PRODUCED WATER SOCIETY
PERMIAN BASIN 2023

Permian Basin Produced Water Quality Drivers for Treatment and Reuse

Produced Water Society – Permian Basin Summit 2023
Midland – August 14-16, 2023

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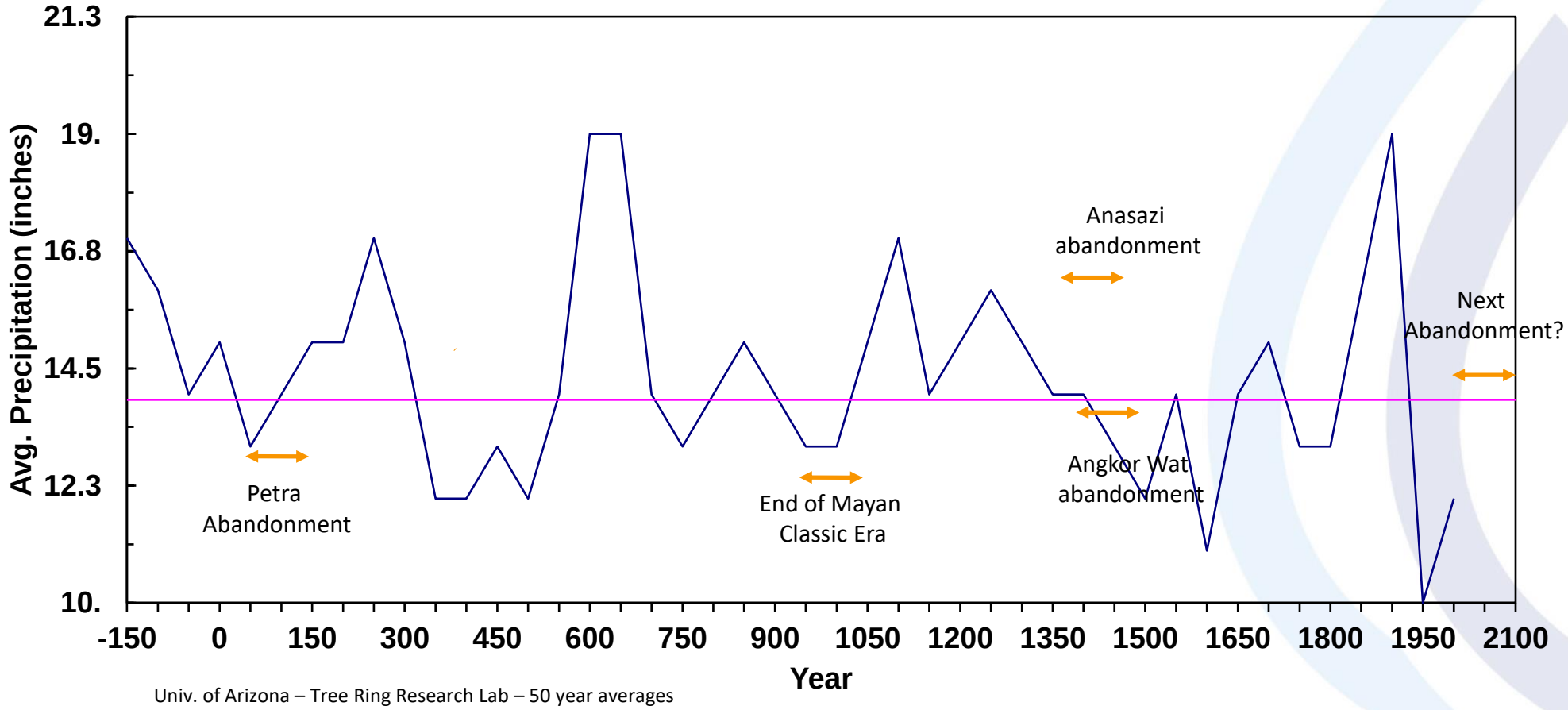
NM STATE NEW MEXICO PRODUCED WATER RESEARCH CONSORTIUM

Southwest Climate History Based on Tree Ring Data



Univ. of Arizona – Tree Ring Research Lab – 50 year averages

The southern U.S. and the mid-latitudes are in the 100th year of a 300 year arid cycle - which in the past has led to stress of civilizations

