Strontium Isotope Detection of Brine Contamination of Surface Water and Groundwater in the Williston Basin, Northeastern Montana

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U.S. Geological Survey

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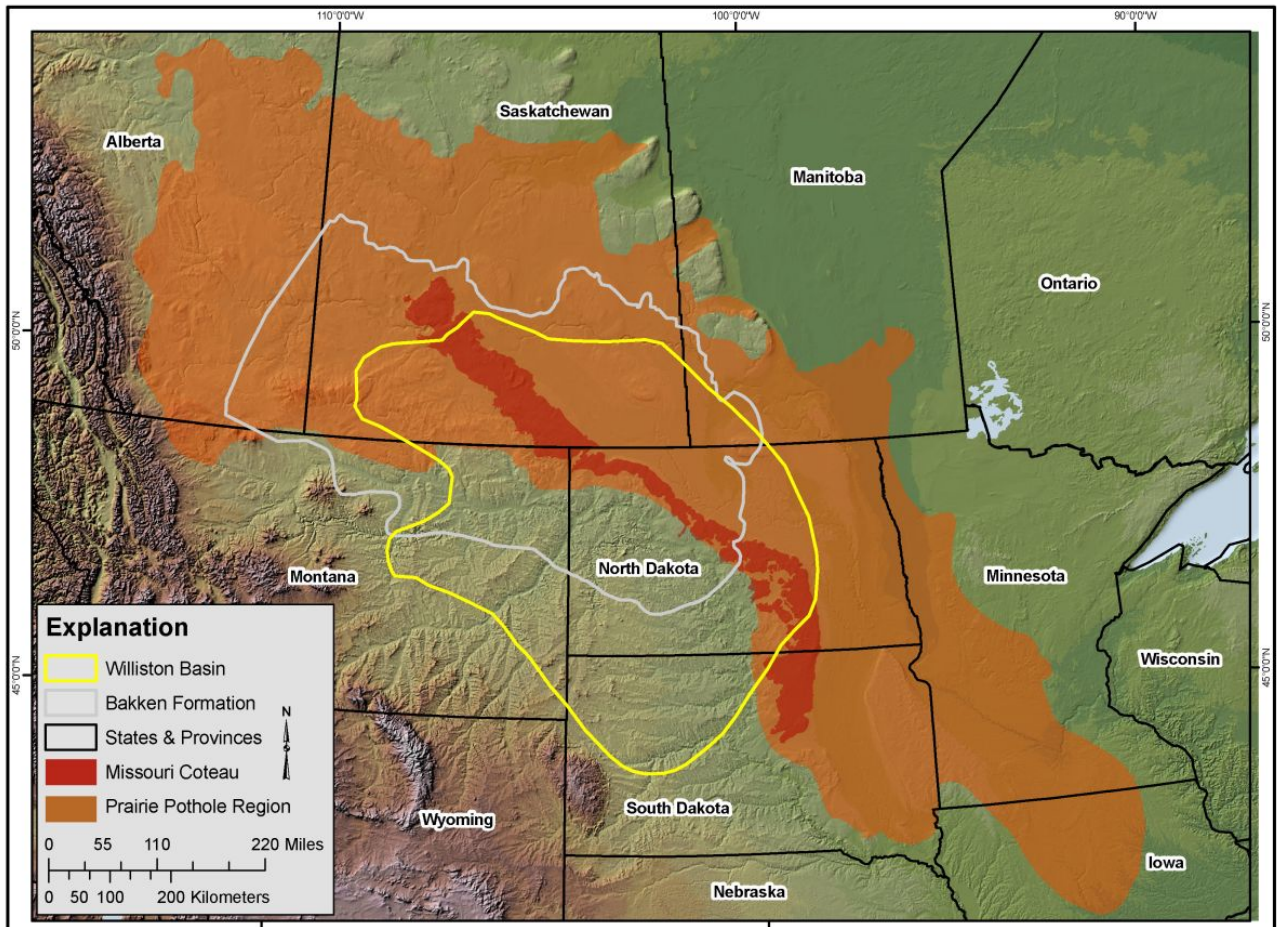
Prairie Potholes and Williston Basin



Study area for: Brine contamination to Prairie Potholes from Energy Development in the Williston Basin.

