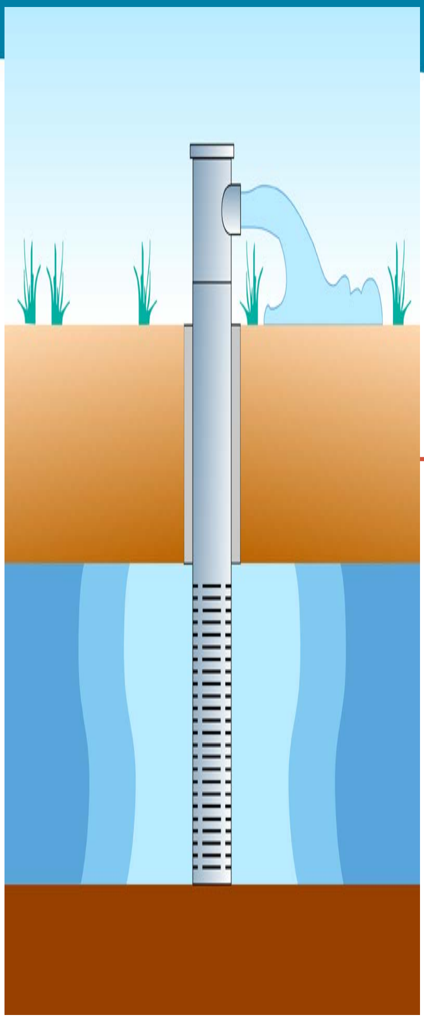

APPLICATIONS OF ASR FOR SUBSIDENCE CONTROL AND CARBON CAPTURE

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Potential ASR Objectives (1/2)

Select and Prioritize One or More Pertinent ASR Applications for each ASR wellfield:

- Seasonal storage
- Long-term storage (“water banking”)
- Emergency storage (“strategic water reserve”)
- Diurnal storage
- Disinfection byproduct reduction
- Restore groundwater levels
- **Control subsidence**
- Maintain distribution system pressures
- Maintain distribution system flow
- Aquifer thermal energy storage (ATES)

Kiawah Island, South Carolina

Potential ASR Objectives (2/2)

- Reduce environmental effects of streamflow and/or reservoir diversions
- Agricultural water supply
- Nutrient reduction in agricultural runoff
- Enhance wellfield production
- Defer expansion of water facilities
- Reclaimed water storage for reuse
- Stabilize aggressive water
- Hydraulic control of contaminant plumes
- Maintenance or restoration of aquatic ecosystems
- Achieve water supply reliability
- **Carbon capture**
- …plus eight other objectives