NM PW Research Consortium Objectives

2019 NM Produced Water Act – encourages produced water treatment and reuse to:

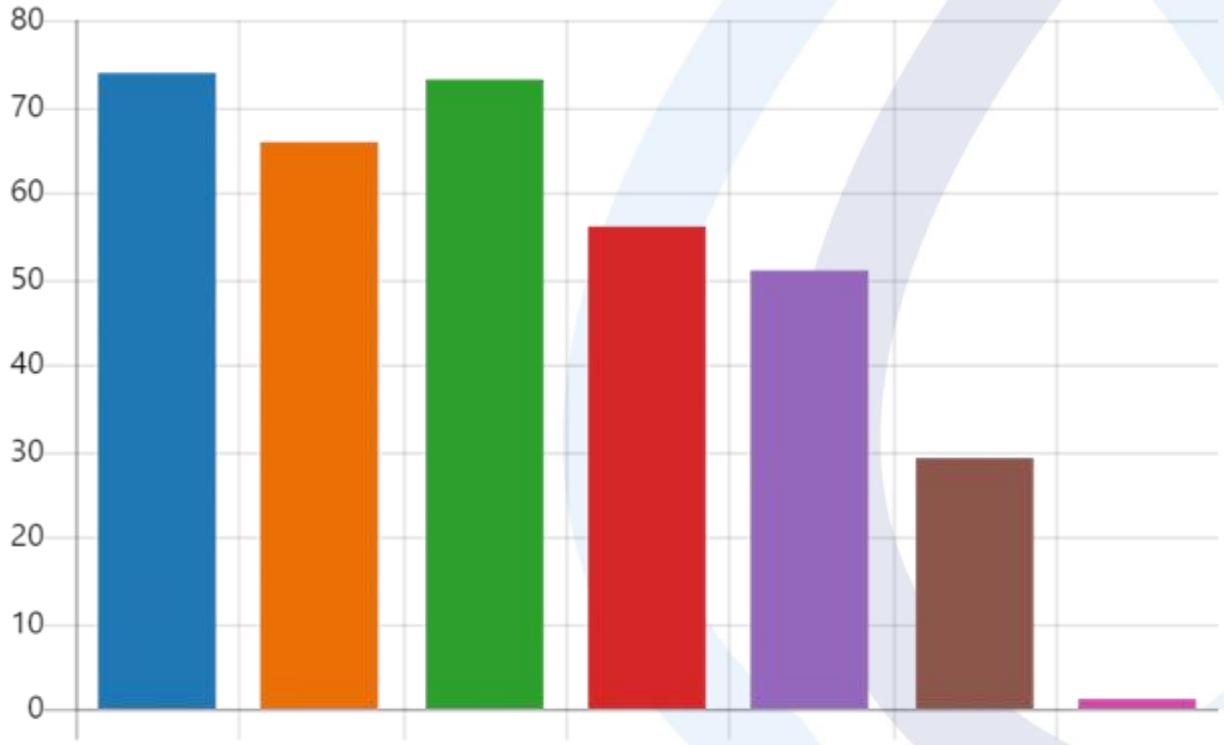
- Reduce/eliminate fresh water use in oil and gas sector (OSE-OCD-industry)
- Create new water supplies for the state (OSE)
- Provide new water for economic development (EDD-industry-communities)
- Assure cost-effective treatment and public and environmental safety (NMED-EPA-BLM-SLO-OCD-NGOs)

Consortium – a group that shares a common lot (goals, objectives, timeframe – in harmony)

Water Stewardship in Transboundary Basins

Significant NM Public Support for Better Fresh Water Stewardship by Produced Water Reuse

- Use inside oil and gas
- Industrial use outside oil and gas
- Ag uses (non-food crops)
- Multiple ag uses (food crops)
- Supplement drinking water
- Need more info
- Do not support any use



(NMPRC Public Surveys - 5 venues to date – 6 more venues by fall 2023)

