Pathway for Recovering Critical Minerals and other Elements of Interest from Produced Water

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Presentation Outline

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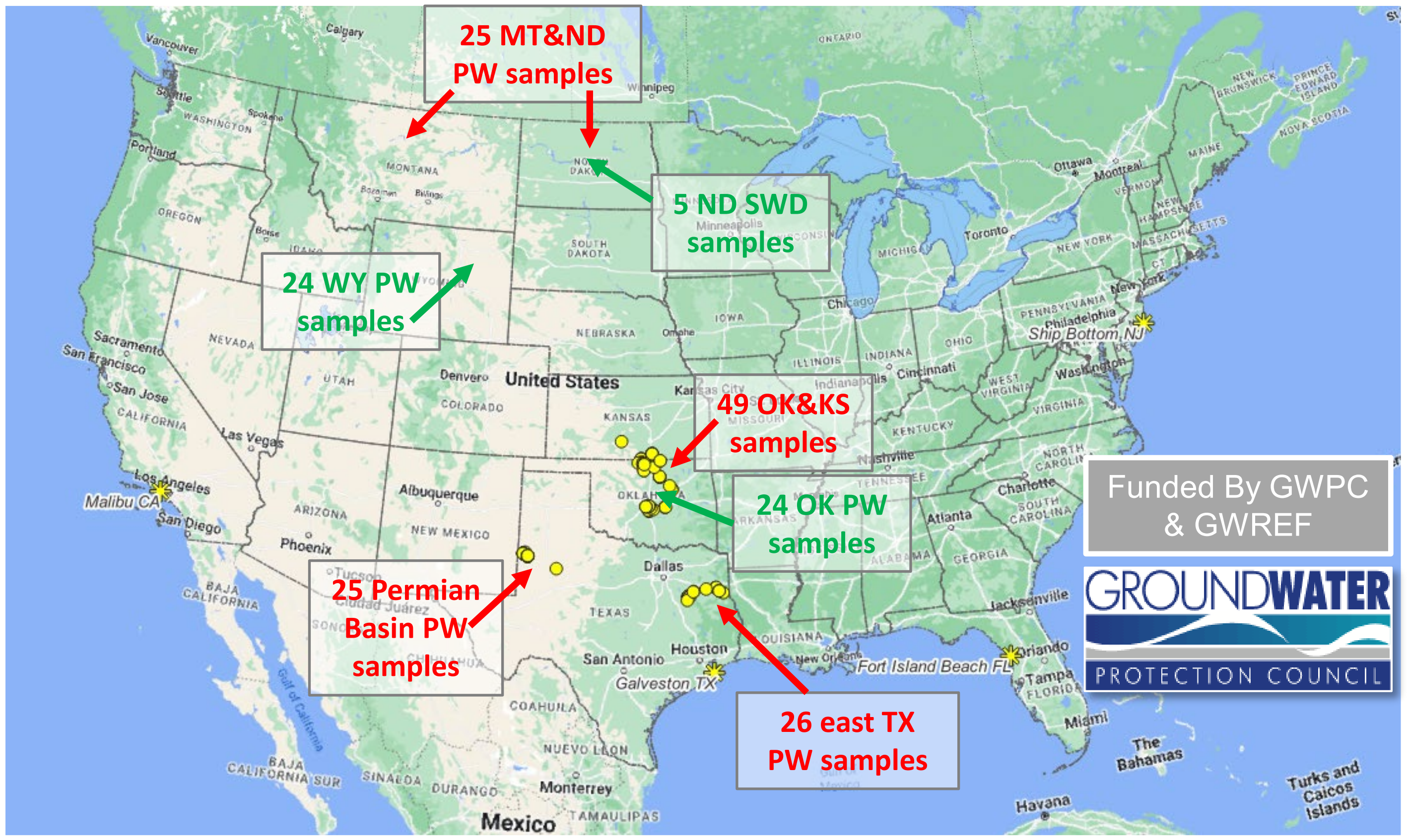
- Motivation
- What are Elements of Interest (EOI)?
- Pathway for Recovering EOI from Produced Water (PW)
- Introduction to Gross Values (GV)
- GV Case Study: Permian Basin
- GV Case Study: Well OK 005
- Daily GV Cases: Numerous
- Exploratory Data Analysis (EDA) & Prospecting



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GROUNDWATER PROTECTION COUNCIL

