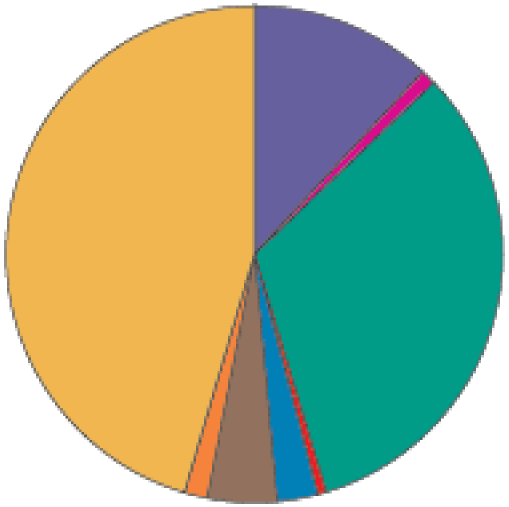
Water Treatment and Low-Quality Waters

Ted Peltier
Department of Civil, Environmental and Architectural Engineering

Kansas Water Workshop
October 11, 2017

Water Withdrawals in the U.S. and Kansas



2010 withdrawals by category, in million gallons per day

Public supply	42,000
Self-supplied domestic	3,600
Irrigation	115,000
Livestock	2,000
Aquaculture	9,420
Self-supplied industrial	15,900
Mining	5,320
Thermoelectric power	161,000

Values do not sum to 355,000 Mgal/d because of independent rounding

	US	KS
Totals (mgd)	**355,000**	**4,000**
Groundwater	22%	80%
Surface Water	78%	20%
Freshwater	86%	100%
Irrigation	32%	76%
Public Supply	12%	10%
Power	45%	9%
Livestock	0.6%	3%

USGS Circular 1405 “Estimated Use of Water in the United States in 2010”

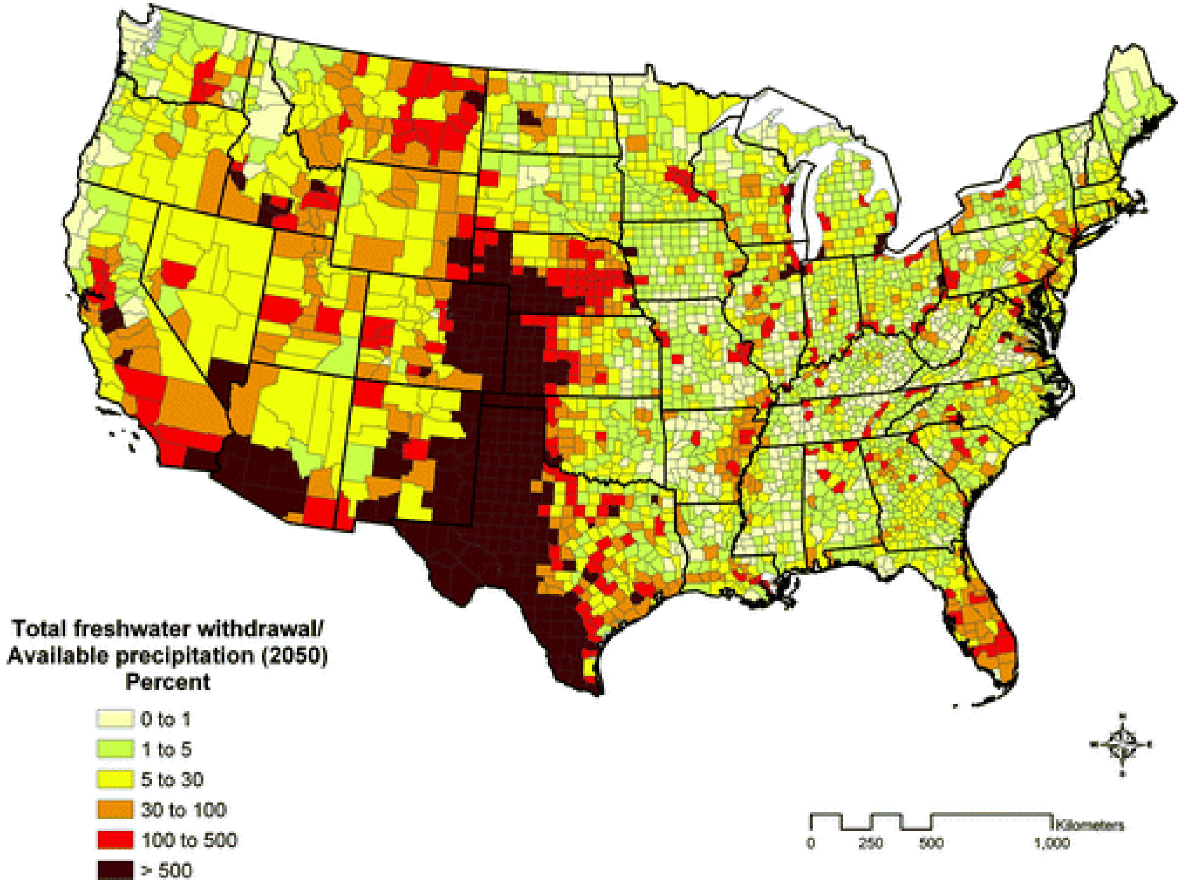
Water Stress and Scarcity

Population growth in the US is often concentrated in areas with low or declining water reserves