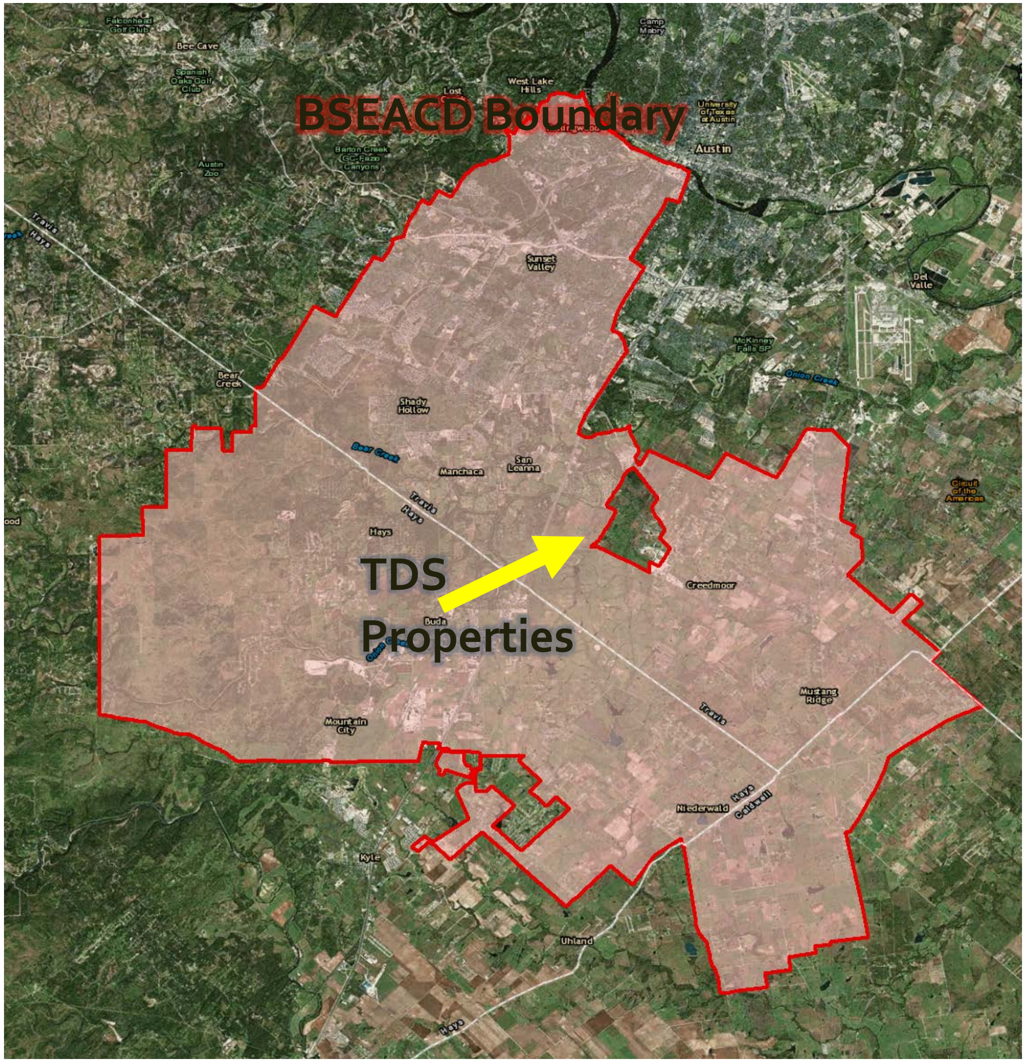
Manatee County, Florida
ASR Well, 1983

ACEC Grand Award, 1984

Barton Springs Edwards Aquifer Conservation District, Texas

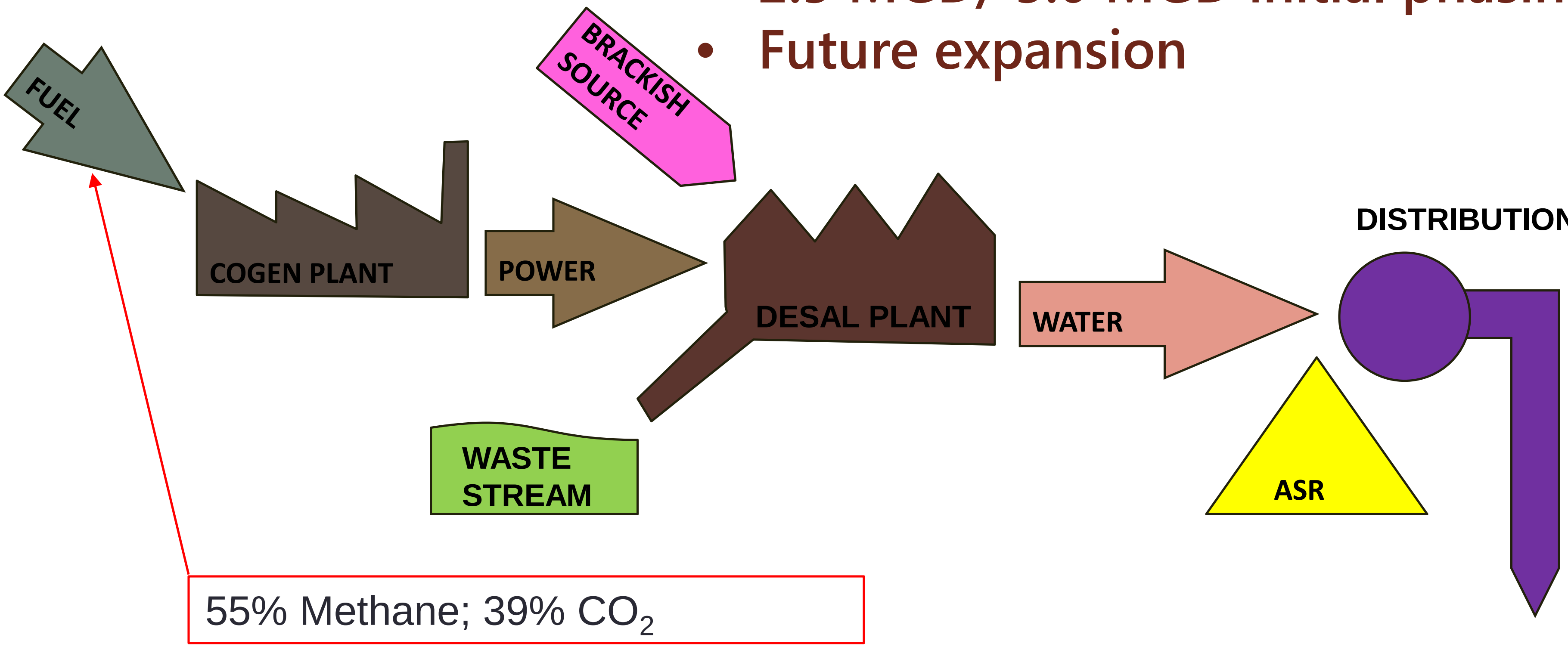
Landfill at Creedmoor owned by Texas Disposal Systems (TDS) (about 2,000 acres)

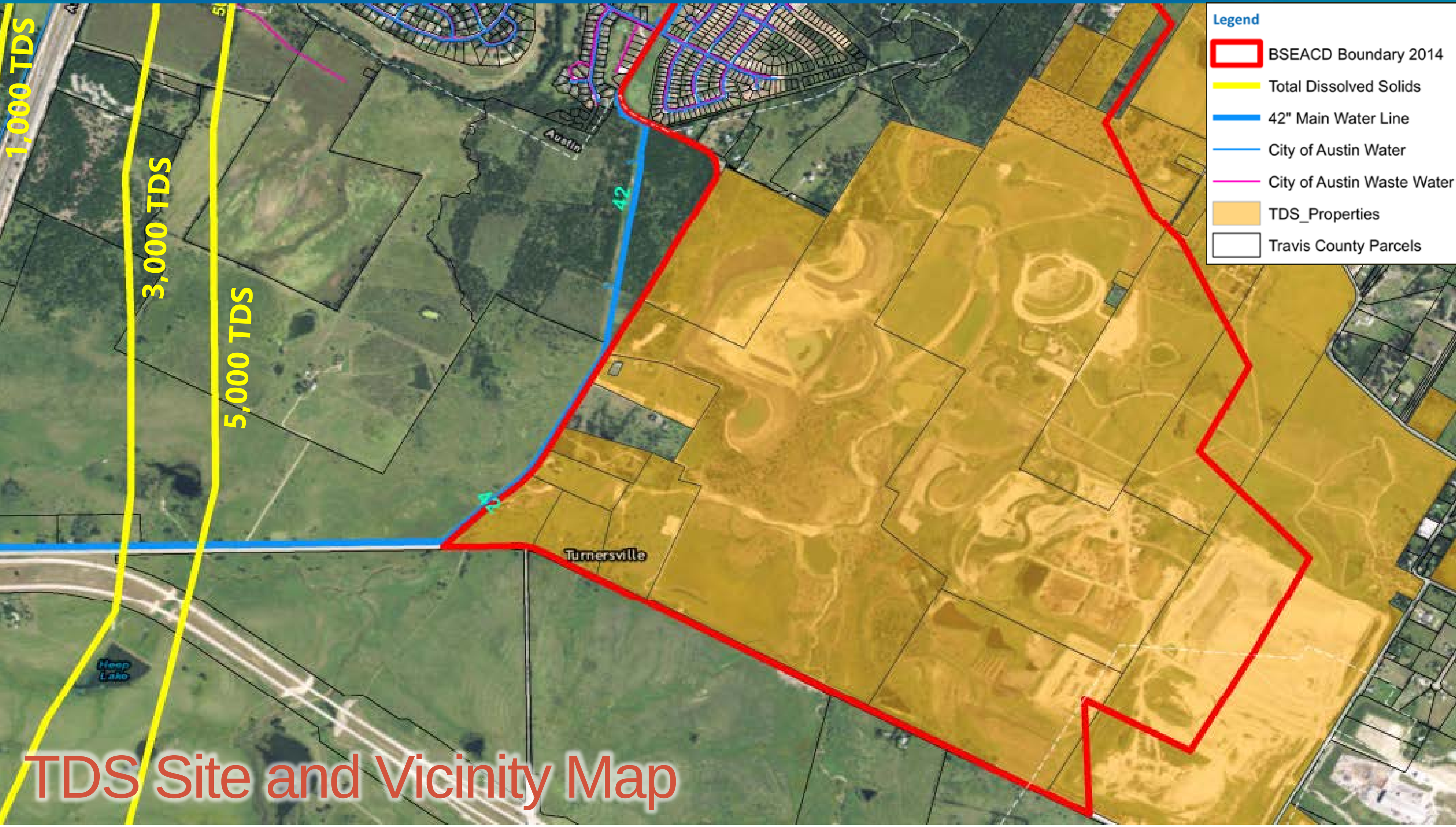
Serving the Austin and Central Texas area



