

Figure 2-2. Alternative Water Supply Shortlisting Approach

Figure 2-3. Shortlisted Alternative Water Supply Options

SECTION 3 – CHARACTERIZATION OF SELECTED AWS OPTIONS

Following a review of the potential AWS identified in Section 2, KIT shortlisted seven AWS Sub-Options for more detailed characterization, including surface water development, demand management, brackish groundwater desalination, onshore seawater desalination, centralized and decentralized reclaimed water treatment and ASR with surface water. Characterization of the aforementioned AWS options will include the following information:

- Narrative descriptions of the sub-options, implementation approach and cost estimate basis
- Regulatory area(s) served
- Anticipated users
- Water quality considerations
- Estimated magnitude of supplies
- Budgetary/planning level cost estimate ranges, including capital costs, operation and maintenance costs, and life cycle costs on a volumetric (e.g., per thousand gallon) basis
- Implementation timelines
- Permitting and legal considerations
- Vulnerability to climate change
- Subsidence impacts

3.1 SURFACE WATER DEVELOPMENT

Given that all surface water development sub-options were considered viable, these sub-options were aggregated into a broader “surface water development” option comprising new and/or off-channel reservoirs, inter-basin transfers, and appropriated but undeveloped water. Surface water supplies have historically been the preferred AWSs within the HGSD and FBSD regulatory areas, and it is expected that they will continue to play a major role in the AWS portfolio moving forward. Although the availability of undeveloped surface water rights is rapidly diminishing, it was considered sensible to retain all of these sub-options, as surface water supplies are likely to remain the preferred AWS for many providers in both the near- and long-term horizons.

3.1.1 IMPLEMENTATION APPROACH

The utilization of surface water sources will require a combination of steps displayed in **Figure 3-1**. Supplies can take the form of running rivers and streams or impounded water from lakes and reservoirs. An intake structure pumps raw water through conveyance infrastructure to a surface WTP where it is treated for potable water uses. Treated water is then stored and distributed through the potable water distribution system.

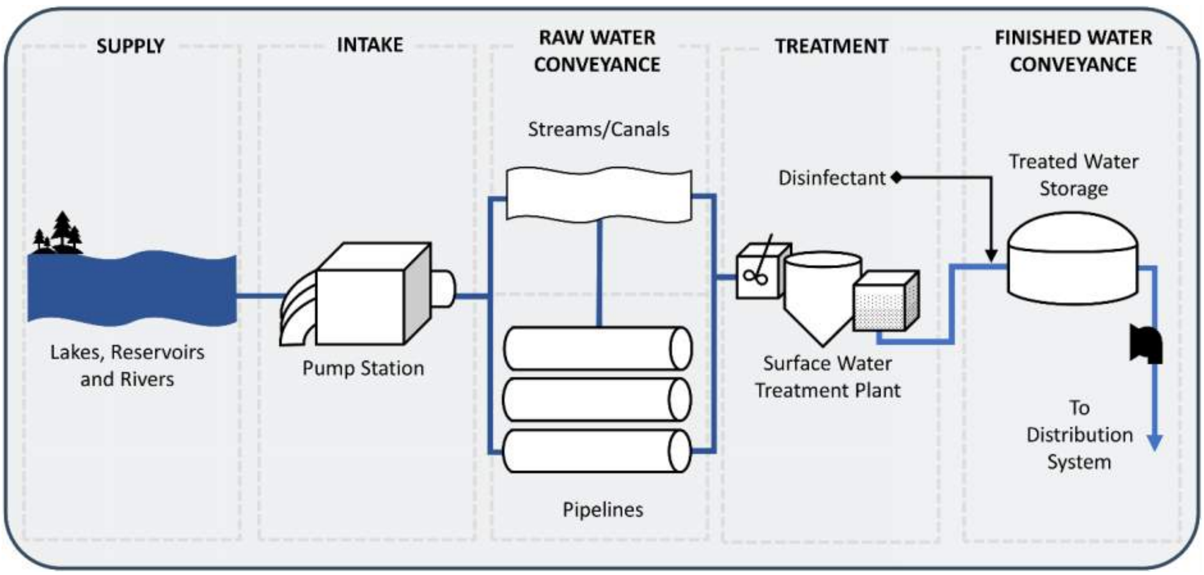

Figure 3-1. Process Flow Diagram for Surface Water Development

The sub-options of surface water sources for HGSD/FBSD regulatory areas can evolve from the three major potential sources: the Allens Creek Reservoir, the East Texas Transfer, and undeveloped but appropriated water from the Trinity River, San Jacinto River, Brazos River, and coastal basins.

The majority of the Districts' regulatory areas lie within the Brazos and San Jacinto River basins. HGSD Area 1 mostly lies within San Jacinto-Brazos basin, and Trinity-San Jacinto and Brazos-Colorado also cover smaller areas of FBSD and HGSD areas (**Figure 3-2**).

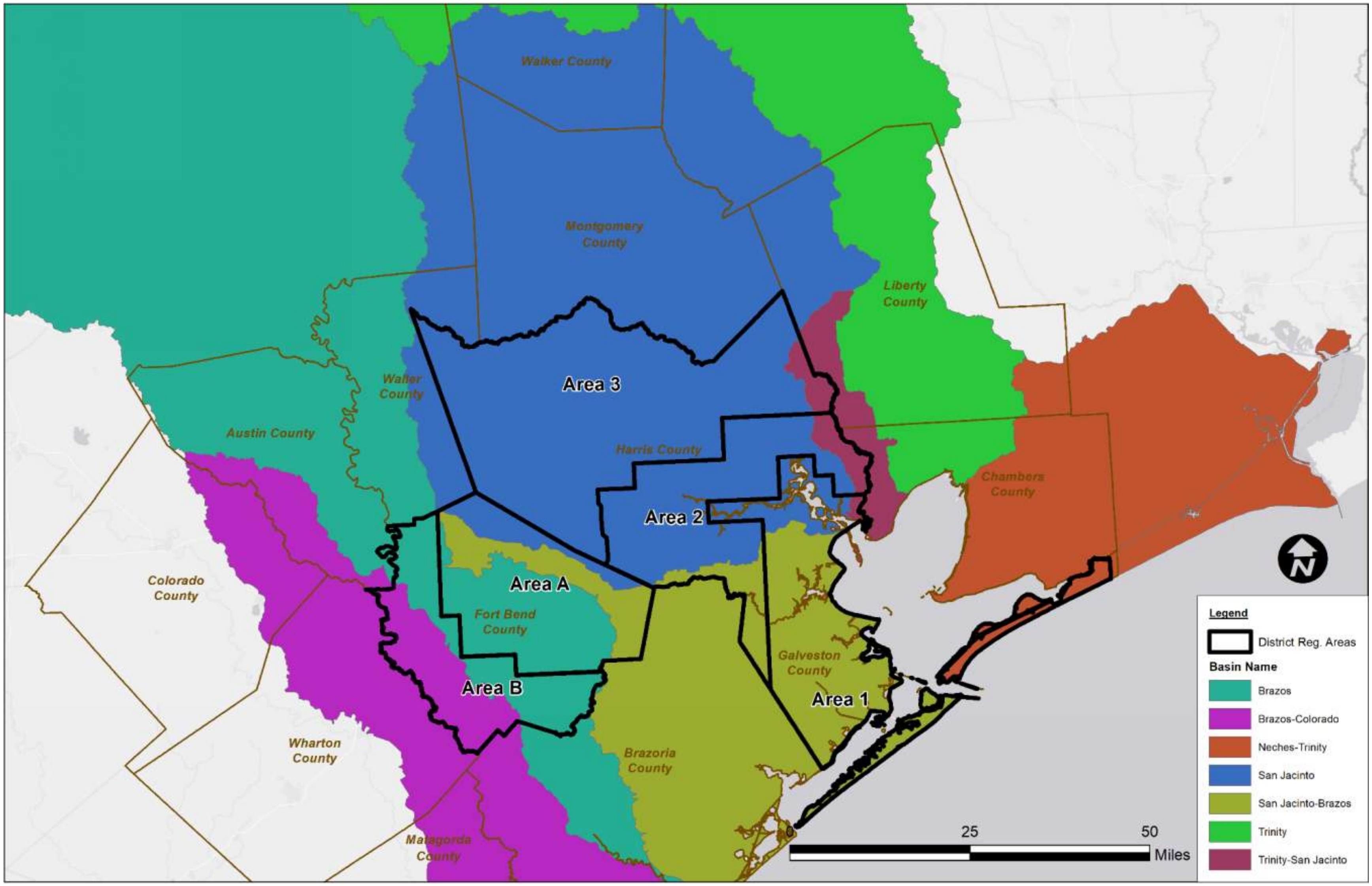

Figure 3-2. HGSD and FBSD Regulatory Areas, Counties, and River Basins

The Allens Creek Reservoir is an off-channel reservoir on Allens Creek, a tributary of the Brazos River. **Figure 3-3** shows the location of the proposed reservoir.

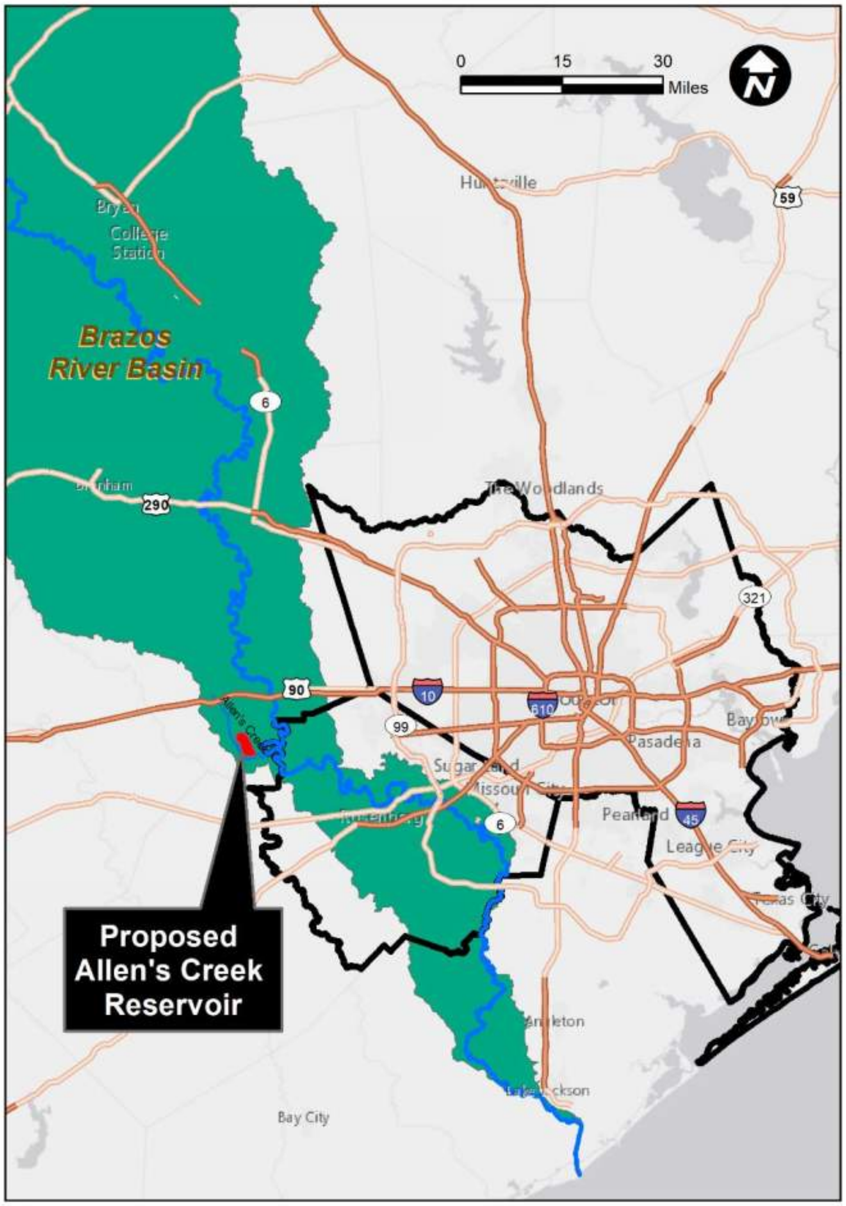

Figure 3-3. The Location of the Proposed Allens Creek Reservoir within the Brazos River Basin

The site was jointly purchased by BRA and City of Houston. The current permit grants the construction of most likely one, if not two, pump stations to divert storage flows from the main stem of the Brazos River to the newly built reservoir. The construction of the dam to form the reservoir will remove a significant amount of the Brazos River floodplain from flood storage. In order to offset this loss, there will likely be required flood storage capacity established in the project vicinity (2021 RWP).

The East Texas Transfer involves conveyance of water from Neches and Sabine River Basins to the Trinity and ultimately to the Brazos River Basins. This involves a network of intakes, canals, pipelines, and transfer pump stations that will convey water from eastern basins to the west. **Figure 3-4** shows the movement of water in this series of transfers across basins. As shown by letter **A**, water from the Sabine River Basin/Toledo Bend Reservoir will be transferred to the Neches River Basin. Letter **B** shows the flow of water from the Neches River Basin to the Trinity River Basin, and letter **C** shows conveyance of water from the Trinity River Basin to the Brazos River Basin. Note that Figure 3-4 is a generalized depiction of the transfer and not reflective of the actual route of the water's movement across the basins. The East Texas Transfer of water will require significant infrastructure to accomplish as well as coordination across large water rights holders in order to make the exchanges.

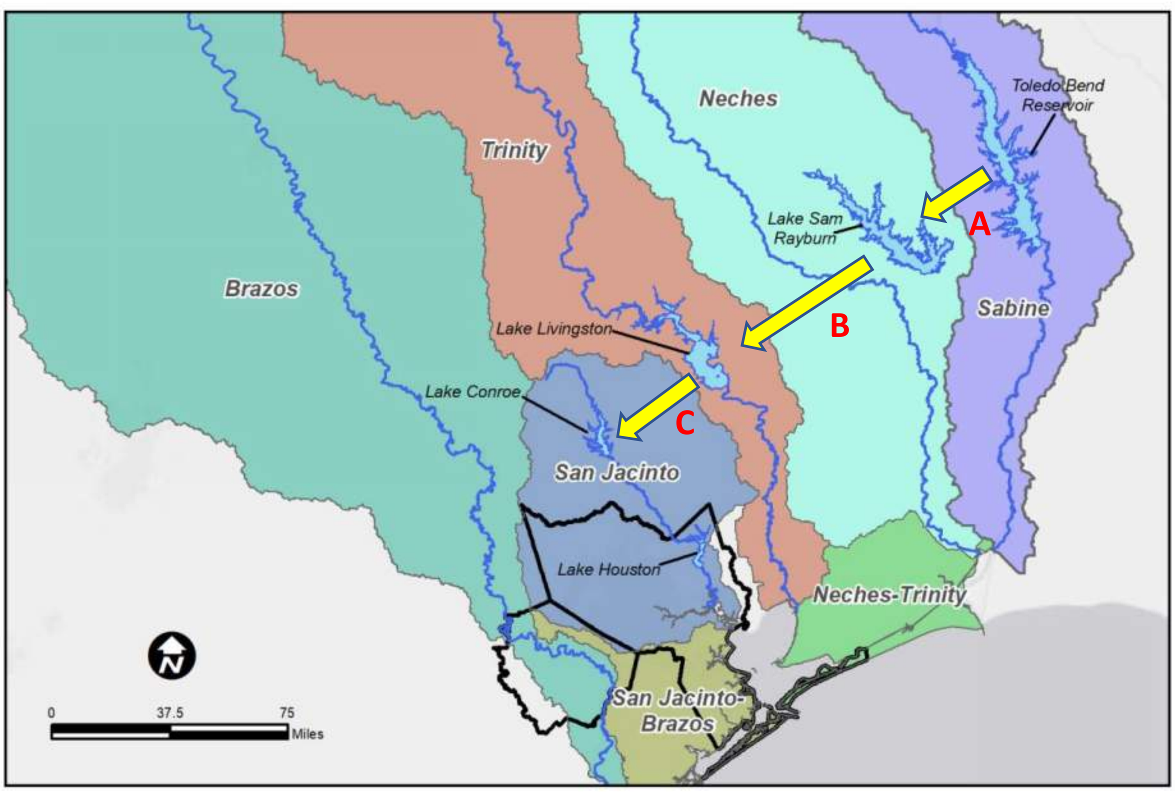

Figure 3-4. The Transfer of Water Across River Basins for the Proposed East Texas Transfer

Appropriated but undeveloped surface water is described as available surface water acquired by a water user through permitting but is yet to be developed. This can occur due to various reasons, such as lack of demands by the water user group or insufficient capacity through infrastructure. This surface water sub-option will assist with meeting the region's future AWS supply needs and water demands if developed by the water users.

3.1.2 REGULATORY AREA(S) SERVED

HGSD Areas 1 and 2 are already established to require ninety and eighty percent conversion to alternative water requirements, respectively. Those with GRPs in HGSD's Area 3 will be required to operate at eighty percent alternative water utilization starting in 2035. Undeveloped but appropriated water rights from the BRA Permit can serve Area 1 specifically through GCWA. Supplies from the East Texas Transfer and City of Houston's appropriated but undeveloped surface water rights can potentially be used throughout HGSD, however, conveyance infrastructure can be a limiting factor. Future studies will have to revisit the possibility of serving more areas through the expansion or installation of infrastructure, such as canals and pipelines. Allens Creek Reservoir water will be available to City of Houston and BRA, and can be utilized to meet the future municipal and industrial demands in HGSD and FBSD regulatory areas.

Figure 3-5 shows the areas served by the water providers within the HGSD boundary. Much of Harris County is served by the City of Houston and large regional water authorities. Other parts of Harris County and the majority of Galveston County have municipalities functioning as public water suppliers, such as the City of Pasadena, City of Texas City, and City of League City. Although not shown in Figure 3-5, the Gulf Coast Water Authority is a major regional provider of raw and treated surface water for both municipal and industrial use for numerous entities within the HGSD regulatory area.

Figure 3-6 shows the areas served by water providers within FBSD. As can be seen on the map, the large majority of areas served are located in Area A of the District with most of Area B and portions of Area A being undeveloped. The North Fort Bend Water Authority is a major regional water authority within the District and County, and other water authorities, municipalities, MUDs, and water control and improvement districts (WCIDs) provide raw and/or treated surface water to other developed areas. Within both maps for HGSD and FBSD, other smaller entities that serve as public water systems such as small municipalities (i.e., City of Bellaire), MUDs, and WCIDs are shown in gray. Extra-territorial jurisdiction (ETJ) systems that are within a labeled provider's GRP are colored as such and included with the rest of that provider.

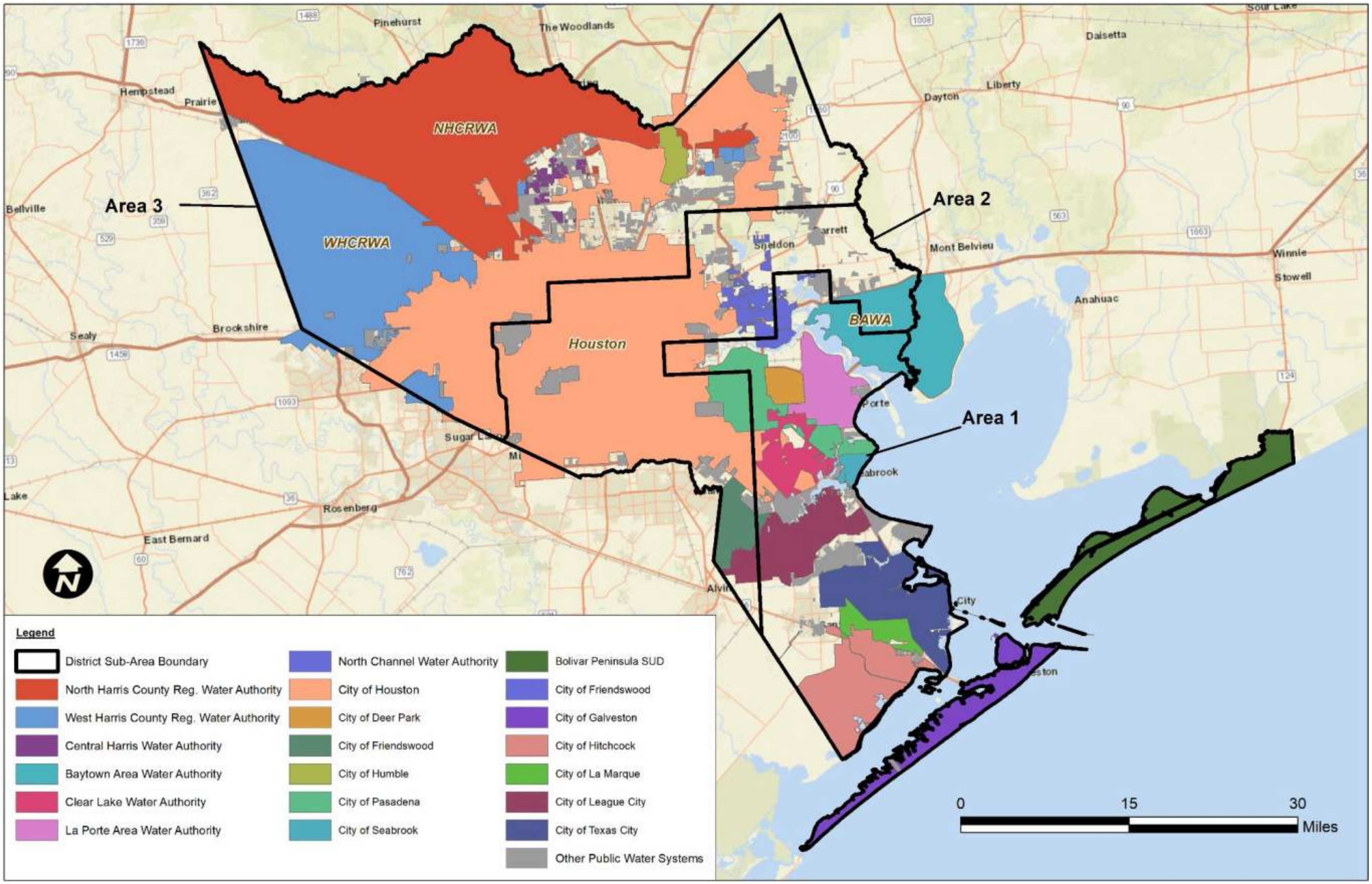

Figure 3-5. Major Water Providers in HGSD

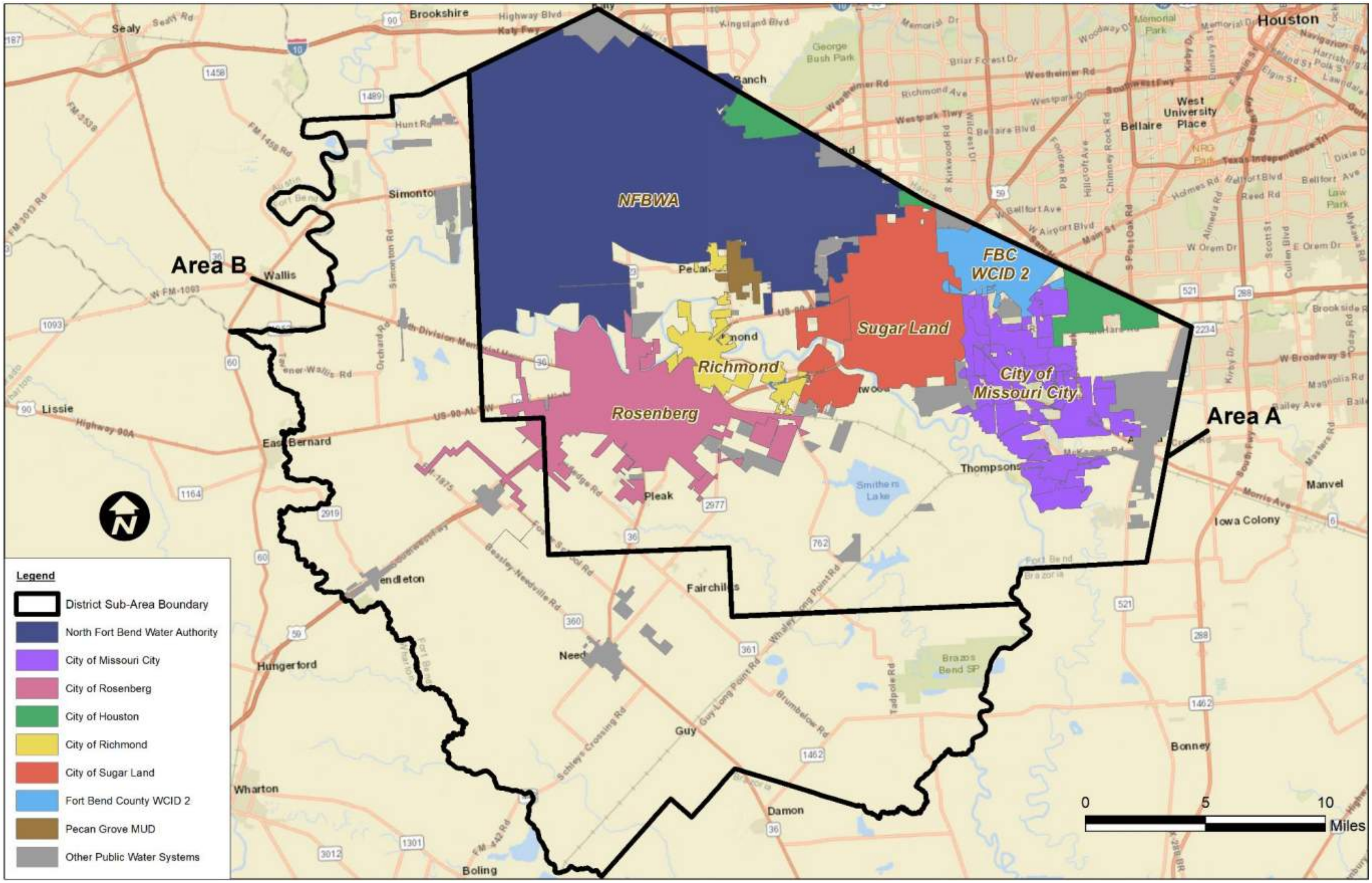

Figure 3-6. Major Water Providers in FBSD

3.1.3 ANTICIPATED USERS

Water obtained from the Allens Creek Reservoir can be utilized for municipal, industrial, irrigation, and some recreational uses (2021 RWP). The East Texas Transfer and development of appropriated water can be utilized for municipal, industrial, and irrigation purposes (2021 RWP, 2021 Brazos G RWP).

3.1.4 MAGNITUDE OF SUPPLIES

The Allens Creek Reservoir has an estimated firm yield of 99,650 acre-feet per year (AFY), or 89 MGD. Additional yields may be available through combined operations with other reservoirs. **Table 3-1** shows a summary of major existing and planned water supply reservoirs in the region and their associated storage and diversion rights. The conservation capacity refers to the maximum amount of water a reservoir is designed and authorized to hold under normal operations.

Table 3-1. Major Future and Existing Reservoirs

	Permitted Annual Diversion Volume (MGD)	Permitted Storage Capacity (MG)	Conservation Capacity (MG))
Lake Livingston	1,199	588,585	583,831
Lake Houston	175	52,136	40,621
Lake Conroe	89	140,201	133,932
Allens Creek Reservoir	89	47,419	47,411

Figure 3-7 shows a graphical representation of the reservoirs' locations and permitted storage capacities. The Allens Creek Reservoir will yield an equivalent diversion volume to that of Lake Conroe; however, its storage capacity is close to that of Lake Houston.

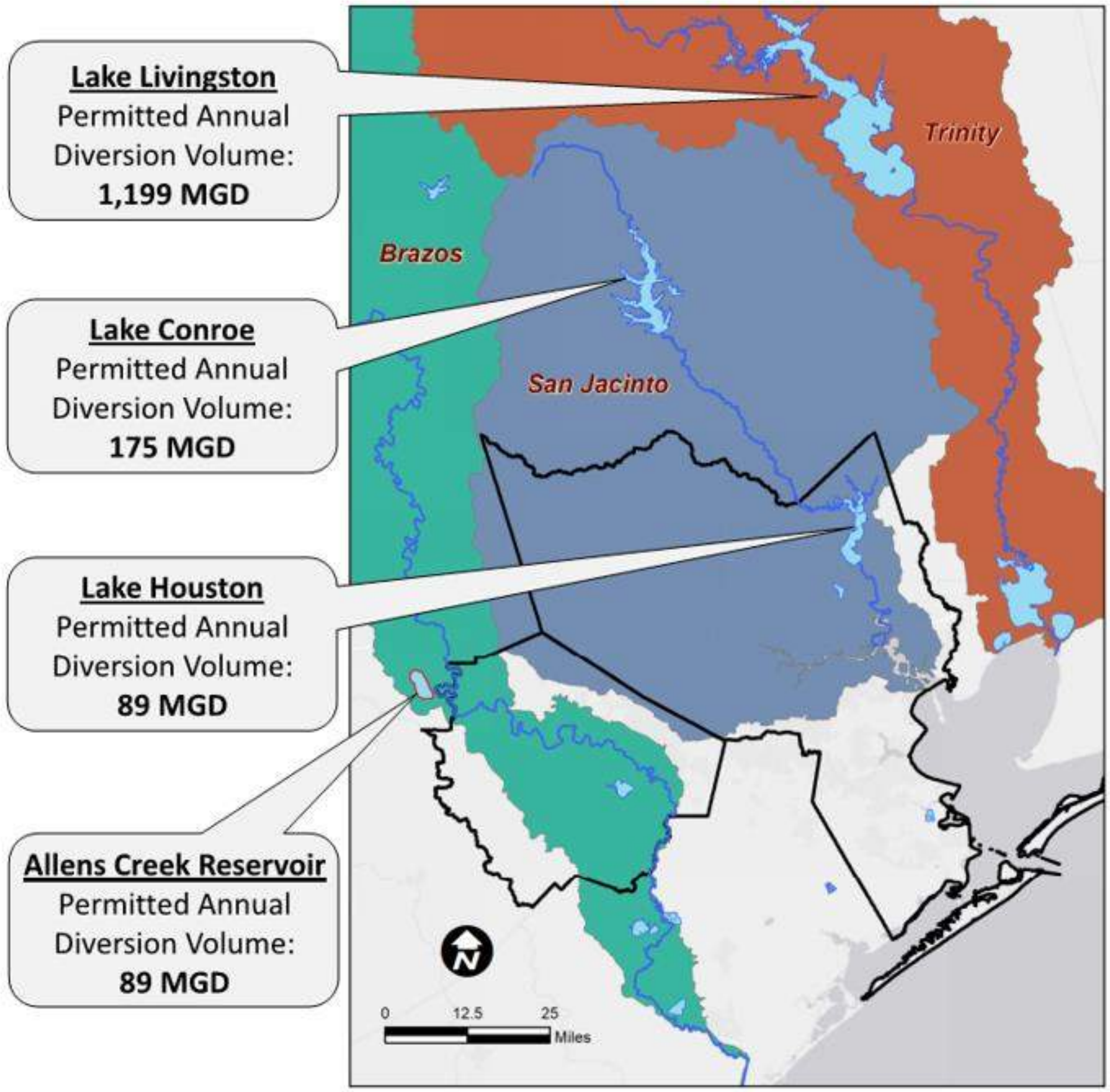

Figure 3-7. Major Future and Existing Reservoirs

According to the 2021 RWP, the East Texas Transfer has an anticipated maximum yield of 250,000 AFY, or 223 MGD. However, this supply's magnitude could be higher or lower than the anticipated maximum depending on a number of factors, including alternative water demands, availability of water rights, and the timing of project implementation.

Table 3-2 shows the major run-of-river water rights held in the four relevant basins for HGSD and FBSD regulatory areas. The largest water rights holders for each basin are typically either large, regional water providers or commercial customers that treat and apply water for industrial purposes.

Table 3-2. Run-of-River Rights in Brazos, San Jacinto, Trinity, and San Jacinto-Brazos River Basins

River Basin	Water Rights Owner	County	Permitted Annual Diversion Volume (MGD)
Brazos	Gulf Coast Water Authority (GCWA)	Fort Bend	339
	Dow Chemical Company	Brazoria	273
	NRG Texas Power LLC	Fort Bend	61
	Brazosport Water Authority (BWA)	Brazoria	40
	Fort Bend County, other		4
	Brazoria County, other		3
San Jacinto	City of Houston	Harris	116
	San Jacinto River Authority (SJRA)	Harris	49
	Harris County, other		5
	Montgomery County, other		1
Trinity	Chambers-Liberty Co Navigation District	Chambers	101
	SJRA	Chambers, Liberty	77
	City of Houston	Polk, Liberty	74
	Liberty, Walker, Madison, Leon, Trinity Counties, other		6
San Jacinto-Brazos	GCWA	Brazoria	51
	City of Sugar Land	Fort Bend	16
	Tigner Irrigation Company	Brazoria	6
	The Randolph Co. et. al.	Brazoria	4
	Brazoria County, other		23
	Fort Bend, Harris, Galveston Counties, other		2

The City of Houston is a top holder for water rights particularly in the San Jacinto and Trinity River Basins. According to 2021 RWP, the City of Houston currently has a combined total of 1.2 billion gallons per day (BGD) of water rights from surface water sources. **Table 3-3** shows the current production capacities of each existing City of Houston surface water treatment facility, which in combination represent the total amount of water that the City is theoretically capable of producing. Currently, the three surface Water Purification Plants (WPPs) of the City of Houston have an estimated combined production capacity of approximately 630 MGD. This still leaves between 400 and 500 MGD of appropriated but undeveloped surface water rights with the City of Houston. With the ongoing expansion of the Northeast WPP, as well as potential for expansion other WPPs and building of new WPPs in the future, the possibility of treating and distributing even more of these undeveloped supplies is much greater in the near and long-term future. Presented in **Table 3-3** is the total potential ultimate production capacity for the City of Houston's WPPs. This shows that full utilization of all 1.2 BGD of surface water rights may eventually be possible in the long term.

Table 3-3. City of Houston Water Purification Plants Present and Future Production Capacities

	Current Production Capacity (MGD)	Current + Planned Capacity (MGD)	Potential Ultimate Capacity (MGD)
East WPP	350	350	450
Southeast WPP	200	200	300
Northeast WPP	80	400	560
Total	**630**	**950**	**1,310**

In 2016, the TCEQ approved a System Operations permit (Permit No. 12-5851) that granted new water rights to the BRA to distribute through long-term supply contracts. This permit was unique in that the new water was modeled through efficient operations of existing reservoirs in the Brazos River Basin in conjunction with downstream river flows and also accounted for wastewater return flows. Considering these new factors as well as constraints from existing intake and treatment plant capacities, Water Availability Models (WAM) determined that additional supplies could be made available to water users. The BRA determined that through this permit, a total of 106,031 AFY (95 MGD) of diversions could be made firm under the Permit. The BRA has allocated portions of this available water, and according to the Brazos G 2021 RWP, plans to provide 78,276 AFY (70 MGD) of additional supplies to users in Region H including the Districts' regulatory customers. **Table 3-4** shows the firm water supplies that will be made available to HGSD/FBSD customers from the Permit.

Table 3-4. Supplies from BRA System Operations to HGSD/FBSD Regulatory Areas

Customer	Diversion County	Region	Use Type	Volume (MGD)
GCWA	Fort Bend	H	MUN, IND, IRR	32
City of Sugar Land	Fort Bend	H	MUN	9
Marathon Galveston Bay Refinery	Fort Bend	H	IND	5
City of Richmond	Fort Bend	H	MUN	2
			HGSD/FBSD Areas Total	**49**

Of the 70 MGD allocated to Region H from this permit, water users in HGSD and FBSD are set to acquire 49 MGD. The largest portion of this will be allocated to GCWA, a major water provider for customers in both Fort Bend and Galveston Counties.

This amount, combined with the estimated 400-500 MGD of undeveloped surface water supplies from City of Houston, results in an estimated 400-549 MGD of surface water rights that can be potentially developed in the Districts' regulatory areas. **Figure 3-8** shows a graphical representation of the total magnitude of surface water supplies from all potential sub-options for surface water supplies, which can potentially exceed 700 MGD due to further incorporation of appropriated water rights.

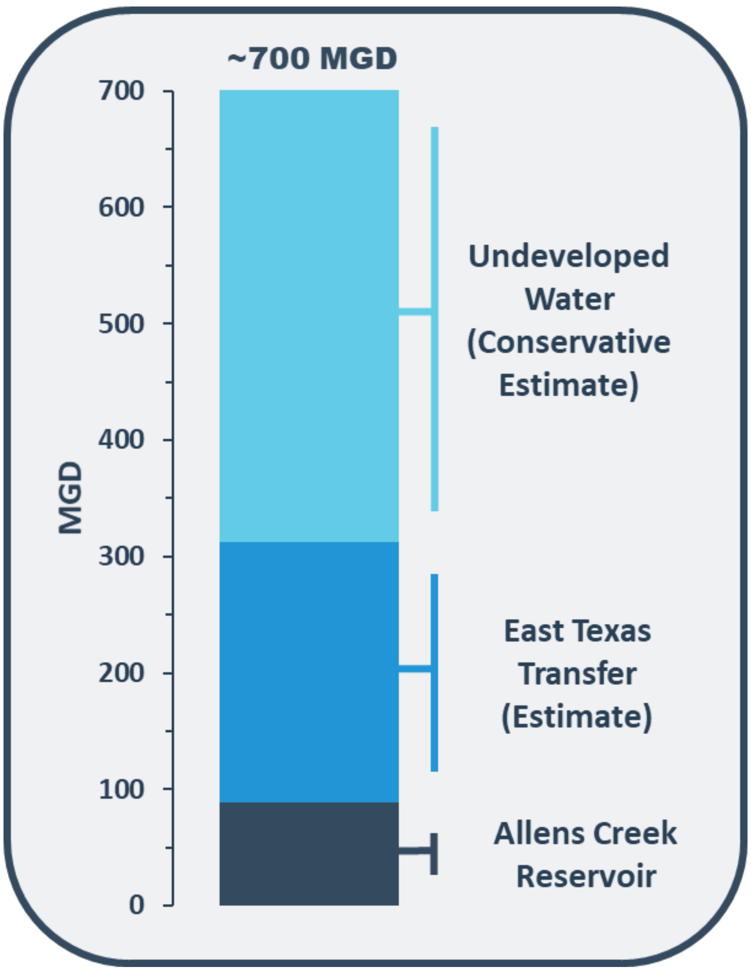

Figure 3-8. Total Magnitude of Supply from Surface Water Development

3.1.5 BUDGETARY COST OPINIONS

Planning level, order of magnitude cost opinions were developed for each water supply option based on consistent "big-picture" assumptions. The costs developed are intended for use as a planning level evaluation for conceptual projects, and are commensurate with the AACE Level 5 estimates. The developed costs rely on comparable feasibility studies or construction costs. Cost opinions were determined in a manner consistent with planning level order-of-magnitude cost estimates based on cost curves, the TWDB Unified Costing Model, professional judgement and other resources. All costs presented in this report are in 2021 dollars. Following assumptions were used to develop capital cost opinions from direct costs:

- Contractor overhead and profit - 15% of direct project costs
- Mobilization and demobilization – 5% of direct project costs
- Permits, bonds and insurance - 15% of direct project costs
- Engineering and design - 10% of direct project costs
- Contingency - 30% of direct project costs

While recognizing that implementation of each shortlisted AWS option can comprise a wide variety of supply magnitudes, treatment technologies, source water qualities, local constraints, etc., cost opinions were developed based on what are believed to be reasonably representative assumptions that are broadly applicable to the region. In particular, AWS production magnitudes were set at levels that are considered to be feasible for providers in the Districts' regulatory areas while providing sufficient economy of scale for the option to be financially viable.

For surface water development, these costs include the components that are shown in **Figure 3-1** and account for direct and indirect costs. Costs were developed based on assumed construction of a new 25-MGD surface water treatment plant (SWTP). This production magnitude was viewed as a reasonably representative middle-ground between smaller SWTPs in the region (1 – 2 MGD) and the large regional City of Houston WPPs (80 – 350 MGD). These costs include several line items (e.g., land acquisition, intake construction) that may not be required for expansion of an existing SWTP. However, as noted below the table, these costs exclude several items that may also be required, such as the reservation of raw water supplies and distribution system expansion.

The assumptions used for development of capital and O&M cost opinions for the surface water supply options are summarized in **Table 3-5** and **Table 3-6**.

