2022 Technology Demonstration, Testing, and Evaluation

2022 ANNUAL UPDATE

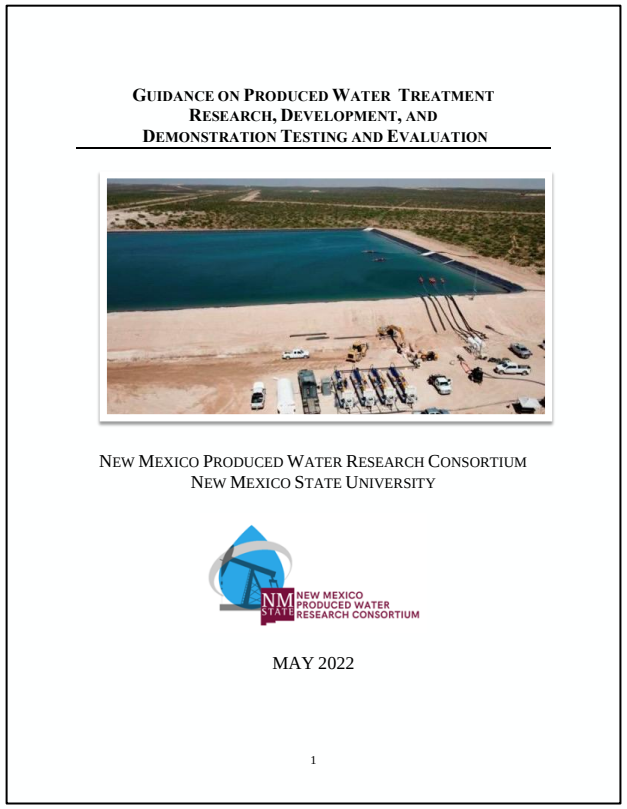
DEC 6, 2022

Mike Hightower, Director

New Mexico Produced Water Research Consortium

NM STATE NEW MEXICO PRODUCED WATER RESEARCH CONSORTIUM

Treatment System Demonstration, Testing, and Evaluation


GUIDANCE ON PRODUCED WATER TREATMENT RESEARCH, DEVELOPMENT, AND DEMONSTRATION TESTING AND EVALUATION

NEW MEXICO PRODUCED WATER RESEARCH CONSORTIUM
NEW MEXICO STATE UNIVERSITY

MAY 2022

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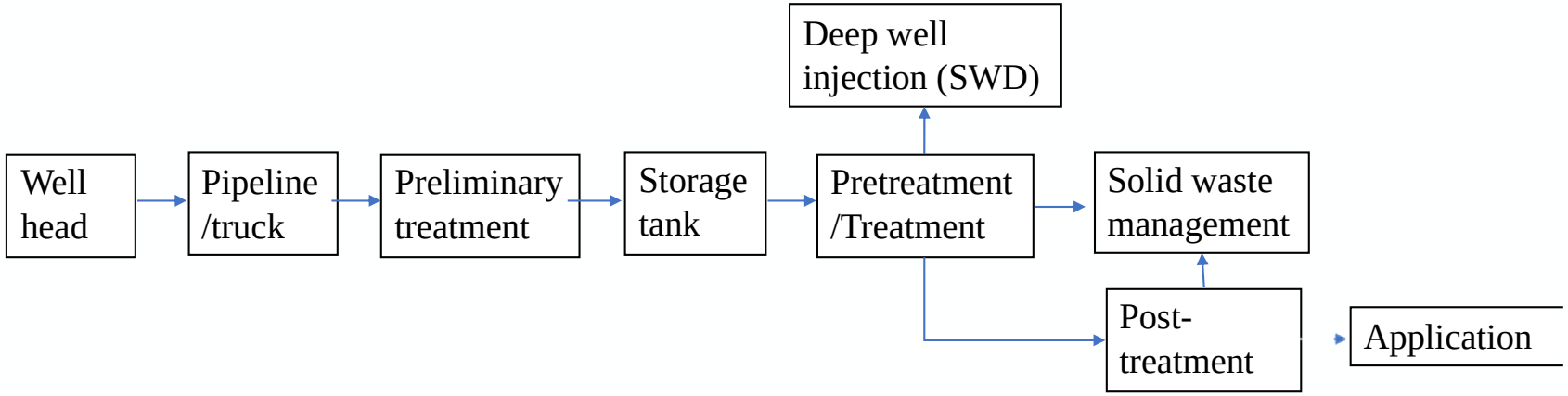
- Approach based on federal environmental test and evaluation approach established by EPA, DOE, DoD
- Project protocols developed for bench-scale and pilot- testing demonstrations
- Technical review teams for each project will evaluate Identified costs/performance indicators by considering pre and post treatment via laboratory testing as needed



