Produced Water Reuse and Recovery in Kansas: Assessing our Options

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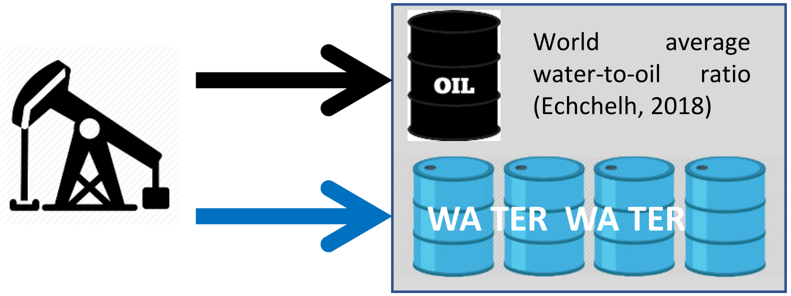
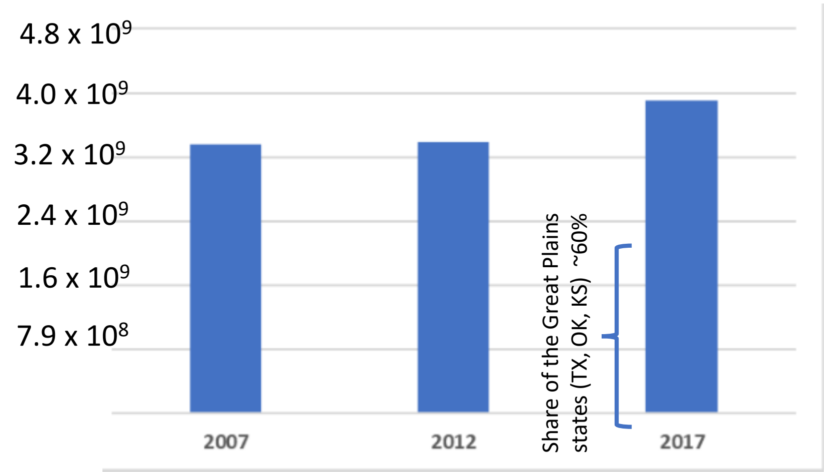
Produced water volume and quality



State	Water-to-oil ratio
U.S. onshore	7.6 (2007), 9.2 (2012)
Kansas	21.8 (2007)

Veil (2020)



Volume of PW in the U.S. (m^3/year) *Veil (2020)*

Main components of produced water:

- Dissolved formation minerals (salts and heavy metals) and anions (chloride, sulfate, carbonate)
- Dissolved and dispersed oil (hydrocarbons)
- Production chemical compounds (e.g. formation solids, anti-corrosion and anti-scale products)

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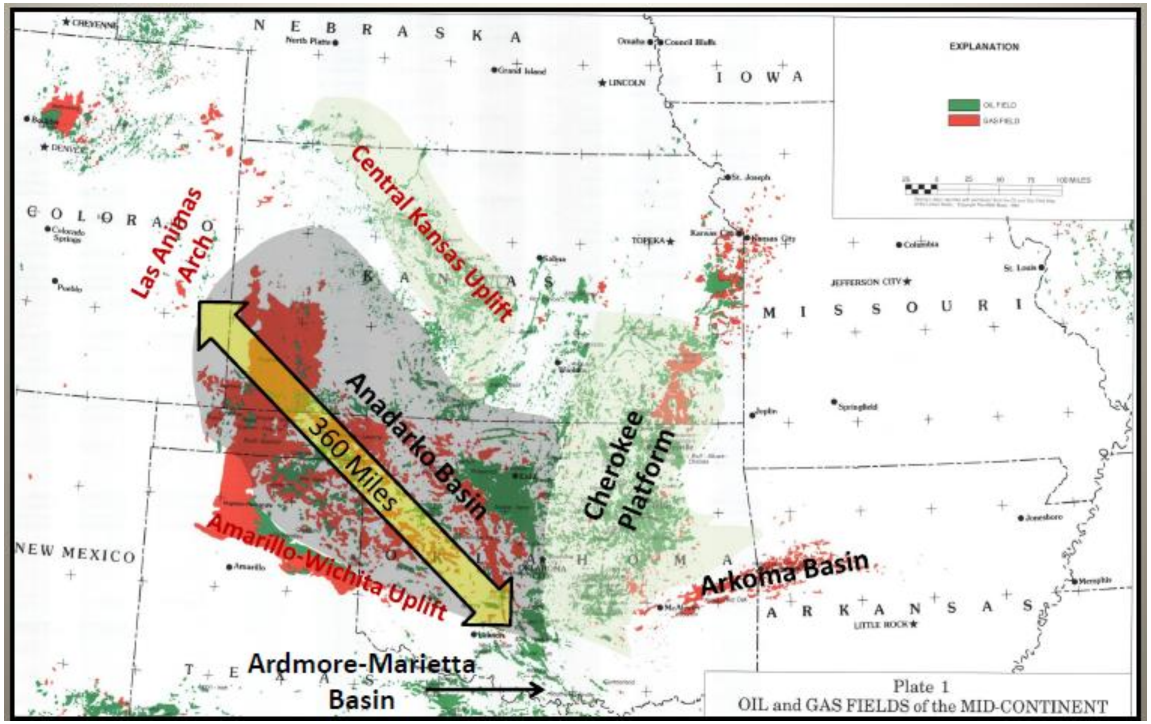
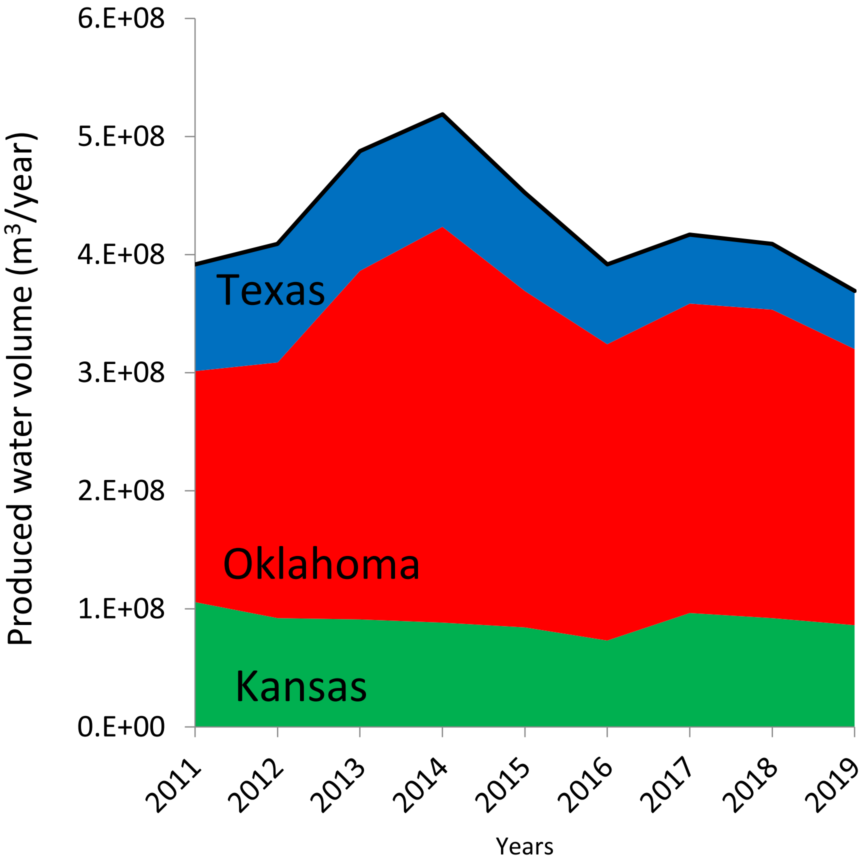
The Anadarko Basin

We estimate that 113 billion gallons of PW per year were generated from 2011-2019 (Echchelh at al, *in preparation*)