Table 3-5. Capital Cost for 25-MGD Surface Water Development

Item No.	Capital Cost	2021 Estimated Cost ($)
1	Raw Water Intake and Pump Station	$ 22,534,000
2	Surface Water Treatment and Filtration	$ 15,100,000
3	Disinfection	$ 300,000
4	Storage	$ 10,500,000
5	Distribution System Pumping and Piping	$ 22,534,000
6	Residuals Handling	$ 4,555,000
7	Site Civil	$ 338,000
8	Yard Piping	$ 500,000
9	Land	$ 1,500,000
10	Civil, Mechanical, Electrical and Instrumentation	$ 10,985,000
	Subtotal Capital Cost	**$ 88,848,000**
	Contractors Overhead & Profit (15%)	$ 13,328,000
	Mobilization and Demobilization (5%)	$ 4,443,000
	Permits, Bonds & Insurance (15%)	$ 13,328,000
	Engineering and Design (10%)	$ 8,885,000
	Contingency (30%)	$ 26,655,000
	Total Capital Cost	**$ 155,487,000**
	Annualized Debt Service Payment ($/yr)	**$ 11,296,000**

[Assumptions]

1. Includes cost for raw water intake pump station (25 MGD) and 1.5 miles of piping (36-inch).
2. Treatment includes rapid mix, flocculation/sedimentation, and granular media filtration.
3. Includes cost for disinfection and feed pumps.
4. Includes cost for storage tank for treated water (10 MG) and storage for chemicals.
5. Includes cost for treated water pump station (25 MGD) and 1.5 miles of piping (36-inch).
6. Includes cost for dewatering, gravity thickener and solids disposal.
7. Cost for site civil includes re-gradation for construction, erosion control, construction entrance, well and equipment pad and paving, excavation and fill.
8. Includes cost for process pipe. Piping costs include material and installation costs.
9. Assumed 15 acres of land for plant at an average cost of land per acre of $100,000.
10. Miscellaneous - Civil cost is 10%, mechanical cost is 5% and electrical and instrumentation cost is 10% of respective discipline capital costs.

Table 3-6. O&M Cost for Surface Water Development

Item No.	Annual Operation and Maintenance Cost	2021 Estimated Cost ($)
1	Labor	$ 1,200,000
2	Chemicals	$ 2,666,000
3	Power	$ 2,920,000
4	Supplies	$ 888,000
5	Sludge Disposal	$ 913,000
6	General Maintenance	$ 1,777,000
	Subtotal O&M Cost	**$** 10,364,000
	Miscellaneous Costs (10%)	$ 1,037,000
	Total Annual O&M Cost	**$** 11,401,000

[Assumptions]

1. Accounts for 15-20 FTEs for operating surface WTP.
2. Cost includes chemicals for pre- and post-treatment.
3. Electricity cost for intake pump station, process power, distribution pump power, and building services.
4. Assumed 1% of capital cost for supplies.
5. Assumed sludge volume of 0.05% of total plant capacity (25 MGD) will be produced per day. Assumed sludge disposal cost of $0.2/gallon
6. General plant maintenance cost was assumed to be 2% of capital cost.

It is important to note that these high-level cost estimates exclude the following:

- Raw water supply reservation costs
- Distribution system infrastructure costs
- Site-specific limitations and constraints
- Routing analysis, detailed engineering feasibility and design considerations.

At this stage of project development, there are still many unknowns, and further investigation is required to develop refined cost estimates for project and capital planning. As such, the costs presented in this document are intended for use in comparing alternatives to each other for long-range planning purposes only. The level of accuracy ranges from the low end of +/- 20 to 50 percent to the upper range of +/- 30 to 100 percent. The range for total costs shown are -30% for a low end and +50% for a high end from the opinion of probable construction costs (OPCC).

Summary of the capital, O&M and life-cycle cost opinions are in **Table 3-7**. As shown in this table, the capital cost to develop surface water supply is approximately $6.22 per gallon per day (GPD) with a range of $4.35 – $9.33 per GPD. The total cost for this water supply option is $2.49 per 1,000 gallons with a range of $1.74 – $3.74 per 1,000 gallons. **Figure 3-9** illustrates the capital and total costs for surface water development.

Table 3-7. Surface Water Development Life-Cycle Costs

Option No.	Option Name	2021 Estimated Cost ($)
1	Total Capital Cost	$ 155,487,000
2	**Total Capital Cost per GPD ($/GPD)**	**$ 6.22**
3	Annualized Debt Service Payment ($/yr)	$ 11,296,000
4	Total Annual O&M Cost	$ 11,401,000
5	Total Annual Capital and O&M Cost ($/yr)	$ 22,697,000
6	Annual O&M Cost ($/1,000 gallons)	$ 1.25
7	**Total Cost ($/1,000 gallons)**	**$ 2.49**

[Assumptions]
3. Amortized for a period of 30 years and 6% interest rate.
5. Based on 25 MGD of surface water supply
6. Based on 25 MGD of surface water supply

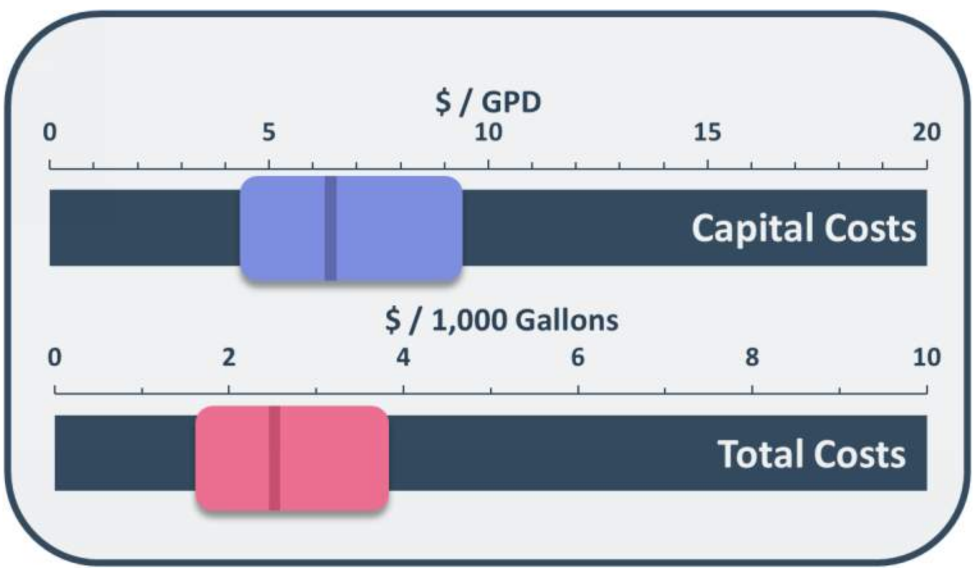

Figure 3-9. Capital and Total Costs for Surface Water Development

3.1.6 IMPLEMENTATION TIMELINES

Of the three sub-options presented for surface water, appropriated but undeveloped water can be planned and implemented in the least time. For example, the expansion of the Northeast WPP from 80 to 400 MGD capacity will be completed by 2025, and will thus increase the potential for 320 MGD additional surface water supply to the region. However, according to the Brazos G 2021 RWP, full utilization of appropriated but undeveloped water from the BRA Permits may take up through 2070 to develop due to infrastructure-related requirements. The Allens Creek Reservoir is set to begin construction in 2025 and be completed in 2040 with a fifteen-year implementation timeline.

Figure 3-10 shows the typical timelines to plan, design and integrate surface water supplies. Anticipated timelines for surface water development can be between 15 – 17 years.

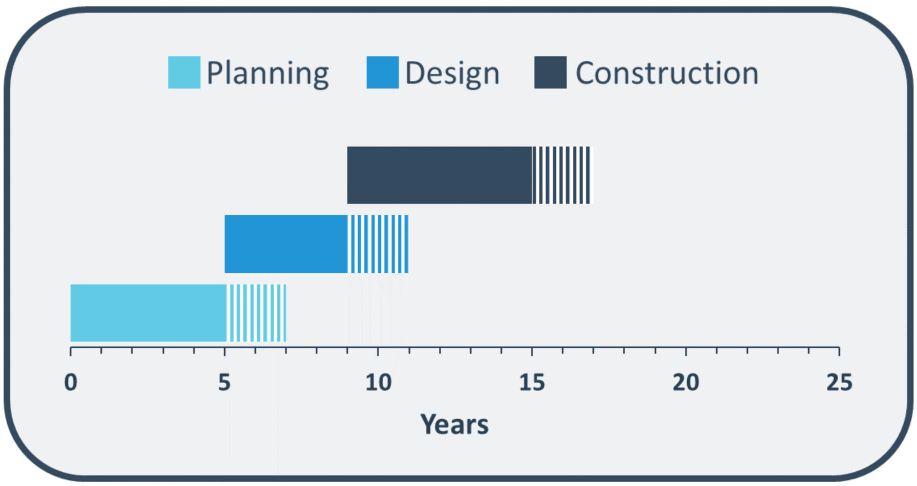

Figure 3-10. Implementation Timeline of Surface Water Development

3.1.7 WATER QUALITY CONSIDERATIONS

Surface water qualities vary seasonally among the various river basins. Surface water sources are also vulnerable to climate change and this can have impacts on water quality as well. **Table 3-8** summarizes the major water quality parameters for key future surface water sources. Available data were collected from the TCEQ Surface Water Quality Web Reporting Tool for the years 2000 – 2019. Values for the Sabine River Basin are based on the averages of water quality data from all available sites for the Toledo Bend Reservoir. Similarly, values for Neches River Basin are averages of water quality data available for the Sam Rayburn Reservoir. Values for Brazos River are averages from three sample sites closest and upstream of the future Allens Creek Reservoir location. Chlorophyll-a concentrations are in units of micrograms per liter (µg/L), and conductivity readings are in units of microsiemens per centimeter (µS/cm).

Table 3-8. Key Water Quality Parameters for Future Suface Water Supplies

Water Quality Parameter	Toledo Bend Reservoir (Sabine River)	Sam Rayburn Reservoir (Neches River)	Brazos River (Near Future Allens Creek Reservoir)
Total Alkalinity (mg/L)	28	24	154
Total Organic Carbon (mg/L)	7	7	8
Chloride (mg/L)	15	14	87
Chlorophyll-a (µg/L)	14	13	38
Total Suspended Solids (mg/L)	5	9	280
Total Dissolved Solids (mg/L)	108	105	396
Conductivity (µS/cm)	153	145	661

3.1.8 PERMITTING AND LEGAL CONSIDERATIONS

The amended water use Permit 2925 granted Allens Creek Reservoir water rights to the City of Houston, BRA, and TWDB (2021 RWP). The priority use under 2925A allocates seventy percent of water to City of Houston and thirty percent to BRA. Additional yields will be considered under the context of the BRA System Operations Permit (2021 RWP, Brazos G 2021 RWP).

Due to the multitude of potential environmental impacts that projects at such a large magnitude may cause, several permits will apply to both the Allens Creek Reservoir and the East Texas Transfer. These are: USACE Section 404 Individual Permit, National Environmental Policy Act (NEPA) Environmental Impact Statement (EIS), Cultural Resources Survey and National Register of Historic Places Testing, U.S. Fish and Wildlife Service, and TPWD Ancillary Studies. The Allens Creek Reservoir will require the development of a mitigation plan as part of the Section 404 permitting process.

The water rights in the Sabine River Basin are currently held for storage and appropriation of water, amendments to existing permits will be necessary to convey water to the western basins. For the use of unappropriated waters through inter-basin transfer, permits under Section 11.085 of the Texas Water Code must be obtained. This involves transparent communication on the permitting process in both the donating and receiving basins and developing associated costs with the transfer. Business cases for water need and availability, economic and environmental impacts, and end use purposes will need to be made to the regulatory agencies and the involved stakeholders. Permits are generally granted if benefits to the receiving basin will outweigh detriments to the donating basin, and if drought contingency plans and conservation plans are developed and implemented. Because of these requirements, there are significant institutional constraints that need to be addressed in East Texas Transfer of surface water supplies. Cooperation of stakeholders and institutions from across counties and locations is imperative.

3.1.9 VULNERABILITY TO CLIMATE CHANGE

Surface water sources are vulnerable to climate change impacts through reduced streamflow and reservoir storage, as shown measured in **Figure 3-11**. Predictive climate models show an increased drying effect for Texas in both the east and west due to declines in precipitation as well as evaporative losses from warmer atmospheric temperatures. It is predicted that the severity of droughts particularly in the latter half of the 21st century will be even greater than that of the driest centuries from the past 1,000 years (Nielsen-Gammon et al., 2020). Not only is Texas increasingly becoming vulnerable to extreme weather events, but the disparity between regions with ample water supplies and those without may be exacerbated. Because of this, it is imperative that strategies for surface water management in the short- and long-term be modeled and evaluated under a greater range of extreme weather conditions to account for greater uncertainty. Not only will operations protocols for reservoirs be impacted, but safety margins for dams and existing infrastructure may change, leading to a need for retrofitting or reduced conservation pool size.

Figure 3-11. Climate Resiliency Rating of Surface Water Development

The water quality of surface water sources can also be impacted by climate change through increased water temperature, and reduced stream flow which can impact chloride, sulfate and total dissolved solids concentrations. It may also cause a decrease in dissolved oxygen and pH (Nielsen-Gammon et al., 2020, Dawson et al., 2015). These changes will impact the ability of surface water to be used for human consumption and recreation.

Planning for reservoirs is typically based on a single target number: for the current region of interest, this is the firm yield that will be available under the drought of record scenario. This drought of record is currently still modeled after the Texas drought of the 1950s. However, Nielsen-Gammon et al. (2020) discuss the merit of rethinking WAMs that only project to a single target in the first place, or redeveloping WAMs that are able to account for a nonstationary climate. This is undoubtedly challenging, and the required data inputs may also not exist at this stage. However, it may be worth it to start putting resources into accounting for more structural uncertainties due to climate change.

3.1.10 SUBSIDENCE IMPACTS

There are no direct subsidence impacts from the increased use of surface water sources. As shown in **Figure 3-12**, surface water does not result in any land subsidence.

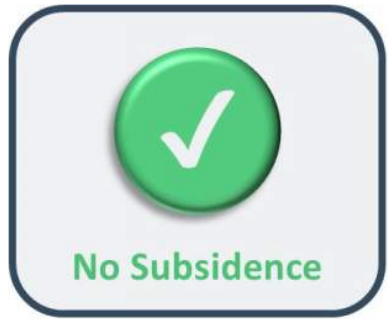

Figure 3-12. Subsidence Impacts of Surface Water Development

3.2 SEAWATER DESALINATION

As discussed in Section 2, onshore and offshore desalination were considered sufficiently promising for further study and more detailed characterization. Given that onshore and offshore desalination differ only in the location of treatment facilities, these sub-options were combined into a single option to carry forward. Although the extremely high salinity and variable water quality of seawater make treatment more difficult and energy-intensive relative to most options, seawater desalination has several key differentiating benefits. The Gulf of Mexico is an effectively unlimited supply, making this option extremely resistant to drought and climate variability. The scale of seawater desalination supply is often limited by the infrastructure investment and not by supply availability. Seawater desalination will require a regional consortium or partnership to develop a reliable water supply. In this option, the desalination plant will be located close to the Gulf, serve the needs of coastal communities, and share the plant costs with inland systems. In return, the inland systems will trade and pick up the water rights in the upstream basins from the coastal communities that are benefiting from the desalinated water supply.

With this option, cost has traditionally been the most significant barrier to implementation. However, as available fresh surface water supplies become increasingly scarce and/or distal and as desalination treatment technology improves, this option could become viable within this study's planning horizon.

3.2.1 IMPLEMENTATION APPROACH

Seawater can be desalinated with no risk of subsidence impacts; however, with TDS concentrations greater than 35,000 mg/L, costs for treating seawater will be substantially higher than other saline or freshwater sources. In water-stressed areas with little low-cost options available, like the Middle East, seawater has already been embraced as a water supply source. The Gulf Coast of Texas could reap significant benefits from the implementation of seawater desalination, especially as the availability of alterative supplies and desalination operating costs continue to decrease.

Seawater desalination is most often achieved through membrane filtration treatment technologies, the most common of which is RO. The entirety of the seawater desalination process is illustrated in **Figure 3-13**. The key components for seawater desalination include an intake in the Gulf, pre-treatment system with screens and MF/UF membranes, multi-stage RO membranes, and disinfection, storage, and pumping. The pre-treatment system is tailored to remove debris, silt, and materials that can scale the RO membranes. The RO membranes used for seawater desalination require significant energy to remove the high concentrations of sodium and chloride in the water. To achieve the desired recovery of potable water, the RO membranes are operated in multiple stages, wherein the reject or brine water from the initial stage becomes the feed water for the later stage(s). The brine or concentrate stream generated from the desalination treatment is returned back to the Gulf. The product water is disinfected and stabilized prior to pumping into the potable water distribution system.

Thermal-based distillation can also be used to treat the salinity of seawater, but due to this technique's high-energy requirement and low water recovery they represent only a minority of desalination plants. When considering the treatment technology, energy demand, membrane fouling, and water recovery are important factors that affect the efficiency and operating and maintenance costs of a plant (WRF, 2009). The two largest US desalination facilities located in Carlsbad, California (50 MGD) and Tampa Bay, Florida (25 MGD), both use RO technology and employ MF ahead of RO to improve efficiencies in the desalination process (TWDB, 2018a).

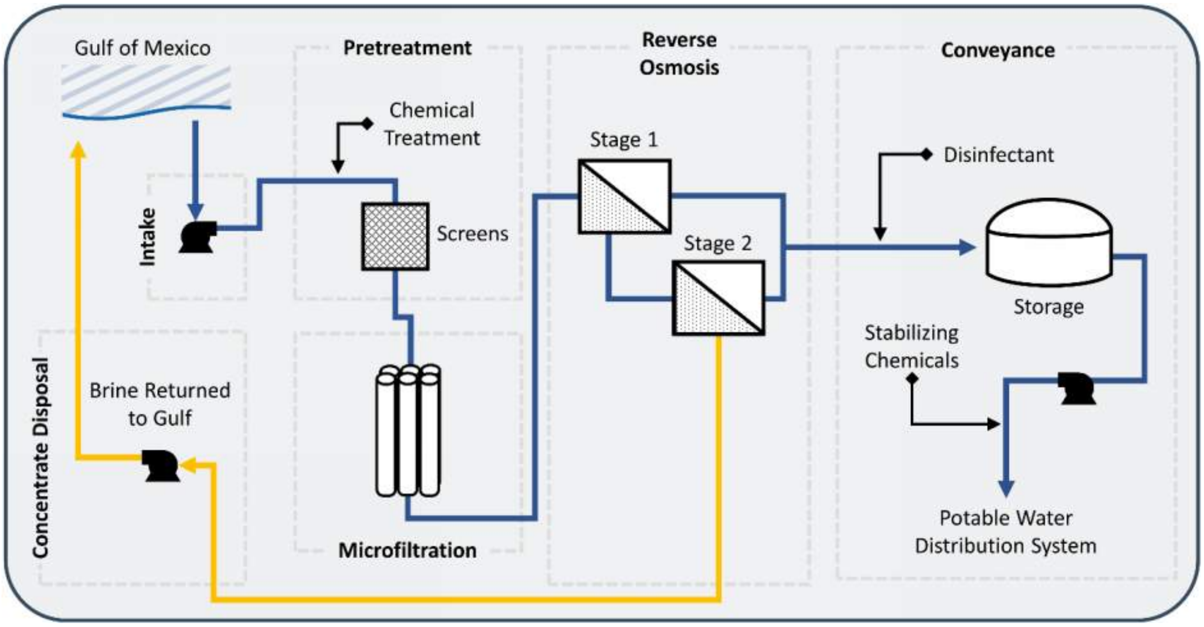

Figure 3-13. Process Flow Diagram for Seawater Desalination

The Carlsbad, CA and Tampa Bay, FL plants made two similar design decisions regarding the location and project delivery to reduce the life-cycle costs for desalination. Both plants have been co-located near power generation facilities; in addition to providing a source of energy for the intensive desalination process, the co-location allows the desalination plants to make use of any existing intake structures that take in seawater used for cooling or other industrial processes (TWDB, 2018a). Locating the desalination plant and intake and discharge structures in already industrialized areas be advantageous to protect more environmentally sensitive areas, avoid public discontent with the construction, noise, and structures, and garner support from industrial water users seeking additional supply opportunities.

Partnership with other public and private entities will spread costs between multiple stakeholders. Entities seeking supply, either through direct connection to the desalinated supply or by purchasing surface water made available upstream after costal entities offset their usage with desalinated supply, can bear some of the planning, construction, and operation costs and allow for larger plant capacities. Private entities can also provide alternative procurement models which may reduce costs, training, or staffing needs for water suppliers. The Carlsbad plant was financed by Poseidon Water and is operated by IDE Technologies; San Diego County Water Authority purchases the desalinated water. The Tampa Bay facility, in contrast, is financed and owned by Tampa Bay Water, but they rely on a private operator for operations, management, and maintenance (TWDB, 2018a).

The intake structure for a seawater desalination plant can have a significant impact on the downstream processes necessary for treatment. Average suspended solids concentrations, fluctuations in temperature, presence of pollutants (like oil) and debris (like seaweed and algae), and the impact and risk to marine wildlife are challenges the selection of an intake type and locations should consider. The major intake types are open surface intakes, which draw in water from above the seabed through a set of screens, and subsurface intakes, where wells extract water from below the seabed or from the sands below the beach. Because of the natural barrier of sand, the subsurface intakes can provide a higher quality source water needing less pretreatment without the threat of entrainment and impingement of marine organisms; however, these intakes are dependent on the suitability of on- and off-shore geological formations, have shorter useful life, and could negatively affect coastal aquifers, estuaries, and wetlands (WRF, 2009).

In order to minimize negative environmental impacts to the body of water receiving the concentrate waste from the desalination process, careful considerations also need to be given for the discharge structure. Discharging untreated concentrate back into a dedicated ocean outfall is the most common disposal method for large seawater desalination plants. The key challenge for the discharge structures is to minimize the zone of elevated salinity around the outfall until adequate mixing can be achieved with the ambient water. Tidal zones may have the appropriate mixing capacity but diffusers can also be used to encourage mixing and dispersion of the concentrate plume (WRF, 2009). Additional planning and design considerations are discussed in the following sections.

3.2.2 REGULATORY AREA(S) SERVED

The extent from the coastline for which seawater desalination can serve is economically limited by transmission and pumping feasibility and costs. Generally, in-land communities would not consider seawater desalination over other local AWS. However, if local supplies are unavailable, the transmission and pumping costs for treated seawater may be equivalent to moving water as part of an inter-basin transfer; in this particular scenario, distance from the coast would no longer be a factor in the comparison of AWS sources. While this equalization of cost may occur in the future, in the near term it is expected that HGSD Regulatory Area 1 and the south-eastern portion of Fort Bend County are the primary candidates for seawater desalination. In addition, inland regulatory areas may be served through water exchange deals with the coastal regulatory areas mentioned above. As water providers along the coast connect to and receive desalinated water, the amount of surface water they need to withdraw can be reduced and made available for providers and utilities upstream. Effective collaboration will be necessary so that the upstream entities carry some of the financial burden of constructing and operating the desalination plant.

3.2.3 ANTICIPATED USERS

The reverse-osmosis treatment process is an effective treatment method to produce high-quality water for residential and commercial potable water needs or industrial applications. Due to the energy- and cost-intensive treatment, desalinated seawater is not the most economically advantageous choice for meeting non-potable water demands; other alterative supply options, like reclaimed water, may be more suitable for non-potable users.

3.2.4 MAGNITUDE OF SUPPLIES

Seawater desalination, unlike other AWS options, is unique because the magnitudes of supply are not limited by the water available; The Gulf of Mexico is, effectively, an unlimited supply. However, the cost-intensive desalination process will limit the scale at which this AWS can be implemented. In addition to treatment costs, pumping and transmission between the Gulf, desalination plant and service areas will increase the unit cost of desalinated water and further reduce the economically-achievable size of a desalination plant.

The installed global seawater desalination capacity in 2016 was approximately 15.8 BGD (TWDB, 2018a). Due to the scarcity of freshwater and an abundance of energy resources, approximately half of the global desalination capacity can be found in the Middle East (WRF, 2009). Plants in the Middle East operate on massive scales, such as the Ras Al Khair plant in Saudi Arabia, which uses a hybrid thermal multistage flash and RO technology to produce 228 MGD (Water Technology, 2020), or the Israeli Sorek Plant, which uses RO membranes to produced 165 MGD (IDE Technologies, 2018). Desalination in the United States, on the other hand, has been implemented on a more modest scale; only two facilities have design capacities greater than 25 MGD: the Claude “Bud” Lewis Carlsbad Desalination Plant in California (50 MGD) and the Tampa Bay Seawater Desalination Plant in Florida (25 MGD). The remainder of the US’s seawater desalination plants for municipal purposes, like the Santa Barbara’s Charles Meyer facility or the Florida Keys Aqueduct Authority’s facilities, have design capacities of less than 3 MGD (TWDB, 2018a). The theoretically unlimited supply of water in the Gulf of Mexico and the range of typical plant sizes expected for future Texas desalination plants are illustrated in **Figure 3-14**. The availability of other AWSs and the energy and cost intensive treatment process are two factors which limit the adoption of more US plants at larger scales, but as water demands continue to grow and RO operating costs decrease seawater desalination will become a more important water supply option.

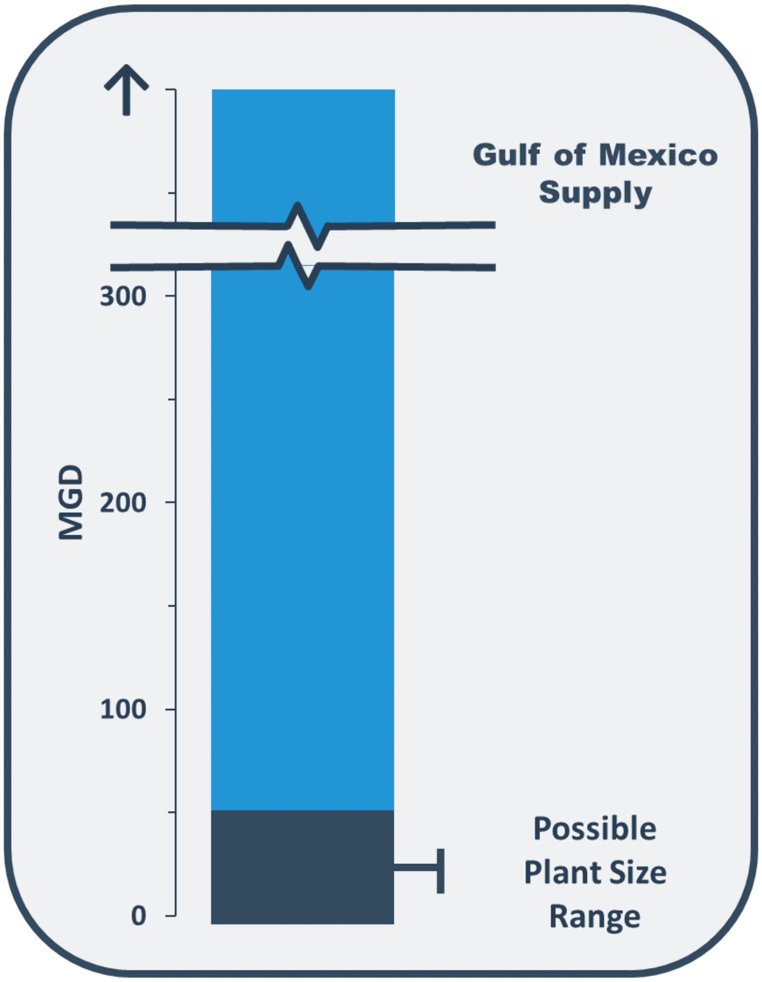

Figure 3-14. Total Magnitude of Supply from Seawater Desalination

Seawater desalination as a long-term water supply strategy in Texas has had its fair share of attention; it has been included as a Water Management Strategy in every State Water Plan since 2002. In the most recent State Water Plan, the TWDB expects a seawater desalination capacity of 116,00 AFY (or 103 MGD) by 2070 (TWDB, 2017). Regions H, M and N have all proposed seawater desalination plants as part of their regional water supply management strategies. The City of Corpus Christi has been actively planning for two 20 MGD (with future expandable capacity) desalination plants (Corpus Christi, 2020). The BRA has investigated the feasibility of a 10 MGD demonstration plant in the City of

Freeport, with a final expanded capacity of 50 MGD (CDM, 2004). Additionally, the City of Brownsville and the Laguna Madre Water District (who provides water for Port Isabel, South Padre Island, and Laguna Vista) investigated the feasibility of smaller magnitude plants of 2.5 and 2.3 MGD respectively in the late 00s, but neither have moved forward with those projects (TWDB, 2018a). The anticipated magnitude of supplies for desalination plants in Texas will most likely mirror California and Florida larger facilities with plants that produce approximately 50 MGD at full capacity; assuming two plants are implemented to serve the regulatory areas, seawater desalination supplies could provide up to 100 MGD of alternative water by 2070.

3.2.5 BUDGETARY COST OPINIONS

Planning level, order of magnitude cost opinions were developed for each water supply option based on consistent "big-picture" assumptions. A 50-MGD capacity was chosen for the seawater desalination facility budgetary cost opinion to represent a plant built to achieve sufficient economy of scale, reflective of a size desirable for a regionally collaborative group and has been implemented at this scale in the US. Given the relatively energy-intensive RO treatment and brine concentrate disposal processes, seawater desalination likely requires a relatively high production capacity to achieve a cost per thousand gallons that is competitive with other AWSs. This facility includes pretreatment and ultrafiltration, an RO membrane treatment process, and distribution and disposal connections; components reflective of the process flow diagram in **Figure 3-13**. The assumptions used for development of capital and O&M cost opinions for the seawater desalination water supply option are summarized in **Table 3-9** and **Table 3-10**, respectively.

Table 3-9. Capital Cost for 50-MGD Seawater Desalination Facility

Item No.	Capital Cost	2021 Estimated Cost ($)
1	Seawater Intake Pump Station	$ 57,722,000
2	Pretreatment	$ 15,300,000
3	RO Treatment	$ 33,750,000
4	Storage	$ 45,500,000
5	Distribution System Pumping and Piping	$ 52,540,000
6	Brine Disposal Costs	$ 19,319,000
7	Site Civil	$ 303,000

Item No.	Capital Cost	2021 Estimated Cost ($)
8	Yard Piping	$ 800,000
9	Civil, Mechanical, Electrical and Instrumentation Cost	$ 30,510,000
10	Land Cost	$ 3,000,000
11	Site Security	$ 88,000
	Subtotal Capital Cost	**$ 258,832,000**
	Contractors Overhead & Profit (15%)	$ 38,825,000
	Mobilization and Demobilization (5%)	$ 12,942,000
	Permits, Bonds & Insurance (15%)	$ 38,825,000
	Engineering and Design (10%)	$ 25,884,000
	Contingency (30%)	$ 77,650,000
	Total Capital Cost	**$ 452,958,000**
	Annualized Debt Service Payment ($/yr)	**$ 32,907,000**

[Assumptions]

1. Feed water for the seawater desalination plant will be taken from the Gulf of Mexico approximately 2.5 miles from the plant. Capacity of feed water pump station will be 70 MGD.
2. Cost for pretreatment includes screening, UF and filtration building. Filtration building area was assumed to be 25,000 SF.
3. TDS of Seawater is approximately 30,000-35,000 mg/L. Includes costs for RO building, membrane, feed pumps, chemical feed systems, RO permeate stabilization and cleaning system. Assumed approximately 75% recovery (50 MGD) for RO system.
4. Includes costs for storage for RO treated water (25 MG), wet well for brine (10 MG), and chemical storage (0.5 MG).
5. The desalination plant was assumed to be near the Gulf Coast and serve the cities and communities nearby. Piping from storage to distribution was assumed to be 1.5 miles and capacity of Booster Pump Station and Storage was assumed to be 50 MGD and 10 MG, respectively.
6. RO concentrate will be disposed 3 miles into the ocean. Assumed approximately 25% RO concentrate (20 MGD) will be pumped via 36-inch pipe.
7. Includes cost for regrading, erosion control, stabilized construction entrance, paving, excavation and fill.
8. Includes cost for spent backwash pipe, drain pipe and process pipe. Piping costs include material and installation costs.
9. Miscellaneous - Civil cost is 10%, Mechanical cost is 5% and electrical and instrumentation cost is 10%.
10. Assumed 30 acres of land will be required for the desalination plant construction and

Item No.	Capital Cost	2021 Estimated Cost ($)
average cost of land per acre was assumed to be $100,000 11. Includes cost for fence, gates and CCTV.		

Table 3-10. O&M Cost for Seawater Desalination

Item No.	Annual Operation and Maintenance Cost	2021 Estimated Cost ($)
1	Labor	$ 900,000
2	Chemicals	$ 5,180,000
3	Electric Power	$ 20,463,000
4	Membrane Replacement	$ 5,180,000
5	Supplies and General Maintenance	$ 5,180,000
	Subtotal O&M Cost	**$ 36,903,000**
	Miscellaneous Cost (10%)	$ 3,691,000
	Total Annual O&M Cost	**$ 40,594,000**
[Assumptions] 1. Cost for 15 FTEs for operating the desalination plant. 2. Cost includes chemicals for post treatment. 3. Electricity cost ($0.10/kWh) for well pumps, process power, Distribution pump power, Building services. For seawater intake, assumed static head to be 5 feet and for HS PS assumed static head to be 10 feet for energy cost calculations. 4. Membrane replacement cost was assumed to be 2% of capital cost. 5. Supplies and general plant maintenance cost was assumed to be 2% of capital cost.		

Summary of the capital, O&M, and life-cycle cost opinions are summarized in **Table 3-11**. As shown in this table, the capital cost to develop a seawater supply is approximately $9.06 per GPD with a range of $6.34 – $13.59 per GPD. The total cost for this water supply option is approximately $4.03 per 1,000 gallons with a range of $2.82 – $6.05 per 1,000 gallons. **Figure 3-15** illustrates the capital and total costs for seawater desalination.

Table 3-11. Seawater Desalination Life-Cycle Costs

Option No.	Option Name	2021 Estimated Cost ($)
1	Total Capital Cost	$ 452,958,000
2	**Total Capital Cost per GPD ($/GPD)**	**$ 9.06**
3	Annualized Debt Service Payment ($/yr)	$ 32,907,000
4	Total Annual O&M Cost	$ 40,594,000
5	Total Annual Capital and O&M Cost ($/yr)	$ 73,501,000
6	Annual O&M Cost ($/1,000 gallons)	$ 2.22
7	**Total Cost ($/1,000 gallons)**	**$ 4.03**

[Assumptions]

3. Amortized for a period of 30 years and 6% interest rate and at a yield of 50 MGD.
5. Based on a seawater desalination plant of 50 MGD capacity
6. Based on a seawater desalination plant of 50 MGD capacity

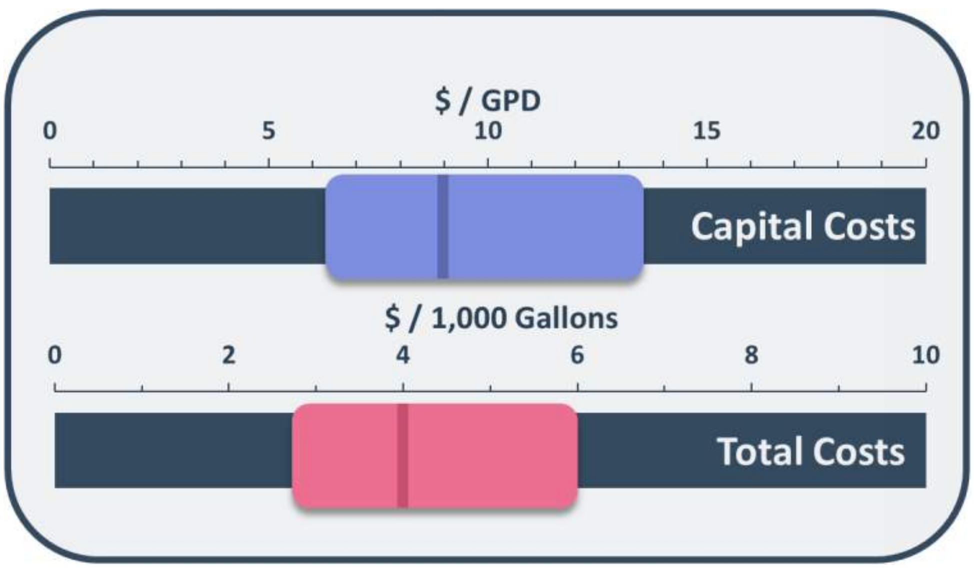

Figure 3-15. Capital and Total Costs for Seawater Desalination

3.2.6 IMPLEMENTATION TIMELINES

The implementation timeline for a seawater desalination project can vary significantly due to the complexity of the planning and permitting phases. The 50 MGD Carlsbad Desalination Plant in California took 18 years to move from concept to completion, beginning in 1998 and coming online in late 2015. Designing the facility took 3 years and construction also took 3 years, excluding 2 years spent on the project conception, the remaining 10 years were spent on environmental reviews, regulatory approvals from the Regional Water Quality Board and other stakeholders, and financing agreements between Poseidon Water and the San Diego Water Authority (Carlsbad Desalination Project, 2017). Tampa Bay Water initially had a shorter timeline of 6 years, releasing their request for qualification in 1997 and performing the initial plant start-up in 2003. However, due to the bankruptcy of the construction firm, Tampa required 4 additional years in order to remediate and finish the construction and bring the plant fully online in late 2007 (Tampa Bay Water, 2010).

Corpus Christi may be the first water system to set an implementation timeline precedent for seawater desalination facilities in Texas. Beginning Phase I in 2014, after an extended pause following the completion of an earlier feasibility study in 2004, Corpus Christi and its industrial partners re-investigated the feasibility of seawater desalination. Corpus Christi received a TWDB State Water Implementation Fund for Texas loan in 2017 which kicked off Phase II including site-assessment and permit development (TWDB, 2018a). The two discharge and two diversion permits were submitted to the TCEQ in January of 2020 and the City hopes to complete Phase III including procurement, financial closing, and design, construction, and commissioning of the plants by 2025 (Corpus Christi, 2020). A conservative estimate for a full concept-to-completion timeline for seawater desalination could be, as **Figure 3-16** illustrates, up to 20 years. However, with effective partnering, expedited permitting opportunities, and ample financing options, water suppliers have options to reduce the implementation timeframe.

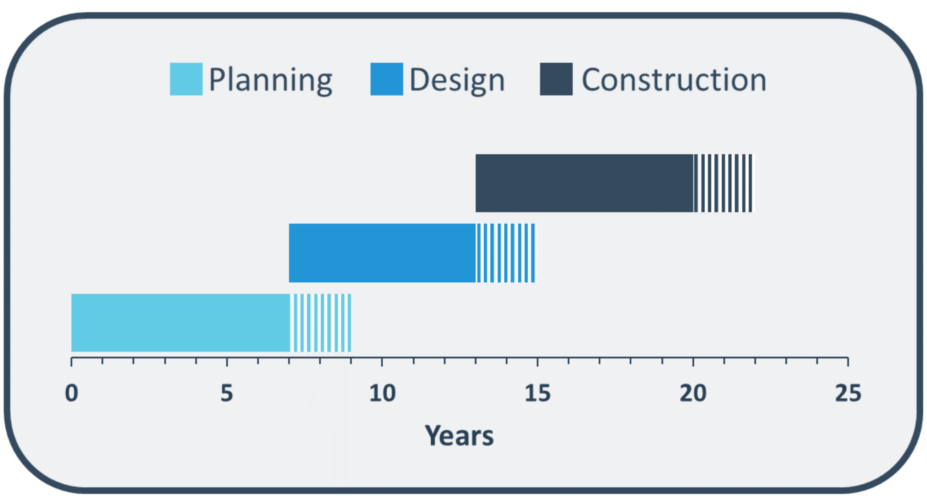

Figure 3-16. Implementation Timeline of Seawater Desalination

3.2.7 WATER QUALITY CONSIDERATIONS

As discussed earlier in this Section, the intake structure can have significant impacts on the desalination plant feed water quality. Open seawater intakes are susceptible to high algal and biological contamination and growth; sunlight, elevated temperatures, and high nutrient concentrations from wastewater effluents or commercial or industrial port activities can increase the bio-activity of the water and cause membrane biofouling. Larger aquatic life-forms, like Asian green mollusks encountered by the Tampa Bay plant, can also cause clogging or integrity issues particularly around the intake. Subsurface intakes, on the other hand, collect a higher quality seawater with reduced suspended solids, turbidity, and marine organism concentrations. However, the quality of subsurface intakes may also be influenced by nearby aquifers and contain elevated levels of metals like iron and manganese (WRF, 2009).

RO membranes are capable of producing very high-quality water, but, due to their susceptibility to fouling, require well-defined pre-treatment in order to work effectively and maximize membrane life. Historically conventional treatment (coagulation, flocculation, and media and cartridge filtration) has been the most common method of pre-treatment for seawater prior to RO (WRF, 2009). Tampa Bay uses conventional pretreatment with sand filters, diatomaceous earth filters, and cartridge filters all prior to the RO treatment (Tampa Bay Water, 2010). More frequently, however, MF or UF membranes are being considered as alternatives to conventional pretreatment for RO. The Carlsbad desalination plant uses a two-stage pre-treatment process consisting of a multi-media filter followed by MF (TWDB, 2018a). Even the most robust pretreatment systems can be challenged by unexpected events like tropical storms or algal blooms; a strong pilot-testing period is pivotal for systems to determine and define their pretreatment and fouling-prevention strategies in response to the source water quality.