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Prairie Potholes

- Lakes, wetlands, and sloughs are recharged by precipitation, runoff, and inflow from groundwater
- Evaporation increases natural salinity of lakes (SO_4 dominated)
  - Some lakes are economic sources of mirabilite (sodium sulfate)
- Some lakes are perennially saline as a result of a delicate balance between evaporation and recharge
- Contamination by produced water also increases salinity (Cl dominated)
- Region is a major nesting ground for ducks and other waterfowl

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Science Team on Energy in Prairie Pothole Environments (STEPPE)

http://steppe.cr.usgs.gov/

- **STEPPE is a USGS multidisciplinary team studying impact of energy production on prairie pothole region in Williston Basin**
  - **Evaluating potential risk to natural resources**
  - **Determining spatial extent of impact**

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Produced Water Factoids

(National Energy Technology Laboratory, Argonne National Laboratory, and Produced Water Society)

- Approximately 20 billion barrels produced annually in US (about 55 million barrels/day)
  - 3 to 4 barrels per barrel of oil in Williston Basin
- Salinity as much as 400,000 mg/L (sea water is 35,000 mg/L)
- Disposal
  - 65% is re-injected into producing units
  - 30% injected into deep formations for disposal
  - 5% is disposed of at the surface

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Sources of Salinity in Potholes

- Solutes are acquired by water-soil-rock interaction
- Evaporation increases solute concentrations
- SO_4/Cl will not change unless mirabolite or halite precipitates
- Contamination with produced water will increase Cl while decreasing SO_4/Cl ratios
- Sr isotope ratios are not changed by evaporation

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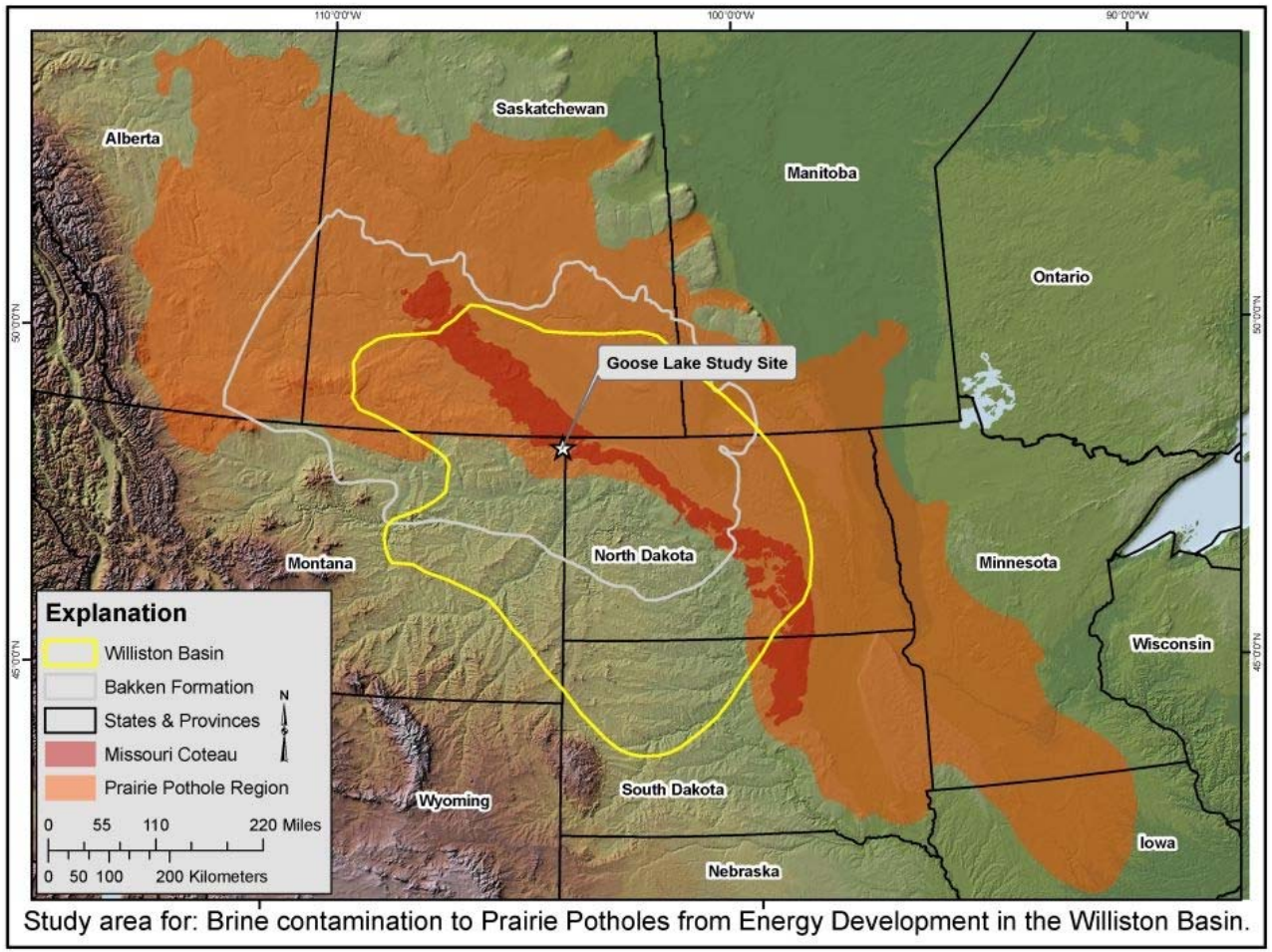
Goose Lake Study Site