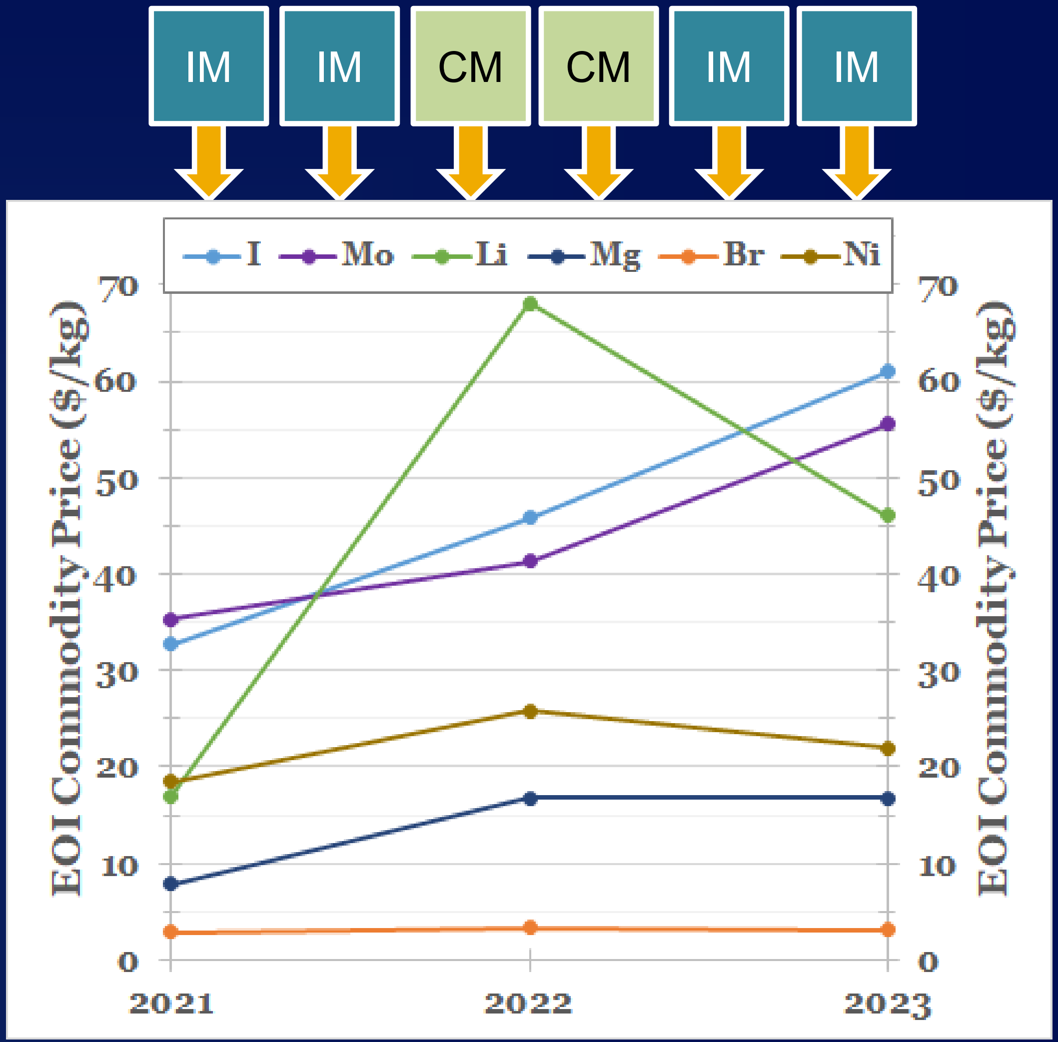
Motivation

Critical Minerals (CM) **are elements that are critical to the U.S. economic and national security because they have important uses, no viable substitutes, are mostly imported, and face potential disruption in supply.**

Mineral commodities are vital for economic growth, improving the quality of life, providing for national defense, and the overall functioning of modern society. Minerals are being used in larger quantities than ever before and in an increasingly diverse range of applications— from telecommunications (cell phones and computers), to renewable-energy generation (wind turbines, solar photovoltaics, and fuel cells), to clean forms of transportation (electric and hybrid cars).

