Produced Water Characterization, Treatment, and Reuse

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Radioactive and Hazardous Materials Committee

October 10, 2023

NM STATE

NM STATE NEW MEXICO PRODUCED WATER RESEARCH CONSORTIUM

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NM Produced Water Research Consortium

https://nmpwrc.nmsu.edu/

- Created under the New Mexico 2019 Produced Water Act
- The objectives of the Consortium are to:
  - Fill the scientific and technical gaps associated with treatment and reuse of produced water
  - Inform future development of science-based policies and regulations
  - Coordinate a robust education, outreach, research, and development program
  - Encourage water stewardship through produced water treatment and reuse:
    - Reduce/eliminate fresh water use in the oil and gas sector
    - Provide new water for economic development
    - Assure public and environmental health and safety using cost-effective treatment

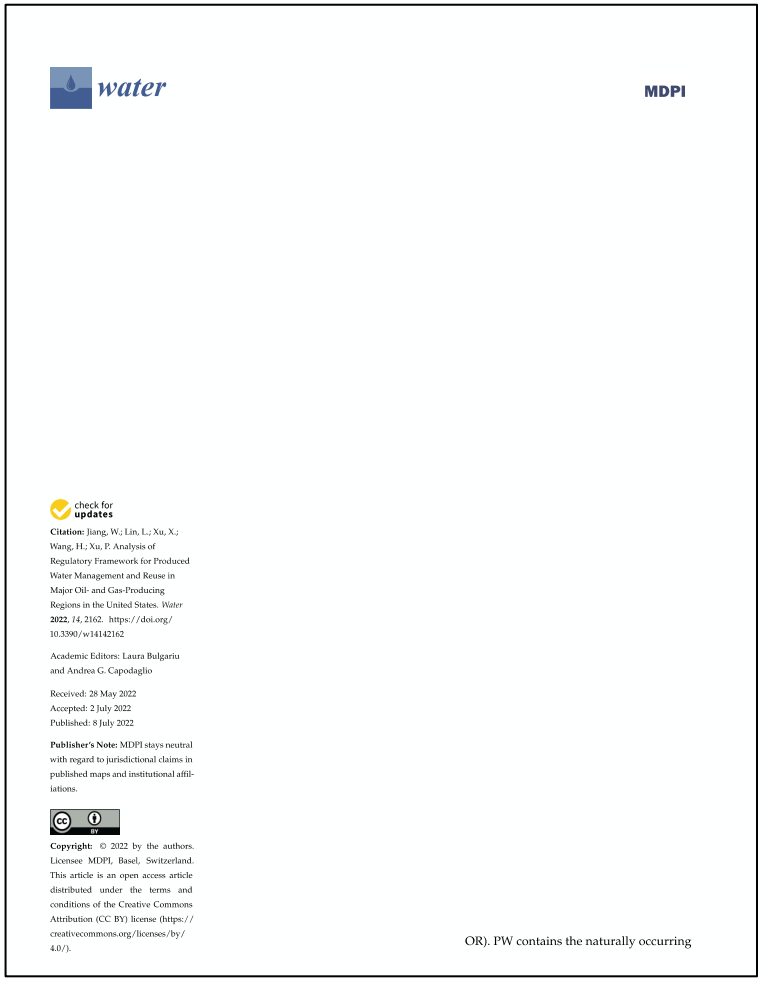
Consortium – a public-private partnership with state and federal agencies, organizations of industry, NGOs, companies, national labs, and academia

Produced Water Characterization is Challenging

- Constituents of concern in produced water (formation water and flowback water):
  - Suspended solids, oils, and grease
  - Salts (referred to as dissolved solids) and metals
  - Dissolved organics (e.g., petroleum hydrocarbons, volatile and semi-volatile compounds)
  - Dissolved gases (e.g., H_2S, NH_3)
  - Naturally occurring radioactive material (NORM)
  - Microorganisms
  - Chemical additives (well completion and on-going well maintenance)
  - Transformation/degradation products, and unknowns
- Produced water quality and quantity are highly variable, spatial and temporal
- High salinity and complex water chemistry cause challenges in analytical methods and treatment
- Costly and time-consuming for “comprehensive” analysis

