Overview and Updates

Produced Water Characterization, Risks and Toxicology Assessment

Pei Xu - Overview, NMSU

Himali Delanka-Pedige and Robert Young – Non-targeted Analysis, NMSU

Yanyan Zhang – PW Polishing and Toxicity Study, NMSU

2023 ANNUAL MEETING

NM STATE NEW MEXICO PRODUCED WATER RESEARCH CONSORTIUM

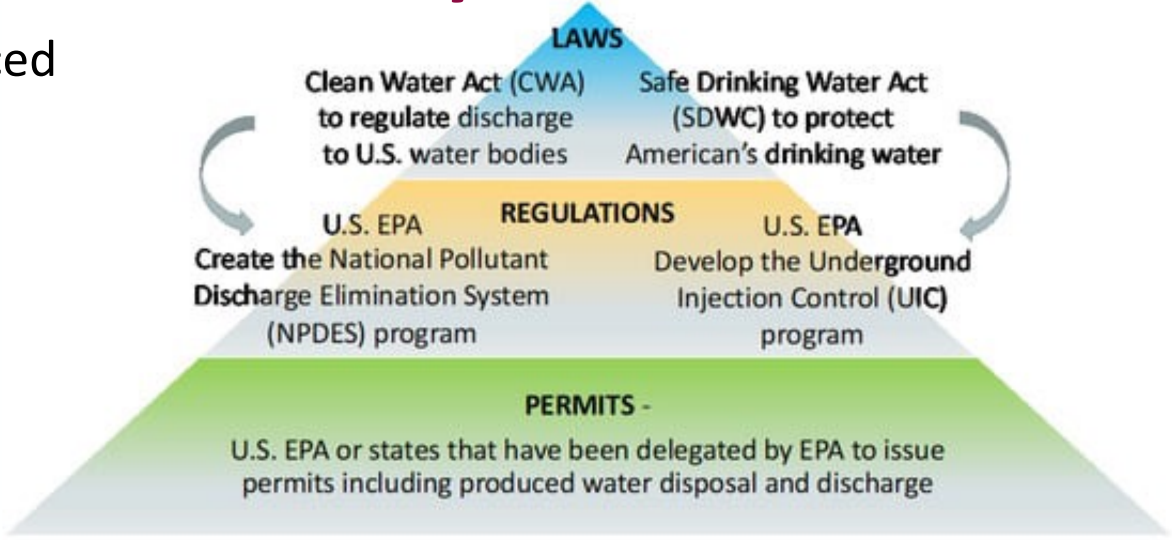
Goals and Research Activities

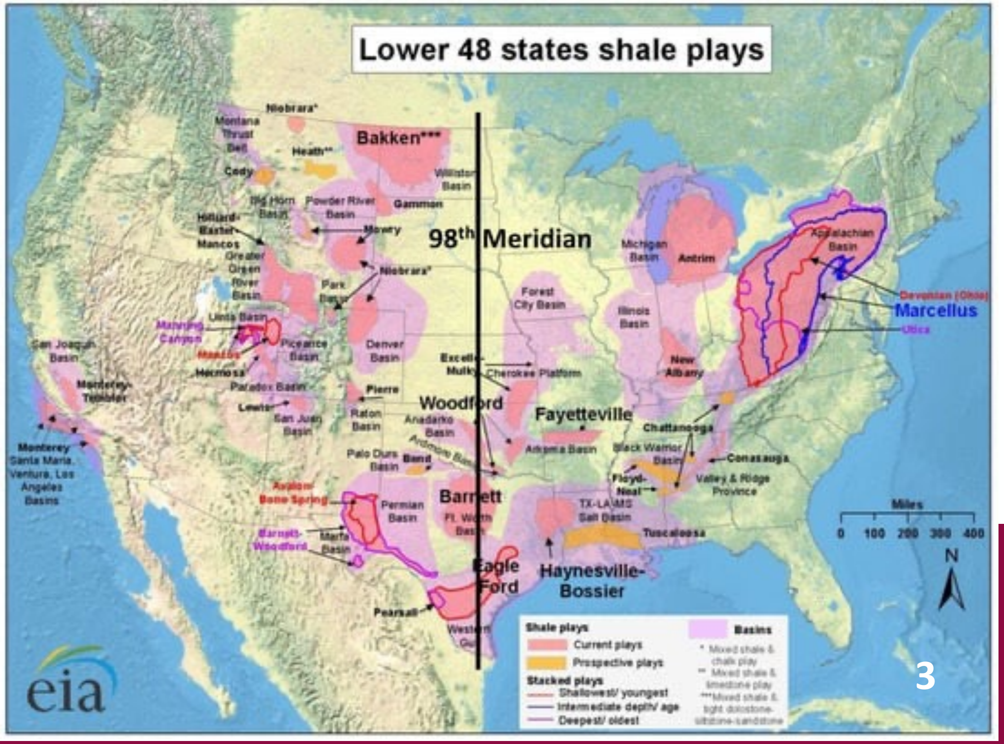
- Thorough understanding of raw produced water (PW) and treated PW quality for effective management, treatment, risk assessment, and fit-for-purpose reuse.
  - Developed an NPDES+ analyte list
  - Developed a sampling protocol and a testing guidance
  - Collect water samples for analysis and assessment of treatment efficiency
  - Use the best available analytical methods for targeted and non-targeted analyses of the constituents in PW and treated PW
  - Conduct bioassays and greenhouse irrigation experiments to evaluate the application of treated PW on aquatic organisms, human cell line, plants, and soil.
- Develop Human Health & Environmental Risk Assessment Framework to assess, minimize, and manage the risks during fit-for-purpose reuse
- Collaborate with federal and state agencies, other institutions, and stakeholders

What Constituents Should We Analyze?