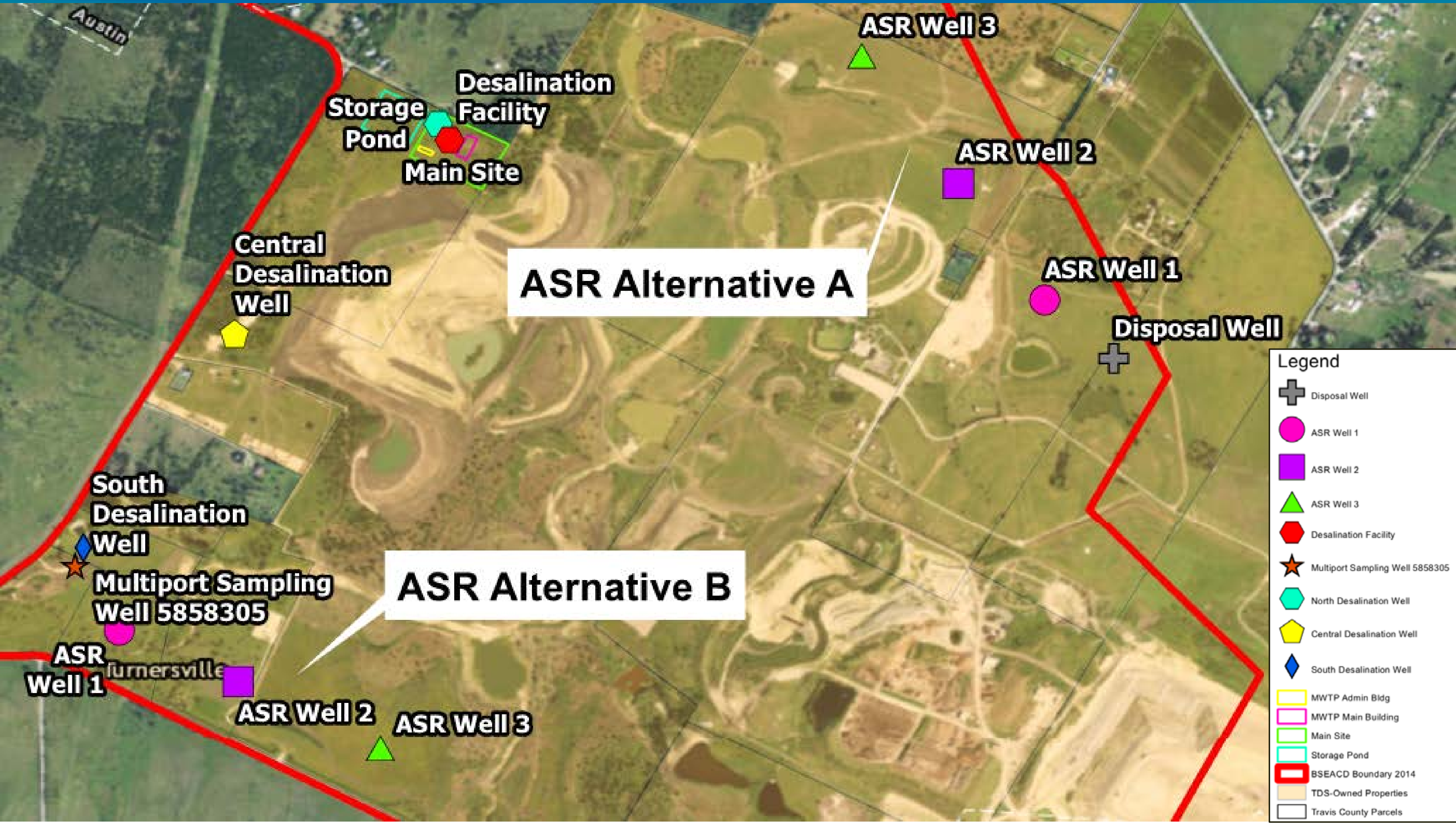
The purpose is integrated application of brackish water desalination and ASR, powered by combustion of methane derived from landfill gas