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Oil Spill Impact on Wetland

(Photo by Jerry Rodriguez, Medicine Lake National Wildlife Refuge)

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Produced Water Impact on Wetland

(Photo by Jerry Rodriguez, Medicine Lake National Wildlife Refuge)

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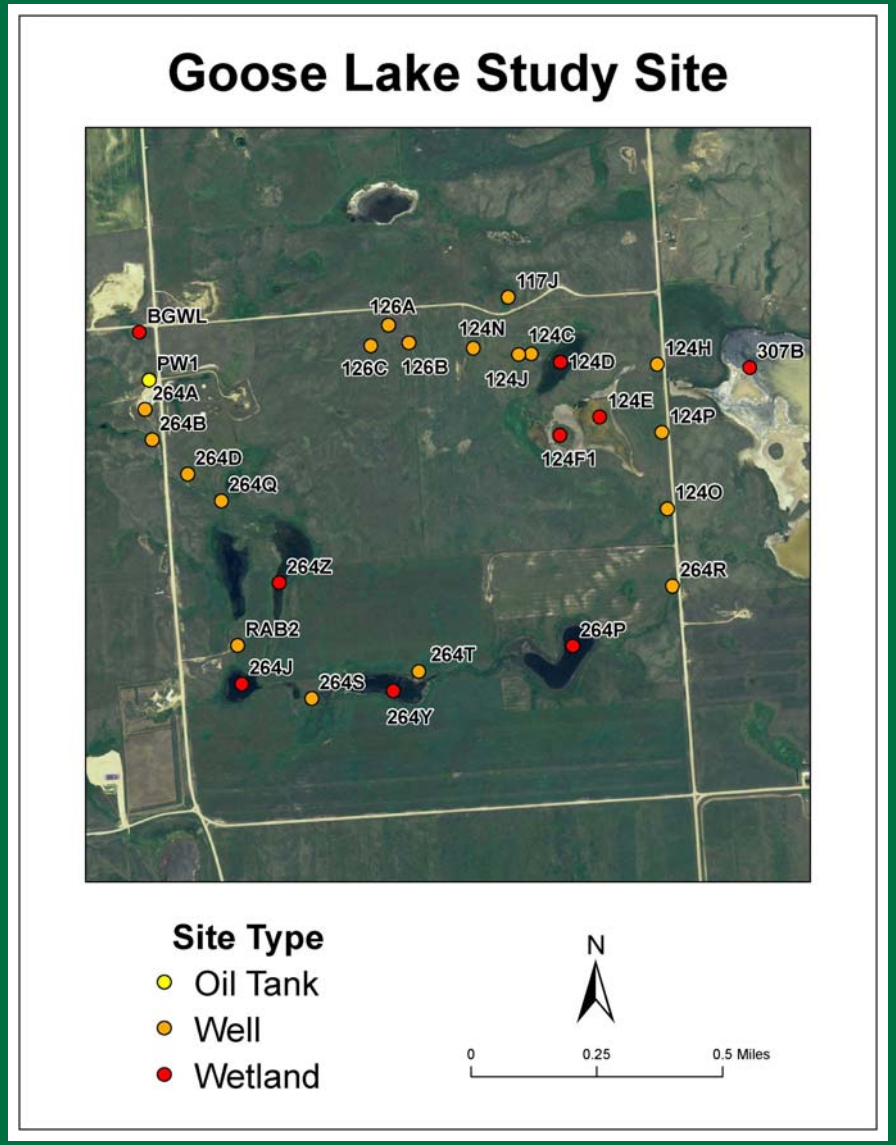
Goose Lake Study Site

USGS activities include:

- **Hydrochemical analyses identify contamination**
  - **Majors and trace elements**
  - **Strontium isotopes (this study)**
- **Electromagnetic studies**
  - **High conductivity zones delineate brine plumes (Bruce Smith et al.)**