Groundwater use rates are depleting existing aquifers

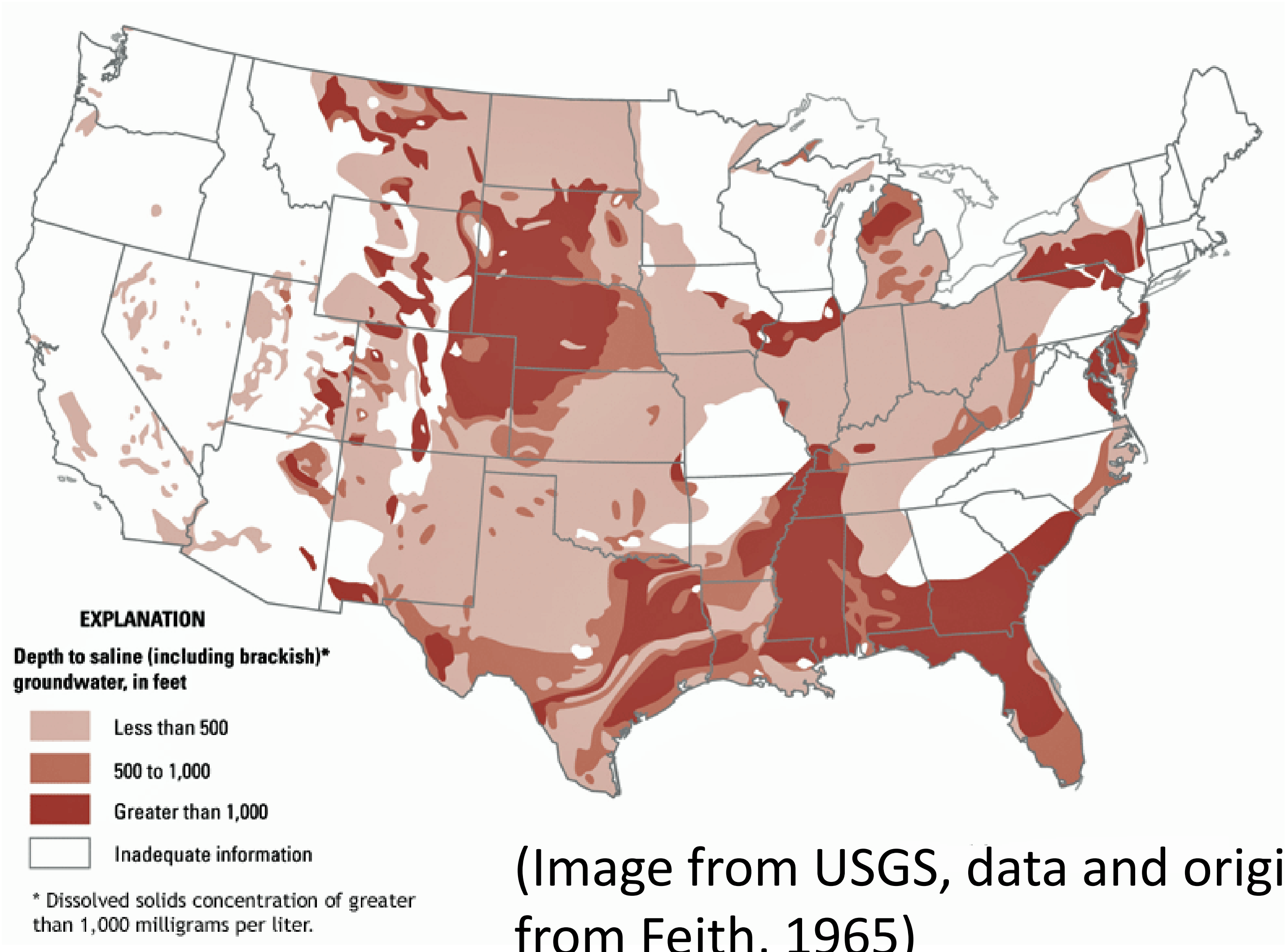
Water Reuse and Recycling options:

- **Gray water reuse**
- **Groundwater recharge**
- **Wastewater treatment for indirect or direct potable reuse**
- **Industrial WW Recovery**



Projected water withdrawal ratios in 2050 (Roy et al. 2012)

Alternative Water Source Development



(Image from USGS, data and original map from Feith, 1965)

Challenges in Utilizing Low Quality Waters

- **Lack of treatment standards**
- **Variable quality, including ‘uncommon’ pollutant compounds**
- **Higher treatment requirements and energy costs**
- **Compatibility with water storage and transmission system**
- **Ownership and other legal issues**
- **Public cooperation and acceptance**

KU Strengths in Low Quality Water Treatment

- **People**
- **Expanded research facilities and equipment**
- **Existing multi-disciplinary research groups addressing related topics**
- **State agency interest and related work**
- **History of successful collaboration with water and wastewater utilities and organizations at local and national level**

Water Treatment Technologies

- **Stephen Randtke (CEAE)- Drinking Water Treatment Processes and Infrastructure**
- **Belinda Sturm (CEAE)- Biological WW Treatment and Bioreactor Design**
- **John Devlin (Geology)- Groundwater remediation and contaminant transport**
- **Mark Shiflett (CPE)- Energy-efficient desalination**
- **Gibum Kwon (ME)- Membranes for Oil-Water Separation**

Water and Energy Research

Algal Biofuels Research

Belinda Sturm (CEAE) and Susan Stagg-Williams (CPE)

Reduced Cooling Water Use at Power Plants

Ted Bergman and Ron Dougherty (ME)

Water use in Oil and Gas Production

Reza Barati (CPE)

Shahin Negahban, Karen Peltier and Stan McCool (TORP)

Produced Water Management and Treatment Group

An Overview of the Produced Water Management and Treatment Program

Produced Water Research Program

- NSF-Sponsored Program at KU and West Virginia University
- Goal: Develop management strategies to reduce the impact of oil and gas production on existing water resources and to increase use and reuse of produced water
- Specific Research Objectives
    1. Treatment of produced water and formation brines to encourage beneficial use and reuse
    2. Minimization of freshwater use in oil and gas production
    3. Assessment of impacts of produced water on aquatic ecosystems

Participants

University of Kansas

Collaborators
Edward Peltier
Stephen Randtke
Karen Peltier
Reza Barati
Belinda Sturm
Jyun-Syung Tsau