- **2.5 MGD/ 5.0 MGD initial phasing**
- **Future expansion**

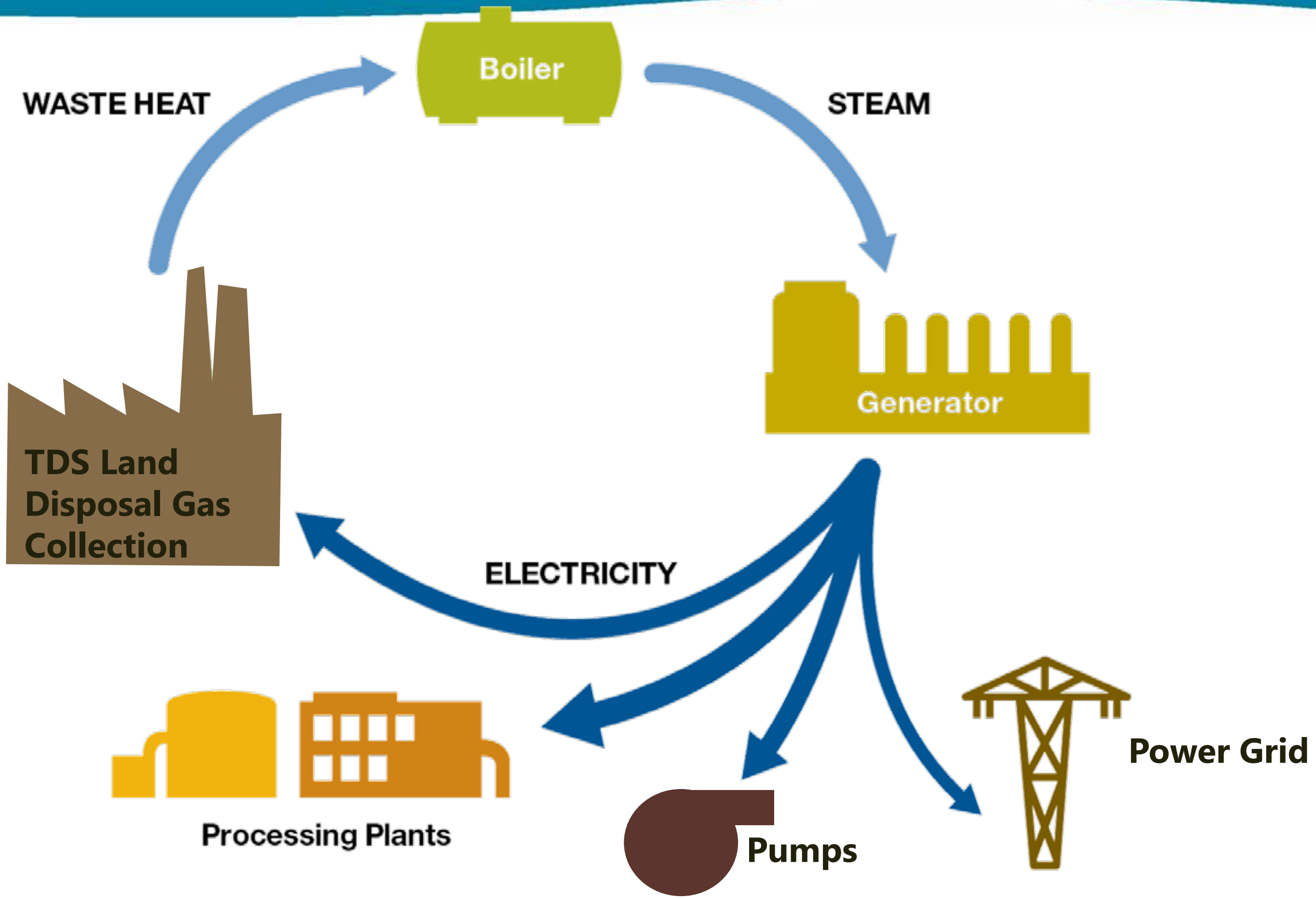




TDS Site and Vicinity Map

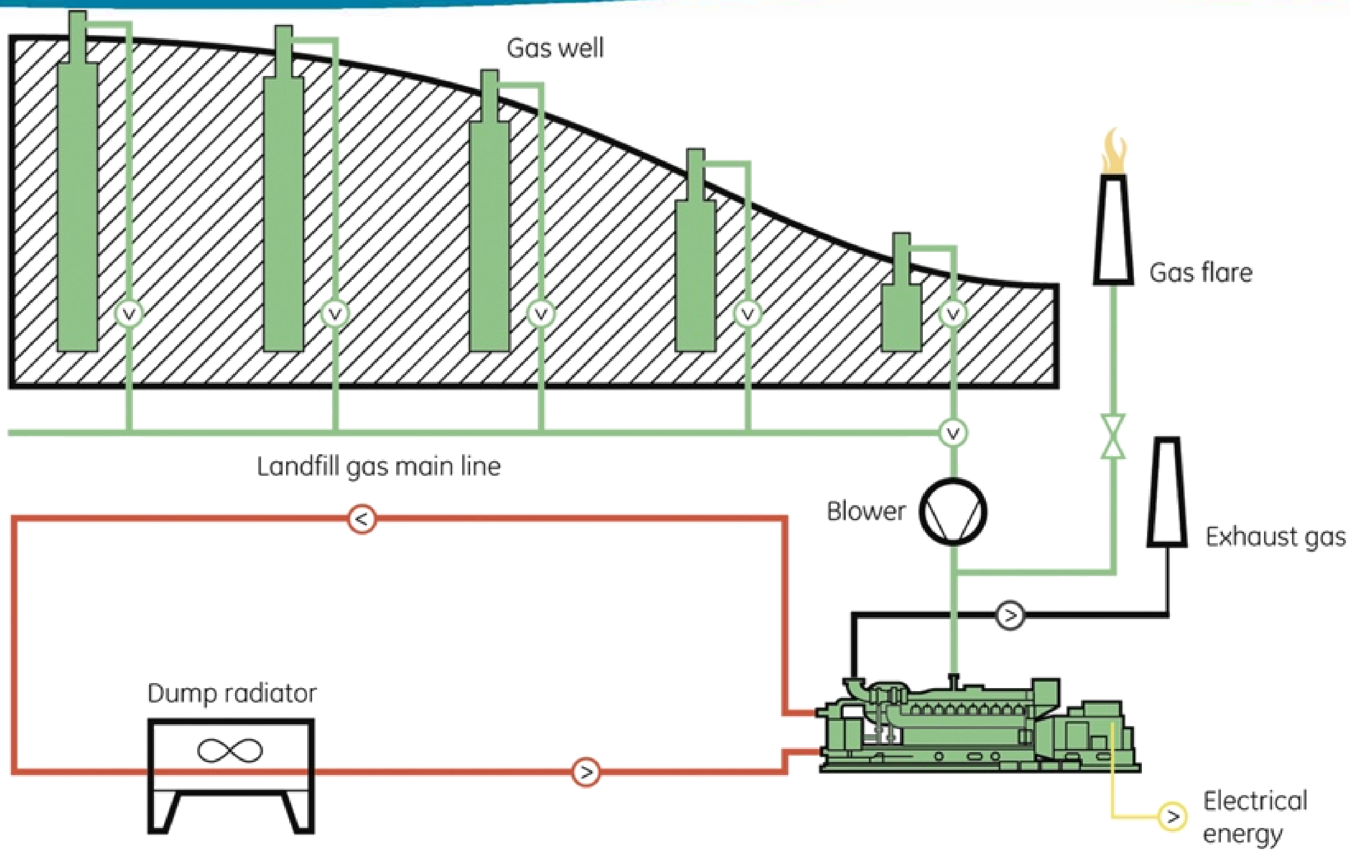

Austin
ASR Well 3
Desalination Facility
Storage Pond
Main Site
ASR Well 2
Central Desalination Well
ASR Alternative A
ASR Well 1
Disposal Well
South Desalination Well
Multiport Sampling Well 5858305
ASR Alternative B
ASR Well 1
Turnersville
ASR Well 2
ASR Well 3
Legend
Disposal Well
ASR Well 1
ASR Well 2
ASR Well 3
Desalination Facility
Multiport Sampling Well 5858305
North Desalination Well
Central Desalination Well
South Desalination Well
MWTP Admin Bldg
MWTP Main Building
Main Site
Storage Pond
BSEACD Boundary 2014
TDS-Owned Properties
Travis County Parcels

