

Pump Example Calculation

energy cost	23.45	USD/MMBTU
energy cost	0.080	USD/kWh
uptime	100	%
uptime	365	days/year
downtime	0	days/year
total days / year	365	days/year

Pump power calculation

flow rate	20,000	bbl/day
flow rate	3,180	m3/day
flow rate	132	m3/hr
flow rate	583	gpm
density of the water	1,025.0	kg/m3
differential pressure	144.0	psig
differential pressure	9.93	bar
differential head	98.76	m
fluid pumping power	36.5	kW
pump efficiency	0.60	
shaft power	60.9	kW
shaft power	81.7	HP
hours in a day	24	hours/day
energy per day	1,462	kWh/day
energy per barrel water	0.073	kWh/bbl
energy per cubic meter water	0.4598	kWh/m3
energy cost	0.08001	USD/kWh
energy cost	116.97	USD/day
energy cost	116.97	USD/day
energy cost	0.00585	USD/bbl
energy cost	0.0368	USD/m3
energy cost	117	USD/day
energy cost	42,694	USD/year

Solar Taurus 60 - power output		
power output	5,670	kW
energy output	136,080	kWh/day
energy output	49,669,200	kWh/year

Single Calc - for verification

20,000	Bbl/day
144.00	psig
6.29	Bbl / cu m
14.5	psi / bar
0.60	pump efficiency
1,462	kWh/day

Example pressure to Head conversion		
pressure	90.0	psig
pressure	6.21	bar
head	61.7	m

Example head to Pressure conversion		
head	57.5	m
pressure	5.8	bar
pressure	83.84	psig

compare

Electricity cost for individual technologies		
Feed flow rate	20,000	BWPD
Electricity unit price	0.080	USD/kWh

Pumping Energy	IGF + WSF	PES UF	Ceramic UF	ZwitterCo UF	RO	MVC	MD	OARO	Units
Differential pressure	14.5	72.0	72.0	144.0	870.0				psig
Differential pressure	1.0	5.0	5.0	9.9	60.0				bar
Energy cost	4,299	21,347	21,347	42,694	257,942				\$/year
Energy cost	0.001	0.003	0.003	0.006	0.035				\$/bbl

Thermal/Other Energy	IGF + WSF	PES UF	Ceramic UF	ZwitterCo UF	RO	MVC	MD	OARO	Units
Energy cost									kWh/bbl
Energy cost	-	-	-	-	-	-	-	-	\$/bbl

TOTAL	0.001	0.003	0.003	0.006	0.035	0.318	0.250	0.245	\$/bbl
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Bartholomew et al. (2017) [98]	TDS (mg/L), Recovery	kWh/m ³	\$/bbl
OARO	140k, 50%	19.3	\$0.25
MVC	150k, 50%	25	\$0.32
RO	35k, 50%	2	\$0.03

Membrane Distillation		
	kWh/bbl	\$/bbl
Cassard and Park [59]	3.1	0.25

Conversion factors

3.785	L / gal
42	gal / Bbl
7.48	gal / cu ft
5.62	cu ft / Bbl
159	L / Bbl
1.195	gr mol / scf
42.21	gr mol / scm
454	gr / lb
1.00E+06	scf / MMscf
2633	lb mol / MMscf
14.7	psi / atm
1.013	bar/atm
3.14159	pi
3,600	seconds / hour
1,440	minutes / day
24	hours / day
365	days/year
60	minutes / hour
60	seconds / minute
3.2808	ft / m
12	inch / foot
144	in^2 / ft^2
1000	mm / m
100	cm / m
1,000,000	micron/m
10,000	micron/cm
25.4	mm / inch
35.31	cu ft / cu m
264	gal / cu m
1,000	L/cu cm
1,000	L/cu m
28.32	L/cu ft
5.62	cu ft / Bbl
9.81	g constant
1.34	HP / kilowatts
0.4327	ft water / psi
3.415	BTU/hr / Watt
3,412	BTU / kWhr
100,000	Pa / bar
1,000	gr / kg
1,000	cc / L (or mL/L)
1,000	L/m3
1,000,000	cc/m3
1	Pa/(N/m2)
1	N/(kgm/sec2)
1,000	mg/gr
3.60E+06	Joule/kW

4.5. Comparison of OARO energy consumption to other brine treatment processes

The energy consumption is a key metric for assessing the effectiveness and economic feasibility of the OARO process relative to state of the art evaporative processes, such as MVC. Fig. 10 provides literature reported energy consumption values for RO, MVC, and our OARO simulations at a feed pressure of 65 bar and a membrane area per module of 10 and 20 m² for recoveries of 35 and 50%, respectively. RO energy consumption ranges from 1 to 2 kWh per m³ of produced water for brackish (~5 g/L TDS) and seawater (35 g/L TDS) at a 50% recovery [7]. MVC energy consumption ranges from 11 to 25 kWh per m³ of produced water for seawater (35 g/L TDS) to high salinity brines (150 g/L TDS) at recoveries of 35 to 50% [1,6,31]. The OARO energy consumption is estimated as 2.9 to 3.7 kWh per m³ of produced water for feed TDS of 60 g/L at 35 and 50% recovery, respectively. At a higher feed TDS of 140 g/L, these values increase to 12.4 and 19.3 kWh per m³ of produced water for recoveries of 35 and 50%, respectively.

Misc, spares, maintenance

TABLE 4
Solid Waste Disposal

SOLID WASTE:	Quantity per train	Extended Quantity of Elements	Assumed Life	Annual element Replacements	Disposal Unit wgt. (d)	Extended (Lbs/year)	Σ (tons/year)	Comments
SRU Membranes (a)	7,854	15,708	5	3,142	35	109,956	55	Parker 40" x 2.5" FulFlo Mega Bond Plus or Honey Comb, 20 micron Asahi Microza UNA-620A
SRU CIP Cartridge filters (b)	1,304	2,608	1	2,608	2	5,216	3	
MF Membranes (c)	1,584	6,336	7	905	65	58,834	29	
Subtotal							87	
Allowance for staff @ 110 lbs/person/workday(e)							0	
Total Solid Waste Allowance							87	

NOTES:

- (a) U.S. Bureau of Reclamation, C. Bartels, R. Bergman, et al; Industry Consortium Analysis of Large Reverse Osmosis/Nanofiltration Element Diameters, Desalination and Water Purification Research and Development Report No. 114, Agreement No. 03-FC-81-0916,
- (b) CIP only; individual element is ~1.5 lbs, each (1.54 for Avasan AVS 20M40); Assume used/drained weight of 2 lbs.; come individually bagged, 12 per carton.
- (c) Shipping weight (with preservative) is 70lb; dry weight is 60 lbs; used 65 lbs as an average to account for build-up and residual liquid
- (d) Assumes gravity drain of free liquids in housing, prior to removal/disposal
- (e) Assumed to include disposal of packaging from work related activities; meals, etc.
- (f) Solid Waste is hauled in 27 cu. yd. bins which rent for \$11.50 per day and cost \$1662.93 per bin load to have hauled, emptied at the land fill and returned. Assumed 388 tons/year / (200lb/cu.yd/2000) = 3880 cu. yd/year; 3,880 cu. yd/year / 365 = 10.63 cu. yd/day; 3,880
- (g) Assumed unit cost for membrane elements are \$641.69, \$13.05 and \$2500 for the RO, RO CIP cartridge filters and MF/UF elements, respectively. Total membrane value is \$25,950,000

	Annual		Unit Cost	Cost
Process Water Waste	26,000	Mmgal	0	\$ -
Sanitary Waste Water	234,000	gal	0.25	\$ 58,500.00
Solid Waste	388	ton	630	\$ 244,521.00
Hazardous (listed) waste	0	ton	0	\$ -
Total cost/year				\$ 303,021.00

Existing Kuparuk STP - Actual Flows [1]			Kuparuk STP Debottleneck (Req) kBWPD			Kuparuk STP Debottleneck w/ MF & SRU kBWPD			Kuparuk Expansion kBWPD		
Flow (kBWPD)			Flow (kBWPD)			Flow (kBWPD)			Flow (kBWPD)		
Days per Year			Days per Year			Days per Year			Days per Year		
185	60	120	185	60	120	185	60	120	185	60	120
Winter	Breakup	Summer	Winter	Breakup	Summer	Winter	Breakup	Summer	Winter	Breakup	Summer
688			999	1031	17	989	1021	1015	197	221	218

	kBWP	Cost
Existing Kuparuk STP - Actual Flows [1]	688	\$ 303,021.00
Kuparuk STP Debottleneck (Req) kBWPD	1000	\$ 440,437.50
Kuparuk STP Debottleneck w/ MF & SRU kBWPD	1000	\$ 303,021.00
Kuparuk Expansion kBWPD	1000	\$ 303,021.00
Kuparuk Expansion w/ MF & SRU kBWPD	210	\$ 303,021.00

Chemical Cost Summary including results from the pilot study

Reagent Prices

REAGENTS:	Active Conc (%wt)	Price	Price Basis*	Sp. Gravity Product (gr/cm3)	Density Product (lb/gallon)	Specific Price Active Ingredient (\$/kg)	Molar Mass of Active Ingredient (g/mol)
Ammonium bisulfite	60%	\$ 4.50	\$/gallon	1.86	15.5	\$ 1.06	115.11
Sodium metabisulfite	100%	\$ 1.62	\$/lb	-	-	\$ 3.56	104.06
Sodium hydroxide	100%	\$ 0.35	\$/lb	-	-	\$ 0.77	40.00
Citric acid	50%	\$ 8.00	\$/gallon	1.24	10.3	\$ 3.40	192.12
Hydrochloric acid	38%	\$ 5.00	\$/gallon	1.18	9.8	\$ 2.94	36.46
Bleach	12.5%	\$ 0.10	\$/lb	1.20	10.0	\$ 1.76	74.44
Scale inhibitor	60%	\$ 16.00	\$/gallon	1.06	8.8	\$ 6.64	-
Biocide (DBNPA)	20%	\$ 32.00	\$/gallon	1.01	8.4	\$ 41.80	241.87
Corrosion inhibitor	80%	\$ 14.00	\$/gallon	0.85	7.1	\$ 5.43	-

* gallon or lb of product, not active ingredient

Unit Conversion References

454	gr/lb
3785	cm3/gallon
3.785	L/gal
42	gal/bbl
6.29	bb/m3
2.2	lb/kg

Results from pilot study

- TEA Spreadsheet updates with piloted parameters
 - o Flux: 20 LMH
 - o Operating pressure: keep the same **dp** assumptions
 - o Recovery: 99%
 - o Cleaning uptime: Assume 1 **hr** cleaning/day ~95% uptime.
 - o Chemicals- updated cleaning schedule and cleaning concentrations
 - pH 2 HCl: Add 54.75 g (approx. 47 mL) of 38% HCl solution to 15-gal water
 - pH 12 Caustic: 170g of NaOH flake and 188 L bleach to **15 gal** solution
 - Not sure how much volume of water we assumed for CIP systems

UF Cleanings

System Basis **20,000** BWPD feed water

System flowrate	583 gpm
CIP Residence Time	10 min
CIP Volume	5833 gal
CIP Volume	22079 L

Alkaline CIP	
NaOH Concentration	0.03 mol/L
NaOH Dose	26.50 kg-active/CIP
Cost NaOH/CIP	\$ 20.40 \$/CIP-NaOH
Bleach Concentration	100 mg/L
Bleach Dose	2.21 kg-active/CIP
Cost Bleach/CIP	\$ 3.89 \$/CIP-Bleach
Alkaline CIP	\$ 24.29 \$/CIP

Acid CIP	
HCl Concentration	0.01 mol/L
HCl Dose	8.05 kg-active/CIP
Cost HCl/CIP	\$ 23.69 \$/CIP-HCl
Citric Acid Concentration	1000 mg/L
Citric Dose	22.08 kg-active/CIP
Cost Citric/CIP	\$ 75.18 \$/CIP-Citric
Acid CIP	\$ 98.87 \$/CIP

	PES UF	Ceramic UF	ZwitterCo	units
CIP Weekly Frequency	14	14	7	#/wk
Total CIP Duration	3	3	3	hr
Uptime	75%	75%	96%	%
Annual Cost	\$ 154,020	\$ 89,655	\$ 44,828	\$/yr
Specific CIP Cost	\$ 0.0281	\$ 0.0164	\$ 0.0064	\$/bbl
Ex-Uptime CIP Cost	\$ 0.0211	\$ 0.0123	\$ 0.0061	\$/bbl

(includes CEBs for CUF)

Alkaline CIP - PES UF	
NaOH Concentration	0.03 mol/L
NaOH Dose	26.50 kg-active/CIP
Cost NaOH/CIP	\$ 20.40 \$/CIP-NaOH
Biocide Concentration	100 mg/L
Biocide Dose	2.21 kg-active/CIP
Cost Biocide/CIP	\$ 92.30 \$/CIP-Bleach
Alkaline CIP	\$ 112.70 \$/CIP

Desalination Cleaning Chemicals - Literature

C. Fritzmann et al. / Desalination 216 (2007) 1-76

Table 24
Operational cost [63]

Component	UF + 2-stage SWRO [US\$/m ³]	In line coagulation + 2-stage sand filtration + 2-stage SWRO [US\$/m ³]
Investment cost	0.2377	0.2452
Replacement for UF cartridges/ sand filtration material + cartridges	0.0234	0.0026
Replacement RO membranes	0.0161	0.0275
Process and cleaning chemicals	0.0411	0.0488
Power consumption	0.1773	0.1712
Spare parts	0.0382	0.0411
Manpower - O&M	0.0286	0.0360
Overhead	0.0196	0.0196
Total water cost	0.5819	0.5921^a

^aNot considering any penalties for alternative water supply in case of plant under-performance caused by pre-treatment.

Table 3 reports the economics of the process. The treatment cost excluding the revenue derived has been calculated as being approximately \$10/1000 gal (\$2.65/m³) of feed treated.

Table 3
Membrane treatment of fatty acid wastewater (costs in 1989 US\$, adapted from Dangel et al. [10])

Item	Cost (\$)
Capital costs including engineering, equipment and installation	1 500 000
Amortized capital (annual)	220 000
Membrane replacement (annual)	54 000
Labor (annual)	80 000
Electricity (annual)	25 000
Cleaning chemicals (annual)	6 000
Total annual costs (operating+amortized capital)	385 000
Value derived from fatty acid recovered	68 000
Net annual cost	317 000

A manufacturer of fatty acids generates 60 000-105 000 gal (230-400 m³) of wastewater per day containing 3000-4000 mg/l fats, oil and grease (FOG), primarily in the form of emulsified fats [10]. The local

Table 34
Specific chemical consumption and costs for the Al-Fujairah desalination plant [61]

Chemicals	Conc. ppm	\$/kg	g/m ³ (perm.)	\$/m ³ (perm.)	\$/day
Chlorine	3	0.55	0.08	0	0.35
Ferric chloride	3	0.27	20.58	0.00557	959.4
Cationic coagulant	0.85	1.94	2.33	0.00453	779.33
Sulfuric acid	25	0.18	68.63	0.0124	2132.52
Antiscalant	1.05	1.94	2.65	0.00515	886.67
Sodium bisulfite	6	0.5	0.63	0.0003	54
Total				0.03	4812.27

This sheet provides a calculation of the amount of caustic required to raise the pH of produced water to 10.

Objective: raise the pH to 10.0
Assuming initial pH of 7

Produced water flow rate	
produced water flow rate	20,000 bbl/day
fluid volume	3,180 m ³ /day
fluid volume	3,179,650 L/day

Ca(OH) ₂ precipitation	
initial Ca conc (elemental Ca)	5,000 mg/L
initial Ca conc (elemental Ca)	5.00 gr/L
initial Ca conc (elemental Ca)	0.125 mol/L
moles NaOH required	0.250 mol/L
NaOH required	10.0 gr/L

Mg(OH) ₂ precipitation	
initial Ca conc (elemental Mg)	953 mg/L
initial Ca conc (elemental Mg)	0.95 gr/L
initial Ca conc (elemental Mg)	0.039 mol/L
moles NaOH required	0.078 mol/L
NaOH required	3.1 gr/L

Acid titration	
initial pH	7.0
final pH	11.0
pH change	4.0
NaOH required	1.00E-04 moles/L
NaOH required	4.00E-03 gr/L

Boric acid / Borate ion conversion	
initial B conc (elemental B)	200.0 mg/L
initial B conc (elemental B)	0.20 gr/L
initial B conc (elemental B)	0.0065 mol/L
moles NaOH required	0.0065 mol/L
NaOH required	0.26 gr/L

Total NaOH required (Ca, pH, B)	
Total NaOH required	13.4 gr/L
Total NaOH required	42,611.047 gr/day
Total NaOH required	42,611 kg/day
Total NaOH required	93,744 lb/day
Total NaOH required	34,216,671 lb/year
NaOH unit cost	700 \$/short ton
NaOH unit cost	0.35 \$/lb
Total NaOH cost	11,975,835 \$/year
Total NaOH cost	1.64 \$/bbl

Conversion factors	
3.785	L / gal
42	gal / Bbl
7.48	gal / cu ft
5.62	cu ft / Bbl
159	L / Bbl
1.195	gr mol / scf
42.21	gr mol / scm
454	gr / lb
2.20	kg/lb
3.2808	ft / m
12	inch / foot
144	in ² / ft ²
1000	mm / m
100	cm / m
1,000,000	micron/m
10,000	micron/cm
25.4	mm / inch
35.31	cu ft / cu m
264	gal / cu m
6.29	Bbl / cu m
1,000	L/cu cm
1,000	L/cu m

Molecular weights (gr/mol)	
Ca	40
Mg	24.3
OH	17
H	1.004
O	16
Ca(OH) ₂	74
Na	23
NaOH	40
B	10.8
Boric acid H ₃ BO ₃	30.9
Borate ion H ₂ BO ₃ ⁻	29.9

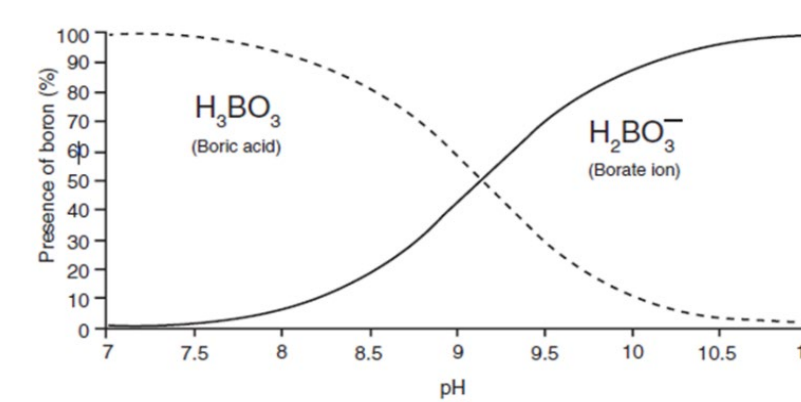
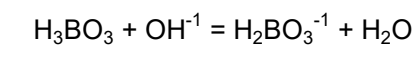
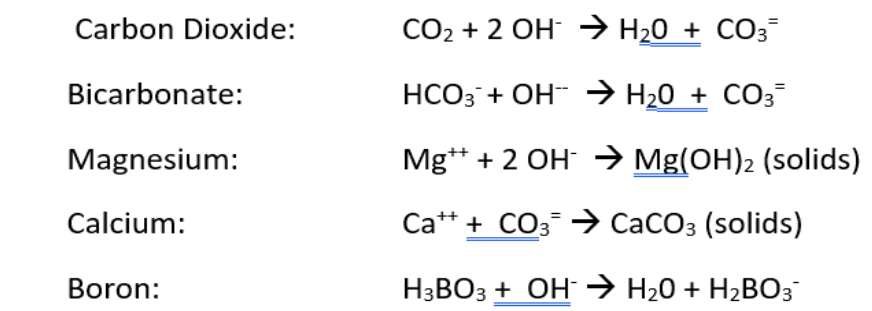


Fig. 1—The behavior and chemical composition of boron varies in an aqueous environment. Borate ions dominate at higher pH, and boric acid dominates at lower pH.



Examining this water analysis the following components will represent a demand for Sodium hydroxide (NaOH) - carbon dioxide, bicarbonate and magnesium plus a small demand for the removal of iron, manganese and sulfide.

The following reactions would be the primary reactions for raising the pH:-



Additional caustic would be required for ionization of silica if present (not reported).

1000 gpm
20,000 BWPD
583 gpm

Estimated Caustic Demand to raise the pH from 6.4 to pH 11 for 1000 gpm of water
Based on a 1000 gpm feed water flow the solids generated would be 1,633 lbs per hour being primarily due to magnesium hydroxide precipitation.

Injected product	lbs/h	4,478.46	pure NaOH, dry material
PW feed - assumed		1,000	gpm
PW feed - assumed		34,286	BWPD
PW feed - actual		20,000	BWPD
dry NaOH consumption		2,612	lbs/hour
dry NaOH consumption		28,499	kg/day
price		0.77	\$/kg-active
NaOH cost		21,944	\$/day
NaOH cost		1.10	\$/bbl

APPENDIX B
BENEFICIAL REUSE UPTAKE – EXTERNAL FACTORS
TECHNO-ECONOMIC ANALYSIS

DATE SUBMITTED

September 14th, 2022

PROJECT PERIOD

February 1st, 2020 - May 31st, 2022

“Fouling-resistant, chlorine-tolerant zwitterionic membranes for treatment of produced water in the Permian Basin”

RECIPIENT ORGANIZATION

ZwitterCo, Inc.