What Constituents Should We Analyze? NPDES+ List

- Published in Water 2022, 14(14), 2162; https://doi.org/10.3390/w14142162
- Water quality standards for surface water discharge, land application, irrigation, wildlife and livestock watering, road application, dust control, and groundwater standards
- Developed a multi-tiered analytical approach with a comprehensive analytical list for characterization of physical, chemical, and biological properties of raw produced water and treated produced water using target and non-target analyses as well risks and toxicity assessment



water

MDPI

check for updates

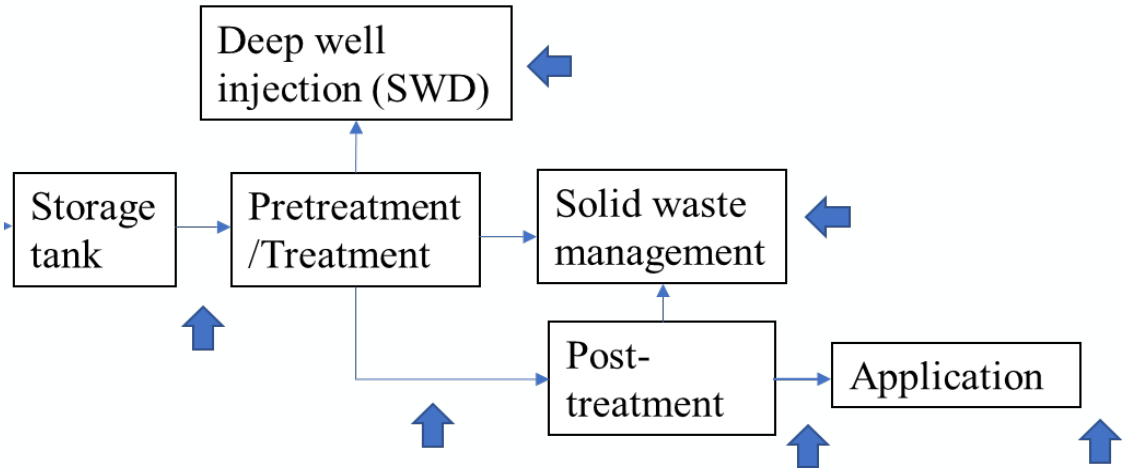
Citation: Jiang, W.; Lin, L.; Xu, X.; Wang, H.; Xu, P. Analysis of Regulatory Framework for Produced Water Management and Reuse in Major Oil- and Gas-Producing Regions in the United States. *Water* **2022**, *14*, 2162. https://doi.org/10.3390/w14142162

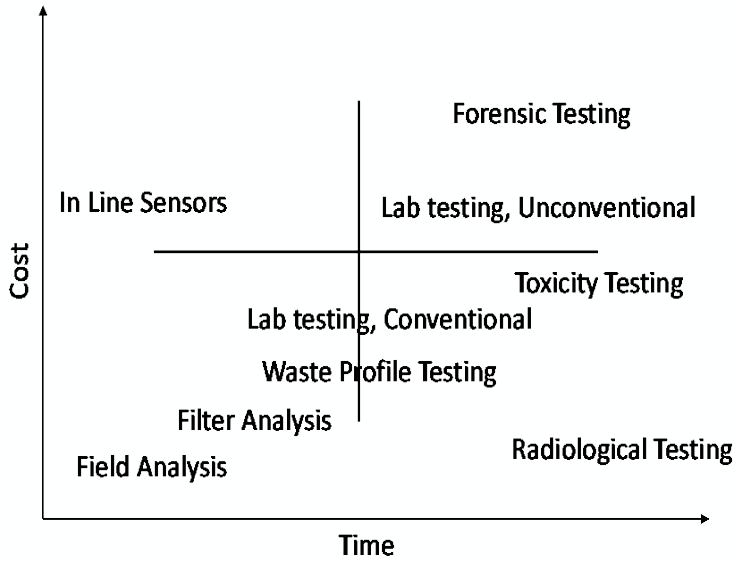
Academic Editors: Laura Bulgariu and Andrea G. Capodaglio

