Unconventional Oil and Gas Exploration

Outlook for Water Reuse and Potential Impacts on Distribution Pipes

May 9, 2018

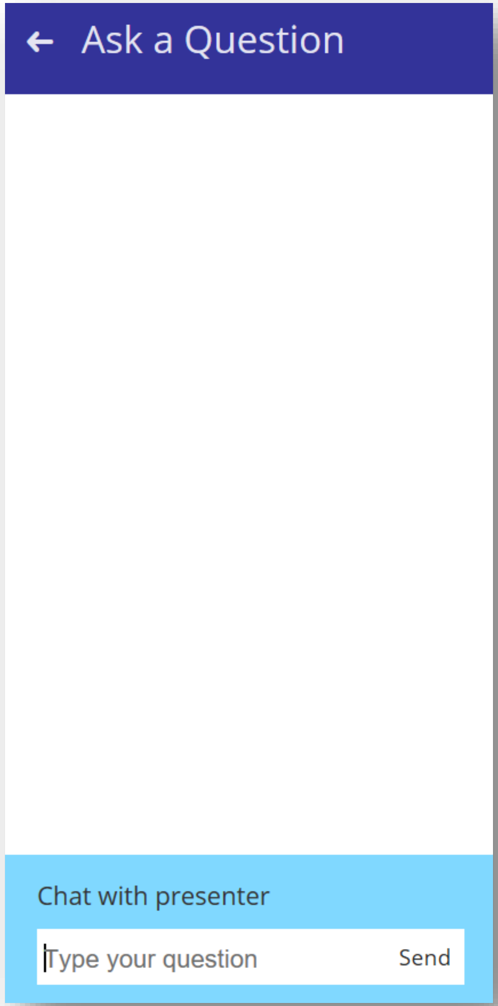
WATEREUSE

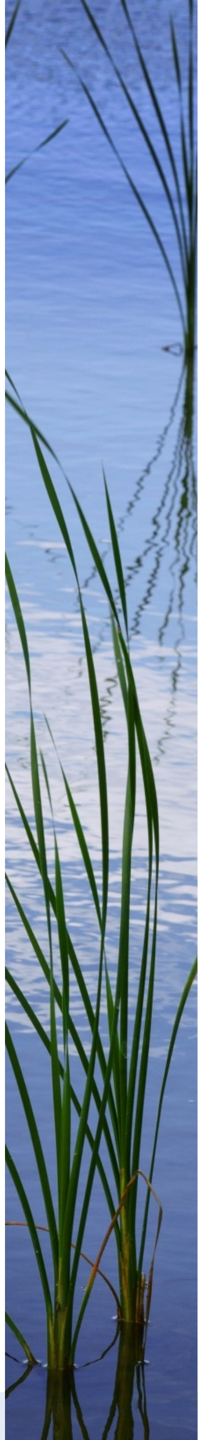
THE Water Research FOUNDATION

WateReuse Webcast Series

A Few Notes Before We Start…

- Today's webcast will be 60 minutes.
- There is one Professional Development Hours (PDH) available for this webcast.
- A PDF of today's presentation can be downloaded when you complete the survey at the conclusion of this webcast.
- If you have questions for the presenters please send a message by typing it into the chat box located on the panel on the left side of your screen.





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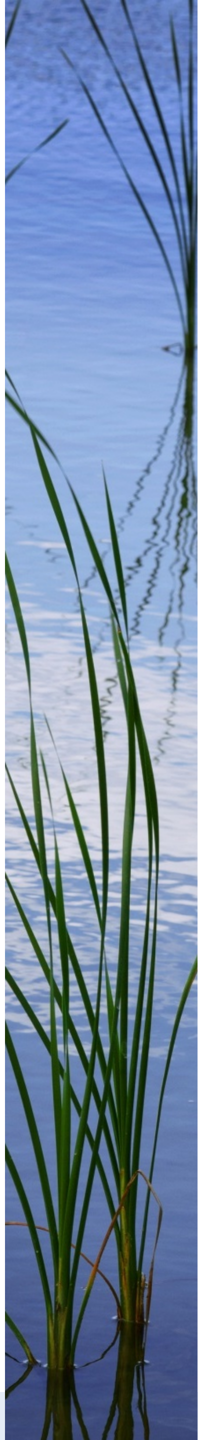
WateReuse is the nation's only trade association dedicated solely to advancing the policy, technology, innovation and public acceptance of water reuse.

Today’s Presenters

Jian Zhang (Moderator)
Water Research Foundation

Christopher Bellona, PhD
Colorado School of Mines

Andrew J. Whelton, PhD
Purdue University



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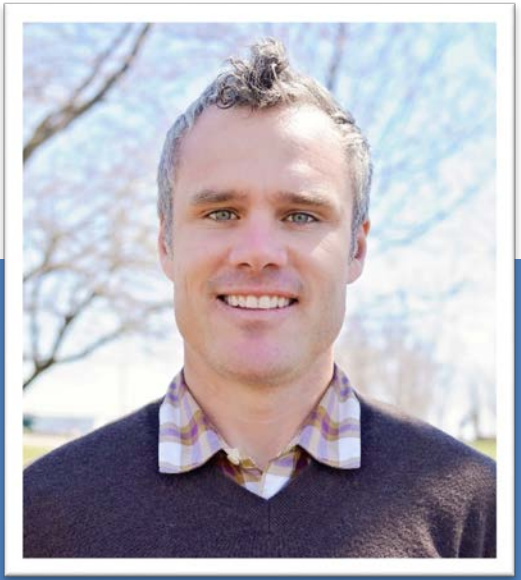

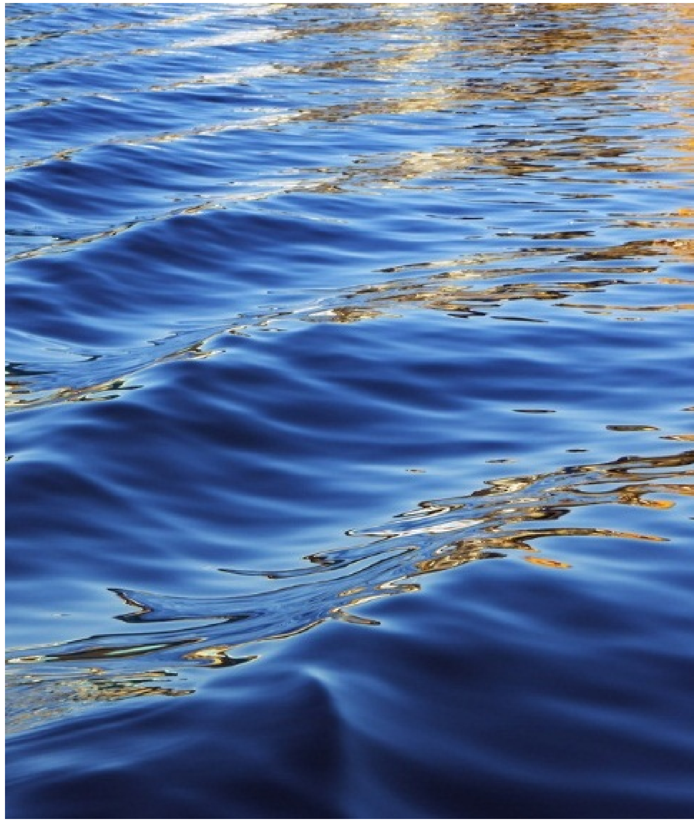

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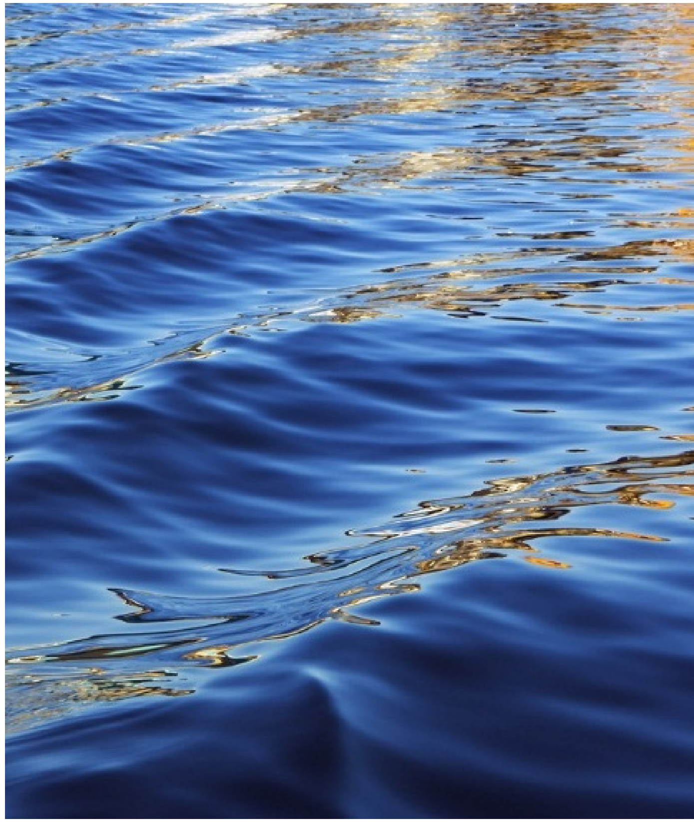
Outlook for Water Reuse in the Unconventional Oil and Gas Industry

Christopher Bellona
Tzahi Cath
Hooman Vatankhah
Travis Stevens
Colorado School of Mines

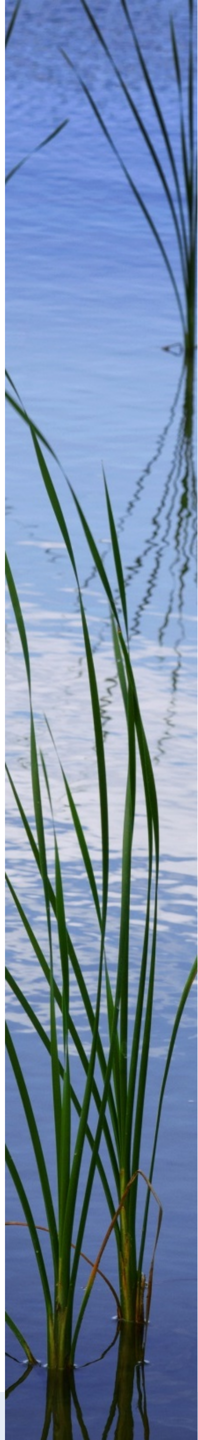
Joon Min
BKT

WRRF Project 14-05



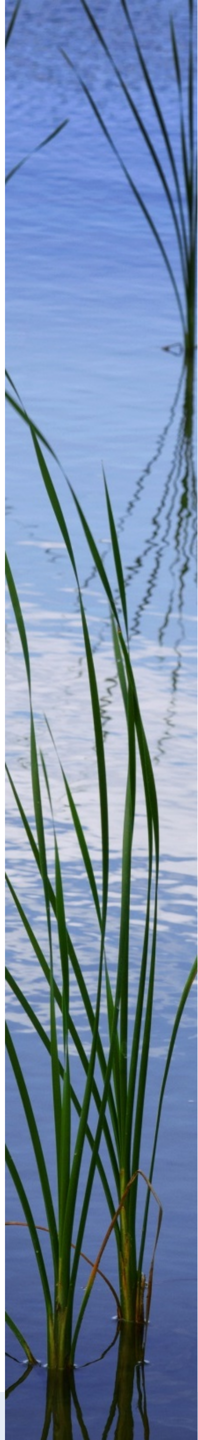
WRRF 14-05 Project Introduction

- Desk-top study to evaluate the prospects of water reuse in the oil and gas industry
- Evaluated a variety of information
  - Peer-reviewed publications
  - Reports
  - Presentations
  - Gray literature
  - Regulations
- Conducted a survey of professionals in the oil and gas industry



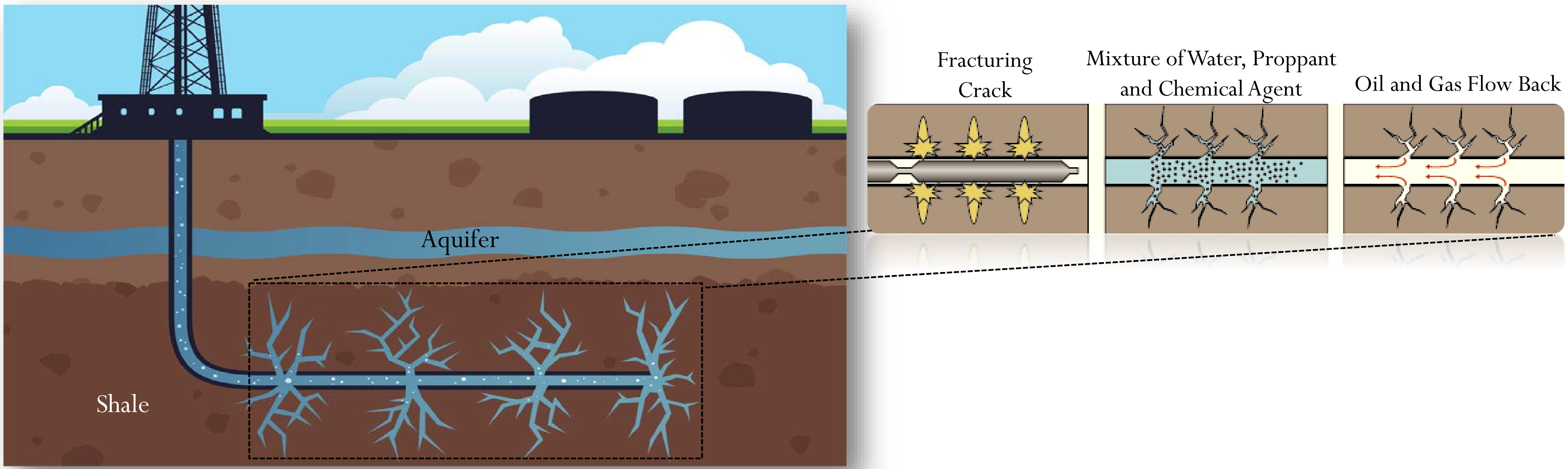
Outline

- Introduction to unconventional oil and gas production and water
- Drivers and challenges for recycling and reuse
- Case studies
- Conclusions

