Fact Sheets: *State of the Science*

Executive Summary

Produced water (PW) is the largest waste stream generated during oil and gas production. In arid regions such as New Mexico, including the Permian Basin and the San Juan Basin, interest in treating and reusing PW has grown due to increasing water scarcity and the substantial volumes of wastewater generated by energy production.

Over the past several years, research supported by the New Mexico Produced Water Research Consortium (NMPWRC) and collaborating institutions has significantly advanced scientific understanding of PW quality and toxicity, treatment technology performance, environmental risks, economic considerations, and potential beneficial reuse applications.

What Does The Current State Of The Science Say?

Raw PW is complex and contains salts, metals, organic compounds, naturally occurring radioactive materials, and other contaminants.

Advanced treatment technologies can remove most contaminants to low levels and substantially reduce toxicity under optimized conditions.

Pilot- Scale studies have shown that high-quality treated PW can meet non-toxic endpoints in aquatic toxicity and human cell bioassays.

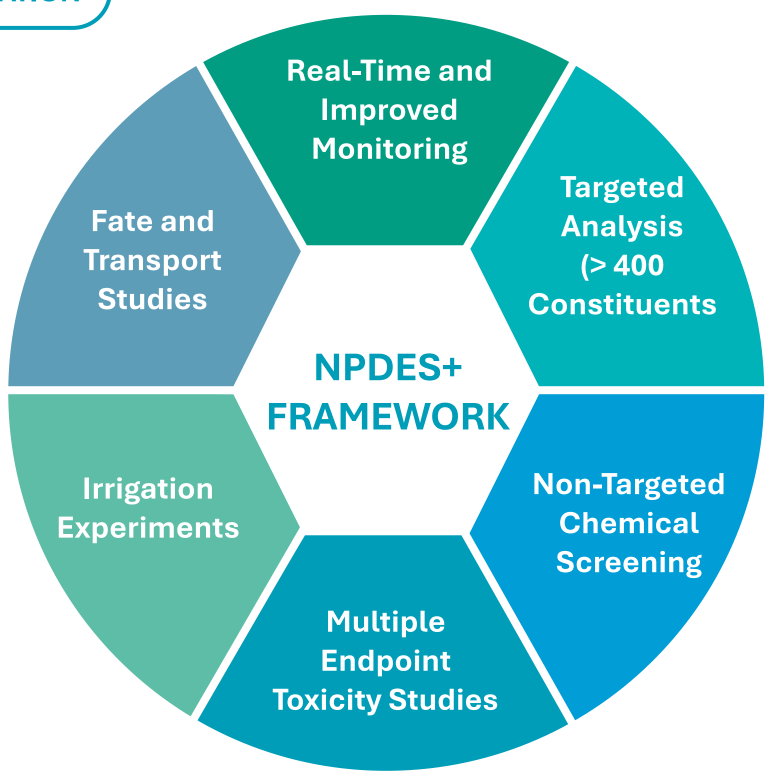
Agricultural and industrial reuse may be technically feasible when treatment is designed for specific end uses.

Future Work should focus on long-term impacts, waste management, monitoring, economics, and the regulatory/permitting framework creation.

Advances In Produced Water Characterization

The NMPWRC developed the “NPDES+ analyte list” as a comprehensive framework for PW characterization and treatment performance evaluation. The list expands beyond conventional discharge-monitoring parameters under the National Pollutant Discharge Elimination System (NPDES) to address the complex chemistry of raw PW and potential risks associated with reuse of treated PW.

The NPDES+ framework uses a multi-tiered approach combining comprehensive chemical characterization, toxicity testing, irrigation studies, and environmental modeling to evaluate produced water quality, treatment performance, and potential reuse risks.



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By The Numbers

75 PW samples evaluated

12,300 analytical data points generated

600 unique analytes tested

290 unique analytes detected across all samples

74 unique analytes detected in only the post-treated water

Produced Water Sampling & Characteriation

The NMPWRC researchers have evaluated 75 PW samples collected during laboratory and pilot testing in the Permian Basin.

To date, approximately 12,300 analyte measurements have been generated across different treatment technologies. Approximately 600 analytes have been tested, and about 290 analytes have been detected at least once in the collected PW samples.

These results show that post-treatment plays a critical role in improving PW quality, with up to 74 analytes were detected once in post-treated desalinated PW.

Treatment Technologies: What Works?

Current peer-reviewed research indicates that no single treatment technology can effectively address the complex and variable composition of PW. Instead, successful treatment strategies typically employ integrated treatment trains combining multiple physical, chemical, biological, thermal, and membrane-based processes (Figure 1).

Pilot-scale studies in the Permian Basin have reported greater than 99% salt removal, elimination of detectable organic contaminants, and post-treated, purified water with no observable toxicity in aquatic and human-cell bioassays. Overall, a multi-barrier treatment approach is the most effective pathway for producing water suitable for beneficial reuse applications.