Staff
Ray Carter Jr.
Mark Ballard

Post-Doctoral Researchers
Ming Chen, Karla Leslie,
Masoumeh Veisi, Sheng-Xue Xie

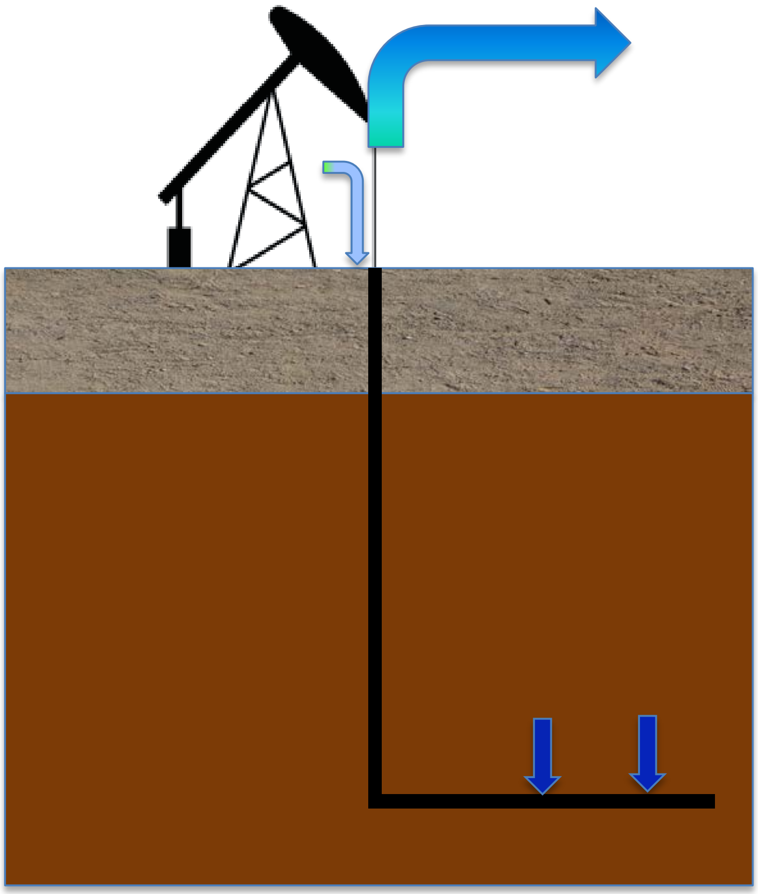
West Virginia University

Collaborators
Paul Ziemkiewicz
Lian-Shin Lin
Joseph Donovan
Harry Finklea
J. Todd Petty
Shawn Grushecky

Staff
Jennifer Hause

Post-Doctoral Researchers
Eric Merriam

What is Produced Water?

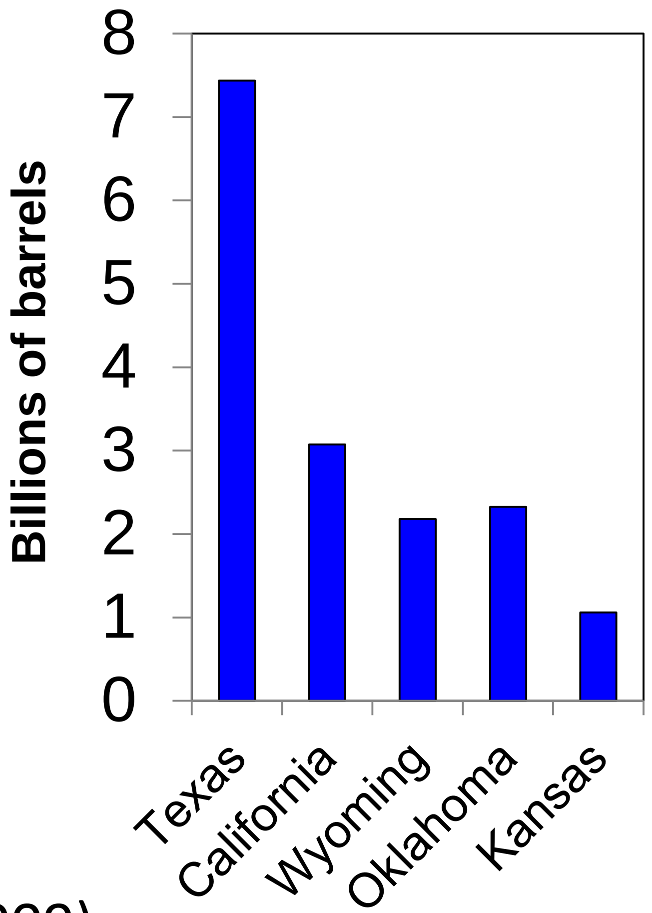


- **Flowback water**
  - Injected fracturing fluid returning to the wellhead
  - Occurs primarily in the first few weeks
- **Formation water**
  - Water from hydrocarbon-bearing formations, or injected for enhanced recovery purposes
  - Composition depends on formation chemistry
  - Returns throughout production

Produced Water Volumes

- **Over 20 billion barrels (3.3 billion m^3) generated in U.S. in 2012**
- **KS is 5th largest generator**
  - 1.1 billion barrels (~ 45 billion gallons) in 2012
- **KS volumes stable from 2007-2012**
  - Oil production increased by ~ 20%
- **KS wells average ~20 barrels of water per barrel of oil**
  - National average ~ 10 bbl/bbl