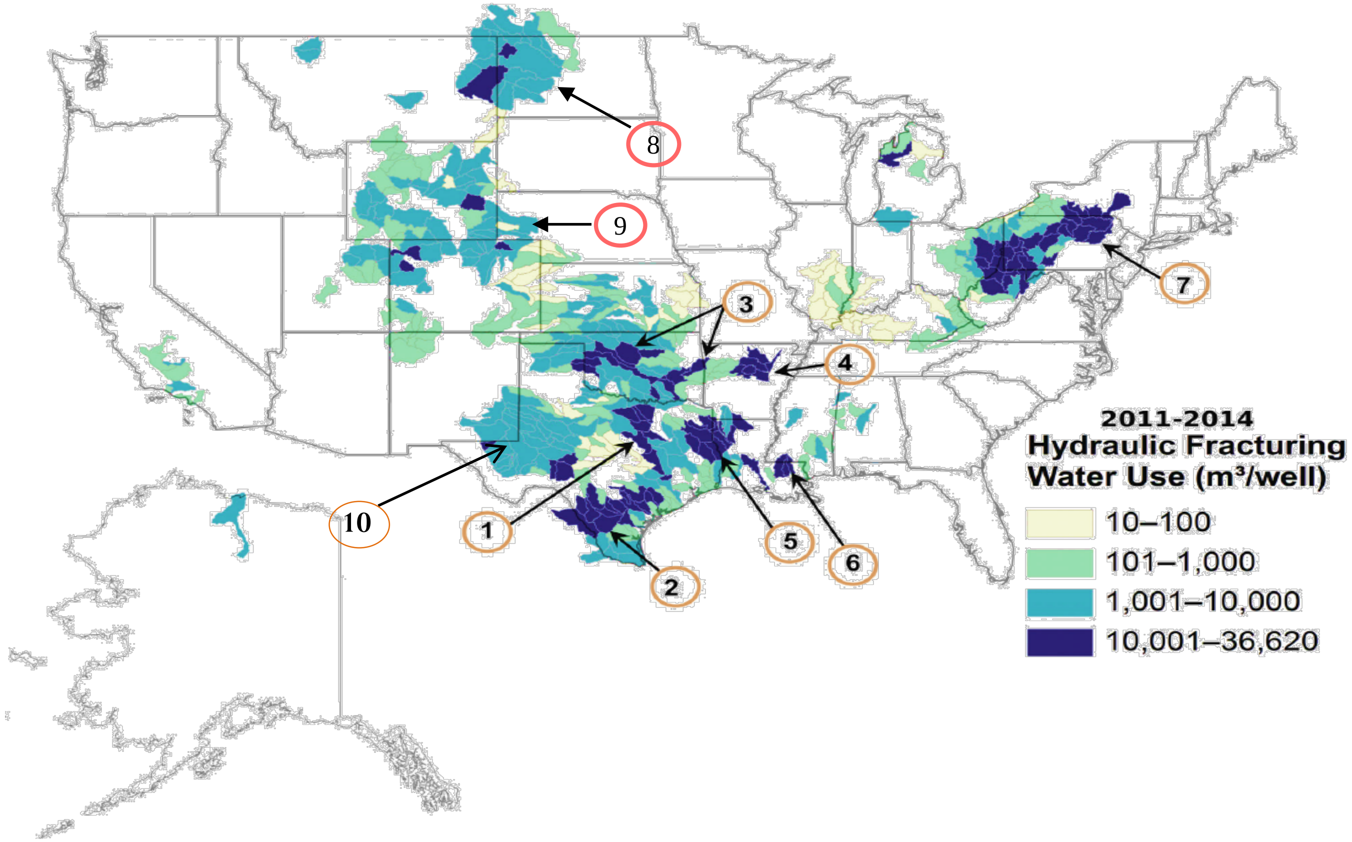


Hydraulic Fracturing

- A process used to stimulate wells in tight shale reservoirs
- Utilize water, sand, chemicals to extend and open fractures to allow the extraction of oil and natural gas



Water Volumes Used for Hydraulic Fracturing Per Oil/Gas Well (Jan 2011 – Aug 2014)



(1) Barnett
(2) Eagle Ford
(3) Woodford
(4) Fayetteville
(5) Haynesville Bossier
(6) Tuscaloosa
(7) Marcellus
(8) Bakken
(9) Niobrara
(10) Permian

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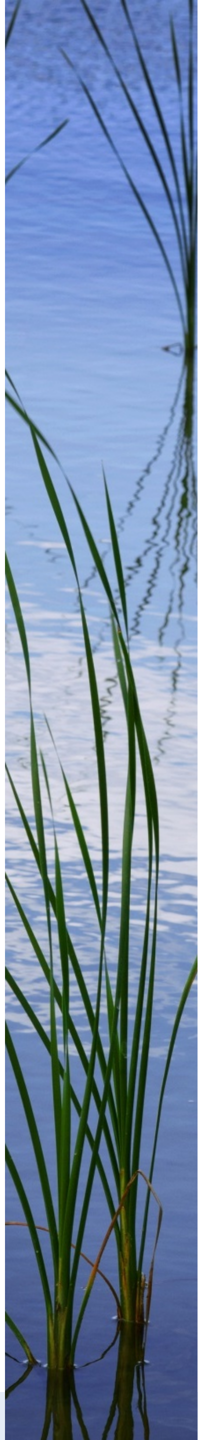
Water Use in the Upstream O&G

- Water plays a significant role throughout the life of a well
  - **Drilling**
    - 100,000 to 1 million gal. per well
  - **Hydraulic Fracturing**
    - 2–5 million gal. per well
  - **Secondary and enhanced oil recovery**
    - Water flooding
    - Steam-assisted gravity drainage (SAGD)

- Two primary challenges:
  - Sourcing a sufficient quantity and quality of water
  - Efficiently and safely managing the wastewater generated



Frac Water Composition:

Volumetric Composition of Shale Gas Fracturing Fluid

- Hydraulic Fracturing solution consist of water, sand, and chemical additives
  - Additives include biocides, corrosion inhibitors, oxygen, scavengers, friction reducers, surfactants, etc.

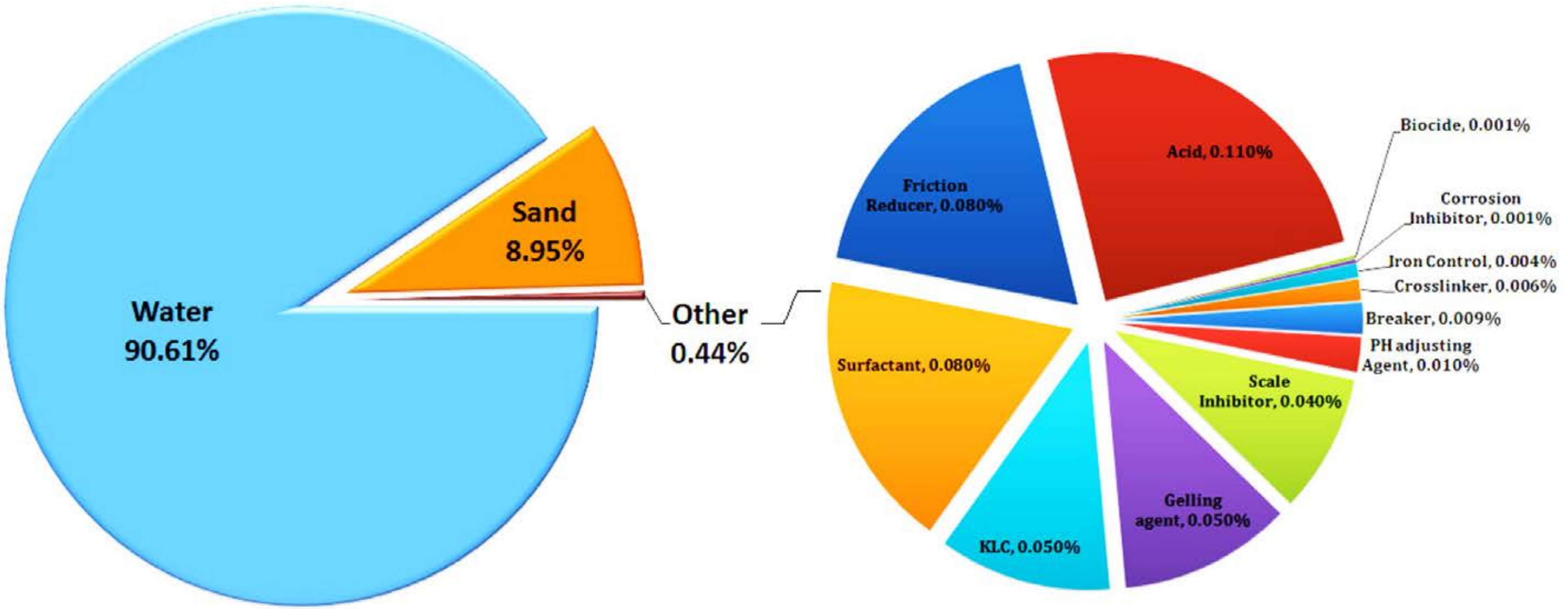
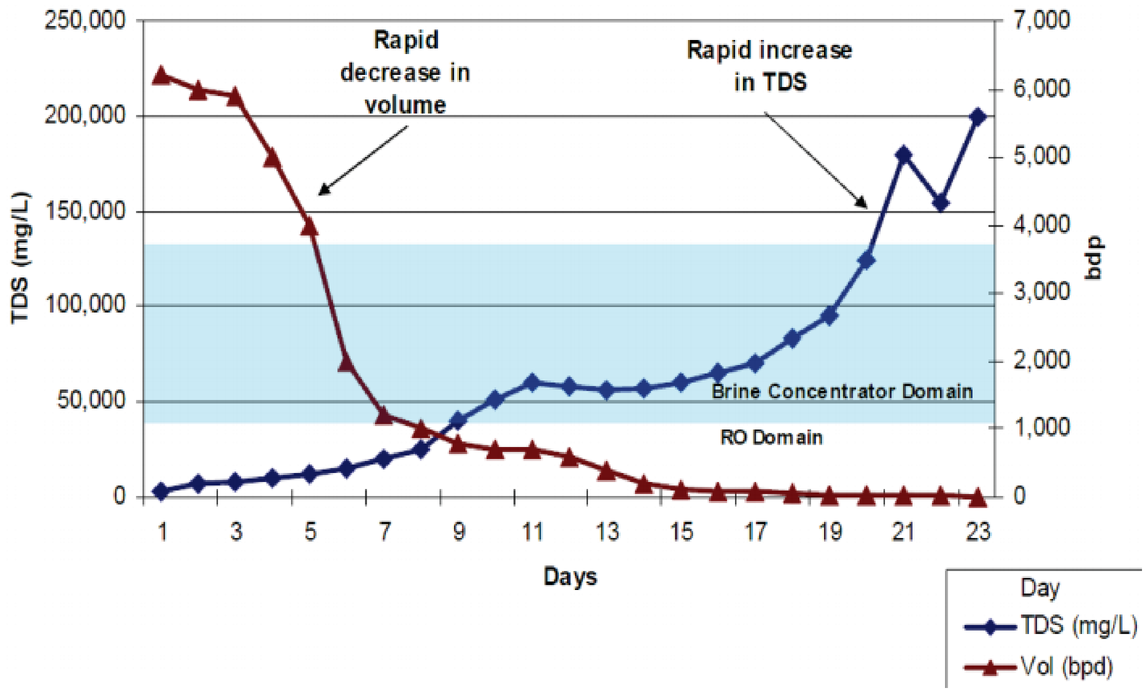


Figure courtesy of http://shalegaswiki.com. Data obtained from Environmental Considerations of Modern Shale Gas Development, SPE 122391

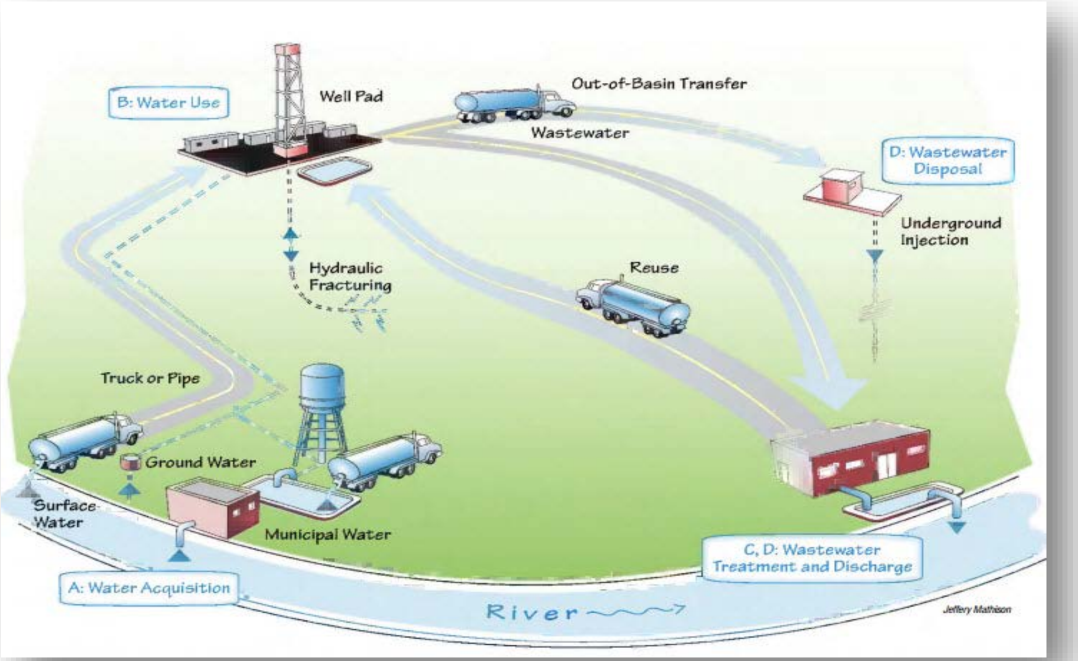
What is Fracturing Flowback and Produced Water?

- Flowback water: fluid returned to the surface after hydraulic fracturing has occurred (typically 10 – 40% of fracturing fluid injected)
- Produced water: fluid coming to the surface together with oil/gas
- Variability in water quality/quantity
  - Between formations
  - Between basins
  - Over time



Definitions

- For our study we defined:
  - Water Recycling – Reuse of flowback and produced water for well stimulation or hydraulic fracturing activities
  - Water Reuse – Beneficial reuse of flowback or produced water. Beneficial reuse could consist of:
    - Use in agriculture (e.g., irrigation, livestock watering)
    - Drinking water production
    - Stream augmentation
    - Aquifer replenishment
    - Dust suppression
    - Road deicing
  - Disposal – Ultimate fate of flowback and produced water



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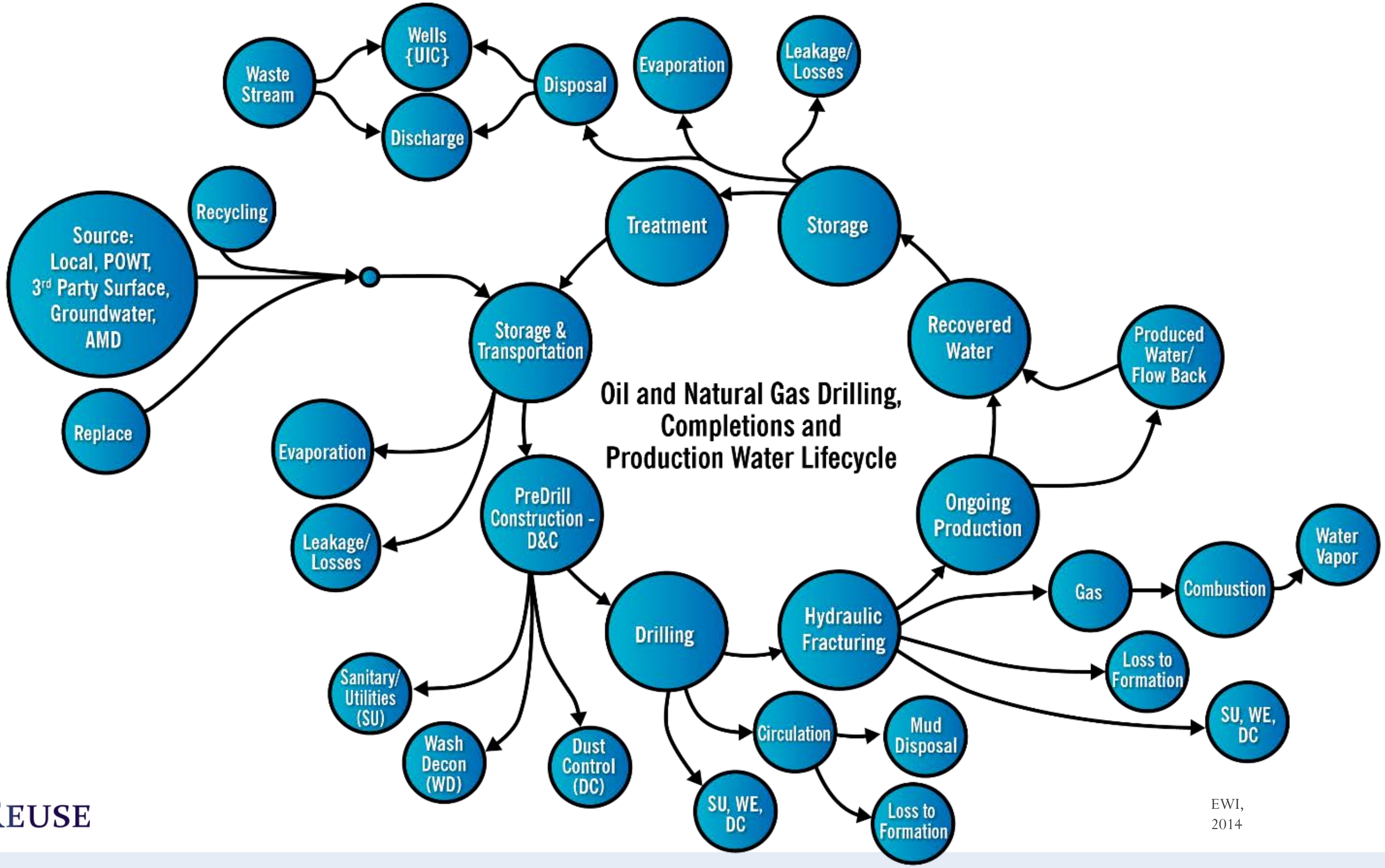
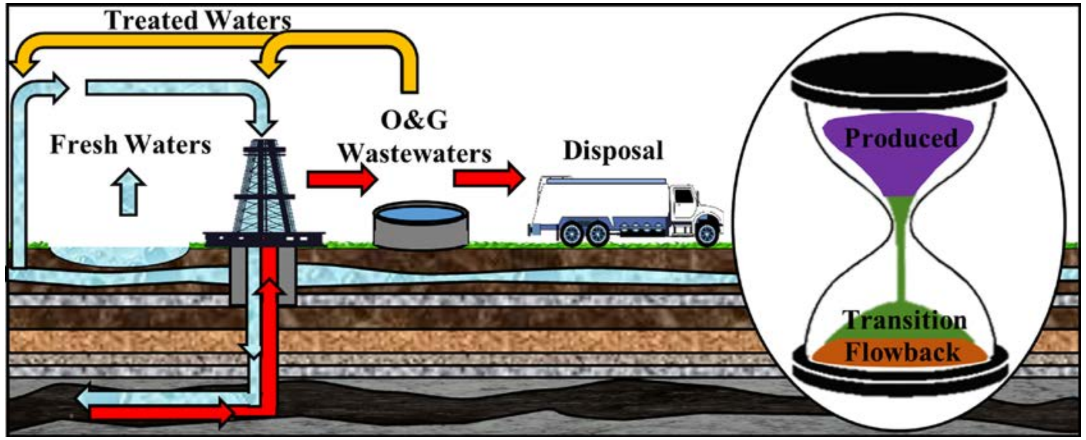
Life Cycle of Water in the Upstream O&G Operations