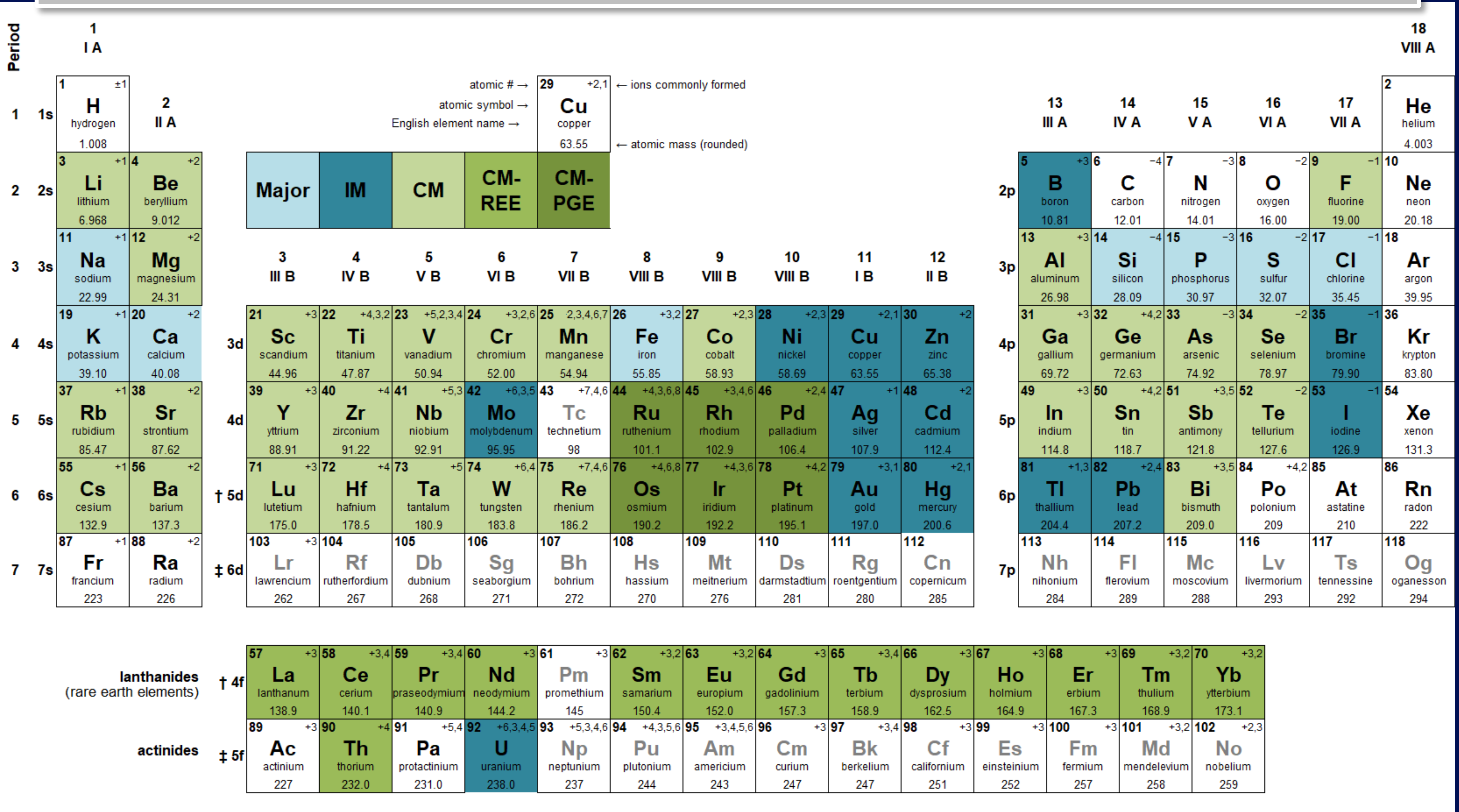
USGS Professional Paper 1802, 2017
American Critical Mineral Independence Act of 2021
American Critical Mineral Exploration and Innovation Act

IM = Industrial Minerals



What are Elements of Interest (EOI)?

Elements of Interest (EOI) are elements that may be economically recovered from waters or solid wastes (i.e., $ value > $ extraction cost) .



Pathway for Recovering EOI from Subsurface Brines and Oilfield Produced Waters

Step 1-Assess Commodity Market for EOI:
- Supply