- Case studies on regulatory framework, water policy, produced water management and reuse, and water quality standards
    - Pennsylvania, Ohio and West Virginia
    - Colorado
    - Texas
    - California
    - Oklahoma
    - Wyoming
    - New Mexico
- Literature review on beneficial use water quality requirements
- NMAC (New Mexico Administrative Code) standards for 20.6.2 (**Ground and Surface Water Protection)** and 20.6.4 (**Standards f** **Interstate and Intrastate Surface Waters**).

Jiang et al., Water 2022, 14(14), 2162





NPDES+ Analytical List

Project						
Sampling Date						
Sampling Location						
Sampling shipment method						
Names of samplers						
Attachment of Chain-of-Custody						

NPDES + list	**Recommended Method**	**Eurofins method**	**Raw Produced water**	**Thermal Distillate**	**Concentrate**	**Post-treated water**
Tier1 (daily or in the field)			☑	☑		☑
Turbidity	EPA 180.1/SM 2130B	EPA 180.1	☑	☑	☑	☑
Total suspended solids	EPA 160.2/SM2540D	2540D	☑	☑	☑	☑
Total Dissolved solids	EPA 160.1/SM2540C	2540C	☑	☑		☑
Hardness Total	SM2340B	SM2340B	☑	☑		☑
Hardness Dissolved	SM2340B	SM2340B	☑	☑		☑
Alkalinity, total and bicarbonate	EPA 310.1/SM 2320B	SM 2320B	☑	☑	☑	☑
Nitrogen, Ammonia	EPA 350.1	350.1	☑	☑	☑	☑
Sulfide	W-846 9030/9034/SM4500S2-	SM4500S2-F	☑	☑		☑
Hydrogen Sulfide in water	SM 4500 H2S	SM 4500 H2S	☑	☑	☑	☑
Total organic carbon (TOC)	SW-846 9060/SM5310C	M5310C	☑	☑	☑	☑
Dissolved organic carbon (DOC)	EPA Method 415.2 or M5310B	M5310C	☑	☑	☑	☑
Chemical oxygen demand (COD)	HACH 8000/EPA 410.1	HACH 8000				

NPDES+ Analytical List

Tier2 (weekly or/and under different operating conditions) Metal elements 6020A (total and dissolved)	Recommended Method	Eurofins method	Raw Produced water	Thermal Distillate	Concentrate	Post-treated water
Aluminum	00.7/200.8/SW-846 6010/6020	6010D	☑	☑		☑
Antimony		6010D	☑	☑		☑
Arsenic		6010D	☑	☑		☑
Barium		6010D	☑	☑		☑
Beryllium		6010D	☑	☑		☑
Boron	6010B (Total and Dissolved met	6010D	☑	☑		☑
Cadmium		6010D	☑	☑		☑
Calcium		6010D	☑	☑		☑
Chromium		6010D	☑	☑		☑
Cobalt		6010D	☑	☑		☑
Copper		6010D	☑	☑		☑
Gold	: Dissolved) and E200.7 (EPA M	6020B	☑	☑		☑
Iron		6010D	☑	☑		☑
Lead		6010D	☑	☑		☑
Lithium	00.7 (EPA Method 6020: Dissolv	6020B	☑	☑		☑
Magnesium		6010D	☑	☑		☑
Manganese		6010D	☑	☑		☑
Molybdenum	6010B (Total and Dissolved met	6010D	☑	☑		☑
Nickel		6010D	☑	☑		☑
Phosphorus	EPA 365.1	6010D	☑	☑		☑
Potassium		6010D	☑	☑		☑
Selenium		6010D	☑	☑		☑
Silicon	6010B (Total and Dissolved met	6010D	☑	☑		☑
Silver		6010D	☑	☑		☑
Sodium		6010D	☑	☑		☑
Strontium	6010B (Total and Dissolved met	6010D	☑	☑		☑
Thallium		6010D	☑	☑		☑
Tin	6010B (Total and Dissolved met	6010D	☑	☑		☑
Titanium	6010B (Total and Dissolved met	6010D	☑	☑		☑
Uranium (total)	0A (Dissolved metals and Total	6020B	☑	☑		☑
Vanadium		6010D	☑	☑		☑
Zinc		6010D	☑	☑		☑
Zirconium	00.7 (EPA Method 6020: Dissolv	6020B	☑	☑		☑
Mercury		6010D	☑	☑		☑
Hexavalent Chromium	SW-846 7196A	3500_CR_B	☑	☑		☑

