Produced Water Management in Kansas: Treatment and Reuse Options

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Governor's Conference on the Future of Water in Kansas
Manhattan, Kansas
November 9, 2017

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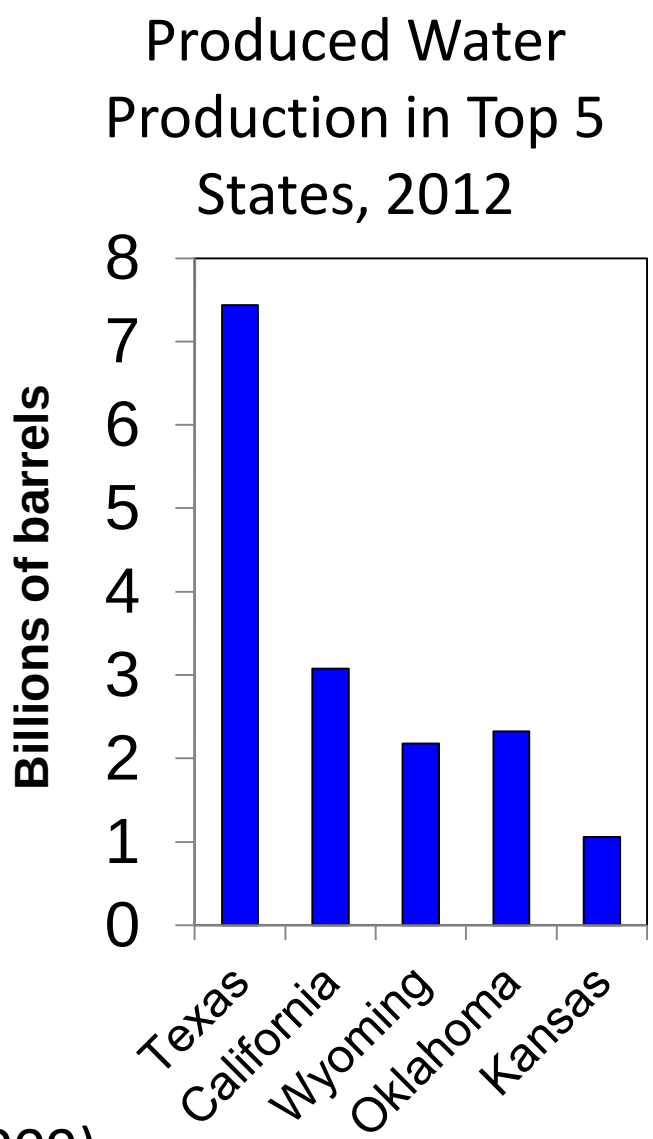
Produced Water Research Program

- **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**

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



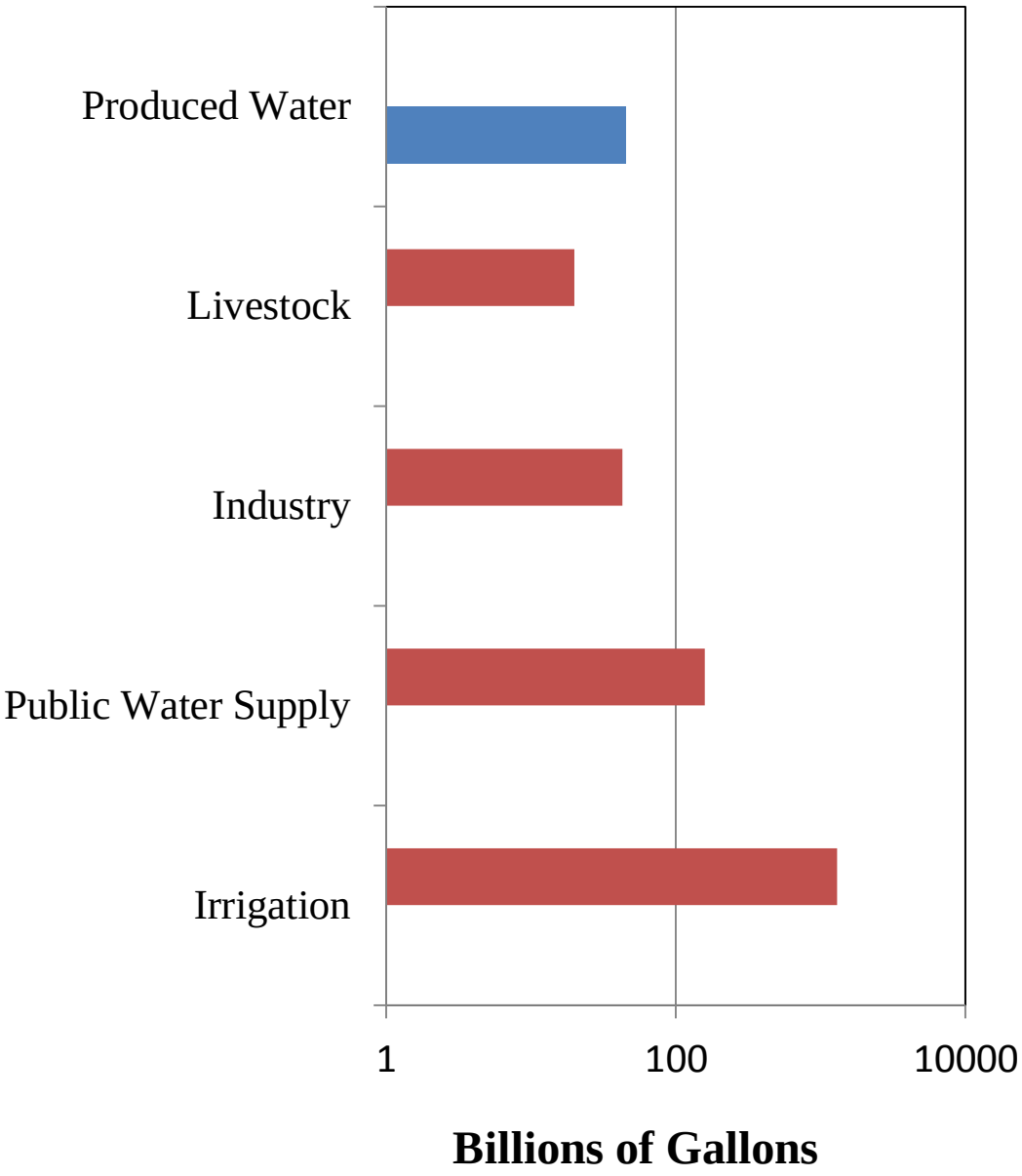
Data from Veil (2015) and Clark & Veil (2009)