- Demand

USD/mass → $/kg

Step 2-Characterize PW and EOI Concentrations:
- Sample PW at wells & tanks
- Analyze 60+ EOI
- Quantify variability

mg/L

Step 3-Compute EOI Gross Values
mg/L × $/kg × unit conversions

$/bbl

Step 4-Evaluate H_2O Prod. Rate:
- PW production & handling
- Process variability

BWPD & $/day

Step 5-Screen T&E Technology:
- Target 60-90% efficiency
- Co-extraction

$/bbl

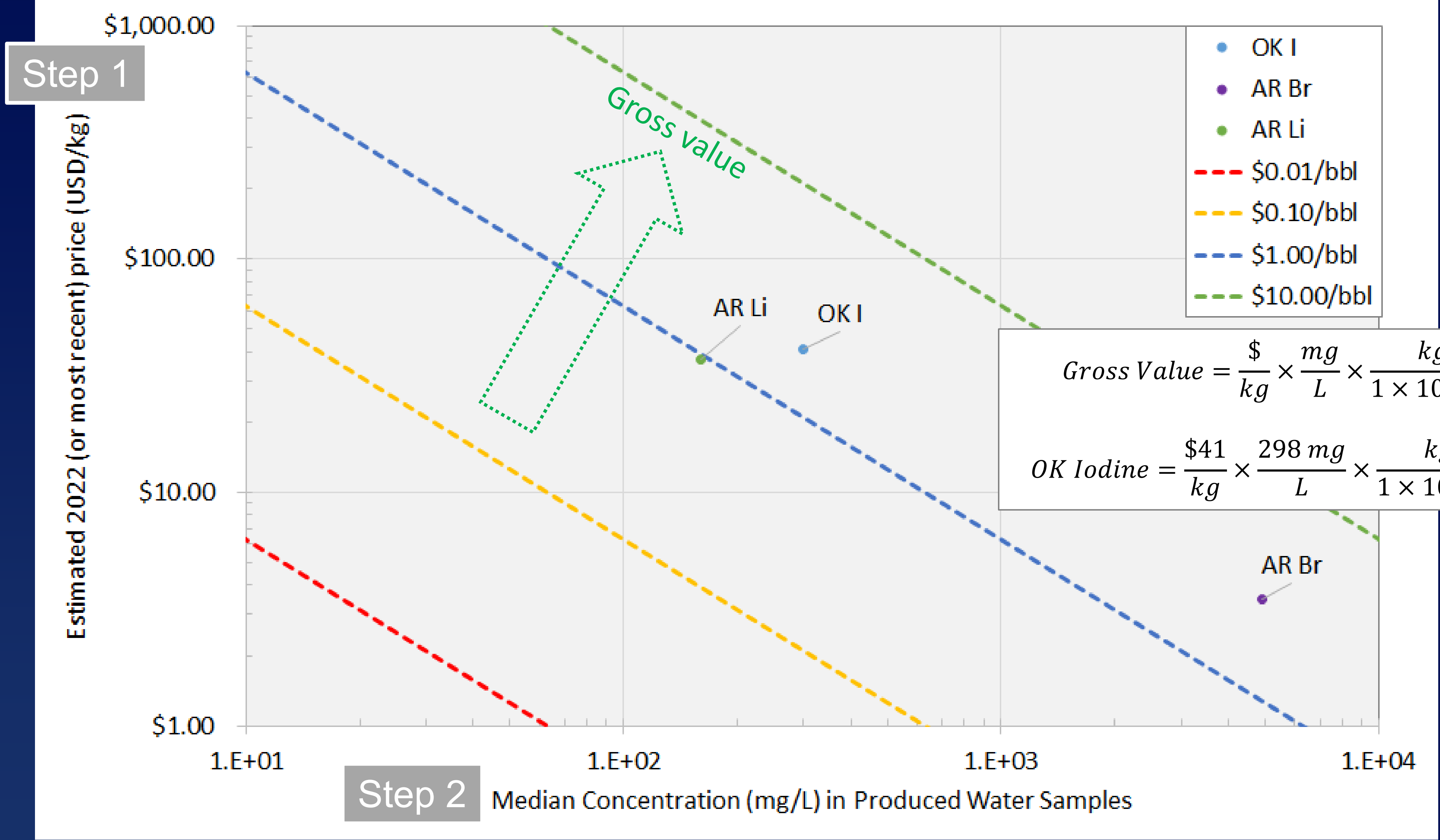
Step 6-Build Extraction Plant:
- Choose EOI & Technology
- Capital, O&M, ROI