Relative Permian Water Quality and Treatment Needs

Raw Municipal Waste Water

~60 major constituents

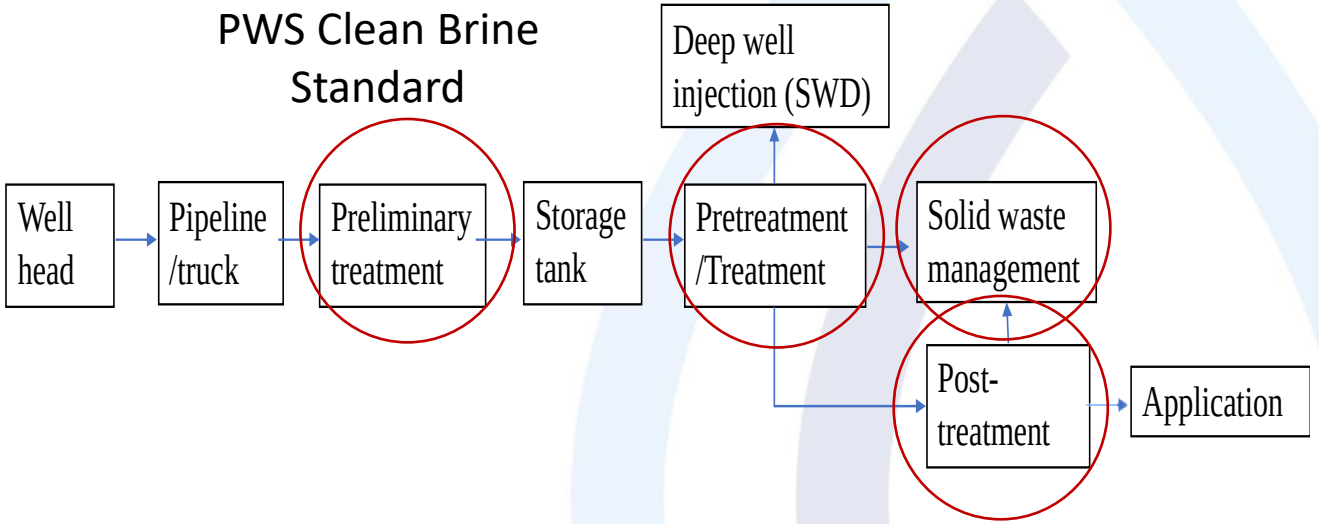
Raw Pecos River Water

~70 major constituents

Permian Raw Produced Water

~90 major constituents

(Based on analyzing for ~300 constituents)



- Integrated pre-treatment, treatment, post-treatment likely required for most Permian PW applications (organics, iron, high TDS)
- Mineral recovery interest growing significantly

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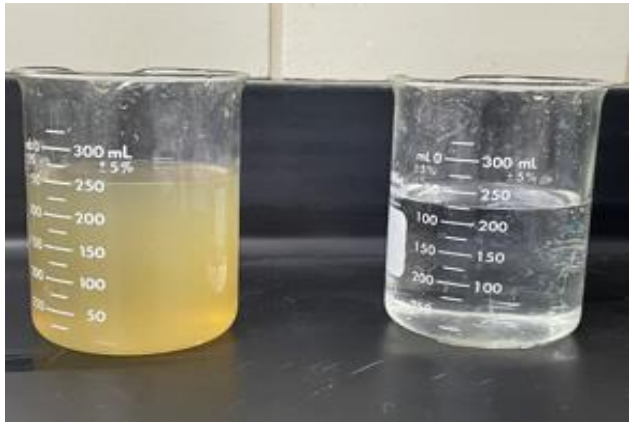
Permian Basin Produced Water Quality Driving Treatment and Reuse

Based on 46 PW samples from Delaware and Midland Basins

		Mean	Max	Min	25th percentile	50th percentile	75th percentile
Alkalinity	mg/L as $CaCO_3$	272	870	100	128	207	336
Ammonia	mg/L	432	750	320	330	400	495
COD	mg/L	1,626	3,100	930	1,250	1,400	1,950
pH	SU	6.6	8.1	3.9	6.3	6.7	7.0
TDS	mg/L	128,641	201,474	100,830	113,441	122,280	134,525
TOC	mg/L	103.5	248.1	2.4	28	90.6	173.3
TSS	mg/L	342.9	790	85	142.5	375	422.5
Turbidity	NTU	116.4	200	23	36	110	200
MBAS	mg/L	1.10	2.1	0.047	0.92	0.97	1.33

Highlighted values show constituents that drive pre, post and treatment processes of produced water for safe and cost-effective reuse