Received: 28 May 2022
Accepted: 2 July 2022
Published: 8 July 2022

OR). PW contains the naturally occurring

Multi-tiered Approach for Produced Water Characterization – NPDES+





The cost and turnaround time of produced water analysis

Multi-tiered Approach for Produced Water Characterization – NPDES+

Level	Use	Parameters	Frequency	Sample
Tier 1	Continuous monitoring, bulk testing, rapid analysis, process control	Flow TSS/Turbidity TDS/EC TOC/DOC/COD pH ORP Iron (total, dissolved, Fe^{2+}) H_2S NH_3 Alkalinity Hardness (total, dissolved) Specific gravity Percent Moisture Optional: UV-Vis, Fluorescence excitation-emission matrix (F-EEM)	Baseline, real-time, continuous, and routine	Feed/produced water Product water Brine

Multi-tiered Approach for Produced Water Characterization – NPDES+

Level	Use	Parameters	Frequency	Sample

Tier 2	Detailed characterization, routine monitoring, and Tier 1 data verification	**Inorganics**
		• Metal elements (33), SW-864 6020A, dissolved, total Hg, SW-846 7470
		• Anions (7), EPA 300
		• Radionuclides
		  • Radium 226, 228
		  • Gross Alpha/Beta
		  • U 235, 236, 238
		  • Strontium 90
			Baseline (at least once)
			Demonstrating treatment efficacy and reliability, beneficial reuse investigation
				Feed/produced water
				
				Product water
				
				Brine

Multi-tiered Approach for Produced Water Characterization – NPDES+

Level	Use	Parameters	Frequency	Sample

Tier 2	Detailed characterization, routine monitoring, and Tier 1 data verification	**Organics**
		• Oil and Grease
		• GRO [C6-C10] by 8015D
		• DRO [C10-C28] by 8015D
		• MRO (C28-40) by 8015D
		• VOCs SW-846 8260 (91)
		• SVOC - General by 8270E (139)
		• SVOC - TPH by 8015 (8)
		• 1-2 samples for screening:
		  • VOC - TPH by 8015
		  • SVOC - Explosives by 8330B
		  • SVOC - Agent Breakdown Products
		  • SVOC - Pesticides/Herbicides by 8081B
		  • SVOC - Polychlorinated biphenyls (PCBs) (8280A)
		  • SVOC - PAHs
		  • SVOC - Organic Acids by 8015D
		  • SVOC – Dioxins
		  • TOX by SW 846 9020
		  • PFOA, PFOS & PFHxS by EPA 537.1 Modified
			Baseline (at least once), Demonstrating treatment efficacy and reliability, beneficial reuse investigation	Feed/ produced water
				
				Product water
				
				Brine

Multi-tiered Approach for Produced Water Characterization – NPDES+

Level	Use	Parameters	Frequency
Tier 3	Risks and toxicology assessment	WET Testing acute and chronic toxicity	Product water (at least once)
		HiRes LC-MS non-target screening	
	Fate/transport modeling.	Analysis of treated effluent on soil, plant, tissue samples	
Tier 4	Waste and residual characterization	Mass balance	As needed

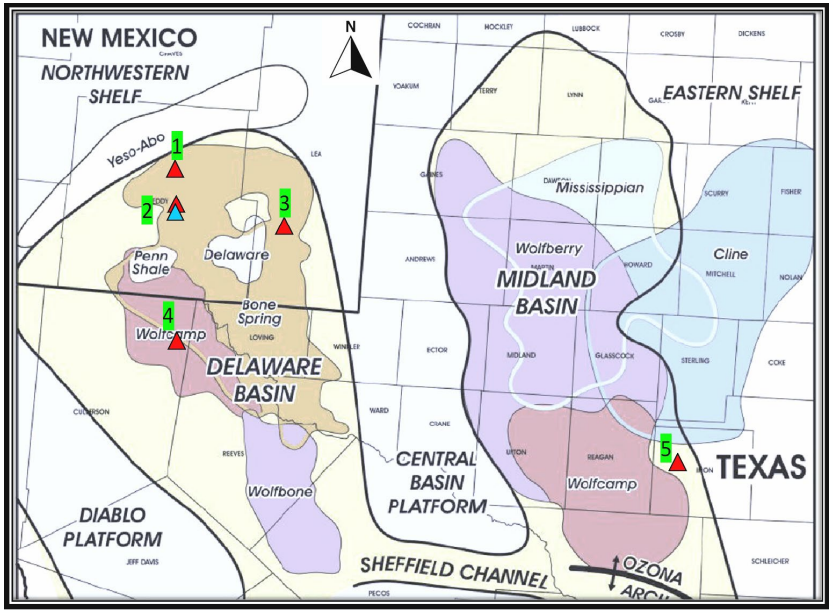
Characterization of Produced Water in the Permian Basin