Produced Water Volume Compared to Water Use in Kansas in 2012*

In 2012, produced water volume ~2.5% of Kansas water use

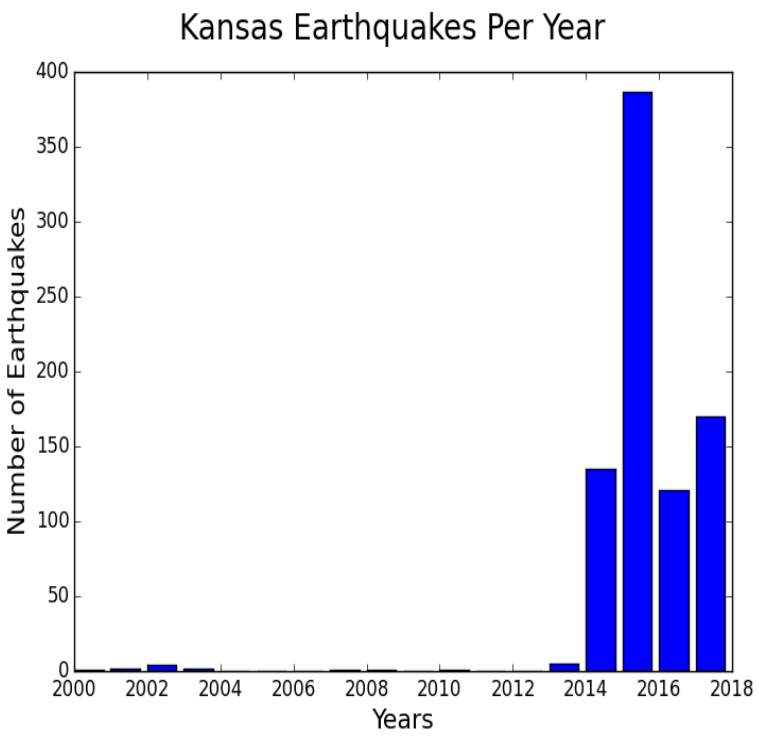
Highest water use is for irrigation, primarily from groundwater sources

(*Water use data from KS Dept. of Agriculture and USGS)