EWI, 2014

Drivers for Flowback/Produced Water Recycling and Reuse

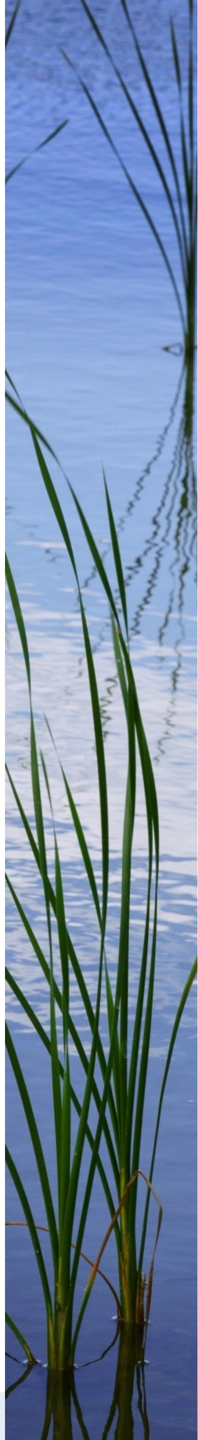
- Reduce need for fresh water for hydraulic fracturing and well stimulation activities
- Reduce wastewater volume and transportation costs
- Reduce deep well injection volumes, and potential seismic activity
- Produce an additional water resource in water stressed areas



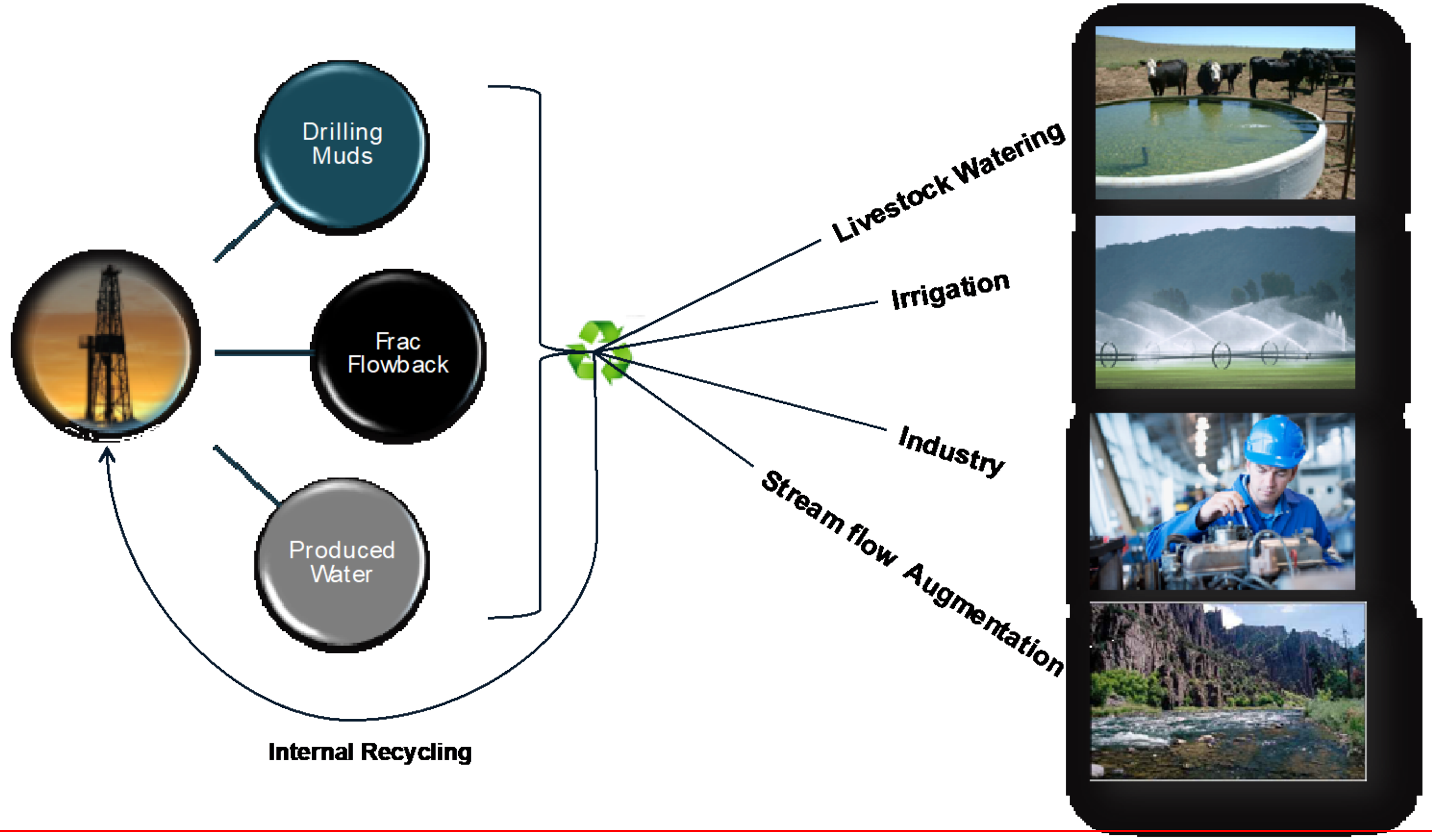
From Oetjen et al. 2018 – Science of the Total Environment

Flowback/Produced Water Recycling

- Recycling with flowback/produced water can save between $70,000 and $100,000 per well
- Certain O&G companies can be adverse to recycling (liability)
- In 2016, it was estimated that 13% of O&G wastewater was recycled in US
- Certain basins have significant recycling activities
  - 70% recycled in Marcellus basin in 2013
  - 47% recycled in Oklahoma in 2015
  - 10 – 20% recycled in Texas in 2013
- Some States are actively pushing O&G companies to increase recycling



Beneficial Water Reuse



Currently, estimated that ~5% of O&G wastewater is disposed through a beneficial reuse scenario

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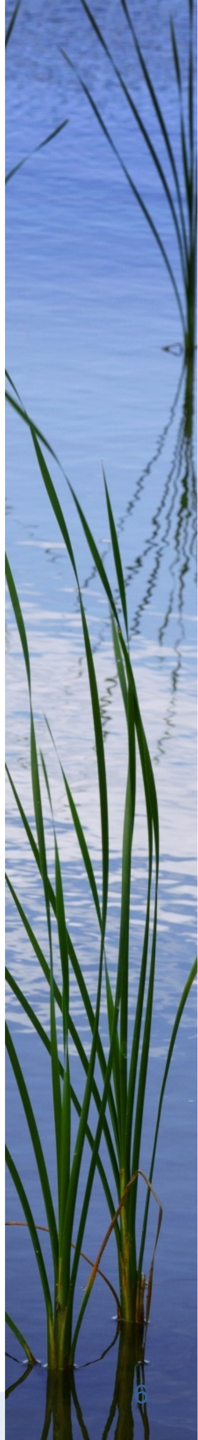


Wastewater Composition

- Flowback and produced water are characterized by
  - High concentrations of suspended solids, oil, and grease
  - High concentrations of dissolved organic matter, including volatile compounds and hydrocarbons
  - High salt concentrations (often > 35 g/L)
  - Metals (e.g., iron, manganese, calcium, magnesium, barium, etc.)
  - Dissolved gases (e.g., H_2S)
  - Naturally occurring radioactive material (NORM)
- Major challenges:
  - Highly variable wastewater quality (spatial and temporal)
  - High salinity

Economic and Treatment Challenges

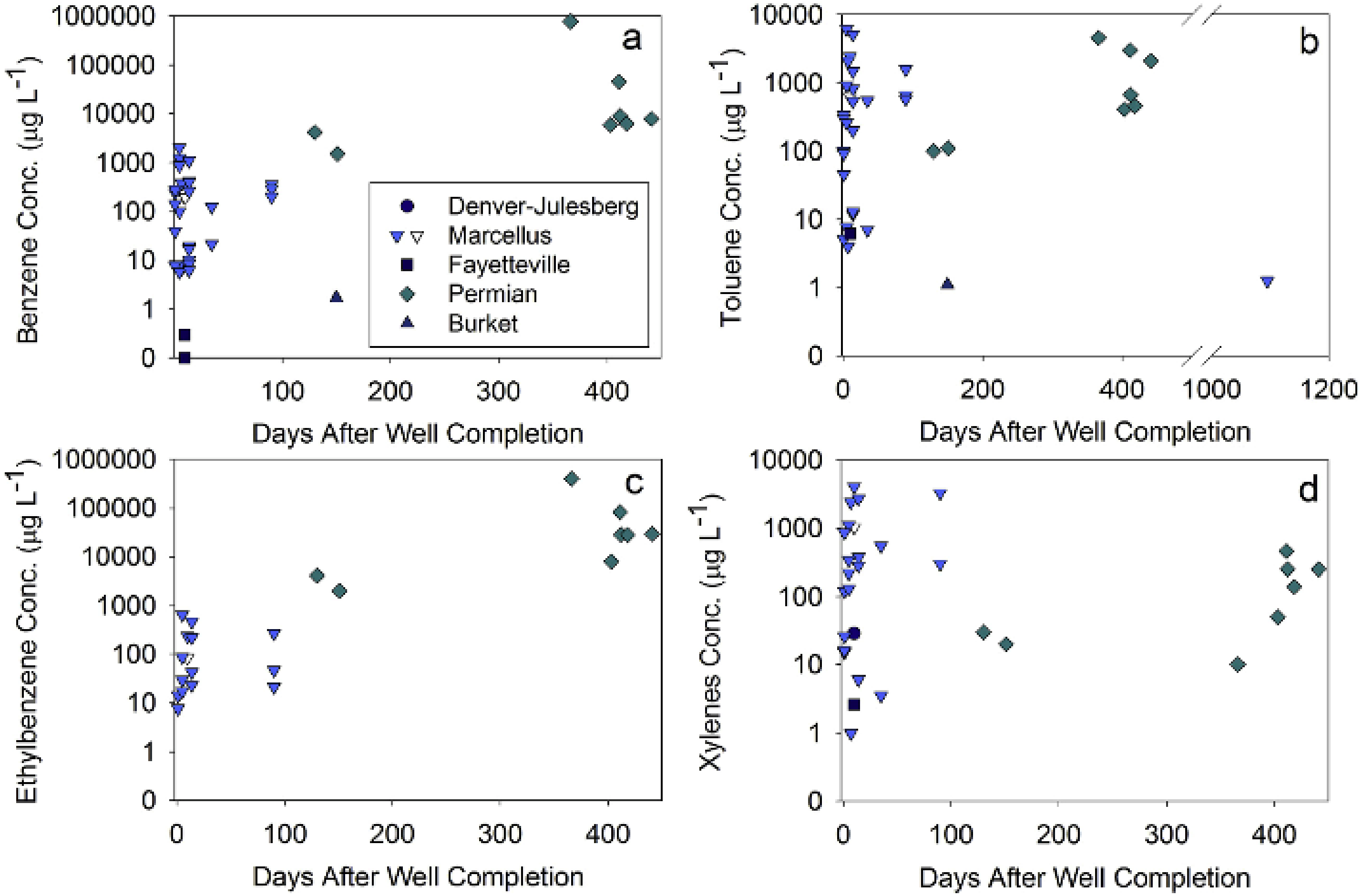
Time (Days)	Cumulative volume returned (L)	Cumulative volume returned (%)	COD (mg/L)	pH	Alkalinity (mg/L)	Turbidity (NTU)	TSS (mg/L)	VSS (mg/L)	TDS (mg/L)
GW			46.8	7.37	119	9.7	42	17	2120
Frac Fluid			115,000	4.65	600	552	ND[a]	ND[a]	3330
1	31,000	0.3%	8215	7.42	1070	1835	545	350	14,220
4	110,000	1.0%	3900	7.10	700	109	320	155	14,613
7	180,000	1.6%	4725	7.05	850	177	378	168	17,763
15	306,000	2.8%	4305	6.90	570	194	378	160	18,586
22	365,000	3.3%	3825	6.56	440	371	380	238	19,433
55	1,410,000	12.7%	2837	6.83	612	196	460	226	15,320
80	1,830,000	16.5%	2890	6.89	553	283	273	195	16,967
130	2,630,000	23.7%	2650	7.01	479	214	205	90	17,482
220	3,330,000	29.8%	2543	6.80	475	223	172	123	18,756

[a] Non-detect (ND).