NPDES+ Analytical List

NPDES + list	Recommended Method	Eurofins method	Raw Produced water	Thermal Distillate	Concentrate	Post-treated water
Anions						
Bromide	EPA 300/SW-846 9056	300	☑	☑		☑
Chloride	EPA 300/SW-846 9056	300	☑	☑		☑
Fluoride	EPA 300/SW-846 9056	300	☑	☑		☑
Sulfate	EPA 300/SW-846 9056	300	☑	☑		☑
Nitrate Nitrogen	PA 353.2/SW-846 9056/EPA 30	300	☑	☑		☑
Nitrite Nitrogen	PA 353.2/SW-846 9056/EPA 30	300	☑	☑		☑
Phosphate	A 365.1/EPA 300.0/SW-846 90	300	☑	☑		☑
Perchlorate	E331	6850	☑	☑		☑
Radionuclides						
Radium 226, pCi/L	EPA 903	903	☑	☑		☑
Radium-228	EPA 904	904	☑	☑		☑
Gross Alpha/Beta	EPA 900	900	☑	☑	☑	☑
U 235, 236, 238	L-300 (Uranium 234,235,238) U	6020A	☑	☑		☑
Strontium 90	E905.0	905	☑	☑		☑
Gamma Scan		901.1	☑	☑	☑	☑

NPDES+ Analytical List

NPDES + list	Recommended Method	Eurofins method	Raw Produced water	Thermal Distillate	Concentrate	Post-treated water
Organics (Please see the Tab - Detailed list of analytyes)			☑	☑	☑	☑
Oil and Grease	EPA 1664A, SW-846 9071A	1664A (HEM only)	☑	☑	☑	☑
GRO [C6-C10] by 8015D	SW846 8015-Modified	8015	☑	☑	☑	☑
DRO [C10-C28] by 8015D	SW846 8015-Modified	8015	☑	☑	☑	☑
ORO (C28-40) by 8015D	SW8015M/D	8015	☑	☑	☑	☑
Volatile Organic Compounds (VOCs) by 8260	EPA 624/SW-846 8260	HPLC, 8260	☑	☑	☑	☑
Organic - SVOC - General by 8270E	EPA 625/SW-846 8270	8270	☑	☑	☑	☑
Organic - SVOC - TPH by 8015	SW-846 8015	8015	☑	☑	☑	☑
Organic - VOC - TPH by 8015	SW846 - 8015	8015	☑	☑		☑
Organic - SVOC - Explosives by 8330B	SW8330 (Aq) (Explosives)	8330B	☑	☑		☑
Organic - SVOC - Agent Breakdown Products			☑	☑		☑
Organic - SVOC - Pesticides by 8081B	EPA 608	8081B	☑	☑		☑
Organic - SVOC - Herbicides by 8081B	EPA Method 8151	8151	☑	☑		☑
Organic - SVOC - Polychlorinated biphenyls (PCBs) (8280A)	SW8082 (PCBs)	8082	☑	☑		☑
Organic - SVOC - Polyaromatic hydrocarbons (PAHs)	EPA 625/SW-846 8270	8270D	☑	☑		☑
Organic - SVOC - Organic Acids by 8015D	8015	8015	☑	☑		☑
Organic - SVOC - Dioxins	EPA 1613	8290	☑	☑		☑
TOX by SW 846 9020	AQ SW-846 9020B	9020	☑	☑		☑
PFOA, PFOS & PFHxS by EPA 537.1 Modified	EPA Method 537.1	537.1				

NPDES+ Analytical List

NPDES + list	Recommended Method	Eurofins method	Raw Produced water	Thermal Distillate	Concentrate	Post-treated water
Others						
SM5540C - Methylene blue active substances - anionic surfactants	SM5540C	SM5540C	✓	✓	✓	✓
Asbestos by EPA 100.1 or 100.2			✓	✓		✓
TIC-Tentitively Identified Compounds (VOC and SVOC)	Mass Spectroscopy		✓	✓	✓	✓
carbaryl by EPA 632	EPA 632	632	✓	✓		✓
chlorpyrifos by EPA 622	608	8141	✓	✓		✓
demeton by EPA 614	EPA 614	8141	✓	✓		✓
diazinon by EPA 614	EPA 614	8141	✓	✓		✓
2,4-dichlorophenoxyacetic acid by EPA 615	EPA 615		✓	✓		✓
Guthion (Azinphos-methyl) by EPA 614	EPA 614		✓	✓		✓
Malathion by EPA 614	EPA 614		✓	✓		✓
Mirex by EPA 617	EPA 608.3		✓	✓		✓
Tributyltin	Organotins	GCMS	✓	✓		✓
Rare Earth Elements		6020A	✓	✓		✓

NPDES+ Analytical List

NPDES + list	Recommended Method	Eurofins method	Raw Produced water	Thermal Distillate	Concentrate	Post-treated water
Tier 3 Toxicty Test (analyze 1-2 final product water sam						
Acute						
Ceriodaphnia dubia acute, definitive (5 conc.), renewal, 48 hr bioassay	Ceriodaphnia dubia acute, definitive (5 conc.), renewal,					☑
Fathead minnow acute, definitive (5 conc.), daily renewal, 96 hr, bioassay	Fathead minnow acute, definitive (5 conc.), daily					☑
Chronic						
Algae chronic, definitive (5 concentration) bioassay	Algae chronic, definitive (5 concentration) bioassay					☑
Ceriodaphnia dubia chronic, definitive (5 conc.), bioassay	Ceriodaphnia dubia chronic, definitive (5 conc.), bioassay					☑
Fathead minnow chronic, definitive (5 conc.), bioassay	Fathead minnow chronic, definitive (5 conc.), bioassay					☑

NPDES+ Analytical List – Analysis at NMSU

- Non-targeted analysis using high resolution LC-MS
- Toxicity study – WET and human cell line
- Irrigation experiments – impact on plants and soil

Sampling Protocol and QA/QC Plan

- Reliability of any project outcome depends on the quality maintained throughout the research project.
- Developed a sampling protocol and a quality assurance and quality control plan (QA/QC)
- Follow USEPA standard procedures and protocols for experimental design, sample collection, preservation, shipping, analysis, and data storage.