Following RO treatment, the desalinated water will require additional post-treatment steps in order to safeguard customer health and the integrity of the distribution system. As a surface water, seawater faces some of the similar challenges post-treatment to a surface WTP: emerging contaminants of concern from wastewater discharge and surface runoff, disinfection by-products (particularly brominated species due to the elevated bromide concentrations in seawater), and algal toxins. In addition, seawater faces some of its own unique challenges such as high boron concentrations, lack of ions like calcium, magnesium, and sulfate, necessary for the human body and plant growth which can also lead to aesthetic complaints from customers, and high corrosivity due to low concentrations of calcium and carbonate. Post-treatment generally consists of stabilization, remineralization, corrosion control, disinfection, and any additional water polishing needed to combat specific compounds found in the source water or developed post-treatment such as boron or disinfection by-products (WRF, 2009).

3.2.8 PERMITTING AND LEGAL CONSIDERATIONS

Similar to surface water permitting process, systems considering integrating a seawater supply into their water portfolio will need to submit a water right permit application with TCEQ. However, in an effort to streamline the regulatory process for seawater desalination, the Texas Legislature passed House Bills 2031 and 4097 in 2015. These bills created an expedited permitting process for marine seawater diversions for desalination, diversions from seawater bays and estuaries for desalination solely for the purpose of industrial uses, and conveyance of treated marine seawater through streams. Diversions of seawater from bays and estuaries for desalination for any purpose other than industrial use must apply for their water rights through the conventional permitting process. The House Bill also charged the TPWD and GLO with delineating zones in the Gulf of Mexico that are appropriate for diversions. These diversion zones were declared in TPWD and GLO's Marine Seawater Desalination Diversion and Discharge Zones Study (TPWD & GLO, 2018) and are shown in **Figure 3-17**. Marine seawater diversions from these allocated desalination zones are eligible for alternative authorization under Chapter 18 of the Texas Water Code. An expedited permit can be obtained for marine seawater diverted from a diversion zone if the point of diversion is less than 3 miles seaward from the coast or averages a TDS concentration of less than 20,000 mg/L; if neither of the aforementioned conditions apply, entities may divert and use marine seawater from a desalination zone without a permit after the location or water sample analysis has been provided to the TCEQ. Any diversion of state water outside these desalination zones, including bays and estuaries, will need to follow the procedures of Chapter 11 of the Texas Water Code to obtain a conventional water rights permit.

Figure 3-17. Zones Recommended by TPWD and GLO as Appropriate for the Diversion of Marine Seawater and Discharge of Desalination Concentrate or Brine

House Bills 2031 and 4097 also created an expedited permitting process for the disposal of brine concentrate from desalination activities. The same zones identified by the TPWD and GLO as appropriate for diversion were also identified as acceptable areas for the discharge of concentrate or brine from the desalination process (**Figure 3-17**). For the discharge of brine or concentrate originating from a marine seawater desalination project into the zones determined by the TPWD and GLO, an operator can apply for an expedited Texas Pollutant Discharge Elimination System (TPDES) Permit from the TCEQ under Chapter 18 of the Texas Water Code. An expedited permit will not cover any discharge of desalination concentrate or brine into zones outside of the locations identified in **Figure 3-17** or into a bay or estuary of the Gulf of Mexico; entities will need to pursue a conventional TPDES permit governed by Chapter 26 of the Texas Water Code for these discharges. In addition, the discharge of treated marine seawater into a stream, lake, or reservoir is eligible for an expedited permit under this chapter as long as it is treated to meet the water quality standards adopted by the TCEQ for the receiving stream or impoundment.

Additional permits and legal requirements will vary depending on the location of the diversion intake and discharge outflow structures and the desalination facility itself. If structures are going to be built in navigable waters, in areas with sensitive or endangered wildlife, in an area with cultural significance, or with the need to cross major roadways or railroads, entities like the USACE, TPWD, Texas Historical Commission, GLO, and the Texas Department of Transportation may need to be consulted regarding additional permit requirements. The desalination plant and intake and disposal structures also need to meet any local building and construction rules and obtain permits, like an erosion control permit, that the rules may require.

3.2.9 VULNERABILITY TO CLIMATE CHANGE

One driver for the implementation of seawater desalination is the stress that climate change and drought conditions are putting on traditional surface water supplies. The supply of seawater is independent of climate ("drought-proof"), as reflected in **Figure 3-18**, and the adoption of seawater into a water provider's portfolio increases the diversity of their water supply, reduces reliance on traditional, climate-dependent sources and increases long-term reliability (WRF, 2009).

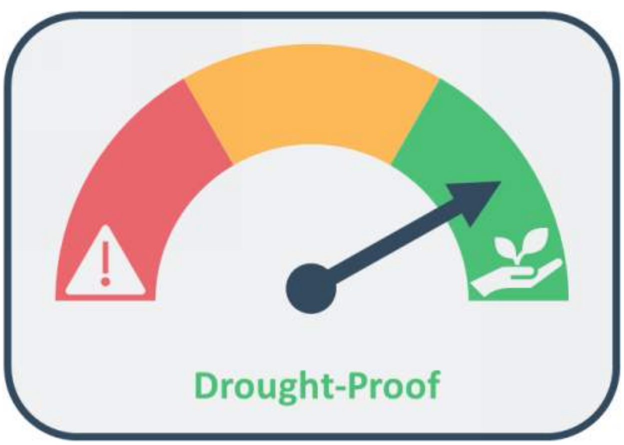

Figure 3-18. Climate Resiliency Rating of Seawater Desalination

Although seawater desalination is resilient to climate change, it also could be a significant contributor. Salinity removal is an energy intensive process; estimated energy demand for a large seawater reverse-osmosis plant can range from 13.2 to 22.7 kilowatt-hour (kWh)/1,000 gallons (WRF, 2009). If energy demands are not met with renewable energy sources, desalination could contribute to climate change with a significant amount of greenhouse gas emissions.

3.2.10 SUBSIDENCE IMPACTS

Desalinated seawater is a drought-proof and subsidence-proof AWS as shown in **Figure 3-19**. Subsidence can be offset by replacing groundwater resources with desalination seawater and other AWS options to compliance or exceedance of the District's regulatory standards.

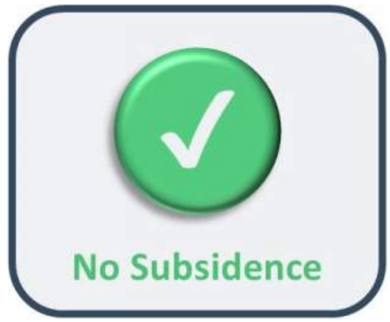

Figure 3-19. Subsidence Impacts of Seawater Desalination

3.3 CENTRALIZED RECLAIMED WATER SUPPLY

Several reclaimed water supply sub-options were considered in the initial AWS screening. Given that reclaimed water integration with a purple pipe network for non-potable use, IPR, and DPR all make use of WWTP effluent as the supply source, these options have been grouped into a single "centralized" option. It is anticipated that centralized reclaimed water treatment for non-potable uses will continue to be the preferred reclaimed water option within the regulatory areas, at least in the near-term horizon. Centralized treatment of wastewater at WWTPs to meet the TCEQ's non-potable reclaimed water criteria has been demonstrated to be a cost-effective AWS, and it is already being implemented by several water providers in the regulatory areas. Although this option requires a separate, dedicated distribution pipe network, the additional facilities required to treat WWTP effluent to meet TCEQ criteria for non-potable uses have relatively low capital and O&M costs.

Although potable reuse is increasingly gaining acceptance and is being implemented in Texas, implementation of DPR/IPR systems has generally been in other parts of the State with scarcity of surface water and groundwater supplies. However, given the increased acceptance of these highly reliable AWS options, the DPR/IPR systems may become an important part of the AWS portfolio for some local water providers in the longer-term horizon. For example, the City of Houston has been issued a water use permit to divert and reuse a combined total of up to 580,923 AFY (519 MGD) of its

WWTP return flows. Although this total is further constrained to no more than 50% of total WWTP volume discharged, meaning that the actual availability may be less than the permitted quantity, this permit demonstrates that substantial reuse potential is present.

3.3.1 IMPLEMENTATION APPROACH

The approach for centralized reclaimed water implementation depends on the intended end use. Although some water providers may elect to implement both non-potable and potable reclaimed water systems, it is anticipated that only one system type would be implemented at an individual WWTP. That is, if a DPR system is implemented, it is assumed that this system's production would be maximized, and a non-potable system would not be implemented at the same facility, other than perhaps in small quantities for onsite equipment washdown. The centralized reclaimed water treatment sub-options are therefore presented and discussed somewhat independently, though a number of the same considerations are globally applicable.

Non-potable Reclaimed Water Supply

As discussed, it is anticipated that non-potable systems will continue to be the preferred centralized reclaimed water supply in the regulatory areas, especially in the near-term horizon. This is especially applicable for developing suburban municipalities and master plan communities, particularly in western Harris County and Fort Bend County. The underdeveloped and undeveloped areas in these counties will make it easier and more economical for dual pipe installations (potable water and non-potable water pipelines) with minimal impact to road closures from invasive construction practices. However, the non-potable, purple pipe network can be implemented in developed areas as well if the installation is not cost prohibitive, such as suburban areas or where there are customers with high non-potable water demands (e.g., industrial facilities, golf courses, etc.).

Non-potable centralized water supply implementation would include the construction of tertiary treatment facilities at or near WWTPs to produce TCEQ Type I reclaimed water. Tertiary treatment would consist of cloth or media filtration, or another equivalent technology, to increase solids removal and meet turbidity requirements. Additional disinfection may also be required to meet bacteriological requirements and maintain a disinfectant residual in the purple pipe distribution system. It is assumed that non-potable reclaimed water storage, dedicated pump station and a purple pipe network to demand locations will be integrated in this supply option. However, it is assumed that pressurization would be sufficient for delivery to customer storage (typically an amenity lake or pond), but that the customer would provide pressurization for irrigation systems, if required. **Figure 3-20** shows the process flow diagram for a typical non-potable reclaimed water supply system.

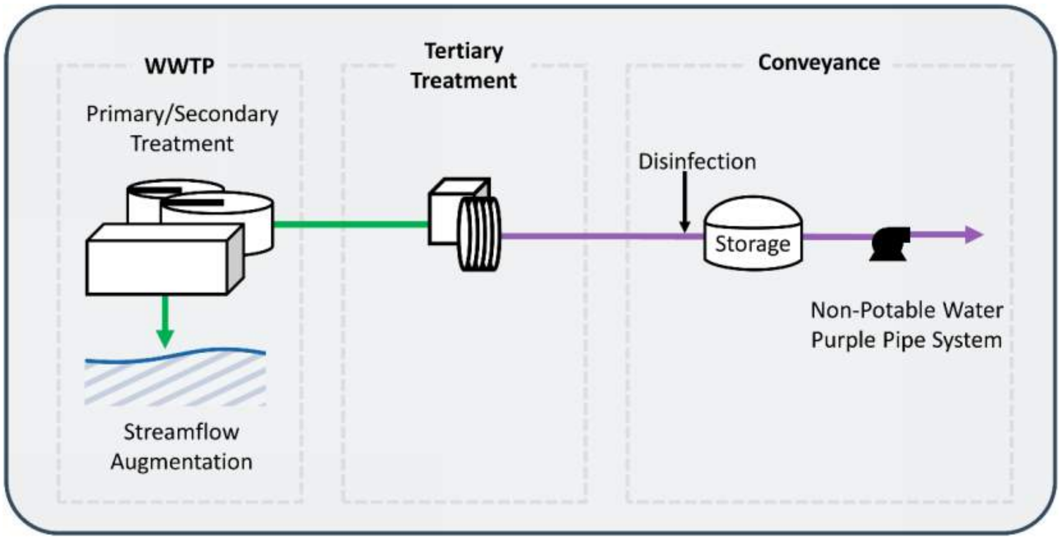

Figure 3-20. Process Flow Diagram of Non-Potable Centralized Reclaimed Water System

Potable Reclaimed Water Supply

For developed and densely populated areas with relatively high potable water demands, DPR/IPR may be cost-effective based on the economy of scale at larger WWTPs and the potentially prohibitive cost of installing a separate non-potable water pipelines in predominantly paved areas. **Figure 3-21** illustrates the process flow diagrams for DPR and IPR systems.

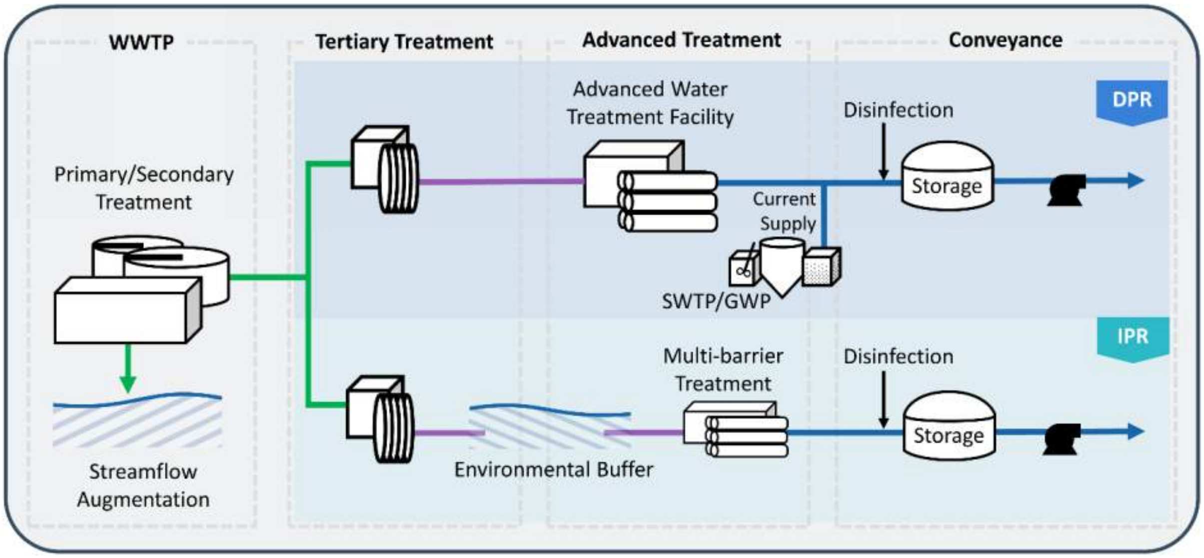

Figure 3-21. Process Flow Diagram of Potable Centralized Reclaimed Water Systems

In both the DPR/IPR systems, WWTP effluent undergoes tertiary and advanced water treatments. The key difference is that in an IPR system, the tertiary treated effluent gets discharged into an environmental buffer before being treated with advanced treatment technologies. In addition, for DPR systems in Texas, the effluent from the AWTF is blended with the current potable water supply from a surface WTP or groundwater plant (GWP) before conveyance to the end users. Environmental buffers can be natural streams, canals, lakes and other engineered buffers that provide residence time and dilution prior to withdrawal for treatment to potable water standards.

The DPR and IPR systems require WWTP effluent to be treated at an AWTF with multi-barrier treatments to meet the rigorous potable water standards. A typical AWTF may include MF/UF membranes to remove particulates and microbial pathogens, RO membranes to remove salts and dissolved pollutants and ultraviolet (UV) advanced oxidation process (AOP) to oxidize micro-pollutants. Some Texas cities such as Big Spring and Wichita Falls have DPR facilities that utilize RO to remove dissolved pollutants (USEPA and CDM Smith, 2017). **Figure 3-22** illustrates the potable reuse treatment trains for several DPR/IPR facilities in the United States.

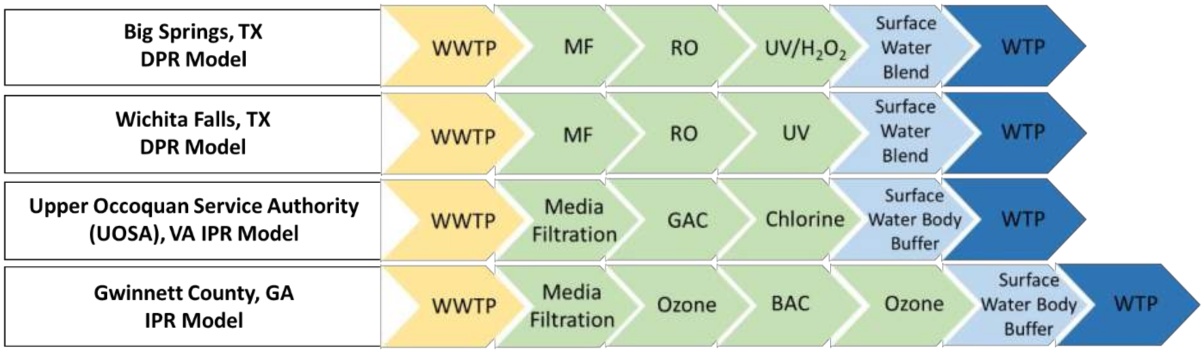

Figure 3-22. Potential Advanced Water Treatment Trains for Potable Reuse

RO achieves excellent removal of inorganic, organic chemicals and contaminants of emerging concern (Howe, 2020). However, its drawbacks such as low water recovery, high energy consumption, and generation of large waste streams prompted exploration in alternate treatment technologies such as ozone coupled with biologically active filtration (BAF) and granular activated carbon (GAC) (Howe, 2020).

Other variations of advanced water treatment trains that include riverbank filtration, ozone disinfection and/or biological filtration, but exclude RO membranes, have also been successfully demonstrated and implemented for DPR/IPR at other locations in the nation (USEPA and CDM Smith, 2017). For example, the IPR facilities of Upper Occoquan Service Authority (UOSA) in Virginia and Gwinnett County in Georgia have implemented treatment trains that do not include RO membranes. As shown in **Figure 3-22**, these facilities use technologies such as GAC and biologically activated carbon (BAC) to meet treatment objectives.

Implementation of RO treatment at inland facilities may be infeasible, for the high cost of brine disposal (Noibi et al., 2020). RO, mechanical evaporation, and RO brine management can yield an estimated cost 2.5 times greater than non-RO-based treatment trains for inland facilities (Noibi et al., 2020).

Both the DPR and IPR systems will additionally involve chemical disinfection to maintain disinfectant residual in the distribution system, treated water storage, and a pumping system to convey potable reclaimed water to the distribution system.

For the purposes of this analysis, it is assumed that potable, centralized reclaimed water supplies will be implemented with DPR systems, as DPR is less impacted by site-specific considerations as compared to IPR. Given that IPR requires an environmental buffer, system-specific considerations will dictate the implementation of such systems. While it is understood that IPR will play a role in the regional water supply, particularly through de facto IPR resulting from return flows to streams and reservoirs, this study sought to generally characterize a "closed loop" potable reclaimed water system implementation that could be implemented throughout the regulatory areas.

3.3.2 REGULATORY AREA(S) SERVED

Centralized reclaimed water practices are broadly applicable across all regulatory areas. However, each specific implementation will need to factor in spatial considerations, particularly with regard to development density, WWTP locations, and proximity of reclaimed water treatment to high-demand non-potable users.

Non-potable Reclaimed Water Supply

Developing areas of HGSD Area 3 and FBSD could be more easily served by purple pipe systems for several reasons, including the following: 1) installation during early stages of development, as opposed to retrofitting, avoids impacts to other infrastructure, thereby reducing construction costs, 2) incorporation into development plans can help achieve adequate economy-of-scale, and 3) early adoption can facilitate efficient purple pipe network design. For example, developing master planned communities featuring amenity lakes and/or golf courses that have high non-potable demands are good candidates for non-potable reclaimed water supply.

Purple pipe systems could also be implemented in lower density areas such as residential communities wherein the purple pipe installation is not cost prohibitive or where there are particularly high non-potable demands, such as large industrial facilities. Given that purple pipe network installation is the main cost driver for non-potable reclaimed water systems, efficiently linking reclaimed supplies to corresponding demands is a key factor in the cost-effectiveness of purple pipe systems. Local non-potable demands are therefore a key consideration in the implementation of such systems. Nonetheless, non-potable centralized reclaimed water treatment is considered one of the most broadly transferable AWSs, as there is a relatively reliable supply source in all regulatory sub-areas.

Potable Reclaimed Water Supply

While potable centralized reclaimed water supply could potentially be implemented wherever there is adequate supply and demand, DPR/IPR is more cost-effective when it can be implemented with sufficiently high production magnitudes and/or where the cost of constructing a purple pipe network is prohibitive. It is therefore anticipated that potable reclaimed water implementation would most likely occur in already developed areas with larger WWTPs and relatively high potable water demands. Given that potable water is produced, this supply need not be targeted for specific customers or end uses. Rather, it can be implemented anywhere with sufficiently high demands and adequately sized distribution system pipelines. Urbanized areas that experience re-development with denser developments replacing low density development would also benefit from DPR/IPR systems, especially if the re-development is in an area close to a WWTP. Potable reuse systems with treatment trains that include RO may be feasible for areas where access to marine discharge or large-scale land application for RO brine disposal is available (Noibi et al., 2020). Moreover, non-RO-based ozone-BAF may be an alternative for further inland facilities or locations where access to marine discharge or large-scale land applications for RO brine disposal is not available (Noibi et al., 2020).

3.3.3 ANTICIPATED USERS

Reclaimed water can benefit a wide range of users. Commercial or institutional customers with green space areas (e.g., golf courses, parks, schools, etc.) or amenity lakes would make the most of non-potable reclaimed water for irrigation and lake filling. In particular, golf courses with ponds or lakes and master planned communities with amenity lakes make ideal non-potable reclaimed water customers because of their high non-potable demands and the storage provided by the ponds/lakes. DPR/IPR would help meet demands for all potable water customers in the vicinity of the reclaimed water system.

Locally, numerous municipalities and MUDs have ongoing and potential reuse projects, and several regional water authorities have reuse incentivization programs. For example, the City of Sugar Land, the City of Richmond, and the City of Rosenberg have centralized non-potable systems supplying reclaimed water primarily for use in amenity lake filling and/or landscape irrigation. Cinco MUD 1 uses reclaimed water to irrigate esplanades, parks, golf courses, and public-school grounds, and Fort Bend County MUD No. 169 maintains levels in amenity lakes with reclaimed water. Overall, nine MUDs in

Fort Bend County collectively used more than 1.6 billion gallons of reclaimed water since 2016 (BGE, Inc., 2020).

3.3.4 MAGNITUDE OF SUPPLIES

The WRF conducted a study on the residential use of water in 2016. With a sample of 838 residential homes, it was estimated that approximately 50% of the annual use for this sample ground was indoor and 50% was outdoor (WRF, 2016). Therefore, of the projected 2070 municipal potable water consumption (1,290 MGD) for the combined districts, it was assumed that 50% would supply indoor water uses and 50% for outdoor water uses.

Figure 3-23 illustrates the potential water balance flow chart for the 2070 water supplies. This figure shows the inventory of available supply for individual and combined districts.

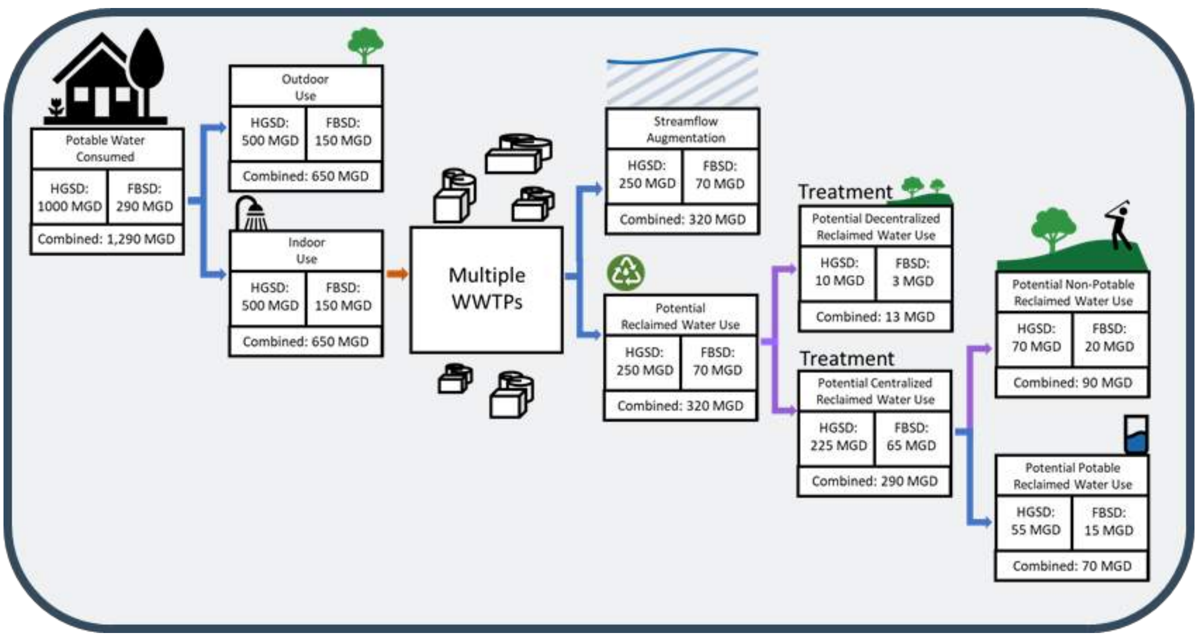

Figure 3-23. Centralized Reclaimed Water - 2070 Water Balance Flow Chart

As shown in **Figure 3-23**, potable water consumed by indoor uses (approximately 650 MGD) is the influent water for the WWTPs. It was assumed that 50% (320 MGD) of the WWTP effluent would augment streamflow and the other 50% (320 MGD) would go to centralized and decentralized reclaimed water use practices. These assumptions were based on reclaimed water permits in the region (e.g., City of Houston's Water Use Permit No. 5827) that require approximately 50% of the WWTP effluent be returned for streamflow augmentation. Although not all reclaimed water permits will have such a restriction, it was conservatively applied across the regulatory areas to ensure a conservative estimate of available reclaimed water supply.

It was assumed that centralized reclaimed water practices would be the dominant reclaimed water supply. Ninety percent (or approximately 290 MGD) of the available reclaimed water supply would be allocated to centralized reclaimed water practices (purple pipe/DPR/IPR). Ten percent of the available reclaimed water supply, with an additional 40% factor to account for seasonal demand (or 13 MGD) would be allocated to decentralized practices (satellite/on-site). Note that these magnitudes of supply are not projections of implementation, but rather an inventory of available supply.

Based on the assumption of seasonal demand of centralized non-potable reclaimed water, an additional 40% factor was applied to the potential supply of this option (yielding approximately 90 MGD). The centralized potable supply option (such as DPR) can operate at full capacity year-round. Therefore, no additional seasonal factor was applied, and this option can yield approximately 80 MGD in 2070. **Figure 3-24** shows the 2070 anticipated reclaimed water availability for the HGSD and FBSD regulatory areas.

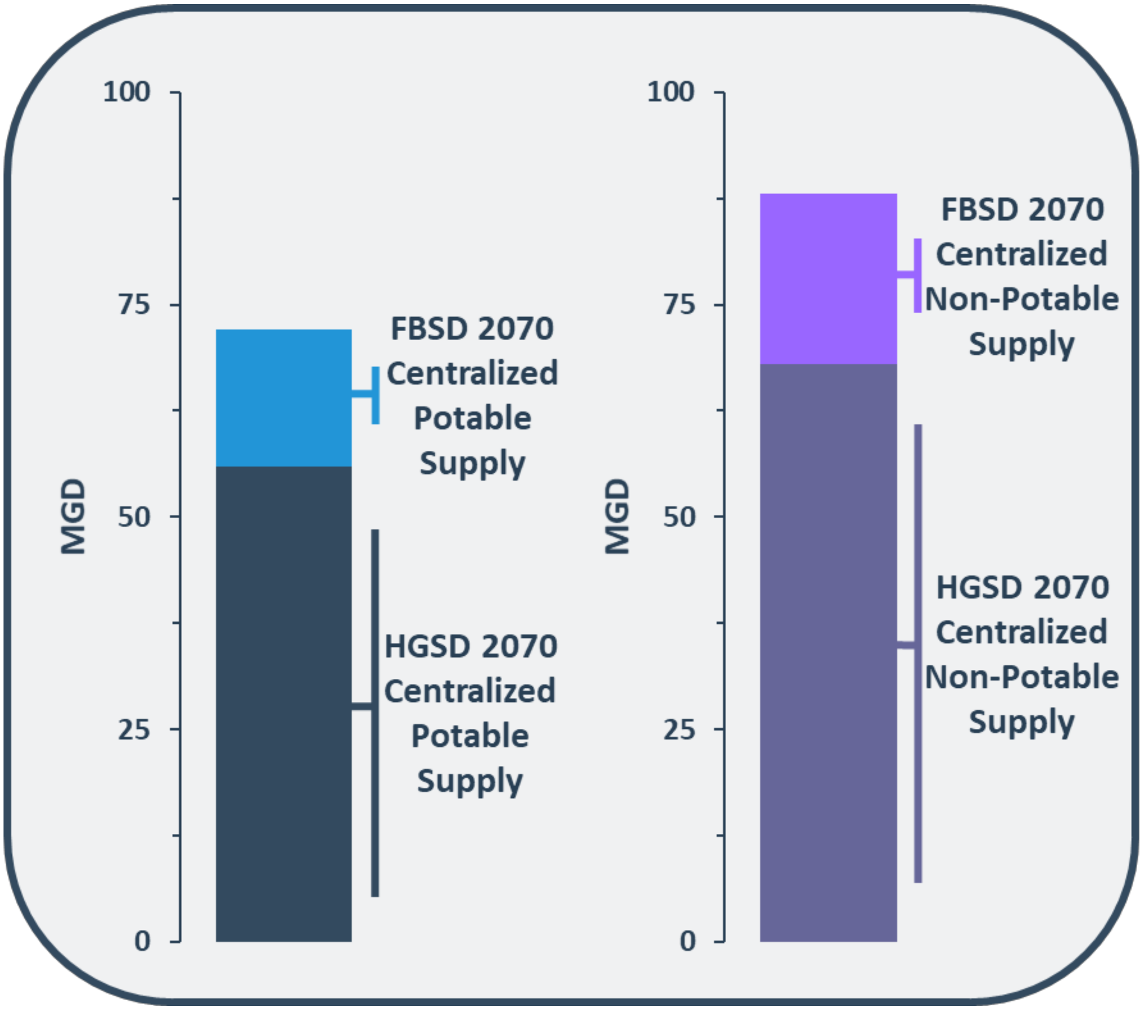

Figure 3-24. 2070 Total Magnitude of Supply from Centralized Reclaimed Water

3.3.5 BUDGETARY COST OPINIONS

Planning level, order of magnitude cost opinions were developed for each water supply option based on consistent "big-picture" assumptions. For the non-potable centralized reclaimed water option, a budgetary cost opinion for a 1.0-MGD system was determined. This capacity was considered sufficiently small so as to be broadly implementable across the Districts' regulatory areas while producing an adequate production capacity to make the installation of a purple pipe network cost-effective. Consistent with **Figure 3-20**, this opinion included construction of a cloth-filtration tertiary treatment unit, additional disinfection, ground storage tank, and a pump station.

For potable centralized reclaimed water treatment, a DPR system was assumed. Although some providers may have access to an adequate environmental buffer for an IPR installation, DPR was considered more broadly applicable across the Districts' regulatory areas. The budgetary cost opinions for the potable centralized reclaimed water option includes cost for a 10 MGD pump station with WWTP effluent storage, treated water storage, brine storage and storage. For treatment, the cost opinion includes cost for strainer, MF/UF units, feed pumps, RO unit, UV AOP and cleaning system, consistent with **Figure 3-21**. Given the more intensive treatment processes involved, this option was sized with a higher production capacity relative to the centralized non-potable option to achieve improved economy of scale.

These costs include the components that are shown in **Figure 3-20** and **Figure 3-21**. The assumptions used for development of capital cost opinions for non-potable and potable centralized reclaimed water supply options are summarized in **Table 3-12** and **Table 3-13**.

Table 3-12. Capital Cost for 1-MGD Non-Potable Centralized Reclaimed Water

Item No.	Capital Cost	2021 Estimated Cost ($)
1	WWTP Effluent Pumping to Reclaimed Treatment	$ 350,000
2	Reclaimed Water Treatment	$ 500,000
3	Treated Water Storage and Pumping	$ 2,575,000
4	Conveyance to Distribution System	$ 1,870,000
5	Site Civil	$ 100,000
6	Land Requirement	$ 300,000
7	Civil, Mechanical, Electrical & Instrumentation	$ 1,077,000
	Subtotal Capital Cost	**$ 6,772,000**
	Contractors Overhead & Profit (15%)	$ 1,016,000
	Mobilization and Demobilization (5%)	$ 339,000
	Permits, Bonds & Insurance (15%)	$ 1,016,000
	Engineering and Design (10%)	$ 678,000
	Contingency (30%)	$ 2,032,000
	Total Capital Cost	**$ 11,853,000**
	Annualized Debt Service Payment ($/yr)	**$ 861,000**

[Assumptions]

1. Includes cost for low lift pump station and 24-inch pipeline from WWTP to reclaimed water treatment facility.
2. Includes cost for 2.5 MGD cloth filtration treatment unit and disinfection.
3. Includes cost for ground storage tank (0.5 MG), reclaimed water pump station (2.5 MGD) and valves and meters.
4. Includes cost for reclaimed water piping ranging from 8-inch to 12-inch in size, valves and meters.
5. Cost for site civil includes re-gradation for construction, excavation and fill.
6. Assumed 3 acres of land for reclaimed WTP construction and average cost of land per acre of $100,000.
7. Miscellaneous - Civil cost is 10%, Mechanical cost is 10% and electrical and instrumentation cost is 15% of respective discipline capital costs.

Table 3-13. Capital Cost for 10-MGD Direct Potable Centralized Reclaimed Water

Item No.	Capital Cost	2021 Estimated Cost ($)
1	WWTP Effluent Pumping and Conveyance to AWTF	$ 8,899,000
2	AWTF	$ 28,990,000
3	Treated Water Pumping and Conveyance to Distribution System	$ 9,599,000
4	Storage	$ 5,000,000
5	Brine Disposal Costs for Deep well Injection	$ 4,044,000
6	Site Civil	$ 374,000
7	Land Requirement	$ 1,000,000
8	Yard Piping	$ 450,000
9	Civil, Mechanical, Electrical and Instrumentation Cost	$ 14,285,000
	Subtotal Capital Cost	**$ 72,641,000**
	Contractors Overhead & Profit (15%)	$ 10,897,000
	Mobilization and Demobilization (5%)	$ 3,633,000
	Permits, Bonds & Insurance (15%)	$ 10,897,000
	Engineering and Design (10%)	$ 7,265,000
	Contingency (30%)	$ 21,793,000
	Total Capital Cost	**$ 127,126,000**
	Annualized Debt Service Payment ($/yr)	**$ 9,236,000**

[Assumptions]
1. Includes cost for 10 MGD pump station and pipeline. Assumed the distance between WWTP and AWTF is 1 mile. 2. Includes cost for strainer, MF/UF units, feed pumps, RO unit, UV AOP and cleaning system. Assumed RO building is 20,000 SF. 3. Includes cost for 10 MGD pump station and pipeline for pumping treated water. Assumed the distance between AWTF and distribution system is 1.5 mile. 4. Includes cost for WWTP effluent storage (1.5 MG), treated water storage (1.5 MG), storage tank for brine (1.5 MG) and storage for chemicals (0.5 MG). 5. RO concentrate will be disposed via deep injection method. Cost for Deep injection wells include logging, testing and surveying, monitoring well, Drilling and Reaming and Installed Casing and Grouting, pumps and 18-inch piping for injection wells. 6. Cost for site civil includes regradation for construction, erosion control, construction entrance, well and equipment pad and paving, excavation and fill. 7. Assumed 10 acres of land will be required for AWTF construction and average cost of land per acre of $100,000. 8. Includes cost for spent backwash pipe, drain pipe and process pipe. Piping costs include material and installation costs. 9. Miscellaneous - Civil cost is 10%, Mechanical cost is 5% and electrical and instrumentation cost is 20% of respective discipline capital costs.

The assumptions used for development of O&M cost opinions for non-potable and potable centralized reclaimed water supply options are summarized in **Table 3-14** and **Table 3-15**.

Table 3-14. O&M Cost for Non-Potable Centralized Reclaimed Water

Item No.	Annual Operation and Maintenance Cost	2021 Estimated Cost ($)
1	Labor	$ 180,000
2	Chemical	$ 68,000
3	Electric Power	$ 76,000
4	Supplies and General Maintenance	$ 68,000
	Subtotal O&M Cost	**$ 392,000**
	Miscellaneous Cost (10%)	$ 40,000
	Total Annual O&M Cost	**$ 432,000**
[Assumptions] 1. Accounts for three FTEs for operating the facility. 2. Cost includes chemicals for treatment and disinfection.		

3. Electricity cost ($0.10/kWh) for treatment, process power, distribution pump power, and building services.
4. Supplies and general plant maintenance cost was assumed to be 1% of capital cost.

Table 3-15. O&M Cost for Direct Potable Centralized Reclaimed Water

Item No.	Annual Operation and Maintenance Cost	2021 Estimated Cost ($)
1	Labor	$ 900,000
2	Chemicals	$ 1,453,000
3	Electric Power	$ 2,738,000
4	Membrane and UV Lamp Replacement	$ 1,453,000
5	Supplies and General Maintenance	$ 1,453,000
	Subtotal O&M Cost	**$ 7,997,000**
	Miscellaneous Cost (10%)	$ 800,000
	Total Annual O&M Cost	**$ 8,797,000**

[Assumptions]
1. Cost for ten FTEs for operating an AWTF.
2. Cost includes chemicals for post treatment. Assumed 2.2% of capital cost.
3. Electricity cost ($0.10/kWh) for AWT facility, brine disposal vis deep well injection, process power, distribution pump power, and building services.
4. Membrane and UV lamp replacement cost was assumed to be 1.8% of capital cost.
5. Supplies and general plant maintenance cost was assumed to be 2% of capital cost.

Summary of the capital, O&M and life-cycle cost opinions are summarized in **Table 3-16** and **Table 3-17**. As shown in **Table 3-16**, the capital cost to develop the centralized non-potable reclaimed water supply option is $11.85 GPD with a range of $8.30 – $17.78 GPD. The total cost for the non-potable reuse water supply option is $3.54 per 1,000 gallons with a range of $2.48 – $5.31 per 1,000 gallons. **Figure 3-25** illustrates the capital and total costs for the centralized non-potable option.

Table 3-16. Non-Potable Centralized Reclaimed Water Life-Cycle Costs

Option No.	Option Name	2021 Estimated Cost ($)
1	Total Capital Cost	$ 11,853,000
2	**Total Capital Cost per GPD ($/GPD)**	**$ 11.85**
3	Annualized Debt Service Payment ($/yr)	$ 861,000

Option No.	Option Name	2021 Estimated Cost ($)
4	Total Annual O&M Cost	$ 432,000
5	Total Annual Capital and O&M Cost ($/yr)	$ 1,293,000
6	Annual O&M Cost ($/1,000 gallons)	$ 1.18
7	**Total Cost ($/1,000 gallons)**	**$ 3.54**

[Assumptions]
3. Amortized for a period of 30 years and 6% interest rate.
5. Based on annual reclaimed water production of 1.0 MGD
6. Based on annual reclaimed water production of 1.0 MGD

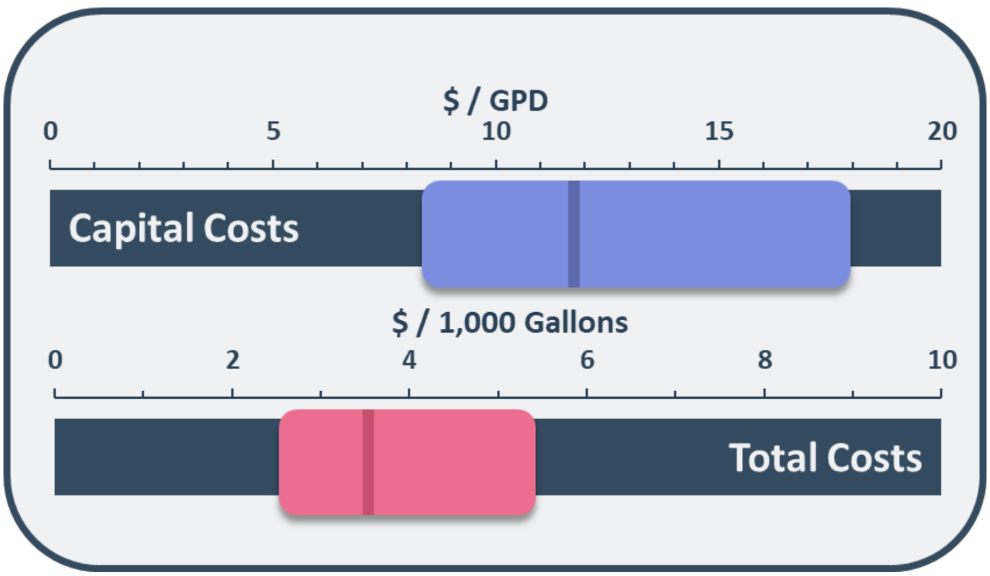

Figure 3-25. Capital and Total Costs for Non-Potable Centralized Reclaimed Water

As shown in **Table 3-17**, the capital cost to develop the DPR supply option is $12.71 GPD with a range of $8.90 – $19.07 GPD. The total cost for the DPR water supply option is $4.94 per 1,000 gallons with a range of $3.46 – $7.41 per 1,000 gallons. Similarly, **Figure 3-26** illustrates the capital and total costs for the centralized potable option.