- Produced water quality is highly variable: by region, within an oil or gas play, with time
- Limited produced water quality data in existing database: primarily inorganic ions

	Permian Basin	Wolfcamp Formation	Delaware Formation	Artesia Formation	Yeso Formation	Bone Spring Formation	San Andres Formation
TDS (mg/L)	10,048-384,963/ 118,253	12,136-249,459/ 95,096	12,708-360,545/ 185,433	10,050-384,963/ 94,584	10,818-381,108/ 123,784	10,048-255,451/ 105,569	10,026-391,007/ 118,879
pH	0.5-11.7/6.8	4.5-8.6/7.0	4.8-8.9/6.9	4.6-9.7/7.1	0.5-8.8/6.7	6.3-7.1/6.8	0.6-11.7/6.9
Mg (mg/L)	3-27,910/ 1,901	84-5,965/ 1,103	3-10,800/ 2,509	12-18,400/ 1,593	12-18,980/ 2,281	54.4-3396.6/ 760	2.7-27,910/ 2,087
Ca (mg/L)	24-60,073/ 6,051	211-40,800/ 6,358	24-46,346/ 12,992	87-25,315/ 3,205	235-40,420/ 6,996	174.5-21,720/ 3347	107-60,073/ 6,952
Cl (mg/L)	40-245,700/ 71,224	3,951-151,900/ 56,362	2,460-225,612/ 113,116	3,794-222,596/ 56,580	2,350-237,245/ 74,606	4,076-156,699/ 60,184	40-245,700/ 70,738
Na (mg/L)	209-143,086/ 71,224	2,625-54,068/ 29,045	5,253-109,024/ 51,113	209-128,175/ 37,470	1,529-107,396/ 35,948	1,982-80,469/ 30,723	1,123-143,086/ 35,479
K (mg/L)	14-33,962/ 861	97-742/ 362	79-1,454/ 548	65-4,620/ 505	14-1,570/ 472	109.8-1,232/ 365	8-33,962/ 1,622
Sulfate (mg/L)	18-12,320/ 2,131	84-12,080/ 1,753	84-6,280/ 1,523	18-11,900/ 2,294	35-11,800/ 2,211	111-5,250/ 1,420	22.4-12,320/ 2,362
Br (mg/L)	10-1,064/ 430	10 - 756/ 390	NA	NA	240-963/ 481	152-1,065/ 382	17-517/ 153
HCO3 (mg/L)	5-7,440/ 731	5-4,204/ 619	5-5,558/ 376	9-7,440/ 878	5-3,851/ 645	5-891/ 390	7-3,960/ 663
TOC (mg/L)	53-184/123	86-184/138	NA	NA	NA	119	NA

Characterization of Produced Water in the Permian Basin

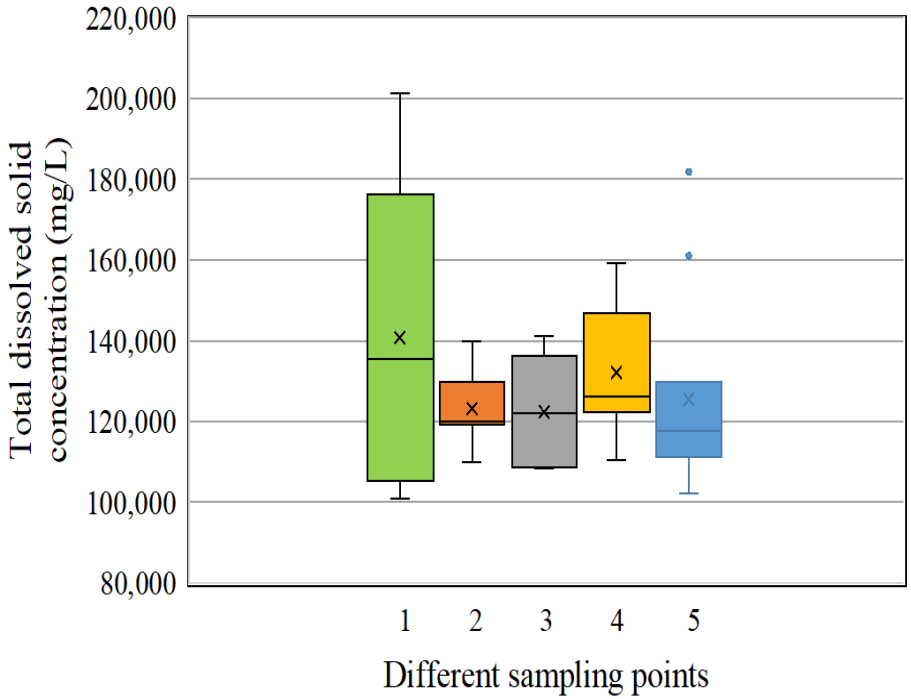
Sampling points of 46 PW and 10 Pecos River water