Cogeneration



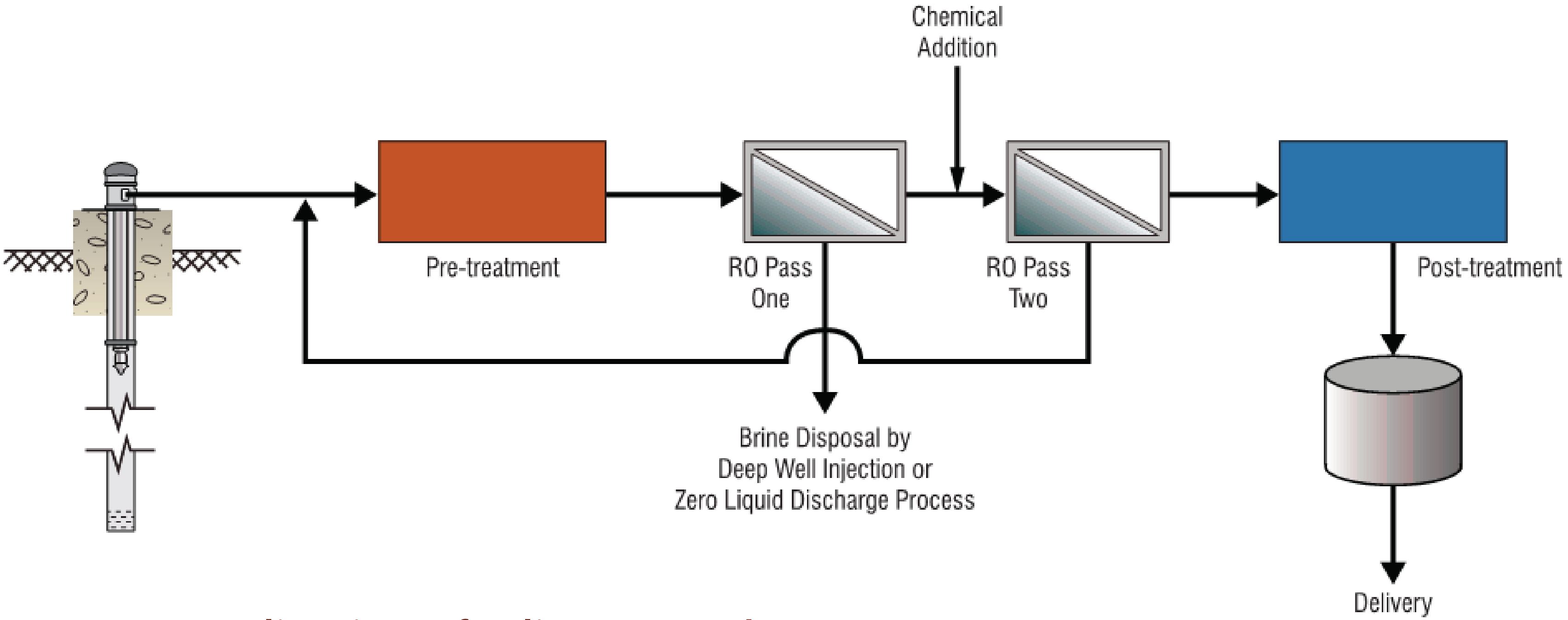
Cogeneration

Landfill



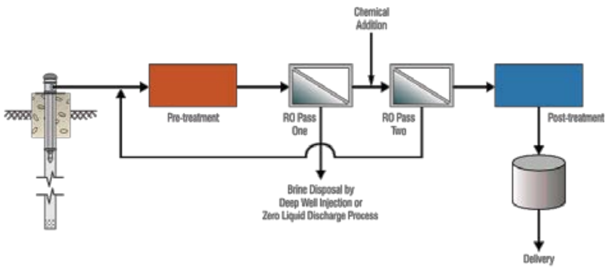
Gas production is estimated at 58.2 Million cubic feet per day or 40,410 standard cubic feet per minute. Total process connected load will be approximately 2.3 MW.

Brackish Water Desalination



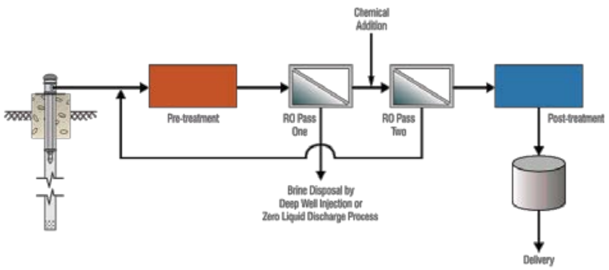
- Desalination of saline groundwater from the Edwards Aquifer.
- The 3 proposed desalination wells will be sized to pump 1,500 gpm each.
- Reverse osmosis (RO) technology

Brackish Water Desalination



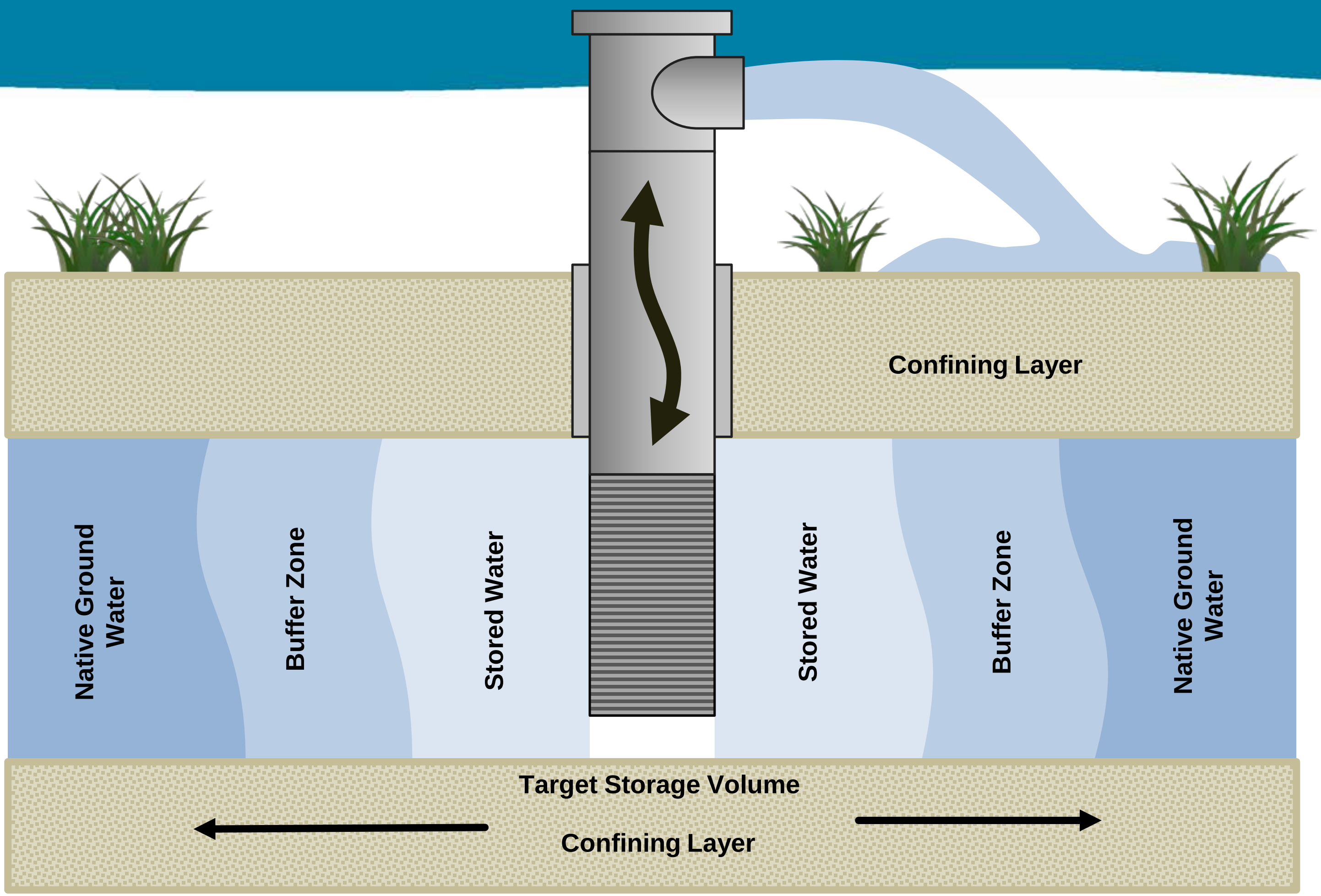
- Desalination of saline groundwater from the Edwards Aquifer.
- The 3 proposed desalination wells will be sized to pump 1,500 gpm each.
- Types: desalination technologies may be defined as pressure-driven, electrically-driven, and thermal.
  - Reverse osmosis (RO),
  - electrodialysis reversal (EDR),
  - and multi-effect distillation (MED)