BWPD & $/bbl & tonnes/yr & $/yr

Step 7-Extract and Deliver EOI:
- Operation
- Sale
- Delivery

$/yr

Introduction to Gross Values (GV) of EOI



$$Gross\ Value = \frac{\$}{kg} \times \frac{mg}{L} \times \frac{kg}{1 \times 10^6 mg} \times \frac{158.987\ L}{bbl} = \frac{\$}{bbl}$$

$$OK\ Iodine = \frac{\$41}{kg} \times \frac{298\ mg}{L} \times \frac{kg}{1 \times 10^6 mg} \times \frac{158.987\ L}{bbl} = \frac{\$1.94}{bbl}$$

Step 3

Case Study: MGC and other EOI Data in PB

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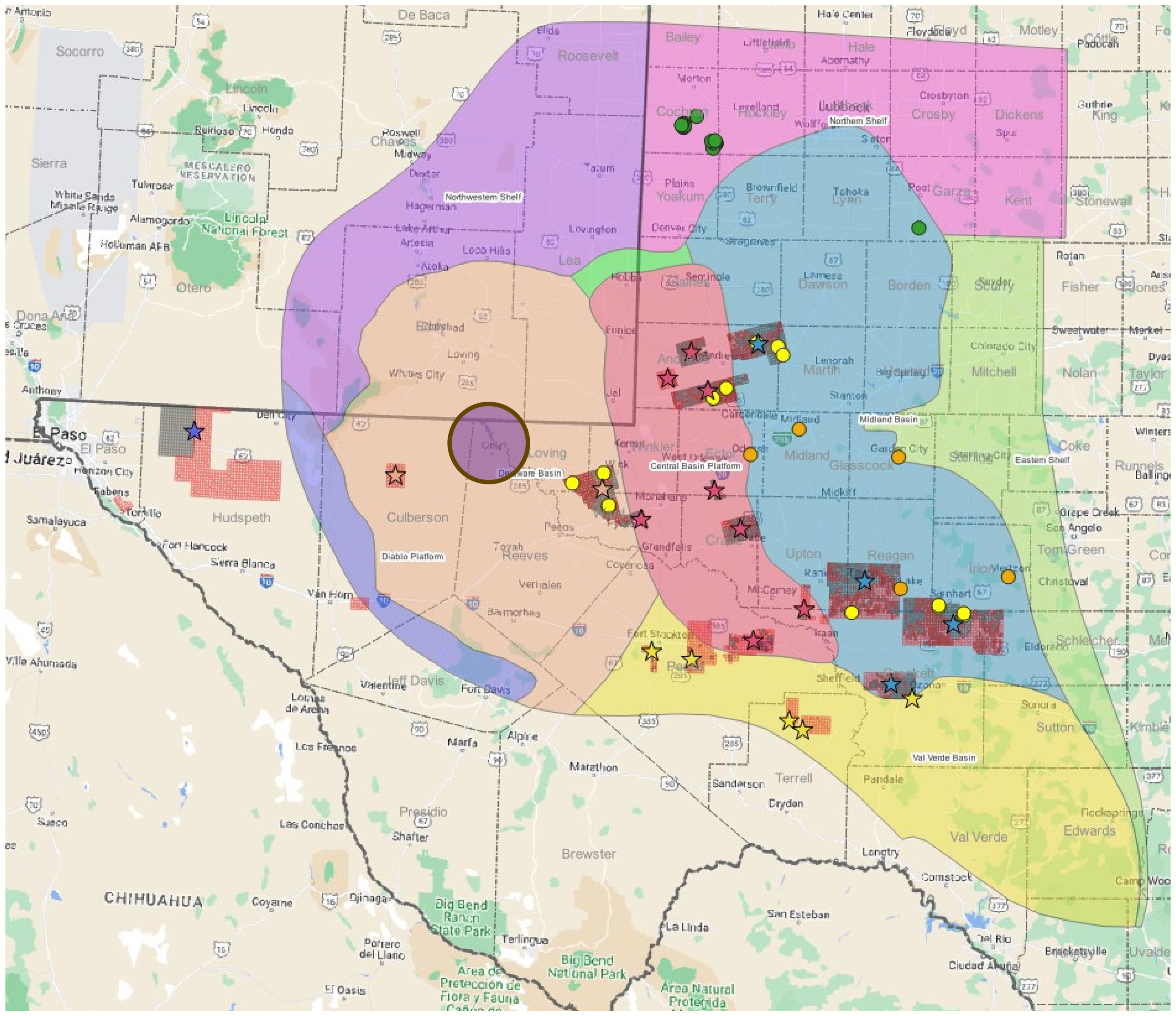
- MGC samples
- TXULproposed
- ✓ Central Basin Platform
- ✓ Delaware Basin
- ✓ Diablo Platform
- ✓ Midland Basin
- ✓ Val Verde Basin
- ✓
- TXULsamples
- Proprietary Data
- Quillinan Samples
- AvailableParcels
- OG_Lease
- Permian Sub Basins
- ✓ Central Basin Platform
- ✓ Delaware Basin
- ✓ Diablo Platform
- ✓ Eastern Shelf
- ✓ Midland Basin
- ✓ Northern Shelf
- ✓ Northwestern Shelf
- ✓ San Simon Channel
- ✓ Val Verde Basin