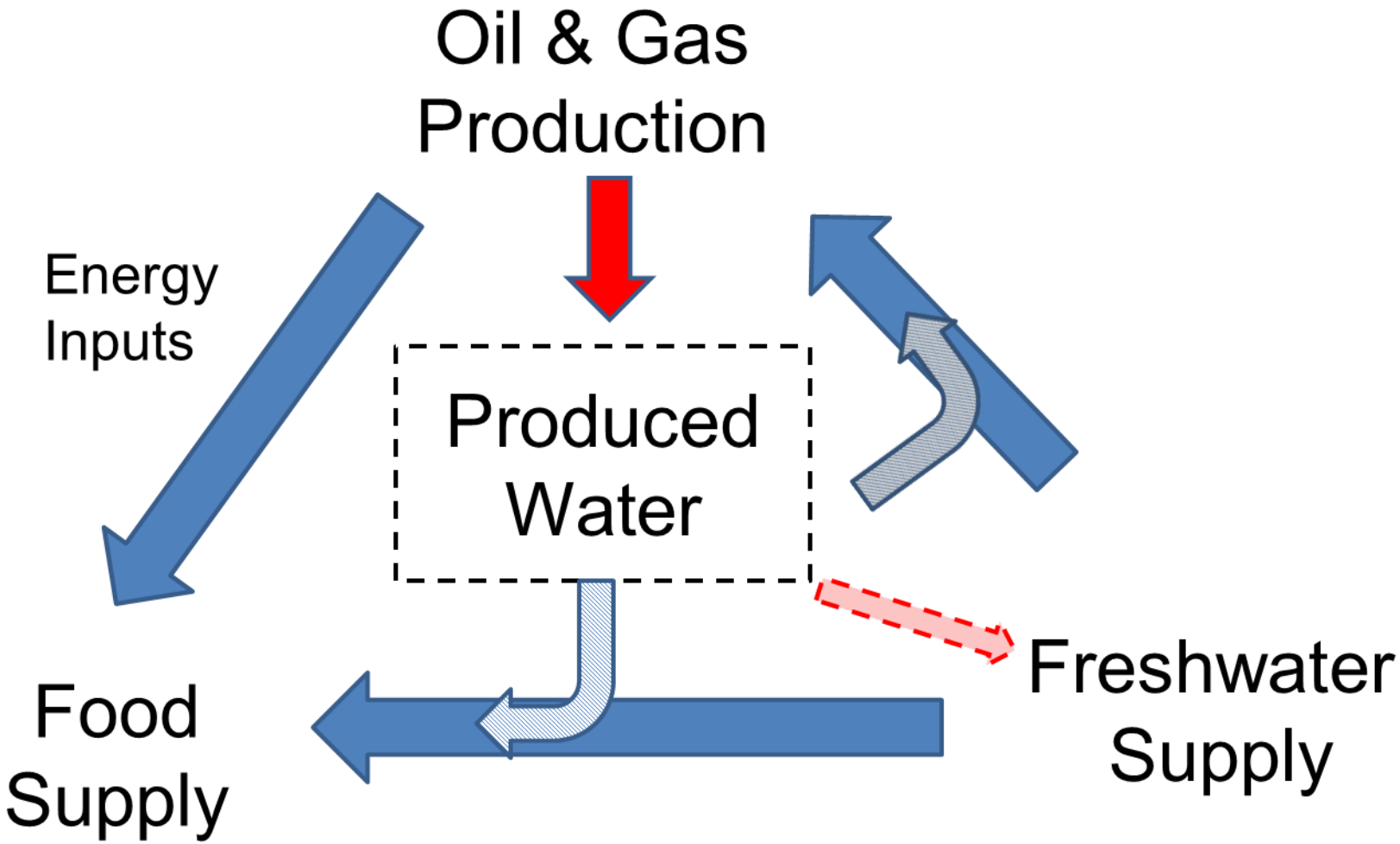


Produced Water Disposal in Kansas

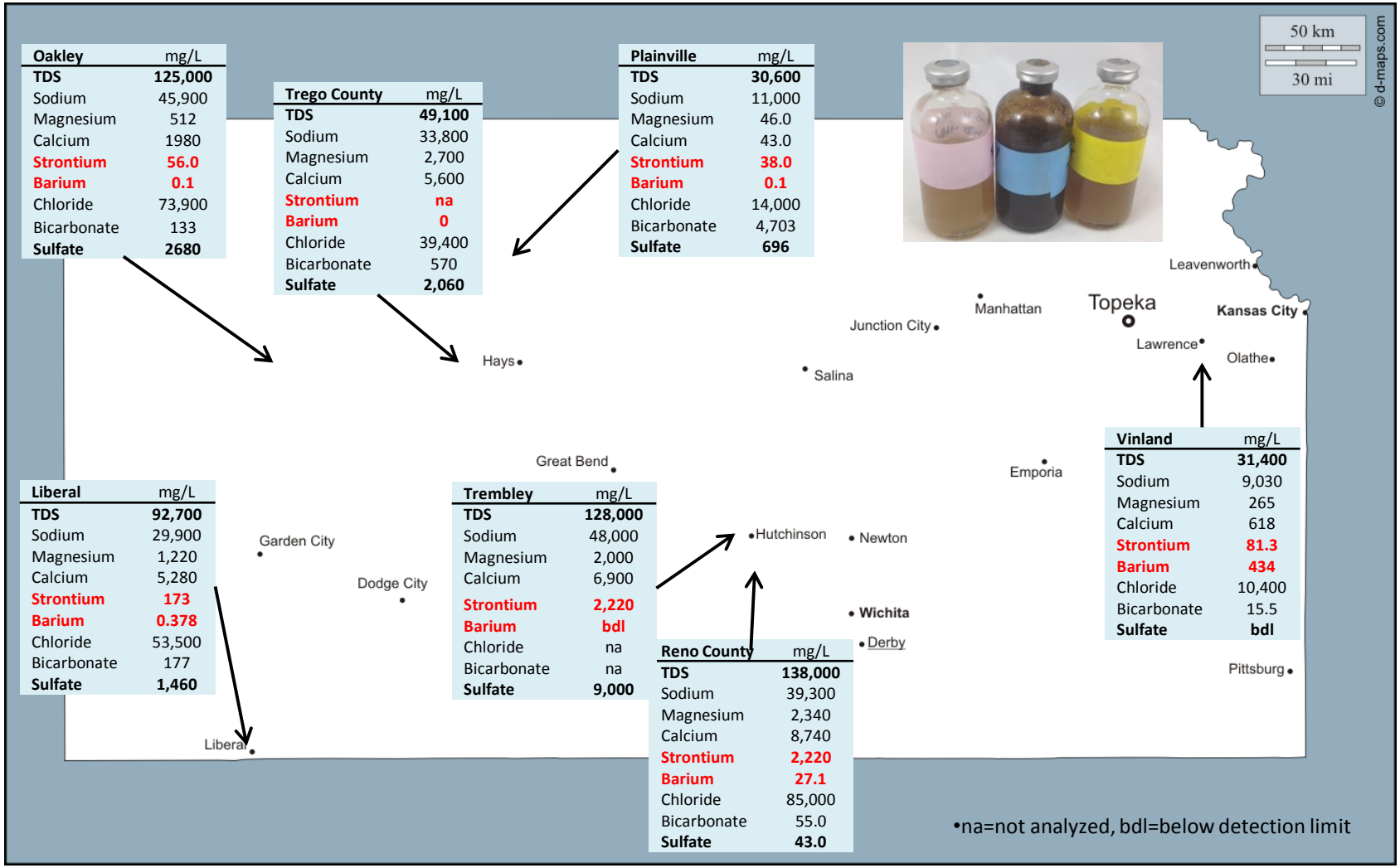
- In Kansas, ~ 2/3 of KS disposed of by deep-well injection; ~ 1/3 reused by oil & gas producers
- Deep-well injection has been linked to increased seismic activity (induced seismicity)
- Area-based restrictions on deep well injection since 2015
- Incentives exist for increased water reuse and recovery,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



Source: Virginia Tech Seismological Observatory


Oil & Gas Production
Energy Inputs
Produced Water
Food Supply
Freshwater Supply

Examples of Produced Waters Across Kansas



Oakley	mg/L
TDS	**125,000**
Sodium	45,900
Magnesium	512
Calcium	1980
Strontium	**56.0**
Barium	**0.1**
Chloride	73,900
Bicarbonate	133
Sulfate	**2680**

Trego County	mg/L
TDS	**49,100**
Sodium	33,800
Magnesium	2,700
Calcium	5,600
Strontium	**na**
Barium	**0**
Chloride	39,400
Bicarbonate	570
Sulfate	**2,060**

Plainville	mg/L
TDS	**30,600**
Sodium	11,000
Magnesium	46.0
Calcium	43.0
Strontium	**38.0**
Barium	**0.1**
Chloride	14,000
Bicarbonate	4,703
Sulfate	**696**

Vinland	mg/L
TDS	**31,400**
Sodium	9,030
Magnesium	265
Calcium	618
Strontium	**81.3**
Barium	**434**
Chloride	10,400
Bicarbonate	15.5
Sulfate	**bdl**

Liberal	mg/L
TDS	**92,700**
Sodium	29,900
Magnesium	1,220
Calcium	5,280
Strontium	**173**
Barium	**0.378**
Chloride	53,500
Bicarbonate	177
Sulfate	**1,460**