Sampling and Analysis

- Permian Basin produced water treated via photocatalytic membrane distillation (MD) processes
- San Juan Basin produced water treated via seawater reverse osmosis (SWRO) process
- Permian Basin produced water treated by thermal distillation and post-treatment via granular activated carbon (GAC)/Zeolite

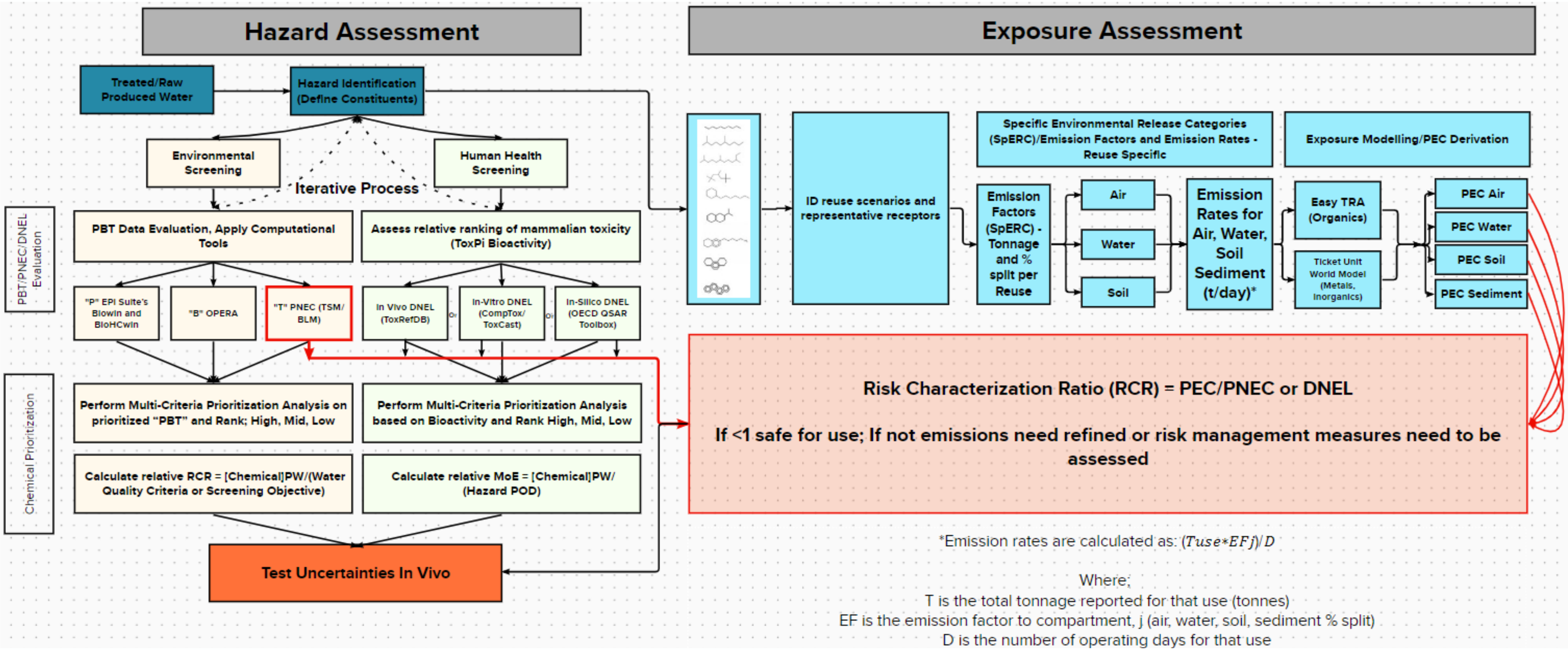
Towards A Transparent Framework for Risk-based Evaluation of Treated Produced Water in the Permian

Craig Warren Davis, Josh Butler, Aaron D. Redman, Cloelle Danforth, Sean Thimons, Michael Jahne, Pei Xu

Presented at the 2023 Society of Environmental Toxicology and Chemistry (SETAC) North America 44th Annual Meeting

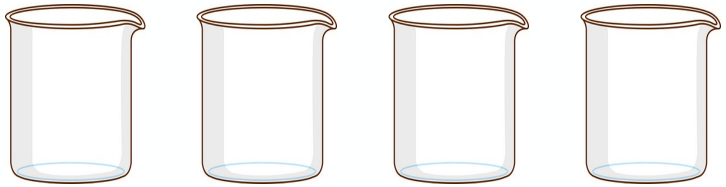
12 – 16 November 2023, Louisville, Kentucky