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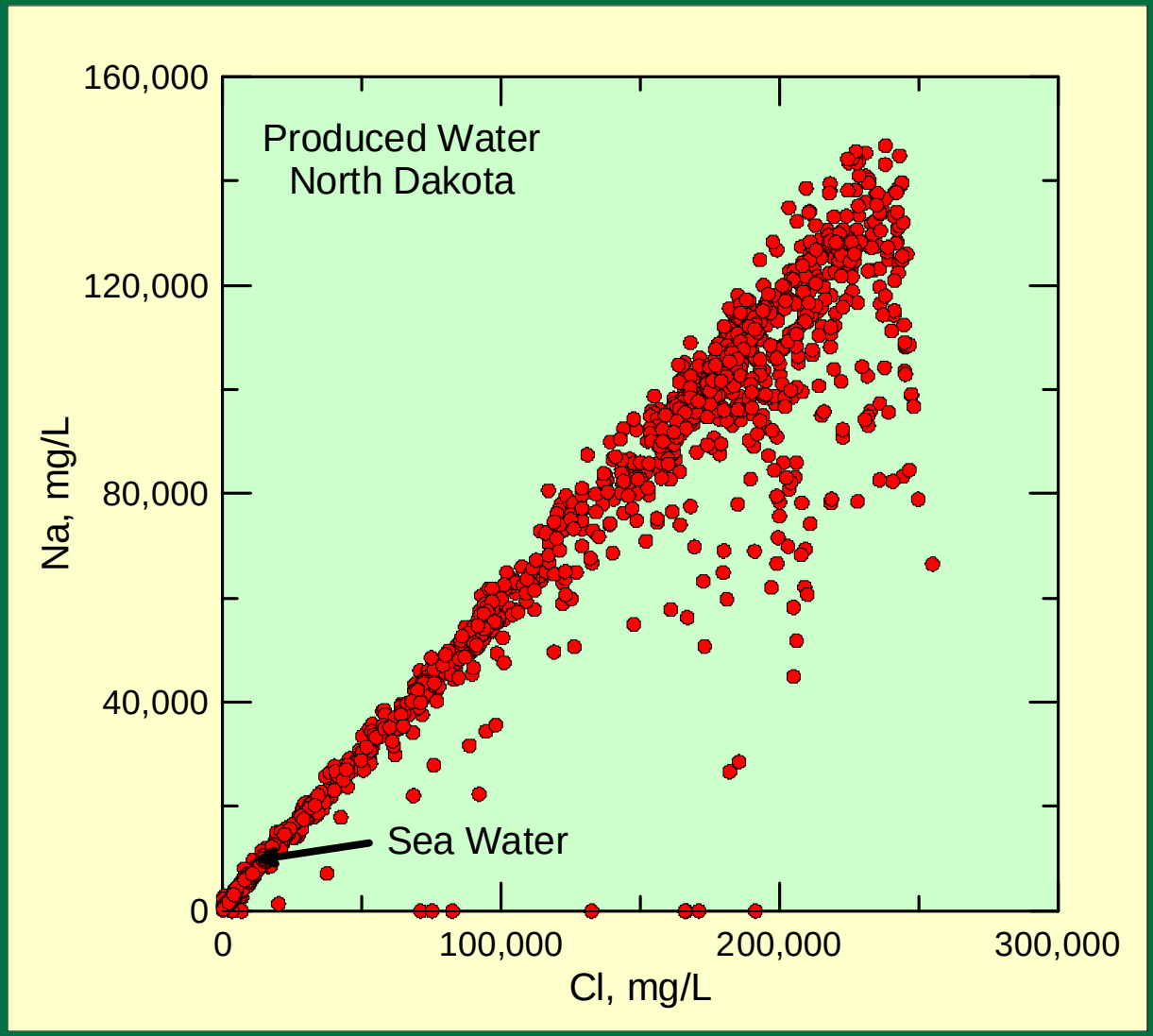
Na and Cl in North Dakota Produced Water (Evaporation Trend?)