Table 3-17. Direct Potable Centralized Reclaimed Water Life-Cycle Costs

Option No.	Option Name	2021 Estimated Cost ($)
1	Total Capital Cost	$ 127,126,000
2	**Total Capital Cost per GPD ($/GPD)**	**$ 12.71**
3	Annualized Debt Service Payment ($/yr)	$ 9,236,000
4	Total Annual O&M Cost	$ 8,797,000
5	Total Annual Capital and O&M Cost ($/yr)	$ 18,033,000
6	Annual O&M Cost ($/1,000 gallons)	$ 2.41
7	**Total Cost ($/1,000 gallons)**	**$ 4.94**

[Assumptions]

3. Amortized for a period of 30 years and 6% interest rate.
5. Based on DPR water production of 10 MGD
6. Based on DPR water production of 10 MGD

Figure 3-26. Capital and Total Costs for Centralized Reclaimed Water - Potable

3.3.6 IMPLEMENTATION TIMELINES

Implementation of centralized reclaimed water systems will depend on approach.

Non-potable Reclaimed Water Supply

Depending on the scale, location and installation ease, a purple pipe system can be planned, designed and installed in approximately four to six years. Planning and contractual agreements are needed prior to design and implementation. Timely communications with TCEQ and other permitting agencies is essential for the execution of a non-potable, purple pipe water system. Figure 3-27 illustrates the timelines for planning, design, and construction of a centralized non-potable water system.

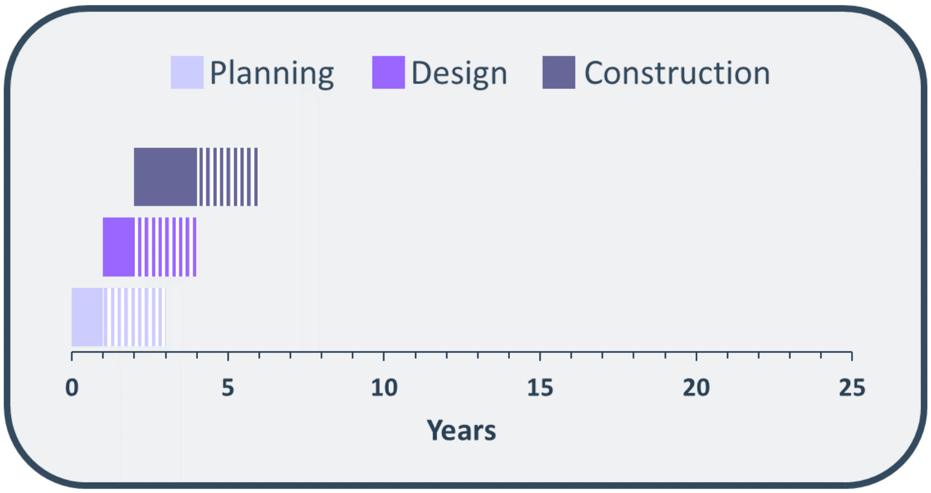

Figure 3-27. Implementation Timelines for Centralized Non-Potable Water Systems

Potable Reclaimed Water Supply

Implementation of potable reuse requires more planning, technology assessments and demonstration and design efforts. Planning for DPR/IPR systems will require extensive stakeholder engagement, public education and outreach, permitting, pilot testing and regulatory approvals. For this reason, it could take 15 years to fully integrate a DPR/IPR water supply. For example, the El Paso Water Utilities (EPWU) Advanced Water Purification Facility or DPR began its planning in the early 2010s. A DPR and IPR feasibility assessment was conducted in 2012, prompting the EPWU Board to approve capital funding to potable reuse in 2013 (Arcadis, 2017). Pilot construction started in early 2015 and now the AWTF is in its final design phase in 2020 (Carollo, 2017). **Figure 3-28** illustrates the implementation timeline of a centralized potable system.

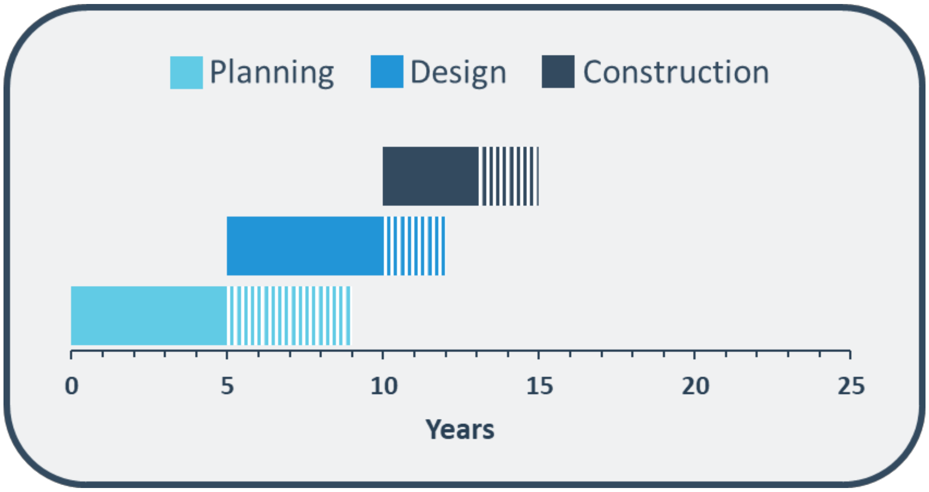

Figure 3-28. Preliminary Implementation Timeline for Centralized Potable Systems

As shown in **Figure 3-28**, planning is the most extensive process of implementing a centralized reclaimed water potable system. This is due to the substantial communication, applications, and lead time needed for approval by the TCEQ and other officials. Design and construction of a potable reclaimed water system requires more time, for the components of such system is advanced and intricate. Thus, it would take roughly 11 to 15 years to implement a centralized potable system.

3.3.7 WATER QUALITY CONSIDERATIONS

Non-potable Reclaimed Water Supply

The TCEQ sets specific standards for reclaimed water. The specific uses and quality criteria for reclaimed water are described in 30 Texas Administrative Code (TAC) §210.32 and §210. 33, respectively.

The TCEQ has two designated classes of non-potable reclaimed water, as determined by end use(s): Type I and Type II. Type I reclaimed water standards apply where people may be present or other uses in which human exposure is possible (30 TAC §210.32(1)). Examples of type I use are residential and urban irrigation of landscape, public parks, school yards, agricultural fields, etc. Type II reclaimed water use includes irrigation in areas where the public does not come into contact with the reclaimed water (30 TAC §210.32(2)). Example uses include dust control, WWTP equipment washdown, cooling tower makeup water, and irrigation at tree farms.

Quality standards for Type I reclaimed water are specified in 30 TAC §210.33(1) and below in **Table 3-18.**

Table 3-18. Quality Standards for Type I Non-Potable Reclaimed Water

Parameters	30-Day Average
BOD5 or CBOD5	5 mg/L
Turbidity	3 NTU
Fecal coliform or E. coli	20 CFU/100 mL*
Fecal coliform or E. coli	75 CFU/100 mL**
Enterococci	4 CFU/100 mL*
Enterococci	9 CFU/100 mL**
* 30-day geometric mean ** maximum single grab sample	

Type II reclaimed water quality standards are specified in 30 TAC §210.33(2)(A), §210.33(2)(B), and below in **Table 3-19**.

Table 3-19. Quality Standards for Type II Non-Potable Reclaimed Water

Parameters	30-Day Average (for a system other than a pond)	30-Day Average (for a pond system)
BOD5	20 mg/L	30 mg/L
CBOD5	15 mg/L	-
Fecal coliform or E. coli	200 CFU/100 mL*	200 CFU/100 mL*
Fecal coliform or E. coli	800 CFU/100 mL**	800 CFU/100 mL** (not to exceed)
Enterococci	35 CFU/100 mL*	35 CFU/100 mL*
Enterococci	89 CFU/100 mL**	89 CFU/100 mL**
* 30-day geometric mean ** maximum single grab sample		

Tertiary treatment and disinfection are required to meet water quality standards for the listed parameters. The purpose of the cloth filtration is to remove the additional solids or particulates needed to meet the turbidity requirements.

Potable Reclaimed Water Supply

The TWDB states important information regarding the water quality standards for DPR in the DPR Resource Document (2015). This document includes the performance targets to inactivate certain microorganisms according to two sources, the WateReuse Research Foundation and the TCEQ.

The TCEQ baseline targets are under the authority of the Safe Drinking Water Act (SDWA), Texas State Health Code, and the TAC; thus, the baseline targets must be achieved in order to obtain project approval (TWDB, 2015). The TCEQ established baseline log removal targets for pathogens such as *Cryptosporidium, Giardia*, and viruses. These removal targets portray the reduction between treated wastewater effluent and finished drinking water (TWDB, 2015). The AWTF processes are to achieve these removal requirements. The TCEQ baseline targets are presented in **Table 3-20**.

Table 3-20. TCEQ Baseline Targets for DPR Pathogen Log_{10} Removal

	Cryptosporidium	Giardia	Virus
Log_{10} Removal	5.5	6	8

The TCEQ also sets project specific requirements for pathogen reduction and inactivation for DPR. Therefore, the baseline targets presented in **Table 3-20** may be increased based on site-specific data. The treatment requirements are determined on a case-by-case basis for DPR and IPR. In DPR, the assigned log removal credits start at the WWTP effluent (TWDB, 2015).

In addition to demonstrating the targets for microorganisms, TWDB describes targets for other constituents of concern such as chemicals, aesthetics, and corrosion control. For chemicals, water quality targets include a minimum compliance with the primary and secondary drinking water maximum contaminant levels (MCLs). Aesthetic targets for potable reuse include certain requirements for color, odor, mineralization, organic matter and organic carbon. These targets are based on secondary MCLs as shown in **Table 3-21**.

The TWDB describes the targets for corrosion control within the drinking water distribution system. Stabilization by alkalinity and calcium hardness is achieved to provide a product water with a Langelier Saturation Index of around 0 and a pH of 7-9 (TWDB, 2015).

Table 3-21. Aesthetic Targets for Potable Reuse (DPR Resource Document, 2015)

	Constituent	Requirements
Aesthetic Targets for Uninformed Consumer	Color, Apparent color units (ACU)	≤ 15
	Odor, Threshold odor number (TON) and flavor profile	≤ 3 No off-flavors
	Mineralization	TDS and hardness similar to local supplies
Aesthetic Targets for Informed Consumer	Dissolved Organic Matter (DOM)	Free of DOM
	Total Organic Carbon (TOC), mg/L or Effluent Organic Matter	≤ 0.5 DOM that is more Natural Organic Matter (NOM)
	Trace organic chemicals	Reduced to acceptable levels
	Performance and health-based chemical indicators	Monitoring Trigger Thresholds (MTTs) and Reporting limits suggested by the TWDB

At the state level, the TCEQ recommends monitoring three levels of chemical contaminants:

- Level 1: Chemicals with enforceable MCLs in the country, state, region, or province of the water purification facility
- Level 2: Unregulated chemicals of special interest to potable reuse
- Level 3: Performance Based Indicators (PBIs)

PBI is an individual chemical that is measured to monitor the effectiveness of a treatment process (Thompson and Dickenson, 2020). Thompson and Dickenson (2020) developed criteria for performance-based indicators (PBIs) and proposed a list of specific chemical constituents that could serve as PBIs to monitor effectiveness of ozone, GAC, and AOP. The proposed criteria for PBIs included concentration, prevalence, measurability, specificity, sensitivity, and diversity. It was concluded that PBIs should occupy a "sweet spot" at which high percentage removal is possible (Thompson and Dickenson, 2020). Thus, the most promising PBI for ozonation is acesulfame, meprobamate or perfluoroheptanoic acid for GAC, and iohexol for UV photolysis (Thompson and Dickenson, 2020). However, site-specific pilot-scale testing is recommended.

3.3.8 PERMITTING AND LEGAL CONSIDERATIONS

Non-Potable Reclaimed Water Supply

30 TAC Chapter 210 lists the general quality, design, and operation requirements for the use of reclaimed water. This chapter also denotes the responsibilities of the reclaimed water producer, provider, and user. These include, but are not limited to, sampling and analysis, unauthorized use notification, compliance with water quality standards, and maintenance and provision of records.

If any party fails to comply with terms of Chapter 210, the executive director may require a permit or permit amendment. Furthermore, commission may issue enforcement order or civil penalties.

Potable Reclaimed Water Supply

Approval process of DPR involves regulatory provisions set by the TCEQ, SDWA, and the Texas Health and Safety Code (THSC). Source water must be evaluated prior to authorization for treatment and potable consumption. The TCEQ uses THSC §341.031-0315 as the statutory basis for review and approval of new sources of water and mandates a number of regulatory provisions.

A detailed source water quality assessment must be provided and approved by TCEQ before DPR implementation (30 TAC §290.41(e)(1)(F)). However, the conventional water treatment provisions in 30 TAC Chapter 290, Subchapter D are not sufficient for DPR projects, as advanced treatment is required. Thus, the TCEQ must evaluate each DPR project on an individual basis.

For authorization, 30 TAC §210.42 and §210.43 state that the reclaimed water provider or user who proposes to utilize reclaimed water in another matter (for potable use), a notification identifying the alternative proposal must be filed to request approval by the executive director. The executive director may request additional information or act on the request within 60 days. The TWDB describes a recommended process for seeking regulatory approval for a DPR project (TWDB, 2015). More information is available in the 2015 TWDB DPR Resource Document.

3.3.9 VULNERABILITY TO CLIMATE CHANGE

It is understood that reclaimed water practices are resilient to climate change, illustratively scored in **Figure 3-29**. Projected 2050 water consumption assumptions show that about 800 MGD of wastewater from indoor use will be collected by WWTPs. Of this amount, 50% of the effluent (400 MGD) would be reclaimed. In short, wastewater collection is agreeably consistent year-round; thus, there is a local, reliable water supply and an effect of climate change, like a drought, would not impact it severely.

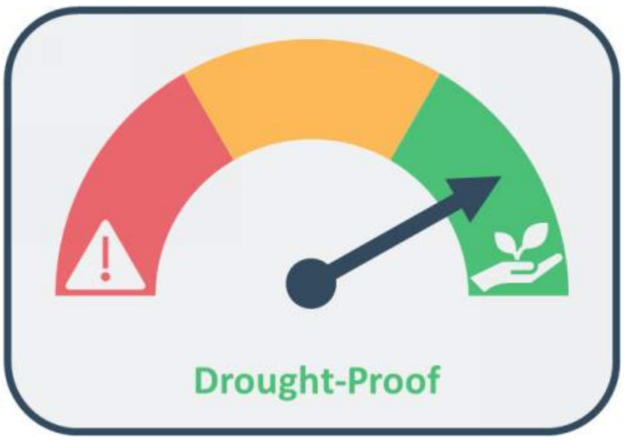

Figure 3-29. Climate Resiliency Rating of Centralized Reclaimed Water

Many Texas cities such as Big Spring, Wichita Falls, and Brownwood, have evaluated or implemented DPR and IPR in response to extreme drought and limited water sources, (USEPA and CDM Smith, 2017).

3.3.10 SUBSIDENCE IMPACTS

Non-potable Reclaimed Water Supply

Water will not be injected to or withdrawn from the ground for this approach, so no impacts to subsidence are expected as shown in **Figure 3-30**.

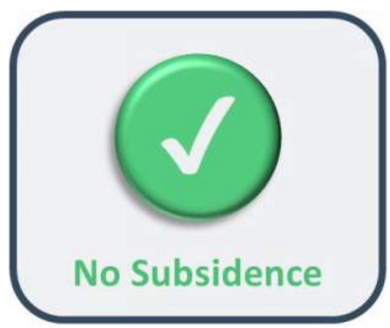

Figure 3-30. Subsidence Impacts of Centralized Reclaimed Water

Potable Reclaimed Water Supply

In DPR practices, treated wastewater is sent directly to WTPs to be mixed with other water sources for treatment and distribution. As an additional intake source for WTPs, DPR would not require any water injection or withdrawal from the ground. Therefore, no impacts to subsidence are expected.

In IPR practices, an AWTF sends treated wastewater to an environmental buffer such as a surface water source before treatment in a drinking WTP. Water is not being injected or withdrawn from the ground for this approach; thus, no impacts to subsidence are expected.

3.4 DECENTRALIZED RECLAIMED WATER TREATMENT

Similar to the centralized reclaimed water options previously discussed, wastewater satellite plants and on-site reuse are considered together as a single "decentralized" reclaimed water AWS. These two approaches are similar in terms of implementation considerations, infrastructure requirements and treatment technologies, with the key difference being that the satellite plants divert wastewater from the collection system while on-site reuse diverts wastewater prior to it entering the collection system. Similar to other reclaimed water options, decentralized water treatment provides a highly reliable supply, and their decentralized nature allows them to be located closer to the end-users of non-potable reclaimed water.

3.4.1 IMPLEMENTATION APPROACH

Non-Potable Reuse - Satellite Plants

MBR technology is the preferred treatment approach for satellite treatment plants. The MBR technology provides unique benefits such as compact footprint, proven technology and automated nature that will consistently produce high-quality Type I effluent. Satellite plants would be located at or near larger, regional wastewater lift stations and high-volume users. The key components of the MBR treatment process include primary treatment, membrane racks, disinfection/chemical storage, sludge pumps, and a pump station. A schematic of a MBR treatment plant is shown in **Figure 3-31**.

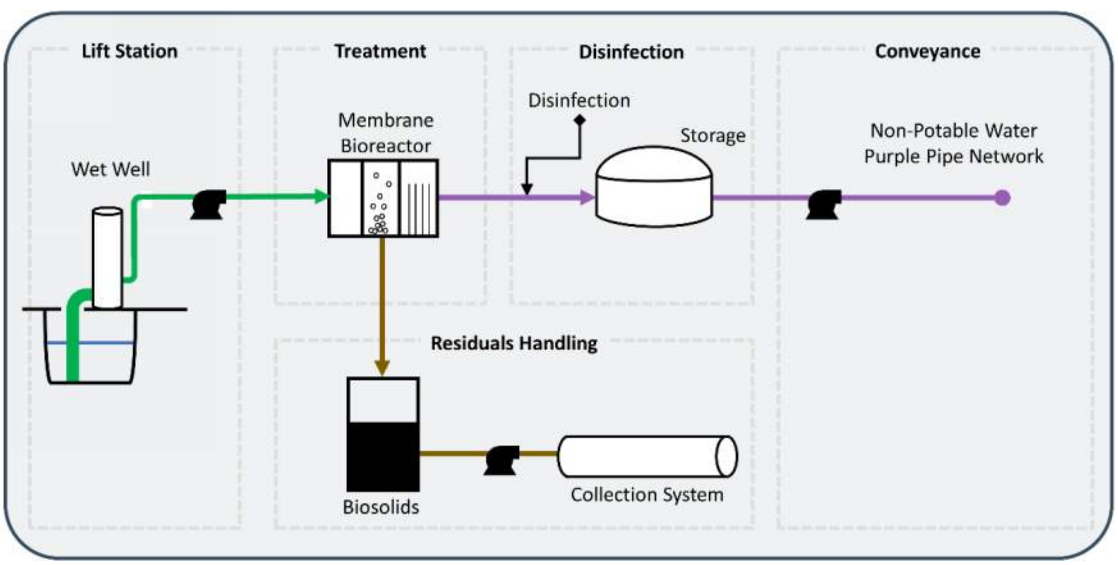

Figure 3-31. Proposed Treatment Process for Satellite MBR Treatment Plant

As shown in **Figure 3-31**, wastewater will be treated in a primary treatment facility and sent to a regional lift station. Next, the effluent will undergo MBR treatment (anoxic zone mixing, aeration, and membrane racks) to produce Type I reclaimed water. During the treatment process, waste sludge or biosolids are returned to the collection system. Lastly, the Type I effluent is dosed with disinfectant to inactivate pathogens and maintain a residual in the non-potable water distribution system.

Preferred locations for wastewater satellite plants are within 0.5 mile, and ideally 1,000 feet, from lift stations. Additional factors such as availability of space and proximity to potential customers will influence the location of a satellite plant.

Non-Potable Reuse - On-site Plants

The implementation approach for on-site reuse is similar to satellite plants given the following assumptions:

- Raw wastewater quality is comparable to standard municipal wastewater
- Removal of facility-specific industrial contaminants (e.g., metals) is not considered and requires separate pre-treatment

Unlike satellite plants, on-site reuse would require lift station installations and all facilities (treatment, piping, etc.) would be housed entirely on a facility property. On-site reuse facilities are generally constructed at industrial facilities with high non-potable water demands. Factors such as adequate space and customer interest will dictate the implementation of the on-site reuse plant.

3.4.2 REGULATORY AREA(S) SERVED

Non-Potable Reuse - Satellite Plants

Satellite plants could be applicable anywhere in the regulatory areas, given the requirements are met per 30 TAC Chapter 321. This includes a domestic wastewater permit for a WWTP located at the terminus of the collection system and authorization to use reclaimed water. In addition, the satellite plant should not alter the permitted flow or effluent limits of the associated WWTP. In residential areas, 30 TAC Chapter 321 has certain restrictions for placement and use of satellite plants, like buffer zone requirements and odor control. Commercial and industrial areas are easier from a permitting standpoint.

Non-Potable Reuse - On-site Plants

On-site reuse could be implemented at industrial facilities with high demands, where it would be cost effective. Thus, while on-site reuse is potentially implementable across the Districts' regulatory areas, it will be subject to site-specific supply and demand considerations.

3.4.3 ANTICIPATED USERS

Major end uses for non-potable water generated by satellite plants could be landscape irrigation, golf courses, community parks, school play grounds, and amenity lake filling.

High demand customers like refineries, chemical plants, or other industrial facilities could use non-potable water generated by on-site plants. A few industrial facilities in the regulatory areas already use on-site reuse plants and the water produced for industrial process water.

3.4.4 MAGNITUDE OF SUPPLIES

Of the projected 2070 municipal potable water consumption (1,290 MGD), it was assumed that 50% (approximately 650 MGD) would be consumed by indoor water demands and the remaining 50% (approximately 650 MGD) will be applied for outdoor water uses. The indoor water (approximately 650 MGD) will be conveyed through wastewater collection systems to centralized WWTPs or publicly owned treatment works. Half of the WWTP effluent (320 MGD) could be developed as centralized and decentralized reclaimed water. The other half of treated wastewater could be discharged to natural streams, wetlands and other per the regulatory requirements in the discharge permits. It was assumed that of the total available reclaimed water supply (320 MGD), approximately 10% with an additional 40% factor to account for the seasonal demand of decentralized non-potable water (yielding 13 MGD) could be developed using decentralized reuse plants as shown in **Figure 3-23**. Please refer to **Figure 3-32** for the magnitude of decentralized water supply for 2070.

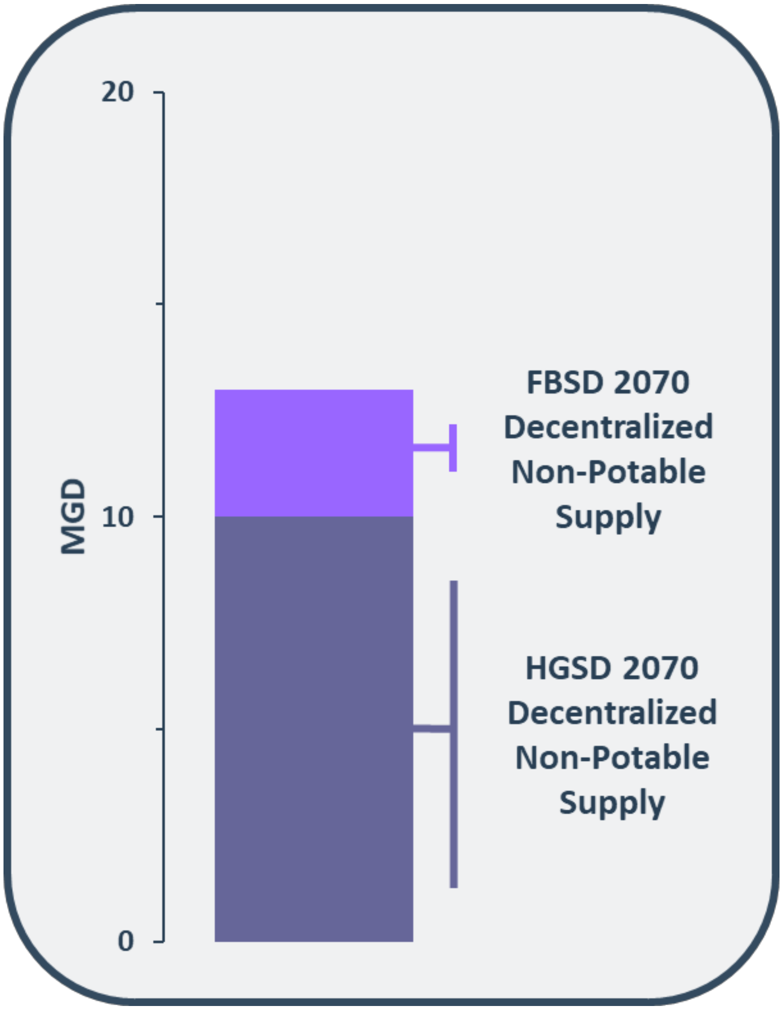

Figure 3-32. 2070 Total Magnitude of Supply from Decentralized Reclaimed Water

3.4.5 BUDGETARY COST OPINIONS

Planning level, order of magnitude cost opinions were developed for each water supply option based on consistent "big-picture" assumptions. For the decentralized non-potable reclaimed water option, a budgetary cost opinion for a 0.4-MGD annual yield MBR system was determined. Although this production magnitude would limit implementation to larger, more regional lift stations, smaller installations were considered unlikely to yield sufficient economy-of-scale to be competitive with other AWS options and insufficient to appreciably impact regional AWS supply totals. This sizing was informed by professional judgment based on prior reclaimed water supply sizing efforts and a TWDB study demonstrating that satellite reclaimed water facility sizing strongly influences unit production costs (TWDB, 2012). Consistent with the components shown in **Figure 3-31**, this option included MBR treatment, a ground storage tank, and a reclaimed water pump station. The assumptions used for development of capital and O&M cost opinions for this decentralized reclaimed water supply option are summarized in **Table 3-22** and **Table 3-23.**

Table 3-22. Capital Cost for 0.4-MGD Decentralized Reclaimed Water – MBR

Item No.	Capital Cost	2021 Estimated Cost ($)
1	Wastewater Intake	$ 195,000
2	Wastewater Treatment	$ 1,450,000
3	Reclaimed Water Storage and Pumping	$ 700,000
4	Odor Control	$ 225,000
5	Non-Reclaimed Wastewater Disposal	$ 145,000
6	Site Civil	$ 53,000
7	Land Requirement	$ 200,000
8	Yard Piping	$ 20,000
9	Civil, Mechanical, Electrical and Instrumentation Cost	$ 310,000
	Subtotal Capital Cost	**$ 3,298,000**
	Contractors Overhead & Profit (15%)	$ 495,000
	Mobilization and Demobilization (5%)	$ 165,000
	Permits, Bonds & Insurance (15%)	$ 495,000
	Engineering and Design (10%)	$ 330,000
	Contingency (30%)	$ 990,000
	Total Capital Cost	**$ 5,773,000**
	Annualized Debt Service Payment ($/yr)	**$ 420,000**

[Assumptions]
1. Includes cost for upsizing of pumps in existing lift station and cost for piping from lift station to satellite MBR plant.
2. Includes cost for 1-MGD MBR package plant and disinfection.
3. Includes cost for GST (0.5 MG), reclaimed water pump station (1 MGD) and valves and meters.
4. Cost for odor control.
5. Includes cost for pump station and non-reclaimed WW piping from satellite plant to lift station.
6. Cost for site civil includes regradation for construction, erosion control, construction entrance, well and equipment pad and paving, excavation and fill.
7. Assumed 2 acres of land will be required for package MBR plant and average cost of land of $100,000 per acre.
8. Includes cost for process pipe, by-pass pipe and drain pipe. Piping costs include material and installation costs.
9. Miscellaneous - Civil cost is 10%, Mechanical cost is 5% and electrical and instrumentation cost is 10% of respective discipline capital costs.

Table 3-23. O&M Cost for Decentralized Reclaimed Water - MBR

Item No.	Annual Operation and Maintenance Cost	2021 Estimated Cost ($)
1	Labor	$ 60,000
2	Chemicals	$ 30,000
3	Power	$ 34,000
4	Membrane Replacement	$ 50,000
5	Supplies and General Maintenance	$ 50,000
	Subtotal O&M Cost	**$ 224,000**
	Miscellaneous Cost (10%)	$ 23,000
	Total Annual O&M Cost	**$ 247,000**

[Assumptions]
1. Cost for one FTE for operating MBR plant.
2. Cost includes chemicals for treatment and disinfection.
3. Electricity cost ($0.10/kWh) to operate package plant, process power, distribution pump power, and building services.
4. Membrane replacement cost was assumed to be 1.5% of capital cost.
5. Supplies and general plant maintenance cost was assumed to be 1.5% of capital cost.

Summary of the capital, O&M and life-cycle cost opinions are summarized in **Table 3-24**. As shown in this table, the capital cost to develop this water supply option is $14.43 GPD with a range of $10.10 – $21.65 GPD. The total cost for this water supply option is $4.57 per 1,000 gallons with a range of $3.20 – $6.86 per 1,000 gallons.

Table 3-24. Decentralized Reclaimed Water Supply Life Cycle Costs

Option No.	Option Name	2021 Estimated Cost ($)
1	Total Capital Cost	$ 5,773,000
2	**Total Capital Cost per GPD ($/GPD)**	**$ 14.43**
3	Annualized Debt Service Payment ($/yr)	$ 420,000
4	Total Annual O&M Cost	$ 247,000
5	Total Annual Capital and O&M Cost ($/yr)	$ 667,000
6	Annual O&M Cost ($/1,000 gallons)	$ 1.69
7	**Total Cost ($/1,000 gallons)**	**$ 4.57**

[Assumptions]

3. Amortized for a period of 30 years and 6% interest rate
5. At a production of 0.4 MGD/146 MGY
6. At a production of 0.4 MGD/146 MGY

Figure 3-33 illustrates the capital and total costs for the decentralized reclaimed water supply development and integration.

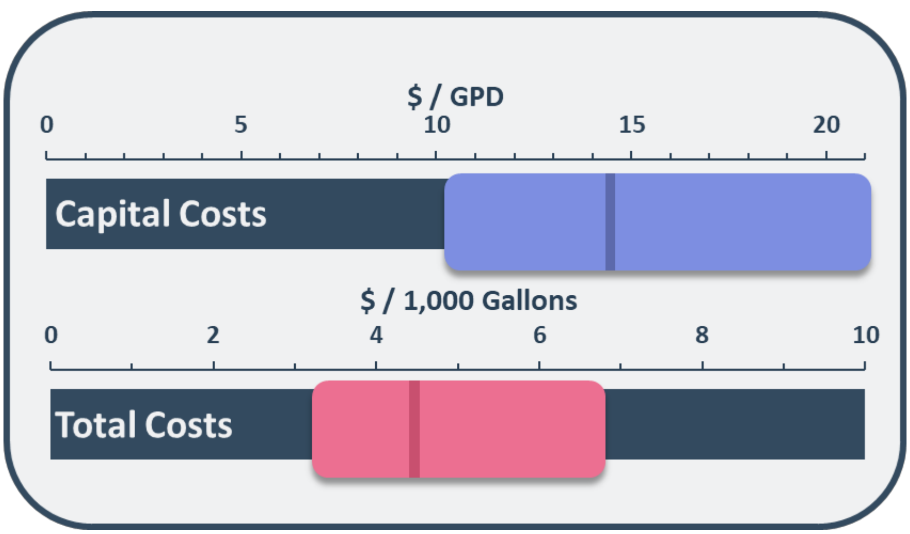

Figure 3-33. Capital and Total Costs for Decentralized Reclaimed Water Supply

3.4.6 IMPLEMENTATION TIMELINES

Non-Potable Reuse - Satellite plants

The largest active satellite plant in Texas uses MBR technology and is in Midland, Texas (Satellite Reuse Plant). It was permitted through 30 TAC Chapter 321, Subchapter P regulations in 2008, started construction in 2012, and opened to serve Type I reclaimed water in 2014. The full implementation timeline for the costed decentralized MBR satellite plant is conservatively estimated at eight to ten years. However, shorter durations may be achievable if permitting proven treatment technologies. **Figure 3-34** illustrates the implementation timeline for a decentralized MBR satellite plant.

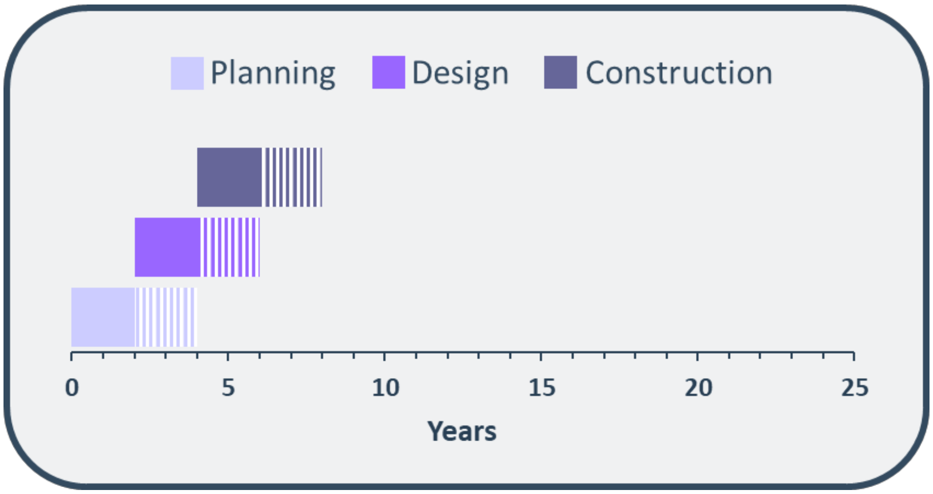

Figure 3-34. Preliminary Implementation Timeline for Decentralized MBR Satellite Plant

As shown in **Figure 3-34**, construction could require the most time in the implementation of an MBR satellite plant. This is due to the location restrictions and preferences (in close proximity to lift stations). Overall, implementing a satellite plant could take up to eight years from concept to completion.

Non-Potable Reuse - On-site Plants

Private undertaking of implementing on-site reuse quickens the timeline. Regulatory review is still needed per 30 TAC Chapter 210, Subchapter A. However, planning and design timelines are likely shorter; thus, it could take approximately 5 years to implement on-site reuse.

3.4.7 WATER QUALITY CONSIDERATIONS

Non-Potable Reuse - Satellite plants

As defined in the 30 TAC §210.32, Type I reclaimed water effluent is intended for end uses in which human exposure is likely, while Type II reclaimed water effluent includes uses in areas where the public access is restricted or unlikely to occur. Both types of reclaimed water have quality standards (30-day average limits) established by the TCEQ (refer to **Table 3-18** and **Table 3-19**). Based on the end use, the MBR treatment and disinfection systems have to meet the appropriate water quality standards for the listed parameters.

The reclaimed water producer, or satellite plant, can only distribute reclaimed water that meet quality standards and must perform minimum sampling and analysis frequency as noted in 30 TAC §210.34.

An additional requirement specific to satellite plants is that biosolids cannot be stored onsite and must be returned to the collection system. This diversion of water, but not solids, results in concentration of the wastewater stream downstream of the satellite plant diversion point, which can have treatment impacts at the downstream WWTP.

Non-Potable Reuse - On-site Plants

The TCEQ sets specific water quality standards for industrial reclaimed water. The quality criteria and specific uses for reclaimed water are described in 30 TAC Chapter 210, Subchapter E.

On-site reuse of industrial reclaimed water is exempted from Type I/Type II requirements, provided that the reclaimed water is not co-mingled with municipal wastewater generated on-site. On-site municipal water reclamation would follow water quality standards stated in 30 TAC §210.32. On-site industrial reclaimed water treatment requirements are case-specific.

Two types of reclaimed water authorization are specified: Level I and Level II. Producers eligible for Level I authorization are those who use wastes like machine condensate, detergent/chemical free wash water, non-contact cooling water, or wastewater with limitations on effluent concentrations on-site (30 TAC §210.53(a)). Level I industrial reclaimed water quality places limits on parameters such as TOC, oil and grease, metals, etc. (30 TAC §210.53(b)). Threshold levels are stated in 30 TAC §210.53(a)(9) and **Table 3-25**.

Table 3-25. Water Quality Threshold Levels for Industrial Reclaimed Water

	Parameter	Threshold (mg/L)	Minimum Analytical Level (mg/L)
Conventionals & Non-conventionals	Total Organic Carbon	55	-
	Oil and Grease	10	-
	Total Dissolved Solids	2000	-
	Nitrate Nitrogen	10	-
Metals	Antimony, total	0.09	0.03
	Arsenic, total	0.030	0.010
	Barium, total	0.030	0.010
	Beryllium, total	0.015	0.005
	Cadmium, total	0.003	0.001
	Copper, total	0.030	0.010
	Lead, total	0.015	0.005
	Manganese	0.05	-
	Mercury, total	0.0002	0.0002
	Nickel, total	0.030	0.010
	Selenium, total	0.030	0.010
	Silver, total	0.006	0.002
	Thallium, total	0.030	0.010
	Zinc, total	0.015	0.005
	Cyanide, free	0.200	-

Producers are eligible for Level II authorization for any of the following:

- Industrial reclaimed water containing pollutant concentrations greater than Level I thresholds
- Industrial reclaimed water containing any amount of domestic wastewater
- Other options listed in 30 TAC §210.53(b)(1-5)).

Wastewater containing radioactive material, pesticides, or other hazardous substances are not covered by the TAC and are prohibited from reclaimed water use (30 TAC §210.54).

3.4.8 PERMITTING AND LEGAL CONSIDERATIONS

Non-Potable Reuse - Satellite plants

TCEQ establishes restrictions and regulations on reclaimed water production facilities or satellite plants in 30 TAC Chapter 321, Subchapter P. To produce reclaimed water, the applicant must have a domestic wastewater permit and authorization to use reclaimed water.

Satellite plants have restrictions on hydraulic capacities, flow rates, design, and treatment processes (30 TAC §321.307). Most of these restrictions are set to not interfere with the operations of the domestic WWTP.

Other key requirements include the following:

- The permittee must be the utility operating downstream of the WWTP
- Solids must be returned to the collection system
- The satellite plant must meet strict buffer zone and odor control requirements near residential areas.

A satellite must locate each treatment unit at least 150 feet from the nearest property line. Reclaimed water production facilities may qualify for enhanced buffer zone requirements if treatment units are located in an enclosed building, equipped with exhaust air systems, and odor control technology.

More information on the permitting and legal considerations for satellite plants can be found in 30 TAC Chapter 321, Subchapter P.

Non-Potable Reuse - On-site Plants

The TCEQ sets regulations for industrial reclaimed water in 30 TAC Chapter 210, Subchapter E. Producers eligible for Level I authorization do not need any notification or written approval by the Executive Director. Also, no additional sampling or monitoring is required (30 TAC §210.57(a)). On the other hand, producers requesting Levell II authorization must submit an application to the Executive Director and receive approval. In addition, sampling reclaimed water after final treatment for the parameters listed in 30 TAC §210.56(d)(1)(A-C) is required for Level II authorizations. An industrial reclaimed water producer must maintain records of notifications made to the executive director, monitoring activities, and maintain an operating log. More information and regulations regarding industrial reclaimed water can be found in 30 TAC Chapter 210, Subchapter E.

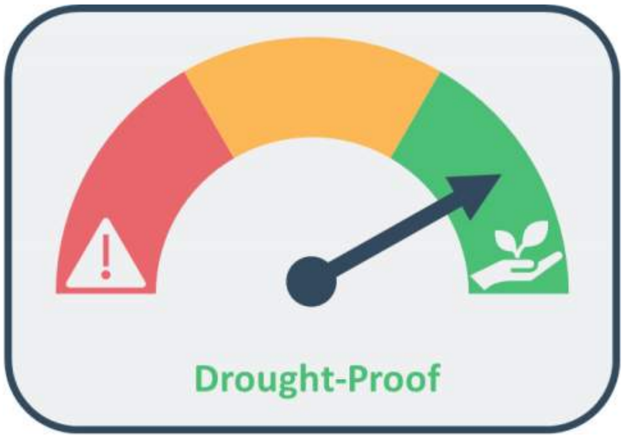

Figure 3-35. Climate Resiliency Rating of Decentralized Reclaimed Water

3.4.9 VULNERABILITY TO CLIMATE CHANGE

Reclaimed water is resilient to climate change. Irrespective of climate variations, indoor water usage will continue and generate wastewater, source for reclaimed water. For the same reason, decentralized reclaimed water systems are relatively resilient to climate change, as shown in **Figure 3-35**.

3.4.10 SUBSIDENCE IMPACTS

Given that the supply is a wastewater collection system, decentralized reclaimed water treatment will have no direct impacts on subsidence, as shown in **Figure 3-36**.