▲ Produced water sampling point

▲ Pecos River water sampling point

TDS distribution of PW at different sampling points



Source: Jiang et al., JHM 2022, 430, 128409

Characterization of Produced Water in the Permian Basin

Targeted Chemical Analysis

More than 300 targeted analytes were quantitatively analyzed, including wet chemistry, inorganics, radionuclides, organics such as VOCs, SVOCs, total petroleum hydrocarbons, organic acids, oil and grease, pesticides/herbicides, dioxins, and tentatively identified compounds, and per- and polyfluoroalkyl substances (PFAS).

For 10 produced water samples collected in 2020, 91 analytes were quantified and 218 analytes were not detected (309 in total)

For 10 Pecos River samples collected in 2020, 67 analytes were quantified and 242 analytes were not detected (309 in total)

Source: Jiang et al., JHM 2022, 430, 128409

Water Quality Characterization

Statistical results of general quality parameters of the 46 PW samples collected from the 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

Source: Jiang et al., JHM 2022, 430, 128409

Water Quality Characterization

Produced Water		Average	Max	Min
Radionuclide				
Gross Alpha	pCi/L	1105.6	1630	660
Gross Beta	pCi/L	874.6	1230	456
Radium-226	pCi/L	43.92	111	0.736
Radium-228	pCi/L	151.27	291	2.56

Water quality of Pecos River water samples		Average	Max	Min	Drinking water standards
Radionuclide					
Gross Alpha	**pCi/L**	**24.6**	**39.8**	**7.7**	**15**
Gross Beta	pCi/L	14.1	24.2	1.4	4 millirems per year
Radium-226	pCi/L	3.56	29.9	0.1	5 pCi/L for
Radium-228	pCi/L	0.42	0.8	0.2	Combined Ra226/228

Water Quality Characterization

Produced Water **VOCs**		Average	Max	Min
Benzene	mg/L	2.61	4.90	1.90
Ethylbenzene	mg/L	0.11	0.16	0.07
Toluene	mg/L	2.53	3.70	1.70
Xylenes, Total	mg/L	1.19	1.60	0.71

No VOCs detected in Pecos River (9 samples)

Produced Water		Average	Max	Min
Oil and Others				
Diesel Range Organics (C10-C20)	ug/L	45,750	130,000	22,000
Gasoline Range Organics [C6 - C10]	ug/L	21,625	46,000	13,000
Motor oil/lube range organics (MRO) (C20-C34)	ug/L	32,444	97,000	12,000
Tributyl phosphate	ug/L	34.6	74	3.3
Tentatively Identified Compound	ug/L	531	1000	280

Pecos River water samples		Average	Max	Min
Oil and Others				
Gasoline Range Organics [C6 - C10]	ug/L		54	ND
Motor oil/lube range organics (MRO) (C20-C34)	ug/L	230	310	180
Tributyl phosphate	ug/L	3.6	5.7	1.7
Tentatively Identified Compound	ug/L	-	55	-