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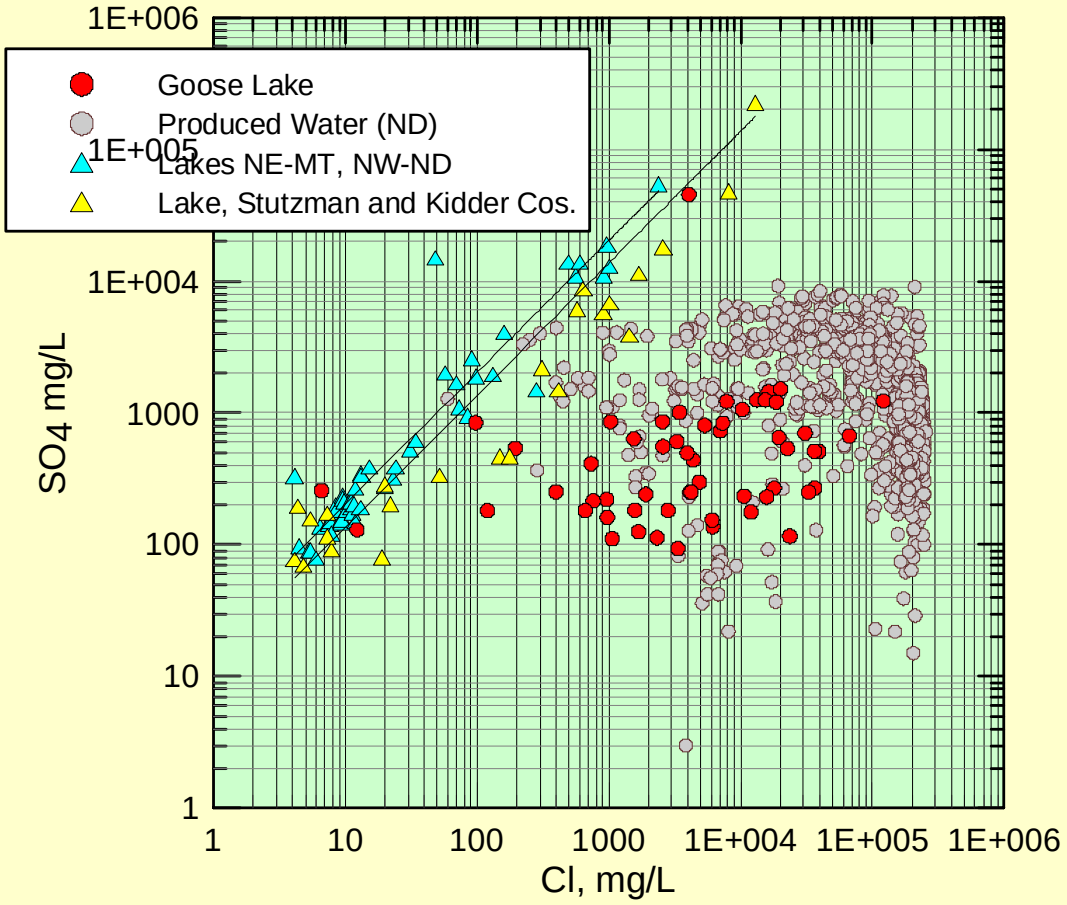
Sulfate and Chloride



- Uncontaminated surface waters show evaporation trends in Cl and SO_4
- Produced waters reach saturation with NaCl but no correlation with SO_4
- Many Goose Lake samples are contaminated

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Strontium (Sr) Isotope Study

- Test use of strontium isotopes for detecting very small amounts of produced water (aka formation water, oil-field brine) contamination
- Goose Lake site in northeastern Montana
  - Hydrochemical, geophysical, and biological studies being conducted by STEPPE
- Sr study is a work in progress

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Small Amounts of Contamination Can be Detected by Sr Isotopes

- Sr contents of fresh water and produced water differ by several orders of magnitude
- Where Sr isotopic composition of fresh water and produced water differ, binary mixing trends are produced by contamination
- Process can involve multiple episodes of evaporation and contamination but net effect will be the same

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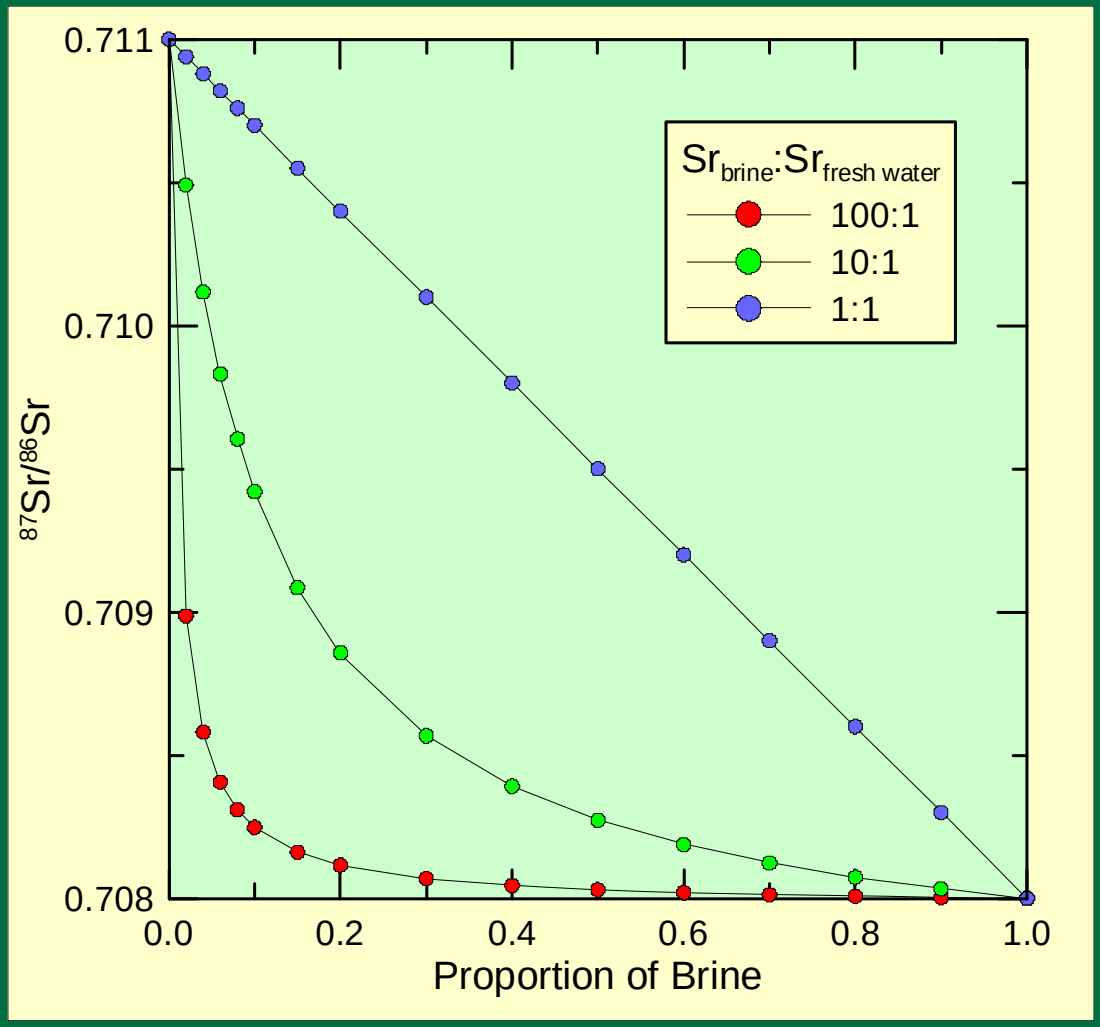
Sr Isotope Binary Mixing Curves