Results of Permian 'Clean Brine' pre-treatment Testing



Parameter	Value	Results
Salinity	Reported	n/A
pH	6.0-8.0	Passed (ozone only)
Oxidation Reduction Potential (ORP)	>350 mV	Passed (ozone only)
Turbidity	<25 NTU	Passed (ozone + filtration)
H_2S	Non-Detectable	Passed (ozone only)
Particle Size	< 25 micron	Passed (ozone + filtration)
Total Iron	<10ppm	Passed (ozone + filtration)
Ferrous Iron	< 5ppm	Passed (ozone only)
ATP	<200 pg/ml	Passed (ozone only)

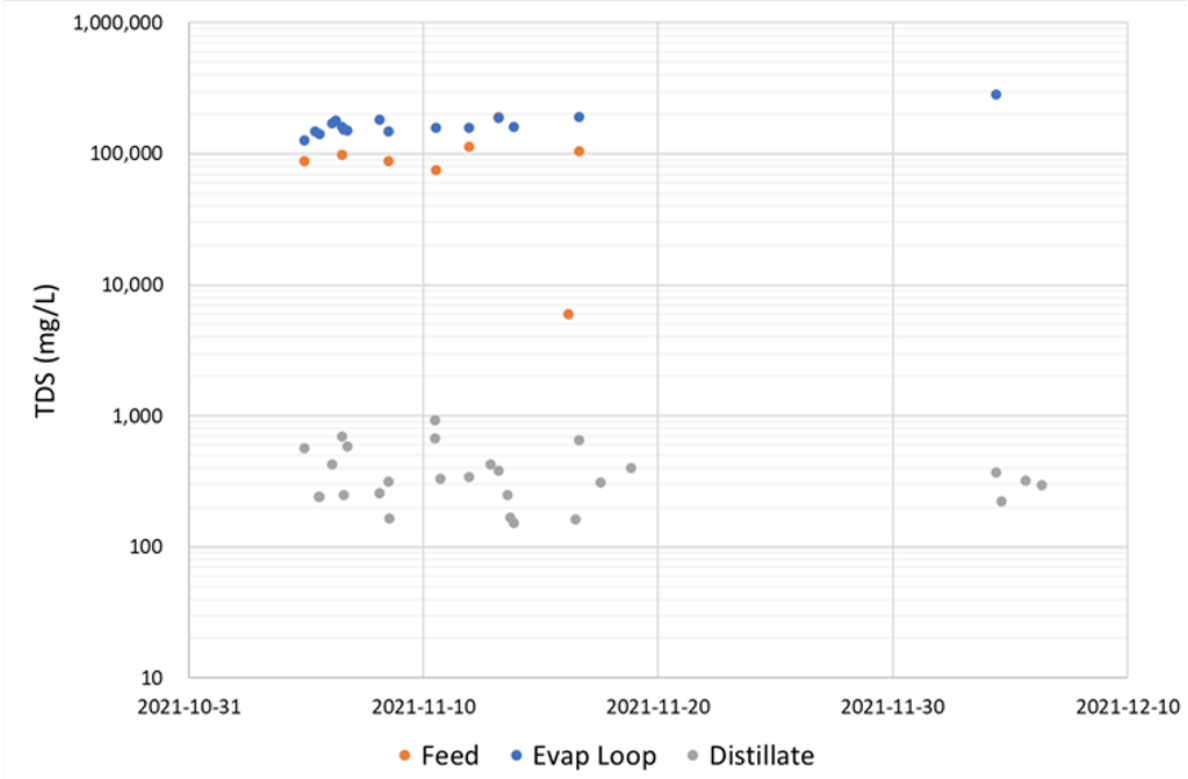
Permian Basin -100,000 TDS PW (left) w/membrane pre-treatment to remove TOC, TSS (right)

Permian Basin -100,000 TDS PW (left) w/membrane pre-treatment and concentrate (right)

Permian Basin -100,000 TDS PW with ozone/filtration pre-treatment

PWS 'Clean Brine' pretreatment cost < $0.20/bbl target
Creates a high quality water for desalination

Thermal Treatment w/o Pretreatment for Organics but w/ Post Treatment for Organics