Source: Jiang et al., JHM 2022, 430, 128409

Water Quality Characterization

Produced water		Average	Max	Min
Organic - SVOC - General		Average	Max	min
1,1'-Biphenyl	ug/L	5.9	8.5	3.8
1,4-Dioxane	ug/L		21	ND
1-Methylnaphthalene	ug/L	23	36	15
2-Methylnaphthalene	ug/L	38	65	26
2-Methylphenol	ug/L	82	98	68
2,4-Dimethylphenol	ug/L	34	42	29
Ethylene glycol	mg/L		27	ND
Methylphenol, 3 & 4	ug/L	90	110	72
Phenol	ug/L	203	250	170
Pyridine	ug/L	238	300	120

Not detected in Pecos River (9 samples)

Water Quality Characterization

Produced Water		Average	Max	Min
Organic - SVOC - Pesticides/Herbicides				
alpha-BHC	ug/L	0.018	0.027	0.0088
Endosulfan I	ug/L	0.855	0.98	0.73
Endrin	ug/L		0.0038	ND

Pecos River water		**Average**	**Max**	**Min**
Organic - SVOC - Pesticides/Herbicides				
Endosulfan I	ug/L	0.00405	0.0042	0.0039
4,4'-DDD	ug/L		0.01	ND
4,4'-DDT	ug/L		0.0057	ND

Produced Water		Average	Max	Min
Organic - SVOC - PAH				
Anthracene	ug/L		1.1	ND
Naphthalene	ug/L	15.44	24	11
Phenanthrene	ug/L	3.76	6.6	2.7
Fluorene	ug/L	4.35	5.6	3.1

Pecos River water		**Average**	**Max**	**Min**
Organic - SVOC - PAH				
Naphthalene	ug/L		6	ND
Fluorene	ug/L		1.2	ND