85 Bolton St.

Cambridge, MA 02140

DUNS Number: 081215694

SUBMITTED TO

U.S. Department of Energy

National Energy Technology Laboratory

Appendix B

Table of Contents

1.0 Introduction	3
2.0 Current Cost Structures	3
2.2 Produced Water for In-field Reuse	7
2.3 Transportation	8
2.4 Disposal	8
2.5 The Economic Case for Desalination in Permian	9
3.0 Raw Produced Water Quality	9
3.1 New Mexico	15
3.2 Texas	16
4.0 Water Quality Required for Beneficial Reuse	18
4.1 Agriculture	18
4.2 Mining	22
4.3 Rangeland	23
4.4 Others (Power plants, Refining, Pecos River relief for NM, Frac sand washing)	24
5.0 Freshwater Quality Currently Used	49
5.1 Quality of groundwater currently	49
5.2 PW blending	50
6.0 Source and Demand Geography	51
7.0 Demand Quantity	52
8.0 Conclusions	56
References	57

1.0 Introduction

Water management is an important aspect of the development of unconventional formations in the United States onshore and, in particular, the Permian Basin of west Texas and southeastern New Mexico. Unconventional formations do not have sufficient permeability to flow oil and gas economically with traditional vertical completions. The application of horizontal completions and hydraulic fracturing creates enough surface area for the ultra-low permeability formations to flow hydrocarbons. The hydraulic fracturing, or hydraulic fracturing, is performed in a series of stages along the horizontal wellbore when high pressure water, sand and chemicals crack the rock open. The sand is left in the fracture and holds the space open for flow. Water management is about sourcing and delivering source water to the well site for hydraulic fracturing, and delivering the produced water to either a disposal well or allowing it to be treated and reused.

The Permian Basin is the largest and most economically viable oil basin globally. It is also notable in that the wells typically produce back as much or more water in the life of the well than was used in the hydraulic fracturing. Currently, the majority of the water is disposed into deep saline reservoirs and a smaller portion of the produced water is reused in subsequent hydraulic fracturing of wells. This report researches the potential for beneficial reuse outside of the oilfield application. For the normally high salinity produced water of the Permian to be used outside of oilfield operations, the water must be desalinated, removal of the majority of the salinity or total dissolved solids (TDS). Additionally, a variety of economic, regulatory and technical challenges must be overcome.

This Appendix is organized as follows:

- The current water management costs and the case for desalination and beneficial reuse.
- Summary of produced water quality in the Permian basin.
- The volumes needed and the water quality needed by the user is analyzed.
- Current practices and desalination technologies are reviewed.

The biggest challenge of beneficial reuse of produced water is the economic challenge. To keep costs low, a high volume, perhaps 100,000 barrels per day or larger, centrally located plant could benefit from the economies of scale. The plant could be located along an existing produced water system and near the end user of the desalinated water to reduce additional transportation costs. New Mexico has the highest water management costs by industry in Permian and is the likely location of the first desalination plants. Irrigation use or discharge into the Pecos River could match the high volumes of a large plant. Municipal or other industrial applications are secondary potential users.

Effective pre-treatment of the produced water can help keep the overall treatment cost lower. Effective desalination not only will remove the TDS from 100,000+ mg/L to less than 500 mg/L, but it will also remove any minor concentration of hazardous elements to below the threat level. The demonstration of the pre-treatment effectiveness is an important aspect of the second phase of this project. Overcoming technical challenges include demonstrating that pre-treatment can be achieved with actual produced water in a field setting. Achieving high quality water and performing sufficient water quality testing will also be important to obtaining regulatory approvals.

2.0 Current Cost Structures

This section provides an overview of cost elements that are important in the introduction of new technology for application in the Permian Basin. The section starts with a discussion of what is currently happening in the Permian in terms of:

- Fresh water sourcing for various end case uses as listed below
- Where are the operating companies getting the fresh water from?
- Groundwater, municipalities, aquifers, freshwater sourcing for fracturing water make-up

- What are the current costs associated with produced water for in-field use?
- What is the cost of trucking versus pipeline?
- What are the cost differences for the various modes of water transport?
- What are the costs for disposal?
- What does it cost to operate an SWD injection well?
- What is happening in terms of permitting?
- What are the costs of permitting and what are the trends in cost?

These costs are provided for both NM and TX with an emphasis on NM. Costs are going up due to pressurization. Water volumes are not a focus of this section. Demand Quantity is discussed in section 6. Costs to source water across the Permian Basin vary widely. Several factors are key to explaining water sourcing costs locally:

- Availability of surface water (rivers & lakes)
- Availability of groundwater reservoirs
- State or local laws and regulations
- Water quality needed (fresh, brackish or saline produced water)
- Transportation infrastructure and proximity

West Texas and southeastern New Mexico are generally arid. Water resources are limited. Groundwater and surface water, rivers and lakes, are the primary water sources, but both have limitations.

In the two most important counties in New Mexico for oil and gas development, here are the sources of the water used in 2015.

<u>County</u>	<u>Surface Source (%)</u>	<u>Ground water (%)</u>
Eddy	60.5	39.5
Lea	0.0	100.0
2-Counties combined	27.0	63.0

Source: New Mexico State Engineer Office water use report

Average annual rainfall for key Cities in Permian & other cities

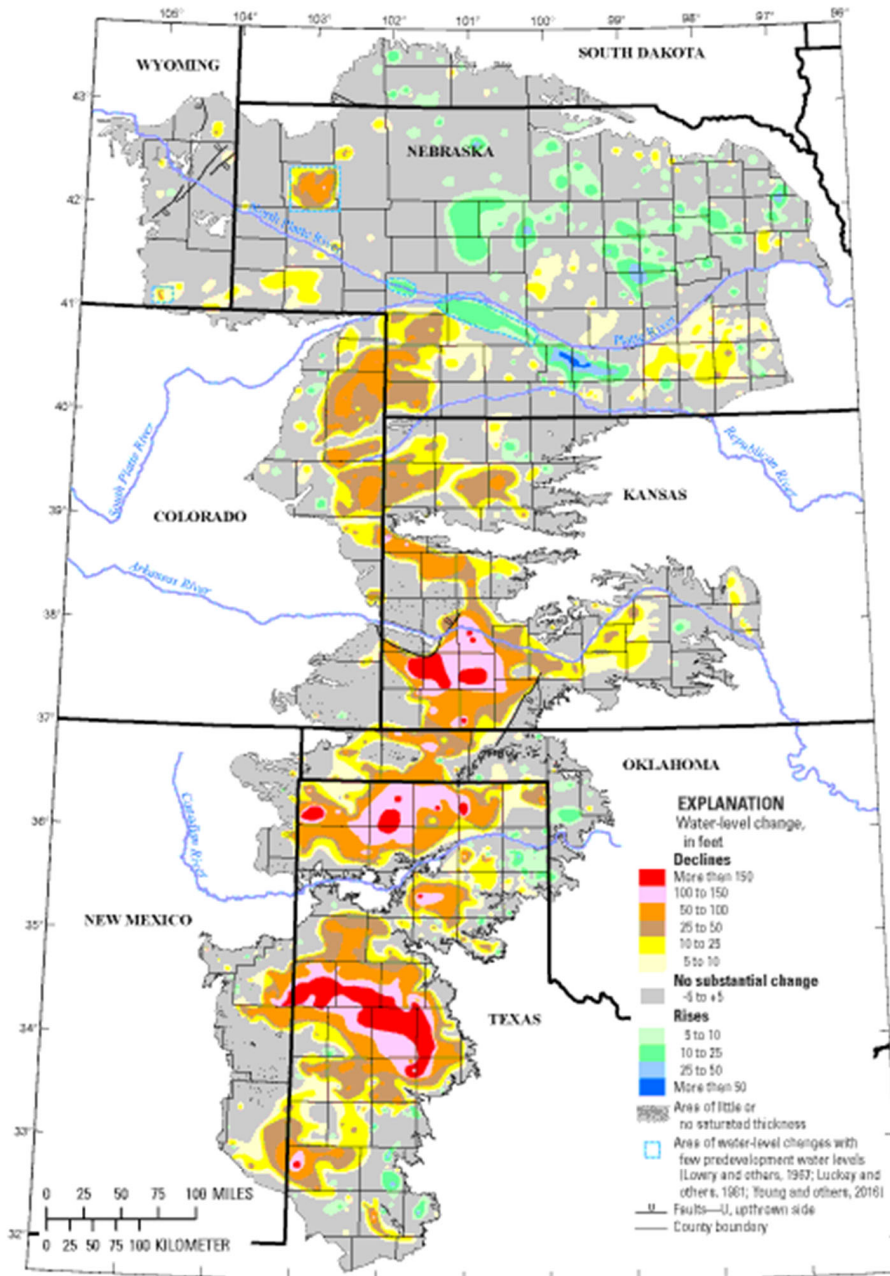
<u>City</u>	<u>Annual inches</u>
Odessa, TX	14.7
Pecos, TX	11.6
Carlsbad, NM	13.4
Jal, NM	13.9
New York, NY	46.2
Houston, TX	45.3

Data source: usclimatedata.com [18].

There are few lakes or rivers that have significant volumes of water. State and local regulations often restrict use of surface water.

Groundwater is also limited. Historic irrigation for farming has significantly depleted some of the region’s key aquifers. The Ogallala aquifer, also known as the high plains aquifer, covers parts of eight states and is the largest aquifer in the

US. The Ogallala has seen substantial depletion since 1950, see graphic below. It is representative of most aquifers in the Permian region.



High Plains aquifer water-level changes, predevelopment (about 1950 to 2015). Figure 1 from [USGS SIR 2017-5040](#) (Public domain.) [19]

Groundwater rights in Texas are property of the surface owner, unless the water rights have been segregated from the surface ownership. Permian Basin property owners have been selling groundwater to the oil and gas industry more significantly since the advent of unconventional development around 2012. Over recent years, the cost of source water for the oil and gas industry has probably averaged about 50 cents per barrel. The cost is higher when oil and gas is booming and lower when it is not. Local supply and demand will cause prices to vary.

Municipal wastewater is a non-traditional water source in Permian. However, in recent years municipal wastewater is being used instead of groundwater or surface water. For example, Pioneer Natural Resources signed an 11 year deal for \$117 million with the city of Odessa, TX in 2016 [Pioneer Odessa water deal](#). The long-term deal to buy a portion of the city's municipal waste water is estimated to translate to about 26 cents per barrel.

Pioneer also signed an agreement in 2018 with the city of Midland, TX to acquire its municipal wastewater. [Pioneer Midland water deal](#). Pioneer will buy water from Midland for 20 to 28 years, upgrade the existing city plant for about \$130 million and pay about \$2.5 million per year for water. The deal is expected to equate to about 13 cents per barrel, without considering the present value for the upfront payments. These long-term commercial deals with Odessa and Midland are clearly at a lower cost per barrel than the typical short-term deal to buy water from a surface owners groundwater well that may have averaged 50 cents per barrel.

Other cities in the area, such as Carlsbad, NM, are known to have sold their wastewater to a variety of industries, including for oilfield use.

Groundwater in New Mexico is owned by the state and there are complex set of regulations. Jurisdictions may include federal, state, county and tribes. Groundwater in New Mexico seems generally less available and that is reflected in commercial pricing. According to a company that aggregates water data in the region, Northern Lee and Eddy Counties have had spot water costs around 85 cents to \$1 per barrel in early 2020. Another industry source stated that prices for source water in Lea County were about \$1.40/BW in 2017 and 2018. As the oil and gas industry has increased produced water reuse for their operations, demand for groundwater has decreased. The same industry source said that prices near Carlsbad were approximately \$1/BW in early 2020.

Since surface water rights are more complex and have been held long-term by surface owners, oil and gas producers in Permian rarely use surface water for hydraulic fracturing.

Often, oil and gas blends fresh or brackish water with the reused produced water. The prices for fresh or brackish water for oil and gas (O&G) do not vary substantially. Since O&G are the primary market for source water in the Permian region, and since they can use fresh or brackish interchangeably, there is generally no appreciable difference in pricing.

It is also widely known that source water is being produced in Loving and Pecos Counties in Texas and transferred across to New Mexico for use for the oil and gas industry. This practice is significant in keeping the state line area's prices lower than northern Eddy and Lee Counties in New Mexico. Since source water pipelines are not generally available to transfer source water across counties, local supply and demand drives water pricing.

Water costs for agriculture within the Carlsbad Irrigation District can range from 0.5 cents per barrel based on the current 2020 allotment to 0.3 cents per barrel for the maximum allotment. This is based on water rights holders paying \$87 per acre in 2020 and the current allotment of 2.3 acre-feet. The maximum allotment is 3.697 acre-ft per acre of water rights. This information was from the Carlsbad Irrigation District office in May 2020.

Inquiries to mining concerns in Permian indicate that most own groundwater rights. Therefore, their cost of water is associated with the purchase of the rights and cost to pump the water. Most do not purchase water commercial as many oil and gas producers do. It is generally accepted that the oil and gas industry generally pays more for water than other industries, perhaps because it is for a short term use for a group of local wells.

There are very limited permanent source water pipeline networks for oil and gas in Permian. Pioneer Natural Resources is known to have connected the Odessa municipal wastewater source to its water network. The Midland wastewater source will be connected when the plant upgrade is complete. But outside of these examples, there are few large scale fresh or brackish water systems. The majority of the major water midstream pipeline systems announced in Permian are for produced water transferring to disposal wells or recycling centers.

Thus, the majority of source water is transferred to the frac well site via temporary lines referred to as lay flat hose. These temporary lines are often 12 inch in diameter to handle the high volumes for short periods of time. When the completions (hydraulic fracturing) are complete, the temporary line is removed. The effect of limited source pipeline networks is that pricing for source water in northern Lee and Eddy Counties is probably the highest in Permian.

2.2 Produced Water for In-field Reuse

Generally, economics drive the decision-making to reuse produced water instead of disposing it in a permitted disposal well. The desire to be more sustainable is also a factor. Almost all of the large producing companies have stated goals to minimize fresh water use and increase recycling.

The Ground Water Protection Council report on produced water (starting on page 158) lists these factors as the key economic factors for beneficial reuse:

1. Treatment costs
2. Transportation, infrastructure and logistics
3. Contracts, agreements, long-term commitments, royalties and sunk costs
4. Energy needs
5. Market factors
6. Solids management
7. Water rights
8. Relative economic feasibility

The economics for reuse are positive when the cost to transfer, store and treat the reused produced water are less than the cost of water sourcing, transfer and disposal. Typical source and disposal costs are:

- Source water for hydraulic fracturing - 50 cents/BW (Range from 25 cents to \$1)
- Transfer source water via temporary layflat hose - 20 cents/BW (Can be up to \$1.50/BW if trucked)
- Transfer produced water to disposal well - 5 cents/BW (Usually via short line)
- Disposal cost at commercial disposal well - 50 cents/BW (Can range from 40 cents to \$1/BW)

The costs above include amortized CAPEX and operating expenses. Thus, the typical all-in source to disposal cost could be about \$1.25/BW.

For reuse, the costs may be broken down as follows:

- Storage of produce water in large impoundment - 25 cents/BW (largely a function of how long hydraulic fracturing continues in the area)
- Treatment in the impoundment - 25 cents/BW (commonly aeration to control bacteria and handling solids)
- Transfer produced water to frac site - 50 cents/BW (May include permanent pipelines and temporary lines and is a function of distance and volumes over time)

Thus, the costs in the above reuse case total \$1.00/BW, just under the typical cost to source, transfer and dispose. The transfer cost with reuse can be more complex since the produced water is not always close to the frac site the way groundwater sourcing may be. Therefore, to transfer the produced water to changing locations often relies on a water pipeline system and the amortization of the capital costs over time and barrels reused. If there is not sufficient volumes of water to transfer to keep the costs per barrel low enough, the pipeline system can not be economically justified. In

other words, if the projected capital and operating costs of the reuse plan exceed the status quo of local sourcing and local disposal, then the potential reuse project is never developed.

2.3 Transportation

Transport of water is involved in the sourcing phase before hydraulic fracturing and transport of the produced water to a disposal well or reuse in a frac well. There are three ways the water is conveyed typically: Temporary surface lines, buried permanent lines and trucking.

Temporary surface lines are employed when the water transfer is only needed for short time periods, perhaps one to three months. This is especially common when sourcing water “the last mile” to a frac site. It is often not practical to run a permanent line to a well pad when the water is only sourced for the duration of the completions. A flexible hose called layflat is often used in this application. The layflat hose is easily laid out and rolled up to be used at the next pad or well location. The layflat hose is frequently provided as a service where the cost is based on distance and time used. Typically, the layflat hoses will have a capacity to deliver water to the frac location at a peak rate of 50,000 BWPD or more.

Permanent buried water pipelines are used when water transfer is expected for years and the volumes of water justify the capital investment. Many producing companies in Permian have the majority of their new wells connected to disposal or reuse facilities via permanent pipe. In some cases, the producing companies have long term agreements with water midstream companies that gather and dispose of produced water.

Trucking is generally used for produced water when water volumes are low. Some unconventional areas, like the Eagle Ford in south Texas, normally have low produced water volumes. In these cases, the limited water flow rates do not justify the capital cost of water pipelines. Water trucks normally have a capacity of 120 barrels and the cost per barrel to transport can be approximately \$1 to \$2 per barrel, depending on distance trucked and potential wait times to unload. Rarely does trucking make sense for delivering source water for hydraulic fracturing. Also, many companies in Permian are trying to reduce the number of trucks on the road as a way to reduce community impacts.

2.4 Disposal

Saltwater Disposal wells (SWDs) have been a reliable method of disposal of produced water in Permian for decades. With the advent of unconventional production starting around 2011 in Permian, the produced water volumes and need for new SWDs have grown. SWDs are permitted through the Texas Railroad Commission and the New Mexico Oil Conservation Division of the Energy Minerals Natural Resources Department (EMNRD). The cost of commercial (third party owned) SWD disposal varies based on the demand for water disposal and the supply of SWD disposal capacity. Higher industry activity, drilling and completions, leads to more produced water. The supply of commercial SWDs has increased recently with the increased activity since 2017. There is variation in commercial disposal costs across the basin, but \$0.50 per barrel is often referenced as a typical cost.

In New Mexico, the regulators have greatly limited disposal into shallower disposal formations in recent years. The basis for restricting shallow disposal is that it might adversely interfere with offset oil and gas production in the horizon. Therefore, the majority of new SWDs in Lea and Eddy County are below the deepest producing formations. The higher cost deep wells require a higher cost per barrel to repay the capital. Thus, the highest disposal costs in Permian are in the northern active areas of Lea and Eddy Counties, and may approach \$1 per barrel.

Oil producing companies also often own their SWDs for their exclusive use, non-commercial SWDs. Their cost per barrel reflects the capital cost of the well, the operating costs of pumps and labor, and the amount of water injected over time.

Depending on the depth and capacity of a SWD, capital costs may range from \$2 million to over \$10 million. Operating costs typically range from \$0.15 to \$0.45 per barrel.

2.5 The Economic Case for Desalination in Permian

While desalination of produced water is not currently ongoing in Permian, there is a scenario where it becomes economically viable. The scenario is driven by continued high levels of water disposal that increase the disposal reservoir pressure to unacceptable levels. It is possible that the state regulators could step-in to limit new disposal wells or even reduce existing permit levels of injection. It is in this path that disposal costs could increase and tip the economics toward getting water out of the system with desalination and beneficial reuse.

The economics can be “boiled down” to this value proposition. If disposal costs by the producer plus the cost of source water are greater than treatment and transport costs for beneficial reuse, then desalination can be viable. With the large volume of produced water in Permian, it is possible to foresee disposal costs increasing to \$2 per barrel or more. It is unlikely that agriculture or other water users will be able to pay more than cents per barrel. Therefore, the value of desalination will be driven by saving disposal costs and could be from \$2 to \$3/BW in the future.

The cost of desalination could have a high variability, depending on the particular scenario. According to the 2017 Oklahoma Produced Water Study, a large-scale (100,000 BWPD), long-term (10-year) project could have total desalination costs of \$2.22 to \$2.52/BW, depending on salinity. More recently, a leading water treatment provider (Gradiant Corp.) thought that \$2/BW for partial desalination using counter flow reverse osmosis (CFRO) would be possible. Notably, the CFRO requires pretreatment for oil and selected suspended solids.

The formation of the New Mexico Produced Water Research Consortium (NMPWRC) in January, 2020 is evidence that the desalination scenario may be needed. NMPWRC is focused on exploring the possibility of reuse of desalinated produced water outside of the oilfield. The consortium is supported by New Mexico state agencies, university researchers and industry.

Both Texas and New Mexico regulators have already taken actions to limit disposal reservoirs or the maximum disposal pressures in attempts to limit disposal. These actions provide insight into the regulator’s concerns about the limitations of disposal reservoirs.

3.0 Raw Produced Water Quality

This section covers the subject of produced water quality. The composition and concentration of dispersed and dissolved contaminants is discussed here. Common analyses such as TDS, multi-ion analysis, pH as well as process parameters such as temperature are given. The concentration of BTEX, aromatic, hydrocarbon and organics are included. Substances such as BTEX, PHA, and NDT can cause swelling, weakening and failure of certain membrane materials.

Substances such as lithium, bromine and transition metals are included since they have potential for extraction, purification and sale. The market and pricing for these recoverable constituents is covered in Section 1. Section 2 (this section) covers the quality of the produced water and how much is found in the water as a function of location (geologic formation). Established and new technologies for extraction are covered in Section 8. Costs associated with different extraction technologies are summarized in Section 1.0 and discussed in detail in Section 8.0.