- **Shapes of mixing curves are a function of proportion of end members and ratios of Sr contents**
- **Given the differences in $^{87}Sr/^{86}Sr$, the greater the contrast in Sr contents, the greater the sensitivity for detecting small amounts of brine**

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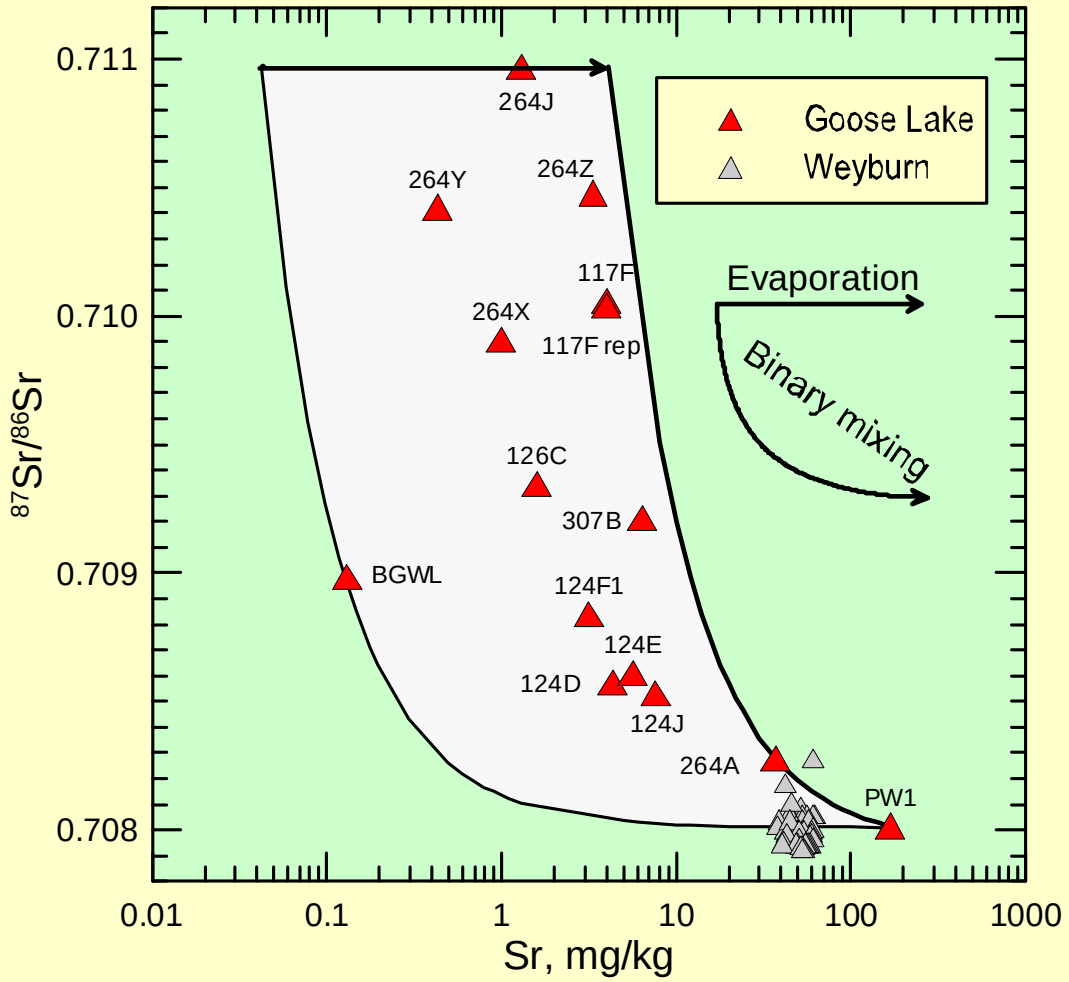
Sr Isotope Systematics at Goose Lake