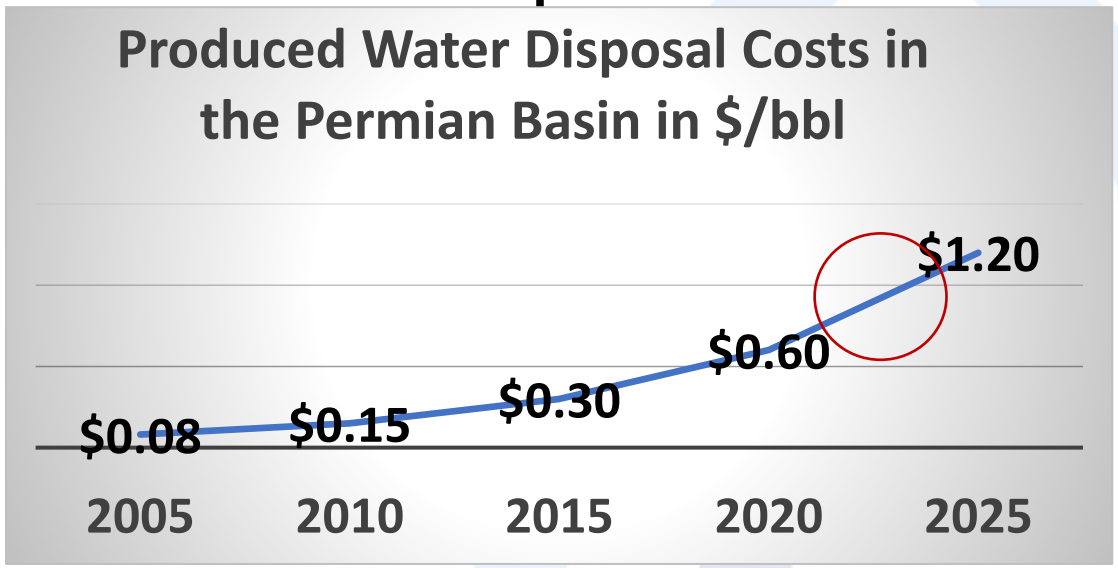


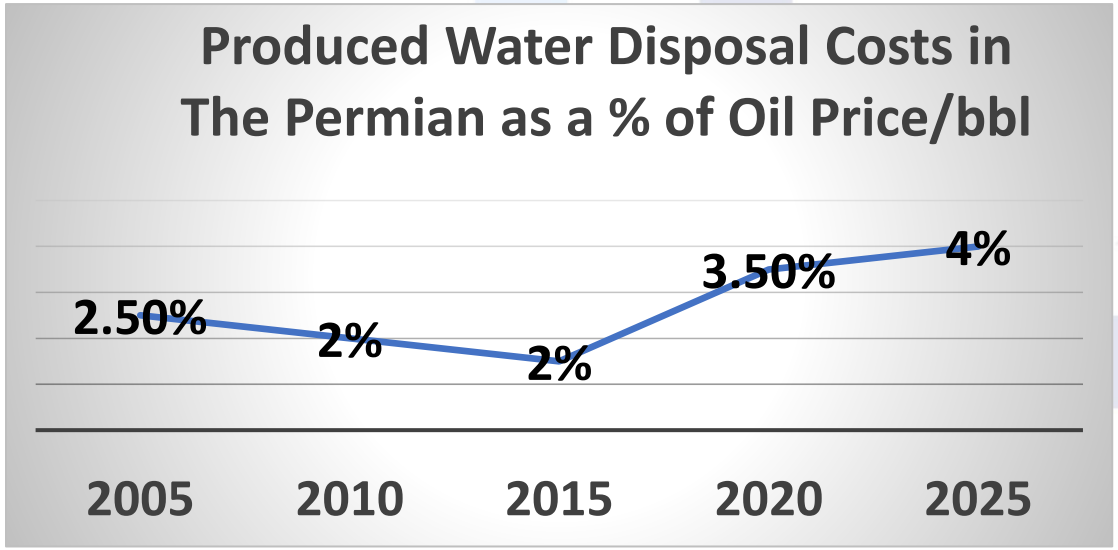
Parameters (mg/L)	Distillate Pre- Carbon Filter Representative Sample	Distillate Post Carbon Filter 12/08/21
Benzene	0.501	<0.000214
Toluene	0.548	<0.000500
Ethylbenzene	0.0214	<0.000515
Xylenes	0.377	<0.000330
TPH (C6 to C12)	1.51	<0.840
TPH (>C12 to C28)	1.53	<0.819
TPH (>C28 to C35)	<0.860	<0.819
TPH (C6 to C35)	3.04	<0.840
Fluorene	<0.00163	<0.00163
Naphthalene	0.00993	<0.000542
Phenanthrene	0.00145	<0.00142
2-Nitrophenol	0.007	<0.00167
Phenol	0.026	0.000693