Produced water quality varies by formation and by location within a formation. The Wolfcamp formation in Midland, for example, has different formation water quality than the Wolfcamp formation in Lea County, New Mexico. This is not surprising given the complex geologic processes that have occurred in the Permian Basin over many millions of years. The industry has expended significant effort to understand the geology of the region since it can shed light on the location of rich hydrocarbon deposits. Many strategies have been employed by geologists in their quest for understanding. Study of formation water quality is one such strategy. As will be discussed, formation water quality and its variation from one location to another has been recently used to shed light on the geology and geologic processes

that have occurred. This information has helped to determine likely suitable locations where Zwitterco technology will have the greatest economic impact.

Produced water is highly complex and highly variable from one location to another and variable over the life of a well. Nevertheless, a framework for characterizing produced water has been developed over several years and is generally accepted across the E&P industry. The characterization of produced water starts with a recognition of dissolved versus dispersed (suspended) contaminants. Suspended contaminants are defined as those substances that can be removed by filtration of the water through a 0.45 micron filter. Occasionally a 0.2 micron filter is used depending on the application of the test. Suspended contaminants that are collected on the filter paper include insoluble liquids and mineral or organic solids. Padaki et al. [16] refer to four classes of oil components:

- aliphatic
- aromatic
- NSO (nitrogen, sulfur, oxygen) containing compounds (aka resins)
- asphaltene

In some applications the NSO fraction is referred to as “resins.”

These oil contaminants are detrimental to membrane filters used for desalination. Thus, they are an important part of the composition of produced water. It is anticipated that the Zwitterco membrane will remove these components.

The dissolved components are equally important since many reuse applications require low concentrations of salt in general and sodium in particular. A good place to start the discussion of the dissolved components of produced water is with a high-level overview across several basins in the US. Below is a chart showing the TDS for produced water across the US oil and gas industry. The chart is based on data from the United States Geological Survey (USGS) database. The link is given here: <https://www.usgs.gov/energy-and-minerals/energy-resources-program/>. The database was established decades ago and includes data from primary conventional recovery, waterflood recovery, and shale produced water. While the database is still in active use today, most of the data were collected prior to the recent shale activity. Therefore, produced water quality from shale developments in the last ten years or so is under-represented. This can be verified by looking at the number of data points in the Marcellus region in Ohio and Pennsylvania as well as the Eagle Ford in south west Texas. The number of datapoints for these shale developments is relatively small. The number of data points in the Permian and in central Oklahoma are, by comparison relatively large. This suggests that the data for all of these regions represent relatively old conventional and waterflooding activities. Nevertheless, as will be discussed, shale formations are often hydraulically connected to underlying conventional sandstone and carbonate reservoirs. Many conventional reservoirs contain hydrocarbons that were expelled, as bitumen, from the overlying kerogen shale. Thus, water quality data for conventional reservoirs tend to correlate with water quality of their bounding shales. As the chart shows, the Permian has a wide range of produced water quality which spans the range of 50 mg/L to above 200 mg/L.

Water Temperatures into Water Systems in Permian

The water temperature as it enters the water treatment facilities is important as it may affect the treatment process or the design of materials. In some cases, particularly hot fluid surface temperatures are problematic for the common use of plastic poly water pipelines.

The surface or wellhead flowing temperature (WFT) of a given well is driven by a variety of factors, including:

- The producing reservoir formation temperature which itself is a function of depth
- The flow rate of the well - more liquids and less gas create hotter WFTs
- Artificial lift - Electrical Submersible Pumps (ESPs) don't impact temperatures much, but gas lift creates a cooling effect. Both ESPs and gas lift are commonly used in Permian.
- Tubing size - the tubing diameter combined with the flow rate determine the fluid velocity and impact the cooling rate as the fluids rise in the wellbore.

There is very little public information on wellhead temperatures via web searches or even in industry papers such as the Society of Petroleum Engineers. A couple of industry veterans agreed that individual wells may range from 70 to 150

degrees F at the surface, depending on the factors mentioned above. Since the formation temperatures near surface are usually 60 or 70 degrees F, that establishes a lower bound of temperatures. The upper limit is a function of heat transfer as the fluids flow up the wellbore and cool down.

Fluids from individual wells come together at a tank battery to separate oil, gas and water. The water may flow in buried or above-ground pipes from the tank battery to the central treatment location. If transferred in buried pipe, the fluids may cool. If transferred in above ground pipes, the ambient temperatures may heat or cool the water.

One major water midstream company active in Eddy and Lea Counties in New Mexico indicated that their system normally has water temperature around 90 to 110 degrees F.

Produced Water Salinity from the USGS Database:

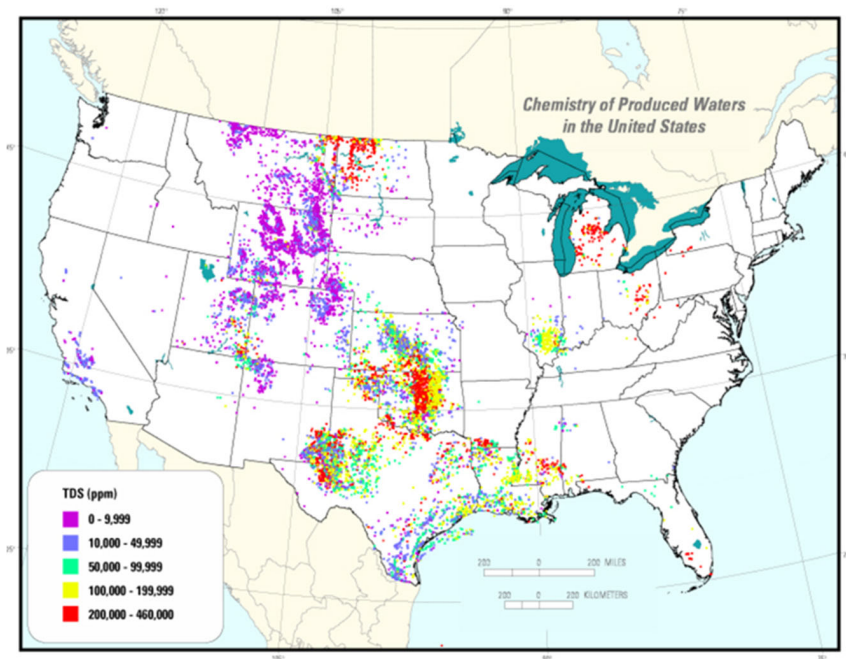


Figure xx. Chart of produced water salinity based on data from the USGS database.

<http://energy.cr.usgs.gov/prov/prodwat/tds.htm>

Focusing more closely on the Permian Basin, the chart below is a graphic from the USGS database using primarily data from before 2010. It shows the wide variation from less than 33,000 mg/L to over 300,000 mg/L.

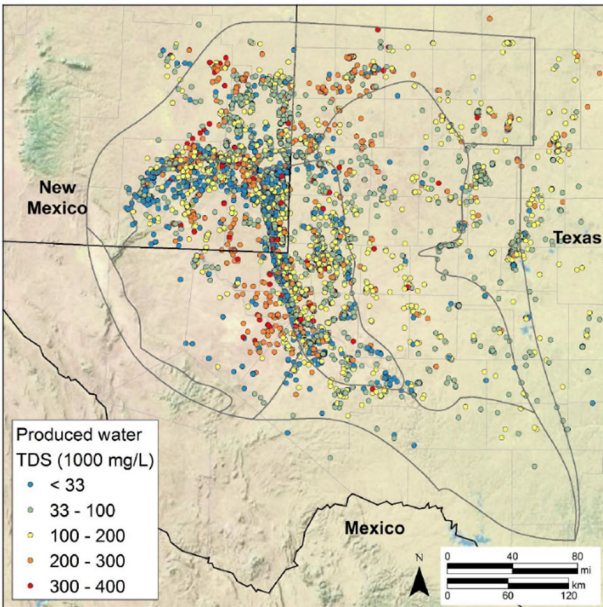


Fig. 530. Distribution of produced water total dissolved solids (TDS) obtained from the USGS produced water database (version 2.2). Original map image created in ESRI ArcGIS version 10.3.1. (Public data available at <https://energy.usgs.gov/EnvironmentalAspects/EnvironmentalAspectsOfEnergyProductionandUse/ProducedWaters.aspx>)

Figure xx. Chart of produced water salinity based on data from the USGS database.

The graphic below by Binod K Chaudhary from a presentation in 2016, and reference [9], shows the variability of TDS by depth in the Permian. This data uses the same USGS database that contains primarily old data pre-shale plays.

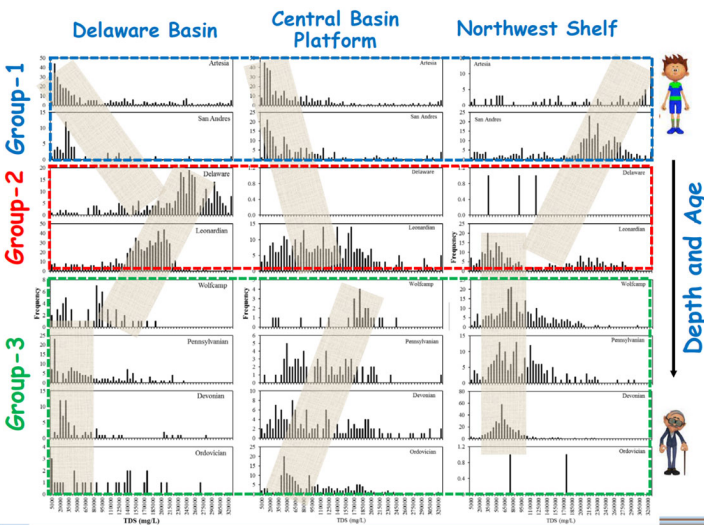


Figure xx. Histograms of TDS as a function of basin (Delaware, CBP, Midland) and as a function of depth (Group 1, 2 and 3) [9].

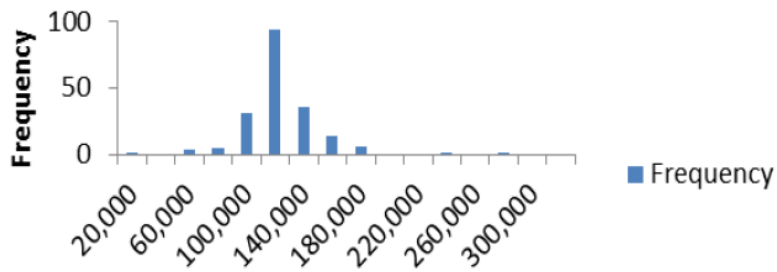
The same Chaudhary presentation indicates that TDS in the Wolfcamp group, Group 3 above, has higher values in the northern Delaware subbasin and lower values in the southern area (Texas).

The above data can be compared to data collected by Champion-Nalco field technicians [1]. The Champion-Nalco data were restricted to specific geological settings but were geographically widespread across the Permian. The three geological settings studied were the Wolfcamp and Bone Spring. In the table below statistical measures are given for a number of constituents. Below the table, histograms are given for the TDS of the Wolfcamp and Bone Spring laminations.

Table xx. Dissolved species analysis for produced water form the Wolfcamp and Bone Springs formations in the Delaware and Midland Basins [1].

Play	Chloride	Sulfate	Bicarbonate	Calcium	Magnesium	Iron	Barium	Strontium	Sodium	Manganese	TDS	Dissolved CO2	Dissolved H2S	Calculated pH	
Wolfcamp	Average	67,960	1,130	402	2,797	478	107	2.63	439	40,468	1.62	113,694	230.5	5.19	5.97
	Min	364	102	12.2	134	103	0.00	0.03	4.46	503	0.00	2,481	10.00	0.00	4.75
	Max	156,000	5,742	3,087	19,649	2,430	2,152	133	1,509	100,174	27.1	263,106	1210	427.5	7.39
	Median	67,000	866	183	2,673	429	77	1.76	472	39,191	1.13	111,090	205.0	0.00	5.90
	Stand Dev	15,125	858	628	1,866	297	205	10.1	229	9,962	2.76	25,428	144.3	40.37	0.41
Bone Springs	Average	70,907	765	300	6,914	1,873	27.1	61.9	596	36,290	3.43	115,933	313	100	5.83
	Min	11,000	36.0	12.2	80.0	42	0.00	0.00	72.8	5,903	0.00	19,194	30.0	0.00	4.38
	Max	167,000	2,667	1,830	27,749	4,851	170	713	2750	106,215	12.6	277,781	600	257	6.85
	Median	53,000	672	146	2,647	1,118	16.1	1.91	134	28,197	0.32	86,800	300	51.0	5.92
	Stand Dev	53,498	662	372	9,125	1,497	32.7	180	873	24,036	4.69	85,441	164	88.3	0.57

Wolfcamp TDS



Bone Springs TDS

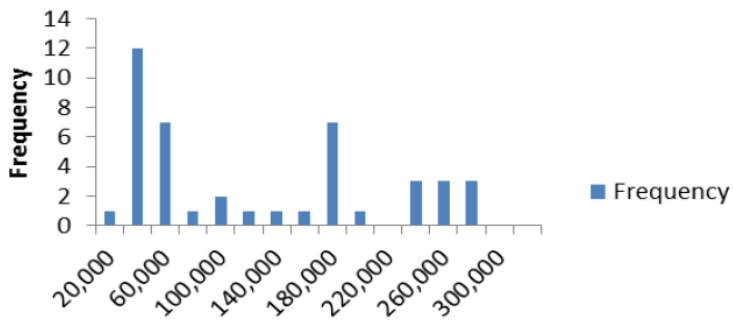
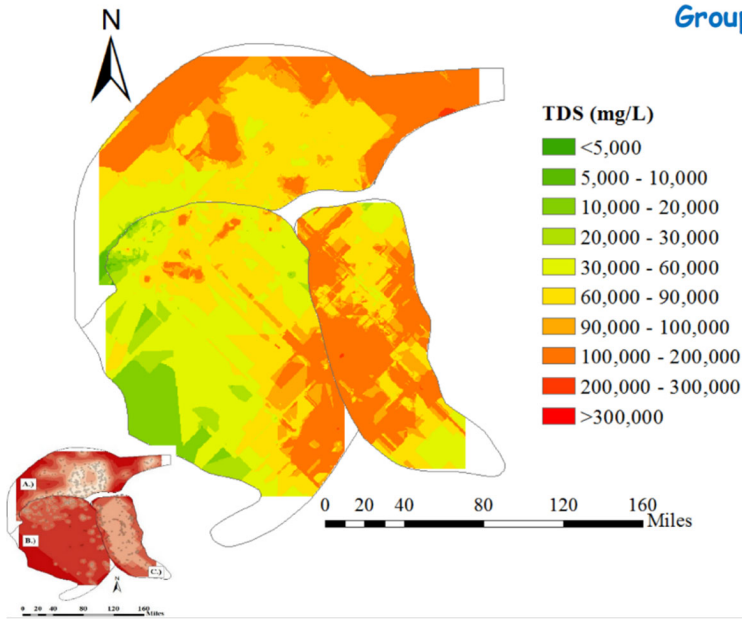
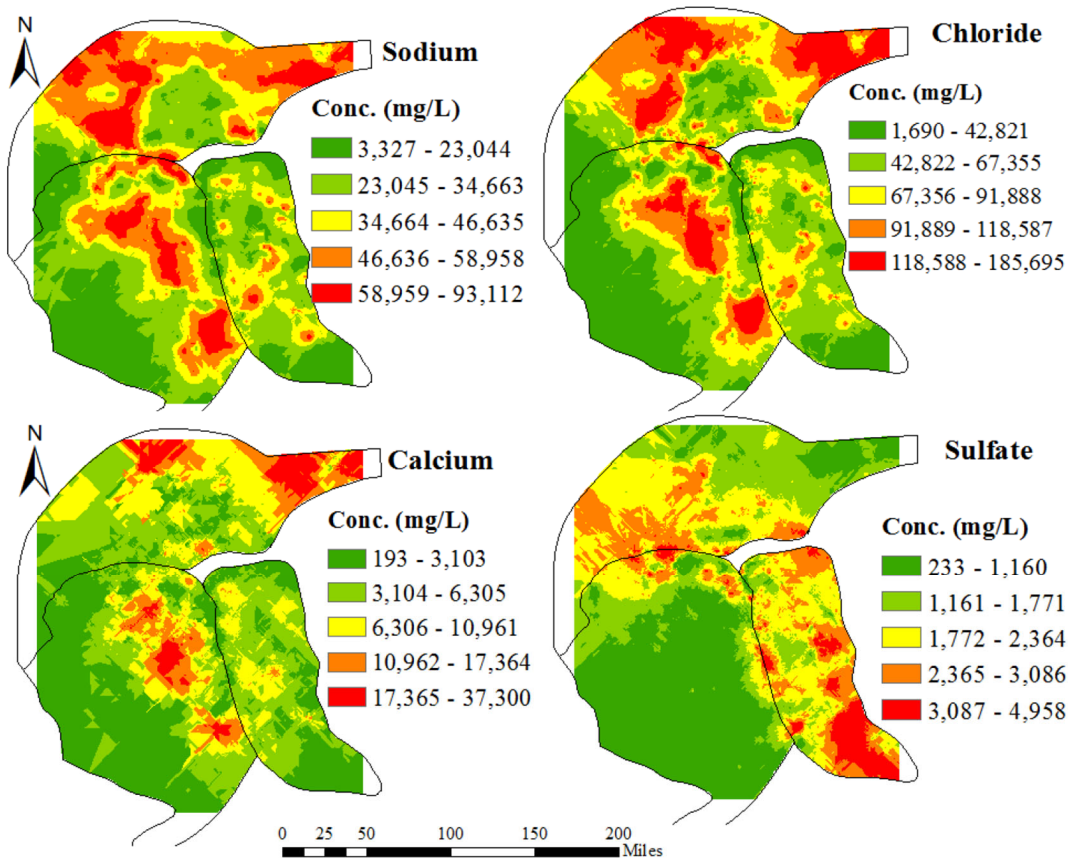


Figure xx. Histograms of TDS for produced water samples taken in the Wolfcamp and Bone Springs formations in the Delaware and Midland Basins [1].

Group-3



This third graphic (below) from Chaudhary [9] indicates the areal variation of four individual parameters.



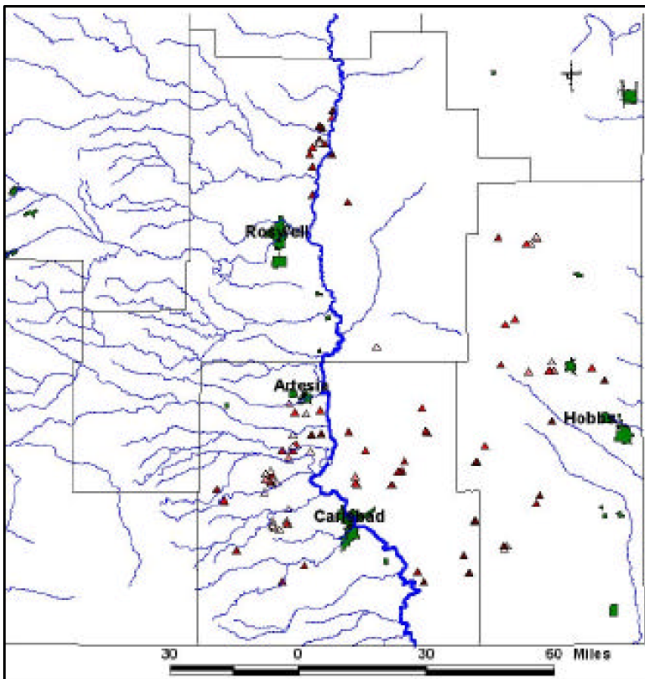
The Ground Water Protection Council report on produced water from 2019 reported produced water quality by basin. Data was collected from a group of producing companies via API. The data was from shale wells and was notably much more current than the USGS database. The shows average and high parameters for various analytes by basin. The Delaware and Midland sub-basins of Permian are highlighted in green.

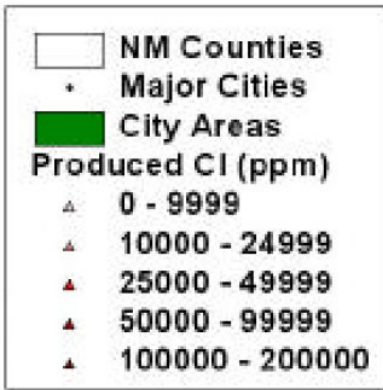
	pH		TDS (mg/l)		Calcium (mg/l)		Magnesium (mg/l)		Bicarbonates (mg/l)		Sulfates (mg/l)		Chlorides (mg/l)	
	High	Average	High	Average	High	Average	High	Average	High	Average	High	Average	High	Average
Bakken	7.2	5.9	317,040	270,743	28,184	15,886	2,198	1,164	530	451	1,109	271	195,999	164,756
Central OK	7.4	6.6	162,884	70,547	12,431	3,376	1,955	776	1,076	476	1,502	530	112,348	44,839
Delaware	7.7	6.7	216,319	129,354	17,078	5,892	4,410	1,150	3,410	516	3,060	904	132,995	79,719
DJ/Niobrara	8.3	7.0	74,940	28,238	4,298	574	766	64	1,382	561	2,849	80	51,289	16,470
Eagle Ford	7.6	6.5	82,669	41,999	5,607	2,300	769	341	1,348	378	399	94	56,850	27,893
Haynesville	7.1	5.5	206,835	111,551	21,121	10,470	812	502	590	199	127	13	138,583	68,965
Marcellus	7.2	6.0	315,118	169,177	45,724	15,207	3,626	1,326	345	137	55	11	192,694	108,748
Midland	7.4	6.7	130,841	112,885	29,139	27,059	659	496	753	489	1,292	754	79,293	66,606
Utica	6.5	5.9	288,318	226,590	36,374	26,874	3,398	2,715	230	67	222	23	185,583	145,253

3.1 New Mexico

Hightower and co-workers [3] provided the following map of chloride content of produced water in the S.E. corner of New Mexico.