Quantitative Exposure & Risk Assessment Modeling Framework



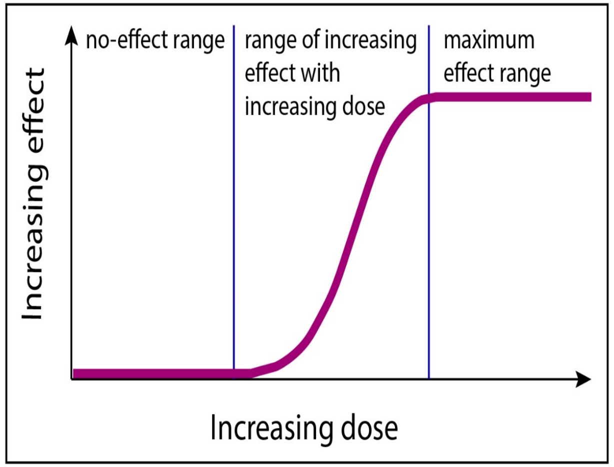
PNEC –Predicted No Effect Concentration; BLM –Biotic Ligand Model; TSM –Target Site Model; PBT –Persistence Bioaccumulation, Toxicity; DNEL –Derived No Effect Level; QSAR –Quantitative Structure Activity Relationship; MoE- Margin of Exposure; POD -Point of Departure; RCR – Risk Characterization Ratio; SpERC – Specific Environmental Release Category; PEC – Predicted Environmental Concentration

Whole Effluent Testing (WET) – In Vivo (Environment) & In Vitro (Human Health)



0% 33% 66% 100%

Treated Produced Water Effluent (%)



Safe reuse of treated produced water outside oil and gas fields? A review of current practices, challenges, opportunities, and a risk-based pathway for produced water treatment and fit-for-purpose reuse

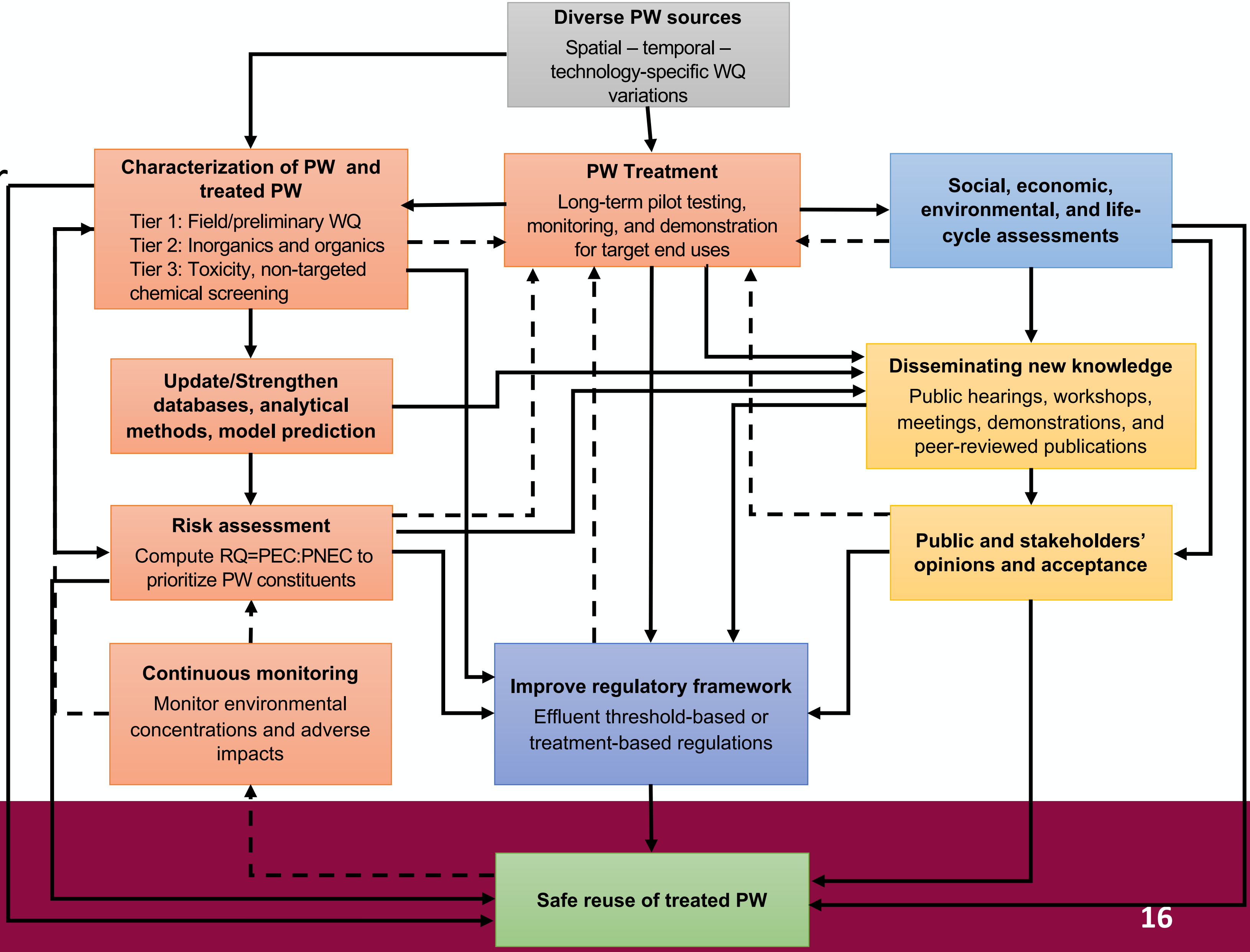
H. M. K. Delanka-Pedige, Yanyan Zhang, Robert B. Young, Huiyao Wang, Lei Hu, Cloelle Danforth, and Pei Xu