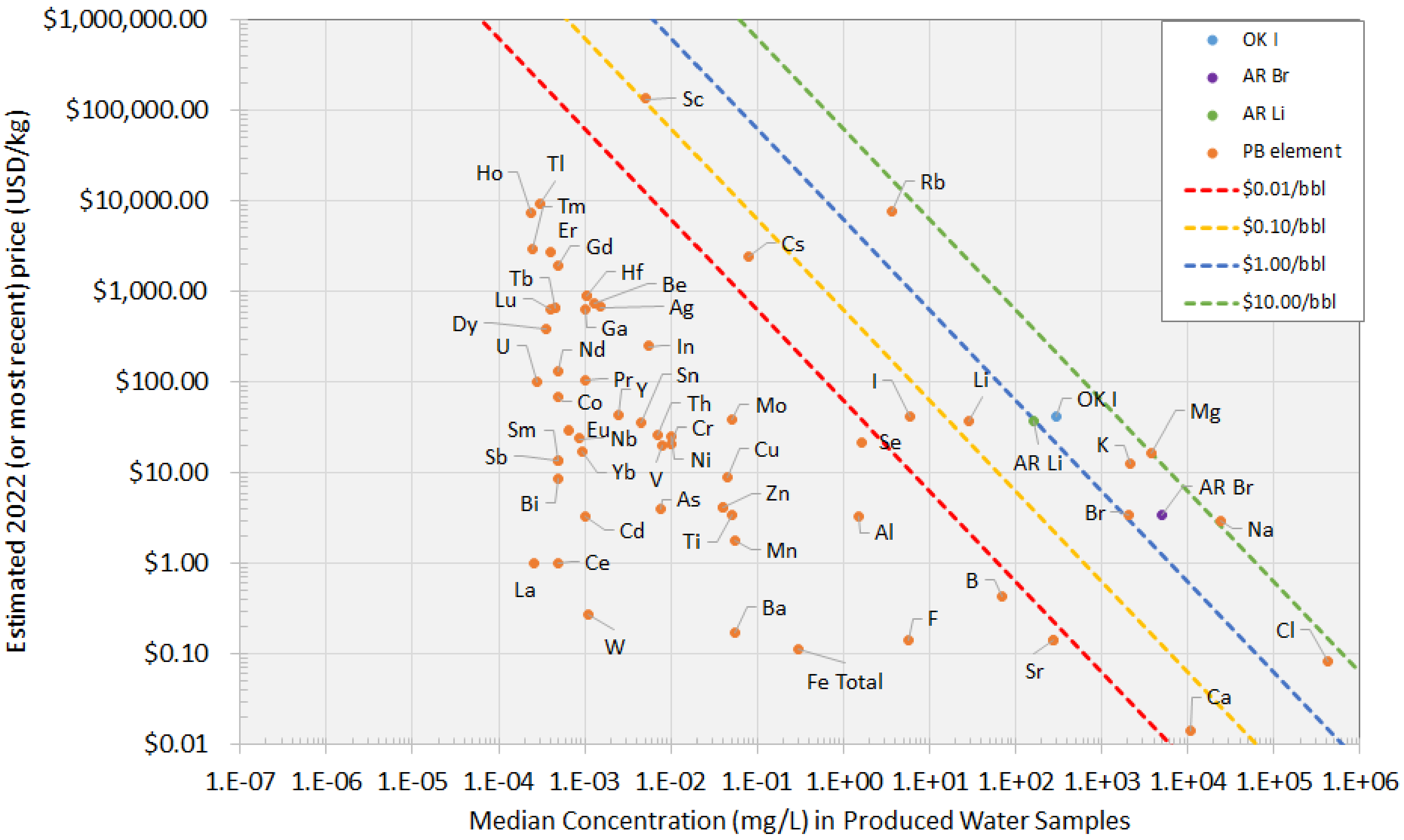


Case Studies: 60+ EOI in Northern Shelf of PB

Compute Gross Values for EOI

in 25 Northern Shelf Permian Basin PW samples

	TDS (mg/L)
min	55,800
25th %	156,000
median	178,000
75th %	193,000
max	537,000



Example for Well OK 005

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EOI	EOI name	Step 1: $/kg in 2022	Step 2: OK 005 mg/L	Step 3: EOI Gross Value $/bbl
Al	Aluminum	$ 3.31	1.4	$ 0.001
B	Boron	$ 0.43	11.9	$ 0.001
Ba	Barium	$ 0.17	3.5	$ 0.000
Br	Bromide	$ 3.50	996.0	$ 0.554
Ca	Calcium	$ 0.01	19580.0	$ 0.044
Cd	Cadmium	$ 3.30	0.001	$ 0.000
Cl	Chloride	$ 0.08	176,000	$ 2.295
Co	Cobalt	$ 68.34	0.0014	$ 0.000
Cr	Chromium	$ 21.00	0.0080	$ 0.000
Cs	Cesium	$ 2,394.00	0.0666	$ 0.025
Cu	Copper	$ 9.04	0.0200	$ 0.000
Eu	Europium	$ 30.00	0.0002	$ 0.000
F	Fluoride	$ 0.14	4.90	$ 0.000
Fe Total	Iron	$ 0.11	18.8	$ 0.000
Ga	Gallium	$ 640.00	0.0020	$ 0.000
I	Iodide	$ 41.00	71.80	$ 0.468
In	Indium	$ 250.00	0.0006	$ 0.000
K	Potassium	$ 12.85	992.00	$ 2.027
La	Lanthanum	$ 1.00	0.0003	$ 0.000
Li	Lithium	$ 37.00	13.8	$ 0.081
Mg	Magnesium	$ 16.76	2520.0	$ 6.713
Mn	Manganese	$ 1.82	4.3	$ 0.001
Mo	Molybdenum	$ 39.25	0.0040	$ 0.000
Na	Sodium	$ 3.00	73000	$ 34.818
Ni	Nickel	$ 25.00	0.0120	$ 0.000
Rb	Rubidium	$ 7,770.00	1.9080	$ 2.357
Sb	Antimony	$ 13.89	0.0002	$ 0.000
Sc	Scandium	$ 137,000.00	0.0080	$ 0.174
Se	Selenium	$ 22.05	2.7600	$ 0.010
Sr	Strontium	$ 0.14	1470.0	$ 0.033
Te	Tellerium	$ 2,000.00	0.0200	$ 0.006
Tl	Thallium	$ 9,400.00	0.0043	$ 0.006
Y	Yttrium	$ 43.00	0.0026	$ 0.000
Zn	Zinc	$ 4.19	0.2460	$ 0.000
			Total Gross Value	$ 49.615
			Economically Feasible	$ 47.063

- Step 1 — Assess Commodity Market for EOI ($/kg)
- Step 2 — Characterize PW and EOI Concentrations (mg/L)
- Step 3 — Compute EOI Gross Values ($/bbl)
- Step 4 — Evaluate PW Rate (BWPD)