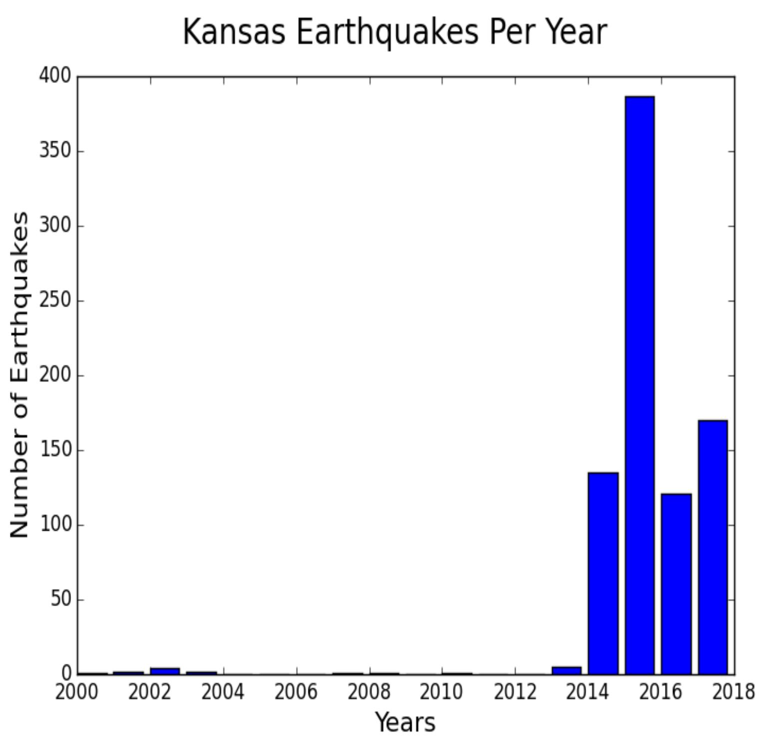
Produced Water Production in Top 5 States, 2012



Data from Veil (2015) and Clark & Veil (2009)

Produced Water Disposal in Kansas

- **In Kansas, ~ 2/3 of KS disposed of by deep-well injection; ~ 1/3 reused by oil & gas producers**
- **Deep-well injection has been linked to increased seismic activity (induced seismicity)**
- **Area-based restrictions on deep well injection since 2015**
- **Incentives exist for increased water reuse and recovery, and for reducing volumes sent to disposal.**



Source: Virginia Tech Seismological Observatory

Inorganic Constituents

Constituent (in mg/l)	Barnett (TX)	Haynesville (AK, LA, TX)	Marcellus (NY, PA WV)	Western U. S.
TDS	40,000-185,000	40,000-250,000	45,000-185,000	1,000-400,000
Chloride	25,000-110,000	20,000-150,000	25,000-105,000	ND-250,000
Sodium	10,000-47,000	15,000-55,000	10,000-45,000	ND-150,000
Calcium	2,200-20,000	3,100-34,000	5,000-25,000	ND-74,000
Strontium	350-3,000	100-3,000	500-3,000	ND-6,250
Magnesium	200-3,000	300-5,200	500-3,000	ND
Barium	30-500	100-2,200	50-6,000	ND-850
Iron	22-100	80-350	20-200	ND
Sulfate	15-200	100-400	10-400	ND-15,000

Reuse Barriers

- **High salinities affect water and nutrient uptake and reduce crop yield.**
- **Presence of dispersed oil and dissolved hydrocarbon compounds**
- **Scale formation in treatment systems and producing formations from divalent cations precipitation with carbonates and/or sulfates**
- **Other constituents with water quality impacts or plant toxicity (e.g. B, Ra^{2+}, Ba^{2+}, Sr^{2+})**
- **Corrosivity (CO_2, H_2S, salinity)**

New & Improved Fracking Fluids

- **Energized fluids, including supercritical CO2 foams stabilized with polyelectrolyte complex nanoparticles (PECNPs)**
  - Reduced freshwater use
  - Better suspension of proppants
  - Improved oil recovery

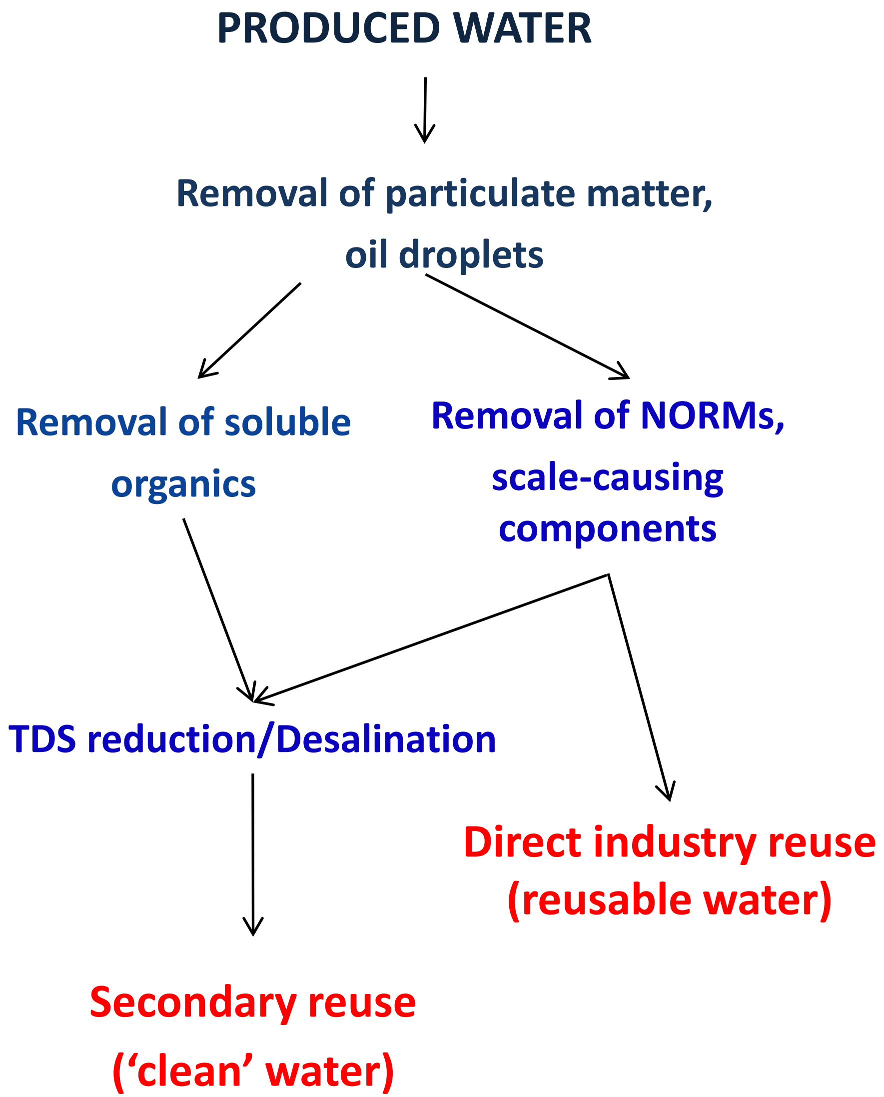
- **Using Produced Water to Prepare Fracking Fluids**
  - Optimized formulations and salinity levels
  - Stabilization with PECNPs
  - Benefits include increased O&G production and reduced demand on freshwater supplies