- Variations in constituent concentrations over time
- Variations in flow rate over time
- In many cases, elevated organic, solids and dissolved solids concentrations

From Rosenblum, 2017 – Science of the Total Environment

Economic and Treatment Challenges



From Luek and Gonsier, 2017 – Water Research

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Economic and Treatment Challenges

Economic and Treatment Challenges

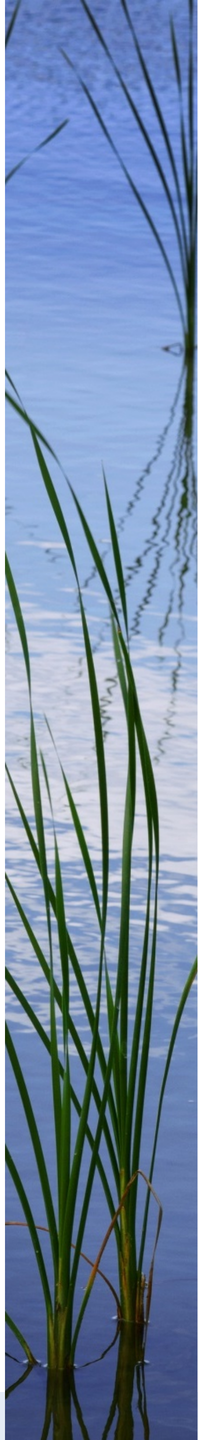
1 gallon = $3.00 ($795/m^3)

1 gallon = $1.00 ($265/m^3)

1,000 gal. = $2.60 ($0.7/m^3)

1,000 gal. = $0.75 ($0.2/m^3)

WateReuse



Economic and Treatment Challenges

1,000 gal.
=
$1.90-6.40
($0.5–1.7/m^3)

1 gallon = $3.00 ($795/m^3)	1 gallon = $1.00 ($265/m^3)	1,000 gal. = $2.60 ($0.7/m^3)	1,000 gal. = $0.75 ($0.2/m^3)

Economic and Treatment Challenges

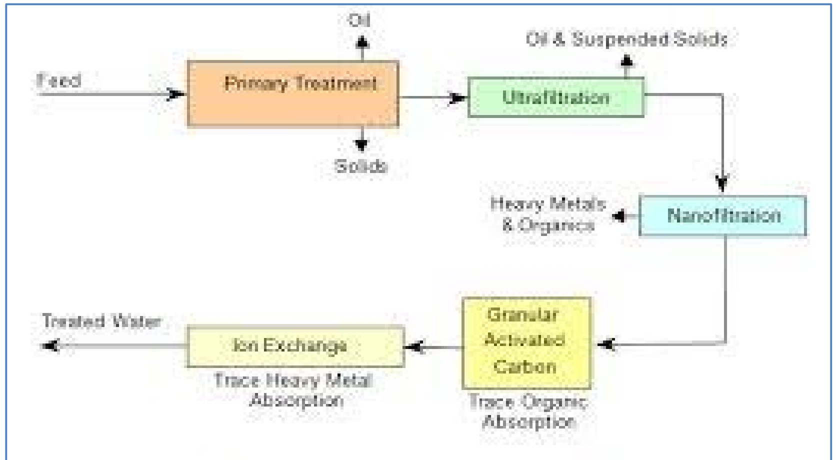
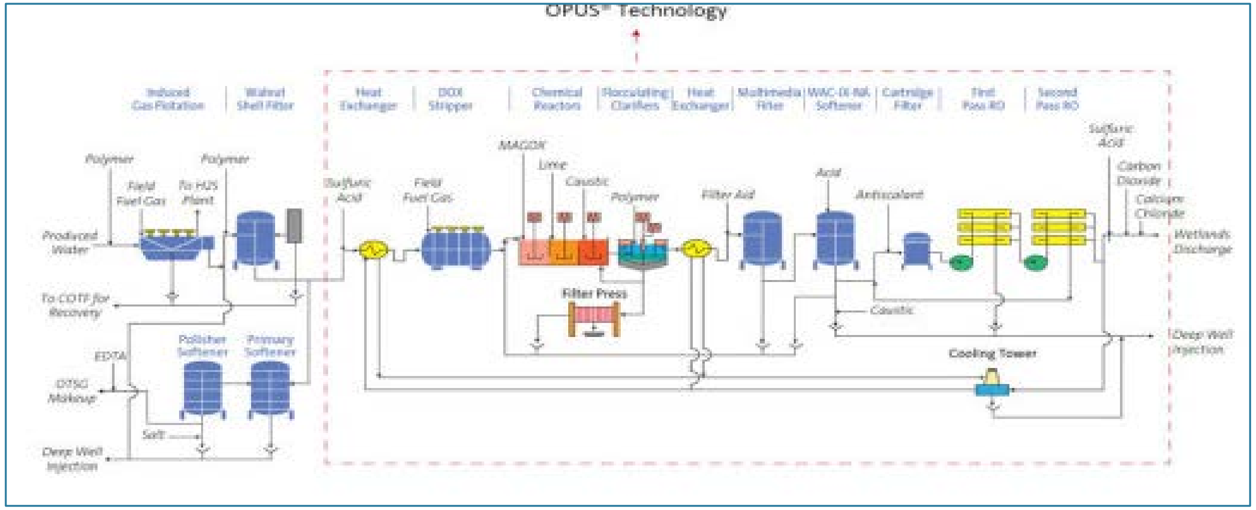
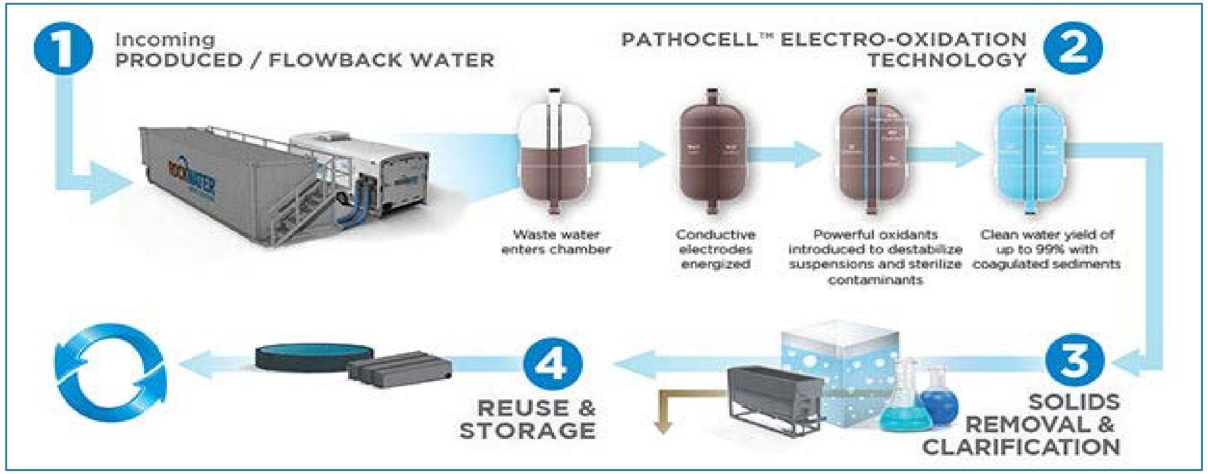
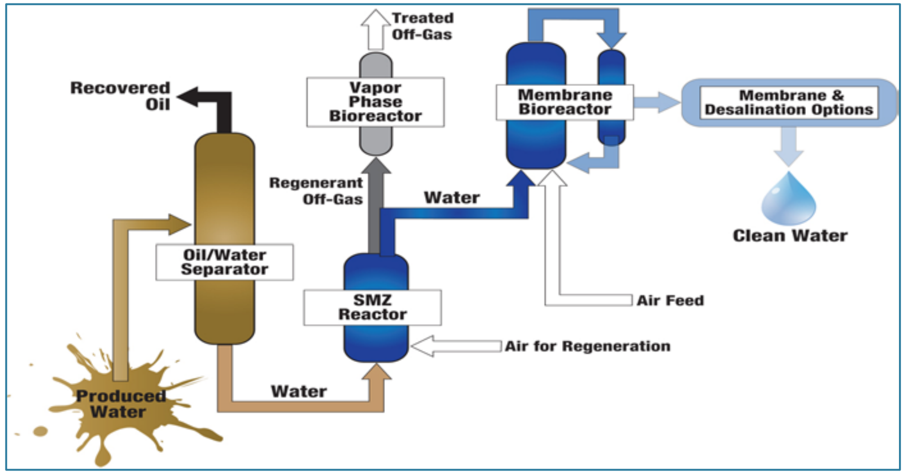


Figure 1. Esmil Produced Water Treatment Plant Schematic







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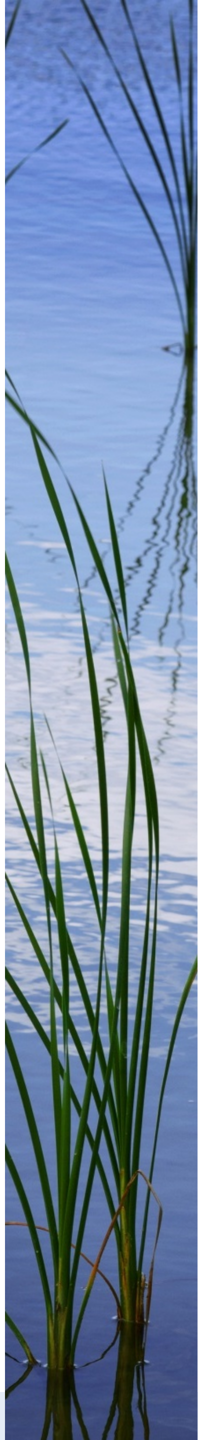
Economic and Treatment Challenges

- Energy for reverse osmosis (SWRO) desalination close to the thermodynamic limit of separation
- Reverse osmosis is limited to low salinity water
  - Desalination of seawater (3.5%) is limited to ~60% water recovery
- The cost of desalinated seawater is **~$1.5/m^3** (CA) or ~**$0.5/m^3** (Israel)
- If for the same feed water salinity (and even lower), the cost of produced water **disposal** is ~$0.5/bbl
  - There are ~6.3 bbl in one m^3…
  - Produced water treatment cost >> ~**$3.5/m^3**



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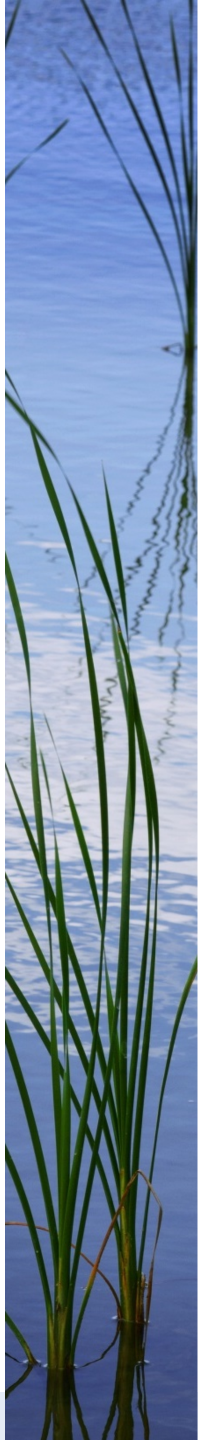
  - There are ~6.3 bbl in one m^3…
  - Produced water treatment cost >> ~**\$3.5/m^3**
- Surveyed O&G participants indicated treatment costs need to be < \$1.9/m^3 (\$0.3/bbl)

Cost-effective treatment approaches are needed to improve the prospects of beneficial reuse!



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Social Challenges

- Public perception issues associated with beneficial reuse of O&G wastewater

Are You Eating Food That Was Irrigated with Oilfield Wastewater?

California environmental activists say oil wastewater doesn't belong on farms until it is proven safe. California water districts disagree.

CIVIL EATS

Sacramento Update: Bill Proposes to limit use of Oil Produced Water for Irrigation

California Citrus Mutual

California Produce Growing Strong on Oil Water

EARTHJUSTICE
BECAUSE THE EARTH NEEDS A GOOD LAWYER

In response to these findings, Assemblyman Mike Gatto (CA-D) introduced a bill that would require agriculture irrigated with water previously used in oil production to display the warning, "Produced using recycled or treated oil-field wastewater." If

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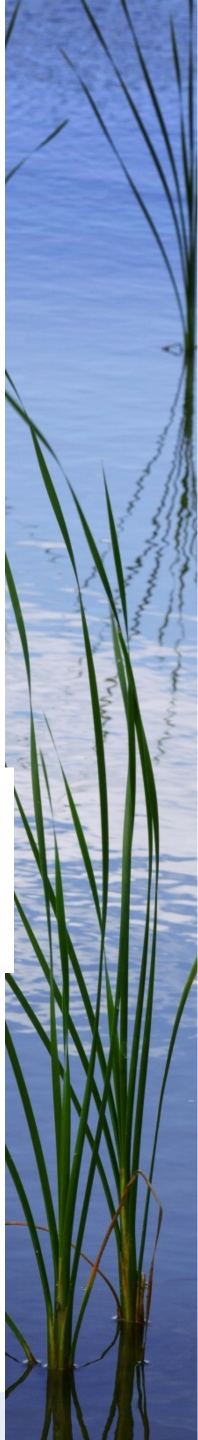


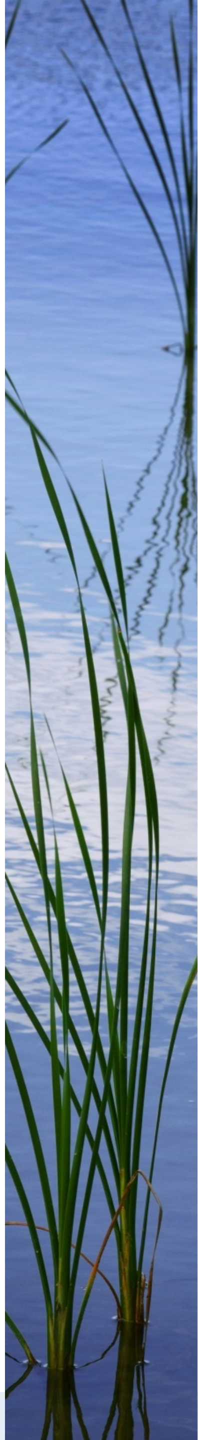
Regulatory Challenges

State	Agency for Oversight	Reuse Guidelines?	Constituents Regulated	Guidelines
California	DOGGR, CWCB	Yes	Various	Requires monitoring and reporting for a variety of water quality paramaeters, organics, and inorganics
Colorado	CDPHE, COGCC	Yes	Oil and grease, TDS, organics, metals, pH, toicity	CDPHE regulates surface water discharges which are based on the CWA; COGCC provides guidelines for groundwater injection, roadspredding, reuse, storage and O&G applications
Montana	MBOGC	Yes	Mainly TDS	Water with TDS less than 15,000 mg/L can be used for various purposes as long as water quality not degraded. Subject to CWA requirements
New Mexico	OCD, WQCC	Not Specified	NA	Must not have detrimental impact on environmental quality
Oklahoma	OCC, OWRB	Yes	Based on CWA and OWRD	Have developed water quality standards related to various aspects of O&G produced water storage, discharge and reuse
Pennsylvania	Penn DEP	Yes	TDS, chloride, barium, strontium	TDS < 500 mg/L; chloride < 200 mg/L; barium < 10 mg/L; strontium < 10 mg/L
Texas	Texas RRC	Yes	Based on TSWQS	Surface water discharge requirements depend on location relative to 98th meridian, must get permit
Wyoming	WOGCC	Yes	TDS, chloride, pH	TDS < 5,000 mg/L; chloride < 2,000 mg/L; 6.5 < pH < 9

- Regulations concerning disposal, discharge and reuse can be complex
- Most States have provisions for certain types of reuse (e.g., road-spreading)
- Reuse/discharge standards based on the Clean Water Act however, States can set much more stringent requirements

Other Challenges

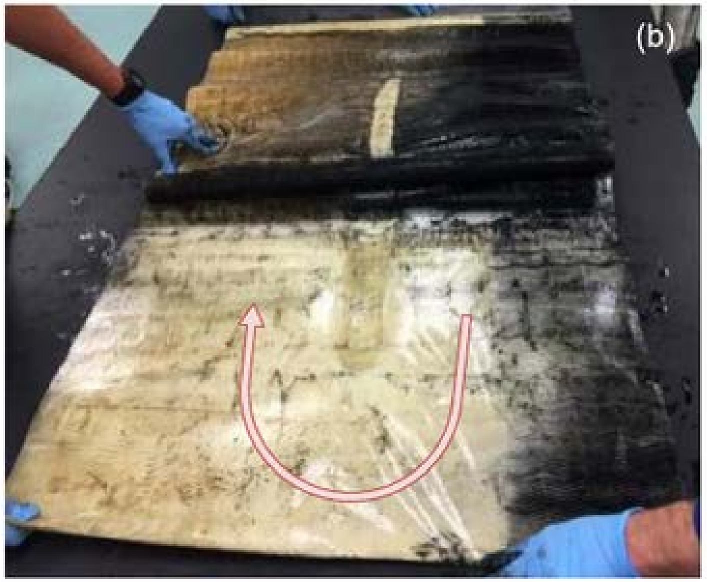
- Water rights
  - Some debate over who owns the water after treatment in certain States
  - Tributary versus non-tributary water
- Logistical constraints
  - Significant conveyance infrastructure needed to transport water to centralized location
  - Oil/gas wells often remote and not in proximity to potential end-users
  - Matching a buyer with a producer
- Liability and environmental degradation
  - O&G companies may be adverse to potential liability associated with O&G wastewater conveyance, treatment and use
- Oil/gas price fluctuations
  - Recent crash in oil/gas prices severely hindered investment in treatment
  - Volatility of oil/gas market may also restrict wide-spread reuse