Mike Hightower, leader of the New Mexico Produced Water Research Consortium (NMPWRC), indicates that there are pockets of conventional produced water in the 25,000 to 50,000 ppm TDS. The Daggered Draw area between Carlsbad and Artesia has conventional produced water around 10,000 ppm TDS. The lower TDS water could typically be treated for lower costs than the typical 100,000+ ppm TDS produced water. If this low salinity conventional water was being used for water flooding, the higher TDS unconventional water could be substituted.

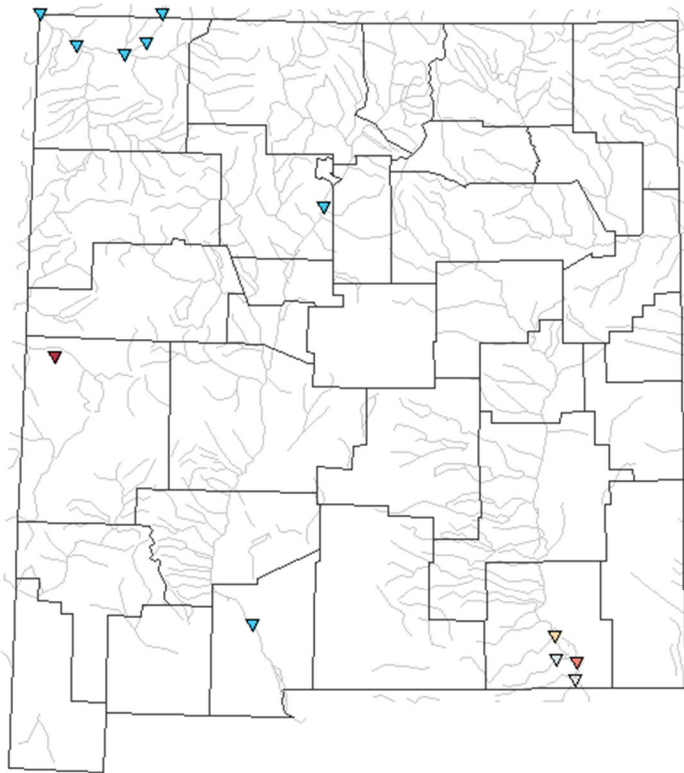




The USGS has information on “real-time” data on Pecos River temperature, conductance and discharge values as shown below.

Real-Time Specific Conductance, in $\mu\text{S}/\text{cm}$

April 17, 2020 09:30ET



Explanation							
▼	▼	▼	▼	▼	▼	▼	▼*
<250	250-749	750-2,240	2,250-4,990	5,000-9,990	10,000-35,000	>35,000	No Data

Temp	Cond	pH	D.O.	Turb	Nitrate	Disch	Chlorophyll
------	------	----	------	------	---------	-------	-------------

USGS NM water

3.2 Texas

In 2016 Engle and coworkers [6] published a paper on the geochemistry of formation water in the Midland region of the Permian Basin. Produced water quality results were associated with their respective geological formations. As shown in the figure below, histograms of TDS are given for a number of reservoirs in the Midland region. As shown by the grey-

shaded areas there are two natural groups in the data. The top grey are slants from the upper left to the lower right. This suggests that TDS increases with depth (i.e. age of reservoir). The second grey area is essentially vertical and highlights strata of relatively low salinities. These older and deeper reservoirs may be the result of the infiltration of meteoric water or the injection of low salinity water during waterflood.

The analysis was restricted to the Midland Basin. Our immediate interest is in the Delaware Basin in New Mexico. However, the Engle paper provides the geologic strata for all of the analyses presented. This makes much of the Engle analysis applicable to the strata in New Mexico.

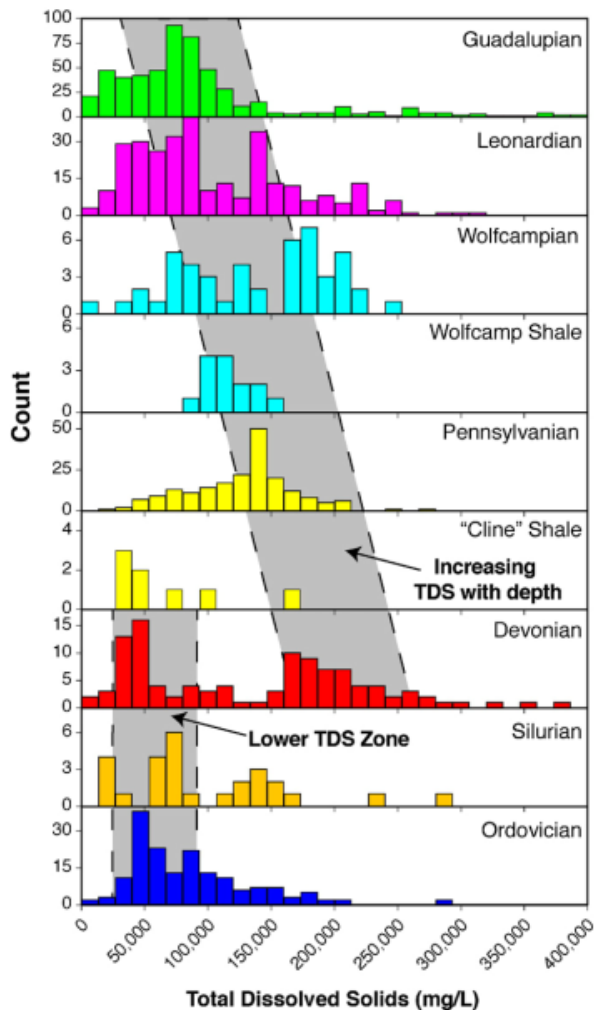


Figure xx. Histograms of TDS (x-axis) as a function of depth (y-axis).

A subsequent paper published in 2019 by Bryndzia et al. [8] applied a similar analysis to that of Engle to the Wolfcamp formation in the Delaware Basin. Most formations in the Delaware Basin have high water/oil ratios. Essentially two regions of the Wolfcamp were found. One region has a salinity in the range of 23 kmg/L. They found evidence that the formation water in this region came from two sources. One source was the original water associated with shale and mudstone sediment when the original sediment was buried some 50 Ma. The second source of water was from the Smectite/Illite transformation that generally occurs. This is supported by a relatively low Smectite concentration and a high Illite concentration. When this conversion occurs water, silica and iron are expelled from the Smectite clay in significant quantities. This expelled water would have low salinity and would dilute the existing Wolfcamp formation water. In this geologic model there is no evidence of dilution of the Wolfcamp formation water. It is proposed that this region of the Wolfcamp formation has water that was originally buried with the original sediment, plus water from in-situ clay conversion.

In a second region of the Wolfcamp formation they found much higher salinity (50 to 125 mg/L). It is proposed that this formation water came in contact with a high salinity seawater evaporite brine that flowed into the Wolfcamp formation. The driving force for the flow of the high salinity brine was an uplifting of the western edge of the Delaware Basin. A osmotic pressure mechanism is proposed to account for high WOR in this portion of the Wolfcamp formation.

4.0 Water Quality Required for Beneficial Reuse

4.1 Agriculture

This section discusses the water quality required for beneficial reuse of produced water for non-food crop irrigation. Government specifications, where they exist are discussed. Also, the toxicity of produced water is discussed. In general, produced water has several classes of compounds that are toxic to varying degrees. These toxic components include:

- volatile aromatic hydrocarbons,
- polycyclic aromatic hydrocarbons (PHA),
- certain organic acids,
- phenols,
- metals,
- radionuclides,
- and salt concentrations above a certain threshold.

The US Federal Government has not thus far promulgated rules or regulations for the reuse of produced water in agricultural applications. The US EPA mostly delegates this authority to the individual states. The Federal Government does however provide a set of guidelines [56]. These guidelines provide useful information regarding state rules and regarding the different state agencies that are involved in permitting produced water for agricultural use.

The United Nations Food and Agriculture Organization (FAO), Rome, provides extensive information and guidelines on irrigation water quality for agriculture [52]. The guidelines do not cover the subject of produced water or reuse. Nevertheless, the guidelines on irrigation water quality are useful for assessing the likelihood of a successful produced water reuse application. Information from these guidelines is given below.

Irrigation of crops using produced water carries a risk of impairing soil function and of killing various soil microorganisms that are important in germination and growth of plants. Besides this toxic effect the salinity of produced water and the ratio of sodium to calcium plus magnesium has a direct and detrimental impact of soil properties. Direct effects of irrigation water on sensitive crops may also occur. Non-food crops are often preferred for irrigation reuse in order to avoid direct ingestion pathways.

The following studies exposed various crop samples to untreated and treated produced waters with a wide variety of results related to product quality and yield, though most indicate at least short-term use with either processed produced water or untreated CBM produced water is acceptable in terms of plant performance, and soil/water ionic interactions.

Ferreira et al. [48, 50] evaluated the effect of using produced water on soil microorganisms in fields of biofuel crops of castor beans and sunflowers. The study was conducted using three different sources of irrigation water:

- ground water
- filtered produced water
- produced water treated with filtration followed by reverse osmosis

No details are given regarding the type of filtration used. Soil quality was analyzed in terms of the species composition, richness and abundance of soil microbes (mesofauna). The ranking of soil quality after a period of cultivation was: groundwater > filtered water > RO water. It was found that the ground water had the highest quality of soil, as expected. Produced water that had undergone RO treatment had a measurably negative impact on the soil quality. A possible

explanation for this effect could have been to required use of biocide (glutaraldehyde) and anti-scalant in order to prevent fouling of the RO membrane.

Sousa et al. [49] evaluated the effect of using groundwater, filtered produced water, and filtered/RO produced water on the seed and plant biomass production of sunflowers. They also measured the accumulation of mineral and metals in the plants. They found that the filtered water had the greatest accumulation of these materials as well as having the lowest biomass and seed production. They concluded that use of RO treated produced water is viable although they also recommended more research into long-term accumulation of minerals and metals in the plants.

Souza et al. 2017 [43] studied the effect of produced water treated by electrocoagulation/reverse osmosis (EC-RO) on the germination and early growth of sunflower crops. EC-RO was found to be very efficient at removing dispersed and dissolved components of the produced water. Treated produced water had no adverse effect on sunflower growth.

Da Costa et al. [40] studied the effect of untreated produced water versus treated produced water on the germination and growth of sunflower seedlings. Electroflocculation (EF) was the only treatment used for the treated produced water. Also, there was no comparison made to produced water versus ground water. Often in studies on the effect of produced water a control or baseline treatment using ground water will be carried out. The measured characteristics of the treated and untreated produced water are given in the table below. One of the findings of the study is that EF was effective at removing suspended contaminants such as oil and grease and turbidity. EF was also effective at reducing color and COD which are composed of a combination of dissolved and suspended contaminants. Comparing the treated and untreated produced water did not reveal any differences in seed germination percentage, speed of germination, germination index, biomass production.

Sunflower was selected because it is an important crop for farmers since it is a short-cycle plant with great adaptability to different soil and climate conditions. It is economically important as a food for cattle, humans, as a source of oil, and as a feedstock for the manufacture of biodiesel. It tolerates relatively high salinity and metal content. The study was carried out in Brazil and was funded by a grant from the Rio de Janeiro State Research Foundation (FAPERJ). Thus, the economic and regulatory drivers would not be entirely applicable to the US.

Niemeyer et al. [41] carried out tests with sunflowers using a laboratory scale produced water treatment system consisting of gravity separation, sand filter, activated carbon filter, and reverse osmosis. Treated and untreated produced water and water from the public water supply were tested. Leachate was tested for toxicity. One of the main findings was the verification that the main impact of produced water on soil quality is due to its salinity. This has been observed in other studies. Niemeyer et al. studied two important soil parameters, habitat function and retention function. Habitat function is a test that measures the ability of a soil sample to serve as a habitat for plants, microorganisms, and soil-living animals. It is considered to be the most important parameter in assessing the health of an agricultural soil. The retention function measures the tendency of a soil to retain contaminants. Other parameters measured include the response of earthworms and insects as well as the aquatic toxicity and leachate retention. Five different treatments were applied to the produced water as given in the table below. For all of the water treatments listed significant deterioration of the soil quality was observed except for the public water and the RO-treated water.

Table 1
Produced water (PW) treatments and control description and abbreviation.

Abbreviation	Treatment
WOS	water-oil separation
SF	WOS + sand filter
AC	WOS + SF + activated charcoal
RO	reverse osmosis
MR	mixture reason (WOS + RO)
WS	public water supply (control)

Yan et al. [51] provide a review of the effects of salinity and water content on soil microorganisms. Soil microorganisms are important in supporting crops since they provide the initial digestion of raw organic materials into nutrients that can be taken up by plants. As the authors point out, salinity increases osmotic pressure which reduces uptake of water into the soil microbes and into the plant. It also delaminates certain clay materials which reduced the permeability of the soil.

As discussed by Ayers and Westcot [52], the two most common water quality factors which influence the normal infiltration rate are the salinity of the water (total quantity of salts in the water) and its sodium content relative to the calcium and magnesium content (SAR). The TDS guideline is given in the table below where it is seen that a TDS of 2000 mg/L is considered to be severely high. A high salinity water will increase infiltration. A low salinity water or a water with a high sodium to calcium/magnesium ratio will decrease infiltration. Acceptable SAR values vary depending on the TDS as shown in the table. Both salinity and SAR may impact the soil at the same time. Secondary problems may also develop if irrigation must be prolonged for an extended period of time to achieve adequate infiltration. These include crusting of seedbeds, excessive weeds, nutritional disorders and drowning of the crop, rotting of seeds and poor crop stands in low-lying wet spots. One serious side effect of an infiltration problem is the potential to develop disease and vector (mosquito) problems. When a soil is irrigated with a high sodium water, a high sodium surface soil develops which weakens soil structure. The surface soil aggregates then disperse to much smaller particles which clog soil pores. The problem may also be caused by an extremely low calcium content of the surface soil. In some cases, water low in salt can cause a similar problem but this is related to the corrosive nature of the low salt water and not to the sodium content of the water or soil. In the case of the low salt water, the water dissolves and leaches most of the soluble minerals, including calcium, from the surface soil.

Toxicity problems occur if certain constituents (ions) in the soil or water are taken up by the plant and accumulate to concentrations high enough to cause crop damage or reduced yields. The degree of damage depends on the uptake and the crop sensitivity. The permanent, perennial-type crops (tree crops) are the more sensitive. Damage often occurs at relatively low ion concentrations for sensitive crops. It is usually first evidenced by marginal leaf burn and interveinal chlorosis. If the accumulation is great enough, reduced yields result. The more tolerant annual crops are not sensitive at low concentrations but almost all crops will be damaged or killed if concentrations are sufficiently high.

The ions of primary concern are chloride, sodium and boron. Although toxicity problems may occur even when these ions are in low concentrations, toxicity often accompanies and complicates a salinity or water infiltration problem. Damage results when the potentially toxic ions are absorbed in significant amounts with the water taken up by the roots. The absorbed ions are transported to the leaves where they accumulate during transpiration. The ions accumulate to the greatest extent in the areas where the water loss is greatest, usually the leaf tips and leaf edges. Accumulation to toxic concentrations takes time and visual damage is often slow to be noticed. The degree of damage depends upon the duration of exposure, concentration by the toxic ion, crop sensitivity, and the volume of water transpired by the crop. In a hot climate or hot part of the year, accumulation is more rapid than if the same crop were grown in a cooler climate or cooler season when it might show little or no damage. Guidelines for evaluation of water quality for irrigation are given in Table 1. They emphasize the long-term influence of water quality on crop production, soil conditions and farm management.

Table 1 GUIDELINES FOR INTERPRETATIONS OF WATER QUALITY FOR IRRIGATION¹

Potential Irrigation Problem	Units	Degree of Restriction on Use		
		None	Slight to Moderate	Severe
Salinity (affects crop water availability) ²				
EC _w	dS/m	< 0.7	0.7 – 3.0	> 3.0
(or)				
TDS	mg/l	< 450	450 – 2000	> 2000
Infiltration (affects infiltration rate of water into the soil. Evaluate using EC _w and SAR together) ³				
SAR = 0 – 3	and EC _w =	> 0.7	0.7 – 0.2	< 0.2
= 3 – 6	=	> 1.2	1.2 – 0.3	< 0.3
= 6 – 12	=	> 1.9	1.9 – 0.5	< 0.5
= 12 – 20	=	> 2.9	2.9 – 1.3	< 1.3
= 20 – 40	=	> 5.0	5.0 – 2.9	< 2.9
Specific Ion Toxicity (affects sensitive crops)				
Sodium (Na)⁴				
surface irrigation	SAR	< 3	3 – 9	> 9
sprinkler irrigation	me/l	< 3	> 3	
Chloride (Cl)⁴				
surface irrigation	me/l	< 4	4 – 10	> 10
sprinkler irrigation	me/l	< 3	> 3	
Boron (B)⁵				
	mg/l	< 0.7	0.7 – 3.0	> 3.0
Trace Elements (see Table 21)				
Miscellaneous Effects (affects susceptible crops)				
Nitrogen (NO₃ - N)⁶				
	mg/l	< 5	5 – 30	> 30
Bicarbonate (HCO₃)				
(overhead sprinkling only)	me/l	< 1.5	1.5 – 8.5	> 8.5
pH		Normal Range 6.5 – 8.4		

Burgos and Lebas [53] observed a sustainable growth rate and quality when using produced water for irrigation of reed canary grass and sorghum with TDS levels up to 2,500 mg/L together with organics. At higher TDS levels up to 7,000 mg/L there was no observed mortality for sorghum NS.

Pica et al. [47] found that non-food biofuel crops of rapeseed and switchgrass were capable of productive growth when irrigated with produced water from the CBM development of the Powder River Basin at TDS levels of 3,500 mg/L.

Andrade et al. [54] studied the ecotoxicological effects of produced water that had been desalinated using mechanical Vapor Recompression (MVR). Algae, fish, lettuce, and earthworms were used in the toxicity testing. The MVR effluent was found to be non-toxic to all species except the algae which experienced chronic toxicity due to the presence of ammonia in the MVR effluent. Once the ammonia was stripped, the algae experienced no toxicological effects.

Lewis et al. [55] blended 4 parts of ground water with 1 part of treated produced water and applied the mixture to a cotton crop. The produced water treatment was provided by Energy Water Solutions (Woodlands, TX). The treated produced water had lower chloride than the ground water and contained lower concentrations of key contaminants. Both water sources gave similar cotton crop yield. The cotton yield was 568 lbs/acre for the treated produced water, and 587 lbs/acre for the groundwater. Soil salinity reduced with the use of the PW/GW blended water.

Burkhardt et al. [45, 46] determined that untreated produced water could be used to irrigate crops for roughly two years before detrimental effects were observed on the plants and soil. Blending of the produced water with high quality irrigation water extended this time period to beyond two years.

De Meneses et al. [44] studied the effect of using produced water for irrigation of oilseed (castor bean and sunflower) crops. They evaluated the effect of treated produced water on the biological properties of the soil. Three water types

were used, ground water, filtered produced water, and filtered/RO treated water. The soil properties (microbiological activity and organic carbon) in the sunflower crop deteriorated with the used of both types of produced water. The deterioration in the castor bean crops was less pronounced.

Burkhardt et al. [45, 46] studied switchgrass and wormwood crops irrigated with coal bed methane produced water. Various blends of produced water with fresh water were evaluated. The blends had higher SAR values than the fresh water control. Biofuel yields decreased with increasing percentage of produced water.

4.2 Mining

The Delaware Basin is a major source of potassium salts. The general terminology for these salts is potash which refers to any of several water soluble potassium salts. The specific minerals found in the Delaware are sylvite (potassium chloride) and langbeinite (potassium magnesium sulfate). Layered deposits are found throughout the region in the Salado formation. The potash mining industry started in 1931. Halite (sodium chloride, rock salt, table salt) are a by-product of potash mining.

The mines use fresh water to wash the minerals. The water picks up salts in the rock and becomes saline. After washing, the saline water is often stored in large unlined evaporation ponds under permits dating back to the early days of the mines.