PW Treatment: General Strategy

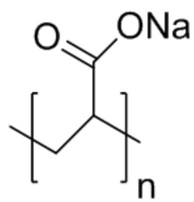
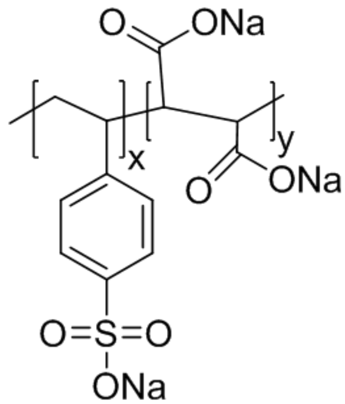
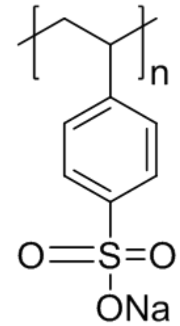
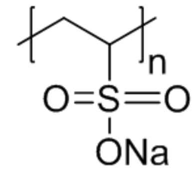
Initial TSS and oil separation occurs at the well site

Minimal treatment for direct reuse, to prevent scaling or clogging

Salinity reduction required for secondary uses

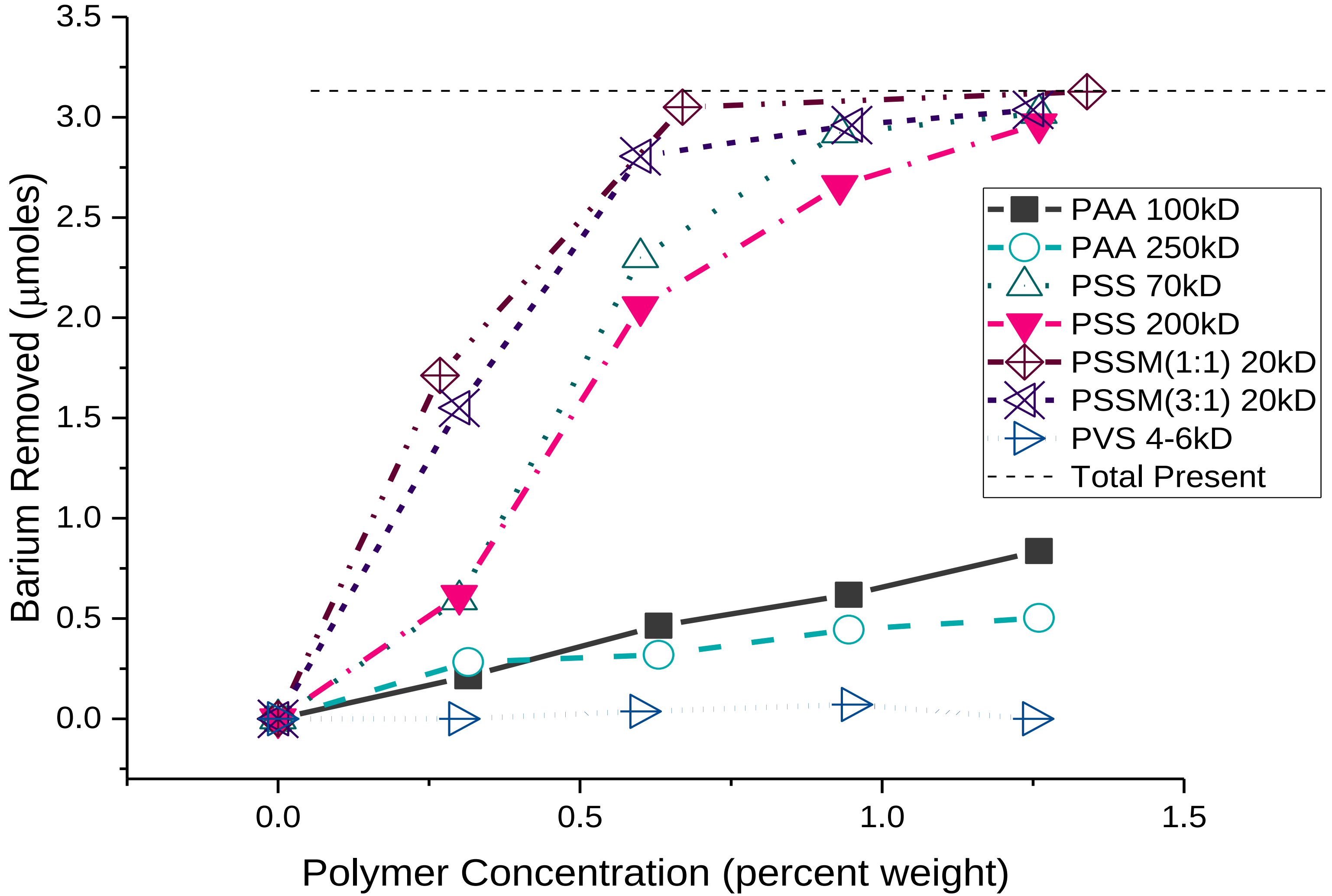


Polyelectrolytes used as "scale inhibitors"