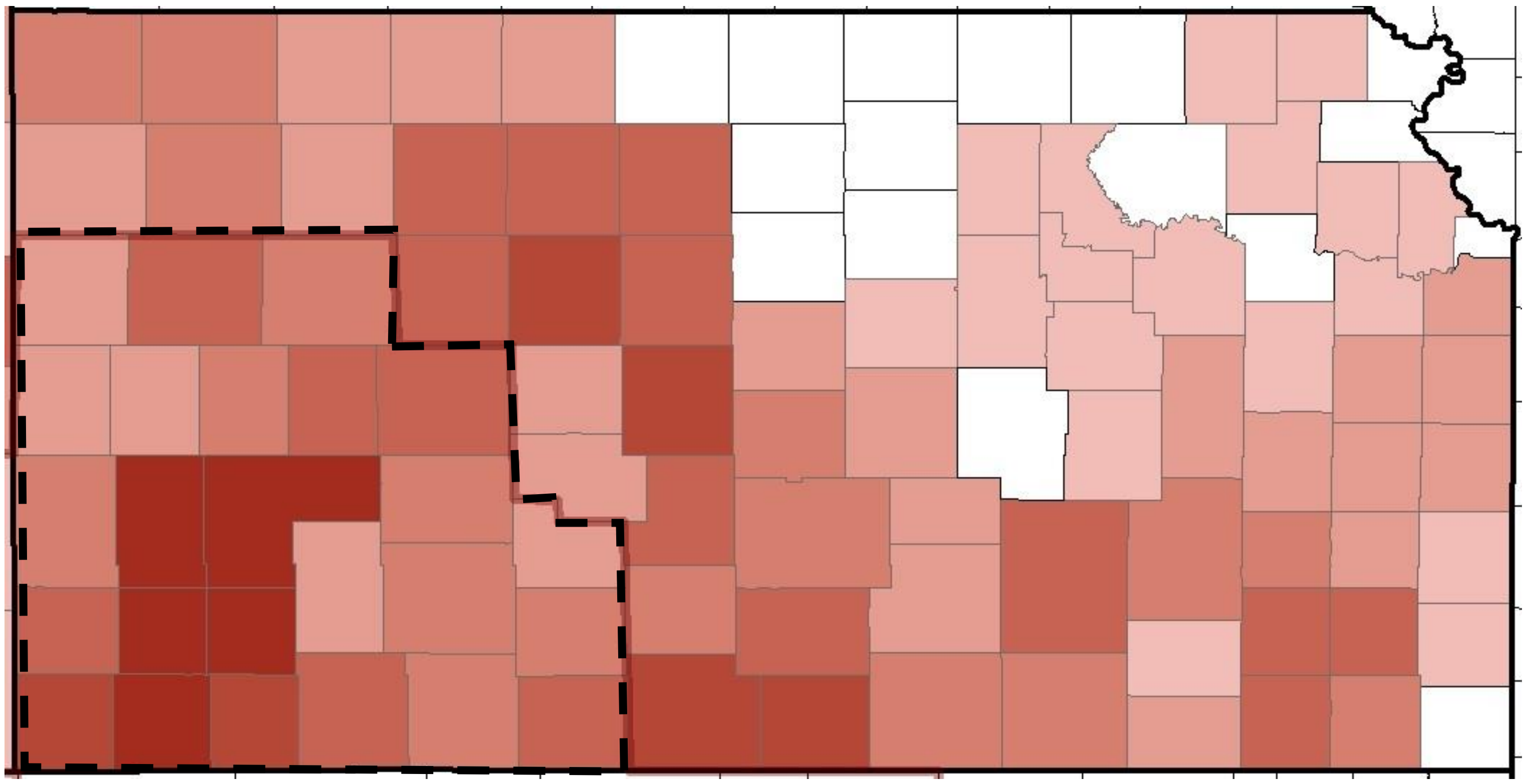
The Anadarko Basin *Rascoe and Hyne (1988)*

PW Generation



- PW volumes generally tied to price of oil
- PW generation peaked in 2014 at 519 million m^3 (137 billion gallons)
- KS PW volume more consistent from year to year
  - 21% of total basin production
- 12 counties (2 in KS) generated more than 10 million m^3/yr

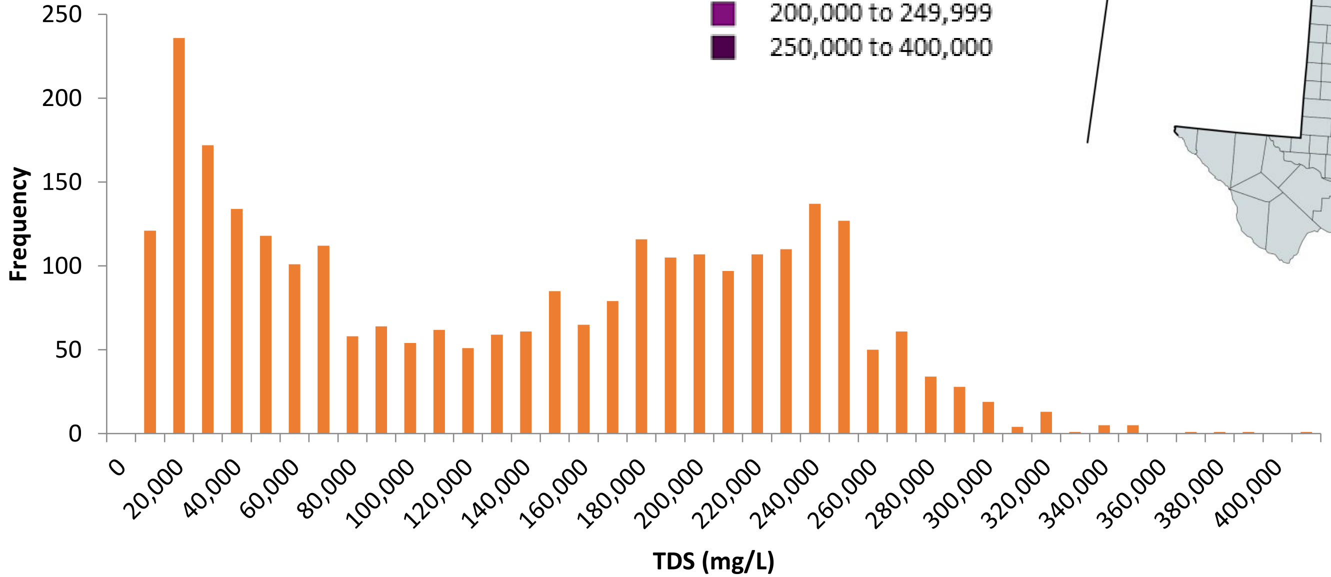
KS PW Generation by County in 2019 (barrels)



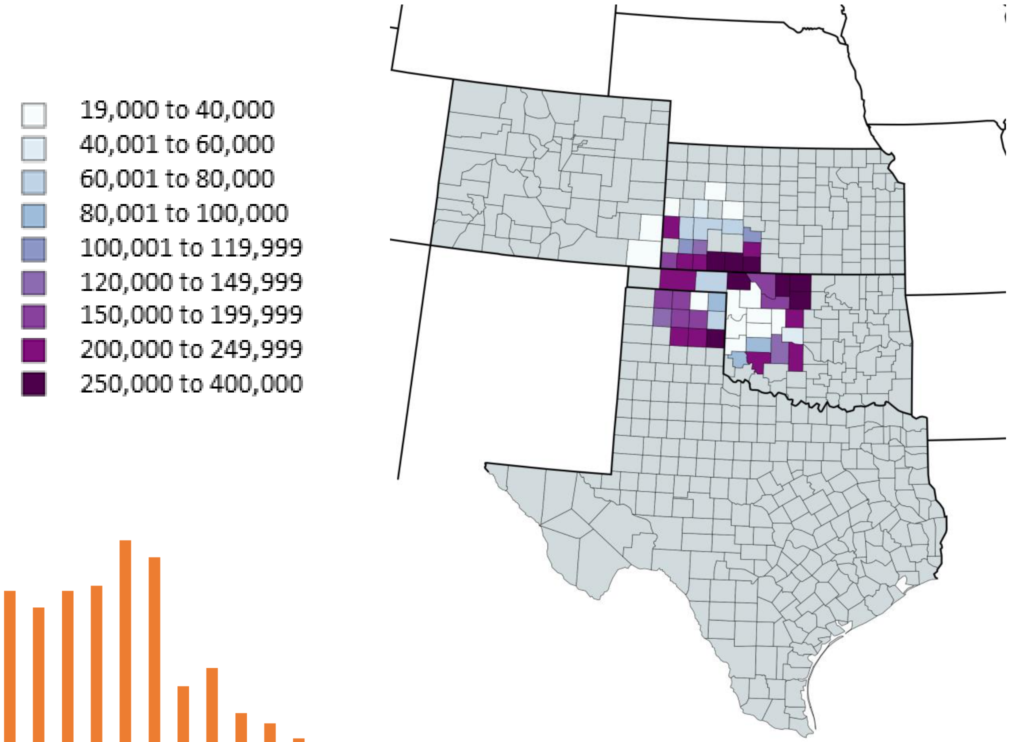
~ 50% of statewide PW generation occurs in the Anadarko Basin