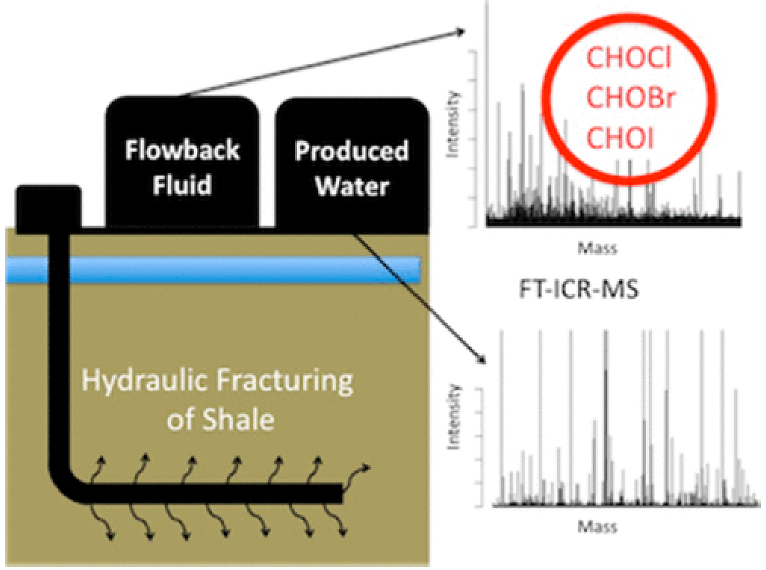
Flowback/Produced Water Reuse Case Studies

- Central Valley California
  - Produced water used for 30-years for irrigation
  - Low-salinity requiring minimal treatment (e.g., oil and solids removal)
  - Produced water blended with fresh water resources prior to application
  - Some recent scrutiny regarding this practice
- Wellington, CO
  - Uses treated produced water for aquifer recharge
  - Groundwater extracted and treated for drinking water production
  - Project challenges included permitting
  - Reported that municipal water valued at $0.25/barrel but frack water at $0.5/barrel
- Oklahoma Water 2060 Study
  - Recently completed by CH2M to assess costs associated with centralized recycling and reuse
  - Develop 10 alternative disposal options and various reuse schemes
  - Costs ranged from $0.57/barrel (recycling) to $7.49/barrel (desalination)

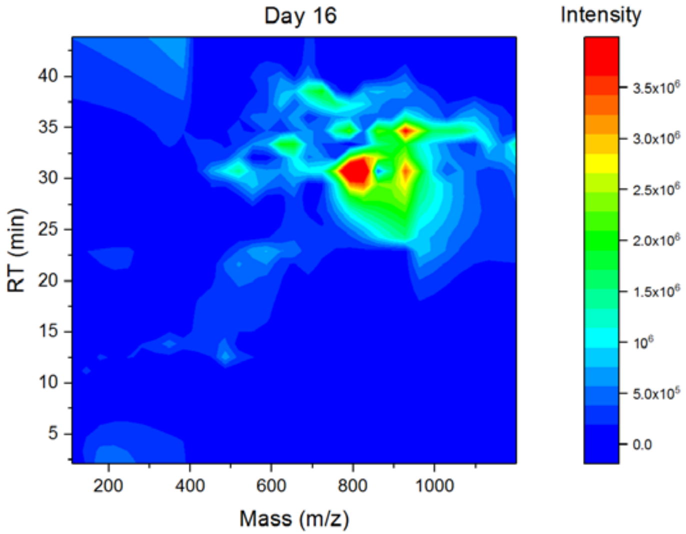
Unintended Consequences



Forward osmosis membranes after produced water treatment (Maltos, et al., 2018 – Desalination)



Mass spectra showing halogenated organics in O&G wastewater (Luek, et al., 2017 – ES&T)



Abundance of unknown organic compounds in produced water (from Karl Oetjen)

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Conclusions

- Two main water challenges associated with unconventional O&G production
  - Sourcing adequate water for hydraulic fracturing and well stimulation
  - Managing O&G wastewater produced during the lifetime of a well
- Recent increased interest in O&G wastewater recycling and reuse
  - Recycling is fairly common among O&G producers
  - Beneficial reuse is much less common but represents an alternative to deep-well injection
- Significant challenges associated with beneficial reuse
  - Cost of treatment versus disposal (deep-well injection)
  - Regulations/permitting, logistics and public perception
  - Unknown risks
- Future drivers may necessitate advanced treatment and reuse
  - Regional droughts may require additional water source
  - Seismic activity may reduce deep-well injection capacity

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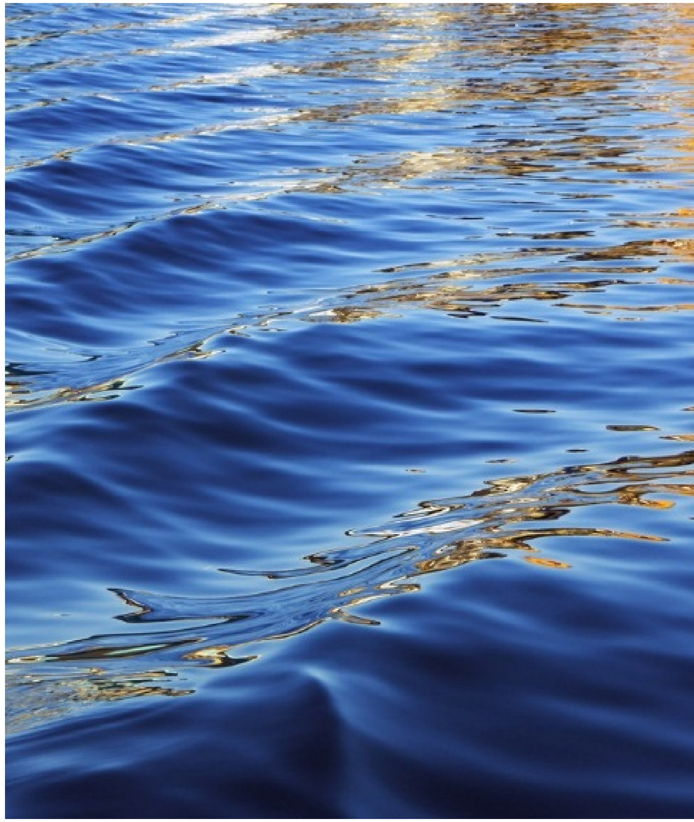

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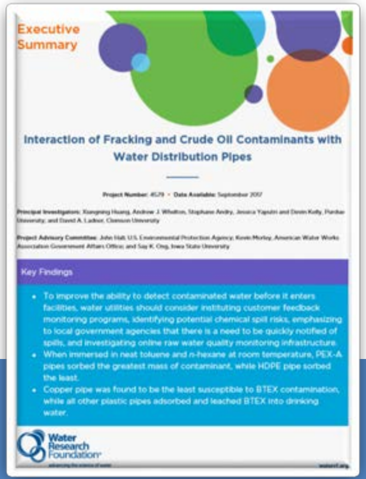

Executive Summary

Interaction of Fracking and Crude Oil Contaminants with Water Distribution Pipes

Project Number: 4579 • Date Available: September 2017

Principal Investigators: Xiangning Huang, Andrew J. Whelton, Stephane Andry, Jessica Yaputri and Devin Kelly, Purdue University; and David A. Ladner, Clemson University

Project Advisory Committee: John Hall, U.S. Environmental Protection Agency; Kevin Morley, American Water Works Association Government Affairs Office; and Say K. Ong, Iowa State University

Key Findings

- To improve the ability to detect contaminated water before it enters facilities, water utilities should consider instituting customer feedback monitoring programs, identifying potential chemical spill risks, emphasizing to local government agencies that there is a need to be quickly notified of spills, and investigating online raw water quality monitoring infrastructure.
- When immersed in neat toluene and n-hexane at room temperature, PEX-A pipes sorbed the greatest mass of contaminant, while HDPE pipe sorbed the least.
- Copper pipe was found to be the least susceptible to BTEX contamination, while all other plastic pipes adsorbed and leached BTEX into drinking water.

Water Research Foundation

waterrf.org

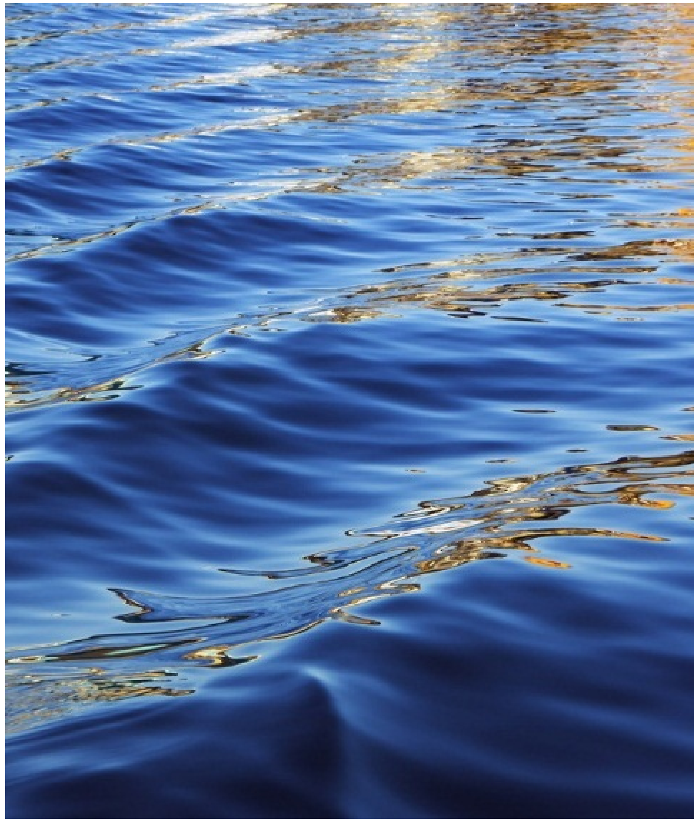
Interaction of Hydraulic Fracturing and Crude Oil Contaminants with Polymer Water Distribution Pipes

Andrew J. Whelton, Xiangning Huang, Stephane Andry, Jessica Yaputri and Devin Kelly, Purdue University

David A. Ladner, Clemson University

WITAF 521/WRF 4579

September 2017



Executive Summary Available: http://www.waterrf.org/ExecutiveSummaryLibrary/4579_projectsummary.pdf

WaterRF and AWWA Disclaimer

The authors gratefully acknowledge that the Water Research FOUNDATION and American Water Works Association and are co-owners of certain technical information upon which this publication presentation is based. The authors thank the Water Research FOUNDATION and the American Water Works Association for their assistance in the research through which this information was discovered.

Interaction of Fracking and Crude Oil Contaminants with Water Distribution Pipes, Project 4579

2004 to 2014, National Response Center Spill Database

United States Coast Guard

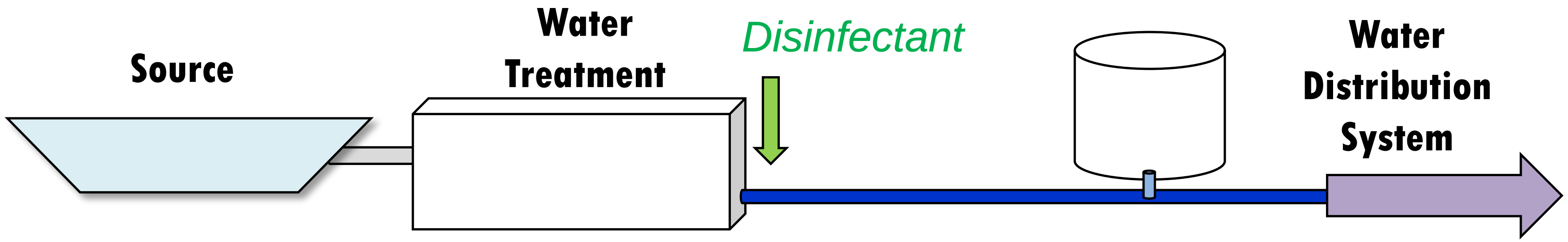
Over 351,000 incidents and chemical spills were reported to the US National Response Center

More than 172,000 impacted US waterbodies

Weidhass et al. 2017. Enabling Science Support for Better Decision-Making when Responding to Chemical Spills. Journ. Environ. Quality. DOI: 10.2134/jeq2016.03.0090

WATEREUSE

Community Water Supplies and Infrastructure are Susceptible to Chemical Contamination



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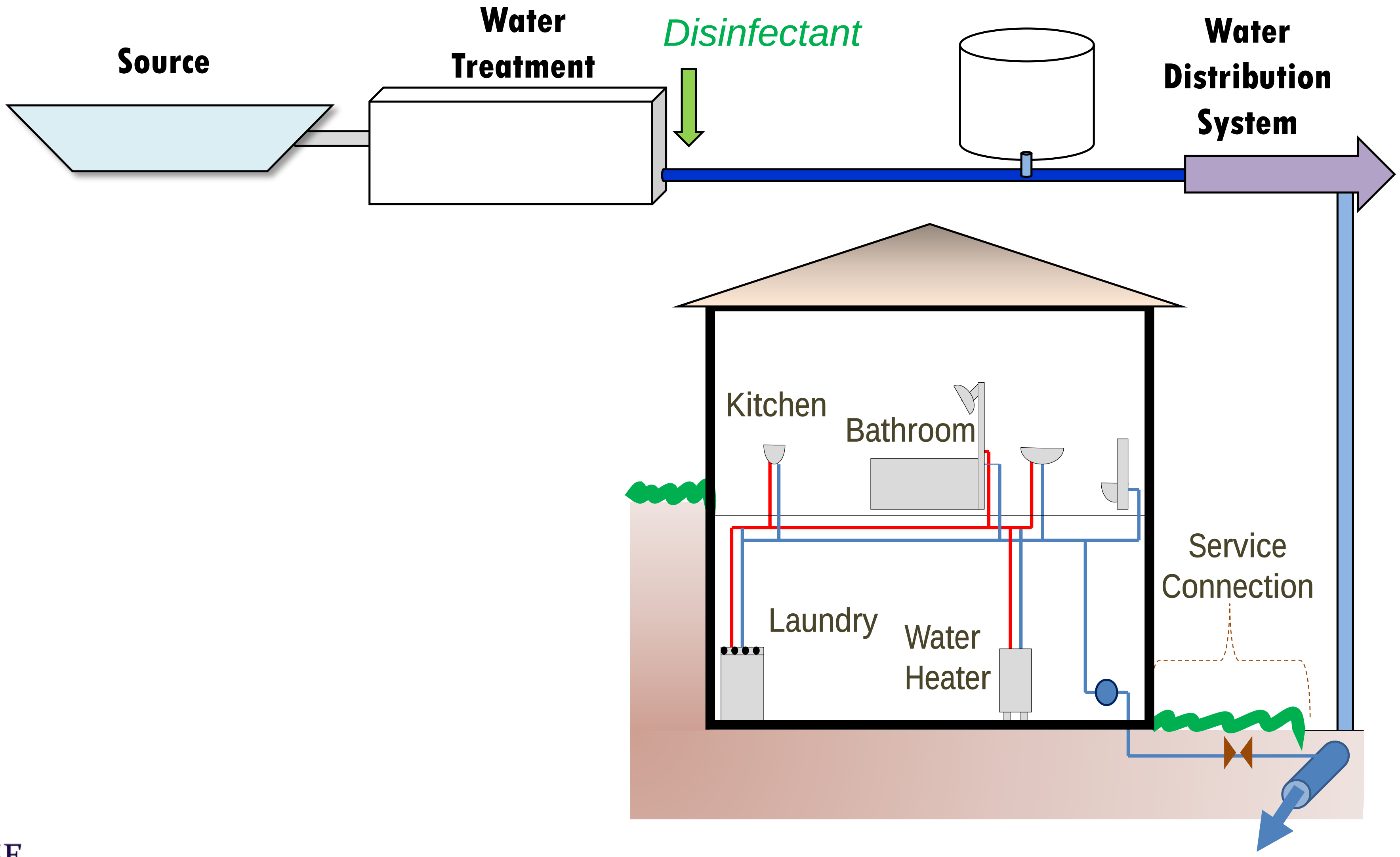