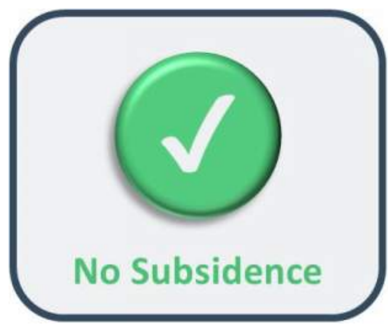

Figure 3-36. Subsidence Impacts of Decentralized Reclaimed Water

3.5 BRACKISH GROUNDWATER DESALINATION

Brackish groundwater desalination is one of two subsurface AWS options retained for further analysis. It is already being evaluated regionally and is gaining increased interest, particularly in areas where surface water supplies may be unavailable. Further, relative to surface water supplies, this option is relatively drought resistant. The necessary treatment technologies, specifically RO membranes, are well understood, though somewhat energy-intensive. Given that this option withdraws groundwater, albeit from different depths/formations, there is an inherent risk of subsidence with this option. It may be possible to adequately mitigate subsidence impacts through careful system design and operation. Regardless, brackish groundwater desalination was considered to be sufficiently promising to warrant further investigation and characterization.

3.5.1 IMPLEMENTATION APPROACH

The TWDB defines brackish groundwater as that having total dissolved solids between 1,000 and 10,000 mg/L. The Districts have studied the occurrence of brackish groundwater within the Gulf Coast Aquifer in their regulatory areas and in surrounding counties (INTERA et al., 2017). Significant volumes of brackish groundwater exist throughout the Gulf Coast Aquifer including the Chicot, Evangeline and Jasper aquifers. However, the evaluation presented here focuses on the Jasper Aquifer portion of the Gulf Coast Aquifer because it is deeper and likely less susceptible to compaction that leads to subsidence than the overlying Chicot and Evangeline aquifers. Approximately 60 percent of the groundwater in the Jasper Aquifer within the Districts contains saline groundwater (TDS greater than 10,000 mg/L) and generally at depths greater than 5,000 feet. Approximately 37 percent of the groundwater is brackish and the small remainder is fresh (INTERA et al., 2017).

Although there are significant quantities of brackish groundwater in storage within the Districts, there are few existing brackish wells in the Jasper Aquifer because, historically, there has been access to high-quality fresh groundwater at shallower depths. However, Cinco MUD 1 in Fort Bend County has drilled a brackish Jasper Aquifer public water supply well capable of producing approximately 1,200 gallons per minute (GPM) with potential plans to drill a second well in the near future. The HGSD has five wells permitted by Denbury Onshore, LLC which would produce saline groundwater from a depth of 4,600 feet below ground surface (BGS). The groundwater use is for secondary recovery in a depleted field and no groundwater has been produced from these wells in recent history.

A primary objective of the District Regulatory Plan is to reduce the reliance on pumping from groundwater to mitigate subsidence. The current District Regulatory Plan requires reductions in groundwater pumping and, in turn, a conversion from groundwater production to AWS options. The need for water, as the region grows, coupled with the regulatory reductions in groundwater pumping has created interest in unconventional water sources which include brackish groundwater development. The District realizes the potential for brackish groundwater development in the region but also recognizes that future development of the brackish groundwater resources requires an improved understanding of these historically undeveloped resources and their potential to cause subsidence. To better understand this, the District recently completed a study to assess the risk associated with development of brackish groundwater in the Jasper Aquifer (INTERA et al., 2018).

The key components of a brackish groundwater desalination supply are shown in **Figure 3-37**. A typical brackish desalination system will include one or more wells drilled into the Jasper Aquifer to produce water that is then conveyed to a central facility. At the central desalination facility, the water is initially treated with screens, granular media filters and/or MF/UF membranes to remove any sand, silt and/or co-occurring contaminants (i.e., arsenic, iron, manganese, sulfides etc.). The filtered water is then conveyed through brackish RO membranes to remove the dissolved minerals and salts. The product or permeate water from the RO membranes is then blended with a by-pass stream as shown in **Figure 3-37.** Blending the RO product water with the by-pass stream allows for stabilization of the treated water in terms of pH, alkalinity and hardness. The treated, blended water is disinfected and pumped to the distribution system. The concentrate or brine stream from the RO is collected and disposed using the appropriately permitted disposal methods. The brine disposal methods include deep well injection, discharge to a natural stream, or wastewater collection system.

The Cinco MUD 1 facility includes pre-treatment of the brackish groundwater with oxidation and MF membranes to remove co-occurring contaminants (such as arsenic and iron) and degasification to remove naturally-occurring methane. This facility also uses blending of microfiltered water with RO product water to stabilize the treated water.

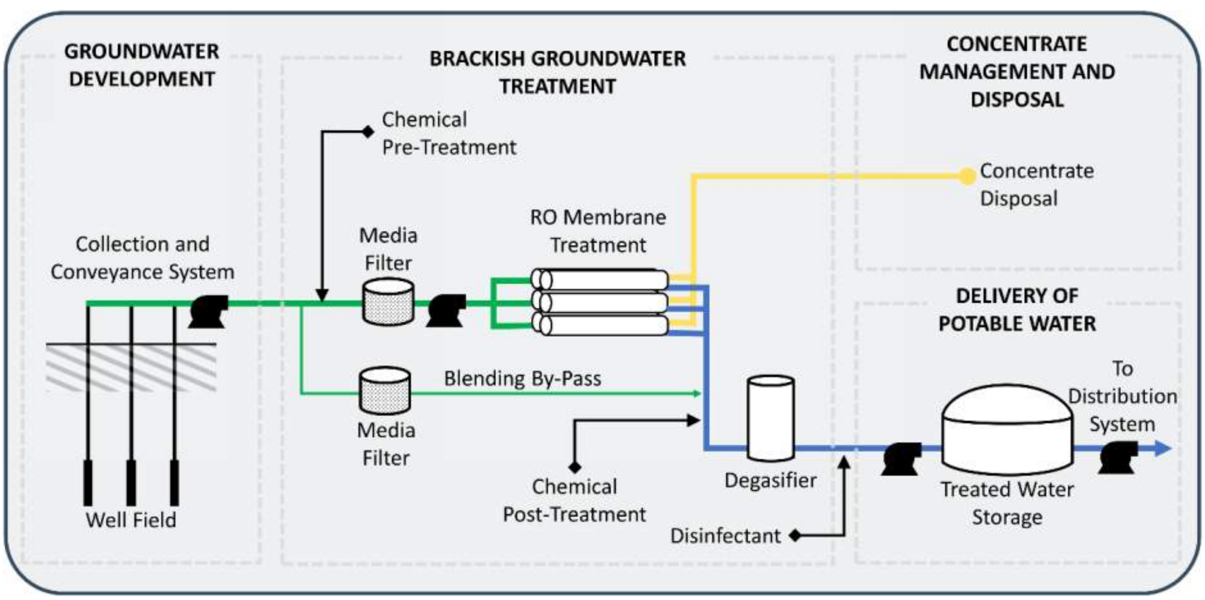

Figure 3-37. Process Flow Diagram for Brackish Groundwater Desalination

3.5.2 REGULATORY AREA(S) SERVED

The evaluation of brackish groundwater desalination as a potential AWS is limited to those areas of the Jasper Aquifer that predominantly contain brackish groundwater (TDS of 1,000 to 10,000 mg/L) in storage. **Figure 3-38** defines the general zone where development of brackish groundwater within the Districts may be viable. The northern boundary is consistent with the downdip limit of freshwater producing wells in the Jasper Aquifer used in INTERA et al. (2018). The downdip (southeastern) boundary of the brackish Jasper Aquifer zone is defined as the approximate limit of groundwater of TDS less than 10,000 mg/L. **Figure 3-38** also shows the approximate location where the base of the Jasper Aquifer is at a depth of 5,000 feet BGS. Few wells would be expected to be completed at depths greater than 5,000 feet because of economic and water quality considerations. From a review of **Figure 3-38,** brackish Jasper Aquifer groundwater could potentially be accessed in portions of each regulatory area in HGSD and FBSD.

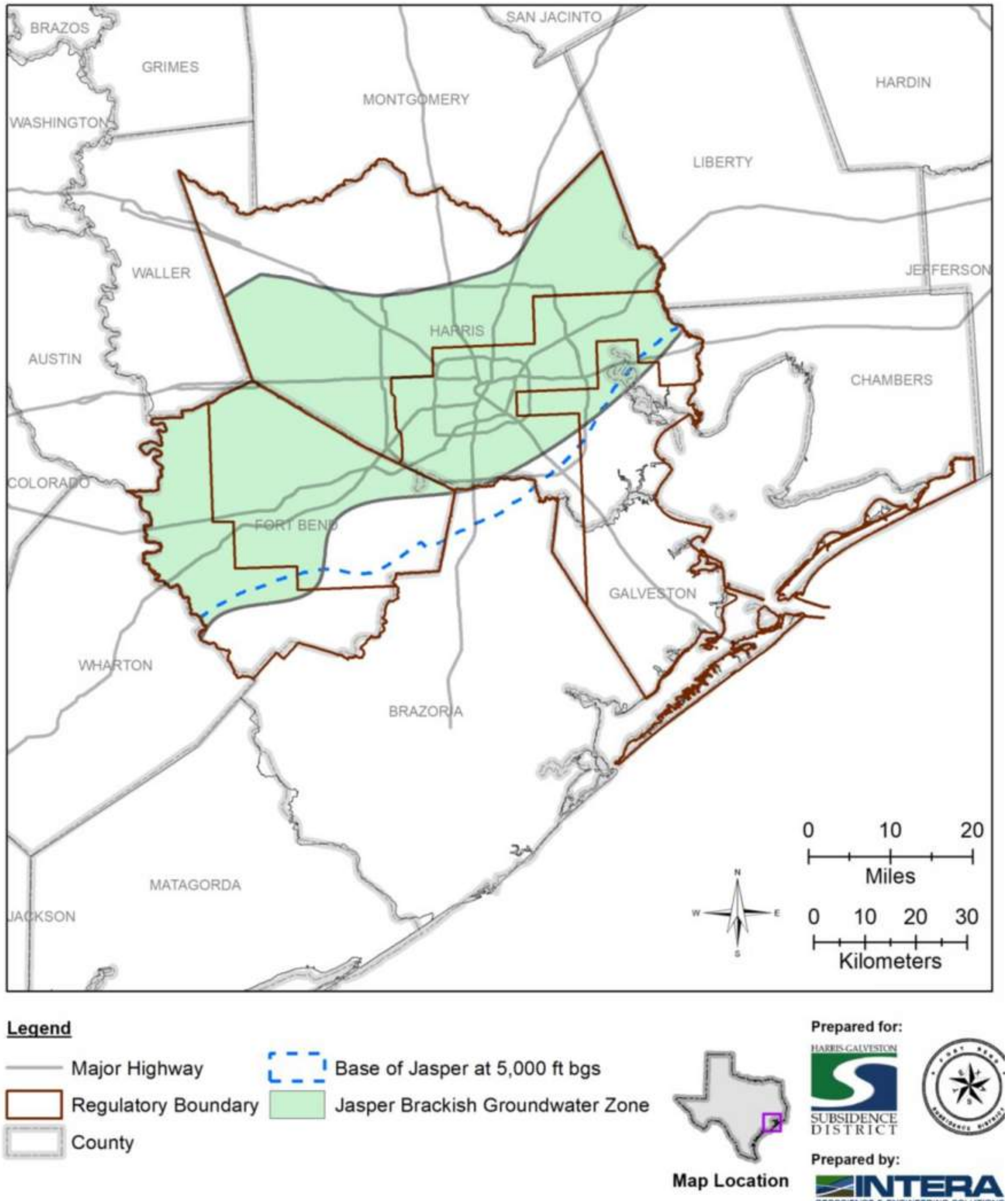

Figure 3-38. Regulatory Areas Served by Jasper Brackish Groundwater

3.5.3 ANTICIPATED USERS

As discussed in Section 3.5.1, there are current brackish groundwater wells within the Districts but very little groundwater production relative to the fresh-water production. Current users of brackish (or saline) groundwater include one Public Water System and one oil and gas operator.

The 2021 RWP anticipates the use of brackish groundwater as a potential unconventional resource for users that are either far removed from more conventional water resources/providers or are limited in their access to fresh-water resources. In addition to generic brackish groundwater production as an alternative, the 2021 RWP identifies specific brackish groundwater projects in Montgomery County (Catahoula Aquifer) and Brazoria County (Chicot or Evangeline aquifers). Brackish groundwater development is not currently identified as an AWS strategy in any District Well Permit or GRP, but there has been some interest in the municipal and industrial sectors.

3.5.4 MAGNITUDE OF SUPPLIES

The potential magnitude of supply from development of brackish groundwater in the Districts is influenced by many factors. Some of these factors such as aquifer depth and water quality are incorporated into the development of the brackish groundwater zone shown in **Figure 3-38**. The compaction and subsidence that occurs – or is expected to occur – due to development of brackish groundwater also strongly influences the magnitude of supply. The more susceptible the brackish portions of the Jasper Aquifer are to subsidence, the less it represents an alternative to groundwater produced from shallower units.

Figure 3-39 shows the relationship between the projected yield of a Jasper Aquifer brackish well (or well field) and depth as described in INTERA et al. (2018). Note that the projected yield is limited to the estimated production that would result in approximately 500 feet of drawdown in the Jasper Aquifer. This was selected to limit the aquifer compaction and resulting subsidence that would occur and is described in more detail in INTERA et al. (2018). As shown in **Figure 3-39**, the yield of a brackish well or well field declines from approximately 1200 GPM in the shallower areas of the Jasper Aquifer (less than 2000 feet) to less than 300 GPM in sections of the Jasper Aquifer deeper than 6000 feet.

There are two notable limitations to the relationship shown in **Figure 3-39** as it relates to estimating the magnitude of brackish groundwater as a potential alternative water supply: 1) it is not limited to the brackish area of the Jasper Aquifer shown in **Figure 3-38**, and 2) each estimate was developed by pumping a single brackish well or well field and did not consider cumulative effects of many Jasper Aquifer brackish well fields pumping simultaneously. **Figure 3-40** reflects a model run developed to address these limitations. The run used the same approach described in INTERA et al. (2018), but pumping is limited to the brackish area shown in **Figure 3-38** and all Jasper Aquifer brackish groundwater production occurs simultaneously. As shown in **Figure 3-40** there is not a substantive decline in well yield compared to **Figure 3-39**. This is reasonable given that the volumes pumped are relatively low and the simulated wells are widely spaced on a regular 9-mile by 9-mile grid.

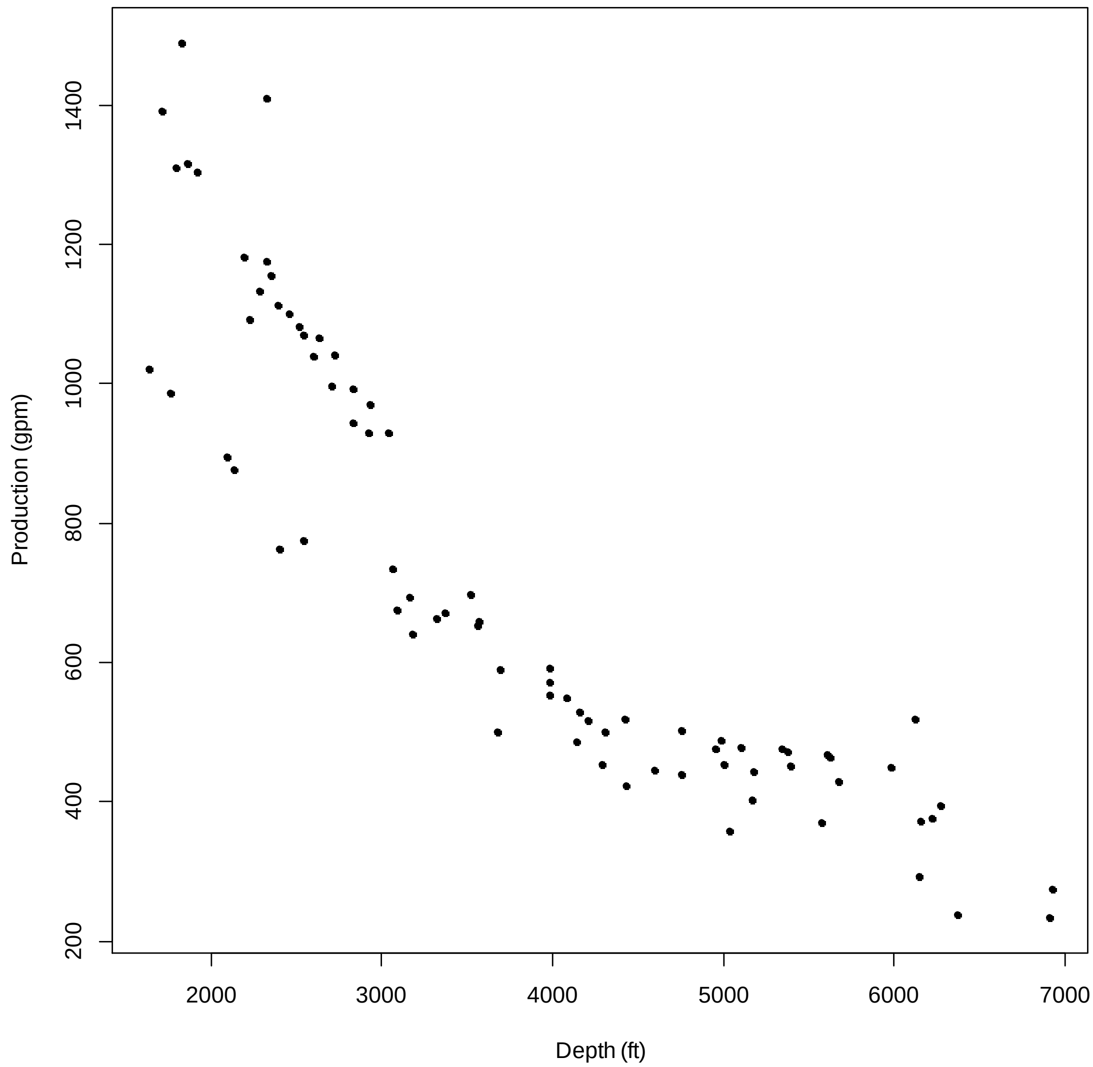

Figure 3-39. Model-Estimated Jasper Production Rate vs. Depth for Single Brackish Well or Well Field

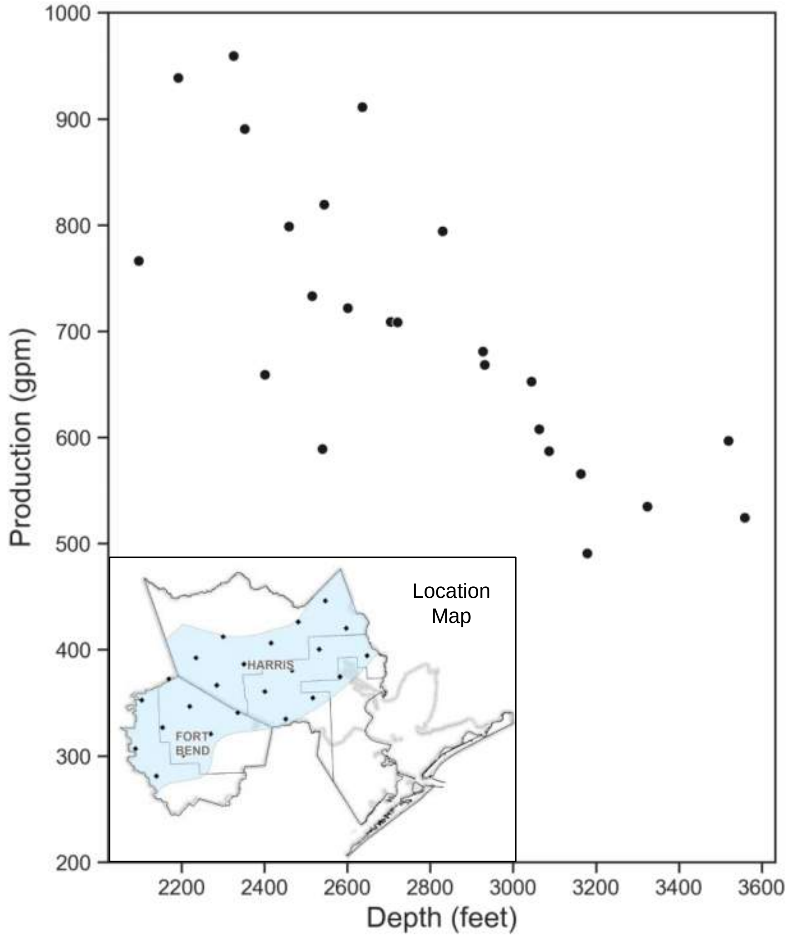

Figure 3-40. Model-Estimated Jasper Production Rate vs. Depth for 24 Brackish Well Fields Pumping Concurrently

Within the brackish area of the Jasper Aquifer shown in **Figure 3-38**, the estimated production ranged from approximately 500 to 900 GPM per well or well field. Approximately 24 projects could be sited in HGSD and FBSD using the same spacing assumptions employed here (see location map on **Figure 3-40**). At an average yield of 700 GPM (1 MGD), this results in a potential magnitude of supply of approximately 24 MGD (**Figure 3-41**).

It is important to note that this magnitude of brackish groundwater supply in the Districts is a conceptual estimate and is not yet supported under District rules. If future projects are developed and subsidence and hydrogeologic data is collected that supports different yields or well spacing, then the availability in the Districts could change.

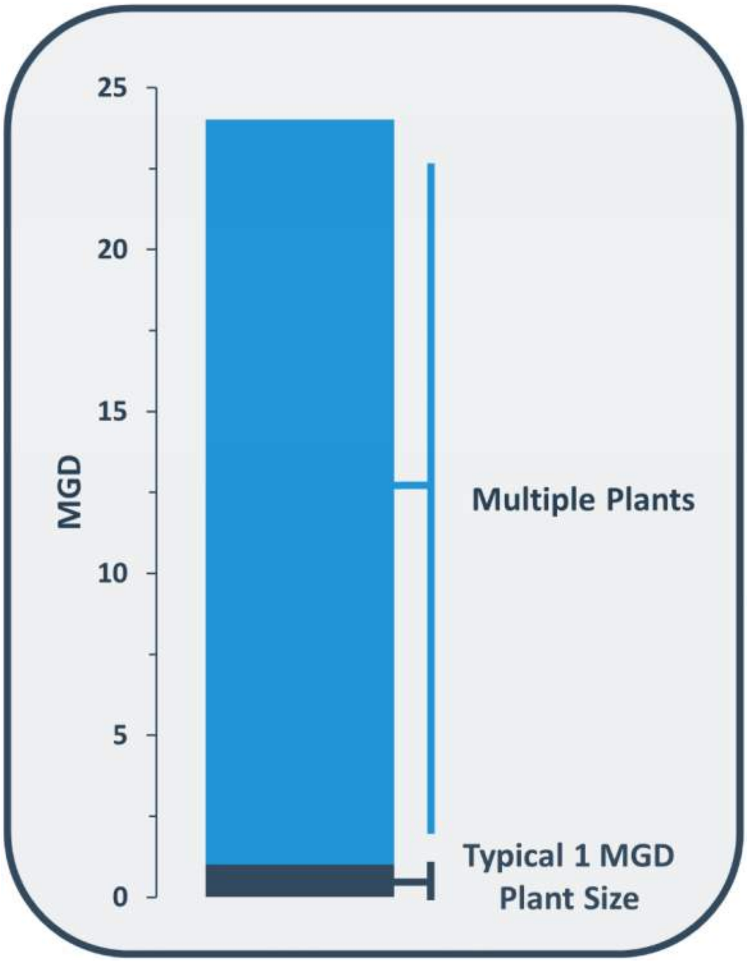

Figure 3-41. Total Magnitude of Supply for Brackish Groundwater Desalination

3.5.5 BUDGETARY COST OPINIONS

Planning level, order of magnitude cost opinions were developed for each water supply option based on consistent “big-picture” assumptions. For brackish groundwater, a budgetary cost opinion for a 1-MGD desalination plant was developed to reflect the average well production that was determined during the modeling run described in the **Section 3.5.4**. This cost opinion includes the components that are shown in **Figure 3-37**, a single production well, chemical and filter pretreatment, a RO system, and deep well injection brine disposal. Notably, the Cinco MUD 1 brackish groundwater desalination plant in Harris County is permitted to discharge brine to a surface outfall. However, it was assumed that most providers would not have an acceptable surface discharge location and that deep well injection would be required for most installations. The assumptions used for development of capital and O&M cost opinions for the brackish water desalination supply option are summarized in **Table 3-26** and **Table 3-27**.

Table 3-26. Capital Cost for 1-MGD Brackish Water Desalination Plant

Item No.	Capital Cost	2021 Estimated Cost ($)
1	Well Construction and Collection System Piping	$ 198,000
2	Wellhead Appurtenances	$ 757,000
3	Pretreatment	$ 550,000
4	RO Treatment	$ 1,637,000
5	Storage	$ 260,000
6	Distribution System Pumping and Piping	$ 690,000
7	Brine Disposal Costs using Deep Well Injection	$ 625,000
8	Site Civil	$ 54,000
9	Yard Piping	$ 45,000
10	Land Cost	$ 200,000
11	Civil, Mechanical, Electrical and Instrumentation Cost	$ 712,000
	Subtotal Capital Cost	**$ 5,728,000**
	Contractors Overhead & Profit (15%)	$ 860,000
	Mobilization and Demobilization (5%)	$ 287,000
	Permits, Bonds & Insurance (15%)	$ 860,000
	Engineering and Design (10%)	$ 573,000
	Contingency (30%)	$ 1,719,000
	Total Capital Cost	**$ 10,027,000**
	Annualized Debt Service Payment ($/yr)	**$ 728,000**

[Assumptions]

1. Depth of brackish groundwater wells in Jasper Aquifer is approximately 2,000-5,000 feet below surface.
2. Brackish groundwater supply plant will be supplied by a single well with a capacity of 1 MGD (700 GPM). Cost for well head appurtenances include well pump, motor column (200 HP), flow meter and piping and valves.
3. Assumed brackish groundwater might contain co-occurring contaminants such as arsenic, iron and others. TDS will be approximately 3,000-5,000 mg/L. Pretreatment costs includes media filtration, anti-scalant chemical addition, and cartridge filters.

4. Includes costs for RO building, membrane, feed pumps, chemical feed systems, RO permeate stabilization and cleaning system. Assumed approximately 75% recovery from RO treatment. 5. Includes costs for storage for RO treated water (2 MG), wet well for brine (0.25 MG), and chemical storage (0.35 MG). Cost was assumed to be $1/gallon storage capacity. 6. Brackish groundwater RO plant was assumed to be located closer to the area being served. Piping from storage to distribution was assumed to be 2,000 LF. This also includes cost for pump station. 7. RO concentrate will be disposed via deep injection method. For deep injection wells, assumed depth of 5,500 feet and associated pumping energy cost calculations. Assumed approximately 0.25 MGD of RO brine or concentrate disposed via deep well injection. 8. Cost for site civil includes re-gradation for construction, erosion control, construction entrance, well and equipment pad and paving, excavation and fill. 9. Piping costs include material and installation costs. 10. Assumed 2 acres of land will be required for plant construction and average cost of land per acre was assumed to be $100,000. 11. Miscellaneous - Civil cost is 10%, Mechanical cost is 5% and E&I cost is 10% of respective discipline capital costs.

Table 3-27. O&M Costs for Brackish Water Desalination

Item No.	Annual Operation and Maintenance Cost	2021 Estimated Cost ($)
1	Labor	$ 30,000
2	Chemicals	$ 58,000
3	Power	$ 558,000
4	Membrane Replacement	$ 58,000
5	Supplies and General Maintenance	$ 58,000
	Subtotal O&M Cost	**$ 762,000**
	Miscellaneous Cost (10%)	$ 77,000
	Total Annual O&M Cost	**$ 839,000**
[Assumptions] 1. Cost includes two FTEs for operating the desalination plant. 2. Cost includes chemicals for post treatment. 3. Electricity cost ($0.10/kWh) for brackish well pumps, deep well injection pumps, process power, distribution pump power, and building services. 4. Membrane replacement cost was assumed to be 1% of capital cost. 5. Supplies and general plant maintenance cost was assumed to be 1% of capital cost.		

Summary of the capital, O&M and life-cycle cost opinions are summarized in **Table 3-28**. As shown in this table, the capital cost to develop this water supply option is $10.03 per GPD with a range of $7.02 – $15.05 per GPD. The total cost for this water supply option is $4.29 per 1,000 gallons with a range of $3.00 – $6.44 per 1,000 gallons. **Figure 3-42** illustrates the capital and total costs for brackish water desalination.

Table 3-28. Brackish Water Desalination Life-Cycle Costs

Option No.	Option Name	2021 Estimated Cost ($)
1	Total Capital Cost	$ 10,027,000
2	**Total Capital Cost per GPD ($/GPD)**	**$ 10.03**
3	Annualized Debt Service Payment ($/yr)	$ 728,000
4	Total Annual O&M Cost	$ 839,000
5	Total Annual Capital and O&M Cost ($/yr)	$ 1,567,000
6	Annual O&M Cost ($/1,000 gallons)	$ 2.30
7	**Total Cost ($/1,000 gallons)**	**$ 4.29**

[Assumptions]
3. Amortized for a period of 30 years and 6% interest rate.
5. Based on 1 MGD brackish water supply.
6. Based on 1 MGD brackish water supply.

Figure 3-42. Capital and Total Costs of Brackish Water Desalination

3.5.6 IMPLEMENTATION TIMELINES

This section addresses the typical time that would be required from project funding through bringing the project online. So, put more succinctly, the time taken to develop a typical brackish groundwater project. We have basically looked at two types of information; timelines put forward in the 2021 RWP and experience gained from the limited number of similar projects in the region. The reality is that the range in time for implementation could be impacted by several factors which may make each project different.

The 2021 RWP discussed several brackish groundwater projects that are being contemplated by various water users as well as a generic brackish groundwater production with blending strategy that was assumed for the Chicot, Evangeline and Jasper aquifers. **Table 3-29** below provides the reported development timelines for the brackish projects identified in the 2021 RWP. Included in **Table 3-29** is the actual development information projected for the Cinco MUD 1 brackish project.

Table 3-29. Brackish Groundwater Desalination Project Implementation Timelines

Project Name	Yield (MGD)	Aquifer	Implementation Timeline (years)	Implementation Decade
Conroe Brackish Groundwater	5	Catahoula	10	2020
SJRA Catahoula Aquifer Supplies	7	Catahoula	1	2020
BWA	10	Unspecified	2	2020
Brackish Groundwater & Blending	NA	Chicot	1	Unspecified
Brackish Groundwater & Blending	NA	Evangeline	1	Unspecified
Brackish Groundwater & Blending	NA	Jasper	1	Unspecified
Cinco MUD-1	2.1(2)	Jasper	>4	2010-2020

Source: 2021 RWP

From a review of **Table 3-29** one can see that planned development timelines are projected to be quite short (1-2 years) with the exception of the City of Conroe brackish groundwater option. The complexity of a brackish groundwater production well is significantly more than a traditional potable water supply well. They are typically deeper and the brackish groundwater quality requires additional treatment considerations that must be addressed to blend with the traditional water source. A means to dispose of the concentrate that is produced through the brackish groundwater treatment process has to be planned, permitted and implemented. Additional issues which must potentially be addressed before full-scale production are special water quality issues such as naturally occurring radioactive constituents and dissolved gas.

The projected timelines for planning, design and construction of brackish desalination system are shown in **Figure 3-43**. Compared to other AWS options, development of brackish water supply can be accomplished in a relatively smaller timeframe, i.e., in 3-5 years. Planning phase will involve obtaining permits for brackish wells and brine disposal strategies. The design and construction aspects are fairly straight forward and well understood.

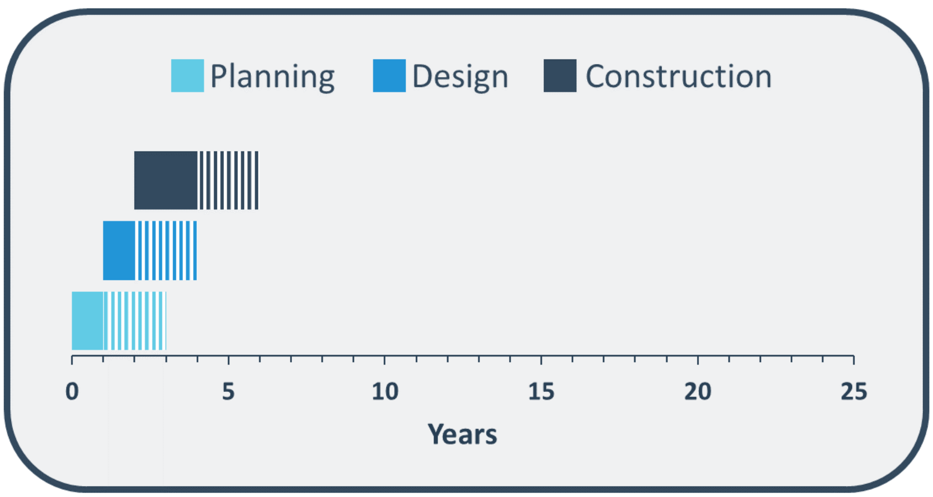

Figure 3-43. Implementation Timeline for Brackish Groundwater Desalination

3.5.7 WATER QUALITY CONSIDERATIONS

Brackish groundwater is typically defined as water that contains TDS between 1,000 and 10,000 mg/L. The portions of the Jasper aquifer most likely to contain brackish groundwater are at depths of 3,000 to 5,000 feet BGS. In addition, water quality at these depths from the deep Jasper aquifer may include co-occurring contaminants such as iron, manganese, arsenic, silica, sulfide, methane, boron, radium and gross alpha radiation (INTERA, 2016). At the Cinco MUD 1 brackish groundwater demonstration facility, several of the co-occurring contaminants have been measured at concentrations that required additional treatment. Few of the contaminants that were detected include arsenic, iron, methane and low levels of radiation.

Planning for brackish water supply should include desktop evaluation of available geophysical logs to identify zones of aquifer for screening, anticipated salinities, depths and thicknesses of production layers. Well design should screen for aquifer zones that produce the desired water quality. A group of nested wells screened at different depths can be used to produce blended brackish groundwater of desired quality. Pilot studies using test wells and proposed treatment technologies will allow in tailoring the design of the wells and desalination plant to the aquifer and site-specific conditions. Pilot study results can be used to obtain the necessary approvals from TCEQ, prior to full-scale implementation.

Fouling or scaling of the RO membranes will result in loss of productivity. Scaling and fouling of RO membranes can occur from the presence of colloidal and particulate materials. Often, the RO membrane manufacturers recommend using Silt Density Index (SDI) testing to estimate the rate at the which the colloidal or particulate fouling could occur. The SDI values can range between 0.0 and 6.0, where 0.0 indicates low fouling potential and 6.0 indicates high fouling potential. Most membrane manufacturers recommend the SDI in RO feed water of less than 3.0 to minimize colloidal and particulate fouling. Pre-treatment using MF/UF membranes often results in SDI of less than 3.0.

In addition to colloidal materials, scaling of RO membranes can also occur sparingly-soluble salts in water. Presence of bi-valent ions such as calcium, barium, sulfate and carbonate can foul or scale the RO membranes. Lowering of pH and addition of anti-scalants reduces the potential for scale formation and fouling from the sparingly soluble salts.

The goal of brackish water desalination treatment is to remove the TDS and other regulated contaminants to meet the end user requirements. For potable water, the treated water has to meet the primary and secondary standards per the TCEQ's 290 regulations.

3.5.8 PERMITTING AND LEGAL CONSIDERATIONS

Not unlike any potable water quality water supply well developed within the Districts' boundaries, a brackish Jasper well will require permitting from the Districts in terms of authorized production and also through TCEQ for construction, operational, water quality and treatment standards. In addition to water well permitting, the brackish groundwater well(s) will require permitting of a disposal mechanism, generally through either a permit authorized under the TPDES or through a Class I or Class II nonhazardous injection well permitted through TCEQ and in some cases the Railroad Commission. This discussion will focus on the permitting requirements associated with the Districts but will also provide a summary of the additional permitting requirements.

The Jasper aquifer is predominantly a freshwater supply for wells in Northern Harris County in HGSD Regulatory Area 3. However, a limited number of wells have been completed in the brackish or saline portions of the Jasper Aquifer in the Districts. The permits for these wells also extend special provision conditions that must be met by each permittee to waive disincentive fees over the duration of the permits.

A key part of the study of brackish groundwater resources completed by the Districts was a set of recommendations for future data and research requirements for brackish groundwater development projects (INTERA et al., 2018). The recommendations were based upon the need for data collection and research to better understand aquifer performance and to better manage subsidence risk, especially for wells deeper than 2,000 feet. A two-tiered system of data collection and research activities was recommended to provide additional information for potential future brackish groundwater development projects. It is recommended that any water provider considering development of a brackish Jasper well water supply project review the recommendations detailed in the study and meet with District staff early in the planning process to define expectations.

In addition to permitting requirements required by the Districts, construction and use of a public water supply well requires permitting and compliance with the TCEQ per 30 TAC 290.41(c) and 30 TAC 290.42(b), which provide regulations for groundwater sources, development by use of a well, and groundwater treatment.

Traditional treatment of brackish groundwater to produce potable water results in generation of a concentrate or brine stream. Brackish groundwater is commonly blended with a lower salinity (fresh in many cases) water source prior to treatment. This lowers the cost of treatment as well as lowers the volume of brine concentrate resulting from the treatment process. In many cases, the concentrate or brine streams are disposed of in underground injection wells under waste rules pertaining to Class I wells in 30 TAC Chapter 331, Subchapter D regulated by the TCEQ. Operators of Class I wells (and dually permitted Class I-II wells) may obtain authorization from the TCEQ to inject nonhazardous concentrate by seeking coverage under the statewide General Permit. Additionally, Class II Type 3 wells used for enhanced recovery may receive desalination concentrate for recovery processes under jurisdiction of the Railroad Commission. TWDB funded a study to provide guidance for permitting of Class I and Class II wells for the injection and disposal of desalinization concentrate (CDM Smith, 2014).

It is also possible that a water user could dispose of the brine concentrate through a surface water discharge authorized under the TPDES. Additional treatment might be necessary to ensure the brine concentrate meets the quality requirements of the receiving stream or reservoir. Zero discharge desalination is an ongoing topic of study and is a possibility for lowering the costs associated with treatment and brine disposal. The EPWU, El Paso, TX is operating a zero-discharge facility with co-operations and have lowered their cost of treatment.

3.5.9 VULNERABILITY TO CLIMATE CHANGE

A benefit of brackish groundwater production from a confined aquifer system such as the Gulf Coast Aquifer is that availability is not significantly impacted by changes in climate. If a system produces water from shallow portions of the aquifer in outcrop regions, the impacts of climate and extended droughts could be significant. In both unconfined and confined aquifers, water levels tend to decrease in times of drought. Especially in the case of confined aquifers, the reduction in water levels is more a result from increased reliance on groundwater (i.e., pumping) than a direct impact of climate. In relation to most water supply strategies, groundwater pumping from a confined aquifer system is not vulnerable to climate change as shown in **Figure 3-44**.

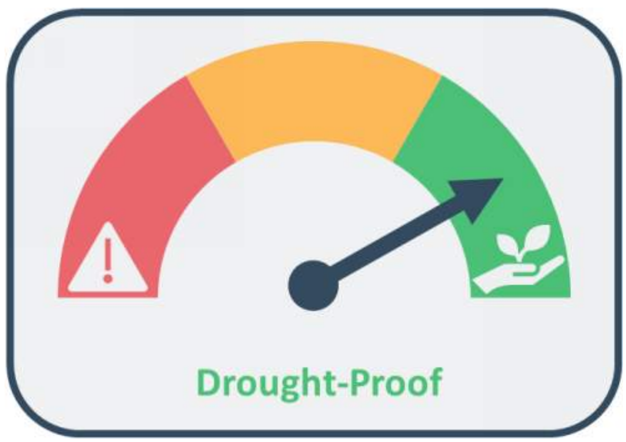

Figure 3-44. Climate Resiliency Rating of Brackish Groundwater Desalination

There could be indirect impacts of climate change that could be relevant to brackish groundwater production such as availability of blending water or lack of sufficient stream flows for concentrate disposal. In most cases it is expected that concentrate disposal will occur through a Class I (or possibly dually permitted Class I/Class II) non-hazardous injection well and therefore beyond the influence of climate.

3.5.10 SUBSIDENCE IMPACTS

Development of brackish groundwater within the Jasper aquifer inherently carries some risk of compaction and subsidence (**Figure 3-45**). Compaction is a thinning of a formation in the subsurface, which may propagate to the land surface to produce subsidence. INTERA et al. (2018) describes the current state of the science of the compaction and subsidence potential of the brackish portions of the Jasper aquifer in detail. The potential for future compaction of the Jasper and resulting subsidence depends on the pumping rates, the spacing between wells and well fields, and the hydraulic properties of the aquifer. In general, to minimize subsidence impacts, brackish development projects should be spaced widely from one another and have relatively low production rates to minimize drawdown in the aquifer.