Concentrate Disposal

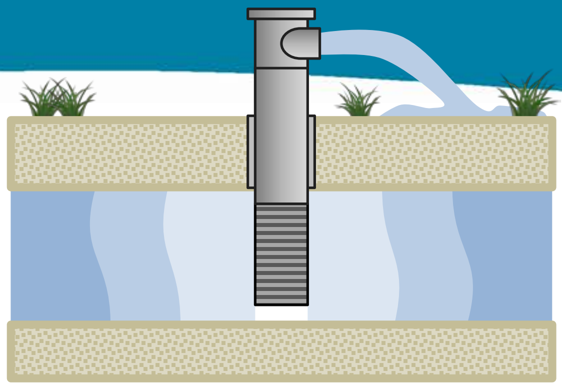


- Deep Well Injection
  - Existing Salt Flat (Edwards) Field Injection Wells in Caldwell County
  - Trinity Injection Wells on TDS Property
  - Edwards Injection Wells in Caldwell County
- Zero Liquid Discharge

Aquifer Storage Recovery

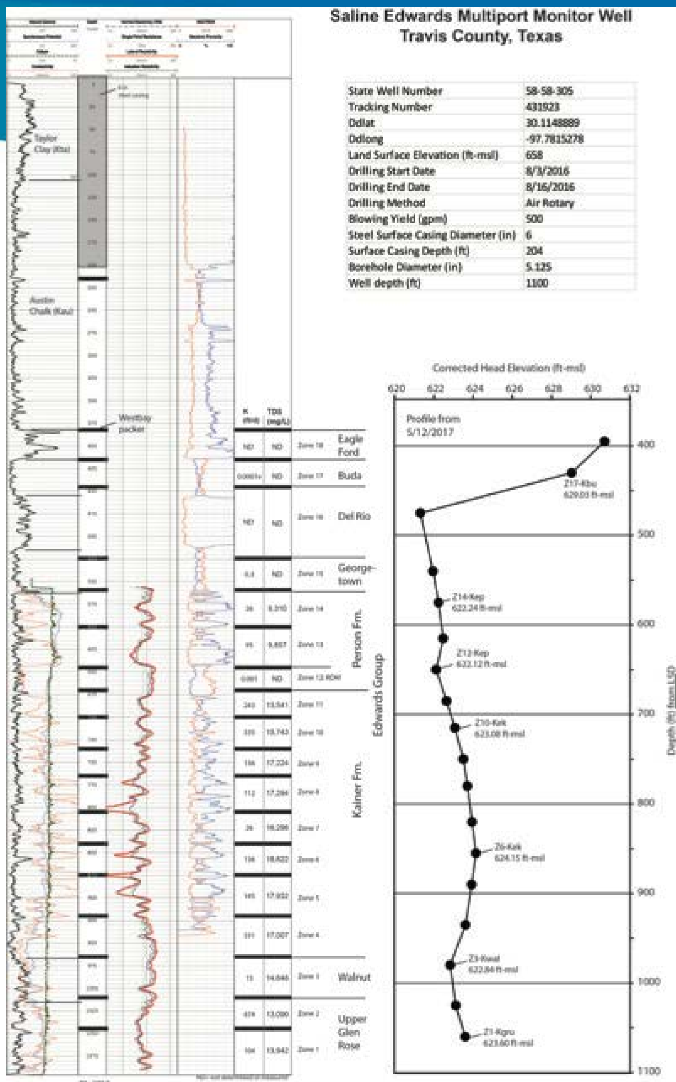


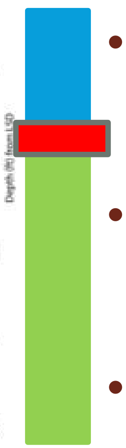
Aquifer Storage Recovery (ASR)



- Three ASR wells are assumed to be needed, each designed to produce 500 gpm.
- Installed capacity will total 1,500 gpm (2.2 mgd).
- Firm ASR recovery capacity with the largest well out of service would be 1,000 gpm, or 1.5 mgd.
- Expansion in subsequent phases

Multiport Monitor Well





Well Depth 1,095 ft

- Total of 18 monitor zones; 11 Edwards zones
- Very high TDS values in all Edwards zones (up to 18,622 mg/L)
- Edwards aquifer confined above and below
- Confining unit between upper two Edwards zones and lower zones
- Upper two Edwards zones would be used for ASR (9,000 mg/l TDS; 550 to 640 ft)
- Lower Edwards zones would be used as source for water desalination (18,000 mg/ TDS)
- Coring planned at another nearby ASR site to better define confining unit