Jal Potash Plant Planned

PolyNatura officials are planning for a \$330 million polyhalite mine to be built and operational 27 miles west of Jal by around 2022. [Potash plant coming soon near Jal NM](#)

Intrepid mine east of Carlsbad

A mine in New Mexico says it needs to use 3.2 billion gallons of drinking water for the next two years, possibly robbing 64,000 people of access to clean water. The Hobbs News-Sun reports that Lea County commissioners voted last week to send a letter to the federal government to protest the potential use of water to flood the fertilizer mines. Commissioners want the U.S. Bureau of Land Management to include Lea County in its environmental review of a proposal spearheaded by Intrepid Potash to extract potash ore from an underground mine by flooding it with water out of Lea County. The project would be an extension to Intrepid's already existing solar solution mine that's located about 20 miles east of Carlsbad. The commission's letter comes as the BLM continues to seek public comment about the project extension. [Intrepid Potash](#) [Intrepid 2015 water plan](#)

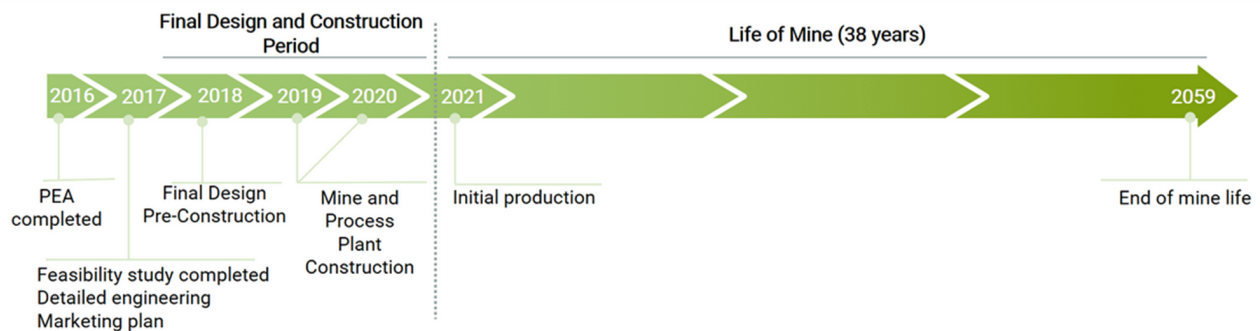
Intrepid Potash, which has mining and processing operations near Carlsbad, announced in May it had finalized leasing agreements with several oil and gas operations for a portion of their water rights. The water will likely be used for hydraulic fracturing, or "fracking," jobs. "Intrepid is one of the largest water rights owners in southeast New Mexico and we have begun to monetize those rights," said Intrepid president and CEO Robert Jornayvaz during a May 2 conference call on first quarter earnings. "During the first quarter, we finalized multiple contracts with various oil companies and water delivery companies to lease a portion of our significant rights, and are currently negotiating additional agreements but most importantly are delivering water and collecting revenue." [Intrepid selling water for frac'ing](#)
[Intrepid & NGL Water deal](#)

[Intrepid selling water 2019](#)

In April, 2020, a NM state district judge ruled that the New Mexico Office of the State Engineer needed to show cause for issuing the company seven "preliminary authorizations" to shift its water rights from use for potash refining to sales to the oil and gas industry, the Carlsbad Current-Argus reports.

Ochoa Project Overview

Timeline: updated from Feasibility Study



Facts at a Glance

Located in Lea County, New Mexico, USA: an excellent mining jurisdiction with ready access to infrastructure, ports, utilities, and skilled labor

Well-positioned to become the only polyhalite producer in North America: first production expected in 2021, ramping up to 2 million tons per year in 2023

Ideally situated: ready access to U.S. clients or for export to Latin America and Asia

38-year mine life: 71 million tons Proven & Probable Reserves (88% polyhalite grade)

Preliminary designs of mine and processing plant: complete to Class 3 level accuracy and relatively low capital intensity (anticipated development capital budget of \$328 million)

Project NPV of \$1,034 million, unlevered IRR of 26%, and payback period of 2.8 years: based on 8% cost of capital and \$193 per ton life of mine average product price

Numerous off-take agreements underway: letters of intent in place or in negotiation for a majority of our planned annual production

Headquarters

600 West Bender Blvd.
Hobbs, New Mexico 88240
USA

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[Ochoa plant](#)

Mosaic has a potash plant in Carlsbad, NM [Mosaic in Carlsbad](#). In a conversation with Mosaic's Scotty Diddle, they indicated to Michael Dunkel that they had a ground water source of 18,000 ac-ft and that they have plenty of water. The Mosaic plant mines a specialized micronutrient. The mine/plant is expected to have a 50-year life.

A summary of mining in Lea and Eddy Counties in New Mexico shows that they have their current water needs met by ground water sourcing. It is possible that in the future the mines will need additional water or may have pressure to preserve the aquifers. In these scenarios, mining could be a potential user of desalinated produced water.

4.3 Rangeland

According to Mike Hightower, leader of the New Mexico Produced Water Research Consortium (NMPWRC), rangelands offer a good option for desalinated produced water. About one third of New Mexico is rangelands that are often federal lands, including the Bureau of Land Management (BLM). Many rangeland areas need two to four inches of additional water per year to allow gas and hay to thrive, usually applied in the spring and fall. The additional hay and grass sequester carbon, reducing greenhouse gas. The additional water and hay also support additional head of cattle per section (320 acres). Since the rangelands are widely dispersed, this application would work more effectively with a series of distributed water treatment plants that could keep the transportation costs of the lower than a centralized plant.

4.4 Others (Power plants, Refining, Pecos River relief for NM, Frac sand washing)

Power Plants in southern New Mexico

Natural gas [\[edit \]](#)

[10]

Name	Location	Capacity (MW)	Operator	Year opened
Cunningham	Lea County	519	Southwestern Public Service Co	1957/1965/1998
Hobbs	Lea County	665	Lea Power Partners	2008
LCEC Generation	Lea County	46.5	Western Farmers Elec Coop, Inc	2012
Maddox	Lea County	212	Southwestern Public Service Co	1963/1967/1976

[Power plants in NM](#)

Water withdrawal and consumption factors vary greatly across and within fuel technologies. Water factors show greater agreement when organized according to cooling technologies as opposed to fuel technologies. Once-through cooling technologies withdraw 10 to 100 times more water per unit of electric generation than recirculating cooling technologies; recirculating cooling technologies consume at least twice as much water as once-through cooling technologies. Natural gas plants may consume 100 to 400 gallons per MWh of power, depending on the system. Therefore, a 519 MW plant like Cunningham could consume 454 million to 1.8 billion gallons of water per year, or 30 kBWPD to 119 kBWPD.

According to the New Mexico State Engineer 2015 Water use report, the plants in Lea County reported 4,472 acre-feet of water use in 2015. This is 34.7 million barrels per year, or 95 kBWPD, for the four plants. If the water use is allocated according to plant MW capacity, the Hobbs plant would have used 44 kBWPD and the Cunningham plant 34 kBWPD. This potential group of water users are relatively small compared to Lea County total produced water estimate of 694 million barrels in 2019, of which 321 million barrels was from unconventional wells(Data source is Bridget Scanlon from UTBEG).

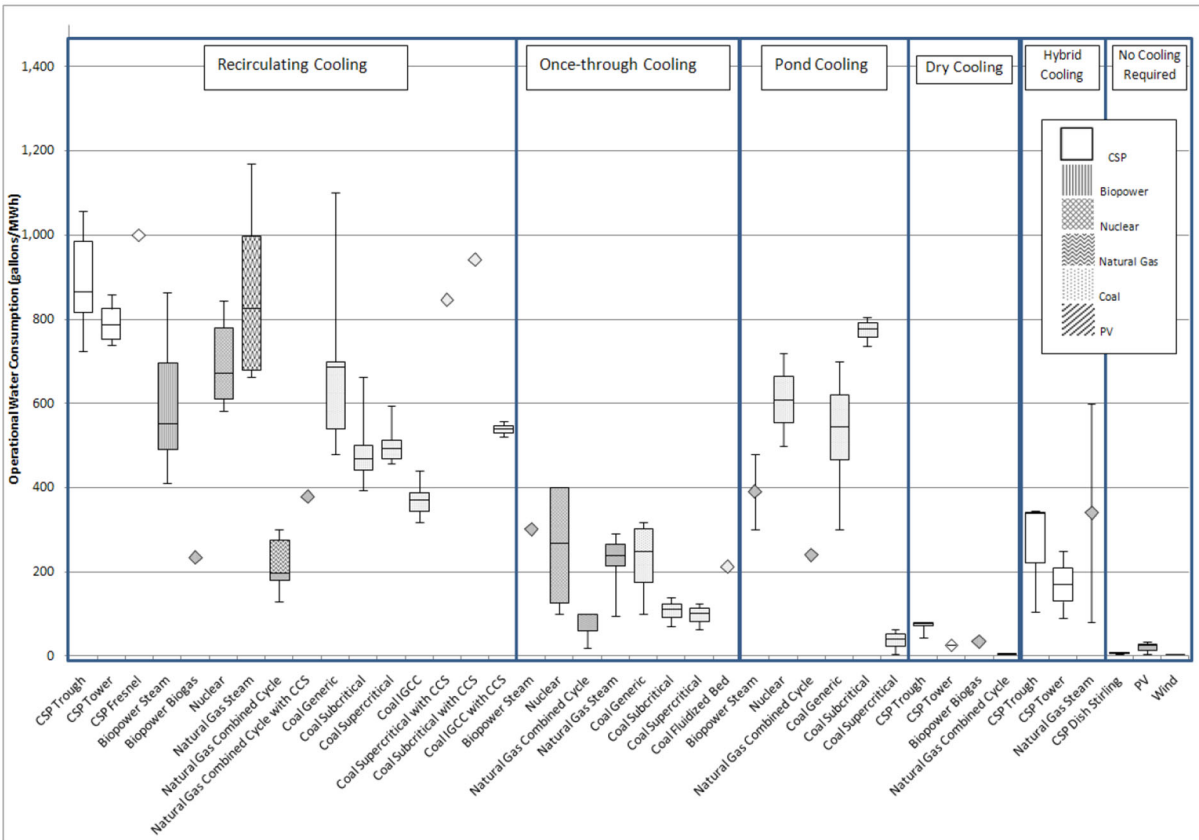


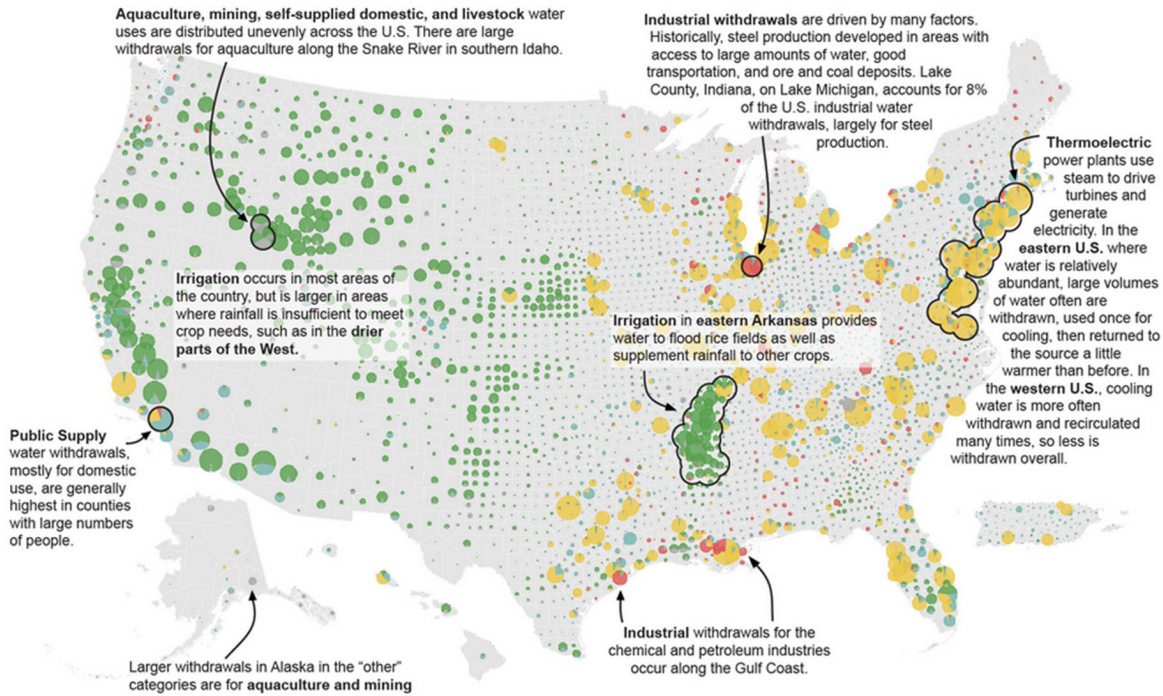
Figure 1. Operational water consumption factors for electricity generating technologies

IGCC: Integrated gasification combined cycle. CCS: Carbon capture and sequestration. CSP: Concentrating solar power. Whisker ends represent maxima and minima. Upper and lower ends of boxes represent 75th and 25th percentile, respectively. Horizontal lines in boxes represent medians.

[NREL study](#)

Water use across the Permian basin of west Texas and southeastern New Mexico is primarily for irrigation as shown on the USGS graphic below <https://owi.usgs.gov/vizlab/water-use-15/#view=USA&category=industrial>

According to Mike Hightower, leader of the NMPWRC, most power plants in New Mexico use evaporation ponds for their concentrated cooling water and have zero liquid discharge.



The Sodium Adsorption Ratio:

The following table provides data on a number of End Use Criteria compiled by ALL Consultants [2]. Also shown in the table are produced water quality data for Coal Bed Methane and conventional hydrocarbon producing well water. Most Coal Bed Methane produced water is used for irrigation but there are exceptions. When the CBM produced water contains high salinity or a high value of Sodium Adsorption Ratio (SAR) the water must be treated before it can be used for irrigation. The End Use Criteria data in the table are taken from field measurements. The data are not location-specific. However, most of the water samples were taken in the Powder River Basin, WY.

One of the important criteria for agricultural reuse is the ratio of sodium ions to calcium plus magnesium ions. This ratio is known as the SAR. A high concentration of sodium ions damages the soil. Sodium exchanges with (takes the place of) calcium and magnesium in the soil clays. When this happens, the clay delaminates (breaks up) forming small particles which clog the pores in the soil. These small particles plug the pores and prevent the flow of water and air into the soil. The soil becomes hard and impermeable. The same mechanism occurs in the hydrocarbon bearing formation when so-called swellable clays are present. When this happens the flow of hydrocarbons is reduced.

In order to estimate whether or not a given water source will cause soil damage, an empirical parameter has been devised, known as SAR.

Specific Irrigation User – Carlsbad Irrigation District (CID)

The Carlsbad Irrigation District (CID) is a quasi-municipality and non-profit organization that uses water from the Pecos River to distribute for agriculture, according to April Travelstead at CID. The web site lists an allocation of 3.697 acre-ft without an explanation. The allocation is multiplied by a surface owner's land, or water rights, to give the annual maximum for the water right owner. For example, a 10-acre plat would be allocated up to 37 acre-feet per year, or 287 kBW. The total acreage in CID is 25,055 acres with a potential allocation of 194 million barrels of water per year or 532,500 barrels per day for 365 days. However, the water is distributed from March 1 to October 31 annually. It can only be used for agriculture and can't be sold. Ms. Travelstead indicated that the irrigated crops include wheat, cotton, pecans and alfalfa.

Brantley dam replaced the McMillan dam and reservoir. The US Bureau of Reclamation (BOR) built the dam that is operated by CID. BOR and CID remain in a partnership. CID has priority water rights from the Pecos River. They work together with the Interstate Stream Commission to determine how much water is conserved in the river and delivered to Texas for the New Mexico and Texas Water compact. Hannah Risely-White, Pecos River Basin Manager, (505) 827-4029 was identified as a good contact at the Interstate Stream Commission. CID also operates the Avalon dam and reservoir and a system to distribute water.

Ms. Travelstead confirmed that the state of New Mexico bought ground water rights to deliver water into the Pecos for the compact with Texas. She also confirmed that CID is in an ongoing litigation with Intrepid Potash. CID is challenging Intrepid's Black River water rights. The Black River feeds the Pecos.

The Carlsbad Irrigation District (CID) has a classified section where individuals post requests to buy and sell water and water rights. <http://cidistrict.com/>

The Carlsbad Irrigation District operates the Avalon Reservoir three miles north of Carlsbad.

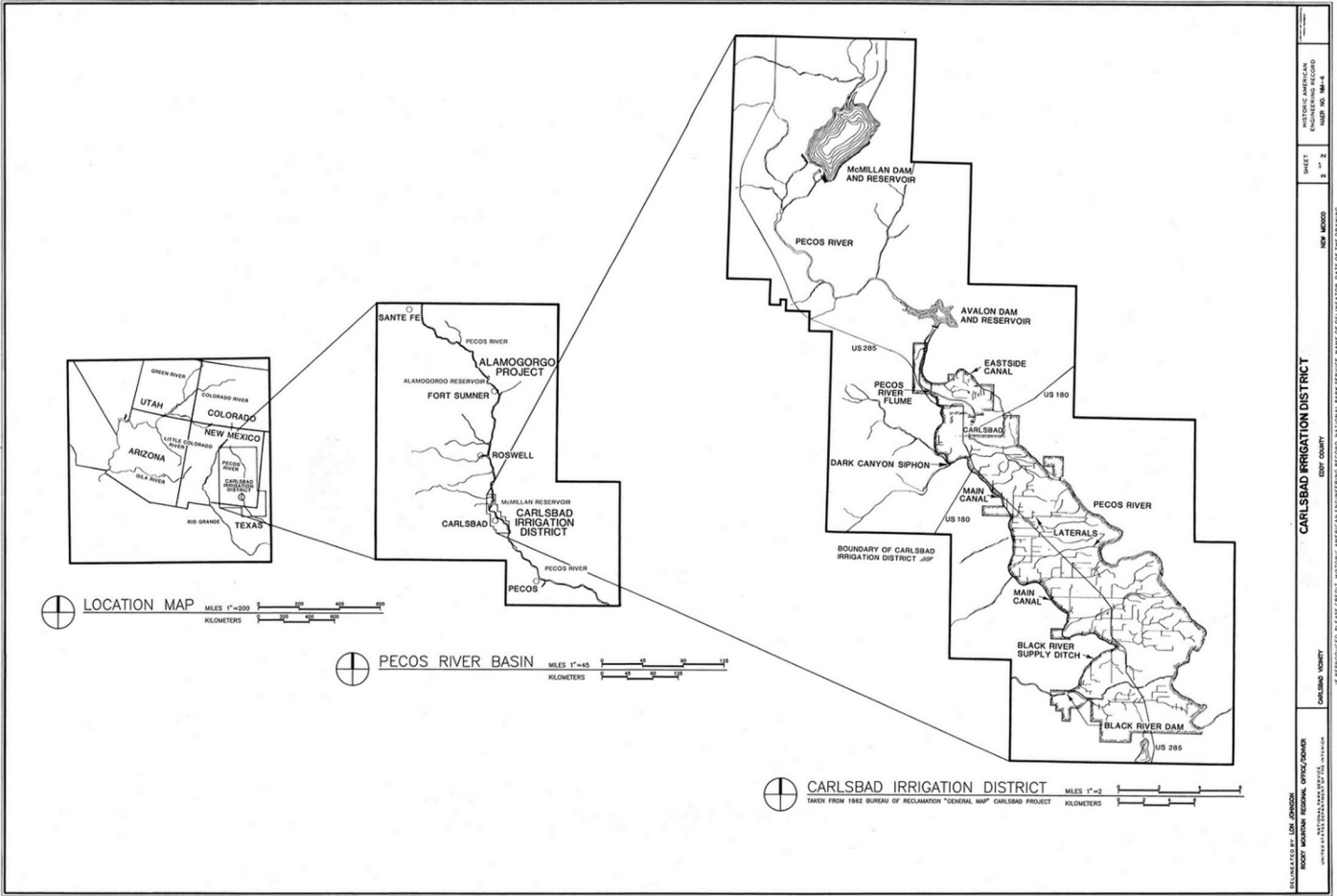
Avalon Reservoir

i Avalon Reservoir does not offer reservations through Recreation.gov.
Please take a look at the area details below for more information about visiting this location. Enjoy your visit!

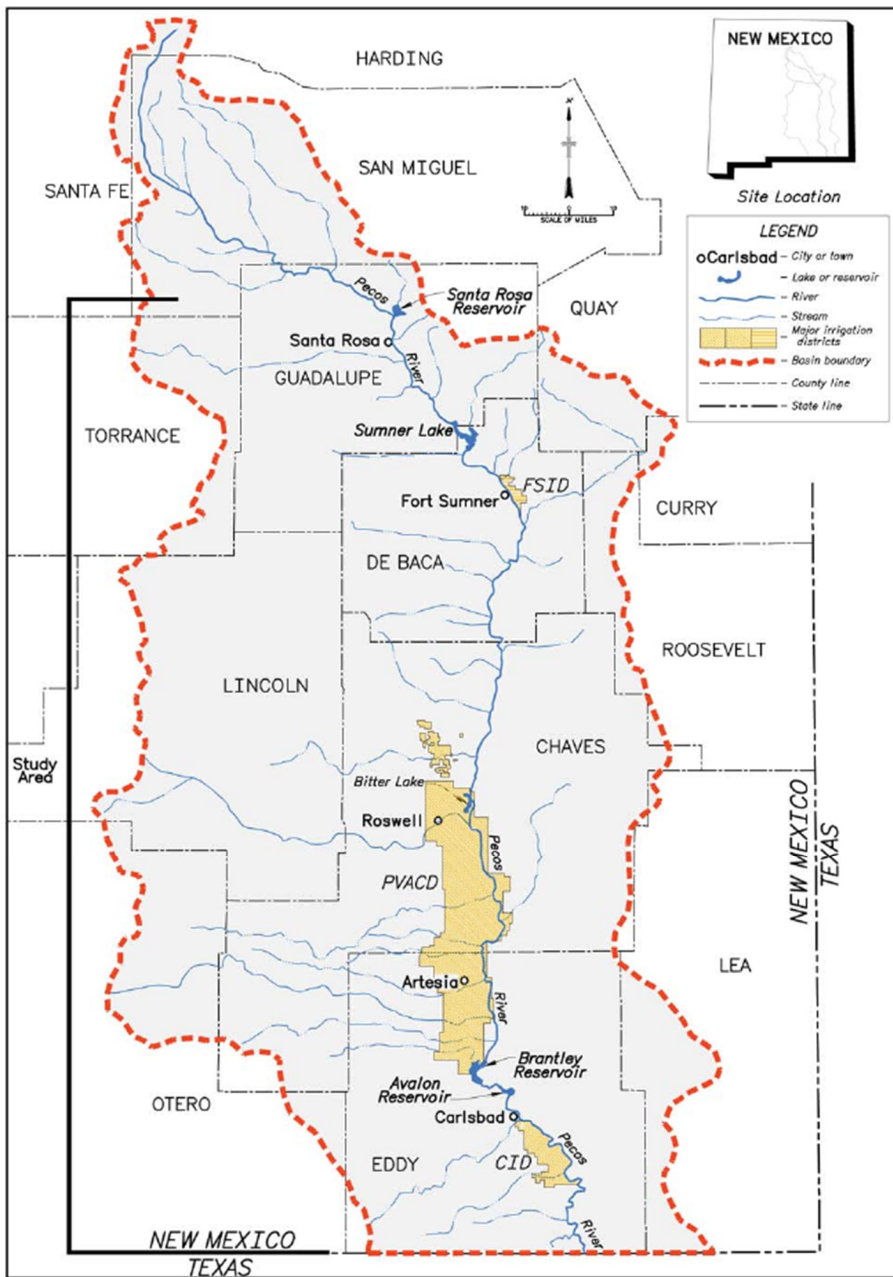
Overview

[Avalon Dam](#) and Reservoir, Carlsbad Project, are located on the Pecos River 3 miles north of Carlsbad, New Mexico. The dam is a zoned earthfill structure constructed in 1907. Recreation at Avalon Reservoir is managed by the Carlsbad Irrigation District under agreement with the Bureau of Reclamation. New Mexico Department of Game and Fish stocks reservoir and provides law enforcement. The recreation area is open year around. This is a non-fee area with primitive facilities. There are surface roads to recreation area and unpaved roads around reservoir. There is year-round fishing for white bass, catfish, and bream. Scuba diving for game fish is permitted. Boating must conform to New Mexico regulations. Boating fees charged. Carlsbad Irrigation District Phone: (575) 885-3203 New Mexico Dept. of Game and Fish Phone: (575) 234-2829

<https://www.recreation.gov/camping/gateways/87>



[Carlsbad Irrigation map](#) This seems to be an old map since it shows Mcmillan dam that was replace by Brantley dam.