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Basis for Produced Water Treatment Technology DTE

- EPA's Superfund Innovative Technology Evaluation (SITE) Program - established to work with state and federal regulatory agencies and technology providers to identify the cost and performance of innovative soil and water treatment and remediation technologies (EPA, 2003). [16]
- The Federal Remediation Technology Roundtable (FRTR) a Consortium established in 1995 to coordinate federal agency use and collection of data to establish standardized technology cost and performance comparisons. "Guide to Documenting and Managing Cost and Performance Information for Remediation Projects," (EPA, 1998). [17]
- DOE's Innovative Treatment Remediation Demonstration (ITRD) Program - established in 1994 to work with state and federal regulators, DOE and EPA laboratories, the EPA Site Program, to utilize the FRTR approach to reduce regulatory and operational risks of innovative treatment technologies at DOE sites. [18]
- EPA's Environmental Technology Verification (ETV) Program - established to utilize independent third parties, such as national laboratories and technical associations, to conduct full-scale, field operations and evaluate and verify the operational cost and performance of environmental monitoring, site characterization, and hazardous waste treatment technologies (EPA, 1996).

Treatment Technology – Measuring Key Performance Indicators

Vendor	Units
Treatment Unit Description :	
Technology readiness level	
Unit design treatment rate	gal/min or bbl/hr
Treatment system footprint	length/width/height in ft
General Raw Produced Water Quality	TDS
Energy Required:	Electric / Heat (grade - Temperature in / out) / Gas btu/bbl - mcf/bbl
Pre-Treatment	Type required
Treatment System Throughput:	
Operations	hrs/day
Duration	days
Max throughput	bbl/hr
Total Downtime during duration	hrs
Avg. throughput per day	bbl/hr/day
Permeate/distillate recovery	bbl/hr
Waste recovery	bbl/hr
Avg. treated water recovery	%
Avg. waste generated	%

Vendor	Units
Permeate Quality	
TDS	ppm
Other constituents volumes	Applicable units
Avg. Waste generated	bbl/day
Waste Type	classification
Consumables	gal or lbs/bbl
Chemicals	gal or lbs/bbl
Post Treatment Needed	Type and volume
Mobilization/demob	Cost and duration in days
Unit treatment costs of energy, manpower, consumables, etc.	$/bbl

Focus is on KPIs associated with Operational Cost, Performance, Reliability, and Final Water Quality

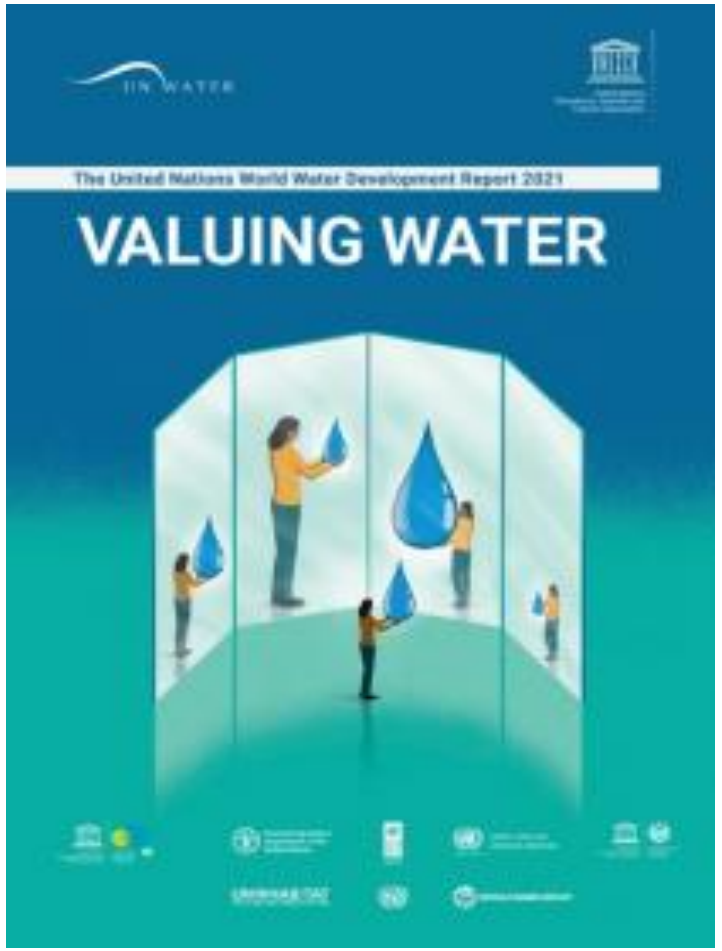
2022 and Currently Scheduled 2023 Consortium Treatment Efforts