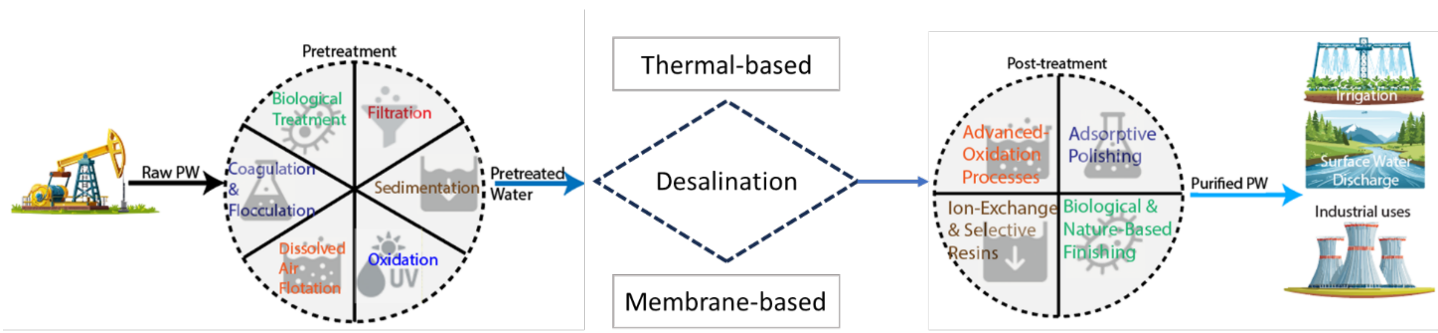

Figure 1: Example of a multi-barrier produced water treatment train showing pretreatment, thermal- or membrane-based desalination, and post-treatment polishing processes used to generate treated water suitable for beneficial reuse applications. Multiple treatment processes are often combined to address the complex composition of produced water, and the specific treatment train may vary depending on the intended end use and required water quality goals.

Raw vs. Treated Produced Water, Toxicity, and Environmental Risk

One of the most important scientific questions is whether treated PW remains toxic after treatment. While it is well known that raw PW is toxic, recent pilot-scale research has shown encouraging results of treated PW. Studies reported elimination of acute and chronic toxicity in treated waters, with post-treated, polished PW passing standardized aquatic toxicity tests involving multiple trophic levels.

Human cell-based bioassays similarly found no measurable adverse effects compared with controls. Current scientific evidence suggests that properly treated PW can achieve substantial reductions in toxicity, but continued monitoring and validation remain essential.

Benficial Reuse Applications

Recent greenhouse-scale studies indicate that treated PW with salinity below approximately 1,000 mg/L total dissolved solids (TDS) may support irrigation without adverse impacts on soil health, microbial communities, or crop quality. Conversely, higher-salinity waters were associated with soil degradation, salinization, and ionic imbalance. These findings support a fit-for-purpose approach in which treatment targets are tailored to intended reuse applications.

Test (End Use)	Raw PW	Pretreated	Desalinated	Post-Treated
WET Test (Surface Discharge)[1-4]	Toxic	Toxic	Signif. Reduced Toxicity	No Toxicity
Bioassays (Human Exposure)[4-6]	Cytotoxic	Cytotoxic	Signif. Reduced Cytotoxicity	No Cytoxicity
Greenhouse (Ag/ Irrigation)[7]	Did Not Test	Did Not Test	Minimal Impacts*	No Adverse Impacts

Figure 2: Summary of observed toxicity and biological effects of PW across different treatment stages and end-use evaluations. Results from aquatic toxicity tests, human cell bioassays, and greenhouse irrigation studies show that multi-barrier treatment trains with post-treatment polishing can substantially reduce, or eliminate, toxicity and adverse biological impacts.

* Study used post-treated water and blended in brine from the desalination system to achieve a "desalinated" water quality.

References (Year, Author, Journal)
[1] 2025 Ariana et. al., Geohealth
[2] 2024a Tarazona et. al., Journal of Hazardous Materials
[3] 2024b Tarazona et. al., Journal of Water Process Engineering
[4] 2026 Tarazona et. al., Journal of Hazardous Materials
[5] 2026 Edirisooriya et. al., - Separation and Purification Technology
[6] 2025 Wijekoon et. al., Ecotoxicology and Environmental Safety
[7] 2025 Senanayake et. al., Science of the Total Environment

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WHAT ARE NEXT STEPS?

KEY KNOWLEDGE GAPS

Important questions that remain are...

- Long-term ecological impacts of treated PW reuse
- Fate, transport, and bioaccumulation of residual compounds
- Management of waste streams generated during treatment
- Economic feasibility at large scales
- Development of protective regulatory standards
- Public acceptance and risk communication

2026 RESEARCH PRIORITIES

1. Evaluate the technical, economic, and environmental performance of treatment systems
2. Conduct comprehensive toxicological assessments of treated produced water
3. Improve the understanding of the relationships between water chemistry and observed bio-logical effects
4. Develop surrogate parameters and indicator compounds for routine water quality monitoring
5. Compile chemical and toxicological reference values and ecotoxicity data for reuse scenarios
6. Establish risk-based benchmarks to support the development of scientifically defensible regulatory standards

CONCLUSIONS

The peer-reviewed research results demonstrate significant progress in the treatment and reuse of PW. Advanced, multi-barrier treatment systems can now achieve high contaminant removal efficiencies and substantially reduce toxicity. Pilot-scale studies provide evidence that highly purified PW may be suitable for selected agricultural and industrial applications when treatment objectives are tailored to intended uses. However, science also indicates that reuse decisions must remain risk-based and application-specific. Current evidence supports cautious optimism: PW is increasingly viewed not only as a waste stream but also as a potential alternative water resource when managed using scientifically validated treatment and monitoring approaches.