Published on Current Opinion in Chemical Engineering 42, 100973

https://www.sciencedirect.com/science/article/abs/pii/S2211339823000771

Human Health & Environmental Risk Assessment Framework

- Current applications of PW treatment and reuse in the US
- Opportunities and challenges for PW reuse outside O&G fields
- Regulatory framework and risk assessment approaches for PW reuse
- Human health and environmental risk assessment framework



NEW MEXICO PRODUCED WATER RESEARCH CONSORTIUM

Next Step of Work

- Collect the PW samples from pilot projects to treat Permian Basin PW, for physical, chemical, and toxicological analysis, and greenhouse irrigation experiments

Summary

- Developed state-of-the-science in produced water quality analysis methods
- Improved characterization of physical, chemical, microbiological, and environmental toxicity analysis of produced water and treated produced water from San Juan and Permian Basins
- Evaluated treatment efficiency of desalination (reverse osmosis, and thermal distillation) and post-treatment to reduce toxicity
- Over 300 targeted analytes were quantitatively analyzed in PW samples and the Pecos River. Provides baseline analytical information to advance PW research for potential reuse and fills the knowledge gap regarding PW quality to support science-based decision making.

Summary

- Statistically characterized produced water quality, quantity, and water demand in the Permian Basin
- Develop a transparent, environmental and human health risk assessment framework and tools for beneficial use of treated produced water
  - Provide sufficient data to decision-makers so that they may make informed decisions regarding fit-for-purpose use of treated produced water
  - Improve stakeholders' understanding and foster and support the broader interests in the quality of the decision-making process

NMSU Research Publications

1. Jiang, W., Lin, L., Xu, X., Wang, H., Xu, P. (2022) Analysis of regulatory framework for produced water management and reuse in major oil and gas producing regions in the United States. Water 14 (14), 2162. https://www.mdpi.com/2073-4441/14/14/2162

"This study reviews the current regulatory framework for produced water production, management, and reuse in the major oil and gas production areas in the U.S., including Appalachian Basin, California, Colorado, New Mexico, Oklahoma, Texas, and Wyoming."

2. Sabie, R.P., Pillsbury, L., and Xu, P. (2022). Spatiotemporal Analysis of Produced Water Demand for Fit-For-Purpose Reuse—A Permian Basin, New Mexico Case Study. Water 14 (11), 1735. https://www.mdpi.com/2073-4441/14/11/1735

"In this study, a generalized framework was developed for estimating produced water (PW) supply and potential demand for treated PW reuse in agriculture, dust suppression, power generation, and river flow augmentation using Eddy and Lea counties, New Mexico as a case study"

3. Tidwell, V., Gunda, T., Caballero, M., Xu, P., Xu, X., Bernknopf, R., Broadbent, C., Malczynski, L.A., Jacobson, J. (2022) Produced Water-Economic, Socio, Environmental Simulation Model (PW-ESEim) Model: Proof-of-Concept for Southeastern New Mexico. SAND2022-6636R. Published by Sandia National Lab.(SNL-NM), Albuquerque, NM (United States). https://www.osti.gov/servlets/purl/1868149

"A proof-of-concept tool, the Produced Water-Economic, Socio, Environmental Simulation model (PW-ESESim), was developed to support ease of analysis. The tool was designed to facilitate head-to-head comparison of alternative produced water sources, treatment, and reuse water management strategies. A graphical user interface (GUI) guides the user through the selection and design of alternative produced water treatment and reuse strategies and the associated health and safety risk and economic benefits."

4. Jiang, W., Xu, X., Hall, R., Zhang, Y., Carroll, K.C., Ramos, F., Engle, M.A., Lin, L., Wang, H., Sayer, M., Xu, P. (2022). Characterization of Produced Water and Surrounding Surface Water in the Permian Basin, the United States. Journal of Hazardous Materials. 430, 128409. https://doi.org/10.1016/j.jhazmat.2022.128409

"In this research, over 300 analytes for organics, inorganics, and radionuclides were quantitatively analyzed in produced water (PW) samples from the Permian Basin and in surface water samples from the Pecos River in New Mexico. This study provides baseline analytical information to advance PW research for potential reuse and fills the knowledge gap regarding PW quality to support science-based decision making.

5. Jiang, W., Xu, X., Hall, R., Zhang, Y., Carroll, K.C., Ramos, F., Engle, M.A., Lin, L., Wang, H., Sayer, M., Xu, P. (2022). Datasets associated with the characterization of produced water and Pecos River water in the Permian Basin, the United States. Data in Brief, 43, 108443. https://www.sciencedirect.com/science/article/pii/S2352340922006400

"This paper presents data related to the analysis of produced water and river water samples in the Permian Basin with a specific focus on wet chemistry, mineral salts, metals, oil and grease, volatile and semi-volatile organic compounds, radionuclides, ammonia, hydraulic fracturing additives, and per- and polyfluoroalkyl substances."