Proposal Team	Technology Description	Location Identified	Funding Amount	Results
Zwitter Co	Zwitter ionic membrane for pre-treatment	BGNDRF/Permian Basin	Vendor funded Consortium cooperation	Completed March 2022
Kanalis Resources	RO membrane treatment	BGNDRF/San Juan Basin	Vendor funded Consortium cooperation	Completed April 2021 and 2nd Phase October 2022, May 2023
Hydrozonix	Ozone PW pre-treatment	Permian Basin operator	Consortium - $15 in-kind Vendor funded	Technology testing December 2022
Hilcorp/NM Tech	Membrane thermal distillation	San Juan Basin Producer	Vendor funded Consortium cooperation	Early 2023
Bechtel	Thermal hydro-cyclone distillation	Permian Basin Producer	Vendor funded Consortium cooperation	Early 2023

All treatment efforts in 2023 and beyond, both raw and treated produced water will go through the Consortium Risk and Toxicology Protocol
Also, all new projects will require submittal of a 2-page project summary for NMED review prior to starting

Water Stress is Driving a "One Water" Concept

- "One Water" - all water has "**Value**"
- **"Value"** is not synonymous with cost!
- Two of the United Nations' Sustainable Development Goals identify **water reuse as key to a more sustainable future.**
- Focus is on the social, health, environmental, and economic "**Value**" of water, measured by ESG metrics



2021 World Water Development Report

Requested Treated Produced Water Application by Location, Quantity, and Quality

- 200,000 to 400,000 bbls/day of high salinity brine (~200,000 ppm TDS) for solution mining near Carlsbad to reduce fresh and brackish water use/demands by the mining industry.
- 25,000 bbls/day of <2000 ppm TDS treated produced water to create new high-quality water resources to provide environmental flows in the Pecos River just below the NM/TX state line to support ecological protection in support of national environmental NGOs..
- 25,000 bbls/day of ~1000 ppm TDS treated produced water to augment municipal waste water reuse for parks and recreation areas for Eunice and Jal.
- 25,000 bbls/day of ~1000 ppm TDS treated produced water to augment municipal waste water reuse for parks and recreation areas north of Hobbs. This would also be used as and educational training center for NMJC and HHS water treatment licensing.
- 25,000 - 100,000 bbls/day of ~500 ppm TDS treated produced water to reduce fresh water use for power plant cooling 15 miles west of Hobbs.
- 50,000 bbls/day of 500-1000 ppm TDS treated produced water to support water delivery agreements between Artesia and Carlsbad Irrigation Districts north of or into Brantley Lake.
- 50,000 bbls/day of 500-1000 ppm TDS treated produced water for blue and green hydrogen demonstration projects within both the Permian and San Juan Basins. If successful, that could grow to 250,000 bbls per day by 2030 for each basin, and 1M bbls/day total by 2035.
- 50,000 -100,000 bbls/day of 500-1000 ppm TDS treated produced water to support Native American agriculture in the San Juan Basin. Potential for both Navajo Agricultural Products Industry (NAPI) support to replace Colorado River allotment cuts, and support small tribal farmers not associated with NAPI.
- Soil and Water Conservation Districts in SE and NW NM still estimating potential application volumes, but they have expressed the desire for use of 50,000 - 200,000 bbls/day of ~500 - 2000 ppm TDS treated produced water for agricultural applications. This would replace fresh water use, which continues to be reduced due to falling ground water tables.
- The BLM has requested treated produced water for reclamation of grasslands used for quarries, borrow pits, etc. Environmental assessments have been completed on more than 20 different sites, all they need is the water to support the reclamation of these sites. Initial estimates are that they would need 500 bbls/day of ~1500-2000 ppm TDS treated produced water at each site for 3 years. The broad distribution of these sites suggests that smaller-scale mobile systems that can be moved near a given borrow pit would be required.
- 10,000 bbls/day of 500-1000 ppm produced water for rangeland applications in southern San Juan Basin.