Produced Water Salinity

Number of samples (n) = 2762



Echchelh et al., in preparation



Based on data from *USGS (2017)*

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Identifying Reuse Pathways

Supply | **Treatment** | **Reuse**

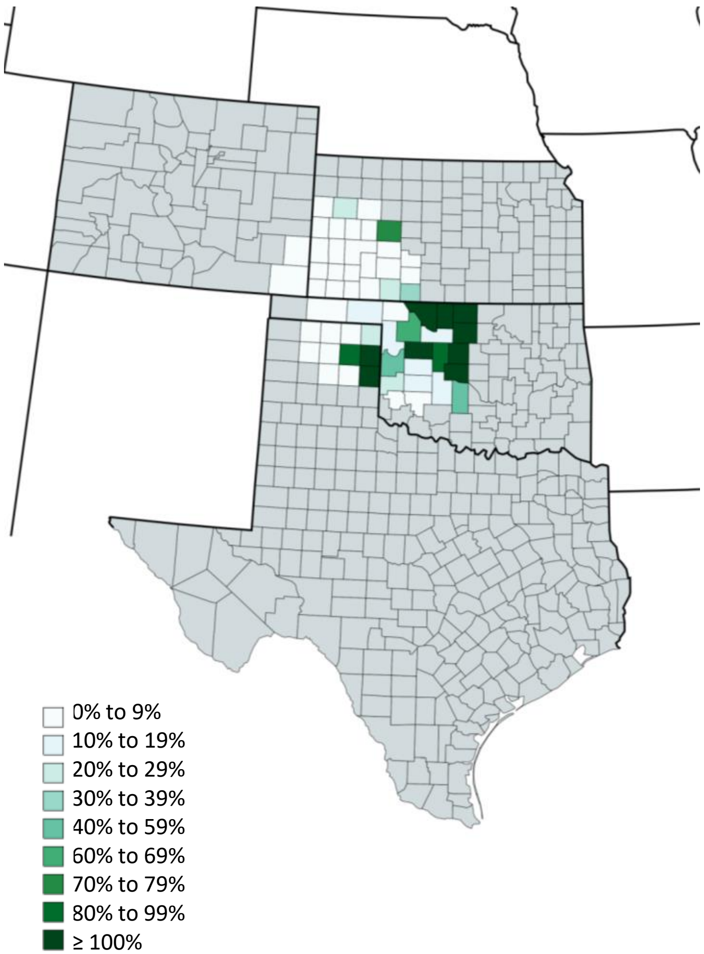
Produced Water

High inorganic content

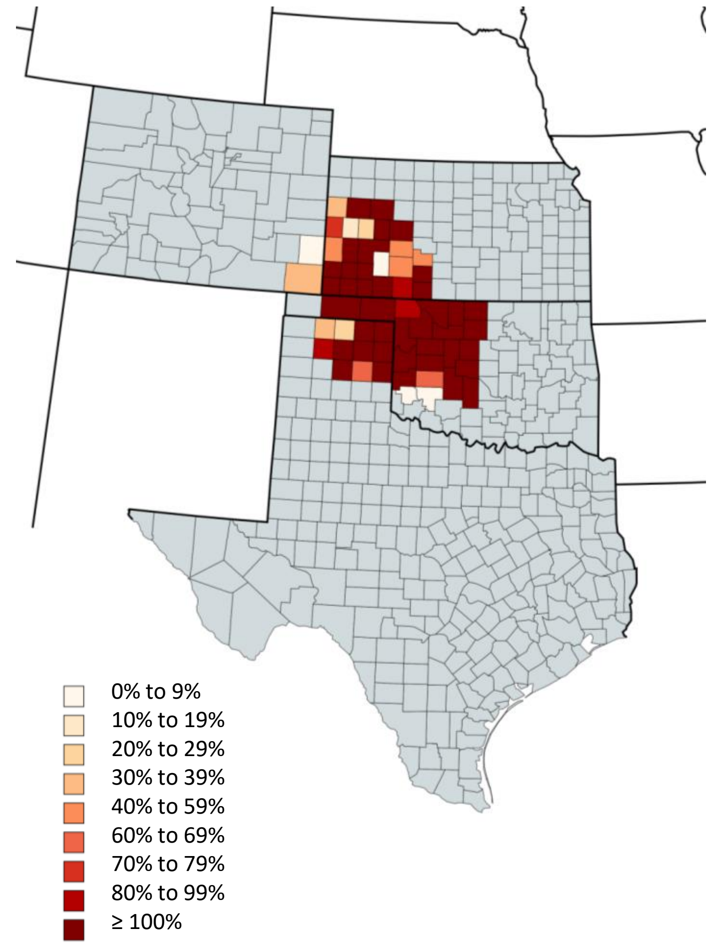
Highly variable composition

- **Non-restricted irrigation**
- **Livestock watering**
- Aquaculture
- **O&G industry**
- Mining and quarrying
- Fire control
- Streamflow augmentation, wetland, aquifer recharge
- Deep-well disposal

Beneficial Reuse Options: PW Volumes as a Percentage of Irrigation and Livestock Water Use



Ratio of produced water volume to irrigation water withdrawals volume by county



Ratio of produced water volume to livestock water withdrawals volume by county

Echchelh et al., in preparation

Based on data from *KGS, OCC, COGCC, RRC (2020)*

Produced water desalination targets

- Irrigation limits are crop-dependent

		Crop						
		Wheat	Corn	Sorghum	Soybean	Sunflower	Cotton	Alfalfa
METALS AND IONS	Units							
Boron (B)	mg/L	1	4	6	No data	1	15	6
Iron (Fe)	mg/L	5,0	5,0	5,0	5,0	5,0	5,0	5,0
Zinc (Zn)		2,0	2,0	2,0	2,0	2,0	2,0	2,0
ACIDITY AND ALKALINITY								
pH		6.0–9.0	6.0–9.0	6.0–9.0	6.0–9.0	6.0–9.0	6.0–9.0	6.0–9.0
MICROBIOLOGY								
Coliform, fecal	cfu/100mL	≤200	≤200	≤200	≤200	≤200	≤200	≤200
SALINITY AND SODICITY								
TDS (approx.)	mg/L	2500	700	3000	2000	2000	4000	800
Electrical conductivity	dS/m	4.0	1.1	4.5	3.3	3.3	5.1	1.3

Based on data from *FAO (1994)*

- TDS threshold for cattle is 5,000-7,00 mg/l (USDA-NRCS)