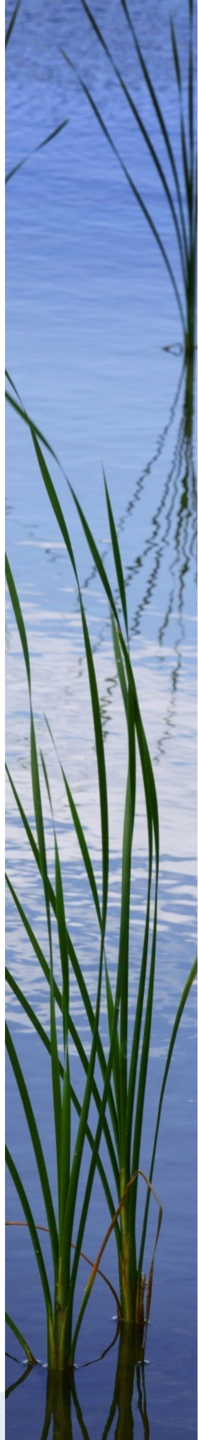

WateReuse

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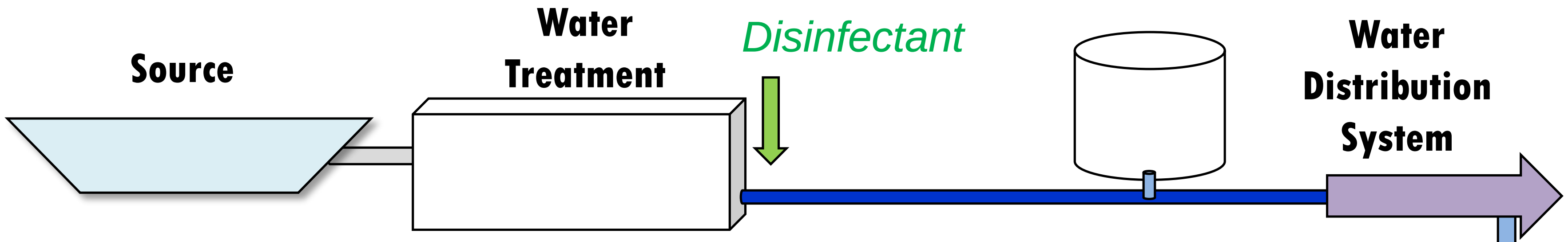
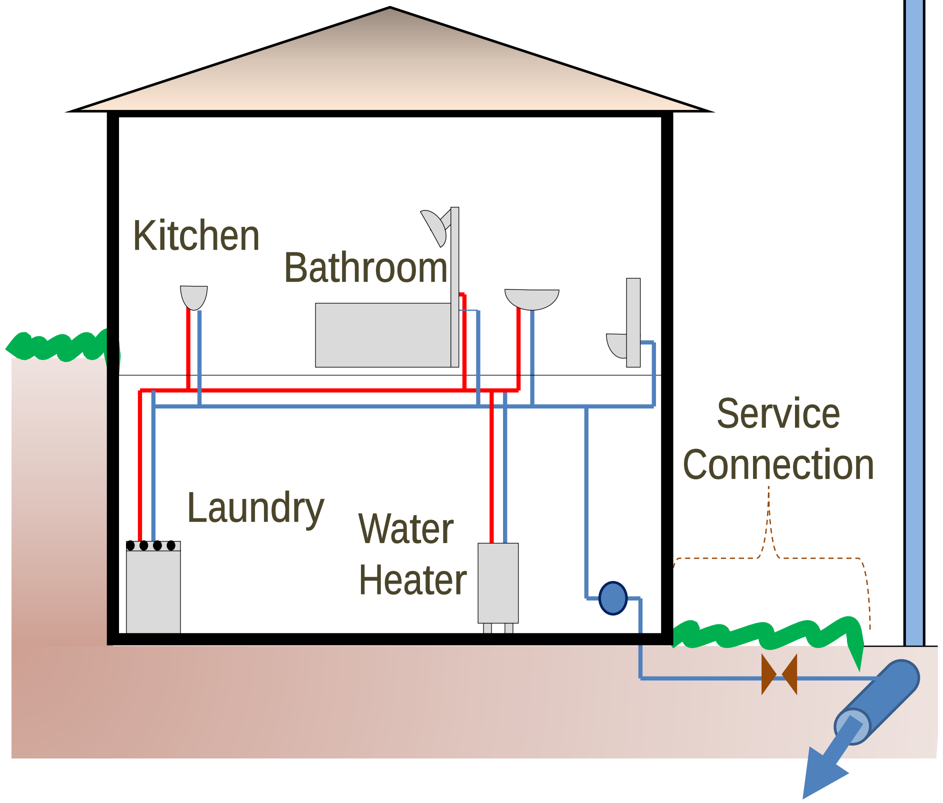


Not Plastics	Plastics	
Concrete cement	PVC (u, o, m, c)	EPDM
Asbestos cement	HDPE	SBR
Steel	PEX (a,b,c)	NBR
Galvanized iron	FRP	Viton
Ductile iron	PEUU	
Cast iron	PU	
Copper	EP	
Lead	CIPP	



Chemical Spills can Happen

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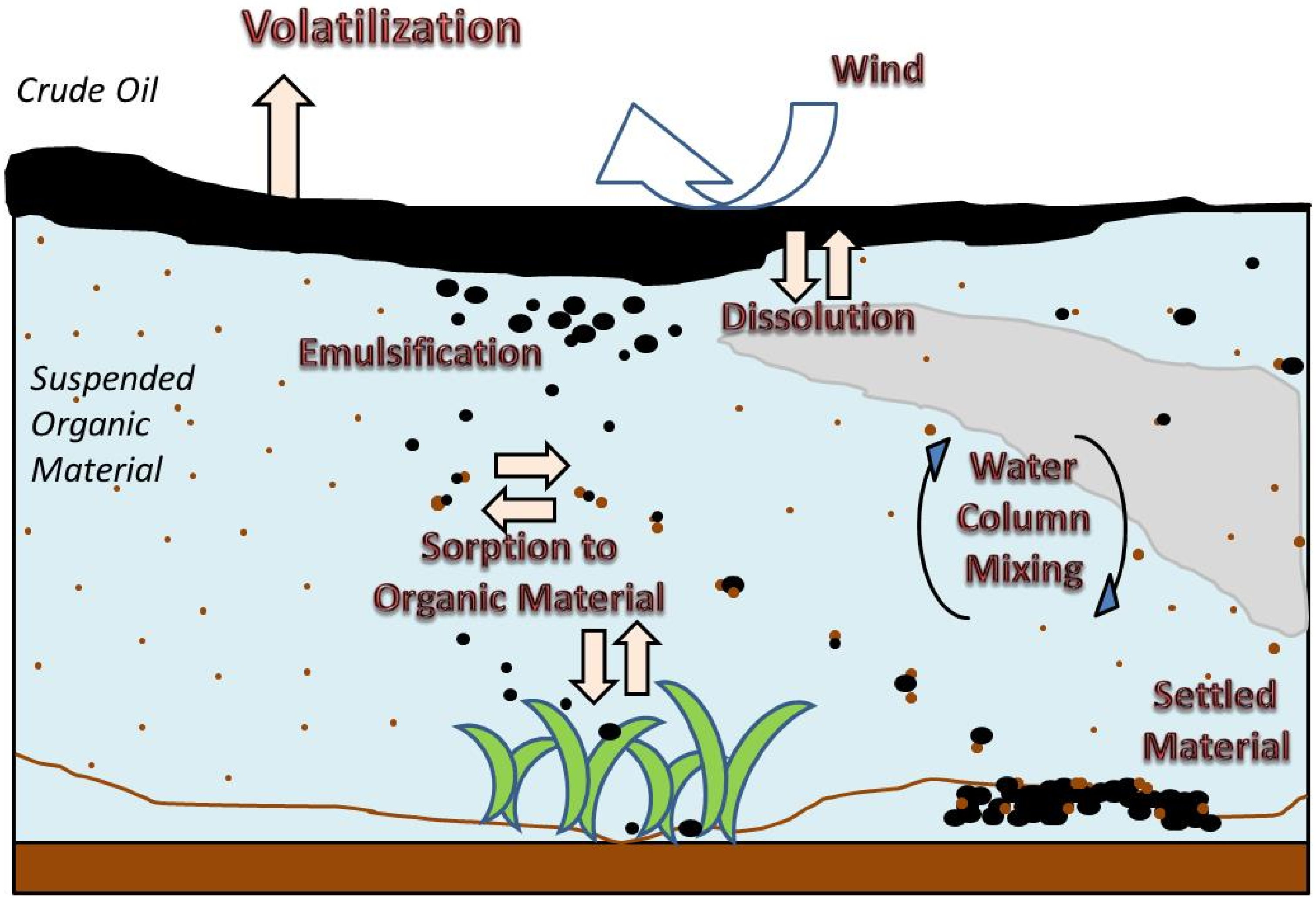

Major Physiochemical Processes that Describe the Fate of Crude Oils in the Environment

Petroleum Spills have Contaminated Drinking Water Sources, Treatment Plants, Water Distribution Systems, and Plumbing Systems

		Spill Details						Utility Details		
Date	**State**	Cause	Chemical	Pipe Shutdown Delay, hr	Spill Volume, Gal	Travel Dist., mi	**Pop. affected**	Assets Affected	Utility Pre-Alert?	Alternate Source
2015	WV	Rail	Crude	N/A	378,000	-	2,000	-	Yes	Ran out; Truck in
	WV	Truck	Diesel	N/A	4,000	-	12,000	WTP	Yes	Ran out; Truck in
	CAN	Tank	Diesel	N/A	7,500	-	300,000	WTP, DS, PS	***No***	Truck in
	MT	Pipe	Crude	>0	30,000	-	5,500	WTP, DS, PS	***No***	Truck in
2014	VA	Rail	Crude	N/A	29,600	-	492,900	-	Yes	Alt source
2013	AR	Pipe	Crude	12	>210,000	-	-	-	-	-
2012	CAN	Pipe	Crude	2.3	12,600	25	-	WTP	***No***	Truck in
2010	MI	Pipe	Crude	>17	>800,000	25	-	-	-	-
1993	VA	Pipe	Fuel oil	> 0	477,436	60	-	WTP	Yes	Alt source
1991	SC	Pipe	Fuel oil	>0	550,000	32	10,500	WTP	Yes	Alt source; Truck in
1988	PA	Tank	Diesel	N/A	>800,000	600	23,000	WTP	Yes	Alt source; Truck in
1963	GA	Pipe	Kerosene	-	60,000	-	625,000	WTP	***No***	Truck in

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Chemicals can Pass Through Water Treatment Plants and Reach the Water Distribution System and Plumbing Systems

2015: Diesel Spill in Longueuil, Canada; 300,000 people impacted

Contaminant Reported by Responders	Max Observed Concentration, ppb			Threshold, ppb	
	Raw Water	Treated Water	Distr. Network	WHO Odor	WHO Taste
Benzene	0.3	0.2	1.3	2000	400
Toluene	3.8	2.6	1	24	40
Ethyl benzene	nd	nd	0.4	2	72
Total xylenes	5.0	2.7	1	20	300
1,2,4-Trimethylbenzene	10.0	5.0	3	5-30	-
Dichloro-2,2-propane	nd	nd	1.2	-	-
Other VOCs (EPA 624)	nd	nd	nd	-	-
Total PAHs	nd	nd	nd	-	-
Other organics	nd	nd	nd	-	-
C10-C50	nd	nd	nd	-	-

Limited sampling data; "Snap-shot" in time; Not representative.

Residents reported "odors" but none of the distribution data show exceedances.

Odor causing contaminants were not identified

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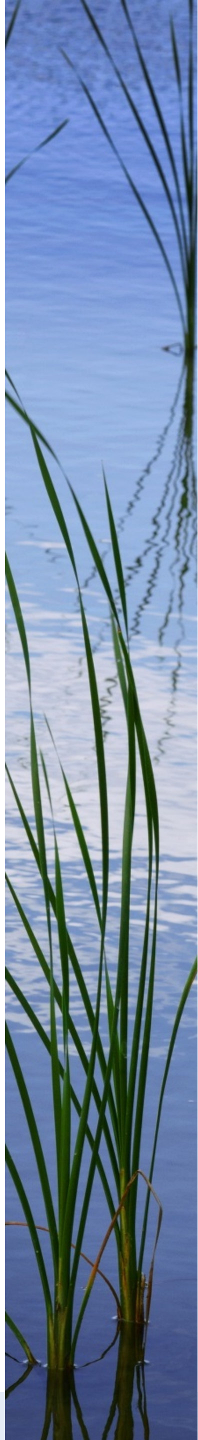

Study Goal & Objectives

Provide utilities information so that they may better investigate and recover from water contamination incidents.

(1) Review past crude oil and hydraulic fracturing chemical spill incidents and identify the types of chemicals that have entered the environment and passed through water treatment plants and water distribution systems [see report]

(2) Determine the diffusivity and solubility coefficients of four contaminants present in neat crude oil and hydraulic fracturing liquids for different plastic pipe materials [see report]

(3) Investigate the fate of benzene, toluene, ethylbenzene, and xylenes (BTEX) present in crude oil-contaminated water with Copper, PEX, HDPE, and CPVC service line pipes, including their potential to desorb from the contaminated pipes over a one-month leaching period [today]

(4) Identify knowledge gaps that inhibit a better understanding of how to investigate and recover from water contamination incidents [today]

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Methods: Contamination and Rinsing of New Service Line Pipes

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Service Line Pipe Materials (*cut into 5 ft. length*):
PEX-A (medium density); *PEX-B* (high density); HDPE (high density); *cPVC* and Copper.