[Pecos River Basin showing Carlsbad Irrigation District](#)

Mike Hightower, head of the NMPWRC, indicated that discussions with the State Engineer have been positive about using desalinated produced water for irrigation. Some of the crops like alfalfa and cotton are not consumed by humans. Crops consumed, such as pecans, would need to show that there is no biological accumulation.

Pecos River Compact

The Pecos River water sharing agreement is summarized in this book available online. [Chapter 2 water rights.](#) According to the latest report on the Office of the State Engineer from August 2018, New Mexico has had overage delivers to Texas in 4 of the last 5 years and 8 of the last 10 years. New Mexico has an accumulated overage of 170,800 ac-ft since 1987, when the balance calculation started. [Pecos compact report 2018](#) The State Engineer's office supports the idea of using desalinated produced water in the Pecos River to help with the water balance. Ideally, the water would be input below Red Bluff, NM and Malaga Bend where the river contacts the

Capitan reef and picks up salinity. This location is near the city of Malaga, NM and only about 10 miles north of the Texas border.

On 4/20, Michael Dunkel Emailed and left a voice message for Hannah Riseley-White to ask about the Pecos River Compact and potential to source water from desalinated produced water.

Table 1. Typical Values for Produced Water Quality Compared to Some Criteria

Parameter	End Use Criteria (ppm)			CBM Water	Non-CBM (Conventional Gas Well) Water
	Drinking	Irrigation	Livestock		
pH	6.5 - 8	-	6.5 - 8	7 - 8	6.5 - 8
TDS, mg/l	500	2,000	5,000	4,000 - 20,000*	20,000 - 100,000
Benzene, ppb	5	5	5	< 100	1,000 - 4,000
SAR**	1.5-5	6	5-8	Highly Varied	Highly Varied
Na ⁺ , mg/l	200	See SAR	2,000	500 - 2000	6,000 - 35,000
Barium, mg/l				0.01 - 0.1	0.1 - 40
Cl ⁻ , mg/l	250	-	1,500	1,000 - 2,000	13,000 - 65,000
HCO ₃ ⁻ , mg/l	-	-	-	150 - 2,000	2,000 - 10,000

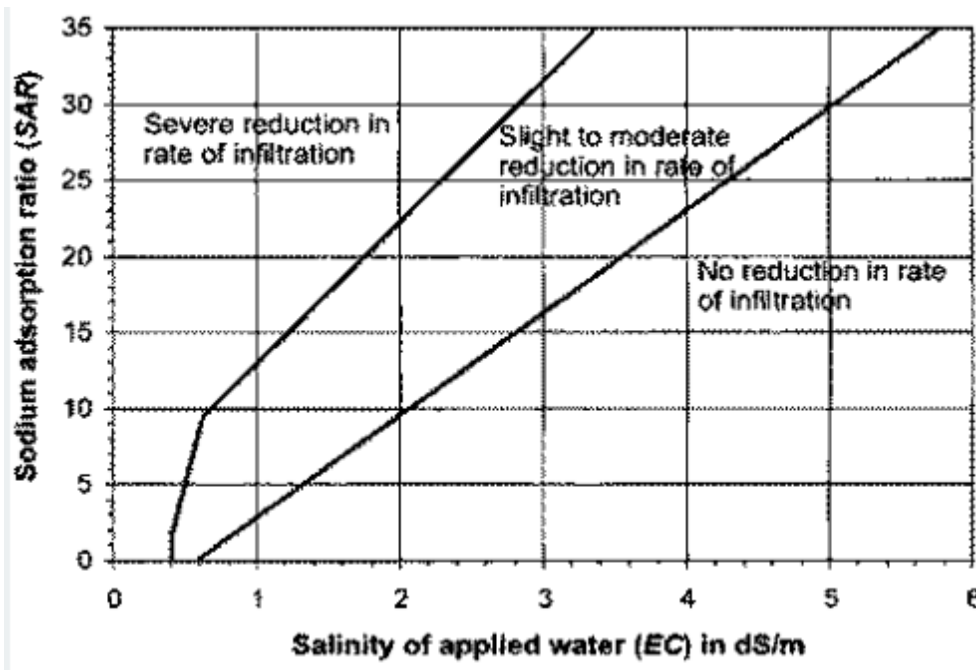
* Total Dissolved Solids (TDS) range estimated for the lower 50 percentile

** SAR = Sodium Absorption Ratio -- a function of a ratio of Na to Ca and Mg Levels.

In the table below, the Australian Water Quality Guidelines are given [2].

<i>Tolerance</i>	<i>SAR of irrigation water</i>	<i>Crop</i>
Very sensitive	2-8	Fruits, nuts, citrus, avocad
Sensitive	8-18	Beans
Moderately tolerant	18-46	Clover, oats, rice
Tolerant	46-102	Wheat, barley, tomatoes, beets, tall wheat grass, crested grass

Source: Extracted from the Australian Water Quality Guidelines for Fresh & Marine Waters (ANZECC)



Livestock. A limited number of studies considered livestock watering as a potential beneficial use of produced water (Horner et al. 2011) or coalbed natural gas produced waters (Jackson and Reddy, 2007a; Zhang and Qin, 2018), with only Horner et al. (2011) specifically conducting a series of conceptual risk evaluations to assess the aggregate risk of the various produced water chemicals in several livestock species, including drinking water and dietary intake exposure pathways.

Agriculture and soil biota. Irrigation of crops and soil, or spillage to soil, risks impairing soil function by decreasing water permeation. Direct effects of irrigation water on sensitive crops may also occur. Non-food crops are often preferred for irrigation reuse in order to avoid direct ingestion pathways. Sunflowers (DaCosta et al. 2015, Sousa et al. 2017), castor beans (deMeneses et al. 2017), switchgrass and wormwood (*Artemisia*) (Burkhardt et al. 2015a, 2015b), and switchgrass and rapeseed (Pica et al. 2017) were exposed to untreated and treated produced waters with a wide variety of results related to product quality and yield, though most indicate at least short-term use with either processed produced water or untreated CBM produced water is acceptable in terms of plant performance, and soil: water ionic interactions. Reverse-osmosis (RO) treatment is not always beneficial to crops. Ferreira et al. (2015a) characterized soil mesofauna and found the produced water that had undergone RO had significant effects on species composition, richness and abundance. Sousa et al. 2016 examined the sunflowers grown in that study and found differences in mineral sequestration with filtered and treated (RO), favoring RO.

Underground Storage and Recovery (USR) in New Mexico

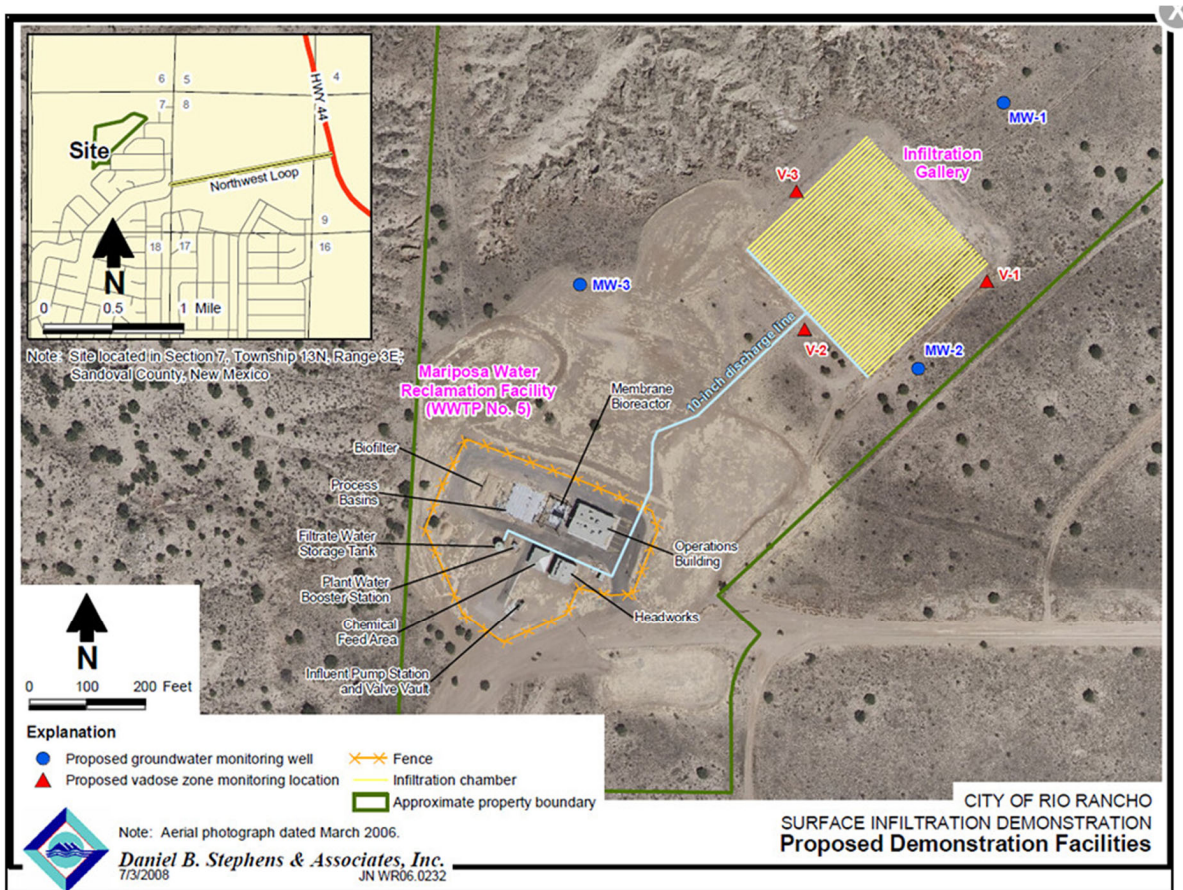
The NM Office of the State Engineer indicates that surface storage of water in the high desert of New Mexico results in approximately 7% loss of stored water to evaporation. Above-ground tanks are costly to construct, require a large land footprint, and are not aesthetically pleasing. There are currently five active Underground Storage and Recovery (USR) projects in NM, at various stages of development and permitting. This summarizes the status of these projects undertaken by the Albuquerque Bernalillo County Water Utility Authority (ABCWUA), and the City of Rio Rancho. The Office of the State Engineer (OSE) reviews technical data and gives final approval for the project.

Below is a summary of four of the five USR projects permitted in New Mexico

NM Underground Storage and Recovery (USR) Projects

Project Name	Applicant	Location	Max. annual Recharge (ac-ft)	Max. annual Recharge (kBWPD)	Status & Comments
Mariposa	City of Rio Rancho	North side of Albuquerque	336	7,142	Operating at less than 5% of design capacity.
Bear Canyon	Albuquerque Bernalillo County Water Authority	Albuquerque	3,000	63,764	First full scale USR permitted in NM. System not run in 2018 due to high nitrate in monitoring wells.
Rio Rancho Direct Injection	City of Rio Rancho	North side of Albuquerque	1,120	23,805	Operations began in October 2017.
Large Scale/DWTP	ABCWUA	Albuquerque	4,500	95,647	Demonstration phase started in Nov 2018.

Below is a summary of one of the USR projects.



Mariposa Site

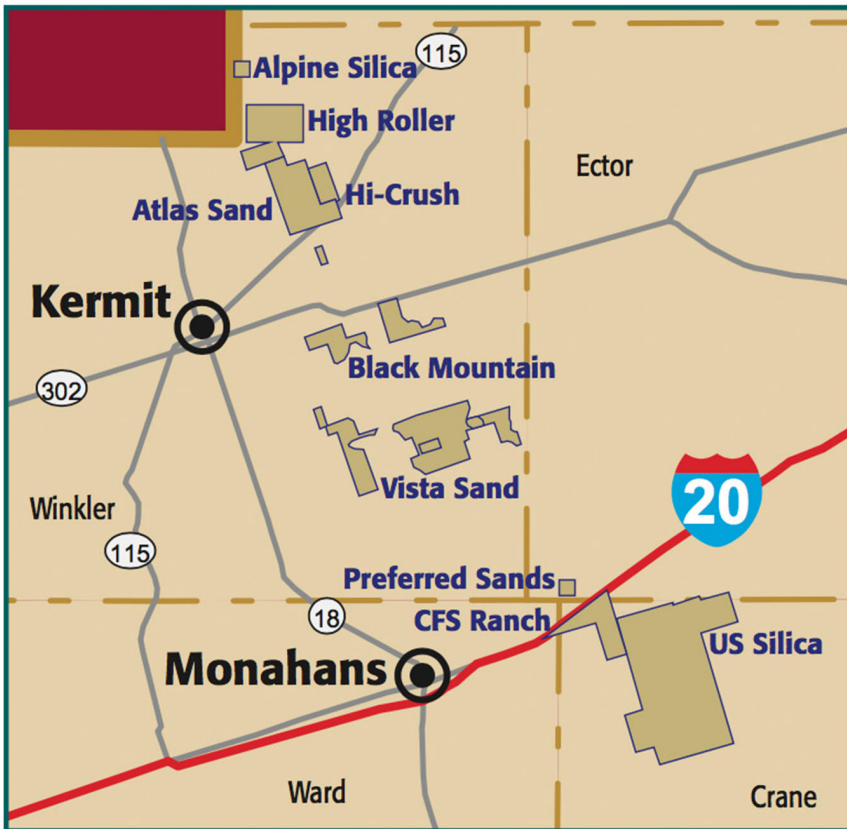
Underground Storage and Recovery

Underground Storage and Recovery is legally different than Aquifer Storage and Recovery. There is a different water quality standard, according to Mike Hightower from the NMPWRC. The potential for USR could be significant in the Ogallala aquifer in the Jal, Eunice and Hobbs area of New Mexico.

Brackish aquifers could also be used as a storage location for desalinated produced water. Roger Peery from John Shomaker & Associates has studied brackish aquifers in New Mexico. [Peery 2016 presentation](#) [Peery 2004](#)

Water Use for Washing Frac' Sand

Frac sand washing occurs at sand mines scattered around the Permian Basin, but there is a concentration of sand mines in Winkler County, east of Highway 18 near Kermit, TX. The mines wash and sieve the sand for frac' use in oil wells. The operations typically allow the fine clay particles to settle out of the water before it is reused. High Roller Sand indicated that they currently source make-up water from groundwater.



[Sand mines in Permian](#)

Natural Gas Plants use of Water

Natural gas plants are scattered around the Permian basin. The plants are positioned downstream of the wells and tank batteries, but before the gas enters major natural gas sales pipelines. The plants use makeup water in their Amine and dehydration processing units. According to one natural gas midstream company, a typical gas plant may use less than 1,000 barrels of water per month. Thus, gas plant water use is too insignificant to be a target for produced water treatment that could be hundreds of times higher.

Regulatory Control of Produced Water Reuse

If water is discharged to a “Water of the United States” (WOTUS), then the USEPA has jurisdiction and may be able to authorize a National Pollutant Discharge Elimination System (NPDES). A WOTUS may be defined as a large river down to an intermittently flowing stream.

Effective on September 1, 2019, the 86th Legislature passed Texas House Bill (HB) 2771, amending Section 26.131 of the Texas Water Code. The legislation transfers the authority to issue permits for the discharge of produced water, hydrostatic test water, and gas plant effluent resulting from certain oil and gas activities from the Railroad Commission of Texas (RRC) to the Texas Commission on Environmental Quality (TCEQ).

Additionally, on or before September 1, 2021, the TCEQ will seek federal delegation from the Environmental Protection Agency (EPA) to supplement or amend the Texas Pollutant Discharge Elimination System (TPDES) program to include delegation of the National Pollutant Discharge Elimination System (NPDES) permit authority for discharges of produced water, hydrostatic test water, and gas plant effluent.

Until the EPA delegates NPDES permit authority to the TCEQ, the RRC will continue to issue discharge permits. A federal NPDES permit may also be required for discharges to surface waters of the state.

[RRC TX produced water legislation](#)

A good summary of federal regulations of produced water discharge and EPA studies is in the GWPC produced water report starting on page 118. [GWPC PW report](#) The report includes examples of NPDES permits in Colorado, California and Wyoming. In the Wyoming case, lab analysis and reports for water proposed for discharge is required for 35 parameters with required detection limits. Examples of the standards for discharge of certain constituents include barium (2000 ug/L), boron (5000 ug/L), chloride (2000 mg/L or 230 mg/L for higher water classes), Radium 226 (5 or 60 pCi/L), and TDS (5,000 mg/L).

Permian Produced Water Desalination Project in 2015

In 2015, Anadarko and Energy Water solutions partnered with Texas A&M AgriLife Research on a study in Pecos, Texas to investigate irrigation of cotton with desalinated produced water blended with well water (1:4 ratio) as compared to existing well water and also evaluate soil salinity parameters. The study found that that the blend did not reduce cotton yield or lint quality and may improve soil salinity as compared to the well water. The treated produced water of 98 ppm TDS was blended with 3218 ppm TDS groundwater to create a blended water with 2470 ppm TDS.

http://www.owrb.ok.gov/2060/PWWG/Resources/Lewis_Katie.pdf

Colorado Study of treated Produced Water for Irrigation

Researchers from Colorado State University and the United States Department of Agriculture (USDA) worked on a greenhouse study investigating the use of treated Denver-Julesburg Basin produced water for irrigation of two salt-tolerant biofuel crops, switchgrass and rapeseed. Researchers used different produced waters with varying total organic carbon (TOC) and total dissolved solids (TDS) levels and relative impacts on seedling emergence, biomass yield, plant height, leaf electrolyte leakages, and plant uptake over one growing season. The findings were that higher levels of both TOC and TDS had negative impacts on multiple endpoints, including yield and growth health. The study concluded that organic content is potentially a greater quality constraint than salinity. The authors hypothesized that such studies and related findings could inform regulatory decision-making on treatment standards for irrigation. For example, the authors discussed potential optimum treatment levels to at least 3500 mg/L TDS to maintain yield and plant health, removal of organic matter to less than 50 mg/L in order to keep leaf cell damage to less than 50 percent, and a TOC of less than 5 mg/l to keep a “sustainable biomass production rate.”

Nasim E. Pica, Ken Carlson, Jeffrey J. Steiner, and Reagan Waskom, "Produced Water Reuse for Irrigation of Non-Food Biofuel Crops: Effects on Switchgrass and Rapeseed Germination, Physiology and Biomass Yield," *Industrial Crops and Products* 100:65–76 (June 2017),

<https://www.sciencedirect.com/science/article/abs/pii/S0926669017301012?via%3Dihub>

Roadspreading in Texas and New Mexico

Lea and Eddy Counties in New Mexico each have an estimated 700 miles of dirt roads. The roads are sometimes watered for dust suppression. It is widely accepted that a modest amount of salinity improves dust suppression. Potentially, very low salinity desalinated produced water (approximately 500 ppm TDS) could be blended with small amounts of produced water to create dust suppression water with a salinity around 15,000 ppm TDS. This water could be spread four times per year. If ½ inch of water were spread on 1400 miles of roads in the two counties four times per year, this would be an estimated 3.5 million barrels per year, or an average of 10,000 BWPD. Thus, this potential use is almost not significant for a large scale plant that could be 100,000 BWPD.

Tasker summarized road spreading regulations for various states in his 2018 article. The recent New Mexico produced water bill changed the rules for road spreading in that state.

Table S4. States with regulations permitting the use of O&G wastewater or solid wastes for road maintenance, dust suppression, de-icing, land spreading, or case-by-case beneficial use practices.