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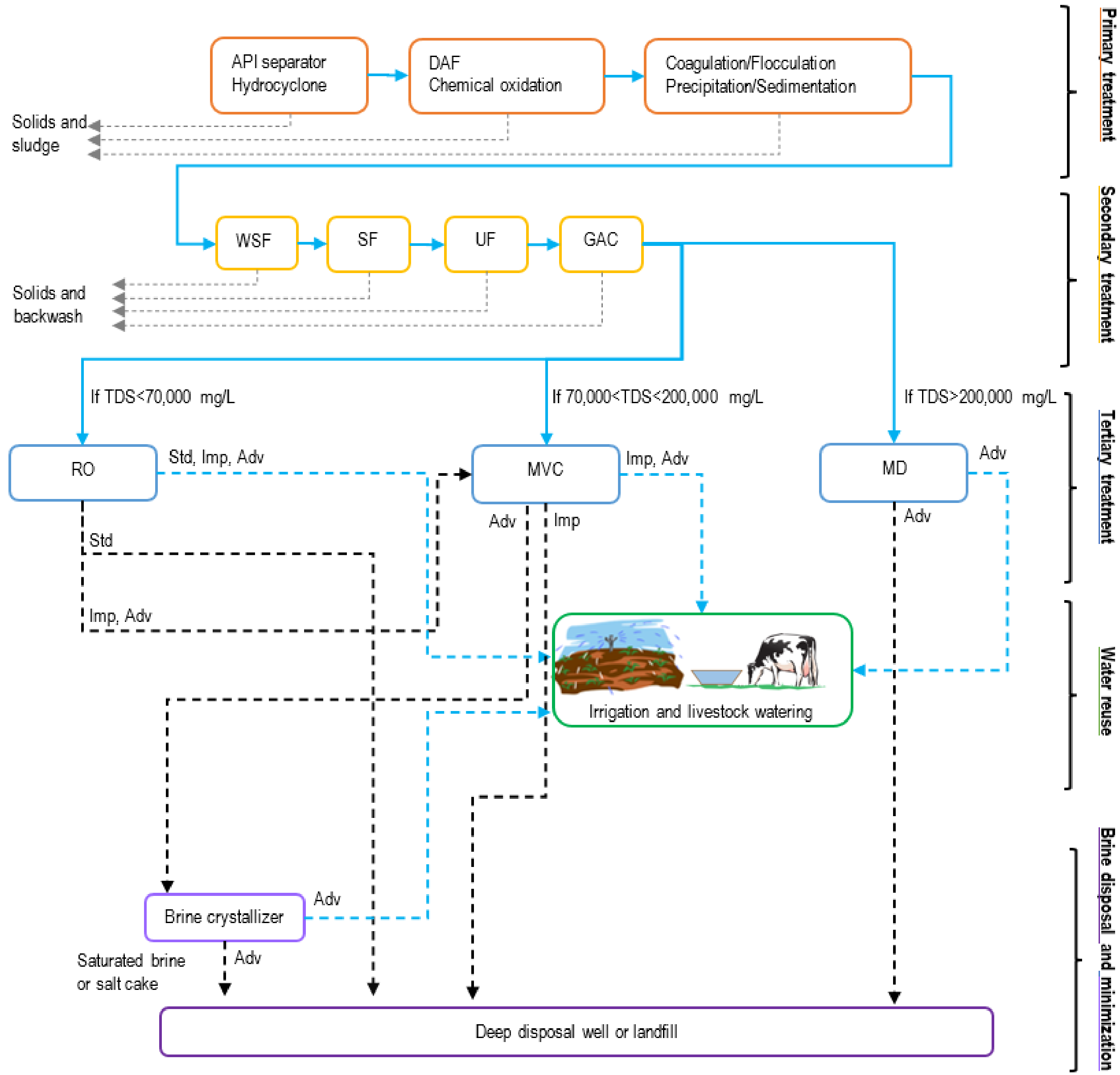
Treatment Scenarios

Primary treatment- removal of of solids, hydrocarbons, sulfur, hardness

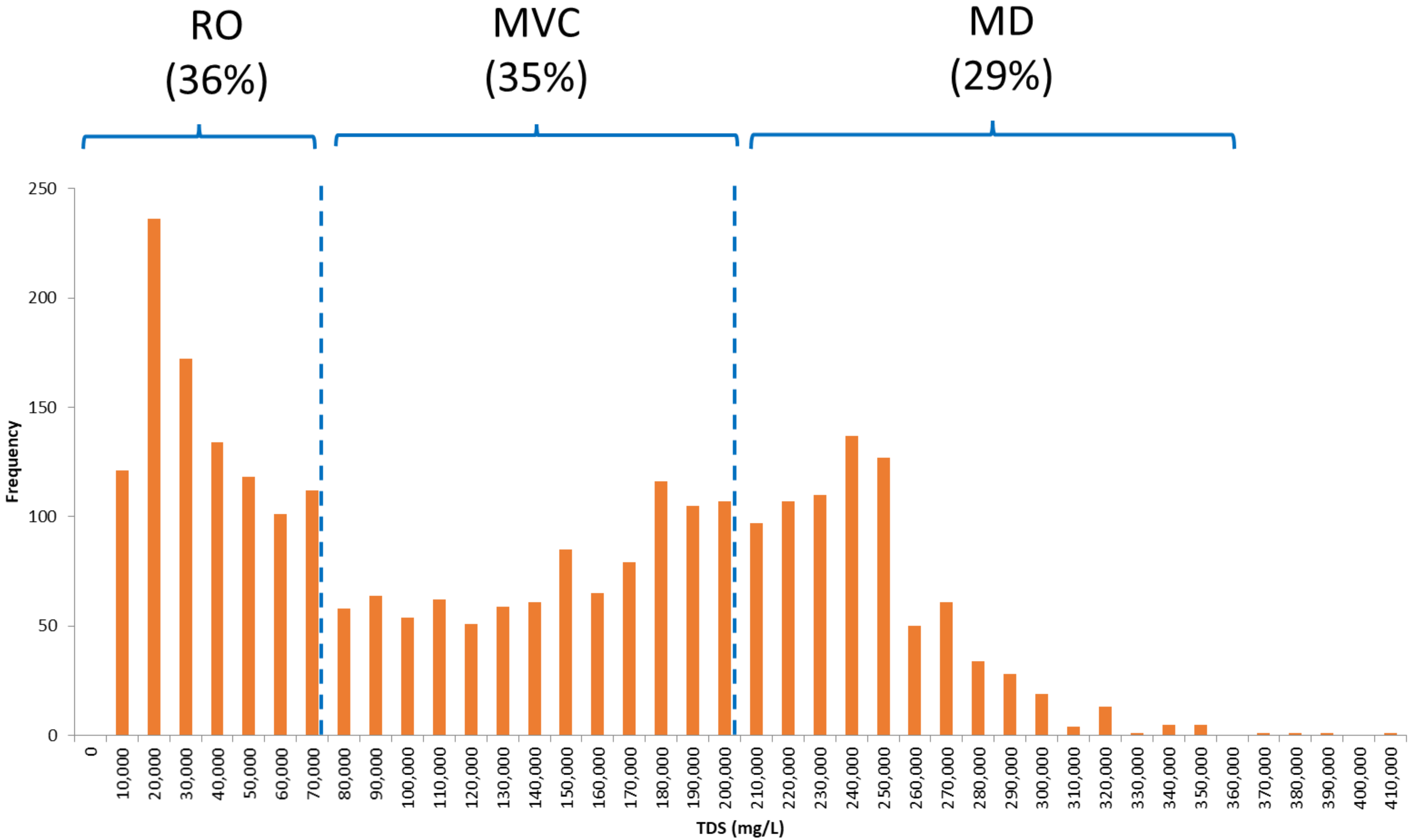
Secondary treatment- trace organics and hardness, metal oxides