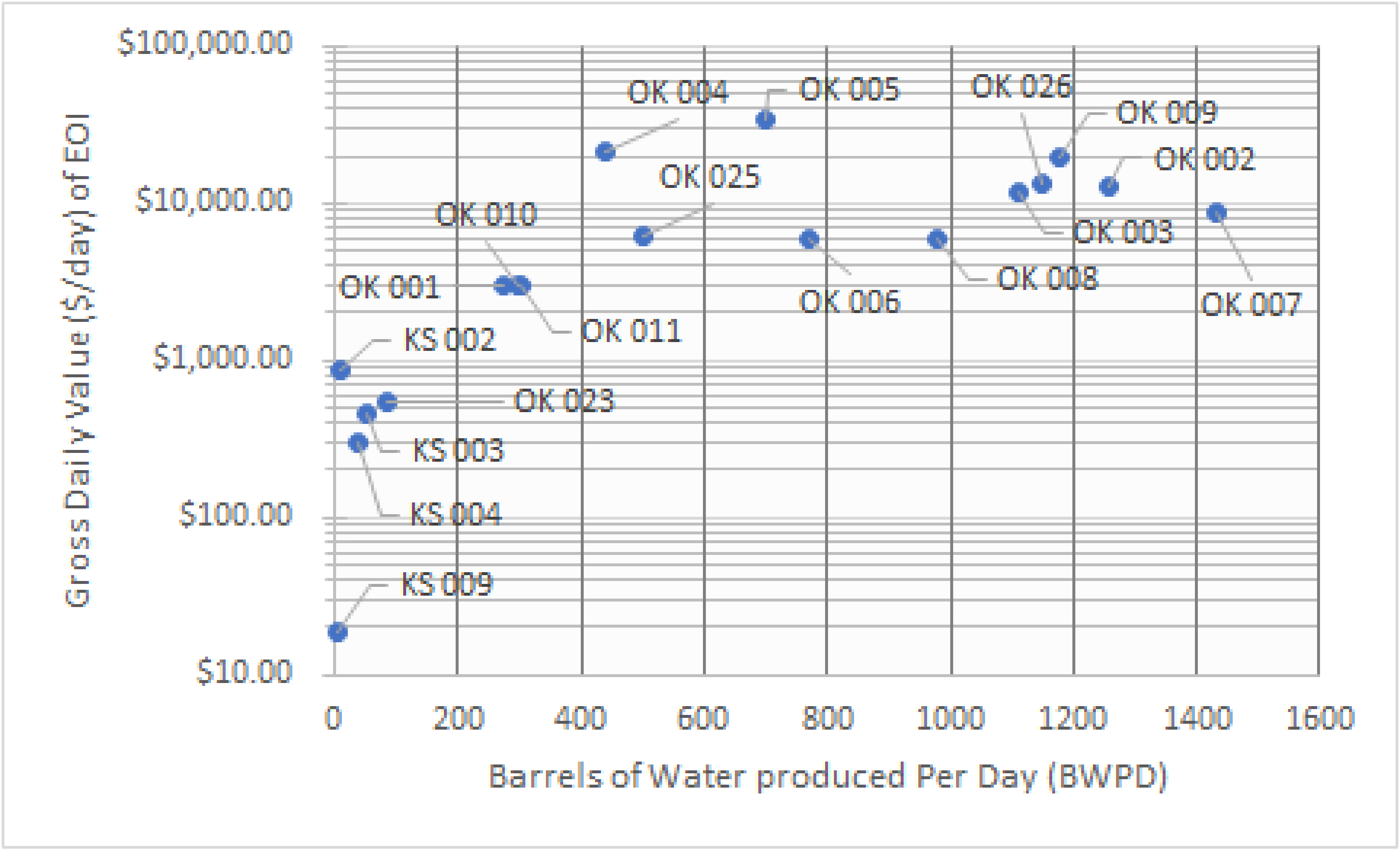
Step 4

vol. prod. rate	units	$/unit	$/day
BWPD	700	$ 49.61	$ 34,730.44
BOPD	106	$ 100.00	$ 10,600.00
MCFPD	126	$ 7.90	$ 995.40

In this example, Well OK 005, the gross value of the EOI in the produced water exceeds the value of the oil and gas.

BWPD = barrels of water per day
BOPD = barrels of oil per day
MCFPD = 1000s of cubic feet of gas per day

Step 4: Daily Gross Values (BWPD x $/bbl = $/day)



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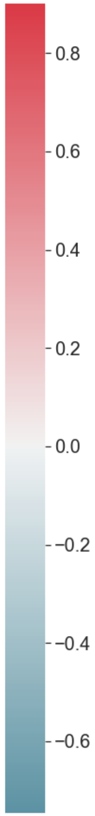
Exploratory Data Analysis (EDA) & Heat Map