Figure 3-45. Subsidence Impacts of Brackish Groundwater Desalination

Since the brackish portions of the Jasper aquifer have not been widely developed, the hydraulic and compaction properties of the aquifer are not as well defined as they are for the shallower Chicot and Evangeline aquifers. To account for this uncertainty in aquifer properties, INTERA et al. (2018) developed “base”, “high impact” and “low impact” scenarios for compaction of the Jasper aquifer after 10 years of development. **Figure 3-46** below presents the range of predicted compaction among the three scenarios. The shallower portions of the Jasper aquifer (that is, the northeastern areas) are more susceptible to compaction and subsidence than the deeper portions of the aquifer closer to the coast. Under the “base” scenario, predicted compaction ranged from approximately 0.5 to 1.0 feet within the brackish portions of the aquifer. As the brackish portions of the Jasper aquifer are further developed and more data are collected, the understanding of the potential for compaction and subsidence impacts will improve.

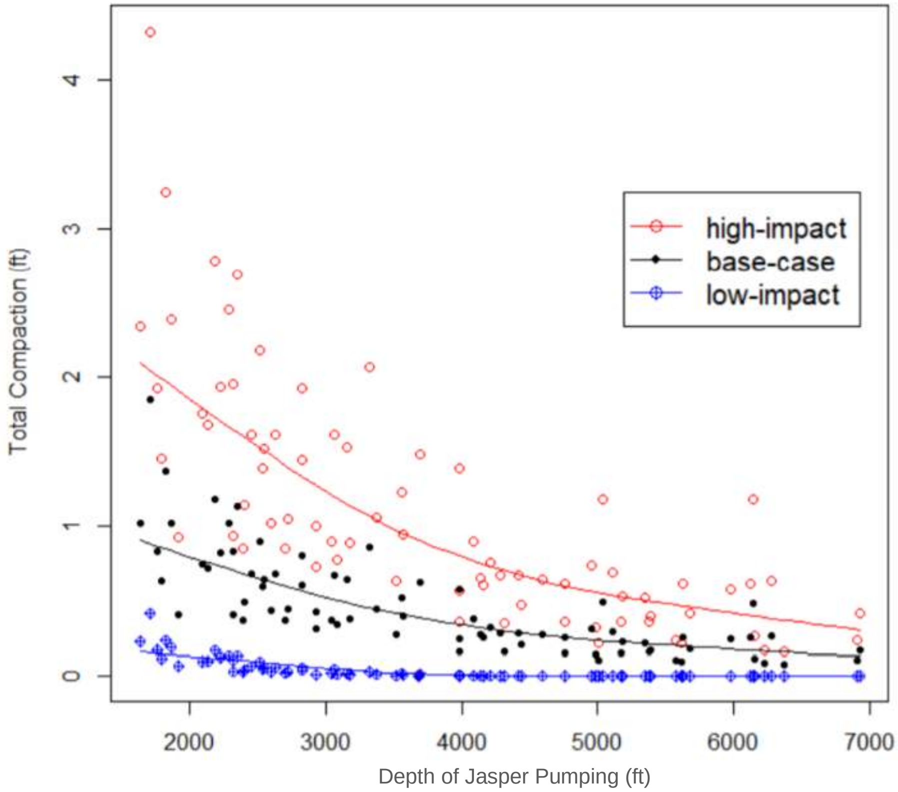

Figure 3-46. Simulated Variation of 10-year Compaction with Depth

(from INTERA et al., 2018)

3.6 AQUIFER STORAGE AND RECOVERY WITH SURFACE WATER

As discussed in Section 2, three variants of ASR were considered in the initial screening of sub-options: ASR with surface water, ASR with stormwater, and ASR with reclaimed water. Of the three approaches, ASR with surface water was shortlisted as the most viable alternative water supply strategy. Stormwater was considered less viable than surface water because it frequently has high turbidity due to sediment wash-off and the potential for other contaminants, both natural and anthropogenic, and is therefore more costly to treat. Although reclaimed water meets TCEQ criteria and has comparatively low solids content, additional treatment would likely be required prior to injection. While ASR with surface water faces several technical challenges, including the potential for subsidence, it may be a viable strategy to buffer seasonal demand fluctuations by storing surface water during periods of lower demand and withdrawing during periods of higher demand.

Unlike most other AWSs, ASR with surface water does not increase the net AWS supply, but rather shifts the seasonal allocation of supplies or makes otherwise interruptible sources of water firm. An ASR project includes periods of recharge (injection) and periods of recovery (pumping). Depending on the application, the period between recharge and recovery can vary significantly. For example, if ASR is used to supply groundwater in a drought, the storage volume and the recharge and recovery periods could be large; in addition, the period between recharge and recovery could also be significant. In contrast, if one were using ASR as a seasonal supply, the storage volume and the recharge and recovery cycles could be relatively small and have an annual frequency or less. Given the potential to reduce reliance on native groundwater during peak demand periods, ASR with surface water was retained for more detailed assessment.

3.6.1 IMPLEMENTATION APPROACH

The key components for an ASR system are shown in **Figure 3-47**. Treated surface water during periods of low demand is injected into an aquifer for storage until retrieval for later use. The recovery of the stored water is most often achieved using the same wells used for injecting surface water underground (TWDB, 2015; Pyne, 2005). The recovered water is polish treated to remove any contaminants (e.g., arsenic, iron) that may have been picked up in the aquifer.

The issue of plugging for traditional injection wells is partially resolved by the inclusion of a pump in ASR wells that allows for both recharge and recovery. The pump can be used periodically to re-develop the well, a crucial maintenance process in which the well screen is cleaned of silt and clay buildup, and is accomplished through the ability of the ASR well to pump flows in both directions (Pyne, 2005).

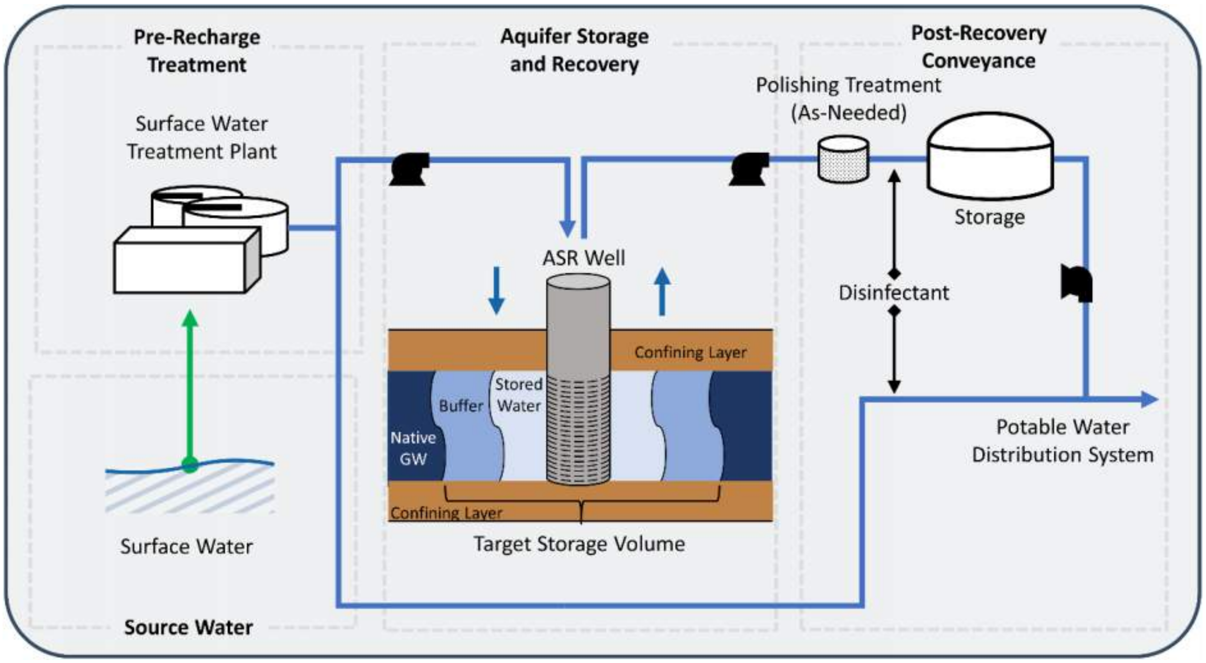

Figure 3-47. Process Flow Diagram for Aquifer Storage and Recovery with Surface Water

Storage and recovery patterns for ASR can be implemented on different time scales: long-term or drought purposes, in terms of years; seasonal, for periods of days to months; or even sometimes diurnal and emergency-use. Storage can take place in confined, semi-confined, or unconfined portions of aquifers. Potential ASR operations in the Districts' areas would likely take place in semi-confined or confined aquifer areas given the presence of clay layers interbedded throughout each of the units of the Gulf Coast Aquifer System.

When assessing surface water for ASR recharge suitability, it is necessary to conduct hydrologic analyses across several years of record to understand natural cycles of water quality and quantity variability. In contrast with the previously characterized AWS options, ASR does not create additional water supply. Rather, it provides a storage mechanism for "surplus" AWS produced during lower demand periods such that these supplies can be made available for later use during periods of higher demands. Thus, if sufficient quantities of excess surface water are not available to be placed into storage, then ASR is not feasible. Additionally, although surface water may meet requirements for diversions in terms of quantity, fluctuations in water quality may cause the water of the same source to be unsuitable for ASR during that same season or time period. Important water quality parameters of consideration are discussed further in Section 3.7.4.

In 1995, Texas legislature passed House Bill 1989 establishing a statutory framework for ASR and calling for further studies to evaluate the potential for ASR projects in Texas. Of the sixteen evaluations conducted in Texas since the passage of the House Bill 1989, only one has resulted in the implementation of an ASR project, which is now the San Antonio Water System's (SAWS) Twin Oaks ASR facility. Constructed in 2004 and expanded in 2006, this ASR facility consists of twenty-nine wells for a total capacity of sixty MGD with a summer peaking seasonal operational scheme. There is currently one other fully functioning ASR system in Texas in addition to SAWS. This is the City of Kerrville's ASR project which utilizes surface water. The EPWU utilizes reclaimed water for a hybrid ASR system, which uses separate wells for injection and recovery (Malcolm Pirnie et al., 2011).

A typical ASR project is generally completed in three phases. The first phase is an analysis of the potential uses for ASR, the conceptual analysis of the recharge water availability and aquifer storage characteristics, and for some projects, an economic analysis. In some cases, the initial conceptual study to determine the viability of ASR is further evaluated with a focus on the integration of the project with recharge water availability, treatment considerations, and costs and integration into the larger water supply. These studies also allow a higher resolution cost estimate.

If an ASR project proves feasible based on desktop studies, the second phase is pilot testing. The purpose of pilot testing is to physically characterize the aquifer in terms of recharge and production potential, recharge water isolation, and water quality compatibility. During field tests, a test well is designed and constructed at full scale and depth so as to collect as accurate results as possible. This stage is a critical phase and field results from this phase are essential to understanding treatment costs. In Texas, the TCEQ requires pilot-testing as part of the process for defining recoverability and for ensuring that aquifer groundwater quality is protected. If the pilot testing indicates that the project can store and recover adequate water within the required water quality constraints, then the project is moved to the third phase, implementation.

This final phase involves the subsequent build-out of the ASR wellfield to bring the intended project to scale. Factors important to consider during this phase of the ASR project are flow rate balancing of recharge and recovery volumes, well spacing and arrangement, and wellfield layout (INTERA et al., 2019, Pyne, 2005). Components involved in a final operating ASR project are shown in **Figure 3-47**.

3.6.2 REGULATORY AREA(S) SERVED

Regions of all three counties and regulatory areas of HGSD and FBSD can be served using water from ASR operations. However, this will depend on both the local availability of excess surface water and the ability to convey recovered water from the operation site to users' distribution systems. Areas closest in proximity to the ASR project site may be the least expensive to serve, so this factor can be included with geologic and chemical suitability studies when determining the location for the ASR wellfield.

Smith et al. (2017) conducted a study in which areas of the Gulf Coast Aquifer were evaluated for suitability for ASR by creating a quantitative index based on aquifer characteristics including transmissivity, hydraulic gradient, density of existing wells, water level, and aquifer depth. Overall, the central and northern regions of the Gulf Coast Aquifer were found to be more feasible for ASR. Human-induced impacts from the Greater Houston area somewhat lowered the feasibility score for the aquifer in its region, particularly for scores relating to hydraulic gradient, well density, and depth to groundwater.

Recently, TWDB released a statewide study of aquifer suitability for ASR using criteria including hydrogeologic characteristics, source water availability, and water supply needs (TWDB, 2020a). Based on these parameters, the Greater Houston area is shown as one of the areas of the state most suitable for ASR.

It is important to note that neither of these studies consider the risk of subsidence risk from ASR, and the Districts do not yet have rules regulating ASR. Development of an ASR project that is subsidence neutral and consistent with potential future District rules may include additional constraints not considered in the above evaluations.

3.6.3 ANTICIPATED USERS

If ASR projects are implemented in the region, they will most likely serve industrial or municipal users. This is in part due to the high treatment costs associated with ASR, which makes it a less attractive option for uses with lower water quality requirements, such as irrigation. There has historically been an interest in ASR for industrial purposes in Texas City in HGSD Regulatory Area 1, though there are currently no other known water users expressing interest in ASR for industrial purposes.

3.6.4 MAGNITUDE OF SUPPLIES

The magnitude of supply from an ASR project is influenced by many factors including hydrogeologic conditions, availability of surface water, the intended use of the water, project economics, subsidence risk, and regulation. The assessment presented here focuses on hydrogeologic conditions as the other factors are addressed elsewhere in this report (e.g., availability of surface water) or are inherently speculative (e.g., future regulations). It is important to remember that ASR using surface water is a storage strategy and does not represent a new source of water.

In 2015, the District Science and Research Plan (HGSD, 2015) called for an assessment of the potential subsidence neutral yield of an ASR project in the Gulf Coast Aquifer System within the Districts. The study results were completed and reported in 2019 (INTERA et al., 2019) and looked at subsidence neutral ASR under two scenarios. The first scenario was modeled after an industrial user in the Houston Ship Channel Area. The second scenario was a municipal user who desired to use ASR to store water in the winter to be used for summer peaking. Refer to INTERA et al. (2019) for detailed information about hydrogeologic conditions of the Gulf Coast Aquifer System that pertain to ASR.

One hydrogeologic characteristic of the aquifer that has not been previously assessed is the storage capacity of the aquifer considering the history of development and compaction. Water removed from storage due to historical pumping can “create space” within the aquifer to receive recharge water from an ASR project. However, water removed can also create a permanent reduction in the storage capacity in portions of the aquifer that compacted. **Table 3-30** shows the reduction in storage in each county and regulatory area of HGSD and FBSD for both types of storage using water budget information from the Houston Area Groundwater Model (HAGM; USGS et al., 2013) between 1910 and 2009. The upper portion of **Table 3-30**, showing elastic storage reduction, indicates an historical decrease in elastic storage of over 6.4 million AF combined in HGSD and FBSD. This is focused primarily on the Chicot and Evangeline aquifers as they have been the source of most groundwater pumping in the Districts. The lower portion of **Table 3-30**, showing inelastic storage, indicates a historical decrease of approximately 6.3 million AF combined in HGSD and FBSD. While inelastic storage declines represent compaction of clays and are permanent, the magnitude of elastic storage reduction is large, indicating that aquifer storage capacity will not be a limiting factor for implementation of ASR.

Table 3-30. Net Reduction in Storage in Sands by Aquifer by Regulatory Areas Predicted by the HAGM from 1910 through 2009

County	Regulatory Area	Chicot Aquifer	Evangeline Aquifer	Jasper Aquifer
Decrease in Elastic Storage Capacity (AF)				
Fort Bend	A	1,416,821	22,828	6,284
Fort Bend	B	805,678	8,347	1,262
Galveston	1	4,782	3,626	-
Galveston	2	6,930	777	-
Harris	1	69,615	5,172	-
Harris	2	256,976	19,518	6,473
Harris	3	3,682,717	53,093	52,653
Decrease in Inelastic Storage Capacity (AF)				
Fort Bend	A	342,392	407,130	181
Fort Bend	B	76,712	59,247	45
Galveston	1	337,395	134,462	-
Galveston	2	56,016	23,444	-
Harris	1	790,352	89,783	-
Harris	2	1,385,257	422,754	242
Harris	3	1,155,048	1,070,982	10,903

The potential supply of several ASR projects in the area has been assessed in previous studies (**Table 3-31)**. In INTERA et al. (2019), two hypothetical ASR projects using surface water were assessed representing drought-of-record and summer peaking operational approaches. The assessments considered the degree to which the ASR project reduced subsidence compared to traditional groundwater production, finding that the summer peaking operational approach provided reduced compaction relative to the drought-of-record approach.

In addition, the Region H regional water planning group conducted a concept-level analysis of an ASR project identified in the SJRA Raw Water Supply Master Plan (2021 RWP; Freese and Nichols, Inc., 2018). The plan looked at surface water as the recharge supply from interruptible Lake Conroe and Lake Creek supplies. The conceptual project had a project yield of approximately 9,426 AFY (8.4 MGD), but it is important to note that it is located outside of the Districts and did not consider the potential for subsidence.

From a review of **Table 3-31,** one can see that annual yields range from approximately 9,246 AF for an annual conjunctive use strategy to 2,000 AF for an annual municipal summer peaking project. The annual yield from the SJRA conjunctive management annual supply average is reported to be 9,426 AFY, but the inter-year variability of that project was not reported. For purposes of this analysis, 2,000 AF to 10,000 AF is the range of ASR project yields that are anticipated to be considered by users within the Districts. As the Districts do not yet have rules for ASR, future ASR projects that do occur in the Districts may be outside this range and/or require recharge volumes significantly above the project yield.

Table 3-31. Operational Details of Conceptual ASR Projects Analyzed for the Region

Conceptual Project Description	Water User Group	Recovery Periodicity	Project Yield (AF)	Project Annual Yield (AFY)	Recovery Rate (MGD)
Banking for Drought of Record	Industrial	5 years (Drought of Record)	16,326	2,332 – 4,198	5.0
Summer Peaking	Municipal	Annual	2,000	2,000	7.1
SJRA Conjunctive Management Annual Supply	River Authority	Drought of Record	9,426	9,426	8.4

Figure 3-48 shows the anticipated magnitude of yields for the HGSD and FBSD regions, with an average of 5 MGD per ASR project. Given limitations on the implementation of ASR including project economics, the availability of surface water, and potential subsidence impacts, only three to four ASR projects were assumed to be implemented long-term in the Districts.

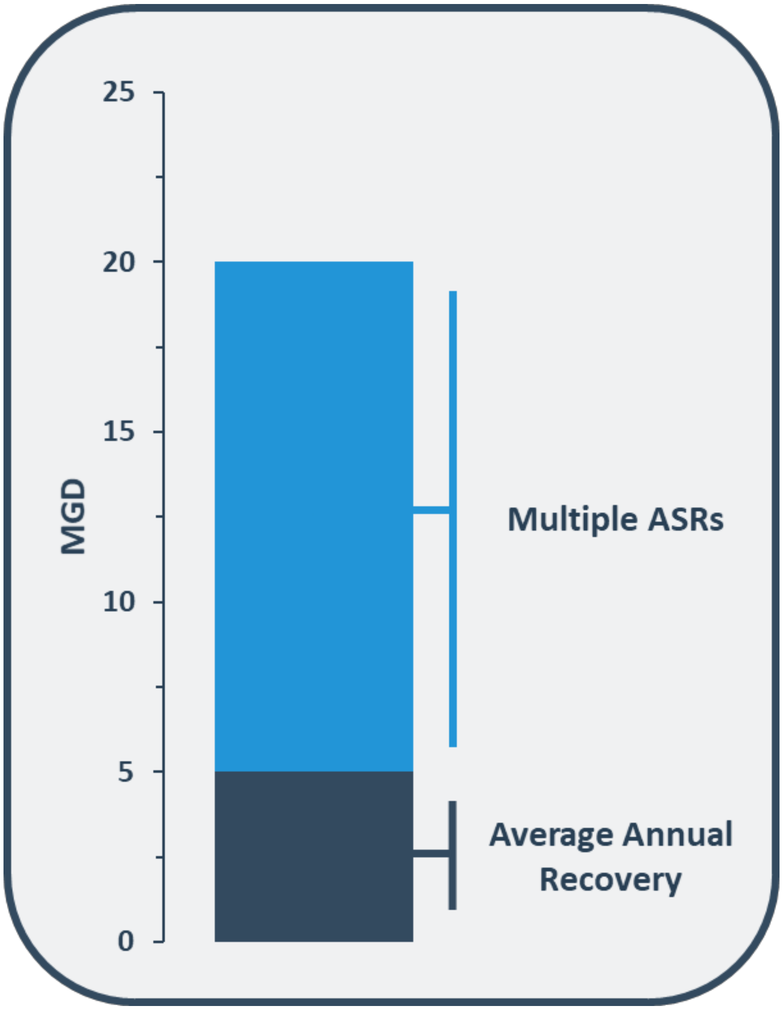

Figure 3-48. Total Magnitude of Supply for Aquifer Storage and Recovery

3.6.5 BUDGETARY COST OPINIONS

ASR costs per unit of water recovered are relatively low, depending on the specifics of the operation. Savings can be made from the minimal land requirement of ASR in comparison to a surface reservoir, as well as the lack of WTP expansions. If located close to demands, conveyance costs can also be minimized (TWDB, 2015; Pyne, 2005). ASR unit costs depend primarily on well yield. ASR well construction costs are not drastically more expensive than traditional well costs and increase with depth, diameter, number of casings, and construction material choice. These factors will naturally depend on the local hydrogeology.

Planning level, order of magnitude cost opinions were developed for each water supply option based on consistent "big-picture" assumptions. These costs include the components that are shown in

Figure 3-47. The assumptions used for development of capital cost opinions for the 2,000 AFY and 10,000 AFY ASR water supply options are summarized in **Table 3-32** and **Table 3-33**.

Table 3-32. Capital Cost for Aquifer Storage Recovery - 2,000 AFY

Item No.	Capital Cost	Estimated Cost ($)	
1	ASR Well	$	2,125,000
2	Wellhead Appurtenances	$	265,000
3	Treatment	$	30,000
4	Site Civil	$	55,000
5	Yard Piping	$	264,000
6	Distribution System Pumping and Piping	$	1,450,000
7	Land Cost	$	300,000
8	Civil, Mechanical, Electrical and Instrumentation Cost	$	603,000
	Subtotal Capital Cost	**$**	**5,092,000**
	Contractors Overhead & Profit (15%)	$	764,000
	Mobilization and Demobilization (5%)	$	255,000
	Permits, Bonds & Insurance (15%)	$	764,000
	Engineering and Design (10%)	$	510,000
	Contingency (30%)	$	1,528,000
	Total Capital Cost	**$**	**8,913,000**
	Annualized Debt Service Payment ($/yr)	**$**	**648,000**

[Assumptions]

1. Assumed ASR of 2,000 AFY/1.8 MGD. Depth of the ASR well was assumed to be 5,000 ft.
2. Cost includes vertical turbine pump, motor and column and pump Installation, valves flow meters and other well head appurtenances.
3. Cost for disinfection (single dosing for all wells).
4. Includes cost for regrading, erosion control, stabilized construction entrance, paving, excavation and fill.
5. Includes cost for raw water pipe. Piping costs include material and installation costs.
6. Includes cost for pump station (1.8 MGD/2000 AFY) and 200 feet of 12-inch of distribution system piping.
7. Assumed 3 acres of land will be required for ASR plant construction and cost of land per acre of $100,000.
8. Miscellaneous - Civil cost is 10%, Mechanical cost is 5% and E&I cost is 10%.

Table 3-33. Capital Cost for Aquifer Storage Recovery - 10,000 AFY

Item No.	Capital Cost	Estimated Cost ($)	
1	ASR Wells	$	8,250,000
2	Wellhead Appurtenances	$	2,285,000
3	Disinfection	$	50,000
4	Site Civil	$	87,000
5	Yard Piping	$	500,000
6	Distribution System Pumping and Piping	$	6,330,000
7	Land Cost	$	500,000
8	Civil, Mechanical, Electrical and Instrumentation Cost	$	2,577,000
	Subtotal Capital Cost	**$**	**20,578,000**
	Contractors Overhead & Profit (15%)	$	3,087,000
	Mobilization and Demobilization (5%)	$	1,029,000
	Permits, Bonds & Insurance (15%)	$	3,087,000
	Engineering and Design (10%)	$	2,058,000
	Contingency (30%)	$	6,174,000
	Total Capital Cost	**$**	**36,013,000**
	Annualized Debt Service Payment ($/yr)	**$**	**2,616,000**

[Assumptions]

1. Assumed ASR of 10,000 AFY/8.9 MGD. Three wells (higher capacity than that in 2,000 AFY option), and depth of each well was assumed to be 5,000 ft.
2. Cost includes vertical turbine pump, motor and column and pump installation, valves flow meters and other well head appurtenances.
3. Cost for disinfection (single dosing for all wells).
4. Includes cost for regrading, erosion control, stabilized construction entrance, paving, excavation and fill.
5. Includes cost for raw water pipe. Piping costs include material and installation costs.
6. Includes cost for pump station (8.9 MGD/10,000 AFY) and 200 feet of 20-inch of distribution system piping.
7. Assumed 5 acres of land will be required for ASR plant construction and average cost of land per acre of $100,000.
8. Miscellaneous - Civil cost is 10%, Mechanical cost is 5% and E&I cost is 10%.

The assumptions used for development of O&M cost opinions for the 2,000 AFY and 10,000 AFY ASR water supply options are summarized in **Table 3-34** and **Table 3-35**.

Table 3-34. O&M Cost for Aquifer Storage Recovery - 2,000 AFY

Item No.	Annual Operation and Maintenance Cost	2021 Estimated Cost ($)
1	Labor	$ 60,000
2	Chemicals	$ 51,000
3	Electric Power	$ 80,000
4	Supplies and General Maintenance	$ 102,000
	Subtotal O&M Cost	**$ 293,000**
	Miscellaneous Cost (10%)	$ 30,000
	Total Annual O&M Cost	**$ 323,000**

[Assumptions]
1. Includes cost for 1 FTE for operating the ASR system.
2. Cost includes chemicals for disinfection.
3. Electricity cost ($0.10/kWh) for operating the ASR plant was assumed to be $45,000/ MGD
4. Supplies and general plant maintenance cost was assumed to be 2% of capital cost

Table 3-35. O&M Cost for Aquifer Storage Recovery - 10,000 AFY

Item No.	Annual Operation and Maintenance Cost	2021 Estimated Cost ($)
1	Labor	$ 180,000
2	Chemicals	$ 206,000
3	Power	$ 400,000
4	Supplies and General Maintenance	$ 412,000
	Subtotal O&M Cost	**$ 1,198,000**
	Miscellaneous Cost (10%)	$ 120,000
	Total Annual O&M Cost	**$ 1,318,000**

[Assumptions]
2. Includes cost for 3 FTEs for operating the ASR system.
3. Cost includes chemicals for disinfection.
4. Electricity cost ($0.10/kWh) for operating the ASR plant was assumed to be $45,000/ MGD
5. Supplies and general plant maintenance cost was assumed to be 2% of capital cost

Summary of the capital, O&M and life-cycle cost opinions for the 2,000 AFY option are summarized in **Table 3-36**. As shown in this table, the capital cost to develop this water supply option is $4.99 per GPD with a range of $3.49 – $7.49 per GPD. The total cost for this water supply option is $1.49 per 1,000 gallons with a range of $1.04 – $2.24 per 1,000 gallons. **Figure 3-49** illustrates the capital and total costs of the aquifer storage recovery, 2,000 AFY option.

Table 3-36. Aquifer Storage Recovery Life-Cycle Costs - 2,000 AFY Option

Option No.	Option Name	2021 Estimated Cost ($)
1	Total Capital Cost	$ 8,913,000
2	**Total Capital Cost per GPD ($/GPD)**	**$ 4.99**
3	Annualized Debt Service Payment ($/yr)	$ 648,000
4	Total Annual O&M Cost	$ 323,000
5	Total Annual Capital and O&M Cost ($/yr)	$ 971,000
6	Annual O&M Cost ($/1,000 gallons)	$ 0.50
7	**Total Cost ($/1,000 gallons)**	**$ 1.49**

[Assumptions]
3. Amortized for a period of 30 years and 6% interest rate.
5. At a yield of 1.8 MGD/657 MGY.
6. At a yield of 1.8 MGD/657 MGY.

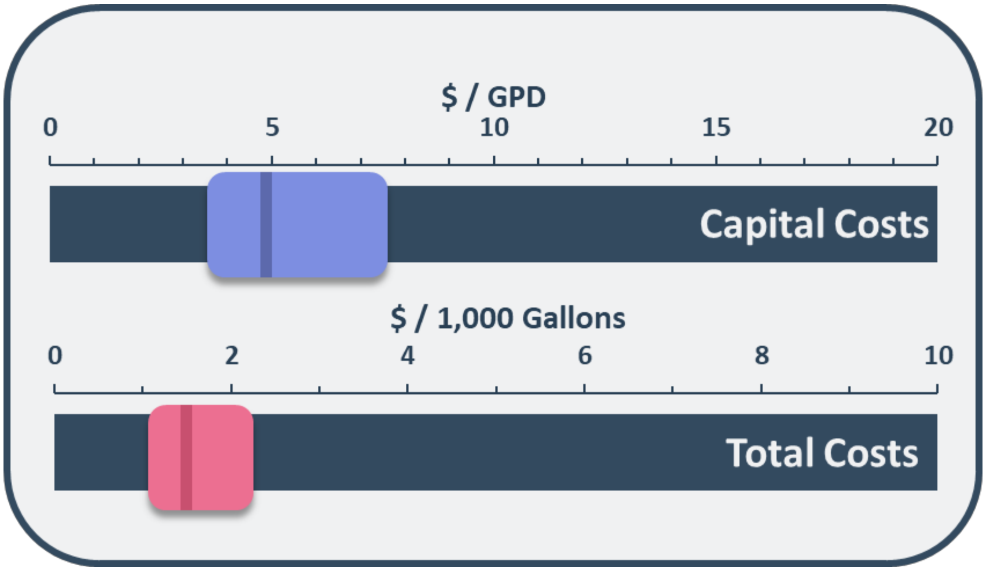

Figure 3-49. Capital and Total Costs of Aquifer Storage and Recovery - 2,000 AFY Option

Summary of the capital, O&M and life-cycle cost opinions for the 10,000 AFY option are summarized in **Table 3-37**. As shown in this table, the capital cost to develop this water supply option is $4.03 per GPD with a range of $2.82 – $6.05 per GPD. The total cost for this water supply option is $1.21 per 1,000 gallons with a range of $0.85 – $1.82 per 1,000 gallons. **Figure 3-50** illustrates the capital and total costs of the aquifer storage recovery, 10,000 AFY option.

Table 3-37. Aquifer Storage Recovery Life-Cycle Costs - 10,000 AFY Option

Option No.	Option Name	2021 Estimated Cost ($)
1	Total Capital Cost	$ 36,013,000
2	**Total Capital Cost per GPD ($/GPD)**	**$ 4.03**
3	Annualized Debt Service Payment ($/yr)	$ 2,616,000
4	Total Annual O&M Cost	$ 1,318,000
5	Total Annual Capital and O&M Cost ($/yr)	$ 3,934,000
6	Annual O&M Cost ($/1,000 gallons)	$ 0.41
7	**Total Cost ($/1,000 gallons)**	**$ 1.21**

[Assumptions]
3. Amortized for a period of 30 years and 6% interest rate.
5. At a yield of 8.9 MGD/3249 AFY
6. At a yield of 8.9 MGD/3249 AFY

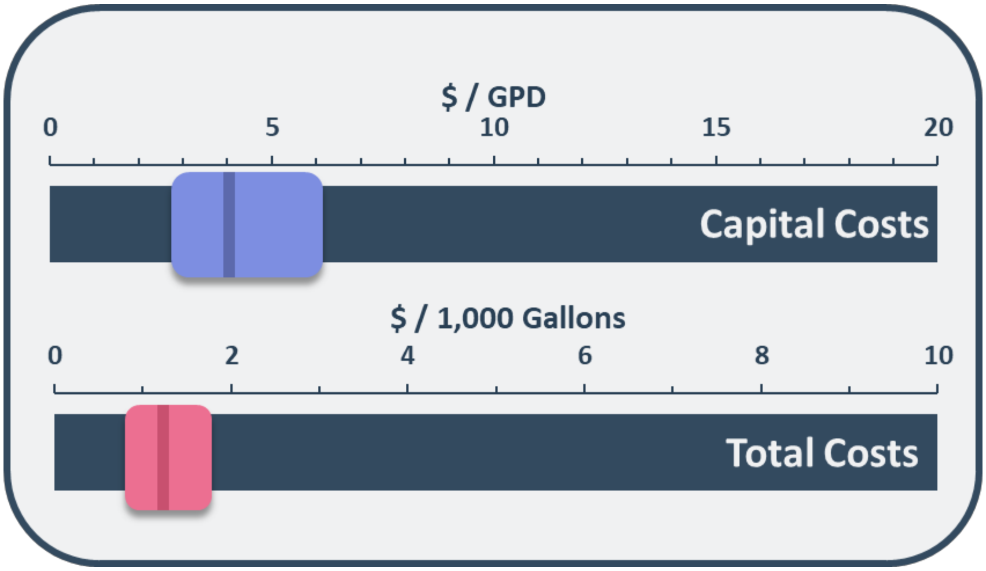

Figure 3-50. Capital and Total Costs of Aquifer Storage and Recovery - 10,000 AFY Option

3.6.6 IMPLEMENTATION TIMELINES

It is very common for ASR projects to have many phases of implementation as the efficacy of the storage and recovery process is proven. A typical timeline is three to four years if a water user is committed to implementation and has readily available water to store in the project. In contrast, the SJRA Conceptual ASR Project analysis in the 2021 RWP projected an implementation timeline of twenty to twenty-five years, including reasonable time to develop adequate stored water supplies, given historical surface water hydrology. This project includes design and construction of a 100 MGD pump station at Lake Creek, a 4,000-AF off-channel reservoir for temporary surface water storage, and ten Jasper Aquifer wells.

The size and the complexity of any ASR project is going to be an important factor in determining the timeline for implementation. Summer peaking is a relatively simple application that could reasonably be expected to be operating within five years. A reasonable timeline for a larger ASR project would be eight to ten years.

Unlike Texas groundwater conservation districts, the subsidence districts have primacy over the regulation of production (or, in this case, recovery) from wells within the District, although TCEQ retains sole regulatory authority for the injection with Class V ASR wells. This dual regulatory authority in the subsidence districts may create additional complexity for permittees that could extend timelines (see section 3.6.8 for further discussion). For a water user contemplating the use of ASR within the Districts, it is recommended that they communicate with the Districts from project initiation. **Figure 3-51** shows the various phases for the implementation of ASR in the Districts' regions.

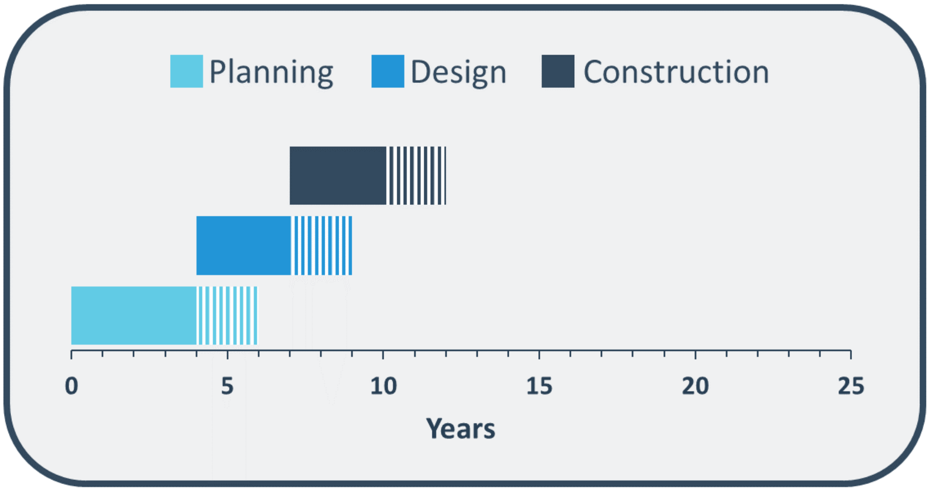

Figure 3-51. Implementation Timeline for Aquifer Storage and Recovery

3.6.7 WATER QUALITY CONSIDERATIONS

Water quality assessments are crucial to ASR operations as geochemical interactions between recharge water, the aquifer, and wells can occur on a range of spatial and temporal scales and are very site-specific. Surface water intended for ASR will likely require treatment before injection to comply with water quality standards and avoid degrading native groundwater quality (Smith et al., 2017; Malcolm Pirnie et al., 2011; INTERA et al., 2019). Additionally, further treatment may be required after meeting regulatory standards to meet the technical requirements of ASR such as reduction of suspended solids and pH adjustment. That said, if proper water quality parameters, aquifer hydraulics, recharge and recovery rates, and volumes are considered and addressed, treatment of ASR water post-recovery is minimal for potable uses and typically only requires disinfection. The information presented in this section is intentionally high-level. For more detailed information, refer to INTERA et al. (2019) for an evaluation of water quality considerations specific to ASR in the Districts.

Table 3-38 lists water quality parameters that should be assessed for ASR systems at a minimum. Depending on the site of interest, other parameters may be necessary to address local needs. This includes laboratory analysis of field samples from source water and native groundwater, as well as simulations from modeling to assess mixing scenarios. In cases where results are inconclusive, core samples of the aquifer of interest can be taken to better characterize the environment in which the recharge water will be stored (Pyne, 2005).

Table 3-38. Water Quality Parameters for Geochemical Analysis

PARAMETERS		
Total alkalinity	Bicarbonate alkalinity	Non-carbonate hardness
Total dissolved solids	Total silica	Calcium hardness
Total suspended solids	Calcium	Nitrate
Turbidity	Magnesium	Phosphate
Color	Sodium	Ammonia
Specific conductance	Potassium	Hydrogen sulfide
pH	Iron	Total organic carbon
Temperature	Aluminum	Total halogenating hydrocarbons
Dissolved oxygen	Copper	Specific gravity or fluid density
Eh	Manganese	Chloroform
Chloride	Zinc	Bromodichloromethane
Fluoride	Cadmium	Dibromochloromethane
Sulfate	Selenium	Bromoform
Carbonate alkalinity	Total hardness	Total trihalomethane
Source: Pyne, 2005		

It is important to note that geochemical, mineralogic, and physical data are limited for the Gulf Coast Aquifer system, with most empirical data restricted to the Chicot Aquifer. This limits the ability to understand the geochemistry of the Gulf Coast Aquifer so it is essential that data are collected from individual potential well locations when planning for ASR projects in the region (INTERA et al., 2019).

3.6.8 PERMITTING AND LEGAL CONSIDERATIONS

House Bill 655, enacted by the Texas Legislature in 2015, established the current regulatory framework for ASR in Texas making the TCEQ the sole regulatory authority for permitting ASR Class V injection wells in Texas through the UIC Program. Statutory requirements for ASR projects are in the Texas Water Code, Chapters 11, 27 and 36. TCEQ is authorized to grant the operation of an ASR Project and use of a Class V Injection Well for storage in an ASR project through a general permit, individual permit and a permit-by-rule. A permit-by-rule (also called authorization-by-rule) forgoes the public comment process generally required for a Class V UIC General or Individual Permit.

In making its determination to issue an authorization for a permanent Class V Injection Well for ASR purposes, the TCEQ considers the following: (1) whether the project complies with the Safe Drinking Water Act; (2) the extent to which the cumulative volume of stored water can be successfully recovered from the formation, taking into account that the injected water may be comingled to some degree with native groundwater; (3) the effect of the ASR project on existing wells; and (4) whether injection of water will alter the physical, chemical or biological quality of the native groundwater to a degree that would: (i) render the groundwater harmful or detrimental; or (ii) require an unreasonably-higher level of treatment in order for the native groundwater to be suitable for beneficial use. These are shared objectives with the Districts.

While TCEQ has regulatory authority of Class V ASR Injection Well authorizations in Texas, House Bill 655 specifically provides that the amendments to Chapter 27 of the Texas Water Code do not affect the ability of the Districts (and four other special purpose districts) to regulate production (recovery) from an ASR project as authorized under Chapter 8801, Special District Local Laws Code for the HGSD. As such, TCEQ has sole authority over injection and the Districts have sole authority over recovery from an ASR well. This makes the District an integral part of an ASR project authorization.

Beyond the dual regulatory authority of ASR within the Districts, a known legal uncertainty is the concept of trespass. It appears to be an undecided legal issue as to whether an ASR project owner could legally be challenged with trespass if the ASR recharge water extends under an adjoining landowner's property. Refer to Bray (2020) and Malcom Pirnie et al. (2011) for additional information.

3.6.9 VULNERABILITY TO CLIMATE CHANGE

Climate change can have a wide range of impacts on infrastructure. The most direct vulnerability of ASR to climate change is a reduction in the availability of surface water used for recharge. Significant sunken time and financial costs would result if an ASR project was constructed only to be left inoperable due to lack of recharge water.