Private, public, federal, environmental, industrial, agriculture, energy users

Many Produced Water Reuse Applications Being Requested Could Require Fate and Transport Modeling and Testing

Water Quality (ppm) TDS	Application	Common Water Quality Requirements (ppm) TDS
Brackish 1500 to 15K **Saline (seawater) 15K to 50K** **Hyper Saline 60K to 200K**	Water Supply Augmentation	200-1,000
	Agriculture	Class 1 <700, <60% Na, B<0.5 Class 2 2000, 60-75% Na, B<2.0 Class 3 >2000, 75% Na, B~2
	Rangeland	2,000 – 6,000
	Energy Development	500 – 2,000
	Environmental Surface Flows	600-2,000
	Mineral Recovery	>100,000 (brine)
	Road Construction	Up to 30,000
	Industrial Applications	500 – 2,000

Identified Target Treatment Goals for Testing Based on Current NM General WQCC Water Discharge Criteria

- Provides a basis for evaluating and selecting technologies for demonstration and performance assessment
- Guide for pre- or post-treatment
  - Assess laboratory-scale pre-treatment or post-treatment polishing rather than full treatment train to reduce testing cost
- Guides system-level treatment train evaluations for better cost-performance and risk analysis

Parameter	Units	Value
pH		6.8-9.0
Temperature	°C	25-30
Turbidity	NTU	<15
Total dissolved solids (TDS)	mg/L	<1500
Chlorides	mg/L	<500
Sulfates	mg/L	<500
Alkalinity	mg/L	<500
Total Organic Carbon	mg/L	<20
BETX	mg/L	<5
TPH	mg/L	<5
Total metals	mg/L	<10
Radium 226+228	pCi/L	<30
Strontium	pCi/L	<10
Gross Alpha	pCi/L	<15
E-coli		
Ammonium (NH_4^+)	mg/L	10, up to 40

Produced Water Pre-treatment to ‘Clean Brine’ Standard

- Bench-scale testing at BGNDRF
- Consortium supplied produced water
- ZwitterCo, new zwitter-ionic membrane, oil phobic
  - Funded by DOE
  - Developed for 30-40% organics
  - Generally Water CIP
  - Ability to meet PWS “Clean Brine Standard” at <$0.20/bbl target per DOE/TEA
- Contact from PWS meeting in 2019

ZwitterCo

Permian Basin -100,000 TDS SWD

FINAL PROJECT REPORT

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.
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SUBMITTED TO

U.S. Department of Energy
National Energy Technology Laboratory

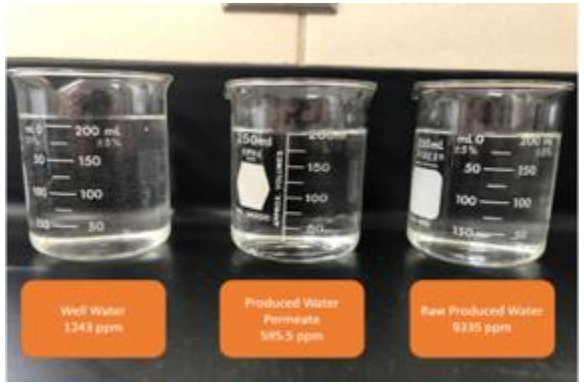
Produced Water Treatment Cost/Performance Testing

San Juan Basin Produced Water

- 10,000 ppm TDS, treatment quality 300 ppm TDS, 50% - 70% recovery with 2nd pass RO
- Minimal pre-treatment
- Full-scale cost <$0.15/bbl
- Tested at BGNDRF

- Green house studies of treated produced water
  - Range grass growth with treated produced water successful, similar to other ag studies – NM and TX

- Treated same water with new membrane in October 2022, provided raw and treated water for Risk and Toxicology Protocol Evaluation




Bench-scale Treatment Study of Produced Water from the Southern San Juan Basin New Mexico

Kanalis Resources

October 1, 2022

Prepared for:

NEW MEXICO PRODUCED WATER RESEARCH CONSORTIUM

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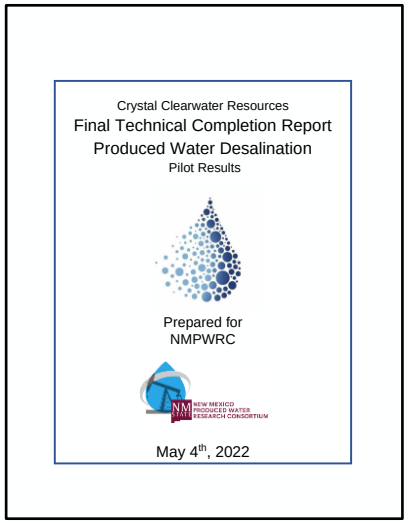
Permian Pilot-scale Produced Water Treatment Cost/Performance Testing