Trembley	mg/L
TDS	**128,000**
Sodium	48,000
Magnesium	2,000
Calcium	6,900
Strontium	**2,220**
Barium	**bdl**
Chloride	na
Bicarbonate	na
Sulfate	**9,000**

Reno County	mg/L
TDS	**138,000**
Sodium	39,300
Magnesium	2,340
Calcium	8,740
Strontium	**2,220**
Barium	**27.1**
Chloride	85,000
Bicarbonate	55.0
Sulfate	**43.0**

•na=not analyzed, bdl=below detection limit

Reuse Barriers: Salinity and Sodicity

- **High salinities affect water and nutrient uptake and reduce crop yield.**
  - Non-saline water (TDS < 500 mg/L) safe for all plants
  - Water with TDS = 500 – 4,000 mg/L may be safe for more salt-tolerant plants

- **Water high in sodium and deficient in other cations, i.e., having a high sodium adsorption ratio (SAR), can cause soils to swell and plug, reducing water infiltration rates.**

- **Livestock cannot tolerate excessive salt levels.**

Reuse Barriers: Specific Elements

- **Boron – universally safe under 0.5 mg/L, some plants can tolerate up to 15 mg/L**
  - Little information on current concentrations

- **Chloride – universally safe under 70 mg/L, tolerances up to 350 mg/L**

Constituent	Permanent irrigation MCL (mg/L)	< 20 years irrigation MCL (mg/L)
Aluminum	5	20
Arsenic	0.1	2
Beryllium	0.1	0.5
Cadmium	0.01	0.05
Chromium	0.1	1
Cobalt	0.05	5
Copper	0.2	5
Fluoride	1	15
Iron	5	20
Lithium	2.5	N/A
Manganese	0.2	10
Molybdenum	0.01	0.05
Nickel	0.2	2
Lead	5	10
Selenium	0.02	0.02
Vanadium	0.1	1
Zinc	2	10

•Trace Element Maximum Contaminant Levels assuming good irrigation practices (Lazarova & Bahri, 2004)

Reuse Barriers: Additional Concerns

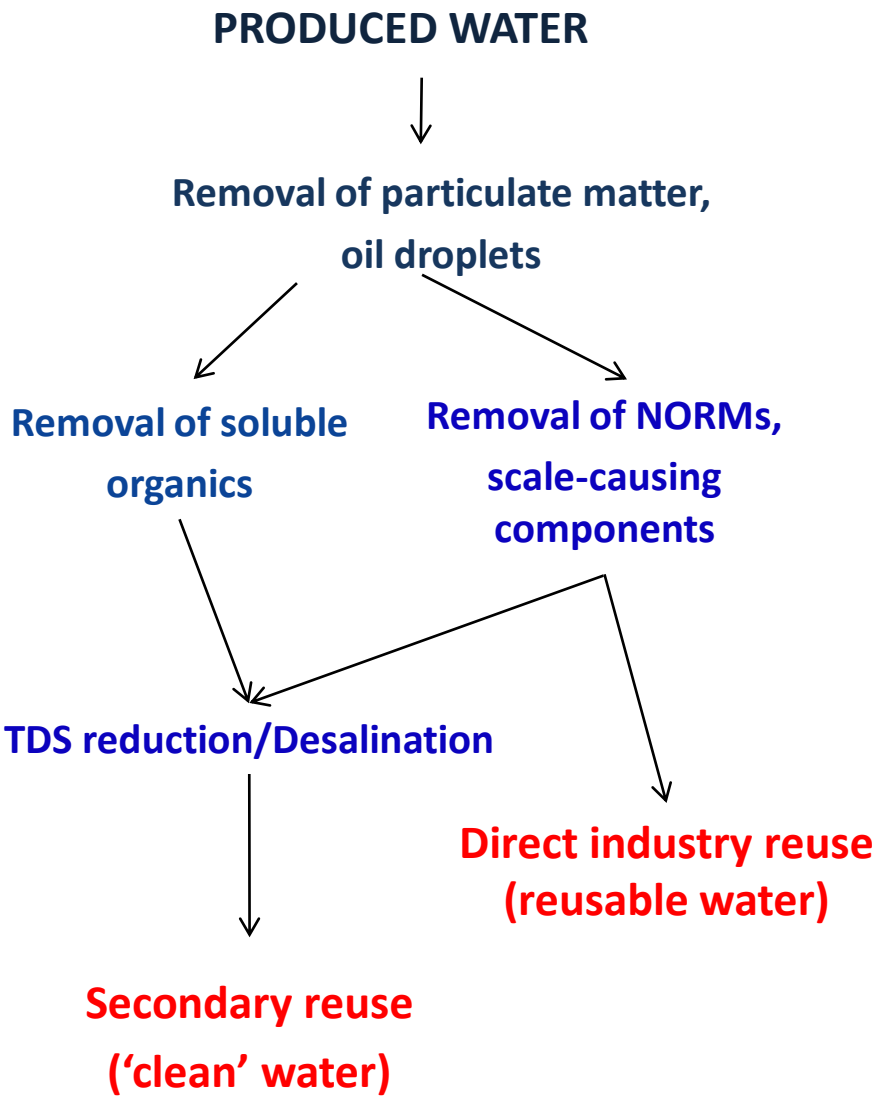
- **Radioactivity (e.g., Ra^{+2})**
- **Scale formation in pipes, treatment systems, wells, producing formations, storage tanks, membranes, …**
  - Carbonate and sulfate scales, those associated with Ca^{+2}, Mg^{+2}, and especially Sr^{+2}, Ba^{+2}, and Ra^{+2}
  - Iron and manganese oxides
  - Sulfides
- **Corrosivity (CO_2, H_2S, salinity)**
- **Other constituents (e.g., Ba^{+2} and Sr^{+2}), esp. those related to current or future MCLs or water quality standards**