Matrix of Pearson's correlation for EOI/WQ measures in 861 PB samples

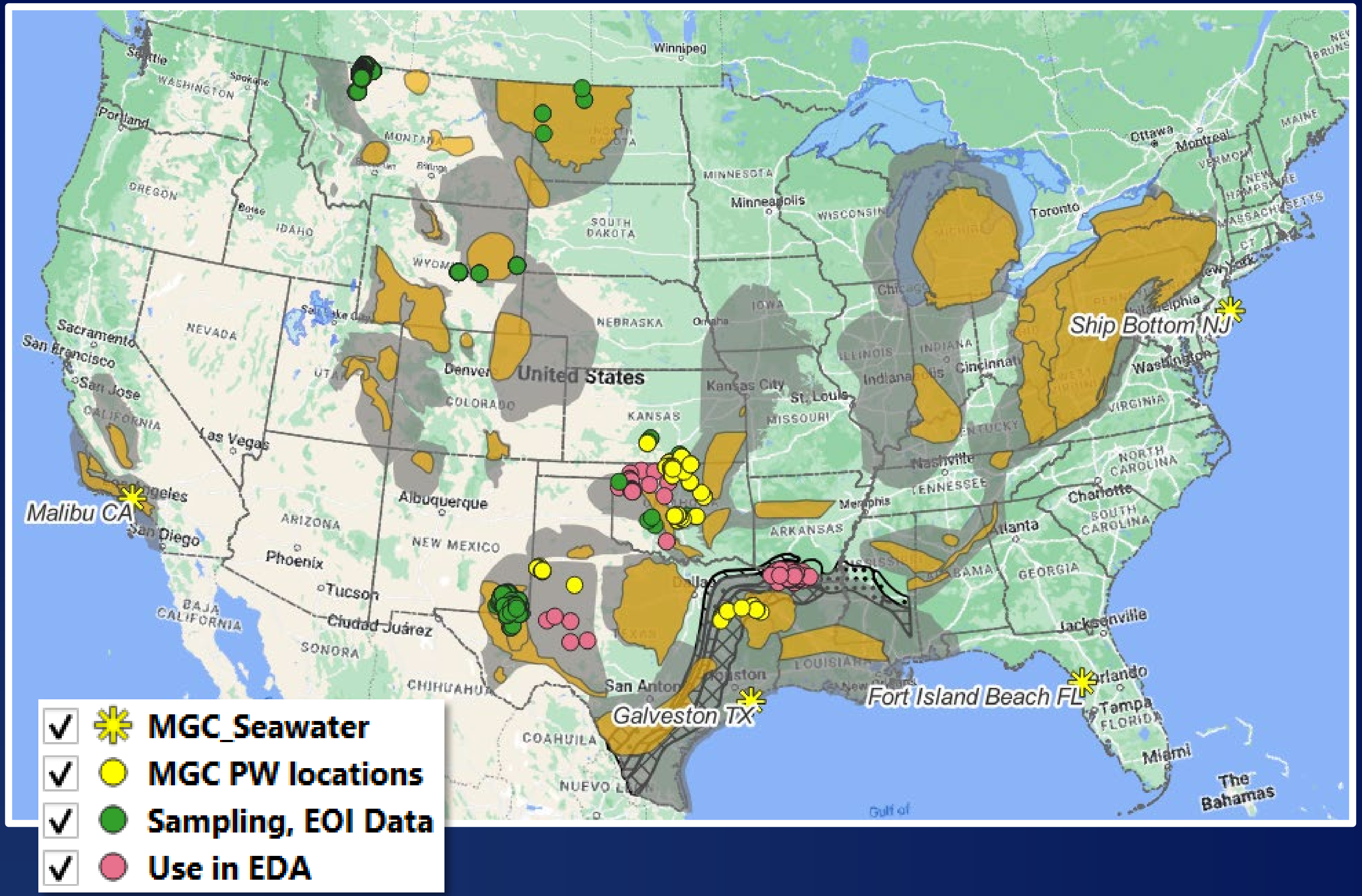
#		PH	TDS	H2S	CO2	B	Br	Ca	Cl	Cs	I	K	Li	Mg	Mo	Na	NI	Rb	Sc	Se	Sr
842	PH																				
849	TDS	-0.4																			
670	H2S	0.0061	-0.014																		
757	CO2	-0.24	0.45	-0.0049																	
323	B	0.18	-0.47	0.049	-0.41																
103	Br	-0.59	0.77	0.25	0.68	-0.35															
845	Ca	-0.35	0.75	-0.02	0.32	-0.42	0.84														
846	Cl	-0.42	0.98	-0.015	0.42	-0.51	0.86	0.77													
28	Cs	-0.13	-0.019			-0.1	0.28	0.43	0.43												
33	I	-0.61	-0.35			-0.36	0.25	-0.43	-0.26	0.81											
842	K	-0.25	0.68	-0.018	0.36	-0.073	0.28	0.47	0.63	0.053	-0.39										
843	Li	-0.03	-0.12	-0.0046	-0.064	0.42	-0.34	-0.13	-0.11	0.22	-0.19	0.29									
849	Mg	-0.23	0.74	-0.017	0.34	-0.071	0.34	0.7	0.67	-0.27	-0.34	0.73	-0.13								
49	Mo	-0.21	-0.1	-0.36	-0.22	-0.11	-0.21	-0.1	-0.06			-0.23	-0.058	-0.099							
825	Na	-0.39	0.91	-0.0084	0.47	-0.6	0.83	0.53	0.9	0.79	-0.025	0.57	-0.11	0.5	-0.16						
55	NI	-0.23	0.071	0.014	0.32	-0.2	0.16	0.047	0.09	-0.038	0.33	-0.066	-0.0018	-0.058	-0.13	0.17					
28	Rb	-0.7	0.85			0.91	0.44	-0.11	0.98	-0.25	-0.58	0.86	0.23	0.8		1	-0.35				
8	Sc	0.52	0.13			0.87	-0.57	0.14	0.24	0.59	-0.44	-0.48	0.98	-0.75			0.82	-0.073			
26	Se	-0.69	0.67			0.62	0.62	0.23	0.81	0.56	0.17	0.52	0.49	0.5		0.83	-0.036	0.85	0.16		
842	Sr	-0.25	0.45	-0.011	0.21	-0.027	0.77	0.72	0.49	0.8	0.94	0.21	0.07	0.45	0.06	0.27	-0.035	-0.54	-0.29	0.18	
#		842	849	670	757	323	103	845	846	28	33	842	843	849	49	825	55	28	8	26	



Strong + correlation

Strong - correlation

Conclusions and Future Directions



1) 10 EOI are economically recoverable from seawater and "un-enriched" brines
2) An EDA can be used to prospect for brines that are "enriched" with EOI
3) Continue characterizing produced, flowback, solution mining, and geothermal waters for EOI in various plays/formations
4) Evaluate extraction costs for target EOI