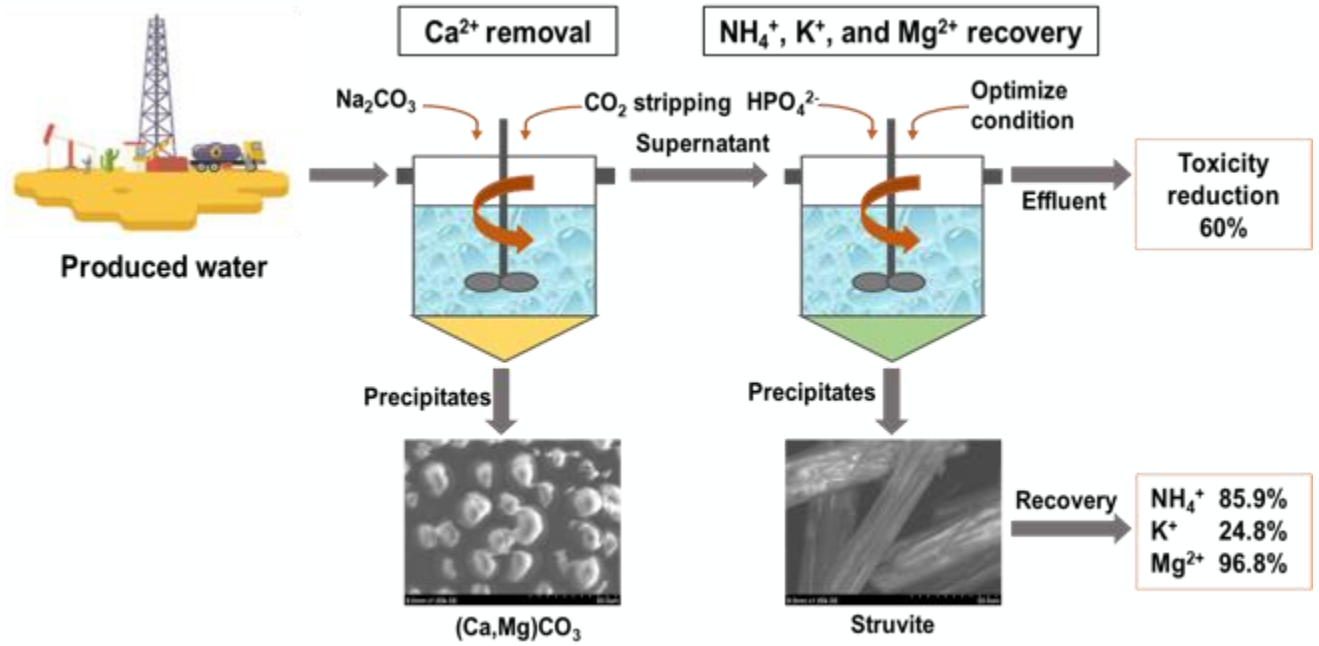
- Multi-stage thermal distillation w/no pretreatment
  - Successfully captured and utilized compressor waste heat, ~2.0 MMBTU/hr low grade waste heat
- Treated 500 bbls/day of 120,000-170,000 ppm TDS feed:
  - Avg distillate- 338 ppm TDS, 11 ppm organics, 45 ppm ammonia
  - Avg. 40% recovery
  - Consistently operated > 16hrs/24-hour day, 70% uptime in Phase 1 and 88% uptime in Phase 2
- Successful range grass treatment study in TX, and ammonia post-treatment lab testing at NMSU


Crystal Clearwater Resources
Final Technical Completion Report
Produced Water Desalination
Pilot Results
Prepared for
NMPWRC
May 4th, 2022

Pilot-testing Nov-Dec 2021

Lab-scale Fertilizer (Struvite) Recovery from Produced Water

NH_4^+
K^+
Mg^{2+}



Hu, L., Yu, J., Luo, H., Wang, H., Xu, P., & Zhang, Y. (2020). Simultaneous recovery of ammonium, potassium and magnesium from produced water by struvite precipitation. *Chemical Engineering Journal*, *382*, 123001.