- Largest $^{87}Sr/^{86}Sr$ is assumed to represent the least contaminated end member
- Mixing zone is bounded by mixing lines between brine and values on evaporation line
- $^{87}Sr/^{86}Sr$ of Goose Lake Brine is identical to mean value for Weyburn brines (Quattrocchi et al, 2006)

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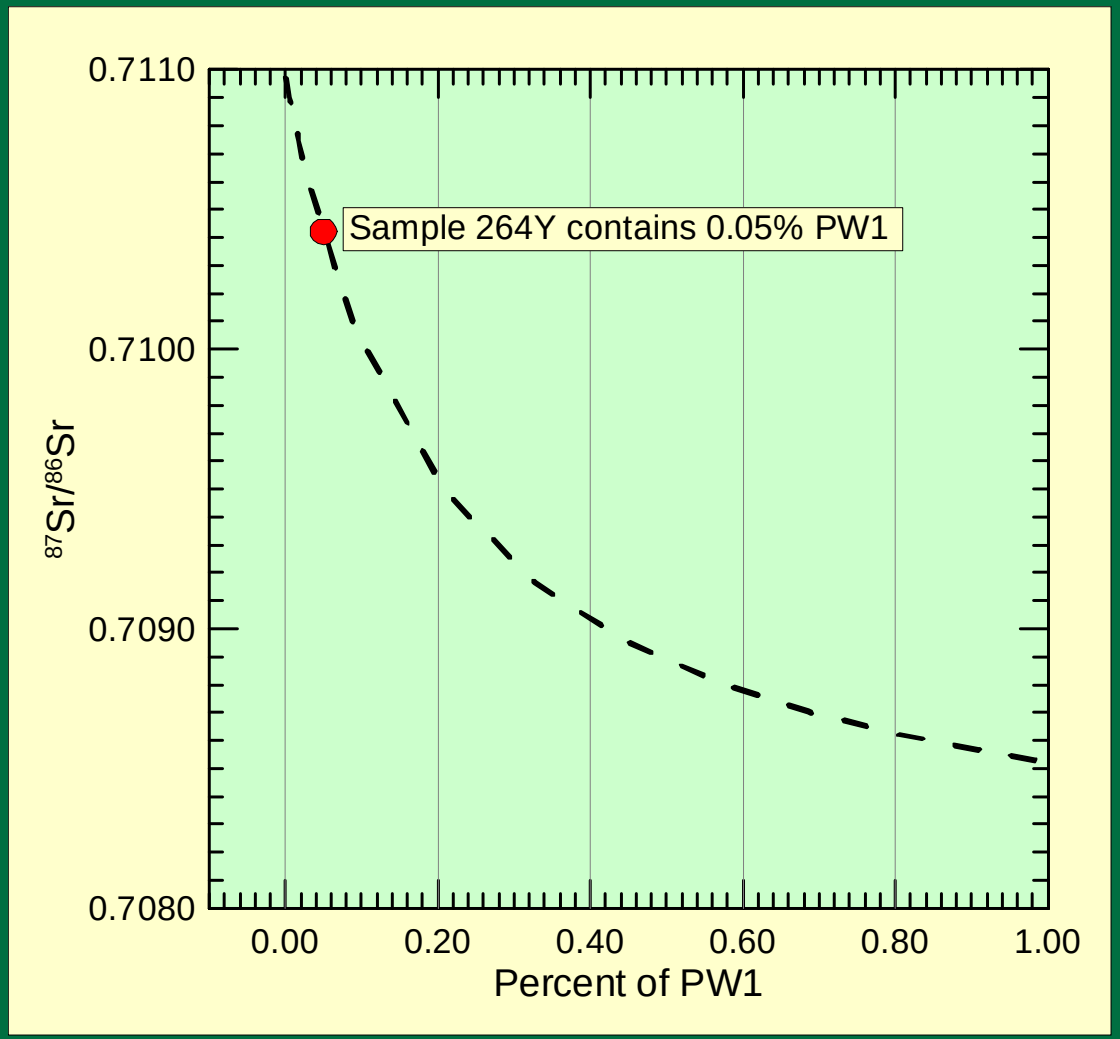
Sensitivity of $^{87}Sr/^{86}Sr$ to Mixing