NMSU Research Publications

6. Hu, L., Jiang, W., Xu, X., Wang, H., Carroll, K.C., Xu, P., Zhang, Y. (2022). Toxicological characterization of produced water from the Permian Basin. Science of The Total Environment. 815(1), 152943. https://doi.org/10.1016/j.scitotenv.2022.152943

"In this study, an in vitro toxicity assessment was conducted using aquatic microorganisms to explore toxicological characteristics of produced water (PW) from the Permian Basin, New Mexico. It was found that high salinity, organic contaminants, metals, and ammonia present in PW are major toxicity drivers and need to be removed for fit-for-purpose beneficial uses of treated PW "

7. Thakur, P., Ward, A.L., Schaub, T.M. (2022). Occurrence and behavior of uranium and thorium series radionuclides in the Permian shale hydraulic fracturing wastes. Environmental Science and Pollution Research 29 (28), 43058-43071. https://link.springer.com/article/10.1007/s11356-021-18022-z

"This study explored the risk of releasing radioactive materials during the oil and gas recovery process in the Permian Basin, New Mexico. The results confirmed the presence of radioactive materials (^{224}Ra, ^{226}Ra, ^{228}Ra) in addition to dissolved salts, divalent cations, and high total dissolved solids in the hydraulic fracturing wastes."

8. Chen, L., Wang, H., Xu, P. (2022). Photocatalytic membrane reactors for produced water treatment and reuse: fundamentals, affecting factors, rational design, and evaluation metrics. Journal of Hazardous Materials, 127493. https://www.sciencedirect.com/science/article/abs/pii/S0304389421024614

"In this study, the potential of photocatalytic membrane reactors (PMR) to treat produced water (PW) was evaluated. The mechanisms of photocatalysis and membrane processes in a PMR, factors affecting PMR performance, rational design, and evaluation metrics for PW treatment were critically reviewed."

9. Jiang, W., Pokharel, B., Lin, L., Cao, H., Carroll, K.C., Zhang, Y., Galdeano, C., Musale, D.A., Ghurye, G.L., Xu, P. (2021). Analysis and Prediction of Produced Water Quantity and Quality in the Permian Basin using Machine Learning Techniques. Science of the Total Environment. 141693. https://www.sciencedirect.com/science/article/abs/pii/S0048969721047689

"In this research, historical produced water (PW) quantity and quality data in the New Mexico portion (NM) of the Permian Basin were comprehensively analyzed, and then, various machine learning algorithms were applied to predict PW quantity for different types of oil and gas wells."

10. Jiang, W., Lin, L., Xu. X., Cheng, X., Zhang, Y., Hall, R., Xu, P. (2021). A Critical Review of Analytical Methods for Comprehensive Characterization of Produced Water. Water, 2021, 13(2), 183; https://doi.org/10.3390/w13020183

"This paper broadly discusses current analytical techniques for produced water characterization, including both standard and research methods. Multi-tiered analytical procedures are proposed including field sampling; sample preservation; pretreatment techniques; basic water quality measurements; organic, inorganic, and radioactive materials analysis; and biological characterization."

NMSU Research Publications

11. Chen, L., Xu, P., Kota, K., Kuravi, S., Wang, H. (2021). Solar distillation of highly saline produced water using low-cost and high-performance carbon black and airlaid paper-based evaporator (CAPER). Chemosphere, 269, 129372.https://doi.org/10.1016/j.chemosphere.2020.129372

"This research introduces a solar-driven carbon black and airlaid paper-based evaporator (CAPER) for desalination of produced water in the Permian Basin, New Mexico. CAPER is low cost, robust, and has the capability of achieving higher removals of salts, heavy metals, Ca, Na, Mg, Mn, Ni, Se, Sr, and V."

12. Hu, L., Wang, H., Xu, P. and Zhang, Y. (2021) Biomineralization of hypersaline produced water using microbially induced calcite precipitation. Water Research, 190, 116753. https://doi.org/10.1016/j.watres.2020.116753

"This study demonstrates the ability of the microbially induced calcite precipitation (MICP) technique that utilizes ureolytic bacteria, to remove Ca^{2+} *and toxic contaminants from high salinity produce water for the first time."*

13. Chen, L., Xu, P., Wang, H. (2020) Interplay of the Factors Affecting Water Flux and Salt Rejection in Membrane Distillation: A State-of-the-Art Critical Review. Water 2020, 12(10), 2841; https://doi.org/10.3390/w12102841

"This review paper deeply examines the effects of membrane characteristics, feed solution composition, and operating conditions on water flux, mass transport, heat transfer and salt rejection in membrane distillation process."

14. Lu Lin, Wenbing Jiang, Lin Chen, Pei Xu and Huiyao Wang (2020). Treatment of Produced Water with Photocatalysis: Recent Advances, Affecting Factors and Future Research Prospects. Catalysts, 10(8), 924. https://doi.org/10.3390/catal10080924

"This review paper investigated the applicability of photocatalysis-based treatment for produced water (PW) treatment. Factors affecting decontamination, strategies to improve photocatalysis efficiency, recent developments, and future research prospects on photocatalysis-derived systems for PW treatment are discussed here in detail."