Proposed integrated operations would include cogeneration, desalination, ASR

- Power production from methane derived from landfill gas
- Baseload production of brackish water from lower portion of Edwards aquifer (2.5 MGD/ 5.0 MGD/ expansion)
- Desalination of brackish water at a steady rate
- ASR storage of desalinized water in upper portion of Edwards aquifer during winter months and recovery of stored water during summer months to meet peak seasonal demands, adding 1.5 MGD initially…plus ASR expansion to meet drought demands
- Potential for supplemental ASR storage of water from adjacent City of Austin potable water transmission pipeline (42-inch)
- Balancing of head differential across confining layer

Reduce carbon emissions

- Landfill flare gas is a major source of carbon emissions
- Make use of landfill gas to produce power through cogeneration plants
- Use the supplemental power to desalt brackish groundwater and provide supplemental power to meet other needs, including power supply for ASR and for concentrate disposal via pumping, deep well injection or zero liquid discharge
- Extend brackish water desalination opportunities to more inland areas where concentrate disposal is a challenge
- This supplements normal carbon sequestration that occurs during ASR storage of water containing Total Organic Carbon (TOC)

ASR for Subsidence Control and Water Supply Reliability

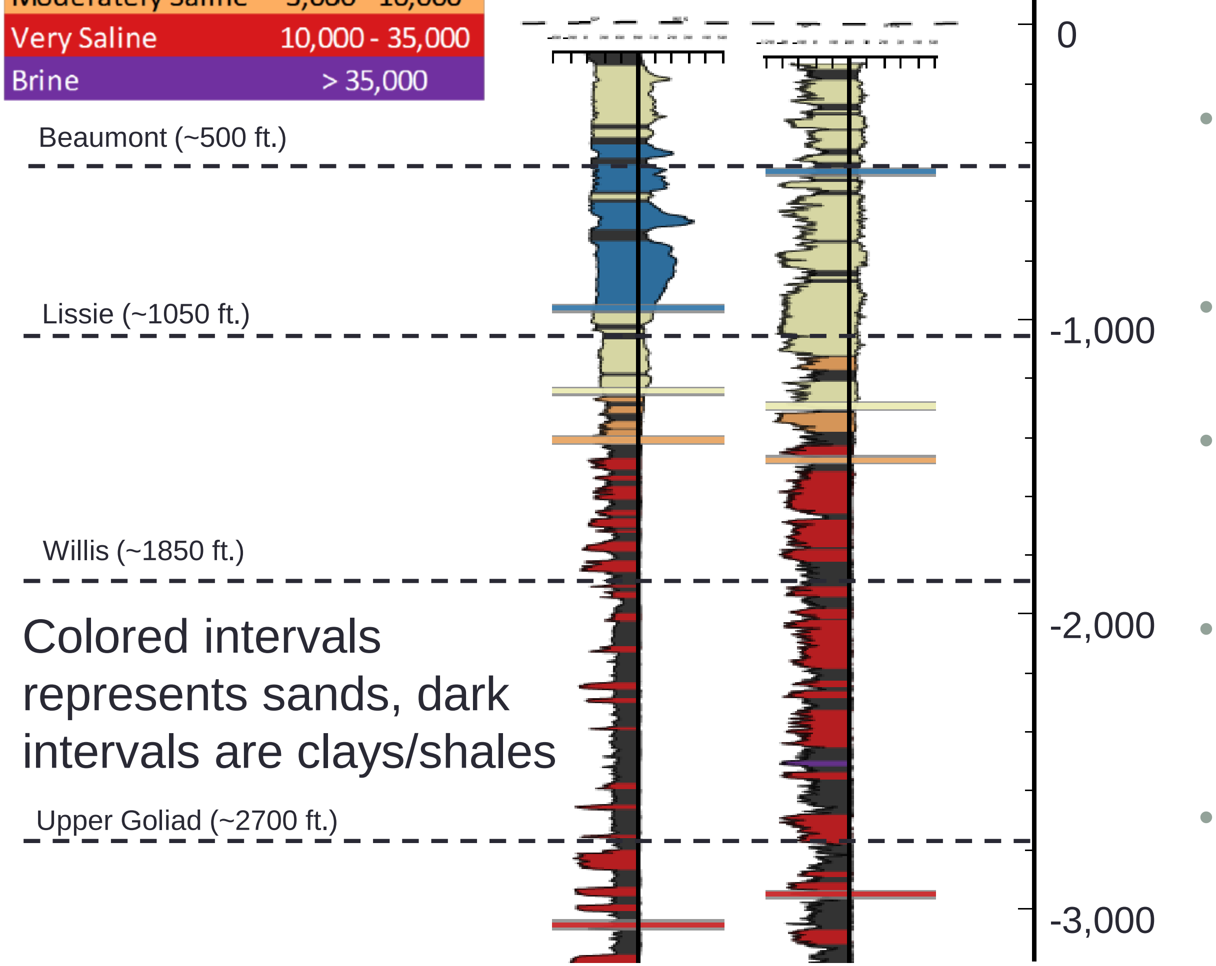
- Subsidence Control examples:
  - Shanghai, China; Las Vegas, Nevada;
  - Secondary objective for planned aquifer recharge program at Hampton Roads, Virginia
  - Refill depleted aquifers to control further subsidence
- Water Supply Reliability examples: Windhoek, South Africa; San Antonio, Texas; Liwa, United Arab Emirates; California and Arizona
  - Long-term aquifer storage for droughts and emergencies
- Galveston, Texas…current project goal is to achieve “subsidence-neutral” water supply reliability with ASR
  - Up to 7 ft of subsidence to date in this low, coastal area
  - Houston area and Texas City Industrial Complex…refineries and other industries need reliable water supplies during droughts and floods

Cautionary Note

- This current ASR project is in an early, hypothetical, developmental stage.
- It is presented at BSMAR16 because the concept is believed to be new and may be applicable in other areas subject to known or potential subsidence, such as in southern California
- Consider the potential applicability of this ASR concept for other areas with which you may be more familiar, and stay tuned for further developments at Galveston Texas.