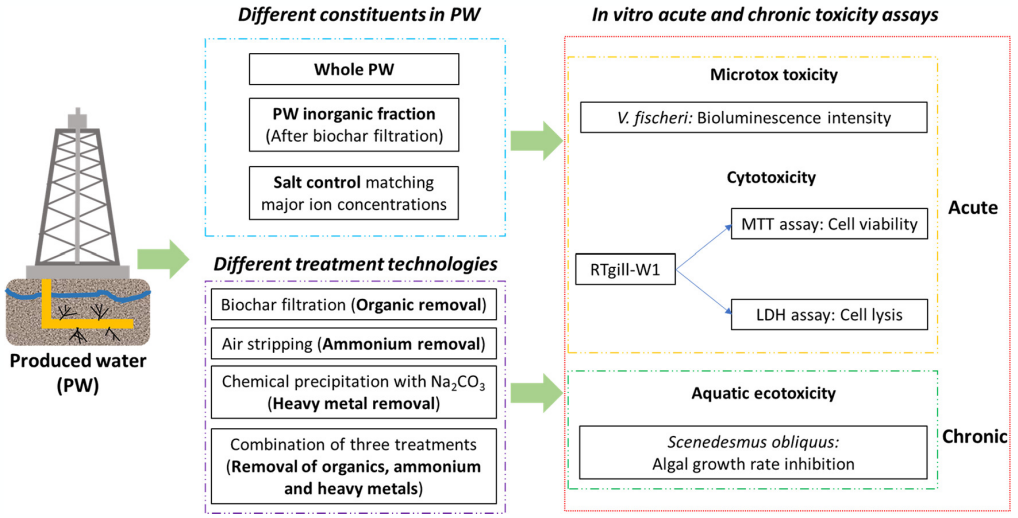
Water Quality Characterization

	PW/ Pecos	PW MDL/RL	Pecos MDL/RL		PW/ Pecos	PW MDL/RL	Pecos MDL/RL
PFBS	0.17 J/2.0	0.15/1.5	0.16/1.6	PFNS	ND/ND	0.12/1.5	0.13/1.6
PFBA	0.31 J B/ 1.3 J B	0.25/1.5	0.28/1.6	PFNA	ND/ND	0.2/1.5	0.21/1.6
PFDS	ND/ND	0.23/1.5	0.25/1.6	FOSA	ND/ 0.54 J B	0.25/1.5	0.28/1.6
PFDA	ND/ND	0.23/1.5	0.24/1.6	PFOS	ND/1.2 J	0.39/1.5	0.42/1.6
PFDoS	ND/ND	0.33/1.6	0.35/1.6	PFOA	ND/1.0 J	0.62/1.5	0.67/1.6
PFDoA	ND/ND	0.4/1.6	0.43/1.6	PFPeS	ND/0.24 J	0.22/1.5	0.24/1.6
PFHpS	ND/ND	0.14/1.6	0.15/1.6	PFPeA	ND/1.8	0.36/1.5	0.39/1.6
PFHpA	ND/0.35 J	0.18/1.5	0.2/1.6	PFTeA	0.24 J/ND	0.21/1.5	0.23/1.6
PFHxS	0.25 J B/ 1.0 J B	0.12/1.5	0.13/1.6	PFTriA	ND/ND	0.94/1.5	1/1.6
PFHxA	ND /1.2 J	0.42/1.5	0.46/1.6	PFUnA	ND/ND	0.8/1.5	0.87/1.6
NEtFOSA	ND/ND	0.63/1.5	0.68/1.6	NMeFOSA	ND/ND	0.31/1.5	0.34/1.6
NEtFOSE	0.98 J/ND	0.62/1.5	0.67/1.6	NMeFOSAA	ND/ND	2.3/15	2.4/16
NEtFOSAA	ND/ND	1.4/15	1.5/16	NMeFOSE	ND/ND	1/2.9	1.1/3.1
4:2 FTS	ND/ND	3.8/15		6:2 FTS	ND/ND	1.5/15	
8:2 FTS	ND/ND	1.5/15		10:2 FTS	ND/ND	0.14/1.5	
DONA	ND/ND	0.13/1.5		HFPO-DA (GenX)	ND/ND	1.1/2.9	
F-53B Major	ND/ND	0.17/1.5		F-53B Minor	ND/ND	0.23/1.5	

Preliminary PFAS Results of 1 Produced Water Sample (5/34 detected) and 1 Pecos River Sample (10/34 compounds detected)

Toxicological Characterization of Produced Water from the Permian Basin

- PW toxicity was studied using in vitro toxicity assays using various aquatic organisms (luminescent bacterium , fish gill cell line RTgill-W1, and microalgae).
- High salinity was the foremost toxicological driver in PW, followed by organic contaminants.
- Treatment required to reduce toxicity:
  - Salts - Desalination
  - Organic removal
  - Ammonia removal
  - Heavy metals removal



Source: Hu et al., Sci. Total Environ 2022, 815, 152943

Journal of Hazardous Materials 430 (2022) 128409

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Research Paper

Characterization of produced water and surrounding surface water in the Permian Basin, the United States

Wenbin Jiang [a], Xuesong Xu [a], Ryan Hall [b], Yanyan Zhang [a], Kenneth C. Carroll [c], Frank Ramos [d], Mark A. Engle [e], Lu Lin [a], Huiyao Wang [a], Matthias Sayer [b], Pei Xu [a,*]

Data in Brief 43 (2022) 108443

Contents lists available at ScienceDirect

Data in Brief

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Data Article

Datasets associated with the characterization of produced water and Pecos River water in the Permian Basin, the United States

Wenbin Jiang[a], Xuesong Xu[a], Ryan Hall[b], Yanyan Zhang[a], Kenneth C. Carroll[c], Frank Ramos[d], Mark A. Engle[e], Lu Lin[a], Huiyao Wang[a], Matthias Sayer[b], Pei Xu[a,*]

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Major Focus: State-of-the-Art Risk and Toxicology Testing

Standardized:

- Standardized Sampling Protocol w/USEPA by NMSU
- NPDES+ Analysis (300 Constituents)
  - 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
- Need to develop advanced analytical tools and risk assessment methods to evaluate the impact on environmental and public health
- High analytical costs

Summary

- Provide data, information, and knowledge to assist in developing science-based regulations for fit-for-purpose reuse of treated produced water
- Improve characterization of physical, chemical, microbiological, and environmental toxicity analysis of produced water and treated produced wate
- Evaluate integrated treatment systems including pretreatment, treatment/desalination, and post-treatment for fit-for-purpose applications
- Evaluate economic, social, and environmental risks/benefits of produced water reuse
- Developed foundational documents such as produced water research roadmaps and gaps Analysis, research plan, testing guidance and protocols
- Published >20 journal papers on produced water characterization, treatment, and regulations
- Collaborate extensively with federal, state, industry, NGOs, TX and CO Consortiums, and other stakeholders

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