TDS good, but carry over of organics and ammonia required post treatment to meet TOC and Whole Effluent Toxicity requirements

Permian Produced Water Treatment Performance Trends vs Disposal

- Pre-treatment 'Clean Brine Standard'
  - Several technologies showing good performance at <$0.20/bbl
  - Likely needed to provide high quality feed for treatment systems
- Treatment
  - $0.20 – $0.30/bbl in San Juan Basin
  - $0.75 - $1.20/bbl in Permian Basin
- Post-treatment
  - Likely required for ammonia or organics removal depending on pre-treatment and application
  - Likely required to meet Whole Effluent Toxicity criteria requirements
  - Likely absorption process for trace constituents
- Human cell-line data
  - Post-treatment possible depending on application and pre-treatment





2023 Affiliated Permian Testing Support – TX and NM

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Company	Process	Land Discharge	Location and Dates	PW Quality	PW Volume/ Duration	Current Status
Hilcorp (1)	Membrane distillation treatment field-pilot	No - closed loop	San Juan Basin, near Bloomfield Summer 2023	40K TDS	20 bbls/day 1-2 months at a couple of sites	NMED and BLM permits, waiting on OCD approval
Kanalis Resources (2)	Small green house pilot of treated PW for pine seedlings	No - closed loop w/in green house	San Juan Basin, near Ojo Encino Chapter House SW of Cuba NM Fall 2023	10K TDS, previous bench testing shows ve	20 bbls/day for 9 months	NMED permits, OCD approval with additional info, waiting on BLM approval.
Infinity Water (3)	Pre and thermal treatment and green house study	No - closed loop w/in green house	Permian Basin , Lea/Eddy County line Summer 2023	120K TDS	200-1000 bbls	NOI to NMED in May
Hydrozonix(4)	Enhanced Evap at SWD	No - closed loop w/in existing pond	Permian Basin near Carlsbad, Summer 2023	120K		NOI to NMED and OCD in May
Apatech /5-e Water (5)	Produced water treatment	Yes - at OCD permitted sites	Permian Basin Roswell/ Artesia Area Second half 2023	Abandoned wells plugging and closure	200-300 bbls/day	Coordinating with OCD on NOIs and permits
Encore Green (6)	Produced water treatment	No - closed loop	Permian June and July 2023	115K TDS	2000 bbls/day	Near Midland TX
Bechtel (7)	Thermal treatment system (c	No - closed loop	Permian Basin Summer 2023	120 K TDS Permian Basin	500 bbls/day for 6 months	Near Midland TX mobilization in July 2023
Industry JIP (8,9,10)	Three pre-treatment, treatment, and post-treatment,	No - closed loop	Permian Basin Summer - Fall 2023	120K TDS	500 bbls/day	Near Midland TX
Texas Pacific Water (11)	Physical/ membrane treatment with green house	No - closed loop w/in green house	Permian Basin Late fall	100K TDS	10-20 bbls/day	In Midland TX
Sun Vapor (12)	Solar distillation Small pilot-scale	No - closed loop	Permian Fall 2023 near Hobbs/ Lovington	100K TDS	20-50 bbls/day	NMED permit, need BLM and OCD permits
Colorado School of Mines (13)	Bioreactor/membrane treatment	No - closed loop	Permian Fall 2023 near Hobbs/ Lovington	100K TDS	20-50 bbls/day	No NOIs submitted yet
Solmem (14)	Solar membrane distillation	No - closed loop	BRNDRF and Permian Near Hobbs	Up to 100K TDS	20 bbls/day	Bench-scale permit submitted to NMED
Intrepid (15)	Sustainable solution mining pre-treatment pilot-testing	No - closed loop w/in existing ponds	Permian Basin Near Carlsbad Fall/Winter 2023	170-250K TDS	50 bbls/day - focus on using 300,000 bbls per day at full-scale	

Water Quality Risk and Toxicology Analysis Challenges

Standardized Collaboration Approaches:

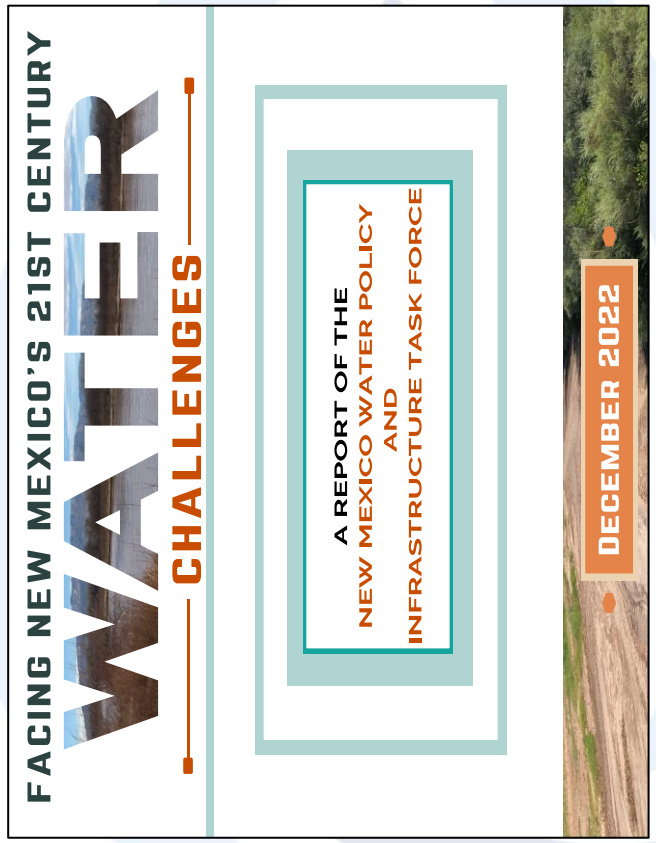
- Standardized Sampling Protocol w/USEPA
- Standardized NPDES+ Analysis (~300 analytes)
  - Certified Lab, NMSU, and USEPA
- TIC/Unknown Analysis – HR-LCMS @ NMSU
- Whole Effluent Toxicity Testing
  - Certified lab and NMSU
- Human cell-line analysis
  - USEPA and NMSU
- State of the Art - Risk and Tox Analysis
  - Predicted Env. Conc. (PEC)
  - Predicted No-effect Conc (PNEC) – supported and coordinated by ExMo and UofDE

Challenges:

- TIC/Unknown Analysis of raw PW difficult for HR-LCMS (mass balance of treated vs raw water)
- Analysis turnaround – how to improve
- NPDES+ and WET analysis over $40K for full suite analysis
- Do we need bio-assays and refugia to better assess safety?

Produced Water Reuse Moving Forward

- New Water is one of 8 policies (Dec 2022)
  - " The need to augment supply regionally, through such tools as brackish groundwater desalination, wastewater reuse, and treated or recycled produced water."
  - Policy aligns with EPA's National Water Reuse Action Plan
- NM Legislature funded $35 M in 2023 to support the characterization and use of nontraditional waters
  - $30M to the State Engineer to characterize brackish aquifers
  - $3 M for NMED to develop fit-for-purpose treatment and reuse rules.
  - Public meetings in fall 2023 for non-traditional waters, with hearings in April 2024 focused on industrial uses (non-discharge - green houses, hydrogen, cooling, etc.)



Pursuing Common Western State Treated Produced Water Discharge Standards

- Current ag standards developed by western ag research centers
  - NMSU, Utah State, Texas A&M, Colorado State, UC Davis
- Integrated treatments for Permian produced water can meet current western state fit-for-purpose discharge standards
- Working with TX on PW treatment requirements for ag, rangeland, and surface discharge considerations for limited pilot projects in the Permian Basin