- Sample 264Y shows sensitivity of Sr isotopes for detecting small amounts of produced water
- In this binary system, as little as 0.005% could be detected given the analytical uncertainty in $^{87}Sr/^{86}Sr$



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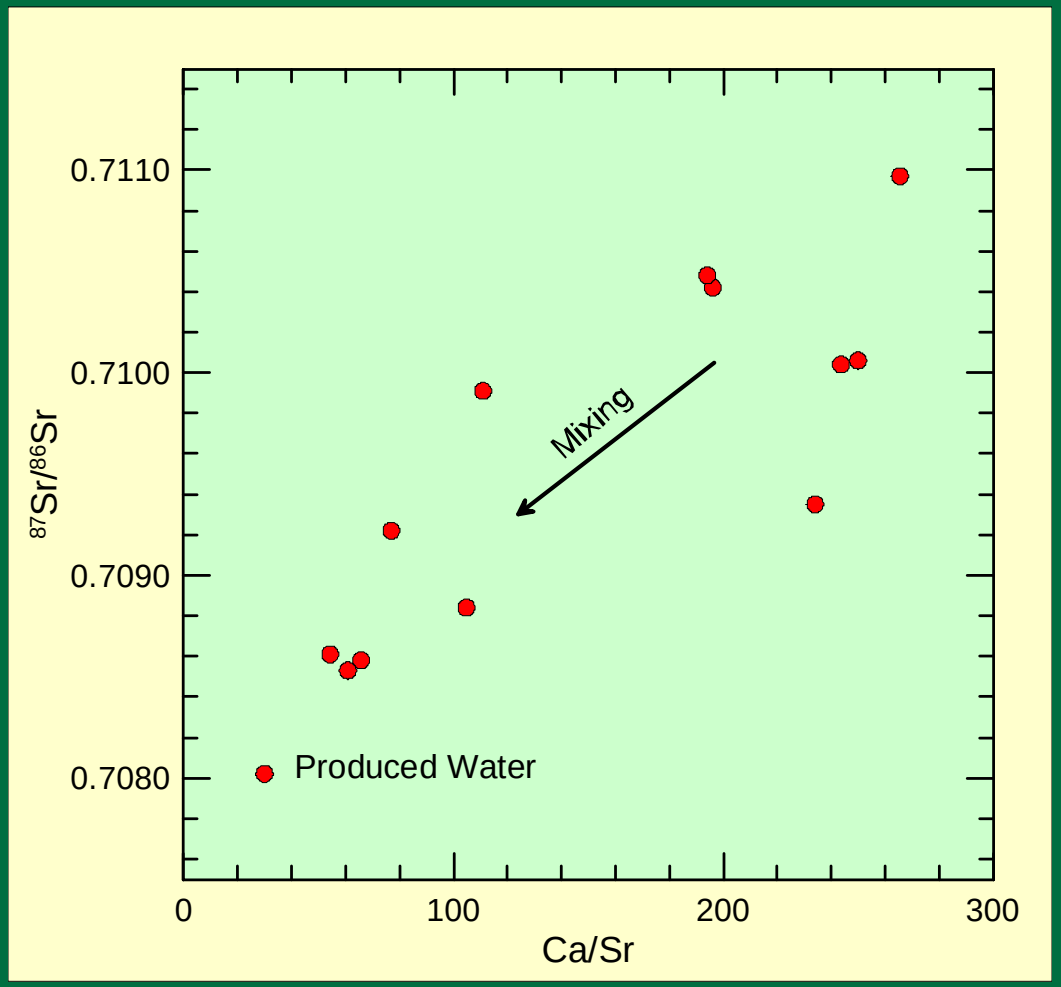
Ca/Sr Ratios

- Ca/Sr ratios are highly variable and also reflect mixing
- Ca/Sr in sea water is about 54
- Ca/Sr is surface water is about 200 or greater
- Binary mixing will produce linear trends



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Conclusions

- Strontium isotopes
  - Sensitive indicators of small amounts of produced water contamination
  - Ratios do not change with evaporation
  - Mixing systematics allow calculation of degree of contamination
- Regional baseline data from other wetland areas in Williston basin are needed in anticipation of increased oil production from tight rocks that require hydrofracturing

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