Conceptual ASR Wellfield Design and Operation to Achieve Project Goals

Quality	TDS (mg/L)
Fresh	< 1,000
Slightly Saline	1,000 - 3,000
Moderately Saline	3,000 - 10,000
Very Saline	10,000 - 35,000
Brine	> 35,000



Colored intervals represents sands, dark intervals are clays/shales

- Alternating layers of sands and clays
- Sand thicknesses up to about 200 ft
- Sand fraction 64%
- Sand Kh 17 to 20 ft/day
- Porosity in range of 33 to 37%
- Clay thicknesses up to about 40 ft

Stack ASR Storage Intervals Vertically

- Five storage intervals to about 1,650 ft, each confined above and below by clay

Zone	Formation	Depth Interval (ft)	Water Quality
1	Beaumont	50 to 500 ft	poor
2	Lissie	500 to 1,000 ft	fresh
3	Willis	1,050 to 1,250 ft	poor
4	Willis	1,300 to 1,400 ft	slightly brackish
5	Willis	1,500 to 1,650 ft	saline

Recharge ASR wells with treated drinking water. Recover stored water when needed to meet seasonal peak demands, emergencies, floods, and a design "five-year drought"

Design "Five Year" Drought

YEAR	RECHARGE (months)	RECOVERY (months)
1	2	5
2	1	6
3	0	7
4	0	8
5	0	9
Normal	5 to 12	0 to 3

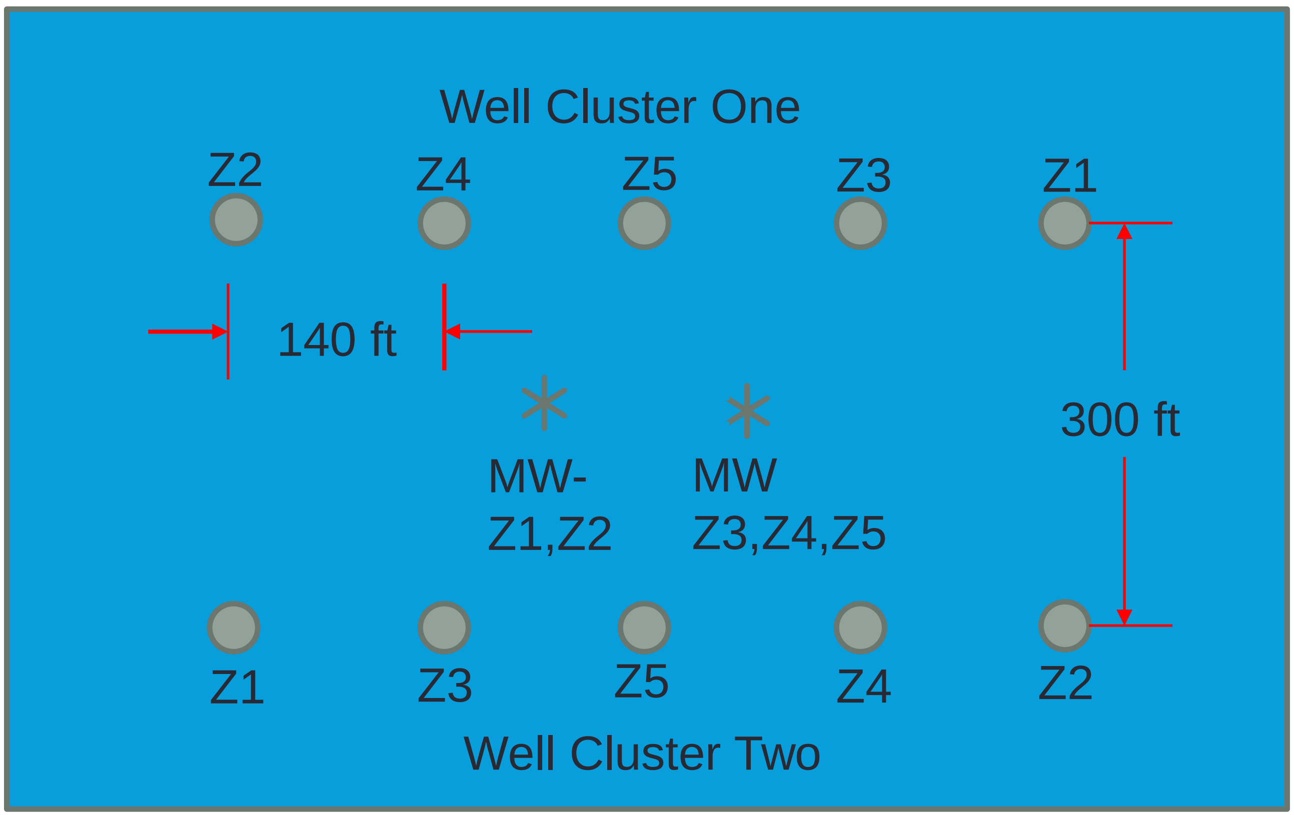
Target Storage Volume (TSV) = Volume required for recovery during design drought, plus a Buffer Zone

Target Design Capacity is 5 MGD

- Recharge specific capacity assumed to be 55% of recovery specific capacity
- Cluster of ASR wells spaced about 140 ft apart, each screened in a different zone, oriented in a line
- Two parallel ASR well clusters on about 15 acres
- Core Hole and Monitor wells
- Recharge capacity about 5 MGD so that Target Storage Volume can be achieved within about five years
- Recovery installed capacity much higher, but limited to 5 MGD by distributing recovery from each zone, meeting geotechnical, geochemical, and water quality criteria
- Construct well clusters at other locations to increase ASR yield while minimizing well interference

ASR Hypothetical Wellfield Layout

Recharge Capacity 5 MGD
Recovery Capacity +/- 18 MGD*



* Distribute recovery flow rate between wells to not exceed 5 MGD

Geochemistry and Geotechnical Issues

- Geochemistry
  - Need to obtain cores of Gulf Coastal Plain sediments in the Galveston area; run core tests, and conduct geochemical modeling for each storage interval
  - Potential issues with calcium carbonate precipitation; sodium montmorillonite clay swelling; mobilization of iron, manganese, arsenic and other metals; carbon dioxide
  - Need to evaluate potential need for pre-treatment/ well conditioning, and post-treatment besides disinfection
  - Different operating rules for different storage intervals/ zones
- Geotechnology
  - Subsidence in Zones 1 and 2 may be continuing even though groundwater production has been reduced and water level recovery has occurred
  - Zones 3, 4, 5 are more likely to be preconsolidated and therefore less subject to subsidence. Also, many clay layers separate them from overlying zones, reducing potential for further subsidence.

Summary

- The number of different applications of ASR continues to increase as the concept of storing water underground is adapted to meet many different needs, constraints and opportunities
- Urban areas have landfills that will produce methane gas for decades, and that can be utilized to produce electricity to power desalination plants and ASR wells, providing water supply reliability in coastal and inland areas.
- Stacking water vertically in fluvial and sedimentary aquifer systems, between confining layers, can potentially ensure water supply reliability during droughts, floods, earthquakes and emergencies while refilling depleted aquifers and preventing further subsidence.

ASR Book, Second Edition

www.asrforum.com