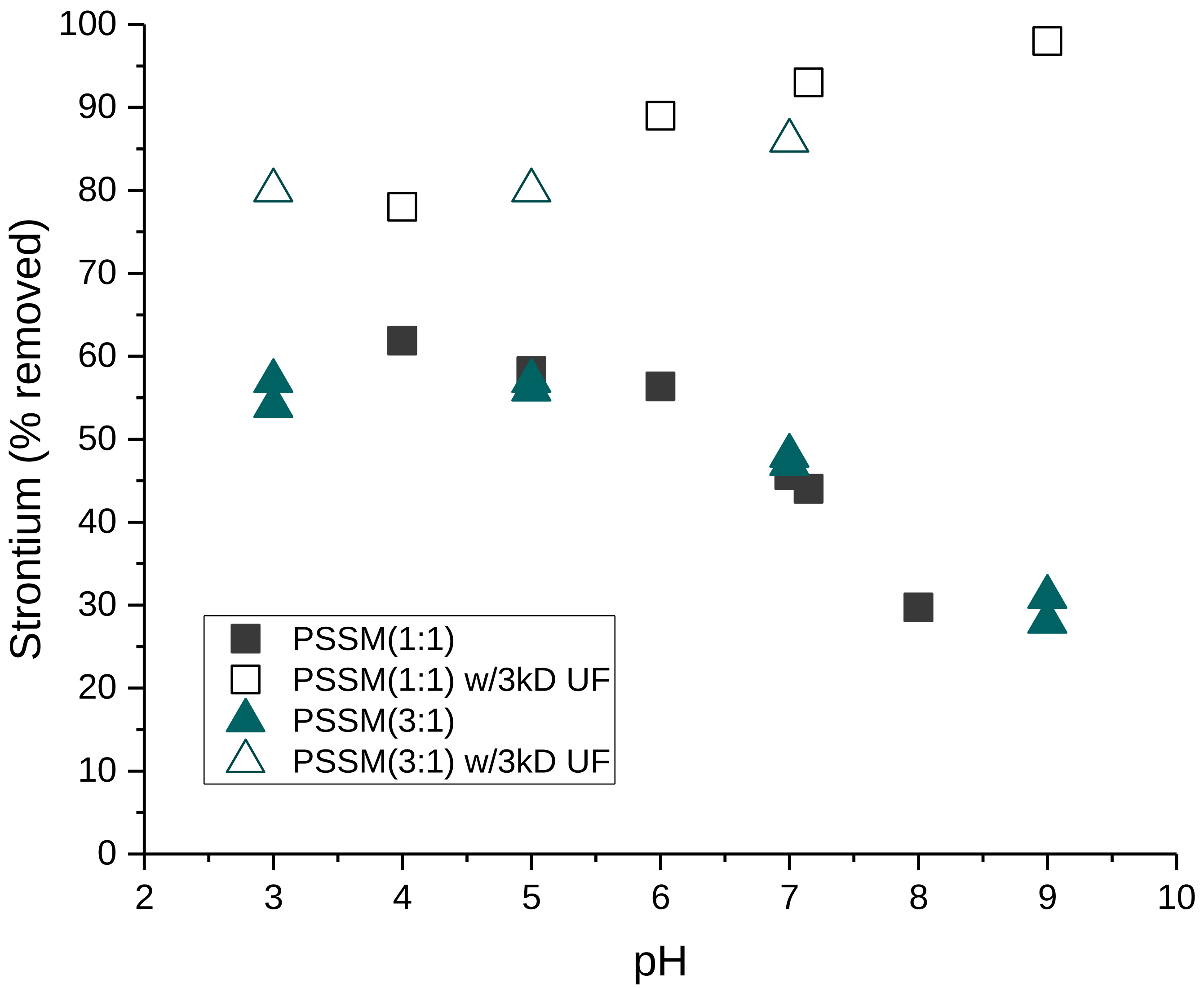
Structure*:				
Abbreviation:	PAA	PSSM	PSS	PVS
Name:	Poly(acrylic acid) sodium salt	Poly(4-styrenesulfonic acid-co-maleic acid) sodium salt	Poly(4-styrenesulfonate) sodium salt	Poly(vinylsulfonic acid) sodium salt
Average MW tested:	5.1, 100, 250 kD	20 kD	70, 200, 1,000 kD	4-6 kD

*Chemicals (as well as structure information and MW data) were obtained directly from Sigma-Aldrich (www.sigmaaldrich.com).