State	Regulation	Date adopted or banned	Use	Wastewater type	Requirements
AL	Code of Ala. § 9-17-6(c)(3)	Banned 05/23/2000 (current as of 09/25/2017)	N/A	N/A	N/A
CO	CO Regulation 404-1-907-c (2)(D)	Effective 08/01/71 (current as of 09/25/2017)	Road spreading	Produced water	<3,500 mg/L TDS
CT	Conn. Gen. Stat. § 22a-473	Banned 07/09/1987 (current as of 2017)	N/A	N/A	N/A
ID	IDAPA 20.07.02	Banned* effective 04/11/2015 (current as of 10/01/2017)	N/A	N/A	N/A
IL	Title 62 Illinois administrative code, Chapter 1, 240.945	Effective 07/09/2001 (current as of 08/11/2017)	Road maintenance	Crude oil	Crude oil bottom sediments with <10% produced water mix
IN	312 IAC 16-5-27(a)(1)	Effective 09/11/2000 (current as of 09/13/2017)	Dust suppression	Oil or fluid contaminated with oil	Fluid spread must not leave the roadbed
KS	K.S.A. § 55-904 (c) K.A.R. § 28-47-4	Effective 05/01/1983 (current as of 09/21/2017)	Dust suppression and road maintenance	Produced water	Map of roads, methods for spreading, application rates, amounts
MI	Mich. Admin. Code R 324.705	Effective 2004 (current as of 09/15/2017)	Dust suppression and deicing	Produced water	<500 ppm hydrogen sulfide; >20 g/L Ca; <1 mg/L Benzene, Toluene, Ethylbenzene, and Xylene
MS	CMSR 26-000-002 R. 1.68 (VII)	Effective 01/01/1952 (current as of 09/09/2017)	Land spreading	NORM contaminated wastes	<600 uR/hr above background, Ra 226 and 228 < 5 pCi/gram after spreading
NE	Nebraska Admin. Code Title 267, Ch. 3, 022.16	Effective 01/01/2009 (current as of 11/01/2017)	Dust suppression and Deicing	Produced water	The estimated volume of fluids spread
NM	19.15.34.20 NMAC	Effective 03/31/2015 (current as of 09/29/2017)	By case	By case	Except as permitted under: 19.15.17 NMAC, 19.15.26.8 NMAC, 19.15.30 NMAC, 19.15.34 NMAC or 19.15.36 NMAC
NY	6 NYCRR § 360-1.15 (d)	Effective 08/25/1993 (current as of 01/01/2017)	Dust suppression and deicing	Produced water only (No Marcellus)	Chemical analyses with chloride, sulfate, sodium, calcium, magnesium, lead, iron, barium, oil & grease, TDS (total dissolved solids), pH, benzene, ethylbenzene, toluene, and xylene; Maps; Application rates; Volume
ND	N.D. Admin. Code 33-24-02-02	Effective 01/01/1984 (current as of 09/21/2017)	Dust suppression and deicing	Produced water only	Chloride >75 g/L; Calcium + Magnesium >10 g/L; Chemical analyses including pH, specific conductivity, iron, manganese, sodium, potassium, phosphorus, SO ₄ , HCO ₃ , CO ₃ , total dissolved solids (TDS), total alkalinity, oil and grease, aluminum, ammonia, arsenic, barium, boron, copper, chromium, lead, nickel, selenium and zinc; Maps; Application rates; Volumes
OH	ORC Ann. 1509.226	Effective 06/30/2010 (current as of 01/01/2017)	Dust suppression and deicing	Produced water only (no horizontal wells)	Locations, application rates, volumes, and gas well permit #s
PA	25 Pa. Code § 78.63	Effective 07/28/1989 (current as of 08/05/2017)	Land spreading and dust control	Only production or treated brines (other than brines produced from shale formations)	Locations, application rates, monthly spreading reports, and chemical analyses including calcium, sodium, chloride, magnesium, and total dissolved solids
SD	ARSD 74:12-04.15	Effective 01/12/2012 (current as of 09/25/2017)	Dust suppression	Produced water	Prohibited unless permitted by the secretary for dust suppression
TN	Tenn. Comp. R. & Regs. R. 0400-45-06-.11 (10)(a)	Effective 12/11/2012 (current as of 08/01/2017)	By case	By case	N/A
TX	16 TAC § 3.8	Banned* (01/01/1976) (current 09/30/2017)	N/A	N/A	N/A
VA	4 VAC 25-150-420	Effective September 25, 1991; current through August 1, 2017	Land spreading	Produced water	Road spreading is permitted through the same code that allows land spreading
WA	WAC § 344-12-225	Banned* (current as of 2003)	N/A	N/A	N/A
WV	Memorandum of Agreement, Dec. 22, 2011, WV	Effective 12/22/2011	Deicing	Produced water (no wastes associated with hydraulic fracturing)	>200 g/L TDS; <175 g/L Cl; <0.15 g/L Na; 5.5 to 8 pH; Fe <10 mg/L, Barium <2 mg/L, lead <10 mg/L, O&G <10 mg/L, Benzene <0.5 mg/L, Ethylbenzene <0.7 mg/L, Toluene <1 mg/L, Xylene <1 mg/L
WY	WCWR 055-0001-4 § 1 (c)(3)(E)	Effective: 06/03/2015, current through August 31, 2017	Dust suppression and deicing	Produced water	Road spreading, land spreading, and landfarming of exploration and production wastes

<https://pubs.acs.org/doi/abs/10.1021/acs.est.8b00716>

In Texas, permits for roadspreading are not issued for beneficial use of produced water on roads, including lease roads, even though a process for permitting land disposal is in place. One paper studying roadspreading for Colorado concluded, "It's all "do-able", and could create savings for oil companies and a window of opportunity for subcontractors, but regulatorily speaking it would be difficult and move at a "snail's pace". Flowback is also heavy in particulates and TDS, which would worry regulators. Every company's flowback recipe is different, and robust sampling would be needed." Dust suppression in Texas is constricted by a tighter approval process than for other beneficial uses. Landowners must give written approval, which can cost a prospective roadspreader money, and a 10-day notice is required, which can open oil/gas companies up to liability. Trucking costs are prohibitive. East of the 98th Meridian,

produced water falls into a dual permit situation between TX and EPA Region 6. EPA evaluates toxicity/chemical analyses, then the Texas Railroad Commission reviews and approves permits (along with the EPA). [Colorado roadspreading](#)

Ohio's regulations for brine spreading do not contain details on water quality. <http://codes.ohio.gov/orc/1509.226>
The Pennsylvania Department of Environmental Protection, which for years allowed municipalities to treat their roads with brine, ending the practice in May 2018, after it was sued by a Warren County resident. Before the decision, over a dozen counties in Western Pennsylvania used oil and gas wastewater on roads, and at least 13 other states — including Ohio, Michigan, West Virginia and New York — allowed the practice, according to the Penn State study. But it was especially common in northwestern Pennsylvania. In 2016, municipalities spread more than 11 million gallons of brine on roads in Pennsylvania, 96 percent of it in northwest part of the state. That represented 6 percent of the Pennsylvania conventional oil and gas industry's wastewater. Roadspreading Study PA

Summary of New Mexico's Produced Water Act – Including Roadspreading

- Eliminates legal vulnerabilities to New Mexico's surface/ground waters that existed prior to July 1, 2019, through:
 - Affirmative state permitting requirements;
 - Affirmative requirements for financial assurance; and
 - Clarified liability for spills.
- Removes obstacles to recycling of produced water.
- Gives EMNRD much-needed penalty authority.
- Explicitly requires that any use of produced water outside the oil and gas industry be regulated by NMED.
- Requires that the New Mexico Water Quality Control Commission (WQCC) adopt regulations for the "discharge, handling, transport, storage, and recycling or treatment of produced water or byproduct thereof outside the oilfield."
- Does not specify what these regulations shall be or what the WQCC determines protective of water quality.



Produced Water Act Implementation

- ✗ NMED is not currently authorizing the discharge of *treated* produced water for any purpose, including:
 - ✗ Surface waters
 - ✗ Drinking water and aquifer storage
 - ✗ Livestock watering
 - ✗ Irrigation for any crops, including food crops
 - ✗ Dust or ice control on roads
 - ✗ Construction
- ✗ NMED will **never** authorize *untreated* produced water to be used outside of oil and gas for any purpose

- ✓ NMED is preparing to implement HB 546
- ✓ NMED is partnering with research and academic institutions to fill critical science and technology gaps related to the safe treatment and use of produced water
- ✓ NMED is engaging the public to talk about the Produced Water Act and developing informative resources on the topic

<https://www.env.nm.gov/new-mexico-produced-water/>

16

NMED’s path for produced water regulations:

- Develop rules that prohibit untreated produced water use(s) outside of the oil and gas industry (e.g., road spreading).
- Develop rules that require companies to analyze and disclose the chemical constituents in produced water intended for treatment and use outside of the oil and natural gas industry.
- Over time and as the science dictates, develop rules for the “discharge, handling, transport, storage, and recycling or treatment of produced water or byproduct thereof outside the oilfield” (excerpt from HB 546).



State Agency Contacts

NMED contacts for treatment of produced water for off oil field use:

- Rebecca Roose, Water Protection Division Director, Rebecca.Roose@state.nm.us
- Annie Maxfield, Assistant General Counsel, Annie.Maxfield@state.nm.us

EMNRD contacts for management of produced water within the oil field:

- Adrienne Sandoval, Oil Conservation Division Director, Adrienne.Sandoval@state.nm.us
- Bill Brancard, General Counsel, Bill.Brancard@state.nm.us

OSE contacts for water rights issues related to produced water management:

- John Romero, Water Resource Allocation Program Director, John.Romero2@state.nm.us
- Owen Kellum, Administrative Litigation Unit Attorney, Owen.Kellum@state.nm.us

[NMED presentation](#)

Who Regulates Produced Water in New Mexico?

Energy, Minerals, and Natural Resources Department (EMNRD)	➡	Produced water disposal and reuse <u>within</u> the oil field
New Mexico Environment Department (NMED)	➡	Treated produced water use <u>outside</u> oil field
Office of the State Engineer (OSE)	➡	<u>No</u> permit required

[NM produced water Fact sheet](#)

New Mexico Regulations on Water Quality & Discharge (Selected portions)

20.6.2.2101 GENERAL REQUIREMENTS:

- A. Except as otherwise provided in Sections 20.6.2.2000 through 20.6.2.2201 NMAC, no person shall cause or allow effluent to discharge to a watercourse if the effluent as indicated by:
- (1) any two consecutive daily composite samples;
 - (2) more than one daily composite sample in any thirty-day period (in which less than ten (10) daily composite samples are examined);
 - (3) more than ten percent (10%) of the daily composite samples in any thirty-day period (in which ten (10) or more daily composite samples are examined); or
 - (4) a grab sample collected during flow from an intermittent or infrequent discharge does not conform to the following:
 - (a) Bio-chemical Oxygen Demand (BOD) Less than 30 mg/l
 - (b) Chemical Oxygen Demand (COD) Less than 125 mg/l
 - (c) Settleable Solids Less than 0.5 mg/l
 - (d) Fecal Coliform Bacteria Less than 500 organisms per 100 ml
 - (e) pH Between 6.6 and 8.6

20.6.2.2102 RIO GRANDE BASIN--COMMUNITY SEWERAGE SYSTEMS:

- A. No person shall cause or allow effluent from a community sewerage system to discharge to a watercourse in the Rio Grande Basin between the headwaters of Elephant Butte Reservoir and Angostura Diversion Dam as described in Subsection E of this Section if the effluent, as indicated by:
- (1) any two consecutive daily composite samples;
 - (2) more than one daily composite sample in any thirty-day period (in which less than ten (10) daily composite samples are examined);
 - (3) more than ten percent (10%) of the daily composite samples in any thirty-day period (in which ten (10) or more daily composite samples are examined); or
 - (4) a grab sample collected during flow from an intermittent or infrequent discharge does not conform to the following:
 - (a) Bio-chemical Oxygen Demand (BOD) Less than 30 mg/l
 - (b) Chemical Oxygen Demand (COD) Less than 80 mg/l
 - (c) Settleable Solids Less than 0.1 mg/l
 - (d) Fecal Coliform Bacteria Less than 500 organisms per 100 ml
 - (e) pH Between 6.6 and 8.6

20.6.2.3103 STANDARDS FOR GROUND WATER OF 10,000 mg/l TDS CONCENTRATION OR LESS:

A. Human Health Standards

(1) Numerical Standards

(a)	Antimony (Sb) (CAS 7440-36-0).....	0.006 mg/l
(b)	Arsenic (As) (CAS 7440-38-2).....	0.01 mg/l
(c)	Barium (Ba) (CAS 7440-39-3).....	2 mg/l
(d)	Beryllium (be) (CAS 7440-41-7).....	0.004 mg/l
(e)	Cadmium (Cd) (CAS 7440-43-9).....	0.005 mg/l
(f)	Chromium (Cr) (CAS 7440-47-3).....	0.05 mg/l
(g)	Cyanide (CN) (CAS 57-12-5).....	0.2 mg/l
(h)	Fluoride (F) (CAS 16984-48-8).....	1.6 mg/l
(i)	Lead (Pb) (CAS 7439-92-1).....	0.015 mg/l
(j)	Total Mercury (Hg) (CAS 7439-97-6).....	0.002 mg/l
(k)	Nitrate (NO ₃ as N) (CAS 14797-55-8).....	10.0 mg/l
(l)	Nitrite (NO ₂ as N) (CAS 10102-44-0).....	1.0 mg/l
(m)	Selenium (Se) (CAS 7782-49-2).....	0.05 mg/l
(n)	Silver (Ag) (CAS 7440-224).....	0.05 mg/l
(o)	Thallium (Tl) (CAS 7440-28-0).....	0.002 mg/l
(p)	Uranium (U) (CAS 7440-61-1).....	0.03 mg/l
(q)	Radioactivity: Combined Radium-226 (CAS 13982-63-3) and Radium-228 (CAS 15262-20-1).....	5 pCi/l
(r)	Benzene (CAS 71-43-2).....	0.005 mg/l
(s)	Polychlorinated biphenyls (PCB's) (CAS 1336-36-3).....	0.0005 mg/l
(t)	Toluene (CAS 108-88-3).....	1 mg/l
(u)	Carbon Tetrachloride (CAS 56-23-5).....	0.005 mg/l
(v)	1,2-dichloroethane (EDC) (CAS 107-06-2).....	0.005 mg/l
(w)	1,1-dichloroethylene (1,1-DCE) (CAS 75-35-4).....	0.007 mg/l
(x)	tetrachloroethylene (PCE) (CAS 127-18-4).....	0.005 mg/l
(y)	trichloroethylene (TCE) (CAS 79-01-6).....	0.005 mg/l
(z)	ethylbenzene (CAS 100-41-4).....	0.7 mg/l
(aa)	total xylenes (CAS 1330-20-7).....	0.62 mg/l
(bb)	methylene chloride (CAS 75-09-2).....	0.005 mg/l
(cc)	chloroform (CAS 67-66-3).....	0.1 mg/l
(dd)	1,1-dichloroethane (CAS 75-34-3).....	0.025 mg/l
(ee)	ethylene dibromide (EDB) (CAS 106-93-4).....	0.00005 mg/l
(ff)	1,1,1-trichloroethane (CAS 71-55-6).....	0.2 mg/l
(gg)	1,1,2-trichloroethane (CAS 79-00-5).....	0.005 mg/l
(hh)	1,1,2,2-tetrachloroethane (CAS 79-34-5).....	0.01 mg/l
(ii)	vinyl chloride (CAS 75-01-4).....	0.002 mg/l
(jj)	PAHs: total naphthalene (CAS 91-20-3) plus monomethylnaphthalenes ...	0.03 mg/l
(kk)	benzo-a-pyrene (CAS 50-32-8).....	0.0002 mg/l
(ll)	cis-1,2-dichloroethene (CAS 156-59-2).....	0.07 mg/l
(mm)	trans-1,2-dichloroethene (CAS 156-60-5).....	0.1 mg/l
(nn)	1,2-dichloropropane (PDC) (CAS 78-87-5).....	0.005 mg/l
(oo)	styrene (CAS 100-42-5).....	0.1 mg/l
(pp)	1,2-dichlorobenzene (CAS 95-50-1).....	0.6 mg/l
(qq)	1,4-dichlorobenzene (CAS 106-46-7).....	0.075 mg/l
(rr)	1,2,4-trichlorobenzene (CAS 120-82-1).....	0.07 mg/l
(ss)	pentachlorophenol (CAS 87-86-5).....	0.001 mg/l

(tt) atrazine (CAS 1912-24-9).....0.003 mg/l

(2) **Standards for Toxic Pollutants.** A toxic pollutant shall not be

B. Other Standards for Domestic Water Supply

(1) Chloride (Cl) (CAS 16887-00-6).....250.0 mg/l

(2) Copper (Cu) (CAS 7440-50-8).....1.0 mg/l

(3) Iron (Fe) (CAS 7439-89-6).....1.0 mg/l

(4) Manganese (Mn) (CAS 7439-96-5).....0.2 mg/l

(5) Phenols0.005 mg/l

(6) Sulfate (SO₄) (CAS 14808-79-8).....600.0 mg/l

(7) Total Dissolved Solids (TDS) TDS.....1000.0 mg/l

(8) Zinc (Zn) (CAS 7440-66-6).....10.0 mg/l

(9) pH.....between 6 and 9

(10) Methyl tertiary-butyl ether (MTBE) (CAS 1634-04-4).....0.1 mg/l

C. Standards for Irrigation Use - Ground water shall meet the standards of Subsection A, B, and C of this section unless otherwise provided.

(1) Aluminum (Al) (CAS 7429-90-5).....5.0 mg/l

(2) Boron (B) (CAS 7440-42-8).....0.75 mg/l

(3) Cobalt (Co) (CAS 7440-48-4).....0.05 mg/l

(4) Molybdenum (Mo) (CAS 7439-98-7).....1.0 mg/l

(5) Nickel (Ni) (CAS 7440-02-0).....0.2 mg/l

Key Sections of NM Water Regulations

20.6.2.2001 PROCEDURES FOR CERTIFICATION OF FEDERAL NATIONAL POLLUTANT DISCHARGE ELIMINATION SYSTEM (NPDES) PERMITS:

20.6.2.2002 PROCEDURES FOR CERTIFICATION OF FEDERAL PERMITS FOR DISCHARGE OF DREDGED OR FILL MATERIAL:

20.6.2.3107 MONITORING, REPORTING, AND OTHER REQUIREMENTS

20.6.2.3108 PUBLIC NOTICE AND PARTICIPATION:

20.6.2.3109 SECRETARY APPROVAL, DISAPPROVAL, MODIFICATION OR TERMINATION OF DISCHARGE PERMITS, AND REQUIREMENT FOR ABATEMENT PLANS:

<http://164.64.110.134/parts/title20/20.006.0002.html> (This link applies to the NM regs above.)

Landfarming with produced water in Texas

The Texas Railroad Commission authorizes landfarming of the following oil and gas wastes without a permit by Statewide Rule 8(d)(3), provided the wastes are disposed of on the same oil or gas lease where they are generated, and provided written consent of the surface owner of the tract where the landfarming will occur is obtained:

- water base drilling fluids with a chloride concentration of 3000 mg/l or less;
- drill cuttings,
- sands and silts obtained while using water base drilling fluids with a chloride concentration of 3000 mg/l or less; and
- wash water used for cleaning drill pipe and other equipment at the well site.

Other landfarming operations require a permit. Any facility land-applying oil-based drilling fluids and associated cuttings will require a permit. Texas RRC on landfarming

Ground Water Protection Council’s Produced Water Report

The Ground Water Protection Council (GWPC) report on Produced Water was published in June, 2019. Module 1 covers regulations on produced water. Module 2 is a deep dive into reuse within oil and gas operations. Module 3 examines current and future reuse of produced water outside oil and gas operations. Module 3 sites how potential options for the treatment and reuse of produced water outside the oil and gas industry can be sorted into three primary categories: land application (e.g., irrigation, roadspreading), introduction to water bodies (e.g., discharges to surface water, injection or infiltration to ground water) and other industrial uses (e.g., industrial feed streams, product or mineral mining). Some options, such as surface water discharge, are active in limited circumstances today. Others, such as utilizing treated produced water in other industrial systems, are under investigation or theoretical.

The GWPC reports drivers for considering produced water reuse differ for industry and other stakeholders. States and regulators may be driven to investigate reuse for reasons ranging from drought and groundwater depletion to disposal-related induced seismicity. For the oil and gas industry, operational and economic considerations, such as a reduction in nearby cost-effective disposal capacity, may drive a search for produced water management alternatives including reuse.

Module 3 emphasizes a “fit-for purpose” treatment approach for the majority of anticipated reuse scenarios. Produced water quantity and quality is not uniform, and neither are the circumstances of its potential treatment and reuse. Under a “fit-for-purpose” mindset, research, treatment decisions, risk management strategies, and in some cases even approval processes should be tailored to address a particular produced water for a particular type of reuse. Not all reuse scenarios will require the same analysis or approach.

The report suggests that treatment can take many forms, and the particular treatment utilized will depend on the desired quality needed to support the intended end use. Designing an appropriate treatment train will play a vital role in reducing potential risks to health and the environment. Treatment of produced water for reuse objectives that demand consistent high quality can present unique challenges such as managing variability; significantly reducing high total dissolved solid levels, difficult-to-treat organic constituents, and naturally occurring radioactive material; and handling residuals.

The GWPC report also advocates risk-based decision-making in assessing and reducing risks. The report also includes an extensive literature review.