PW Treatment: General Strategy

Initial TSS and oil separation occurs at the well site

Minimal treatment for direct reuse, to prevent scaling or clogging

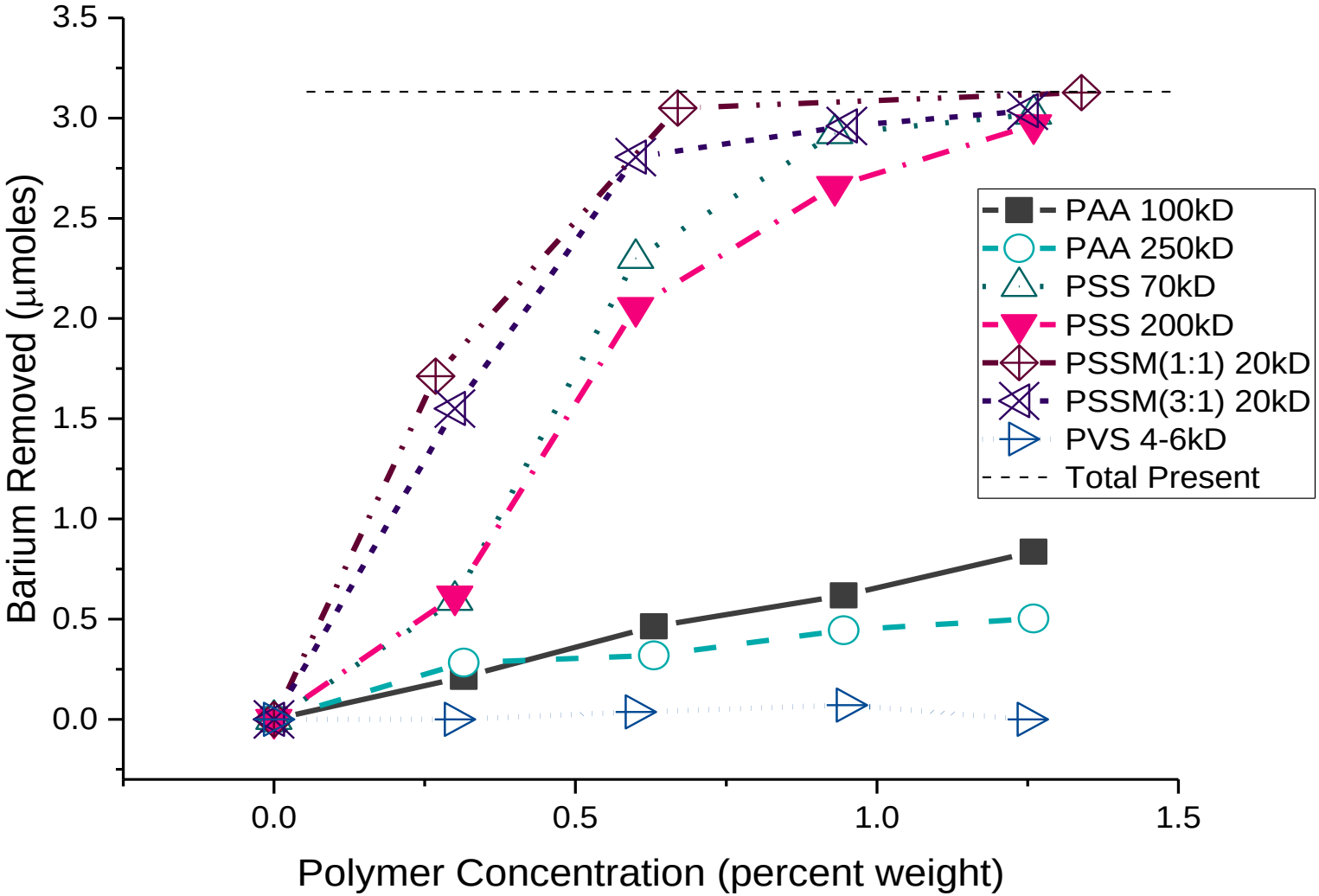
Salinity reduction required for secondary uses



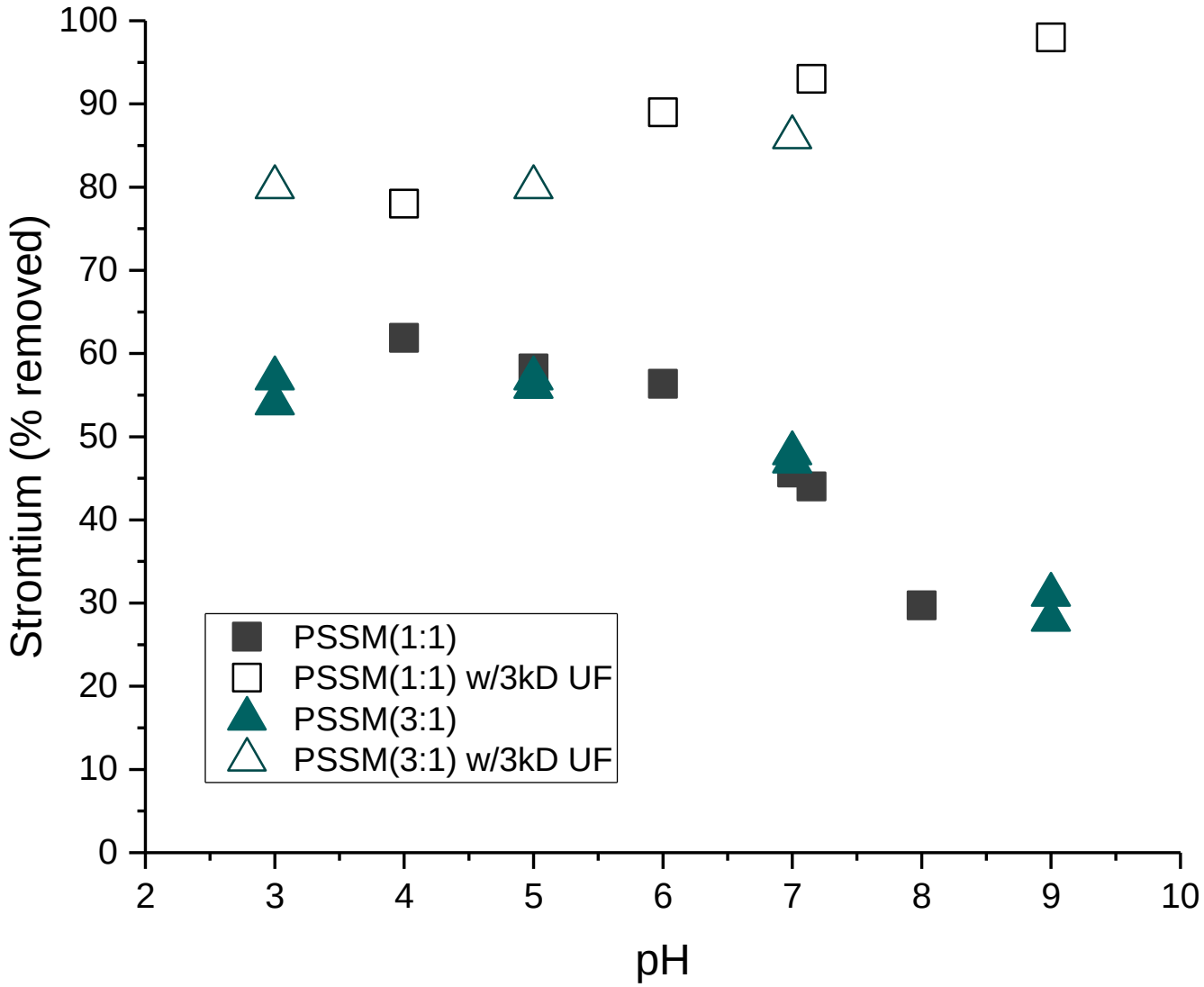
Treatment to Remove Scale-Forming Cations