15. Alfredo Zendejas Rodriguez, Huiyao Wang, Lei Hu, Yanyan Zhang, and Pei Xu. (2020). Treatment of Produced Water in the Permian Basin for Hydraulic Fracturing: Comparison of Different Coagulation Processes and Innovative Filter Media. Water, 12(3), 770. https://doi.org/10.3390/w12030770

"In this research, chemical coagulation [using $FeCl_3$ *and* $Al_2(SO_4)_3$*] was compared with electrocoagulation (using aluminum electrodes) for their suitability in removing suspended contaminants from produced water for reuse in hydraulic fracturing. The feasibility of several filter media was also studied for refining effluent of the coagulation"*

NMSU Research Publications

16. Scanlon, B.R., Reedy, R.C., Xu, P., Engle, M., Nicot, J.P., Yang, Q., and Ikonnikova, S. (2020). Datasets associated with investigating the potential for beneficial reuse of produced water from oil and gas extraction outside of the energy sector. Data in Brief, 105406. https://www.sciencedirect.com/science/article/pii/S2352340920303000

"This article presents data related to volumes of water co-produced with oil and gas production, county-level estimates of annual water use volumes by various sectors, including hydraulic fracturing water use, and the quality of produced water.

17. Scanlon, B.R., Reedy, R.C., Xu, P., Engle, M., Nicot, J.P., Yang, Q., and Ikonnikova, S. (2020). Can we Beneficially Reuse Produced Water from Oil and Gas Extraction in the U.S.? Science of the Total Environment, 717, 137085. https://www.sciencedirect.com/science/article/pii/S0048969720305957

"This study investigated the quantity and the quality of produced water volumes in major U.S. shale oil and gas plays relative to treatment and potential reuse options in irrigation, municipal use, industrial use, surface water and groundwater recharge, and hydraulic fracturing."

18. 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. https://doi.org/10.1016/j.cej.2019.123001

"This study demonstrated the feasibility of recovering struvite fertilizer from produced water after calcium pretreatment. Recovered struvite was in sufficient quality with no accumulation of heavy metals and organic contaminants."

19. Chaudhary, B., Sabie, R., Engle, M., Xu, P., Willman, S., Carroll, K. (2019) Produced Water Quality Spatial Variability and Alternative-Source Water Analysis Applied to the Permian Basin, USA. Hydrogeology Journal, 27, 2889-2905. https://link.springer.com/article/10.1007/s10040-019-02054-4

"In this research, geochemical variability of produced water from Guadalupian (Middle Permian) to Ordovician formations was statistically and geo-statistically evaluated in the western half of the Permian Basin using the US Geological Survey's Produced Waters Geochemical Database and the New Mexico Water and Infrastructure Data System."

20 .Geza, M., Ma, G., Kim, H., Cath, T.Y., Xu, P. (2018). iDST: An integrated decision support tool for treatment and beneficial use of non-traditional water supplies – Part I. Methodology. Journal of Water Process Engineering, 25, 236-246. https://www.sciencedirect.com/science/article/abs/pii/S2214714418303350

"In this study, a Visual Basic for Applications (VBA) - based integrated decision support tool was developed to select a combination of treatment technologies/trains for different types of alternative water sources (municipal wastewater, geothermal water) and beneficial reuse options (portable reuse, irrigation, surface discharge, and power plant cooling)."

21. Ma, G., Geza, M., Cath, T.Y., Drewes, J.E., Xu, P. (2018). iDST: An integrated decision support tool for treatment and beneficial use of non-traditional water supplies – Part II. Marcellus and Barnett shale case studies. Journal of Water Process Engineering, 25, 258-268. https://www.sciencedirect.com/science/article/abs/pii/S2214714418303362

"This study presents an integrated decision support tool to assist in selecting treatment technologies and potential water reuse options for produced water considering the Marcellus Shale in Pennsylvania and the Barnett Shale in Texas as case studies."

NMSU Research Publications

22. EMNT Edirisooriya, H Wang, S Banerjee, K Longley, W Wright, W Mizuno, P. Xu. (2024) Economic feasibility of developing alternative water supplies for agricultural irrigation. Current Opinion in Chemical Engineering 43, 100987

23. HMK Delanka-Pedige, Y Zhang, RB Young, H Wang, L Hu, C Danforth, P. Xu. Safe reuse of treated produced water outside oil and gas fields? (2023) A review of current practices, challenges, opportunities, and a risk-based pathway for produced water treatment. Current Opinion in Chemical Engineering 42, 100973

24. L Chen, P Xu, DA Musale, Y Zhang, R Asfan, C Galdeano, GL Ghurye, H. Wang. (2023) Multifunctional photocatalytic membrane distillation for treatment of hypersaline produced water using hydrophobically modified tubular ceramic membranes. Journal of Environmental Chemical Engineering, 111538

2024 Goals and Objectives

- Conduct pilot demonstration projects for treating produced water using integrated treatment trains (pretreatment, treatment/desalination, post-treatment, resource recovery)
- Collect water samples for targeted and non-targeted chemical analysis
- Conduct Whole Effluent Testing (WET) – In Vivo (Environment) & In Vitro (Human Health)
  - Basis for characterizing risks of non-quantifiable constituents
  - Combine with analysis of chemical constituents of interest
- Conduct quantitative exposure & risk assessment modeling framework

2024 Goals and Objectives

- Peer-reviewed publications on targeted and non-targeted analysis, toxicity studies
- Stakeholder Engagement & Practical Guidance for Implementation
  - Disseminating new knowledge via public meetings, workshops, demonstrations, video, podcasts, and publications
  - Communicating science and knowledge to regulatory agencies
  - Improving framework and research based on stakeholders' opinion and acceptance
- Workforce development – next generation of engineers

2024 Goals and Objectives

Raise funds for research!

Pilot testing of integrated treatment train

Analysis, materials, supplies, labor support