Simultaneous recovery of NH_4^+, K^+ and Mg^{2+} from PW by struvite precipitation

NH_4^+
K^+
Mg^{2+}

$\xrightarrow{HPO_4^{2-}}$

$MgNH_4PO_4 \cdot 6H_2O$ (MAP)

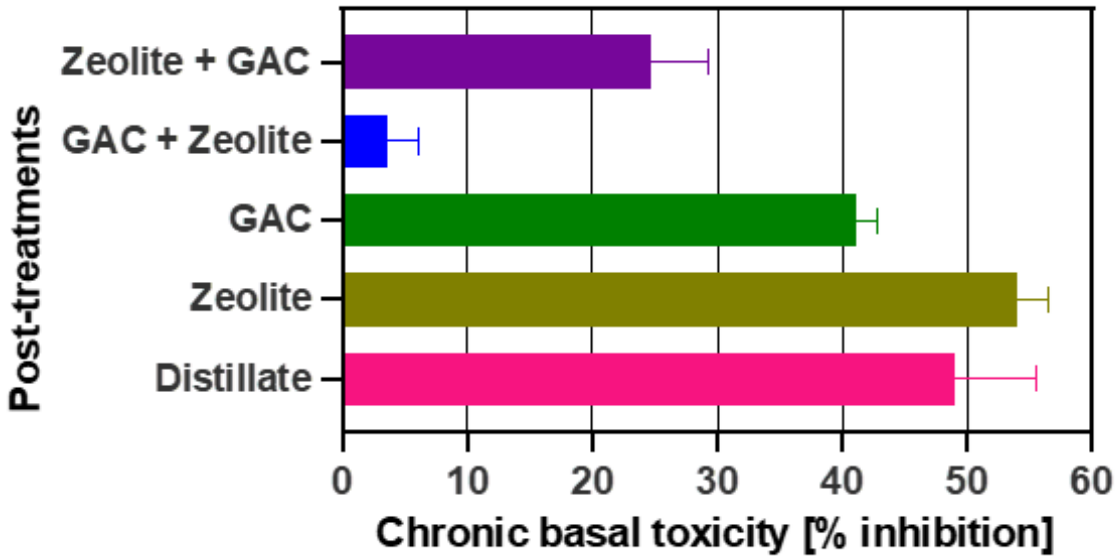
$MgKPO_4 \cdot 6H_2O$ (MPP)

Fertilizer in agriculture

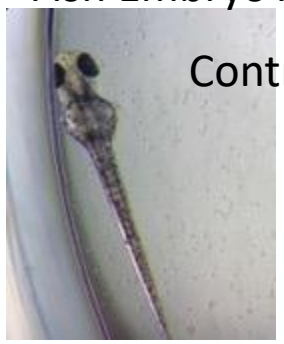
Lab-scale Post Treatment Research of Thermal Desalination

Treatment Process	Water Quality Parameters		
	Ammonia	TOC	Conductivity
	[mg/L]	[mg/L]	[µS/cm]
Distillate	46.4± 0.20	42.3 ± 0.3	288 ± 7
Zeolite	0.04 ± 0.00	45.1 ± 3.3	237 ± 3
GAC	27.1 ± 0.10	5.3 ± 0.1	172 ± 3
Zeolite + GAC	0.01 ± 0.01	5.2 ± 0.2	-
GAC + Zeolite	0.01 ± 0.01	4.5 ± 0.1	171 ± 3