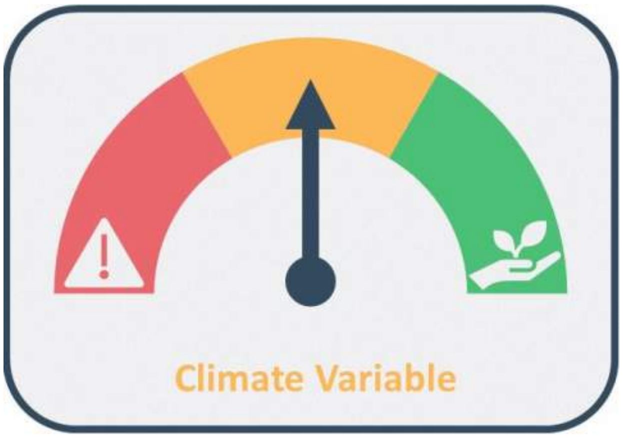

Figure 3-52. Climate Resiliency Rating of Aquifer Storage and Recovery

ASR is typically used to store "surplus" water in times of plentiful supply to be used in times of deficits such as droughts, which may become more severe because of climate change. Unlike surface water reservoirs, this supply option either minimizes or eliminates evaporative losses during storage. Therefore, as a water supply option, ASR is considered to have a lower vulnerability to climate change relative to more traditional sources, although it is not exempt from impacts as shown in **Figure 3-52.**

3.6.10 SUBSIDENCE IMPACTS

There are no operational ASR projects in the vicinity of the Districts, and the relationship between subsidence and ASR in the area has only been estimated based on a desktop analysis (INTERA et al., 2019). A review of case studies of both managed aquifer recharge (MAR), which is recharge (by injection or other means) without intent to recover, and ASR and their relation to subsidence was performed for the INTERA et al. (2019) study. The most significant finding is that, in aquifers that have undergone significant regional subsidence, such as the Gulf Coast Aquifer System in the Districts, subsidence rates can increase in response to additional pumping even when water levels remain above historical minimums. This has been documented in other areas of the country and has been observed in the District in response to increased pumping during the drought in 2011. Maintaining water levels above historical lows does not guarantee the cessation of subsidence. This complicates the analysis of ASR project impacts in aquifers that have experienced significant regional subsidence such as the Gulf Coast Aquifer System in the District.

Figure 3-53. Subsidence Impacts of Aquifer Storage and Recovery

INTERA et al. (2019) investigated the potential for subsidence due to hypothetical ASR projects designed to address either drought or municipal summer peaking demands. Though the modeling described in INTERA et al. (2019) is not exhaustive, it indicates that subsidence may occur and is strongly influenced by (1) well spacing; (2) recovery rate(s); (3) the time the project operator recharges water into storage relative to the time the operator recovers water; and (4) the transmissivity of low clay content intervals used as the storage formation. In INTERA et al. (2019), the summer peaking scenario provided significantly greater benefit (i.e. reduction of subsidence impacts) over traditional groundwater production than did the drought scenario. Since the subsidence that could occur due to an ASR project contains significant uncertainties and is dependent on the local hydrogeologic conditions, the history of development in the area, and the way the project is designed and operated, **Figure 3-53** characterizes subsidence impacts for this AWS as “Moderate”.

3.7 DEMAND MANAGEMENT - BASIC & ADVANCED CONSERVATION

Of the water demand management sub-options considered in the initial screening, the basic and advanced conservation sub-options were considered as the most viable sub-options for inclusion in this study. Basic and advanced conservation, as defined in this report, are, respectively, incentive-based and policy-based conservation measures implemented by water suppliers, municipalities, and local conservation groups such as rebates, education and outreach, and ordinances. Baseline conservation, the passive reduction in water demand due to plumbing code updates and the replacement of older, water-inefficient fixtures and appliances, is already being incorporated into water demand projections being developed as part of the larger 2023 JRPR efforts. Thus, while baseline conservation is anticipated to play an important role in long-term regional water demands, it was not considered necessary to shortlist this AWS sub-option for additional detailed characterization in this study. Water loss control and AMI were viewed as somewhat provider-specific with regards to implementation and efficacy, as water losses vary dramatically across systems. While water loss control is likely to be important for individual systems, it was not viewed as one of the most viable regulatory area-wide AWS options. As with other water demand management sub-options, basic and advanced conservation do not rely on large infrastructure projects, making them relatively inexpensive to implement. For the purposes of detailed AWS option characterization, the demand management option comprises both incentive-based basic conservation strategies and twice-a-week water restrictions, an advanced conservation strategy. Although adoption of this latter advanced conservation measure is likely to vary considerably between water providers, it is anticipated to become a component of AWS portfolios for some entities.

3.7.1 IMPLEMENTATION APPROACH

The core goal of water conservation is to encourage customers to change their behaviors to actions that are less water-intense thereby reducing water demands. Behavioral changes can occur through several broad strategies: industrial innovations (baseline conservation), incentives (basic conservation) and policies (advanced conservation). In addition, a reduction in water demand through any strategy can be economically beneficial for the water customer. As discussed in Section 2, water providers do not need to participate in encouraging innovation in order to reap the water savings benefits. Costs savings and plumbing code updates will drive industrial, commercial and residential water users to implement water saving processes, appliances, and fixtures. However, community education and outreach, conservation-based rate structures, rebate/refund programs, and regulatory enforcement are all strategies that water utilities can engage in order to reduce water demands.

Many water utilities have initiated or plan to integrate water conservation strategies through the development of their Conservation Plans. In 2007, Section 13.146 of the Texas Water Code was updated to require water utilities with greater than 3,300 connections to develop a Conservation Plan for reaching specific 5- and 10-year conservation savings targets. Updating this plan every five years provides water utilities an opportunity to re-evaluate existing conservation measures and implement new measures to expand their program(s). To assist in the development of these plans, the TWDB has released a Best Management Practices Guide, Guidance and Methodology for Water Conservation Reporting, and a Municipal Water Conservation Planning Tool (MWCPT). A full list of the conservation BMPs that the TWDB recommends can be found in **Table 3-39** (TWDB, 2020b).

Table 3-39. Conservation Best Management Practices

Conservation Analysis and Planning BMPs
Conservation Coordinator
Cost-Effectiveness Analysis
Water Survey for Single-Family and Multi-Family Customers
Customer Characterization

Financial BMPs
Water Conservation Pricing
Wholesale Agency Assistance Programs
System Operation BMPs
Metering of All New Connections and Retrofit of Existing Customers
System Water Audit and Water Loss Control
Landscaping BMPs
Athletic Field Conservation
Golf Course Conservation
Landscape Irrigation Conservation and Incentives
Park Conservation
Residential Landscape Irrigation Evaluations
Outdoor Water Schedule
Education and Public Awareness BMPs
Public Information
School Education
Public Outreach and Education
Partnerships with Nonprofit Organizations
Rebate, Retrofit, and Incentive Programs BMPs
Conservation Programs for Industrial, Commercial, and Institutional Accounts
Residential Clothes Washer Incentive Program
Residential Toilet Replacement Program
Showerhead, Aerator, and Toilet Flapper Retrofit Program
Water Wise Landscape Design and Conservation Programs
Customer Conservation Rebates
Plumbing Assistance for Economically Disadvantaged Customers
Conservation Technology BMPs
New Construction Graywater
Rainwater Harvesting and Condensate Reuse
Water Reuse

Regulatory Enforcement BMPs
Prohibition on Wasting Water
Conservation Ordinance Planning and Development
Enforcement of Irrigation Standards

Utilities can use the many facets of conservation that are covered within this set of BMPs or may choose more creative options tailored to the demands of their unique customer bases.

Education, Advertisement and Outreach

Pivotal to the success of every conservation measure is effective notification and education of the public. Without this crucial step customer buy-in on conservation measures will be minimal and behavioral changes necessary for reducing demands will not occur. In the TWDB's BMPs they recognize Public Outreach and Education as a "Strategic BMP" that has unidentifiable savings but is useful in implementing other BMP measures. The TWDB recommended five implementation steps, described in **Table 3-40**, for developing education and outreach to pair with other conservation measures (a more detailed description can be found in the TWDB, 2020b reference):

Table 3-40. Steps for Water Conservation Public outreach and Education

1. Target Audience Analysis
• Understand key audience in order to convey a clear message
2. Identify Barriers and Develop Priority Messages
• Priority messages will address the elements of the conservation plan that are the least understood or most resisted
3. Assess Resources and Develop Strategies to Meet Priority Needs
• Resources include print materials (bill inserts, door hangers), online outreach (web pages, social media posts), and community events (facility tours, special topic presentations) • TWDB, TCEQ, AWWA, and others have premade templates for educational materials
4. Determine Where Partnerships Can Expand the Message
• Gardening clubs, environmental groups, universities, and neighborhood associations can assist in promoting conservation
5. Consider a Recognition Program
• Recognize commercial customers with public awards that benefit their image • Recognize residential customers with a loyalty program

Ordinance Development and Enforcement

Utilities with the appropriate authority have the option to further customer participation in conservation practices by drafting conservation ordinances or rules. Due to the magnitude of outdoor water demands, one of the most common and successful ordinances pursued by municipal utilities is a twice-a-week outdoor watering schedule. In addition to a watering schedule, conservation ordinances often include prohibitions against wasting water and time-of-day watering restrictions for outdoor watering. Restricting watering during precipitation or freezing events, watering of sidewalks or other impervious surfaces, excessive runoff, and leaking irrigation equipment can reduce water waste and increase the savings realized from an outdoor watering conservation ordinance. Limiting the time-of-day that watering can occur to in-between the late evening and early morning hours reduces the magnitude of water lost to evaporation during the hotter and windier times of the day.

Using knowledge of daily demand peaks and the customer characterizations, utilities will be able to tailor their conservation ordinance to fit their unique needs. Twice-per-week restrictions are well established within Texas, however some communities who have successfully managed once-per-week restrictions during extended drought periods may choose to pursue that more stringent option. The division of customers should be well established to avoid difficulty determining watering days; in addition to address numbers, garbage pickup day, zip codes and other municipal divisions could be used in developing customer classes. The selection of customer classes and scheduled days may create outdoor watering demand peaks as watering is less spread out across the week. Care should be taken to avoid pressure or supply problems in the distribution system; additionally, the hours available for watering can be expanded or shortened to flatten outdoor demand peaks or distance outdoor watering from indoor demand peaks. Shifting outdoor watering hours may burden residences without automatic irrigation systems, or those who may water their gardens or landscapes by hand with hoses. Exceptions for hand watering, drip irrigation systems, athletic fields, city parks, and other outdoor water users may be necessary. Engagement with neighborhood associations, property management companies, gardening groups and field managers will be necessary to determine necessary exceptions and encourage early buy-in.

Pivotal to the success of a conservation ordinance is well-defined education and enforcement mechanisms. A clear, understandable watering schedule will increase the ease of communicating and enforcing the ordinance. Education and outreach methods described earlier in this section can be used to communicate the schedule to the utility's water customers. Planning for enforcement requires three primary elements: detection, validation and penalty. Time for utility staff members or local peace or code-enforcement officers may need to be set aside for patrolling and violation detection. Some cities, like Frisco and Fort Worth, have an online form where community members can report violations. Validating a violation has occurred can be done simply through a time-date stamped photograph submitted to the utility for review. Finally, the utility will need to determine the penalty for violating the watering schedule. The utility will need to decide if first-time offenders receive just a warning or if they incur a fee. Fees may reflect the cost of education and enforcement or be the estimated volume of water wasted. With subsequent offences, the utility could increase the fines incurred or can employ other strategies, such as Fort Worth, which chose to lock out in-ground irrigation systems with locking devices placed on backflow devices or irrigation meters (Texas Living Waters, 2018).

3.7.2 REGULATORY AREA(S) SERVED

Water conservation would be appropriate for all regulatory areas in FBSD and HGSD. In areas with groundwater reduction requirements, demand management can decrease the magnitude of AWSs that need to be developed in order to meet the regulatory standards. For FBSD Area B, water conservation measures can reduce the magnitude of groundwater being pumped resulting in cost savings for water providers and reduced stress on the underlying aquifers.

3.7.3 ANTICIPATED USERS

Conservation techniques can be used to reduce water demands across all water users including: residential, commercial, institutional, industrial and irrigation customers. Curbing domestic indoor use and outdoor landscape watering will reduce the demand from residential, commercial and institutional users, and industries and irrigators are encouraged to seek additional costs savings through the implementation of water-efficient techniques and processes. Water utilities can tailor their conservation programs to target the specific makeup of their service area.

3.7.4 MAGNITUDE OF SUPPLIES

Water conservation is an important element to ensure Texas can meet its future water needs; the 2017 State Water Plan estimates that by 2070 approximately 725 MGD of water could be saved through state-wide municipal conservation efforts on top of 790 MGD expected from Baseline Conservation. The 2021 RWP estimates that the region will contribute 110 MGD of savings in water usage to the statewide total from their efforts in Basic and Advanced Conservation by 2070. If water savings are proportional to demands in the region, this would result in approximately 73 MGD in water savings in the HGSD and FBSD regulatory areas by 2070.

Although the magnitude of these savings continues to enhance the attractiveness of the water conservation strategy, there has been traditionally much difficulty in the calculation of these magnitudes. This is in part due to a lack of knowledge and data regarding the effectiveness of conservation practices, but also because customer participation, the main driver for conservation success, is controlled by a multitude of factors and is difficult to predict. While some literature, like the TWDB's MWCPT, can help water providers estimate the water savings and costs of implementing a conservation program, program participation is generally left up to determination of the individual water providers because budgets, education/enforcement efforts, and customer behaviors dramatically vary.

Basic Conservation

In 2018, the TWDB released the MWCPT. The MWCPT was developed for water utilities to more easily develop long-range conservation plans and compare alternative conservation measures in terms of water savings or implementation cost. The spreadsheet-based tool at its core is built upon unit savings and unit cost values that have been retrieved from literature or case studies. While the tool allows users to input conservation measures that they define themselves, a set of basic, incentive-based measures for single-family, multi-family, and commercial customers are built into the tool. The list of the MWCPT's pre-defined single-family conservation measures and their typical unit savings is summarized in **Table 3-41** (the empirical equations used to calculate these values can be found in Appendix B of the MWCPT's User Guide) (TWDB, 2018b). Outdoor water use makes up a significant amount of a single-family residence's water demand so incentivizing a reduction in outdoor watering can result in the greatest unit savings. Due to budgeting constraints, water providers will only be able to implement a set number of rebates or retrofits in a given fiscal year. This limit on conservation measures will determine the number of years a conservation program will need to be active to meet a goal water demand reduction.

Table 3-41. TWDB Conservation Tool Pre-Defined Conservation Measures

Conservation Measure	Unit Savings (GPD)
WaterWise Landscape Rebate	57.4
Rainwater Harvesting Rebate	55.2
Rain Barrel Rebate	42.9
Irrigation Audits (High Users)	33.0
Bathroom Retrofit	31.0
HE Toilet Rebate	28.5
Smart Irrigation Controller	22.7
Home Water Reports	19.8
Clothes Washer Rebate	16.8
HE Sprinkler Nozzle Rebate	9.0
Showerhead and Aerator Kits	7.0

Advanced Conservation

Outdoor watering restriction ordinances have also been shown to produce a significant water savings yield. Typical restrictions allow lawns to be watered at most twice a week. Dallas and Austin have been able to reduce their total municipal use by seven percent with the implementation of a twice-per-week watering schedule, and The Woodlands saves thirteen percentage of their total single-family use. **Table 3-42** summarizes the savings that water utilities in Texas have achieved from implementing twice-per-week watering schedules. Texas Living Waters, who summarized these percentages in their 2018 report *Water Conservation by the Yard*, estimates that water utilities in Region H could save four to twelve percent from their total-single family use (or two to seven percent of total municipal use.) Education and enforcement are necessary in order to maximize the amount of savings that can be generated from an outdoor watering restriction. The lower end of the spectrum (2% of municipal use) represents savings from low levels of enforcement and education, while a high level of effort in education and enforcement will be needed to achieve the 7% of total municipal use. More than other municipal users, single-family residences have the greatest percentage of outdoor water use, so communities made up predominantly of single-family home, like the Woodlands, can see savings above the 7% of total municipal use.

Table 3-42. Outdoor Water Schedule Savings

Water Utility	Year(s)	Annual Percent Water Savings	Category of Use
Fort Worth	2013 - 2016	1 - 9%	Total Municipal Use
Tarrant Regional Water District	Projected	4%	Total Municipal Use
Dallas	2012	7%	Total Municipal Use
Austin	2009	7%	Total Municipal Use
The Woodlands	2012-2013	13%	Total Single-Family Use

3.7.5 BUDGETARY COST OPINIONS

Conservation measures can be an inexpensive way to generate water savings because unlike other supply option they do not require any infrastructure investment. Conservation still requires careful planning phases and extensive education and marketing outreach. Planning and developing a conservation program can have a wide array of costs depending on the utility's unique conservation program and their approach to planning. For individual conservation measures found in the TWDB's Conservation Tool, the TWDB has developed cost assumptions in conjunction with the expected savings to help utilities better plan for water conservation. The suggested rebate incentive, other costs, and total cost per single-family home are summarized in **Table 3-43** (TWDB, 2018b). The other costs include an assumed cost of processing and marketing the rebate, except in the case of retrofits or audits, where new fixtures or audits are provided directly to participants and no rebates are offered.

Table 3-43. Cost Assumptions from the TWDB Conservation Tool's Measures

Conservation Measure	Suggested Rebate	Other Cost per Implementation	Total Cost per Implementation
WaterWise Landscape Rebate	$500	$50	$550
Rainwater Harvesting Rebate	$284	$71	$355
Rain Barrel Rebate	$50	$14	$64
Irrigation Audits (High Users)	-	$99	$99

Conservation Measure	Suggested Rebate	Other Cost per Implementation	Total Cost per Implementation
Bathroom Retrofit	-	$329	$329
HE Toilet Rebate	$85	$28	$113
Smart Irrigation Controller	$200	$10	$210
Home Water Reports	-	$7	$7
Clothes Washer Rebate	$284	$28	$312
HE Sprinkler Nozzle Rebate	$100	$10	$110
Showerhead and Aerator Kits	-	$10	$10

Apart from the costs associated with rebates, the remainder of costs of a conservation program include planning, implementation and education/enforcement. These elements can be covered by utility employee time. In addition to Section 13.146 of the Texas Water Code requiring the development of a conservation plan, it also requires the designation of a conservation coordinator within the utility responsible for the implementation of the water plan. For smaller utilities, the responsibility of planning for and implementing conservation may be divided between current staff roles, but for larger utilities a conservation manager or director may be responsible for these tasks.

3.7.6 IMPLEMENTATION TIMELINES

Until other water supply options, demand management through basic and advanced conservation measures, does not require any infrastructure investments. The implementation timeline for conservation measures will require two stages: planning and execution. In their BMPs for Water Conservation, the TWDB recommends allowing at least 12 months for the development of plans for incentive-based programs or the development of a conservation ordinance. Within these initial 12 months, utilities can locate water-efficient fixture providers or other teaming partners, communicate with local stakeholders, develop education and advertisement methods and plan for budgetary allocations. However, the continued life of the program after its implementation is pivotal to the success of any conservation measures.

Execution phases can last anywhere from a couple of years to indefinitely. Incentive programs can continue until a goal number of rebates or retrofits have been supplied. Education and outreach efforts can be scaled based on the goals set for the current year. For water conservation ordinances, education, outreach and enforcement will continue indefinitely while the ordinance lasts. Cities like Frisco and the Woodlands make random patrols through neighborhoods as part of their continued enforcement policy. Enforcement efforts may lessen over time as more customers comply and are educated on the ordinance.

3.7.7 WATER QUALITY CONSIDERATIONS

Unlike the other AWS options, demand management does not add any new water supplies. Without any additional sources, the source water quality of a utility implementing conservation measures will not change as a result of those measures. A reduction in water usage may have the potential to concentrate waste flows being collected at the WWTPs; however, the concentration of waste flows would not be immediate. Conservation savings are recognized gradually over time, so the timescale of wastewater concentration would allow the treatment plant operators time to adjust to the changing conditions.

3.7.8 PERMITTING AND LEGAL CONSIDERATIONS

Common conservation measures will not require any permits to implement. However, when it comes to conservation ordinances, there may be some investor-owned utilities or water supply corporations who will have the full regulatory authority to implement a water conservation ordinance. These utilities can partner with the governing authorities of the municipalities or areas they serve, or choose to offer recognition or loyalty awards to customers who comply with a watering schedule. Utilities that purchase wholesale water from other providers may also be required to comply with conservation measures that their provider has implemented for their own customers. Careful review of the water supply contract should be taken to ensure that all measures contractually obligated are implemented by the customer utility.

3.7.9 VULNERABILITY TO CLIMATE CHANGE

Savings generated from water conservation activities are not vulnerable to climate change, as shown in **Figure 3-54**, but instead increase a water utility's reliance to climate change. Strict, short-term forms of demand management are often used as a tool to combat the effects of short-term climatic conditions like droughts. Retail water supplies with over than 3,300 connections are required, under the Texas Water Code, to have a Drought Contingency Plan. In these plans, unessential water use restrictions, water conservation measures and public notification and outreach stretch existing supplies to ensure essential demands are met during a short-term water supply shortage. Analogously, long-term conservation methods as discussed above can ensure demands are met in the face of the negative effects of climate change on water supplies.

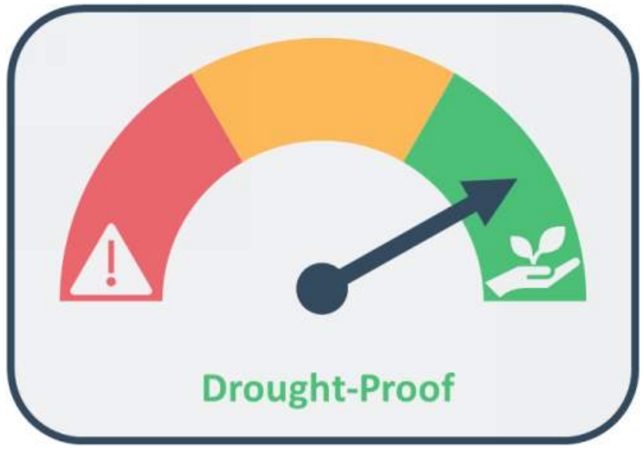

Figure 3-54. Climate Resiliency Rating of Demand Management

3.7.10 SUBSIDENCE IMPACTS

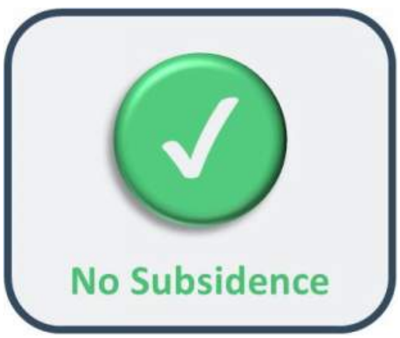

Figure 3-55. Subsidence Impacts of Demand Management

Demand management activities will not cause any additional subsidence impacts, shown in **Figure 3-55**, but instead can help to slow or reduce subsidence caused by extracting groundwater supplies. A reduction in demand will consequentially reduce the amount of groundwater that will need to be extracted in order to meet those water demands. Reduced demands can also make developing other subsidence-independent AWS options more economically feasible because water utilities will be able to pursue projects with smaller yield magnitudes than if demand had remained unchanged.

SECTION 4 – CONCLUSIONS AND NEXT STEPS

This section includes a summary of the AWSs characterization findings, information from stakeholder outreach, conclusions, and next steps.

4.1 AWS CHARACTERIZATION SUMMARY

The following subsections summarize notable findings from the AWS option characterization that was detailed in Section 3.

4.1.1 OVERVIEW

This study evaluated the potential supplies that are available to meet the potable and non-potable water demands for near-term and long-term (2070). A summary of the supplies that are available to meet the potable and non-potable demands, including interdependencies among the conventional and emerging alternative waters are shown in **Figure 4-1**.

Presently and in the future, surface water supply will continue to be the most dominant AWS to meet the potable water demands. Appropriated but undeveloped water from the Trinity, San Jacinto and Brazos River basins will be a key component of new surface water for this region. The East Texas Transfer of surface water will likely eventually bring in new supply to the region as well. Development of regional water storage solutions such as new reservoirs or ASR projects will assist in delivering more surface water to the future growth areas of Harris, Galveston and Fort Bend counties.

However, surface water is prone to climate impacts, and water providers will continue to explore and integrate drought-proof supplies, such as reclaimed water. Depending on the end use and regulatory requirements, reclaimed water can be treated to the desired water quality using proven treatment technologies. Reclaimed water will continue to be developed as a resilient supply option to meet non-potable, and possibly over the long-haul, potable demands as well.

Incentive-based conservation and ordinance-based outdoor water restrictions will be key water conservation strategies that municipal systems will continue to use to manage water demands. Monitoring and managing water demands will reduce the need for additional water supplies.

Evolution in desalination technologies and alternative energy sources can bring down the life-cycle costs for brackish and seawater desalination. Systems may consider desalinated water to diversify water portfolios. Development of seawater desalination supply will require regional consortium and cooperation among coastal and inland water users.

For clarity, the detailed characterization of these options presented in Section 3 addressed each option independently. However, as shown in the figure, many of these options, and therefore their potential implementation, are interrelated in meeting the potable and non-potable water demands.

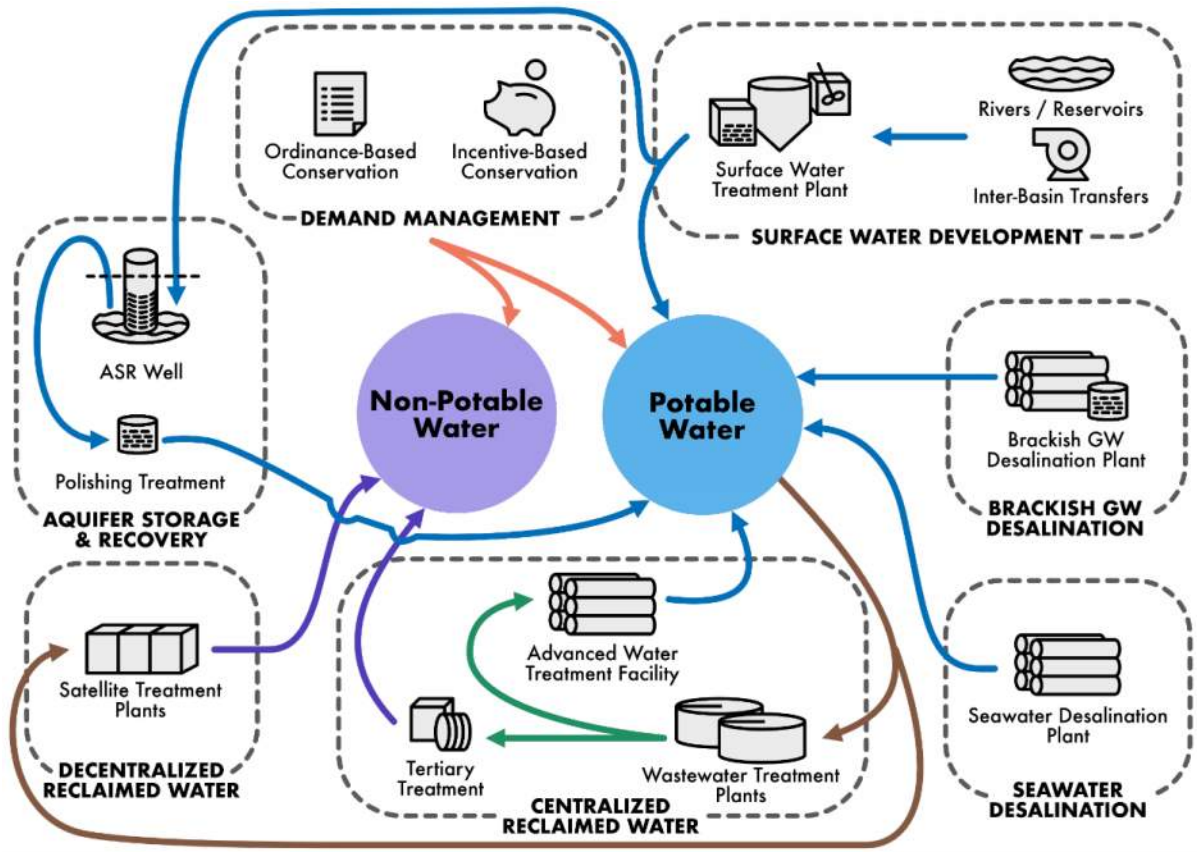

Figure 4-1. AWS Option Interdependencies

4.1.2 MAGNITUDE OF SUPPLIES

Potential AWS and demand management magnitudes are summarized in **Table 4-1**. As shown in the table, surface water development and centralized reclaimed water treatment for both potable and non-potable uses are considered to have the highest potential supply magnitudes. Note that these are not implementation projections, but rather an inventory of potential supply availability.

Table 4-1. AWS Magnitude of Supplies Summary

Alternative Water Supply	Potential 2070 AWS Magnitude (MGD)
Surface Water Development	~700
Seawater Desalination	100
Centralized Reclaimed Water Treatment	160
Decentralized Reclaimed Water Treatment	13
Brackish Groundwater Desalination	24
Aquifer Storage and Recovery	20[a]
Demand Management through Conservation	73[b]

a – ASR requires treated surface water as a supply source. It is assumed that this surface water supply would be derived from interruptible rights that are not already reflected in the magnitude of surface water development.

b – Demand management is not a supply option. Rather, the listed magnitude represents a reduction in water demands.

Figure 4-2 presents the potential AWS magnitudes in the form of a "waterfall" chart, depicting how these options could augment existing supplies to expand the combined HGSD/FBSD regional water supply portfolio. This chart provides a simplification to facilitate comparison with future demand projections, with several notable caveats:

- This figure shows only AWS magnitudes. Groundwater supplies are omitted from these totals.
- As noted, these quantities are not implementation projections, but rather potentially available supplies. Development of these supplies would occur based on 1) phased implementation of AWSs according to certified GRPs, and 2) increases in AWS demand (i.e., growth), and only a subset of these potentially available supplies may therefore be developed by 2070.
- Further, implementation will not necessarily be proportional to supply availability, but rather by costs, local access to specific AWSs, and other factors. Some options may therefore be omitted from the regional supply portfolio if demands can be more feasibly met with other AWSs.

- Given that demand management is not a supply option, it is omitted from this chart and instead discussed in the context of demands.

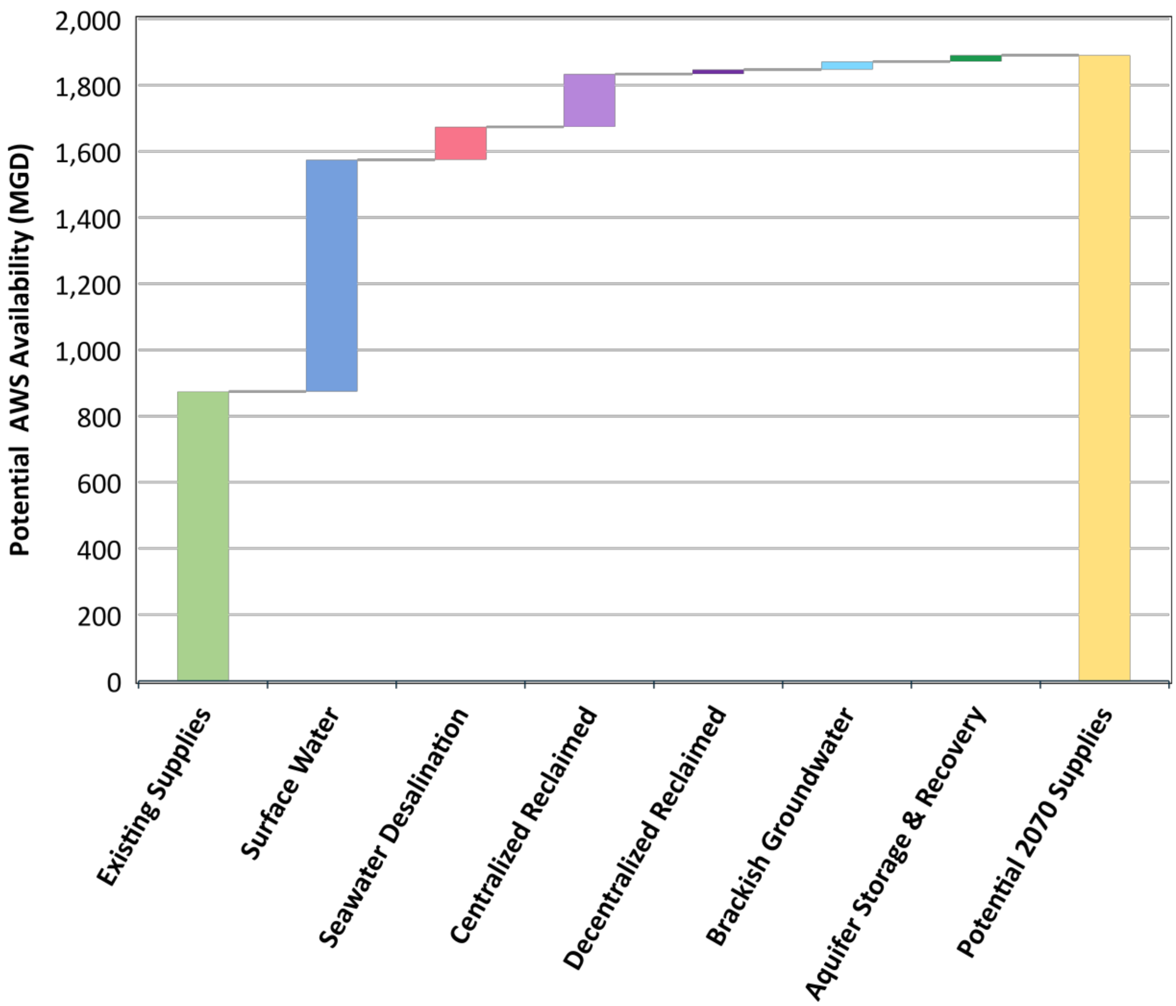

Figure 4-2. Potential 2070 AWS Availability

Figure 4-3 presents a waterfall chart of existing and potential future demands for the combined HGSD/FBSD regulatory areas. Existing AWS demands are derived from HGSD AWS data. Demand growth and future AWS demands have been computed based on data obtained from the 2021 RWP. In this figure, the computed "conversion demands" represent the additional AWS demands resulting from existing HGSD and FBSD District Rules. These demands result from the additional future conversion from fresh groundwater supplies to AWS that will occur based on the phased conversion goals for entities with GRPs in HGSD Area 3 and FBSD Area A. Note that this value assumes no changes to District Rules. In effect, these conversion demands quantify the additional AWS that will be needed to serve the existing water users in the HGSD/FBSD regulatory areas, with no additional population growth.

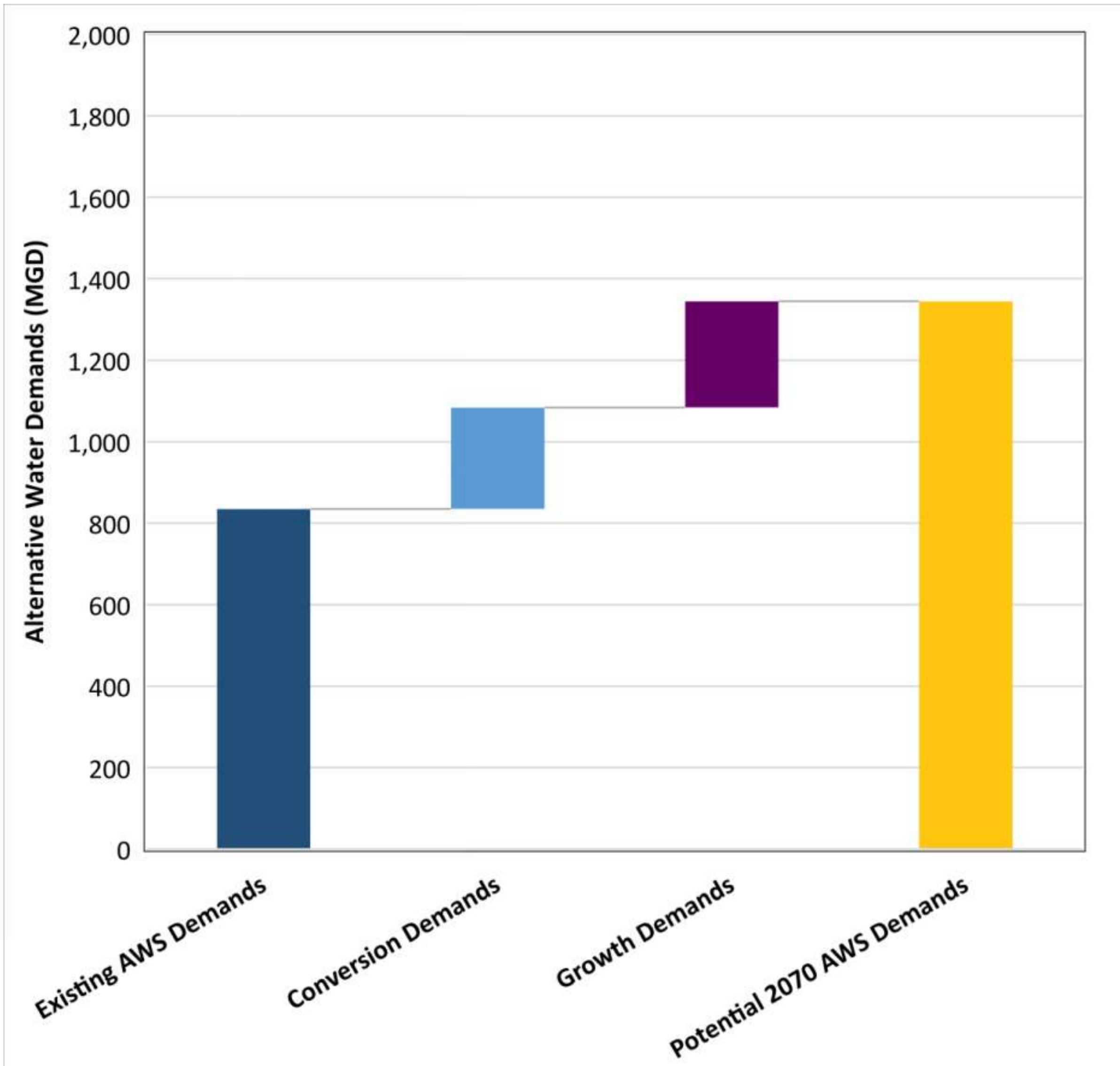

Figure 4-3. Potential 2070 Alternative Water Demands

The “growth demands” bar quantifies the additional AWS demand that is expected to occur as a result of population growth by 2070. Consistent with the conversion demands, this value assumes no further changes to the Districts’ Rules. The potential 2070 AWS demands assume some water savings from baseline conservation, but omit any savings that may be achieved from basic and advanced water conservation measures. Basic and advanced water conservation measures could offset some of the AWS demand growth, potentially resulting in somewhat lower 2070 AWS demands. However, for the purposes of comparison with future AWS supplies, these charts conservatively omit these potential savings.

Detailed demand projections are being developed as part of the JRPR, and these projections may deviate from the values shown herein. However, these projections will be completed after the conclusion of the AWS Availability study efforts, and the values shown herein are considered sufficient for order-of-magnitude comparison with potential 2070 supply magnitudes based on the best currently available data.

Figure 4-4 further summarizes the existing and potential 2070 supplies and demands to facilitate direct comparison. As shown in the figure, potential AWS availability magnitudes exceed projected future demands, suggesting that AWS availability will be sufficient to supply future growth and AWS conversion in the districts. It is recognized that AWS availability is not spatially uniform, and implementation of these options will be influenced by a host of geographic and provider-specific considerations, as demonstrated in **Figure 4-5**. Several of the highest magnitude AWSs will also require substantial regional coordination among providers to implement at the scales shown herein. For example, the East Texas Transfer would likely require participation from numerous providers in the HGSD, and potentially FBSD, regulatory area. Similarly, seawater desalination at this scale would likely require partnerships involving both coastal and inland providers, potentially involving the transfer of surface water rights in exchange for project financing. Nonetheless, these calculations suggest that there is adequate AWS to offset future demand growth in the regulatory areas, provided that some of the high-magnitude AWSs can be brought to fruition within the planning horizon.