Current Ag Discharge Criteria

NM - 15-20 Constituents

CO, WY, OK, CA, BofRec– 36-43 Constituents

Current Pecos River Discharge Criteria

NM – 41 aquatic impact constituents

110 - human impact constituents

Artesia quality – 2600 ppm TDS

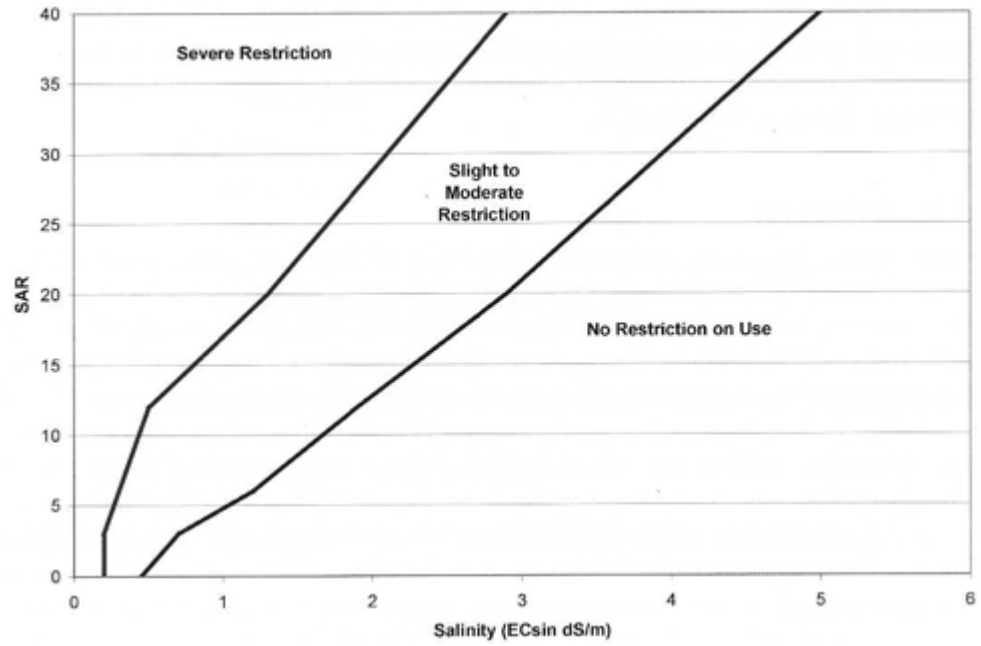
State line quality – 3600 ppm TDS

TX – 45 aquatic impact constituents

110 – human impact constituents

Red Bluff quality – 4000 ppm TDS

Ag Examples of Treated PW Quality Needs



Parameter	Units	General Treated PW Quality	Permian Treated PW Quality	Irrigation Water Class 1	Class 2	Class 3
pH		6.5-8.0	6.5 - 8.0			
Temperature	°C	20-30	20 - 35			
Turbidity	NTU	<30	<30			
Total Suspended Solids	mg/L	< 20	< 20			
Total Dissolved Solids	mg/L	200-1000	< 1,000	<700	<2000	>2000
Chlorides	mg/L	<100	< 200			
Sodium	mg/L	<100	< 200	400	800	>1000
Calcium	mg/L	-	< 200			
Magnesium	mg/L	-	< 300			
Sulfate	mg/L	-	< 150			
Nitrogen	mg/L as N	<10	10-30			
SAR		10-15	6 -10			
Total Metals	mg/L	<15	-			
Barium	mg/L	-	< 0.5			
Strontium	mg/L	-	< 0.5			
Naturally Occurring Radioactive Material (NORM)	pCi/L	<30	-			
Adjusted gross alpha	pCi/L	<15	< 15			
Radium 226+228	pCi/L	<30	< 30			
Total Petroleum Hydrocarbons	mg/L	<10	< 10			
Total Organic Carbon	mg/L	<10	< 10			
Total Ammonia	mg/L as N	<5	< 2			
Silica	mg/L	-	< 2			
Sulfide	mg/L	-	< 0.5			
Benzene	ppb	-	< 10			

Local irrigation water application criteria:

- Less sensitive crop - can be lower quality
- Greater depth to groundwater – can be lower quality
- Lower fresh groundwater quality – can be lower quality
- Sandy or alkaline soil or both - higher SAR and TDS allowed

NMPWRC Priorities on Produced Water Reuse

- OCD – Reuse of treated produced water in plugging and abandoning orphan wells
  - Treated water for cement/concentrate for 10 lb brine
  - Roswell and Artesia, $25 M in federal funding
- NMED - public meetings input in fall 2023, and WQCC hearings in April 2024
  - NMPWRC providing support and contact information
- Working with Lea County on a “produced water authority”
- DOE 2023 FOA proposals – 5 treatment proposals and one Pareto optimization proposal with three NM companies
- Cooperate/team with State of TX and TPWC on testing and standardizing risk and tox approach for produced water
- Western InterState Hydrogen Hub (WISHH) – produced water supplies, ESG, EEEJ, and social economic modeling
- Raw produced water quality collection – raw quality drives treatment, costs, and reuse application opportunities

60 YEARS Economic Development Corporation OF LEA COUNTY