EPA WET test 1003.0 Green Algae



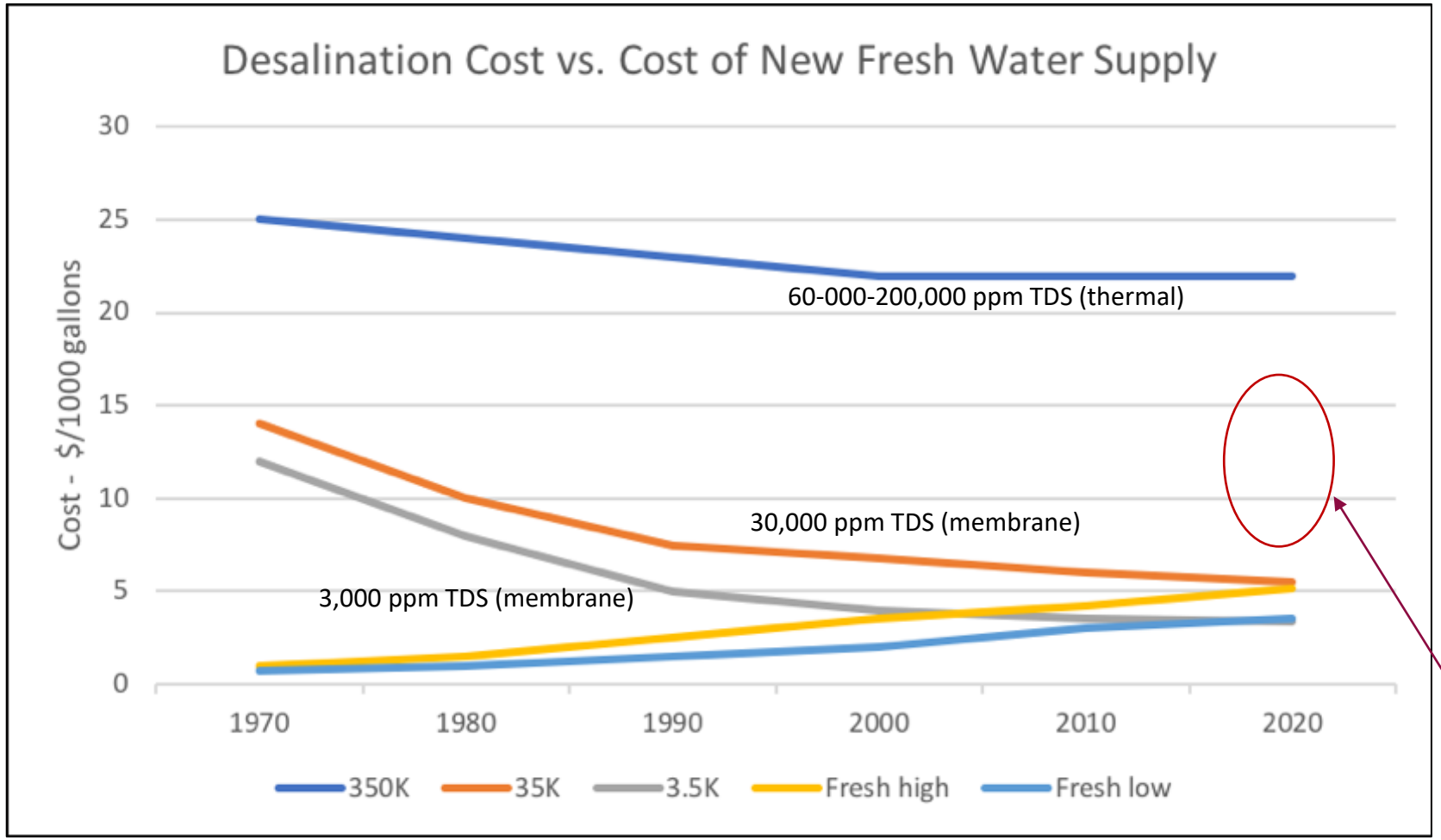
Fish Embryo Acute Toxicity OECD 236



96 h of exposure

- Post treatment is often needed to remove organics and ammonium
- GAC followed by Zeolite has the best performance.
- Algal chronic toxicity test showed the lowest toxicity
- *Ceriodaphnia dubia* survival test (2002.0 acute toxicity) shows no toxicity

Bench-Scale Water Treatment Studies



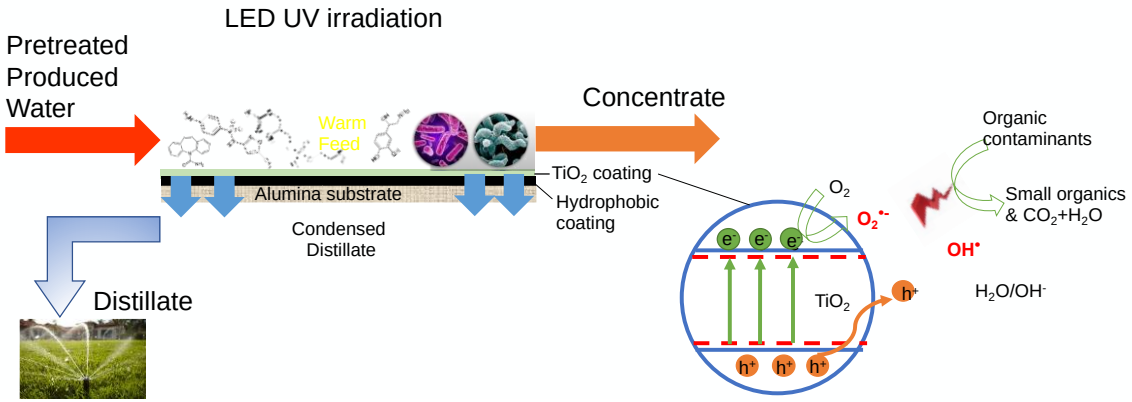
Desalination treatment quality
< 1000 mg/L TDS