Ba^{+2} Removal vs Polymer Type/Concentration



Best case for Sr+2: Combining pH with UF

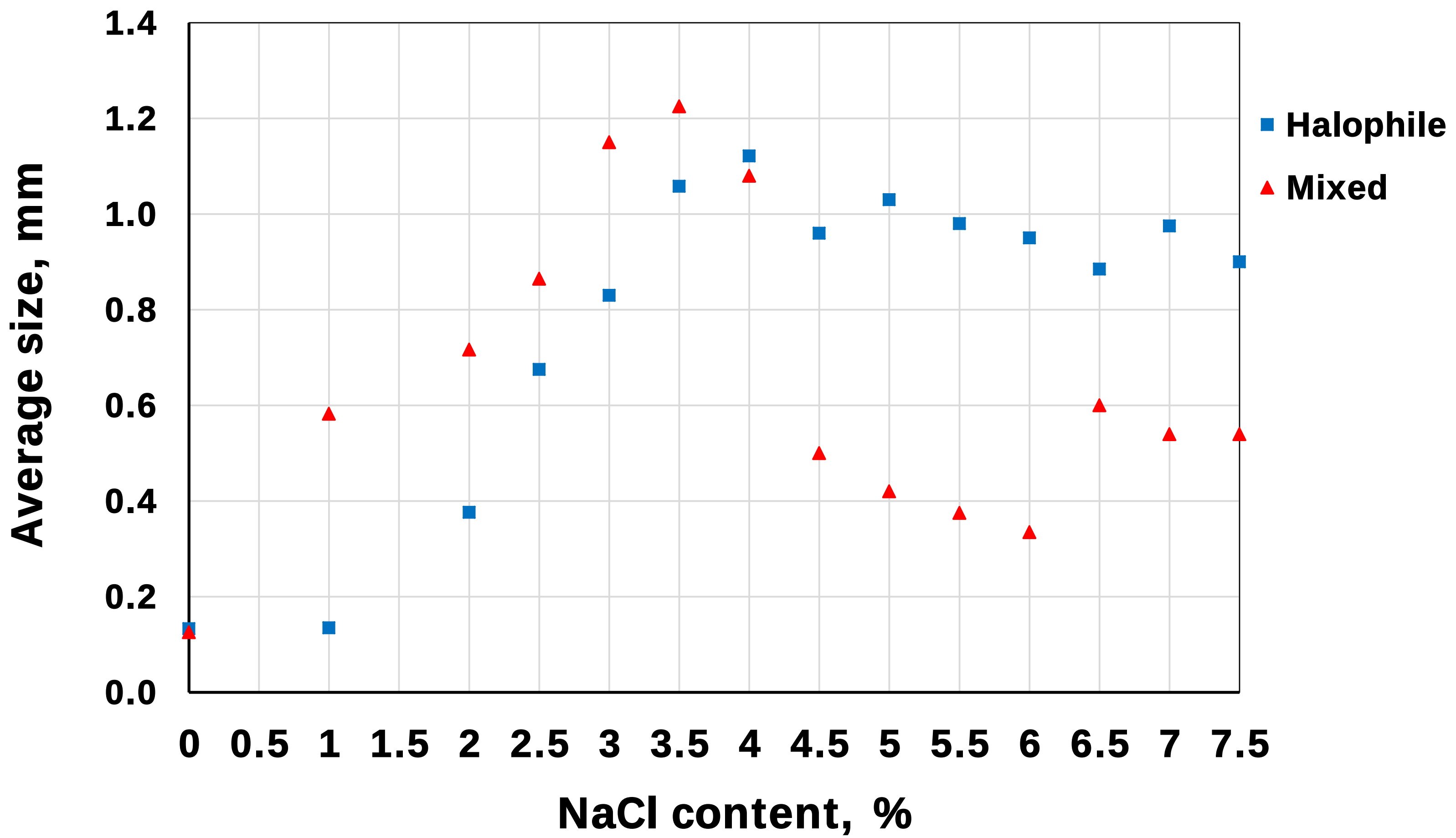


AEROBIC GRANULAR SLUDGE FORMATION IN HYPERSALINE SYNTHETIC PRODUCED WATER

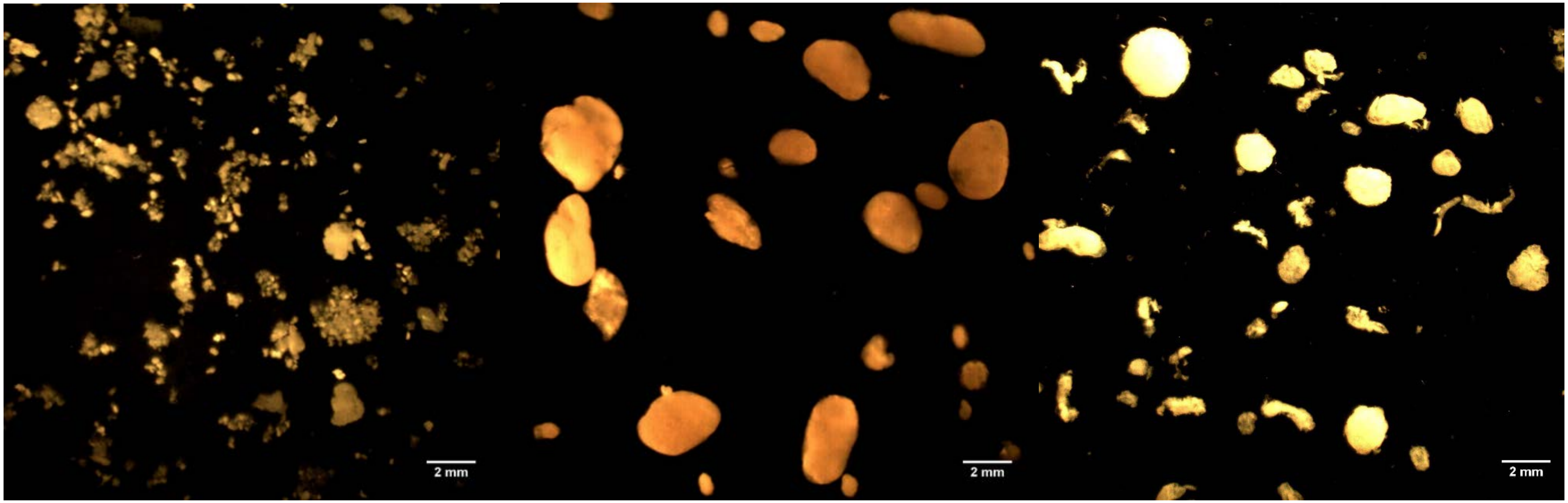
- Inoculated with a mixed culture of combined irregular aerobic granules and flocs

- Inoculated with halophilic microorganisms (*Sporosarcina halophile)*

Aerobic Granule Size & Integrity



Halophilic Microorganisms: Image Analysis*



Granule formation	Granule maturation	Degranulation

NaCl, %	1%	4%	7.5%
Avg. Dia., mm	0.24 ± 0.08	1.12 ± 0.18	0.9 ± 0.57
SVI, mL/g	62 ± 27	12 ± 5	22 ± 0.6
VSS/SS	0.76	0.82	0.8

* Ibrahim et al., WEFTEC 2017

Desalination

- **Reverse Osmosis (RO), Multi-stage Flash (MSF) distillation and Multi-Effect Distillation (MED) account for 94% of global desalination capacity**
- **Energy requirements rise quickly as inlet feeds become more saline**
- **At TDS 150,000-250,000 mg/L evaporative crystallizers can treat brines with zero-liquid discharge (ZLD) or near-ZLD**