Tertiary treatment- desalination

Maximum recovery option included recovery of some waste concentrates



Desalination Options



Echchelh et al., in preparation

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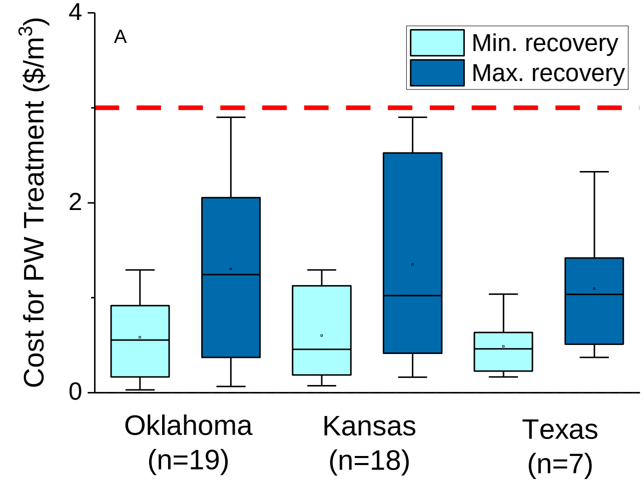
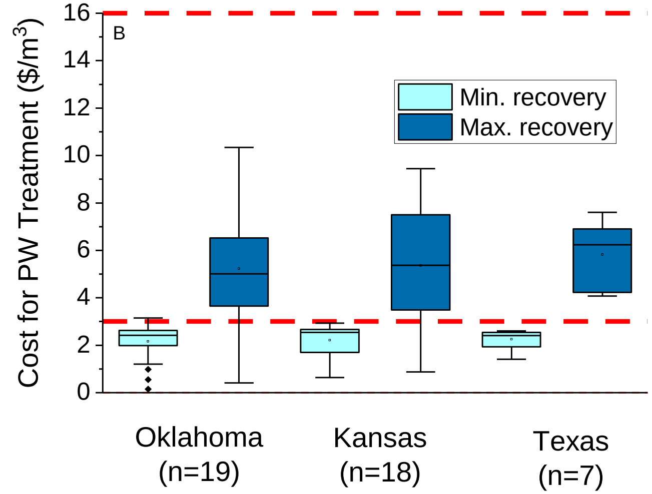
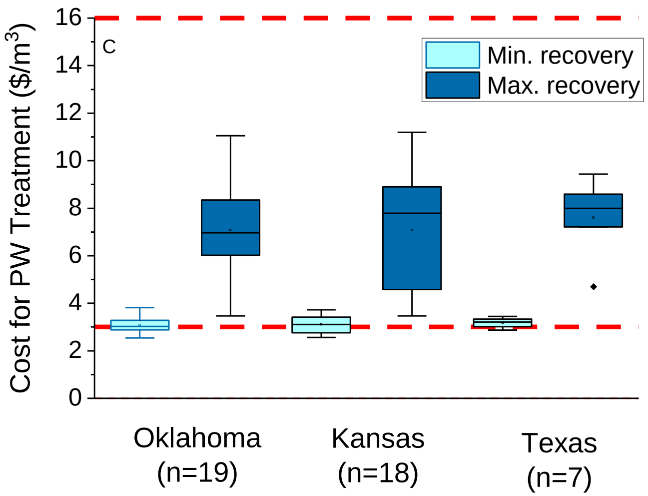
Treatment Cost Comparison







Treatment cost for 'average' TDS water in each county with A) standard desalination (RO), B.) improved desalination (RO+MVC), and C.) advanced desalination (RO+MVC+MD). Dashed lines show range of estimated disposal costs.

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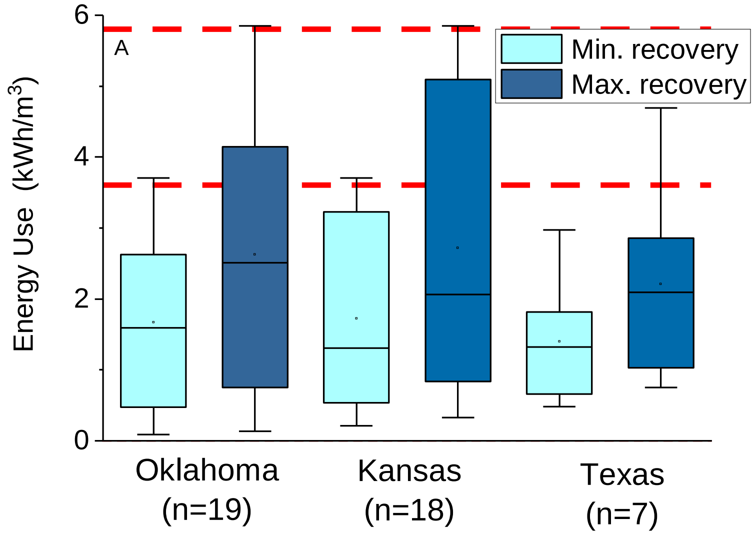
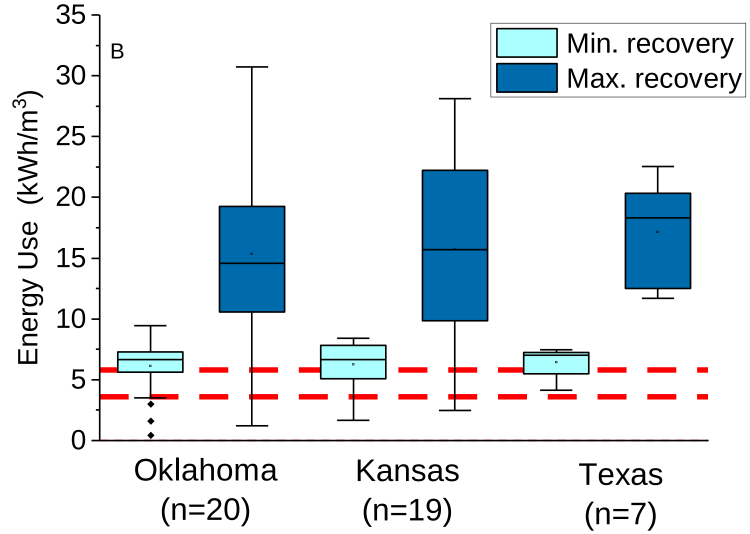
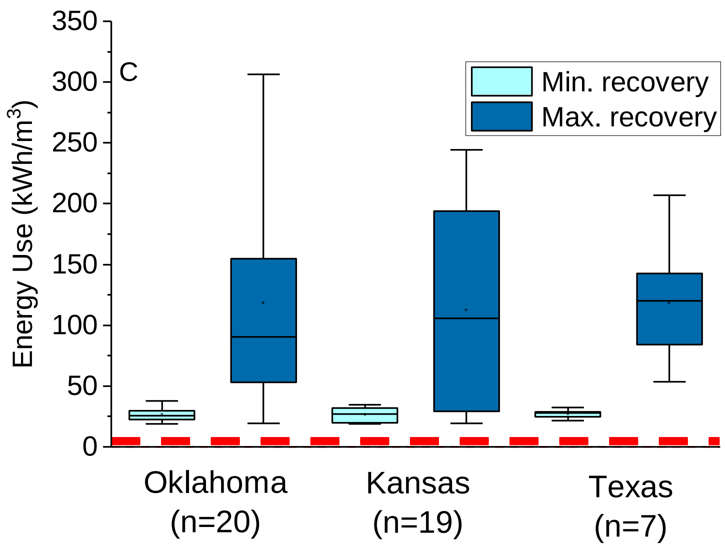
Energy Use Comparison







Energy use to treat 'average' TDS water in each county with A) standard desalination (RO), B.) improved desalination (RO+MVC), and C.) advanced desalination (RO+MVC+MD). Dashed lines show range of estimated energy use for disposal.