- **Conventional Treatment Methods**
  - Sodium sulfate addition
  - Lime and/or sodium carbonate addition (softening)
- **Polymer Addition / Polyelectrolyte complex formation**
  - Objective is to form metal-polymer complexes that can be removed by settling, coagulation and settling, ultrafiltration, centrifugation, or other means
  - Polymer recovery/reuse may be necessary to make this economically feasible
- **Better if selective for Ba^{+2}, Sr^{+2}, and Ra^{+2}**

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



Best case for Sr+2: Combining pH with UF

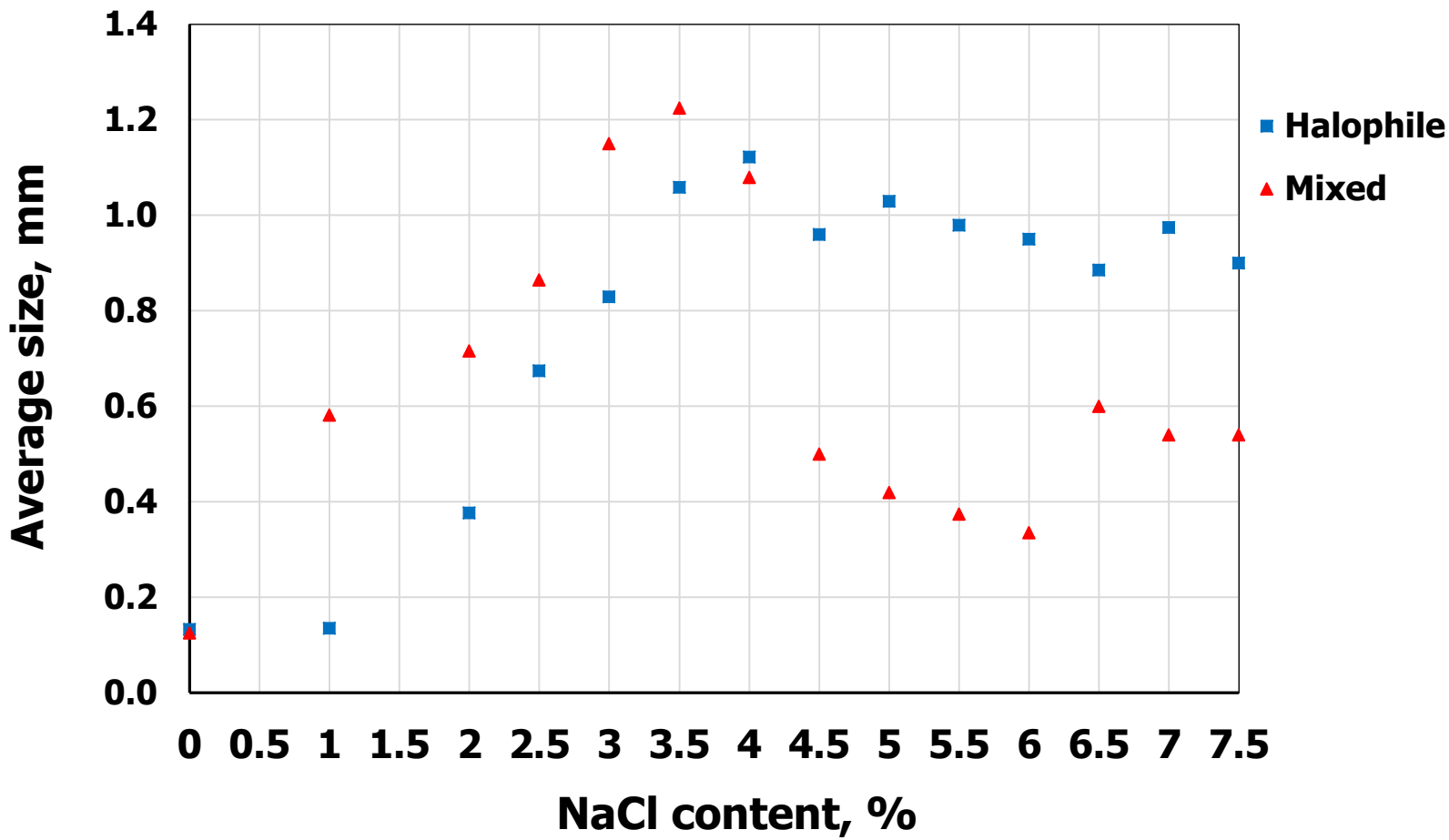


AEROBIC GRANULAR SLUDGE FORMATION IN HYPERSALINE SYNTHETIC PRODUCED WATER

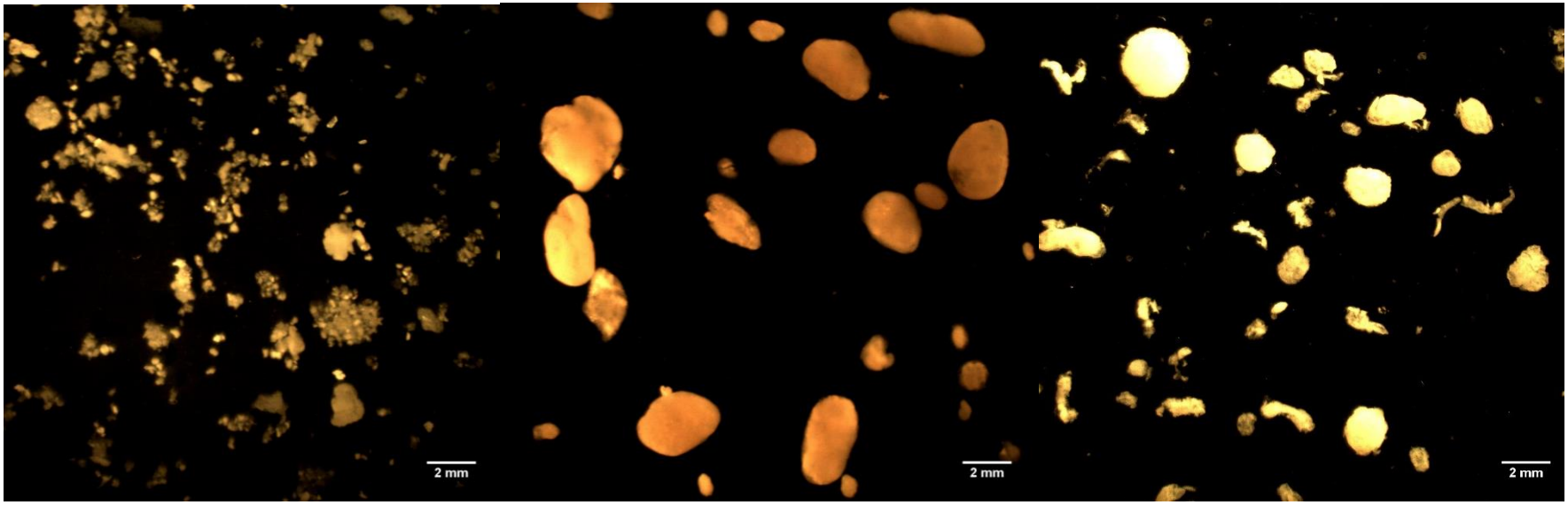
- Inoculated with a mixed culture of combined irregular aerobic granules and flocs

- 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

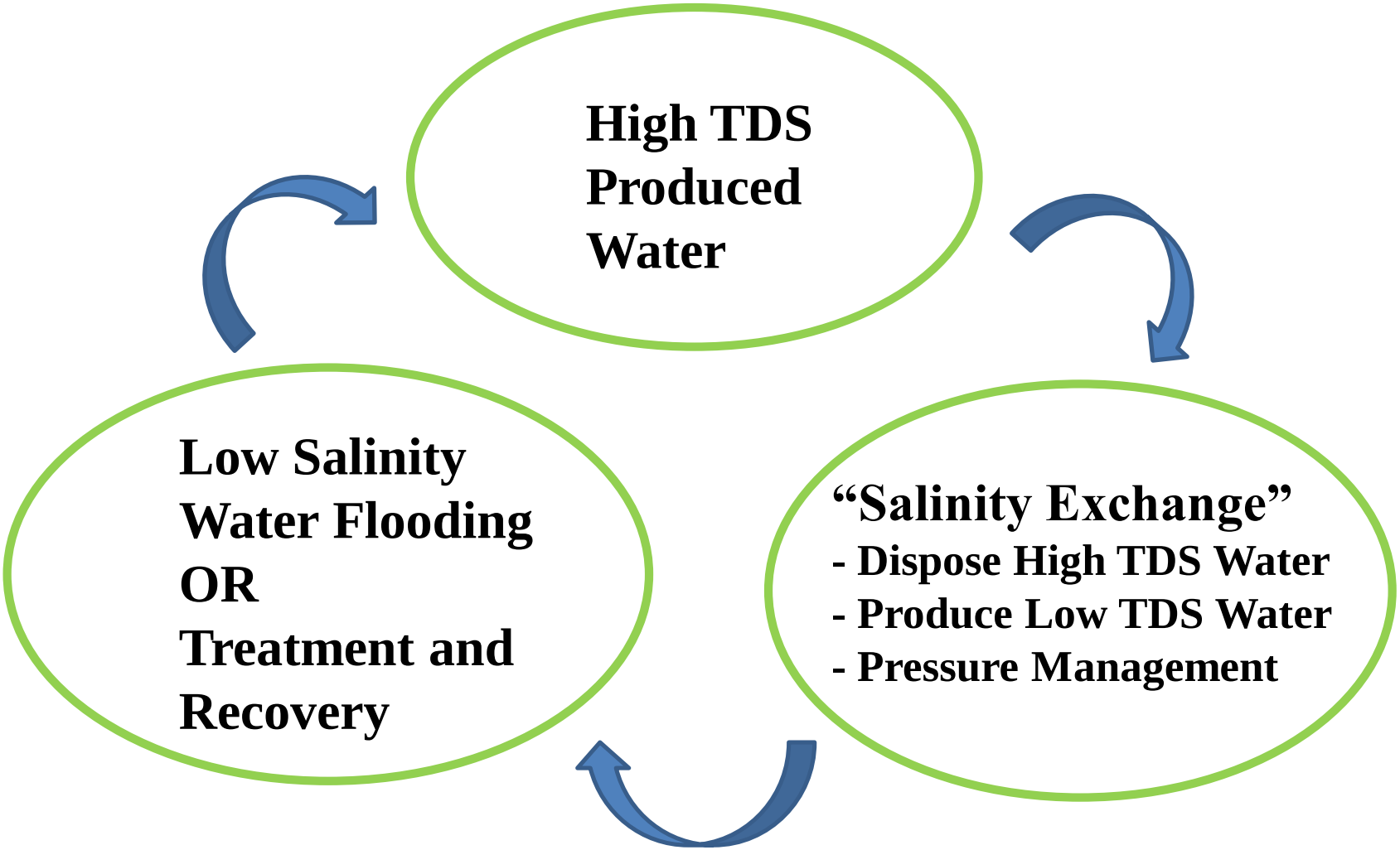
Emerging Desalination Methods

- **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)