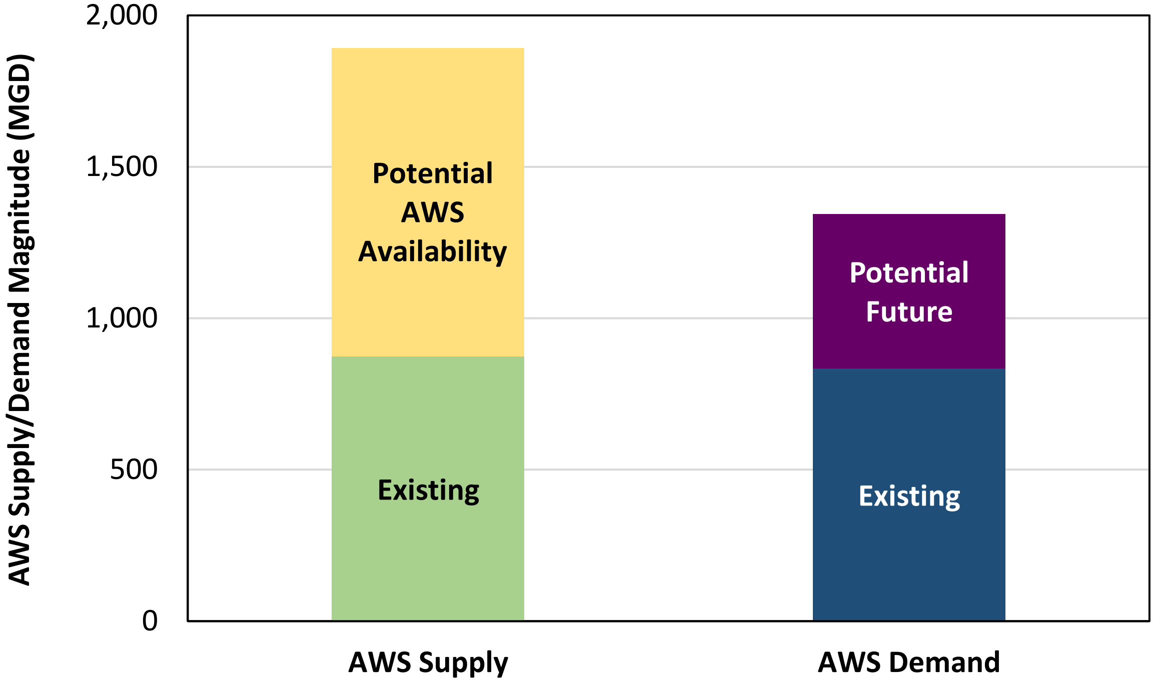

Figure 4-4. Potential 2070 Alternative Water Supply and Demand

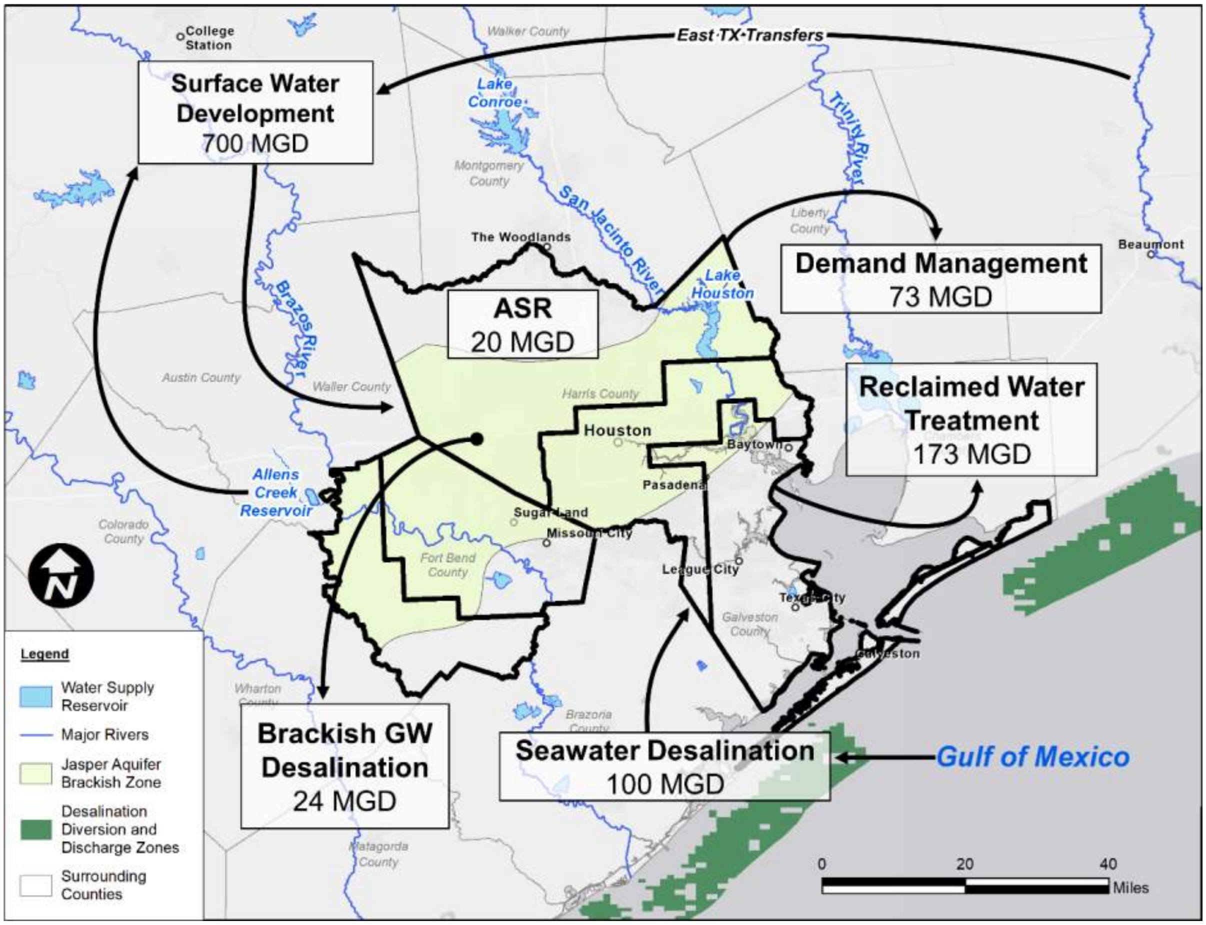

Figure 4-5. Alternative Water Supplies Available Over the Long-term for HGSD/FBSD Regulatory Participants

To illustrate potential 2070 AWS implementation pathways and potential magnitudes, four illustrative regional AWS portfolios were developed, as shown in **Figure 4-6**:

- **Surface Water Dominant** – This regional portfolio, similar to current AWS implementation, relies heavily on surface water supplies, with a relatively low contribution (20 MGD) from centralized reclaimed water supplies. The portfolio includes approximately 450 MGD of additional surface water development which would require near complete development of existing water rights, likely including construction of the Allens Creek Reservoir. However, the East Texas Transfer is not necessarily required to achieve this level of surface water development.
- **Reclaimed Water Emergent** – This regional portfolio assumes greater implementation of centralized reclaimed water supplies (120 MGD) for non-potable and/or potable uses, thereby

reducing the need for additional surface water development, diversifying the water supplies and increasing climate resiliency.

- **Seawater Desalination Emergent** – This portfolio is equivalent to the Surface Water Dominant portfolio, except that 100 MGD of surface water development has been replaced by two 50-MGD seawater desalination facilities. This portfolio also results in diversification of water supplies and reduces impacts of climate change on supplies. However, this portfolio requires careful consideration of water-energy nexus.

- **Hybrid** – The Hybrid portfolio is the most diversified of the four. It includes approximately 340 MGD of additional surface water development, one 50-MGD seawater desalination facility, 60 MGD of centralized reclaimed water treatment, and 20 MGD from decentralized reclaimed water treatment, brackish groundwater treatment, and/or ASR. Notably, given that the 320-MGD NEWPPE is already being constructed and several other surface water treatment plant expansions in the Districts' regulatory areas are in planning or design phases, 340 MGD of additional surface water development essentially represents the lowest likely level of additional surface water development that would be expected.

In reality, it is tough to predict how the future water supplies will be developed and may include one or more combinations of the above-discussed portfolios.

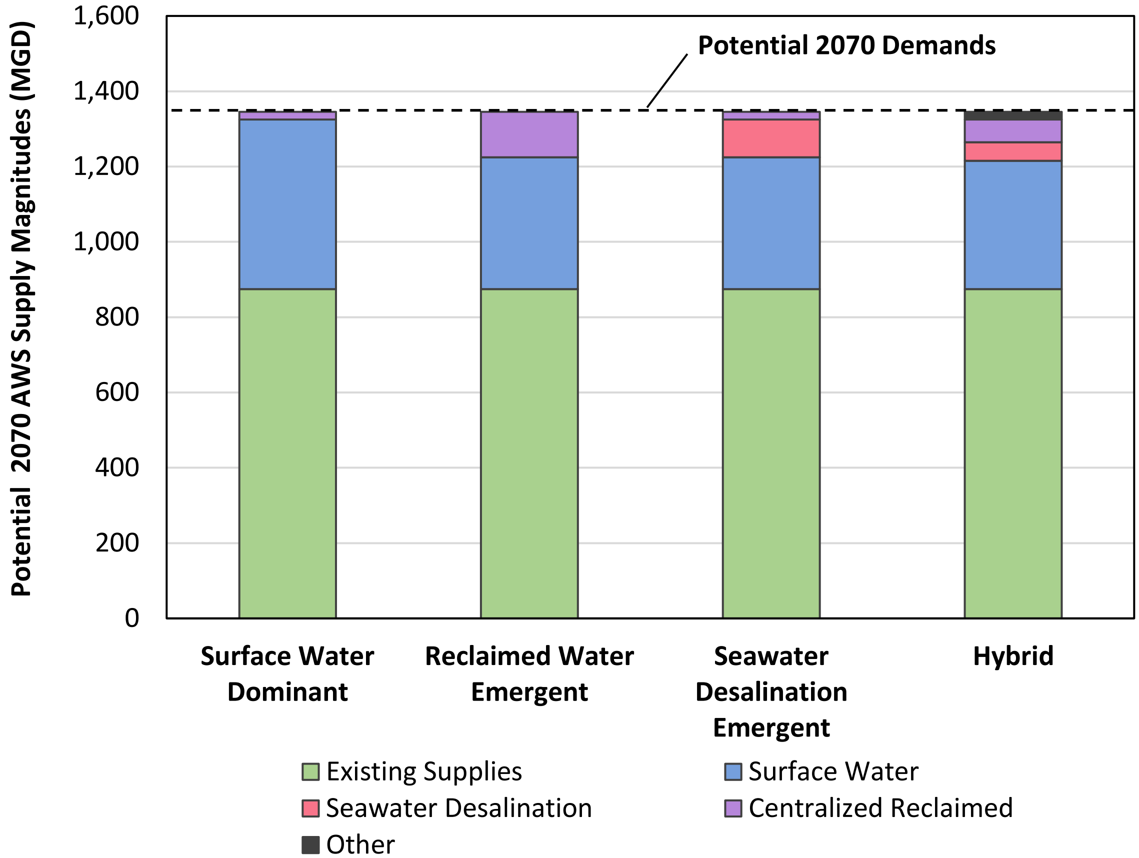

Figure 4-6. Example Potential 2070 AWS Portfolios

As shown in **Figure 4-6**, each of the regional AWS portfolios is potentially capable of meeting 2070 AWS demands. Further, there are many other combinations of AWS options that are potentially capable of meeting regional 2070 AWS demands. Based on a number of factors, including reduced surface water rights availability, diversification of supplies, climate resiliency, etc., individual providers, or groups of providers, are increasingly likely to consider additional AWSs beyond surface water. However, it is clear that surface water will continue to comprise the vast majority of AWS implementation in the Districts for the foreseeable future.

4.1.3 REGULATORY AREAS SERVED

All of the potential AWS options and demand reduction strategies are theoretically available to providers in both the HGSD and FBSD regulatory areas. However, implementation is unlikely to be spatially uniform based on a variety of factors, including the AWS' locations, proximity to corresponding demands, option-specific considerations, and local factors.

As discussed, it is anticipated that surface water development will continue to be the predominant AWS in both subsidence district areas. In addition to undeveloped surface water rights and the LBITP, both district areas will benefit from the construction of Allens Creek Reservoir. The East Texas transfer may also provide supply to providers in the HGSD regulatory area, with potential to additionally supply entities in FBSD regulatory area.

Given the area's proximity to the Gulf of Mexico, entities in HGSD Areas 1 and 2 are the most likely to implement seawater desalination. However, this potential AWS option could indirectly benefit inland water providers, including those in HGSD Area 3 and in both FBSD regulatory areas. This could be accomplished through direct distribution or through a cost-sharing agreement that would result in the transfer of surface water rights from coastal providers to inland providers.

Reclaimed water is a viable AWS throughout both districts' regulatory areas. However, the specific implementation approach will depend on a host of local considerations, such as proximity of supplies and demands, intended end uses, and level of development. It is anticipated that centralized non-potable reclaimed water treatment will be the predominant reclaimed water supply, particularly in the still-developing portions of FBSD and HGSD Area 3. Given the cost of constructing a parallel pipe network for non-potable water, centralized potable reclaimed water treatment may be preferred in more densely developed portions of HGSD Areas 1 and 2.

Based on geologic and water quality considerations, brackish groundwater desalination of Jasper aquifer water is considered to be more favorable within a band crossing portions of both districts' regulatory areas (see **Figure 3-38**). ASR using surface water could potentially be implemented in all HGSD and FBSD regulatory sub-areas. Areas closest in proximity to the ASR project site may be the least expensive to serve, so this factor can be included with geologic and chemical suitability studies when determining the location for the ASR wellfield. However, a study by Smith, et al. (2017) found that ASR may be more suitable for regions of the Gulf Coast Aquifer outside of the districts' regulatory areas.

Basic and advanced conservation approaches are broadly applicable for all FBSD and HGSD regulatory areas. However, the specific implementation approaches will vary based on provider philosophy and customer preferences.

In addition to the need for new AWSs in Fort Bend County and western Harris County, a portion of northeast Harris County currently lacks access to reliable AWSs. This area, which lies outside of the service areas of the City of Houston and the regional water authorities, is shown in **Figure 4-7**. There are no available unappropriated water rights on the San Jacinto River and Lake Houston, and entities in this area will therefore need to purchase surface water from other rights holders or seek out other AWSs. There is a need for a focused assessment on regional and local AWSs for this area.

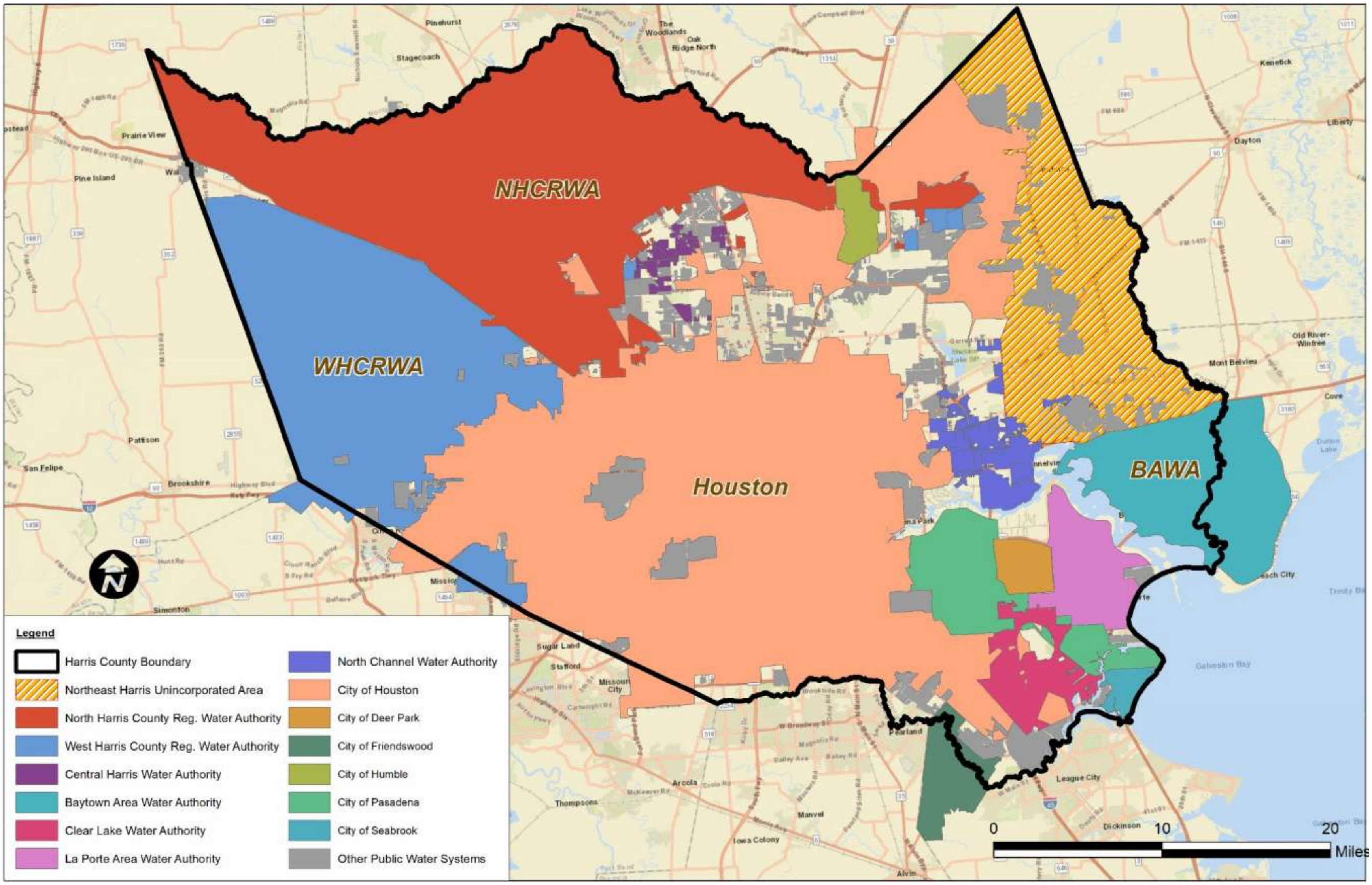

Figure 4-7. Unserved Areas of Harris County

4.1.4 IMPLEMENTATION CAPACITIES AND TIMELINES

Potential AWS and demand management implementation timelines are summarized in **Figure 4-8**. Given the requisite planning, design/permitting, and construction durations, new surface water development, seawater desalination, and centralized potable reclaimed water treatment have the longest anticipated implementation timelines. Thus, entities planning to incorporate one of these options into their AWS portfolio will need to commence feasibility study and planning efforts well in advance of the need for these supplies to meet customer demands. Individual project timelines will vary, but these values demonstrate the relative timelines from concept to full-scale implementation for the various AWSs. As discussed, surface water, seawater desalination, and potable reclaimed water have the longest implementation timelines.

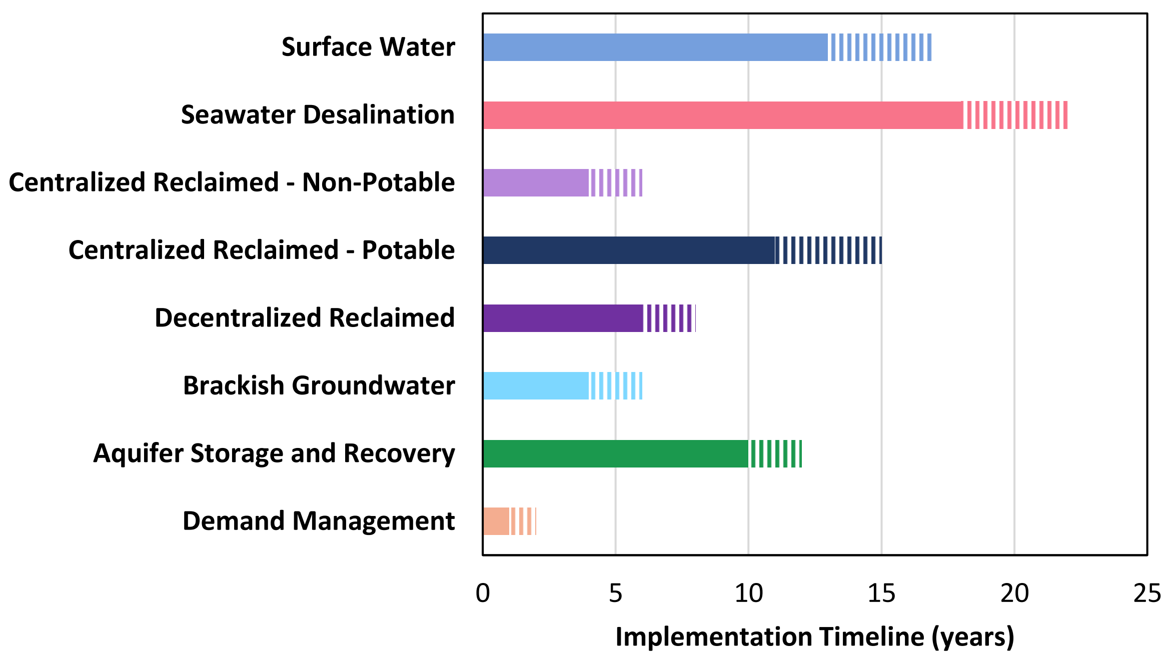

Figure 4-8. Typical Implementation Timelines

Numerous drivers, including population growth, extended droughts, diversification of supplies, re-development in developed areas and future policies can influence the timing of AWS implementation, and it is recognized that these drivers are not spatially uniform. Implementation of individual AWS projects is therefore subject to local drivers and constraints, and projects are therefore likely to be implemented at varying timelines based on these local considerations. Further, while this study examined the availability of AWSs with respect to anticipated 2070 AWS demands, the phasing of these projects over intervening decades was outside the study scope.

Nonetheless, some conclusions can be made regarding future AWS implementation. As shown in Figure 4-6, it is anticipated that surface water will account for the majority of additional AWS implemented by 2070. The majority (320+ MGD) of additional surface water supply will be delivered via the LBITP, NEWPPE, and associated transmission and distribution projects. Given that this infrastructure is already at varying stages of planning, design, construction, and startup testing, it is anticipated that the majority of additional AWS demand in HGSD and northern FBSD Area A will be met via these projects in the near- to intermediate-term horizon. In contrast, given the rapid population growth in FBSD, some users will need to develop and implement additional supply projects within the next ten years. These projects could include surface water development of existing water rights and increased centralized reclaimed water treatment. In the intermediate- to longer-term horizon, one or more regional-scale AWS projects will likely be required to meet AWS demands in the portion of FBSD Area A not served by the NEWPPE. Potential regional AWSs include the Allens Creek Reservoir and seawater desalination. Regardless of which regional AWSs are implemented, cooperative planning and coordination among multiple entities will be needed.

4.1.5 COSTS

The computed capital and total costs for each AWS option are presented in **Table 4-2**. Also shown in the table are the assumed implementation capacities upon which the cost estimates were based. In general, total costs on a per-thousand-gallons basis decrease with increasing capacity due to economy-of-scale gains, and this is particularly applicable for projects with advanced treatment technologies (e.g., seawater desalination, potable reclaimed water treatment). Careful consideration was given to assumed implementation capacity to ensure that all projects would be costed as a scale at which they would be reasonably cost-effective. For example, given the required treatment technologies, a 1-MGD seawater desalination facility is unlikely to be cost effective when compared with other AWSs and is therefore unlikely to be implemented at that scale. However, a regional facility supplying multiple providers appreciably increases economy-of-scale and feasibility for this AWS. It is therefore critical to consider the assumed implementation capacity when comparing costs across options.

Table 4-2. AWS Cost Characterization Summary

AWS Option	Assumed Implementation Capacity (MGD)	Capital Costs (2021 $/GPD)	Total Costs (2021 $/1,000 gallons)
Surface Water Development	25	$4.35 – 9.33	$1.74 – 3.74
Seawater Desalination	50	$6.34 – 13.59	$2.82 – 6.05
Centralized Reclaimed Water – Non-Potable	1.0	$8.30 – 17.78	$2.48 – 5.31
Centralized Reclaimed Water – Potable	10	$8.90 – 19.07	$3.46 – 7.41
Decentralized Reclaimed Water Treatment – Non-Potable	0.4	$10.10 – 21.65	$3.20 – 6.86
Brackish Groundwater Desalination	1	$7.02 – 15.05	$3.00 – 6.44
Aquifer Storage and Recovery with Surface Water	1.8	$8.94 – 19.15	$3.22 – 6.90
Demand Management – Basic and Advanced Conservation	Not Applicable	Not Applicable	Varies

Figure 4-9 shows total implementation costs, including capital, debt service, and annual O&M, for each characterized AWS. Overall, the costs are reasonably comparable across options, but that is based in part on the assumed implementation scales. Seawater desalination and DPR have the highest per-thousand-gallon total costs despite the economy-of-scale gains by sizing these options at relatively high magnitudes. Note that the ASR costs in this table include the corresponding treated surface water supply costs and assume that 20% of the injected surface water is not recovered. This percentage will vary based on local aquifer conditions and other factors, but it is likely that ASR recovery will be lower than the injected volume. As with any infrastructure, actual project implementation costs may vary considerably from project to project based on local factors and design choices. However, these costs demonstrate that each of the potential AWSs shown here can be reasonably cost-effective if implemented at an adequate capacity.

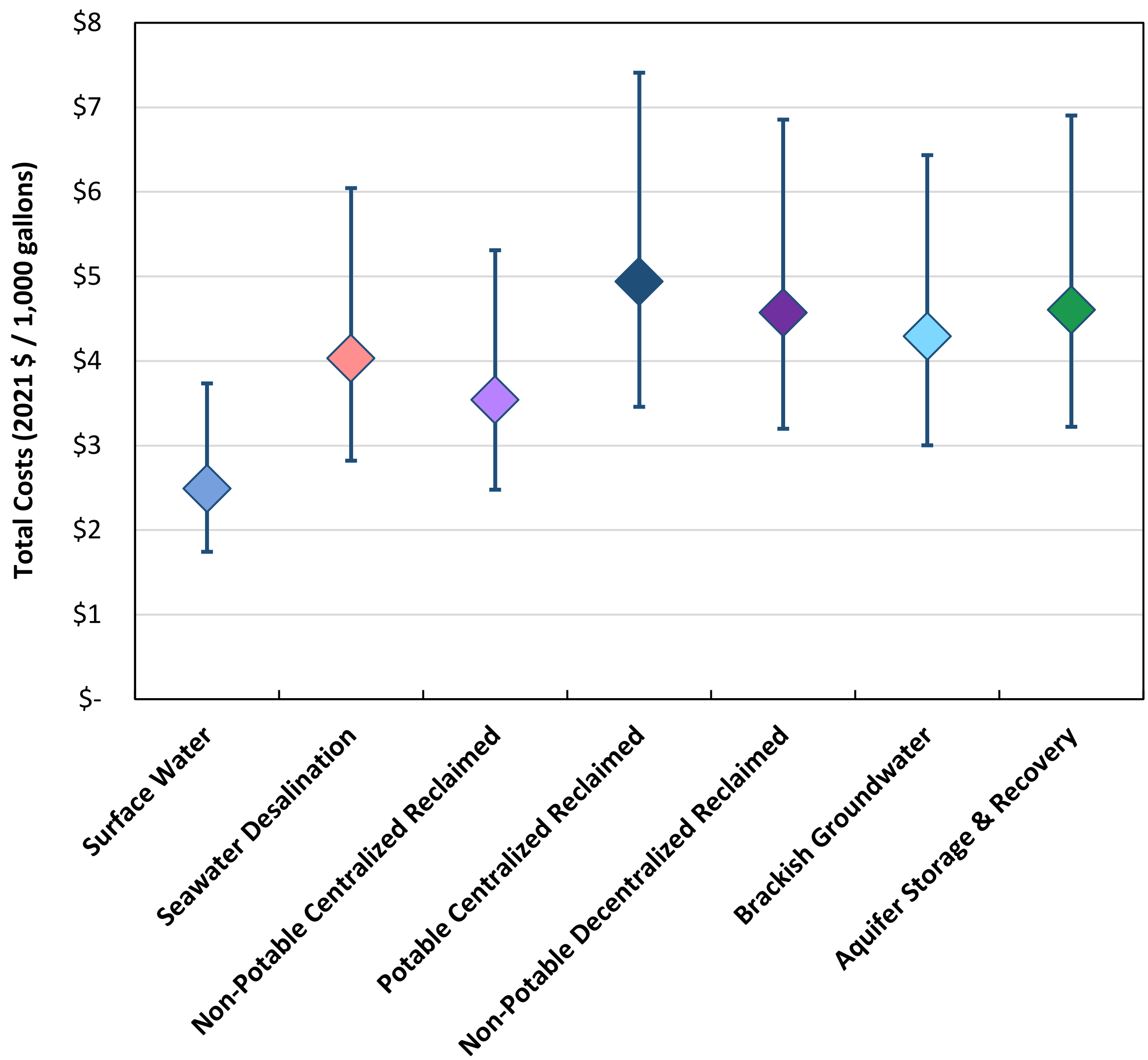

Figure 4-9. Costs per Thousand Gallons

4.1.6 CLIMATE CHANGE AND SUBSIDENCE CONSIDERATIONS

The various AWS options were also characterized with respect to their vulnerability to climate change and potential subsidence impacts, as summarized in **Table 4-3**.

A majority of the options were rated as being relatively resilient to climate change. Notably, surface water development was considered to be the most susceptible to climate impacts. This is especially relevant to the HGSD and FBSD regulatory areas, as surface water supplies are the primary supply in most providers' AWS portfolios. Augmenting surface water supplies with other AWSs would therefore improve AWS resiliency. Given that surface water supplies are the source for ASR injection, this option is also somewhat vulnerable to climate change. However, this vulnerability is somewhat buffered by the proposed operational strategy of injecting seasonally during low-demand periods and withdrawing during peak demand periods. Similar buffering may be achievable by taking advantage of high- and low-flow conditions within a given season.

Table 4-3. Climate Change and Subsidence Considerations

AWS Option	Vulnerability to Climate Change	Subsidence Impacts
Surface Water Development	🔴	None
Seawater Desalination	🟢	None
Centralized Reclaimed Water Supply	🟢	None
Decentralized Reclaimed Water Treatment	🟢	None
Brackish Groundwater Desalination	🟢	Moderate
Aquifer Storage and Recovery with Surface Water	🟠	Moderate
Demand Management – Basic and Advanced Conservation	🟢	None

🔴 – High vulnerability
🟠 – Moderate vulnerability
🟢 – Low vulnerability

Most of the evaluated options do not have potential for subsidence impacts. However, subsidence impacts are still being evaluated for brackish groundwater desalination and ASR. Both of these options include the withdrawal of subsurface supply, though with different approaches. Brackish desalination supply is assumed to originate in the brackish Jasper aquifer in portions of Harris and Fort Bend Counties. ASR would inject and withdraw treated surface water into/from shallower freshwater aquifers. Although ASR withdrawals have the potential to induce subsidence, the risk may be somewhat mitigated through the operational approach. Subsidence impacts from these potential AWSs are being evaluated as part of the HGSD/FBSD Review, but are considered to be moderate.

4.2 SUMMARY OF STAKEHOLDER OUTREACH

A key element of this study involved outreach to HGSD and FBSD stakeholders that included municipal and industrial GRP participants. As part of this outreach process, input was gathered from 12 stakeholders, of the categories illustrated in **Figure 4-10**, on their near-term and long-term plans for AWS options. Information gathered from the stakeholders is summarized in

Figure 4-11. The questionnaire used to obtain the stakeholder's input is attached in **Appendix A**.

All 12 stakeholders are interested in surface water supplies and reclaimed water supplies to meet their potable and non-potable water demands. Surface water will continue to be the dominant AWS. Reclaimed water will be a key, climate-resilient AWS to meet the non-potable and potable water demands.

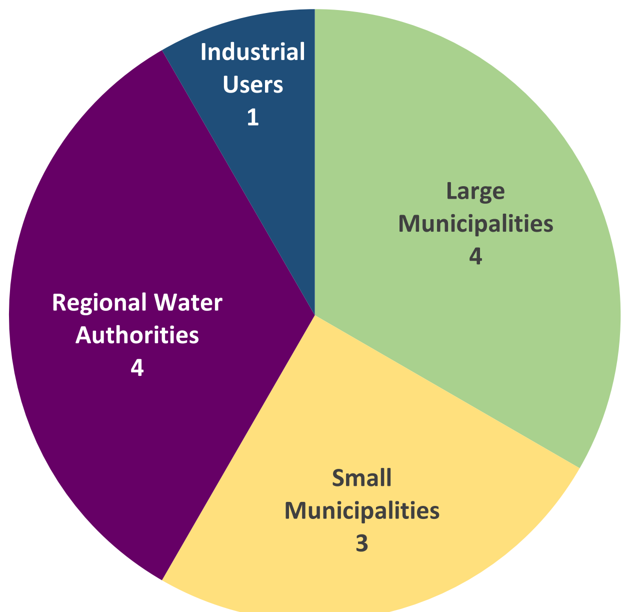

Figure 4-10. Stakeholder Outreach Participants Breakdown

Eleven out of 12 stakeholders are interested in demand management through a combination of basic and advanced water conservation measures. Several of the stakeholders already have fairly elaborate water conservation programs that are geared towards reducing residential and commercial customer water demands. One of the stakeholders has developed a water conservation program tailored to irrigation customers.

Five out of the 12 stakeholders are interested in seawater desalination, if it is developed as a regional water supply with cooperation of coastal and inland entities. In this scenario, the desalinated seawater will be used to meet the demands of coastal communities and in return the inland communities will be traded the surface water rights from the coastal communities.

Only a few stakeholders are interested in brackish groundwater desalination and storage solutions using ASR. These two aquifer-based options have some uncertainties related to land subsidence that are still being evaluated.

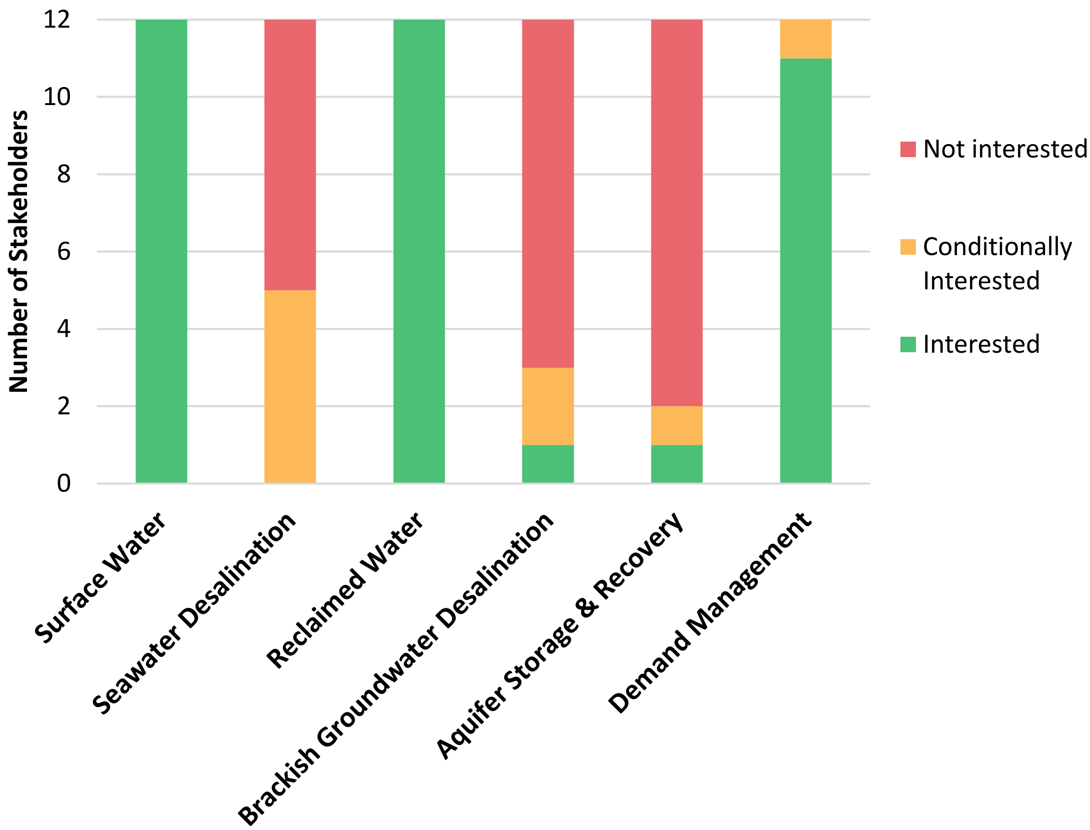

Figure 4-11. Summary of Stakeholder's Input

4.3 CONCLUSIONS AND NEXT STEPS

All of the AWS options included in the detailed characterization were found to be feasible from availability and cost perspectives, though some options are subject to spatial and scale constraints that limit their regional applicability. From a purely arithmetic standpoint, potential AWS availability outpaces future demand growth, and there appears to be adequate AWS to meet future needs within the regulatory areas through 2070.

However, it is recognized that AWS availability is not spatially uniform, and AWS implementation may be more challenging in some regulatory sub-areas. In particular, on a percentage basis, demand growth is anticipated to be greatest in FBSD and in the western portion of HGSD Area 3, as development in these suburban areas continues at a rapid pace. However, the western portion of HGSD Area 3 does not have direct access to surface water supplies and will rely on the delivery of treated surface water from the NEWPPE. Fort Bend providers are dependent upon limited Brazos River and Oyster Creek water rights. Similarly, northeast Harris County does not have a regional water authority or other wholesale treated water provider, and development in this area requires coordination with an entity with surface water rights and treatment capability and/or other AWS.

As summarized in **Table 4-1** and **Figure 4-2**, it is anticipated that future AWS availability will likely predominantly consist of surface water development and centralized non-potable reclaimed water treatment. Desalination of seawater may also provide substantial contributions to the regional AWS portfolio if implemented at a regional scale. Surface water development predominantly consists of development of existing water rights, construction of Allens Creek Reservoir, and East Texas transfers. Development of existing rights and Allens Creek Reservoir are predominantly limited to wholesalers/providers along the major rivers (Brazos, San Jacinto, and Trinity) in the region. The East Texas transfer concept would need to be implemented at a high capacity (likely in excess of 100 MGD) to be cost-effective. Municipal wastewater is readily available as a potential supply, but reclaimed water treatment for non-potable uses requires finding high-demand customers (e.g., golf course, community amenity lakes) in reasonable proximity to reclaimed treatment. It is also much more cost-effective in developing areas (e.g., new MUDs) where a parallel pipe network can be installed prior to or along with road construction. Seawater desalination is an effectively unlimited supply, but is most readily available to providers in HGSD Areas 1 and 2 that have already converted to other AWSs (i.e., predominantly surface water supply). However, implementation of seawater desalination could replace some surface water treatment, potentially allowing for surface water rights to made available to other providers. Brackish desalination of Jasper aquifer supplies is a potential AWS for portions of the FBSD and HGSD regulatory areas. However, its subsidence impacts are still being investigated.

In order for some of the AWS options to be implemented at a cost-effective scale, continued and perhaps increased regional coordination and partnerships will be required in the future. In particular, high-capacity projects with supplies originating outside of the regulatory areas (e.g., inter-basin transfers, seawater desalination) will likely require participation from multiple wholesalers/providers to provide the necessary demands and capital for implementation. Further, seawater desalination may require agreements between coastal and inland entities in which capital contributions are provided in exchange for release of surface water rights, particularly for the Brazos River basin.

Although AWS implementation brings challenges, there appears to be adequate AWS to meet future demands. However, expansion of providers' AWS portfolios will require proactive long-term planning and potentially the need for partnerships with other entities in the region.

This study recommends the following next steps:

- Re-visiting this AWS study report after the 2020 census data and population projections have been completed. Based on the JRPR findings and recommendations on future regulations, the water demands and supplies would need to be re-analyzed. This review should focus on confirming that adequate supplies are available to meet the updated water demand projections for 2070 and the regulatory intent.
- Developing water supply projections to match the demand projections by decade and regulatory areas of HGSD and FBSD. Plotting water supply and demand projections will assist identifying the timeframes when future supplies are needed.
- Conducting a focused assessment of regional and local water AWSs for areas that are unserved by municipalities or water authorities, such as the Northeast Harris County region.
- Assessing the AWS needs for currently unregulated but potentially regulated areas in the future such as the FBSD Area B. Similar to northeast Harris County, a more detailed assessment of AWSs in this region may be required if groundwater reduction requirements are implemented.

SECTION 5 – REFERENCES

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APPENDIX A - STAKEHOLDER FEEDBACK QUESTIONNAIRE

A.1 STAKEHOLDER FEEDBACK QUESTIONNAIRE

A.1.1 INTRODUCTION

1. Does your long-range plan for water supplies include other options beyond those discussed here?
    - Yes
    - No
2. If yes, can you describe in a few words the water supply option(s) that are not part of the 7 shortlisted options?
    - ____________________
    - ____________________
    - ____________________

A.1.2 ALTERNATIVE WATER SUPPLIES

Surface Water Development

3. Are you planning to integrate additional surface water to your water portfolio to meet future demands?
    - Yes
    - No
4. List your future surface water supplies (MGD, Timeline):
    - ____________________
    - ____________________
    - ____________________
    - ____________________

Demand Management

5. Is water conservation a key strategy for your system?
    - Yes
    - No
6. What conservation measures are you considering?
    - ______________________
    - ______________________
    - ______________________
    - ______________________

Brackish Groundwater

7. Are you considering Brackish Groundwater as part of your water supply portfolio?
    - Yes
    - No
8. If yes, what is the anticipated supply magnitude (MGD) and timeline?
    - ______________________
    - ______________________
    - ______________________

Seawater Desalination

9. Are you considering partnership with other entities (public or private) to develop seawater supply over the long haul?
    - Yes
    - No

10. If yes, who would you likely consider partnering with?

    - ____________________
    - ____________________

Reclaimed Water

11. Are you considering reclaimed water as a water source to meet future demands?

    - Yes
    - No

12. If yes, what type and use of reclaimed water are you considering?

    - Centralized / Decentralized
    - Potable / Non-Potable
    - Other

Aquifer Storage and Recovery

13. Are you considering Aquifer Storage and Recovery as an element of your future water supply portfolio?

    - Yes
    - No

14. If yes, what will be the source water for ASR?

    - ____________________
    - ____________________

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