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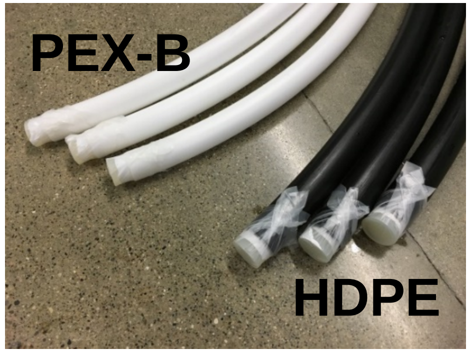
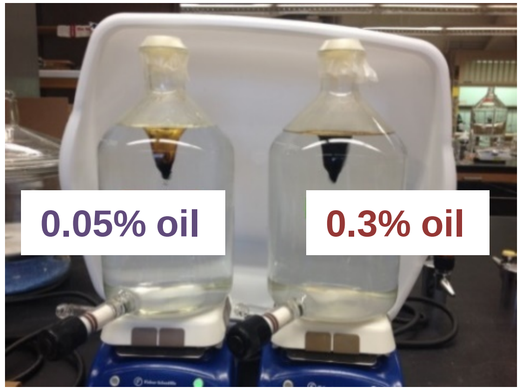
New pipe cleaning:
200 mg/L free chorine

Contamination:
Louisiana light sweet crude (LLSC) solutions
Duration: 3 days

Decontamination:
Refresh clean water
Duration:
Every 3 days to 30 days



"Fill and drain method"



Oil mixing with synthetic water

Why 0.3% oil/water ratio? USEPA used it contaminate ductile iron and cement pipes

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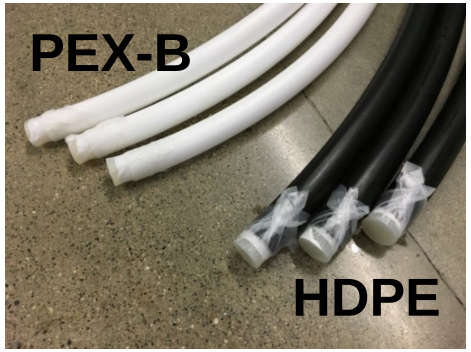

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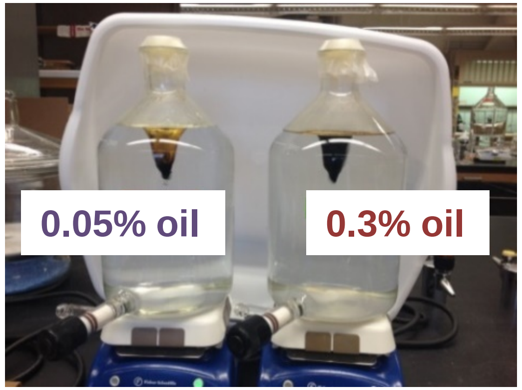


Oil mixing with synthetic water

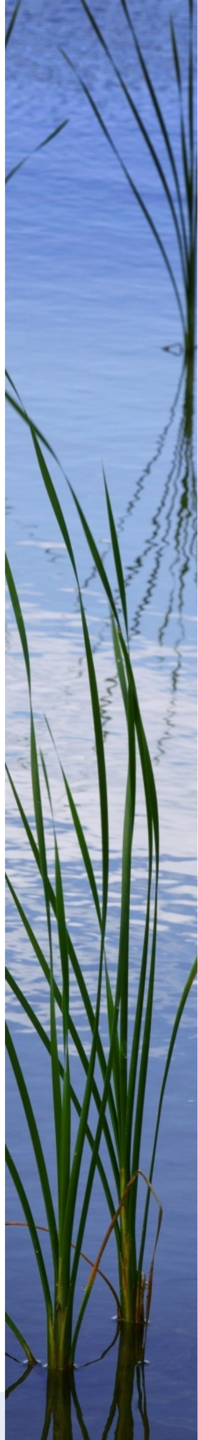
Measurement Techniques

HS-SPME-GC/MS
LLE-GC/MS
TOC analyzer
Statistical analysis

Why 0.3% oil/water ratio? USEPA used it contaminate ductile iron and cement pipes

Results: Over the one-month rinsing period, BTEX levels differed across pipe types and oil/water ratios

Material	Mean Aqueous Concentration (ppb)							
	Benzene	Toluene	Ethylbenzene	Xylenes	Benzene	Toluene	Ethylbenzene	Xylenes
	0.3% crude oil/water ratio Day 3				0.05% crude oil/water ratio Day 3			
PEX-A	1,434.4	140.2**	2.43**	73.0**	77.0	12.6	-	-
PEX-B	1,167.9	116.8**	1.68	66.8**	36.0	3.53	-	-
HDPE	1,274.1	129.0**	2.07**	58.5**	39.6	1.61	-	-
CPVC	81.03	38.88**	2.42**	10.36	9.22	0.76	-	
Copper	5.45	7.9	2.18**	22.6**	0.46	0.85	-	-
	0.3% crude oil/water ratio Day 15				0.05% crude oil/water ratio Day 15			
PEX-A	21.0	9.46	-	-	6.14	-	-	-
PEX-B	16.5	5.33	-	-	3.01	-	-	-
HDPE	18.5	7.63	-	-	2.10	-	-	-
CPVC	1.74	0.28	-	-	0.7	0.37	-	-
Copper	-	-	-	-	-	-	-	-
	0.3% crude oil/water ratio Day 30				0.05% crude oil/water ratio Day 30			
PEX-A	0.23	0.48	-	-	0.79	-	-	-
PEX-B	0.34	0.20	-	-	0.54	-	-	-
HDPE	0.28	0.26	-	-	0.25	-	-	-
CPVC	-	-	-	-	-	-	-	-
Copper	-	-	-	-	-	-	-	-



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HDPE	0.28	0.26	-	-	0.25	-	-	-
CPVC	-	-	-	-	-	-	-	-
Copper	-	-	-	-	-	-	-	-

(1) Susceptibility to contamination….and desorption differences:

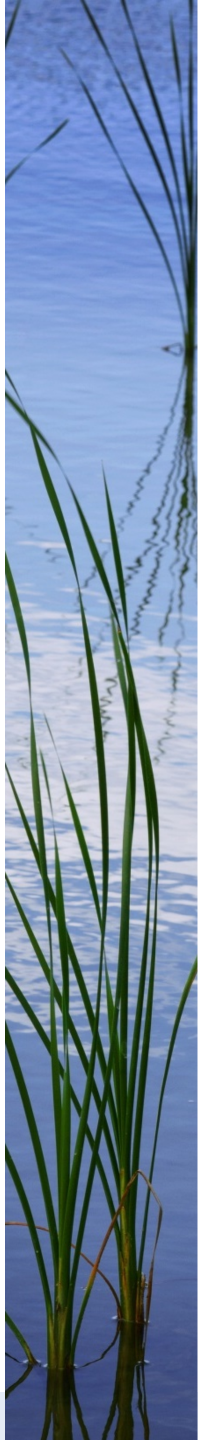
PEX-A pipe > HDPE pipe > PEX-B pipe > CPVC pipe > Copper pipe

(2) On Day 3, **toluene, ethylbenzene and total xylene** exceeded their **taste and odor** thresholds.

(3) By **Day 15,** BTEX not detected for **copper pipe**.

(4) **Plastic pipes** required **multiple flushes for a longer period of time.**

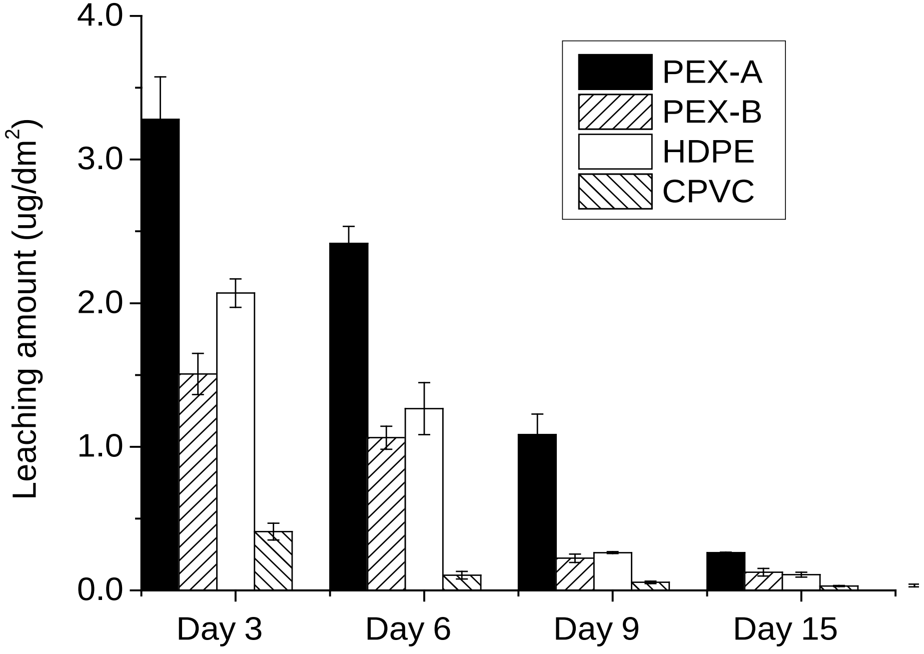
WateReuse



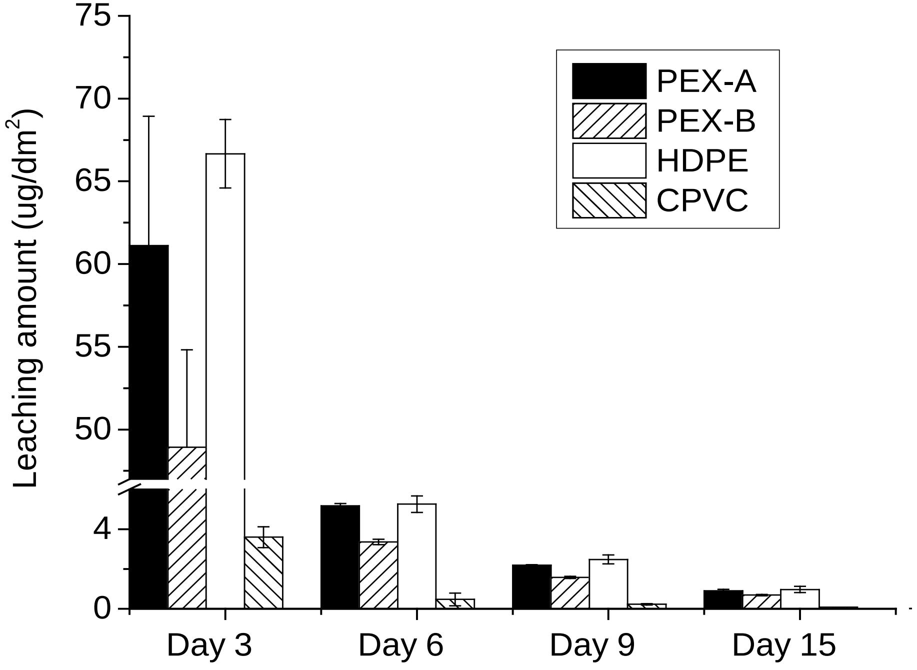
For benzene…

When pipe surface area's were compared, some pipes desorbed a greater amount of chemicals than others:
PEX-A pipe > HDPE Pipe > PEX-B pipe > CPVC Pipe.

0.05% crude oil/water ratio



0.3% crude oil/water ratio



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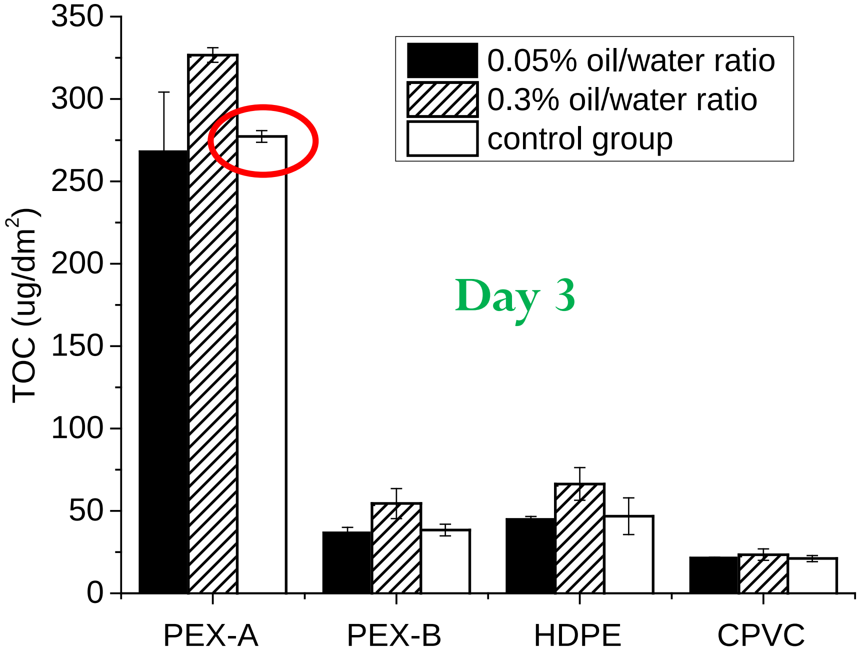
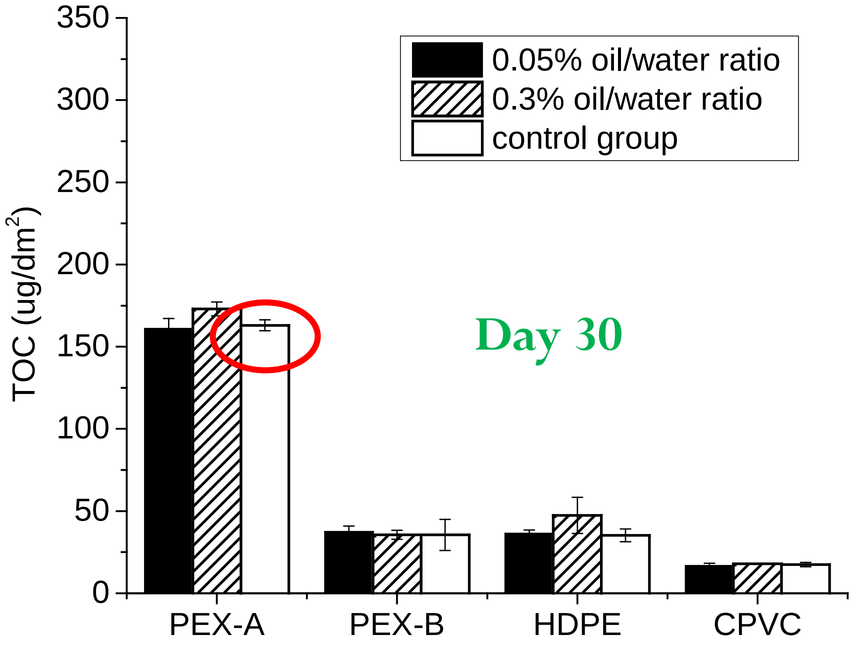
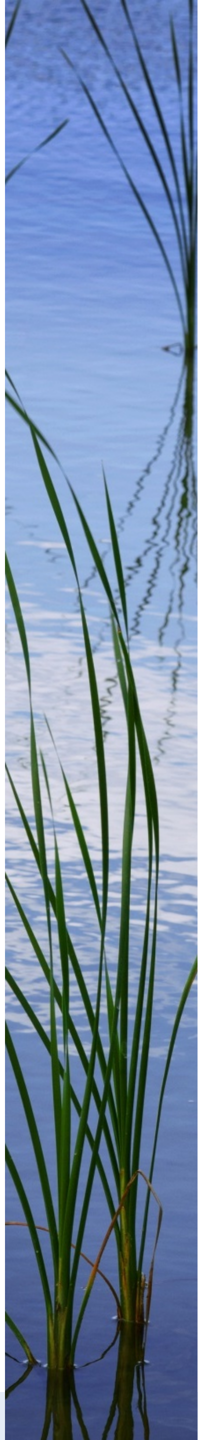




- ✓ **TOC concentration was not a good indicator** of contaminated water.
  - Organics released to water by the new plastic pipes themselves (no oil) was sometimes high. For example, New PEX (6.5 mg TOC/L) vs. Day 30 PEX (3.6 mg TOC/L).