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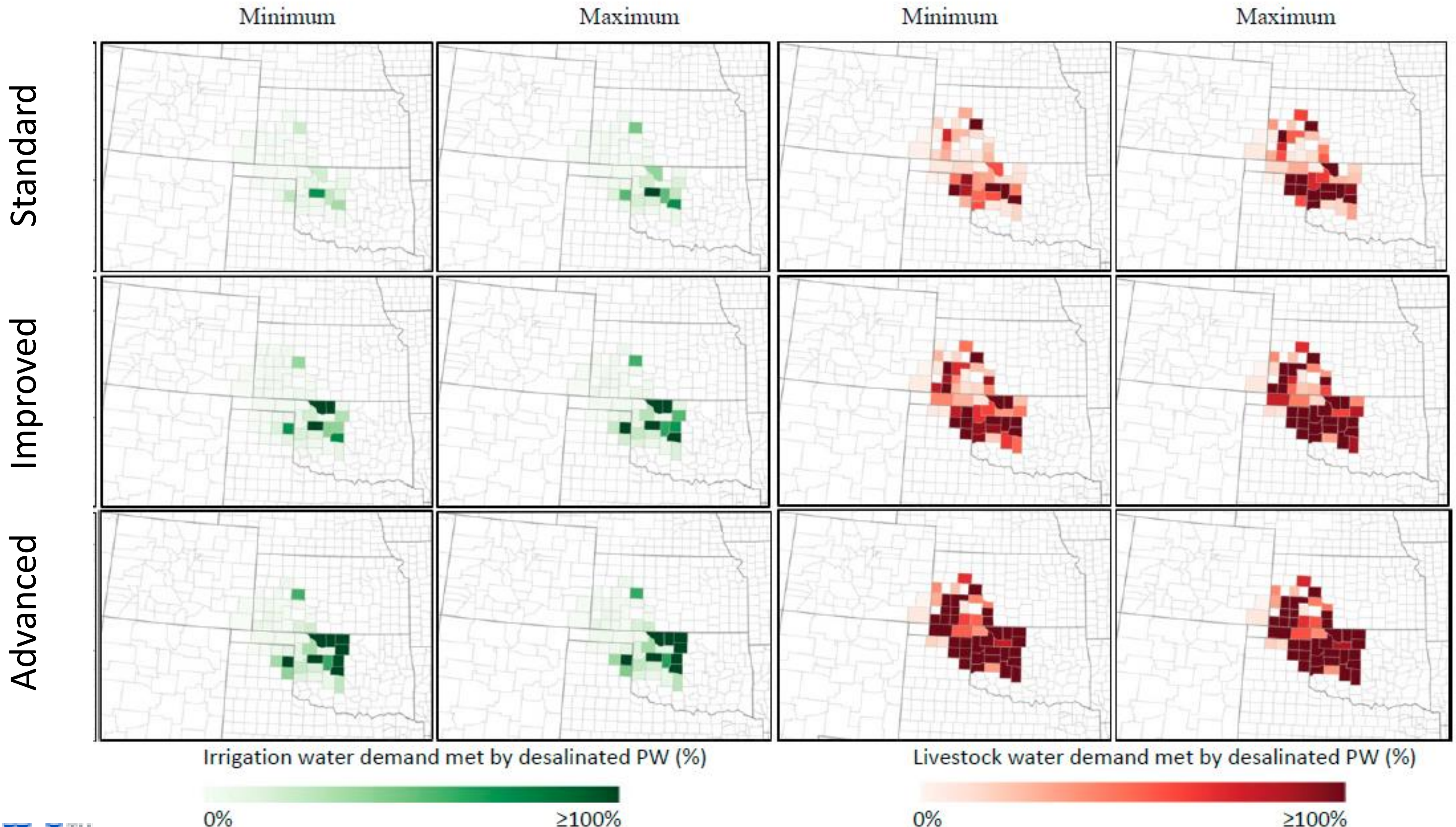
Anadarko Treatment Estimates

	PW Recovered	Energy Required (kWh/m^3)	Operating Expenses ($\$/m^3$)*
Disposal	0%	3.6-5.5	3-16
RO	11-23%	0.1-5.8	0.6-1.3
RO+ MVC	33-58%	0.4-30.7	2.2-5.3
RO+ MVC+ MD	86-93%	18.7-306	3.1-7.0

*- Estimated expenses do not include waste disposal, water conveyance, or storage

RO treatment volume is < 1.5% of irrigation water use, but 20-42% of livestock water use

Water Demand Met By Treatment Scenarios



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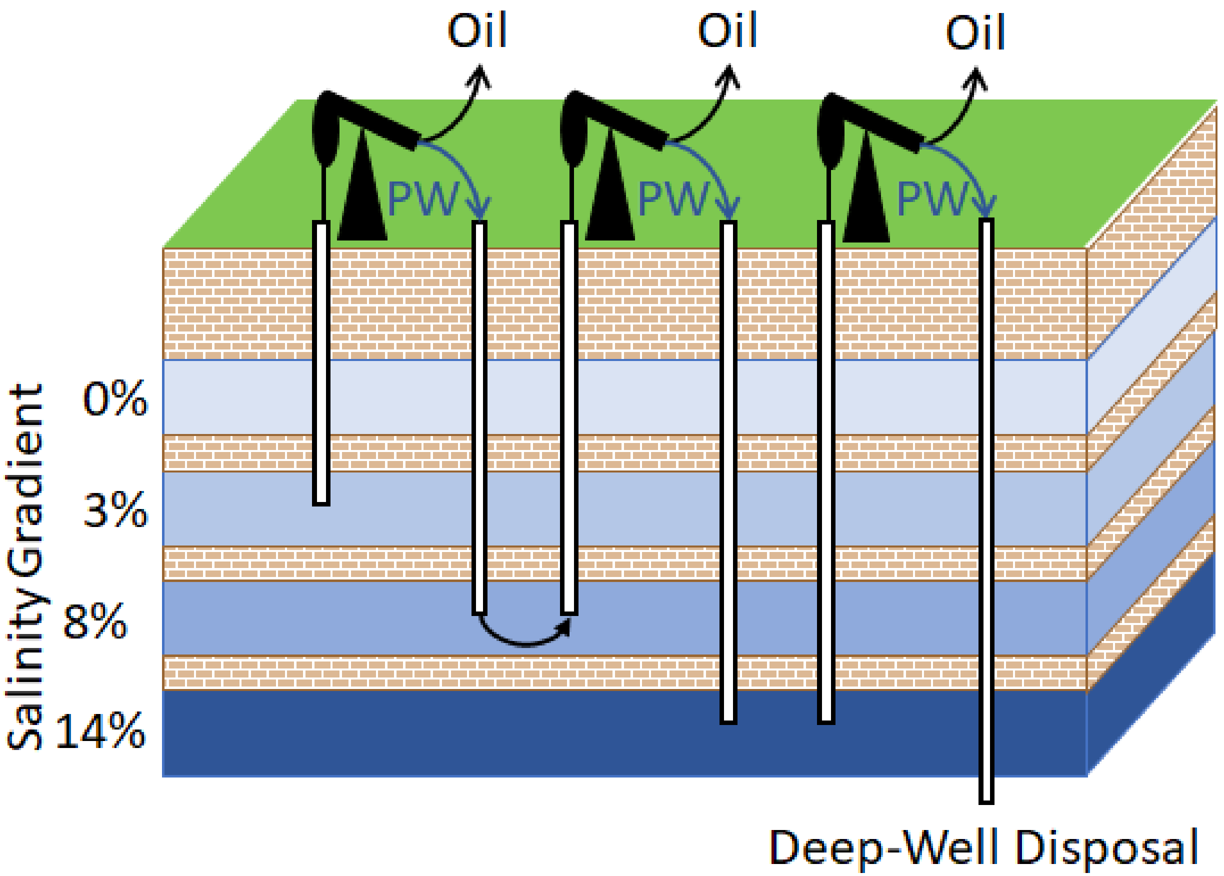
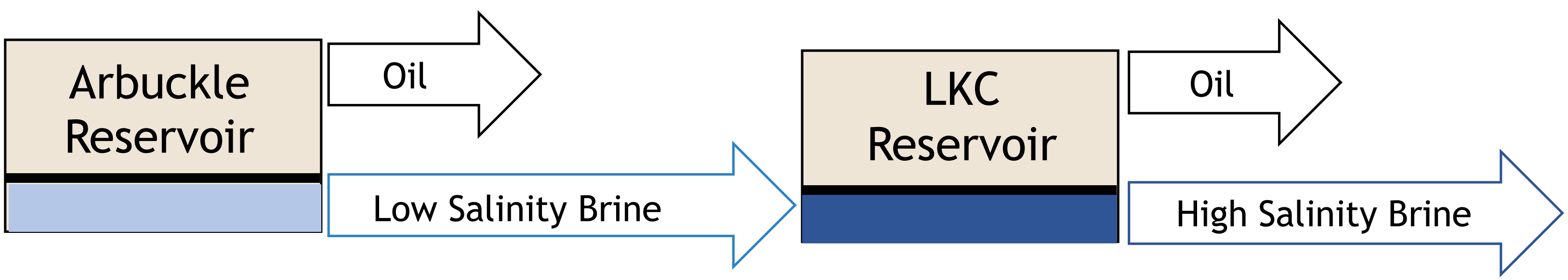
Industry Reuse: Brine Exchange for Enhanced Oil Recovery