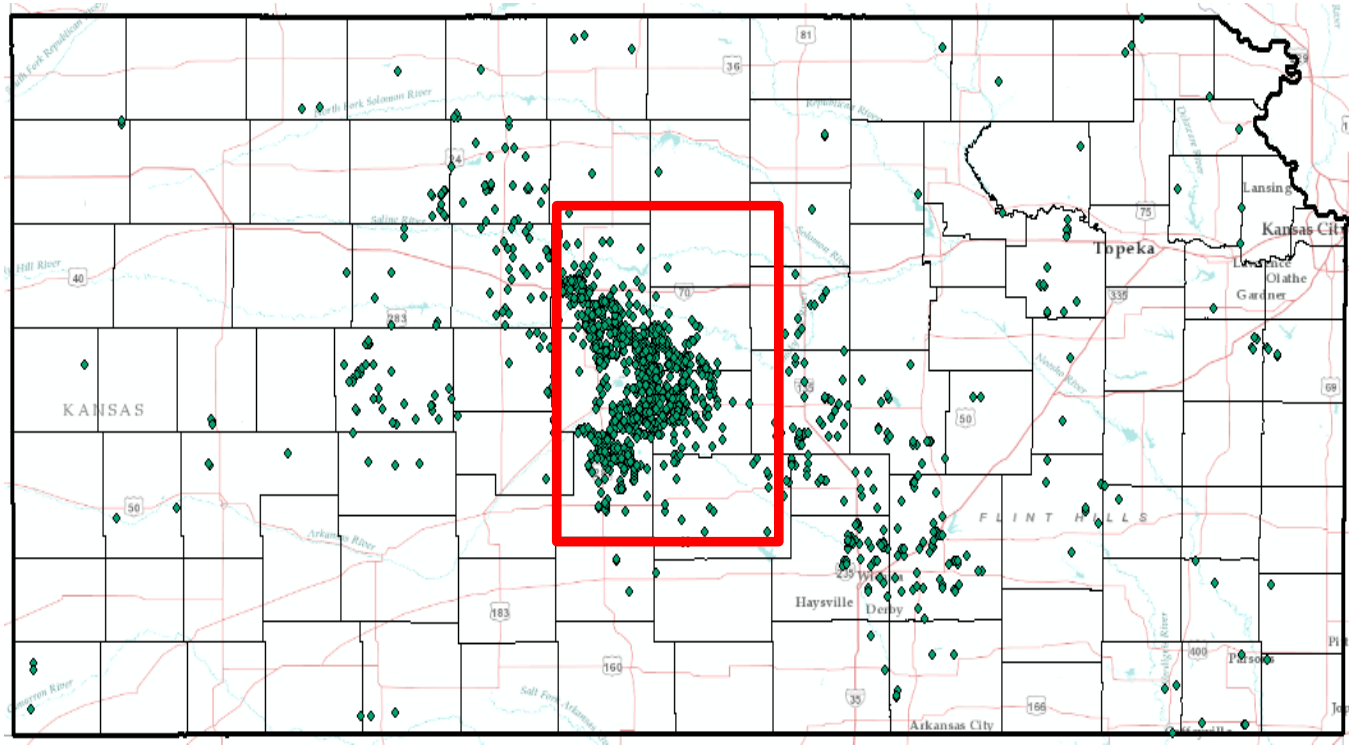
- **Electrodialysis (ED) and membrane distillation (MD) systems have already been tested on a pilot-scale.**

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

Salinity Exchange for High Salinity Produced Water



Oil-Producing Formations with TDS < 40,000 mg/l



Marked region has production from both 'high-salinity' (>100,000 mg/l TDS) and 'low-salinity' formations

- Examine chemistry of produced waters and formation materials for exchange suitability

Ongoing and Future Directions

- **Kansas Water Office project to demonstrate treatment of high salinity produced water**
  - Treated effluent to flow into a farm pond

- **Improved treatment processes**
  - Optimize and improve processes, including those described above, to enhance performance and reduce cost
  - Investigate processes for boron removal

- **Depleted reservoirs to store produced or treated water**
- **Water rights – implications for reuse & recovery**
- **Matching treated-water quality to desired uses**

Concluding Remarks

- **Produced water is a potential water resource for the state of KS**

- **Salinity has the biggest impact on the feasibility of treatment for reuse.**
  - Treatment costs are much higher above the "RO threshold."
  - Pre-treatment will generally be needed to avoid / minimize membrane fouling.

- **Removal or control of scale-forming ions will be needed for some (perhaps many) reuse applications and associated treatment technologies.**

- **Salinity exchange can help to manage the least treatable waters.**
  - More knowledge is needed about the chemistry of mixing formation brines.

Acknowledgements

- **Produced Water Research Group**

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

*Multiple graduate and undergraduate students.

Acknowledgements (Cont'd)

- **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 Engrg.

Acknowledgements (Cont'd)

- **Special thanks to those doing the dirty work**

Novel Treatment Technologies (WVU)

- **Production of alkaline catholyte in a microbial capacitance deionization cell (MCDC)**
  - Electrochemical production of an alkaline solution, which is used to precipitate scale-forming cations
- **Bioelectrochemical Removal of Organics and TDS Using MCDCs**
  - Using biodegradable organics (in produced water) to drive biochemical reactions, thereby removing organics while also powering an electrochemical deionization process