Table 3-1: Pennsylvania WMGR123 Appendix A: Maximum Concentrations – Derived from Drinking Water Standards, Water Quality Standards for Rivers and Streams, and Typical Values Observed in Fresh Water Rivers and Streams (reformatted)

Constituent	Limit	Constituent	Limit
Aluminum	0.2 mg/L	Manganese	0.2 mg/L
Ammonia	2 mg/L	MBAS (Surfactants)	0.5 mg/L
Arsenic	10 µg/L	Methanol	3.5 mg/L
Barium	2 mg/L	Molybdenum	0.21 mg/L
Benzene	0.12 µg/L	Nickel	30 µg/L
Beryllium	4 µg/L	Nitrite-Nitrate Nitrogen	2 mg/L
Boron	1.6 mg/L	Oil & Grease	ND
Bromide	0.1 mg/L	pH	6.5-8.5 SU
Butoxyethanol	0.7 mg/L	Radium-226 + -228	5 pCi/L (combined)
Cadmium	0.16 µg/L	Selenium	4.6 µg/L
Chloride	25 mg/L	Silver	1.2 µg/L
COD	15 mg/L	Sodium	25 mg/L
Chromium	10 µg/L	Strontium	4.2 mg/L
Copper	5 µg/L	Sulfate	25 mg/L
Ethylene Glycol	13 µg/L	Toluene	0.33 mg/L
Gross Alpha	15 pCi/L	TDS	500 mg/L
Gross Beta	1,000 pCi/L	TSS	45 mg/L
Iron	0.3 mg/L	Uranium	30 µg/L
Lead	1.3 µg/L	Zinc	65 µg/L
Magnesium	10 mg/L		

The table above is from the GWPC report on page 122 and shows Pennsylvania’s water quality standard for rivers and streams.

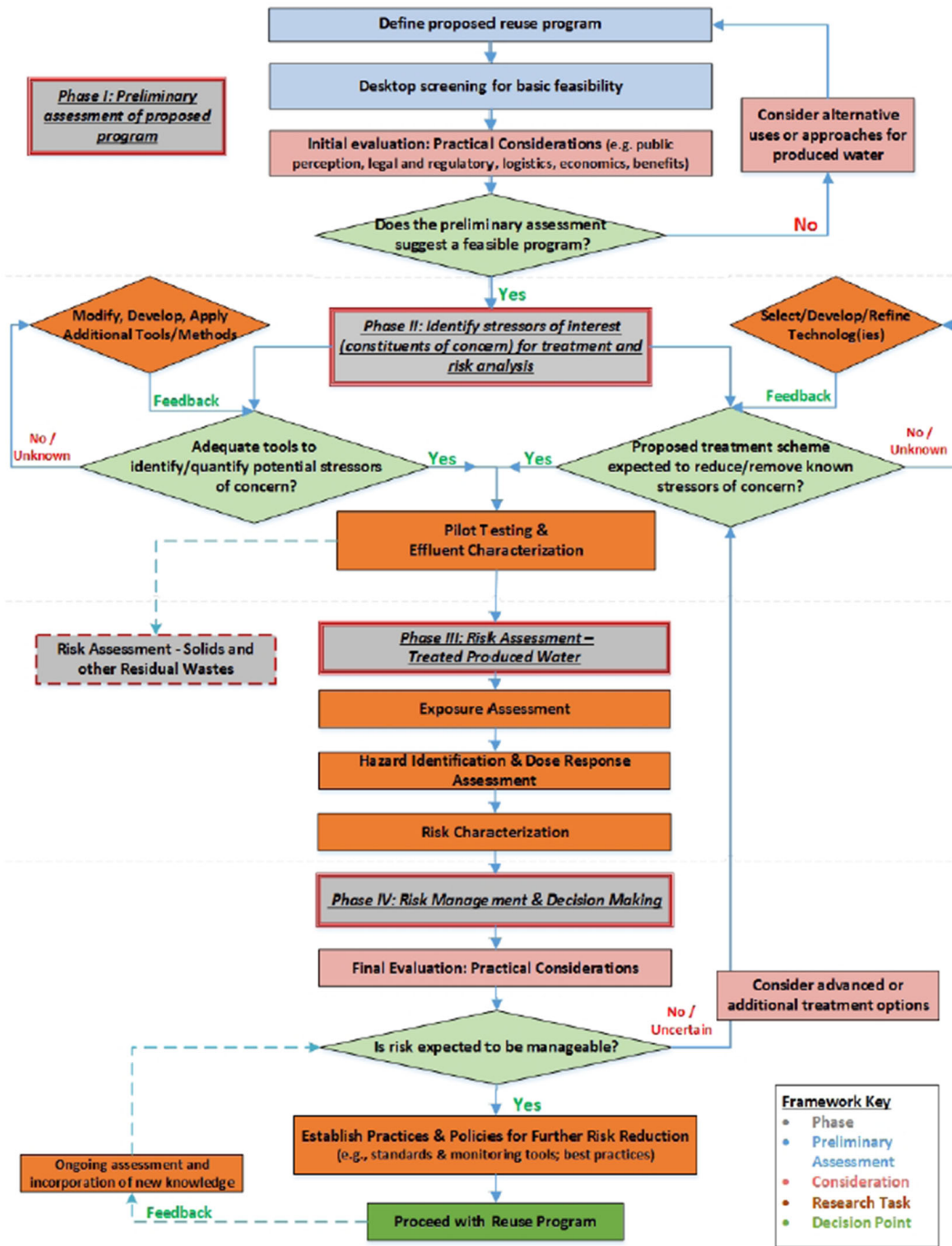


Figure 3-9: Framework for Research, Evaluation and Decision-Making

The diagram above is the summary of the GWPC’s framework for research, evaluation and decision-making, from page 129.

California’s Use of Produced Water on Crops

For decades, California has approved the use of reclaimed produced water from certain oil and natural gas field as a best practice to augment irrigation water supplies. A 2016 report from the California Water Boards Central Valley Regional

Water Quality Control Board Food Safety Expert Panel presents the results of a human health risk assessment performed to establish risk-based comparison (RBC) levels of chemicals of interest (COIs) in irrigation water containing reclaimed produced water. These RBC levels are intended for use as benchmarks for rapidly assessing the acceptability and suitability of reclaimed produced water from oil and natural gas fields for blending and use in agricultural irrigation.

The California Water Board derived the recommended RBC levels for blended irrigation water using the most stringent target risk thresholds applied by the United States Environmental Protection Agency (USEPA) and the State of California. The levels are based on a theoretical upper-bound incremental cancer risk of one in one million, which is 100 times lower than the upper end of the acceptable risk range applied by the USEPA and other agencies, and an acceptable daily intake for theoretical non-cancer effects. The levels were developed specifically for irrigation water for six primary crops grown in the central California district: almonds, pistachios, citrus, grapes, potatoes and carrots. The report states that because of a multitude of conservative assumptions in the process, the recommended RBC levels are likely to be more restrictive (lower) than the actual threshold limits that would be protective of crop consumers.

Recommended Irrigation Water Risk-Based Comparison (RBC) Levels (mg/L)

Inorganics		Organics	
Arsenic	0.1	Acetone	20,000
Barium	2,000	Benzene	0.7
Boron	70	Ethylbenzene	6
Cadmium	70	Ethylene Glycol	5,000
Chromium (VI)	0.4	Methylene Chloride	2
Fluoride	700	Naphthalene	200
Mercury	20	PAHs	0.02
Thallium	10	Toluene	500
Zinc	2,000	Total Petroleum Hydrocarbons	200
		Trimethylbenzene	200
		Xylenes	1,000

mg/L = Milligrams per liter

https://www.waterboards.ca.gov/centralvalley/water.../erm_riskassrpt.pdf

The California Regional Water Quality Control Board, Central Valley Region, Order. R5-2012-0058 contains an oil and grease limit for Chevron discharges to Cawelo’s Reservoir B. of 35 milligrams per liter (mg/L). Analysis in a 2016 report indicated that the historical oil and grease data that has been collected and reported to the Water Board revealed that the maximum recorded concentration of oil and grease in the water was 29 mg/L. This water has been used for blending and irrigation. The report provided details of the organics in the table below:

Table 1. Analytical Results Summary, Volatile Organic Compounds, Semivolatile Organic Compounds, and Total Petroleum Hydrocarbons

Well/Sample ID	Sample ID	Volatile Organic Compounds ¹ (ug/L)							Polycyclic Aromatic Hydrocarbons ² (ug/L)						TPH ³ (mg/L)	
		Acetone	Benzene	Ethylbenzene	m,p-Xylene	o-Xylene	Toluene	Total Xylenes	Acenaphthene	Acenaphthylene	Chrysene	Fluorene	Naphthalene	Phenanthrene		Pyrene
Plant 36	W039	31	0.47 J	0.71	2.6	1.3	0.67	3.9	0.63	<0.098	<0.098	0.37	0.11 J	0.38	<0.098	0.12
Polish Pond	W042	86	0.33 J	0.39 J	1.3	0.74	0.49 J	2.0	0.53	<0.097	<0.097	0.29	0.11 J	0.27	<0.097	0.19
Polish Pond	W043 ⁴	100	0.31 J	0.38 J	1.2	0.59	0.47 J	1.8	0.57	<0.097	<0.097	0.35	0.12 J	0.28	<0.097	0.097
Reservoir B	W044	150	<0.25	0.25 J	0.75 J	0.43 J	0.39 J	1.2	0.49	<0.097	<0.097	0.50	<0.097	0.29	<0.097	0.15
Reservoir B Outflow	W045	50	<0.25	<0.25	<0.50	<0.25	<0.25	<0.50	<0.096	<0.096	<0.096	<0.096	<0.096	<0.096	<0.096	0.080

- Notes:
1. Volatile organic compounds analyzed using U.S. EPA Method 8260B.
 2. Polycyclic aromatic hydrocarbons analyzed using U.S. EPA Method 8270C SIM.
 3. Total Petroleum Hydrocarbons (TPH: carbon range C29-C40) analyzed using U.S. EPA Method 8015B.
 4. Duplicate sample of W042.

Abbreviations:
 < = less than the Reporting Limit.
 J = result is less than the RL but greater than or equal to the MDL and the concentration is an approximate value
 TPH = total petroleum hydrocarbons
 ug/L = micrograms per liter

The report

conclusions included this table breakout box:

Irrigation water provided by the District:

- Contained traces of organic chemicals at concentrations that are at or below drinking water quality standards
- Does not pose a health threat to fruit trees
- Does not pose a health threat to consumers of agricultural products
- Is safe for irrigation of fruit trees

[-https://www.waterboards.ca.gov/rwqcb5/water_issues/oil_fields/food_safety/data/studies/cawelo_irrstudy.pdf](https://www.waterboards.ca.gov/rwqcb5/water_issues/oil_fields/food_safety/data/studies/cawelo_irrstudy.pdf)

A total of 1,242 groundwater samples in the Cawelo GSA have TDS analyses. The majority (63%) of the samples have TDS concentrations less than 500 mg/L, 29% of samples are between 500 and 1,000 mg/L and 8% of samples are greater than 1,000 mg/L (Table 3-3). The TDS concentrations in groundwater of the Cawelo GSA generally meet drinking water quality standards and irrigation requirements. This low level of TDS is highly unusual for oil and gas formations. Because of the low TDS, the produced water only requires oil separation to meet the state criteria.

[Chevron California produced water 2019 report](#)

https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=6&ved=2ahUKEwidpMmxhdfoAhVIKKwKHbToCtwQFjAFegQIBhAB&url=https%3A%2F%2Fwww.cawelord.org%2Fwp-content%2Fuploads%2F2019%2F08%2Fadmin-draft-text_cawelo_gsp_aug12-2019.pdf&usq=AOvVaw2yPdctfOFwN6KcZD8S9DVV

Recent article on Kern County California PW use [California PW use](#)

Agricultural Reuse of Produced Water in California. California produced approximately 175 million barrels of oil onshore in 2016, along with nearly 2.73 billion barrels of produced water.* Interest in produced water reuse has grown due in large part to the ongoing drought. Reusing produced water in irrigation, which has occurred in eastern Kern County for over three decades, has expanded in recent years.** Produced water here contains low concentrations of total dissolved solids and boron, making reuse more feasible than in areas with higher salinity.

Concern over produced water reuse for agricultural irrigation has arisen in recent years and prompted the Central Valley Regional Water Quality Control Board (Central Valley Water Board) to develop a Food Safety Expert Panel (Panel). The Panel's purpose is to guide sample collection and analytical methods for field studies, assess results, identify data gaps, and procure practical outcomes regarding produced water management. The Central Valley Water Board will consider the Panel's recommendations to regulate produced water reuse. Panel meetings are typically held quarterly and are open to the public. The meetings are attended by industry and environmental stakeholders as well as regulators.

In the three years since the Panel's inception, multiple crop sampling events and an irrigation water quality evaluation were conducted in vicinity of the Cawelo Water District, where produced water is currently reused to irrigate crops under a permit issued by the Central Valley Water Board. The Central Valley Water Board has also received chemical disclosures from operators and suppliers through informational orders (California Code § 13267). These disclosures are available to the public on the Central Valley Water Board's website[†] and are being evaluated and incorporated into future sampling efforts. The oilfield chemical additives evaluation is ongoing since several chemicals do not have standardized sampling methods, making water monitoring and crop plant uptake quantification difficult. However, community representatives and Panel members share an interest in evaluating and quantifying chemical additives when feasible and conducting health risk evaluations before the Panel provides its final recommendations.

* Department of Conservation, Division of Oil, Gas, & Geothermal Resources. 2017. 2016 Report of California Oil and Gas Production Statistics. ftp://ftp.consrv.ca.gov/pub/oil/annual_reports/2016/2016_Annual_Report_Final_Corrected2.pdf.

** Food Safety – Oil Field Wastewater Reuse Expert Panel. 2017. Project Charter. https://www.waterboards.ca.gov/centralvalley/water_issues/oil_fields/food_safety/information/offsep_charter.pdf.

[†] Central Valley Regional Water Quality Control Board. 2018. Oil Field – Food Safety. https://www.waterboards.ca.gov/centralvalley/water_issues/oil_fields/food_safety/index.html.

The California PW summary above is from the GWPC report, page 157.

Southwest Energy received an NPDES permit to discharge water from its Arkansas field. The discharge limits were part of a case study in the GWPC report on page 187 and shown below.

Such discharges shall be limited and monitored by the permittee as specified below:

Effluent Characteristics	Discharge Limitations				Monitoring Requirements	
	Mass (lbs/day, unless otherwise specified)		Concentration (mg/l, unless otherwise specified)		Frequency	Sample Type
	Monthly Avg.	Daily Max.	Monthly Avg.	Daily Max.		
Flow	N/A	N/A	Report, MGD	Report, MGD	daily	totalizing meter
Carbonaceous Biochemical Oxygen Demand (CBOD ₅)	14.0	21.0	10.0	15.0	once/month	grab
Total Suspended Solids (TSS)	21.0	31.5	15.0	22.5	once/month	grab
Ammonia Nitrogen (NH ₃ -N)						
(April)	7.8	7.8	5.6	5.6	daily	grab
May-Oct)	7.0	10.5	5.0	7.5	daily	grab
(Nov-March)	14.0	21.0	10.0	15.0	daily	grab
Dissolved Oxygen (DO)	N/A	N/A	2.0 (Inst.Min.)		daily	grab
Chlorides	131.7	197.6	94	141.0	daily	composite
Sulfates	28.0	42.0	20.0	30.0	daily	composite
Total Dissolved Solids (TDS)	496.0	744.0	354.0	531.0	daily	composite
Oil and Grease (O&G)	14.0	21.0	10.0	15.0	daily	grab
Arsenic, Total Recoverable (Ar)	1.9	4.1	1.33	2.95	once/month	composite
Cadmium, Total Recoverable (Cd)						
(May-Oct)	0.0026	0.0052	1.8 µg/l	3.7 µg/l	once/month	composite

Effluent Characteristics	Discharge Limitations				Monitoring Requirements	
	Mass (lbs/day, unless otherwise specified)		Concentration (mg/l, unless otherwise specified)		Frequency	Sample Type
	Monthly Avg.	Daily Max.	Monthly Avg.	Daily Max.		
(Nov-April)	0.0075	0.015	5.4 µg/l	10.8 µg/l	once/month	composite
Chromium III, Total Recoverable (Cr3)						
(May-Oct)	0.41	0.83	295.4 µg/l	592.8 µg/l	once/month	composite
(Nov-April)	1.2	2.4	860.1 µg/l	1725.7 µg/l	once/month	composite
Chromium (VI) (Cr6)						
(May-Oct)	0.017	0.033	11.8 µg/l	23.7 µg/l	once/month	composite
(Nov-April)	0.038	0.076	26.9 µg/l	54.1 µg/l	once/month	composite
Chromium, Total Recoverable (Cr)	0.45	1.05	323 µg/l	746 µg/l	once/month	composite
Cobalt, Total Recoverable (Cu)	26.3	79.0	18.8 µg/l	56.4 µg/l	once/month	composite
Copper, Total Recoverable (Hg)						
(May-Oct)	0.013	0.026	9.2 µg/l	18.5 µg/l	once/month	composite
(Nov-April)	0.026	0.053	18.8 µg/l	37.8 µg/l	once/month	composite
Lead, Total Recoverable (Pb)						
(May-Oct)	0.0038	0.0076	2.7 µg/l	5.4 µg/l	once/month	composite
(Nov-April)	0.011	0.022	7.9 µg/l	15.8 µg/l	once/month	composite
Mercury, Total Recoverable (Hg)						
(May-Oct)	0.000019	0.000038	0.013 µg/l	0.027 µg/l	once/month	composite
(Nov-April)	0.000055	0.00011	0.039 µg/l	0.078 µg/l	once/month	composite
Nickel, Total Recoverable (Ni)						
(May-Oct)	0.14	0.27	97.0 µg/l	194.6 µg/l	once/month	composite
(Nov-April)	0.40	0.79	282.3 µg/l	566.4 µg/l	once/month	composite

Table 1-A-1 Effluent Limitations and Monitoring Requirements. Source: After USEPA

Effluent Characteristics	Discharge Limitations				Monitoring Requirements	
	Mass (lbs/day, unless Otherwise specified)		Concentration (mg/l, unless Otherwise specified)		Frequency	Sample Type
	Monthly Avg.	Daily Max.	Monthly Avg.	Daily Max.		
Silver, Total Recoverable (Ag)						
(May-Oct)	0.0013	0.0026	0.93 µg/l	1.87 µg/l	once/month	composite
(Nov-April)	0.0025	0.0051	1.8 µg/l	3.6 µg/l	once/month	composite
Tin, Total Recoverable (Sn)	0.23	0.47	165.0 µg/l	335.0 µg/l	once/month	composite
Zinc, Total Recoverable (Zn)						
(May-Oct)	0.12	0.24	85.5 µg/l	171.6 µg/l	once/month	composite
(Nov-April)	0.23	0.47	166.0 µg/l	333.2 µg/l	once/month	composite
Cyanide, Total Recoverable (CN)					once/month	composite
(May-Oct)	0.008	1.016	5.8 µg/l	11.6 µg/l	once/month	composite
(Nov-April)	0.024	0.047	16.9 µg/l	33.9 µg/l	once/month	composite

Effluent Characteristics	Discharge Limitations				Monitoring Requirements	
	Mass (lbs/day, unless Otherwise specified)		Concentration (mg/l, unless Otherwise specified)		Frequency	Sample Type
	Monthly Avg.	Daily Max.	Monthly Avg.	Daily Max.		
Bis (2-ethylhexyl) phthalate	0.14	0.30	0.101	0.215	once/month	composite
Butylbenzyl phthalate	0.12	0.26	0.0887	0.188	once/month	composite
Carbazole	0.39	0.84	0.276	0.598	once/month	composite
n-Decane	0.61	1.33	0.437	0.948	once/month	composite
Fluoranthene	0.038	0.075	0.0268	0.0537	once/month	composite
n-Octadecane	0.42	0.83	0.302	0.589	once/month	composite
Radium-226 (dissolved)	N/A	N/A	Report pCi/l ¹	Report pCi/l ¹	once/quarter	grab
Strontium-90 (dissolved)	N/A	N/A	Report pCi/l ¹	Report pCi/l ¹	once/quarter	grab
Beta radiation (gross)	N/A	N/A	Report pCi/l ¹	Report pCi/l ¹	once/quarter	grab
pH	N/A	N/A	Minimum 6.0 s.u.	Maximum 9.0 s.u.	daily	grab
Chronic WET Testing ²	N/A	N/A	Report			
Pimephales promelas (Chronic) Pass/Fail Lethality (7-day NOEC) TLP6C Pass/Fail Growth (7-day NOEC) TGP6C Survival (7-day NOEC) TOP6C Coefficient of Variation (Growth) TQP6C Growth (7-day NOEC) TPP6C			7-Day Average Report (Pass=0/Fail=1) Report (Pass=0/Fail=1) Report % Report % Report %		bi-monthly bi-monthly bi-monthly bi-monthly	24-hr composite
Ceriodaphnia dubia (Chronic) Pass/Fail Lethality (7-day NOEC) TLP3B Pass/Fail Reproduction (7-day NOEC) TGP3B Survival (7-day NOEC) TOP3B Coefficient of Variation (reproduction) TQP3B Reproduction (7-day NOEC) TPP3B			7-Day Average Report (Pass=0/Fail=1) Report (Pass=0/Fail=1) Report % Report % Report %		bi-monthly bi-monthly bi-monthly bi-monthly	24-hr composite

¹ picoCuries/liter

² See Condition No. 5 of Part II (WET Testing Requirement). There shall be no discharge of distinctly visible solids, scum, or foam of a persistent nature, nor shall there be any formation of slime, bottom deposits, or sludge banks. There shall be no visible sheen as defined in Part IV of this permit. Samples and measurements taken as required herein shall be representative of the volume and nature of the monitored discharge during the entire monitoring period. Samples shall be taken after final treatment at the outfall.

Table 1-A-1 Continued- Effluent Limitations and Monitoring Requirements. Source: After USEPA

The Southwestern Energy flow diagram is below.