Treatment Type	Energy Cost (kWh/m^3)	Treatable TDS Limit (mg/L)
RO	3.5-6.0	~70,000
MSF	10-28	~150,000
MED	7-25	~150,000
Brine Concentrator	18-26	N/A
Brine Crystallizer	52-66	N/A
Brine Concentrator /Crystallizer	70-92	~250,000

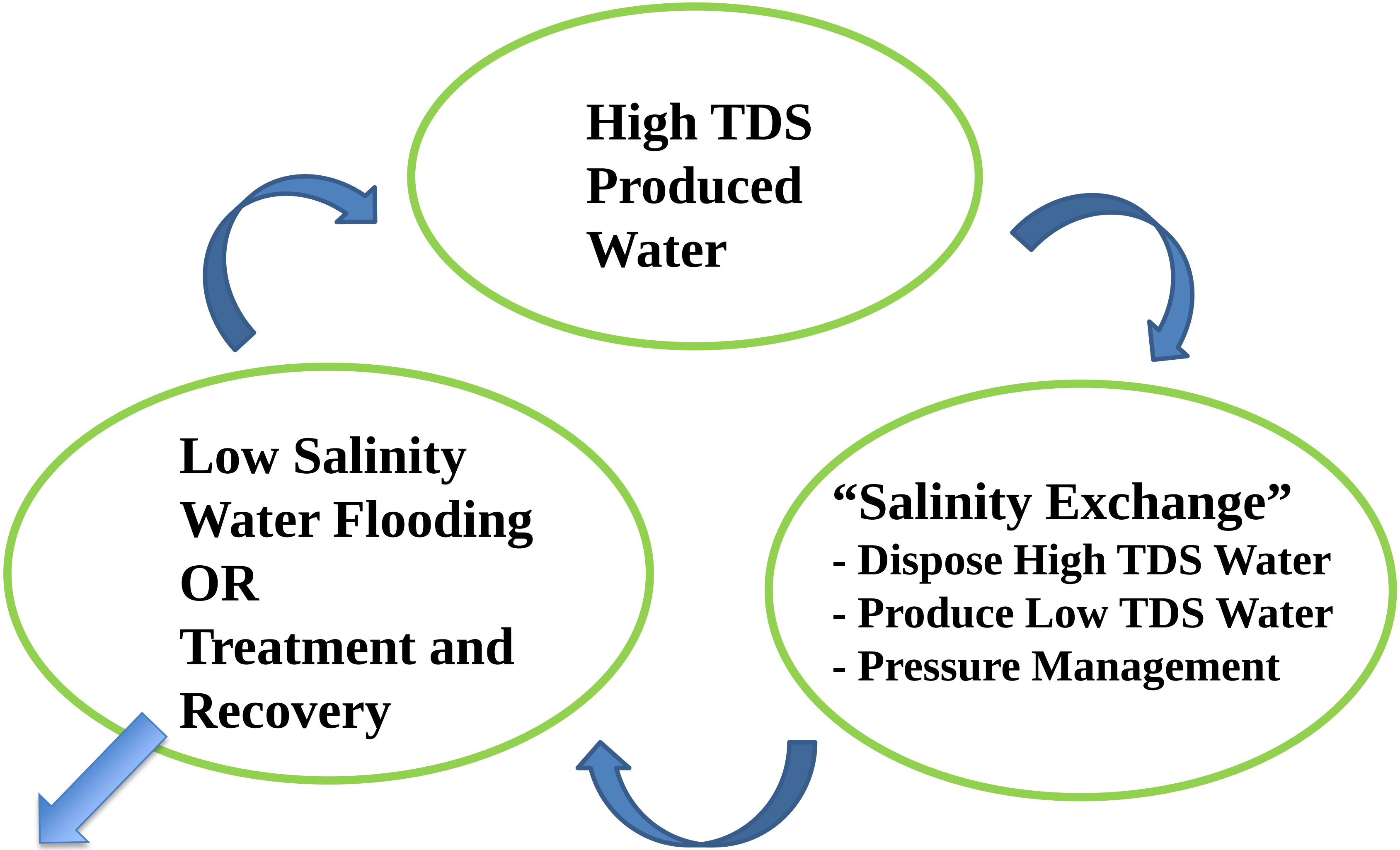
Emerging Desalination Methods

- **Multiple approaches being developed to reduce energy use and costs, or increase range of treatable waters.**
  - Phase change-based separations (gas hydrate freeze-melting, supercritical desalination, humidification-dehumidification),
  - Advanced membrane processes (forward osmosis, membrane distillation)
  - Voltage-driven processes (electrodialysis, microbial desalination cells)

- **Electrodialysis (ED) and membrane distillation (MD) systems have already been tested on a pilot-scale.**

- **Freeze-melting and supercritical desalination have the potential to significantly reduce energy requirements.**

Salinity Exchange for High Salinity Produced Water



Future Research Areas

- **Produced and saline waters are potential resources in KS and elsewhere; improved treatment processes are needed**
- **Matching treated-water quality to desired uses can help optimize treatment requirements**
- **Identify availability of new/water reuse sources and how they can fit specific needs**
- **Cost-benefit of water recovery and management will be important, and will differ across applications**
- **Examine the impacts of water reuse or new source development on existing freshwater systems**

Acknowledgements

- **Produced Water Research Group**
- **Research Partners & Collaborators**
  - Kansas Water Office
  - Kansas Geological Survey
  - Kansas Biological Survey
- **Funding Sources**
  - National Science Foundation, EPSCoR Research Infrastructure Improvement Program: Track-2, Focused EPSCoR Collaboration Award(OIA-1632892)
  - KU Strategic Initiative Grant
  - Tertiary Oil Recovery Program
  - KU Dept. of Civil, Environmental & Architectural Engineering
- **Many Graduate & Undergraduate Student Researchers**