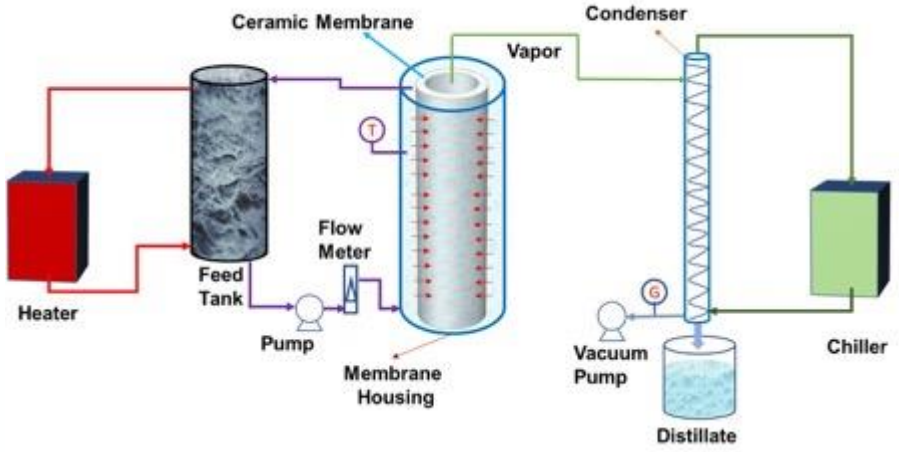
Permian Basin
produced water disposal
$15-20/1000 gal
$0.60-$0.80/bbl

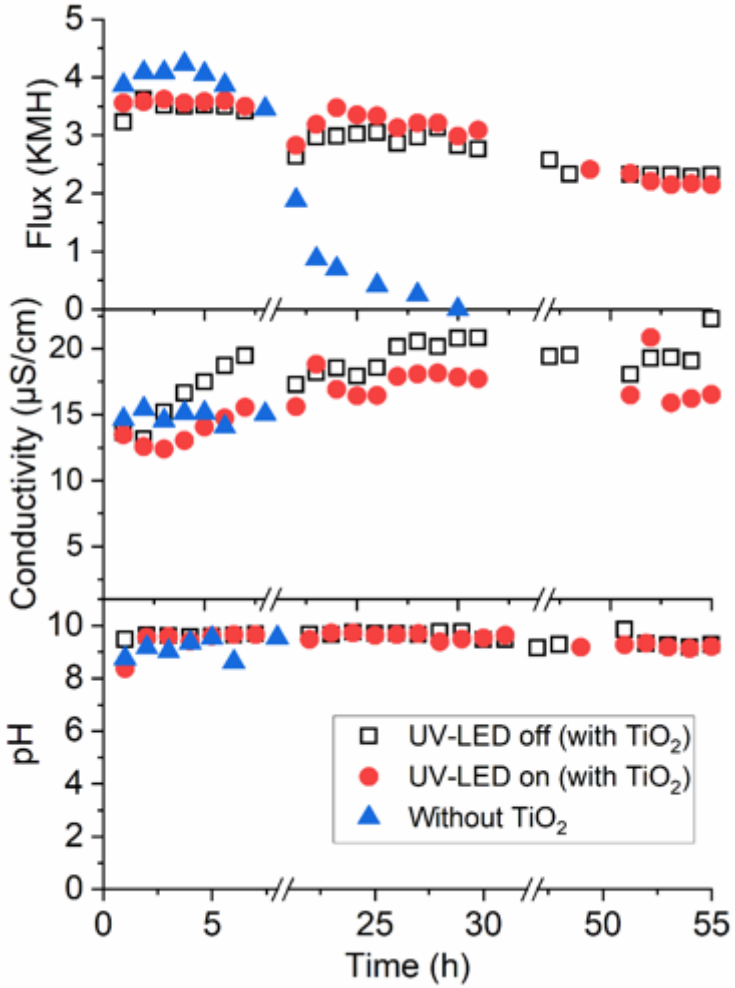
National
produced water disposal
$75-200/1000 gal
$3.00-8.00/bbl

New treatment research area

Lab-scale Multifunctional Membrane Distillation Research







2023 Efforts Will Move to Integrated Testing with Risk and Tox to Help Support Implementation

- Public – Private Partnerships with communities
- Wholesale Treated Produced Water - customer provides permitting and polishing treatment for their application
- Standardize treatment infrastructure designs similar to desalination infrastructure to accelerate deployment
- New treatment evaluation approaches
  - Collaborative with other states
  - Joint industry technology evaluation programs
  - Industry support for bench studies
  - RDD permitting under 40 CFR 270.63 -.65, for fate and transport modeling – to support full reuse applications

Alamogordo 1MGD Desal Plant

Contact Information

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