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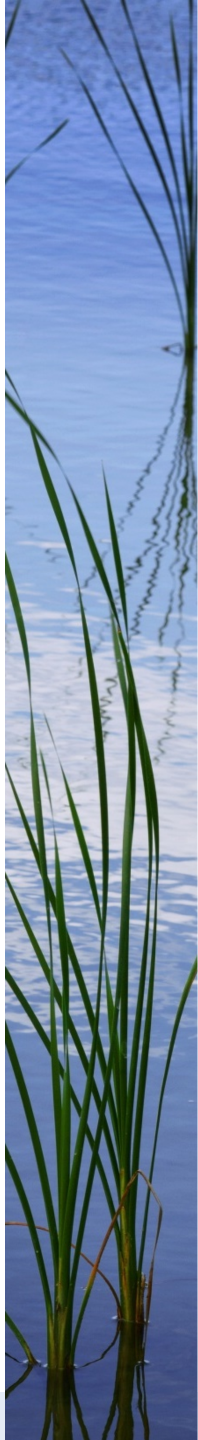
Parameters	BTEXs (µg/dm²)		TOC (µg/dm²)	
	p value	*Significant?*	*p value*	*Significant?*
Main effect				
Oil concentration	<0.05	Yes	0.73	No
Pipe Material	<0.05	Yes	<0.05	Yes
Leaching duration	<0.05	Yes	0.15	No
Interaction effect				
Conc. & material	<0.05	Yes	0.30	No
Conc. & time	<0.05	Yes	0.13	No
Material & time	<0.05	Yes	<0.05	Yes

Aqueous concentration was affected by several factors



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Conc. & material	<0.05	Yes	0.30	No
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Material & time	<0.05	Yes	<0.05	Yes

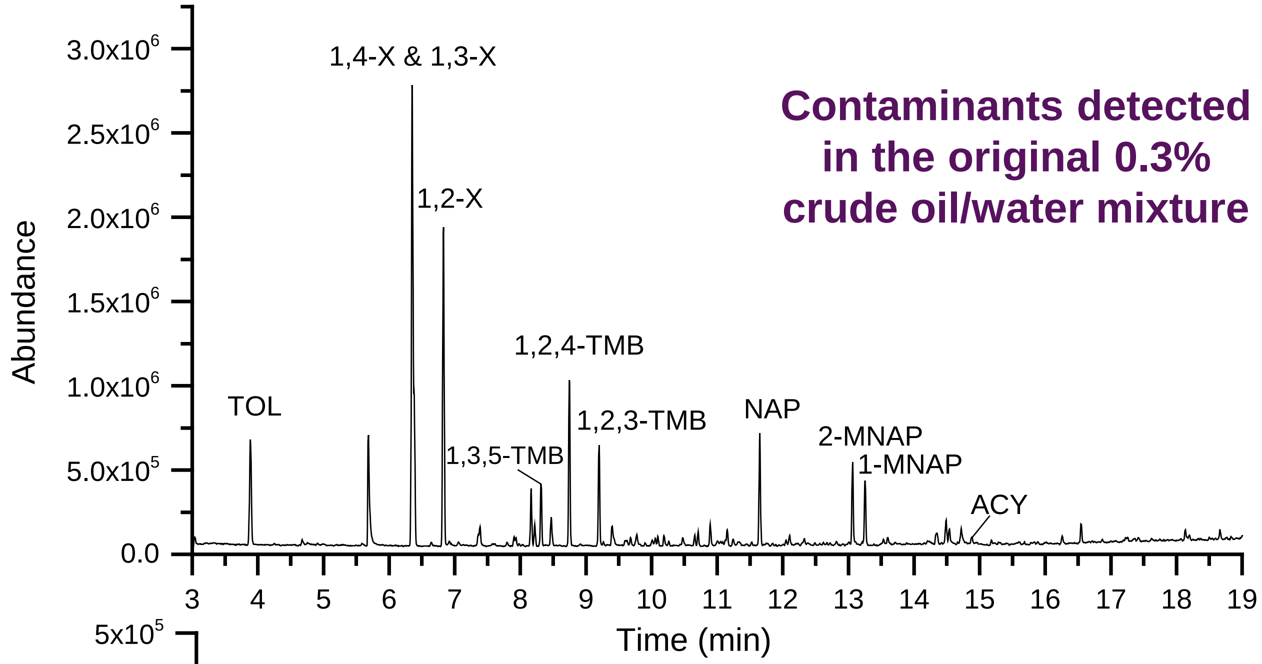
Aqueous concentration was affected by several factors

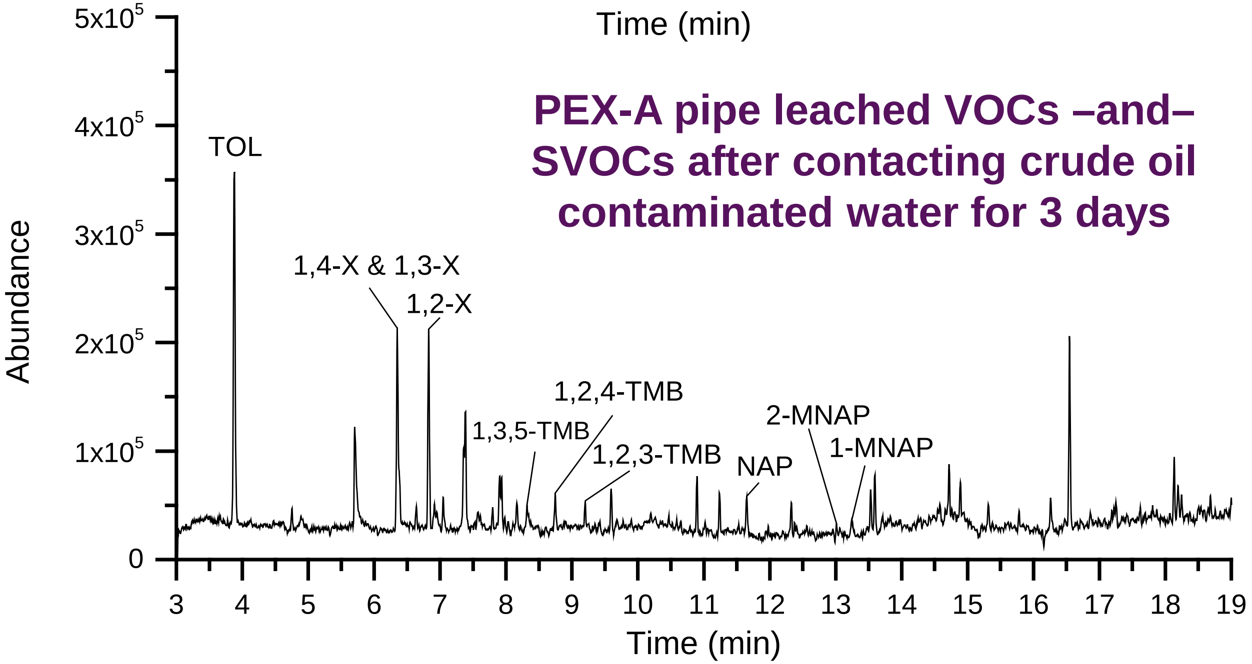
(1) BTEX leaching was affected by initial **crude oil concentration**, **pipe material**, as well as the **leaching duration**.

(2) **TOC** levels significantly **differed** across **pipe materials.**

(3) However, **TOC** was **not a good indicator** for oil contaminated water.

(4) Future work was recommended, such as using **pilot-scale piping systems** and examining **hydraulic conditions (flow vs. no flow)**.





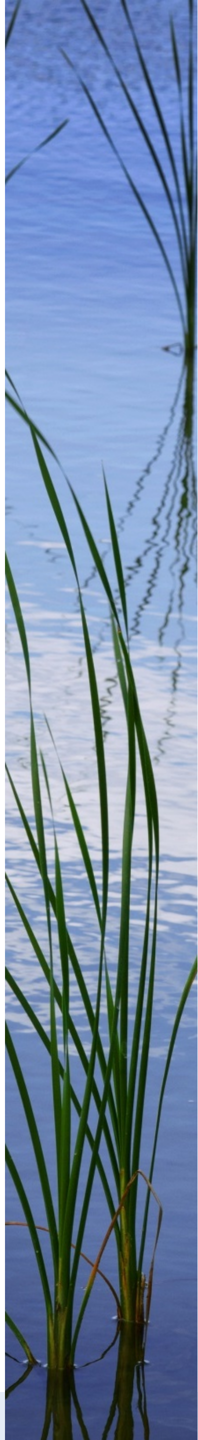
Screening for tentatively identified compounds (TIC) enabled us to find other contaminants

Abbrev.	Contaminant name
1,3,5-TMB	1,3,5-trimethylbenzene
1,2,4-TMB	1,2,4-trimethylbenzene
1,2,3-TMB	1,2,3-trimethylbenzene
NAP	Naphthalene
2-MNAP	2-methylnaphthalene
1-MNAP	1-methylnaphthalene

A Few of the Study Conclusions

- Crude oils contain *thousands of chemicals* and many compounds in addition to BTEX (i.e., *MAHs, PAHs, radionuclides, heavy metals*, etc.).
- Plastic and copper water distribution piping have the potential to *sorb and desorb contaminants* (i.e. BTEX) into drinking water after a crude oil contamination event.
- Among different plastic pipes tested here, CPVC was the most chemically resistant material, whereas *PEX-A and HDPE were more vulnerable*.
- The amount of *BTEX* leached was significantly *affected by various factors*, such as initial contaminated drinking water BTEX concentrations, pipe material, time, etc.
- *TOC was not helpful* in detecting contaminated drinking water.

Some factors not examined, but that may be important: water temperature; pipe scales; biofilms; other materials such as gaskets; and components such as fixtures, valves, appliances, and water heaters.



A Few of the Study Recommendations

Collect and chemically analyze the spilled liquid.* Use this information to inform *all water sampling decisions. A full chemical analysis is recommended to include inorganics, organics, and even radionuclides, especially from oils and hydraulic fracturing liquids.

Screen for tentatively identified compounds (TIC).

- Oil constituents can be chemically altered during water treatment
- Compounds may go undetected when only standard EPA methods are applied.
- TIC reporting is common for the hazardous waste remediation industry, and should be instituted for hydraulic fracturing- and oil-related water contamination incidents.

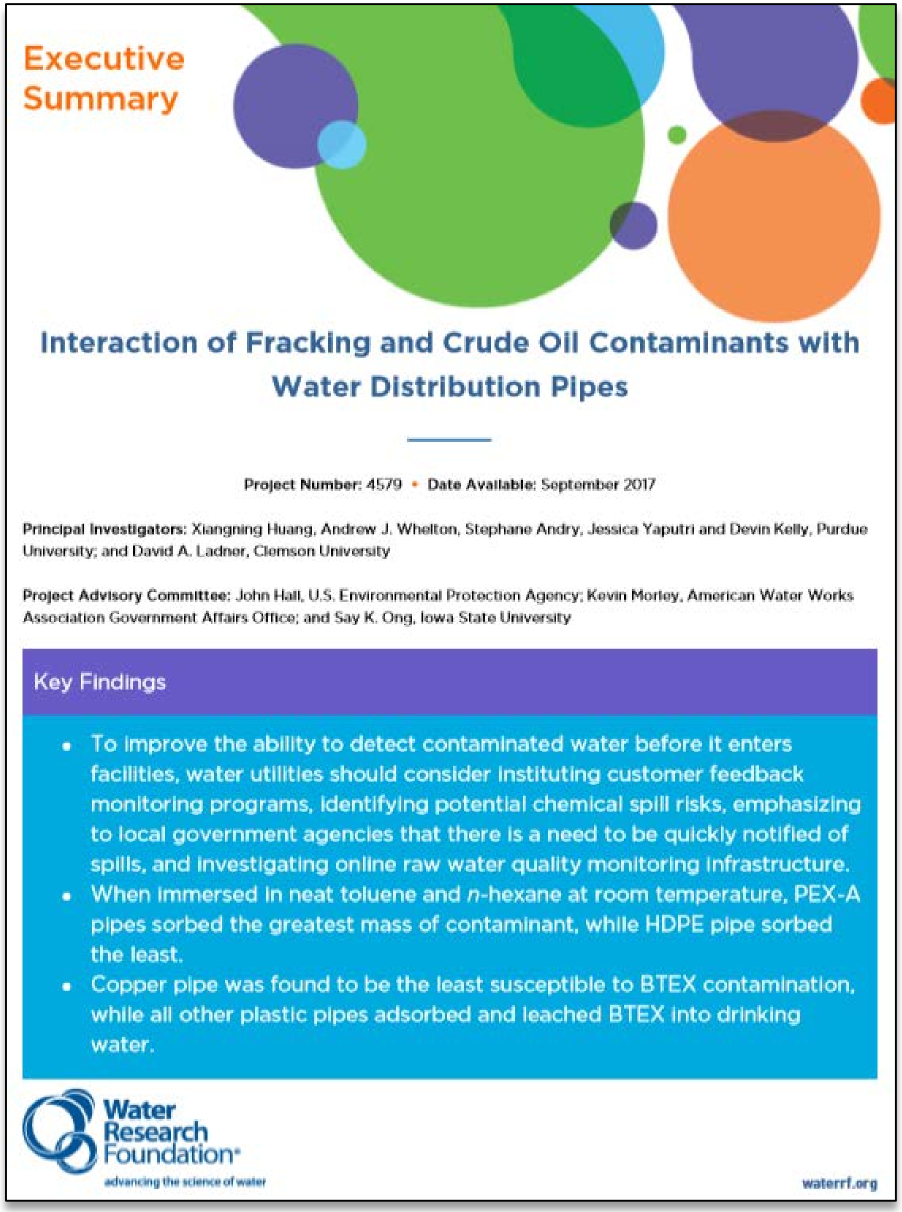
Additional studies should be completed to determine what actions are needed to safely decontaminate distribution and plumbing infrastructure.

The water sector should commission an expert committee charged with identifying the most thorough approach to characterizing complex liquids and mixtures, the waters they contact, and waters that have passed through water treatment plants.

Acknowledgments

Jian Zhang, *Water Research Foundation*

John Hall, Kevin Morley, Say Kee Ong, *WaterRF PAC*



Executive Summary

Interaction of Fracking and Crude Oil Contaminants with Water Distribution Pipes

Project Number: 4579 • **Date Available:** September 2017

Principal Investigators: Xiangning Huang, Andrew J. Whelton, Stephane Andry, Jessica Yaputri and Devin Kelly, Purdue University; and David A. Ladner, Clemson University

Project Advisory Committee: John Hall, U.S. Environmental Protection Agency; Kevin Morley, American Water Works Association Government Affairs Office; and Say K. Ong, Iowa State University

Key Findings

- To improve the ability to detect contaminated water before it enters facilities, water utilities should consider instituting customer feedback monitoring programs, identifying potential chemical spill risks, emphasizing to local government agencies that there is a need to be quickly notified of spills, and investigating online raw water quality monitoring infrastructure.
- When immersed in neat toluene and *n*-hexane at room temperature, PEX-A pipes sorbed the greatest mass of contaminant, while HDPE pipe sorbed the least.
- Copper pipe was found to be the least susceptible to BTEX contamination, while all other plastic pipes adsorbed and leached BTEX into drinking water.

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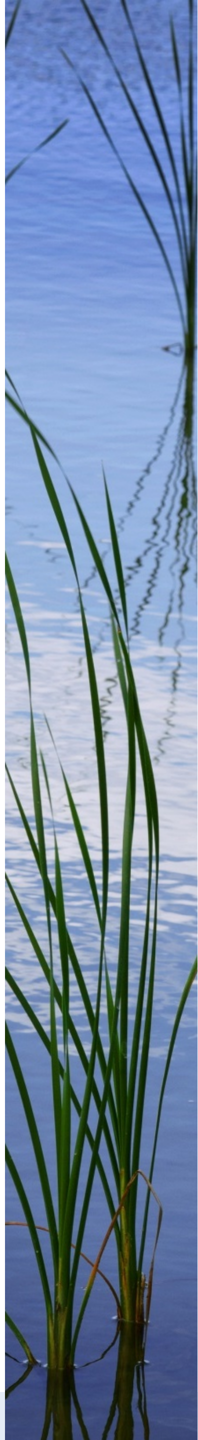
Additional Information:
Huang et al. 2017. Crude oil contamination of plastic and copper drinking water pipes. *Journ. Haz. Mat.*
DOI: https://doi.org/10.1016/j.jhazmat.2017.06.015



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Questions

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