Test Study: Brine Exchange for Enhanced Oil Recovery

Brines used in this study

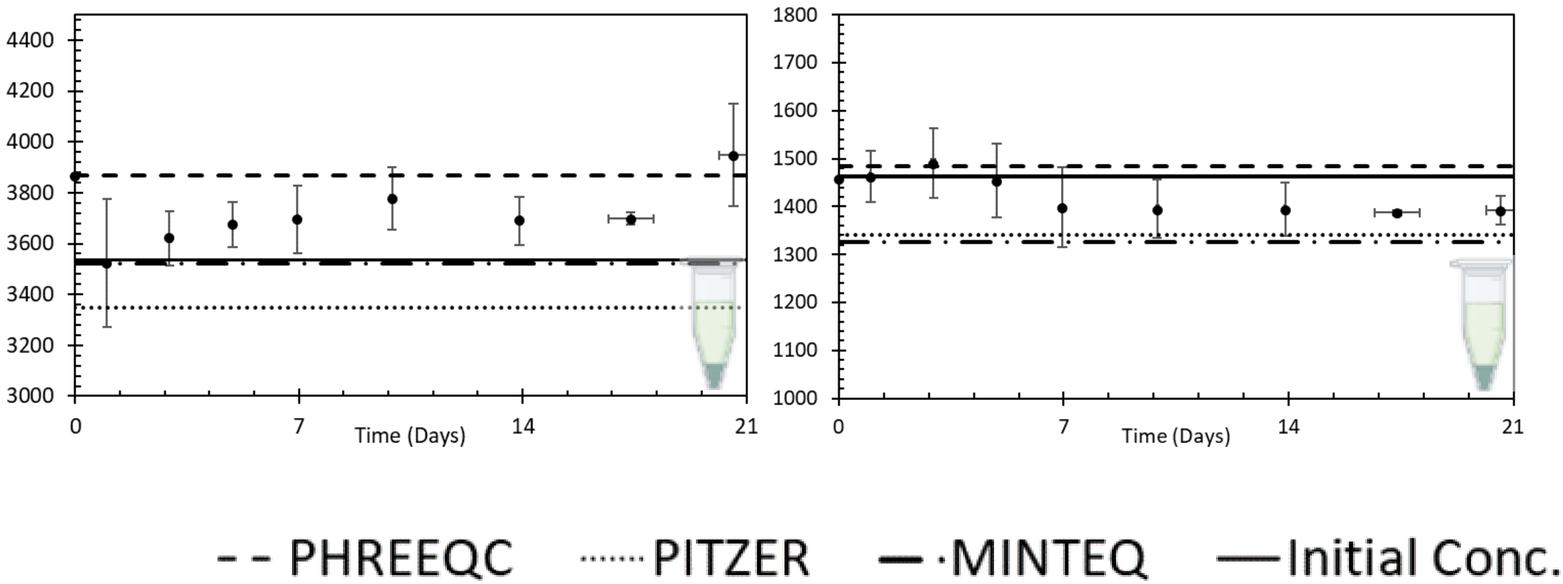
Variable	Arbuckle	LKC
TDS	~ 20,000 ppm	~ 170,000 ppm
Calcium Magnesium Sulfate Barium	1052 mg/L 324 mg/L 1391 mg/L BDL	6064 mg/L 2309 mg/L 864 mg/L BDL



Brine exchange follows the salinity gradient for our two reservoirs

Brine Mixing in Presence of LKC Solids: Dissolved Ca Results

A:LKC 50:50 (I.S. = 1.8 M)	A:LKC 90:10 (I.S. = 0.70 M)



Calcium concentration (mg/L) of Liquid-Liquid-Solid brine mixtures plotted against time alongside predicted equilibrium data calculated by PHREEQC; mixing ratio of 50% low salinity brine (left) and 90% low-salinity brine (right), shown

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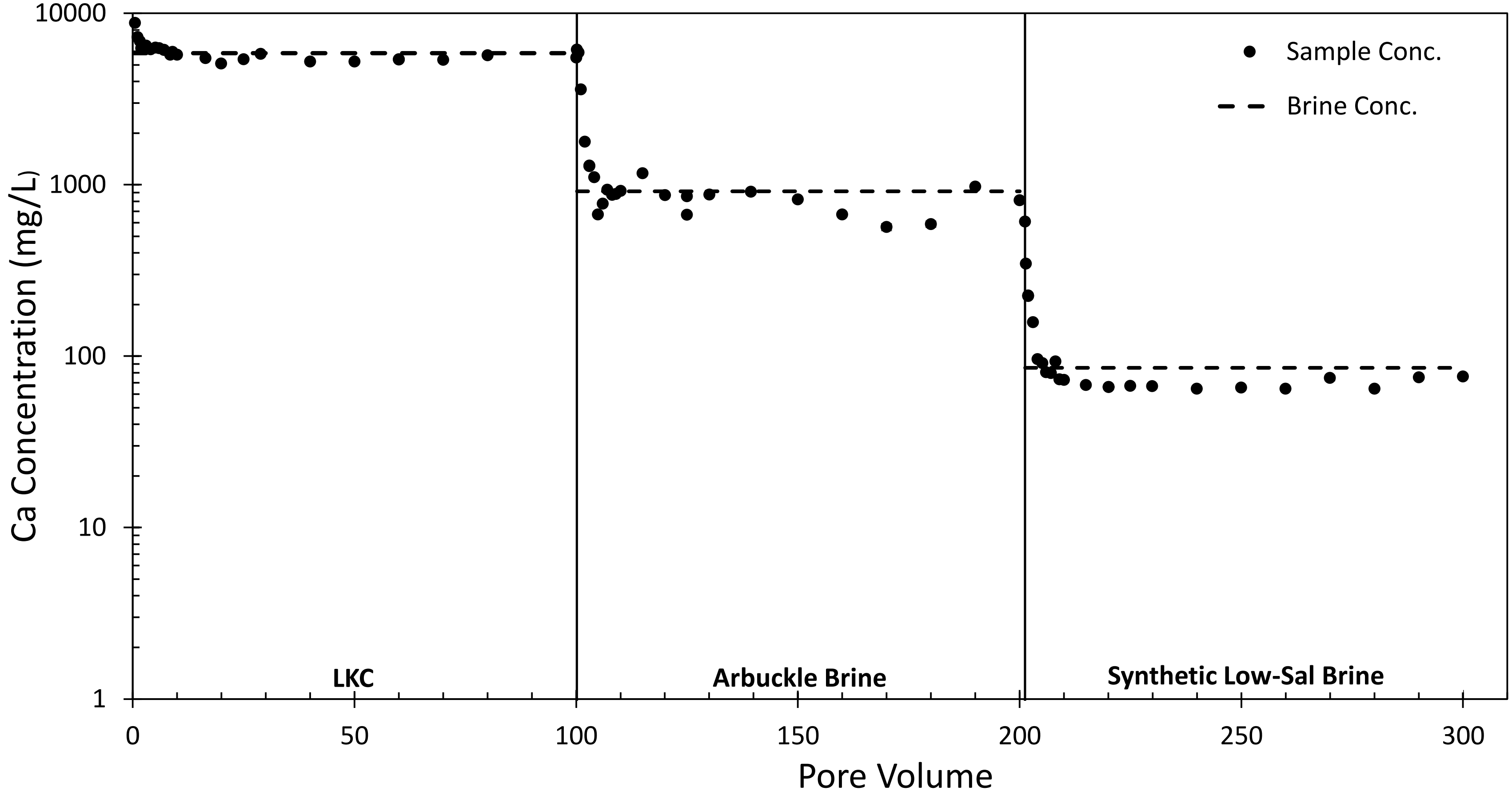
Coreflooding Experiments



Ca concentration of coreflooding effluent obtained through ICP-OES; other ions analyzed exhibited similar trends

Estimating Brine Exchange Costs

Simulate the cost of each individual project component

Infrastructure Cost	Energy Costs	Disposal Savings	Revenue from increased oil recovery

WaterCOSTE

- Developed by University of Arizona
- Complex, highly adaptable
- Emphasizes Construction Costs

Industry Estimation

- Assumes 3rd Party Contracting for Construction Costs
- Cost estimates from Industry Contact
- Less applicable outside of Kansas

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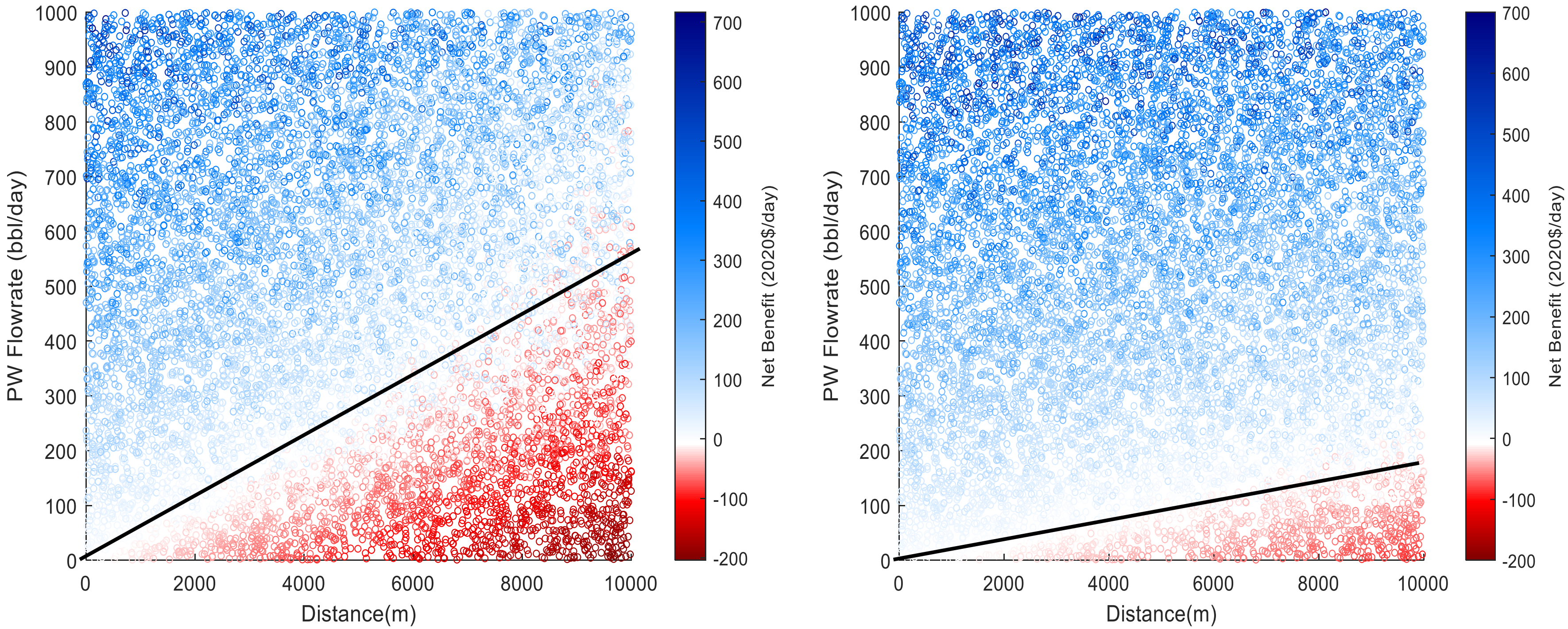
Viable Parameters for Brine Exchange Operations



Heatmap depicted Net Benefit of project as a function of flowrate and distance between reservoirs. Models were developed using WaterCOSTE method (left) and industry estimates (right).

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Possible Limitations for Brine Exchange

- Brine incompatibility and scale formation
- Salinity effects on production chemicals
- Co-location of suitable formations with salinity gradients.
- Waterflooding requirements vs. generated PW volumes

Summary

- PW reuse is not "the" solution to water scarcity issues in this region
  - But is could be part of 'a' solution, along with other proposed and ongoing actions

- Desalination for beneficial reuse could be viable for a significant portion of Anadarko produced water
  - Mostly RO treatment, some MVC

- Livestock watering is a more promising reuse target than irrigation
  - Better match to volume and treatment requirements

- More research needed on secondary components and treatment requirements, especially organics

- 'Low-salinity' waterflooding can be economically viable and increase industry reuse

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Acknowledgements

Grants # OIA-1632892 and 1856084

Kansas Water Resources Institute (KWRI)

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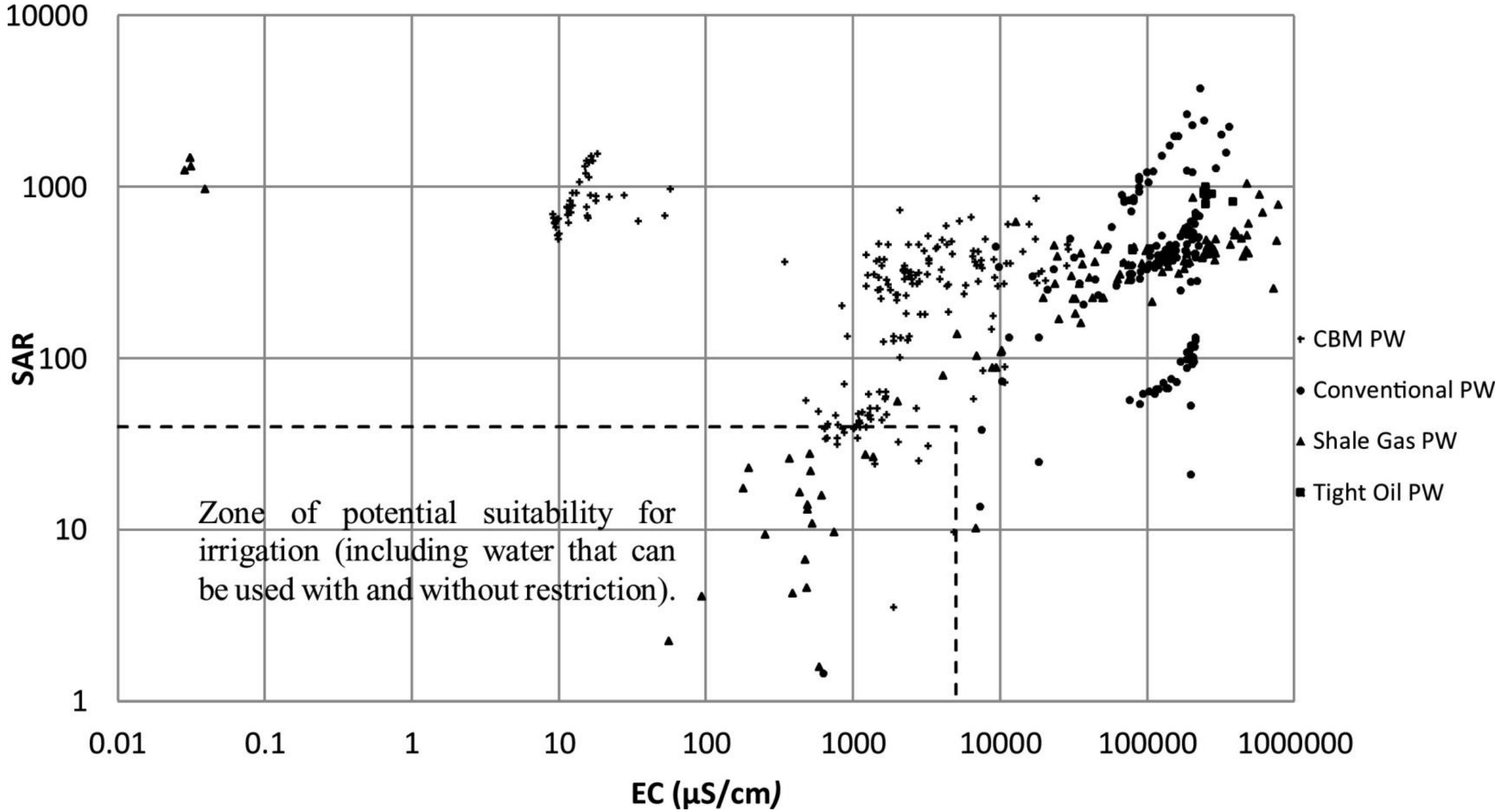
Irrigation and SAR



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