20 Years Later: Reexamining Produced Water Contamination Plumes in the Prairie Pothole Region of Sheridan County, Montana

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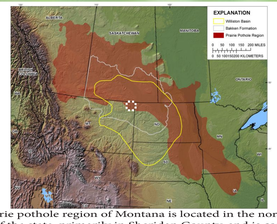
Study Area

Geological Setting

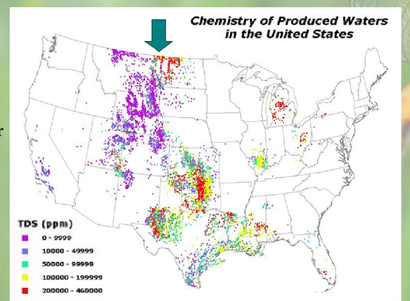
- Montana's prairie pothole region is part of the Missouri Coteau, which is an elevated highland covered by clay-rich Wisconsin age glacial deposits
- The near surface stratigraphy is a complex, 3-D matrix derived from three depositional settings
  - Poorly sorted and vertically fractured till
  - Fine grained, fractured lacustrine deposits
  - Coarse grained glacial outwash deposits
- Murphy[1] reported the textural analysis of 66 till samples as 35.6% sand, 37.9% silt and 26.5% clay



The prairie pothole region of Montana is located in the northeast corner of the state, primarily in Sheridan County, and contained within the Williston Basin. Locally, most oil is produced from the Mississippian Ratcliffe Formation, however advances in drilling techniques has made the area potentially favorable for exploration in the Devonian Bakken Shale. The Bakken Formation is classified as a continuous reserve, meaning it lacks major structural traps, therefore oil and gas development will require drilling thousands of new wells.

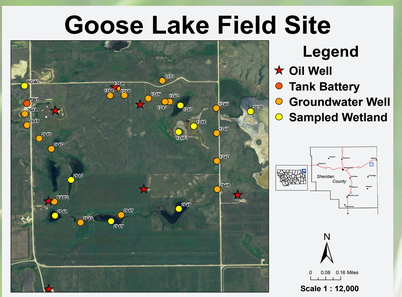
Produced Waters

- Formation waters having high salinity that are coproduced with oil and gas resources
- Produced water can enter the shallow groundwater system through spills, pipeline breaks, disposal pits or reserve pits created during drilling
- Reserve pits, dug at each oil well to hold drilling muds and produced water, typically measure 150 ft x 60 ft x 10 ft and may contain 260 tons of salt
- There are approximately 900-1,000 oil well and associated reserve pit sites in Sheridan County



Goose Lake Field Site

- Defined as T36N, R58E Sec 27 and adjacent areas: the Rabenberg WPA is the southern half section
- Located at the contact between glacial till and glacial outwash, the site is composed of roughly 40 ft of collapsed outwash overlying fractured till
- Potential produced water sources in the study site:
  - Hammer M Battery (PW1) used for 45 years for produced water storage from mulitple wells
  - Abandoned and active oil wells within and adjacent to the section drilled in the 1960's



Natural vs. Produced Water Chemistry

Natural Surface Waters

- Enriched in Na, Mg, SO_4 and HCO_3
- Cl concentrations are minimal, often < 10 ppm
- Natural saline wetlands are sulfate and carbonate dominated

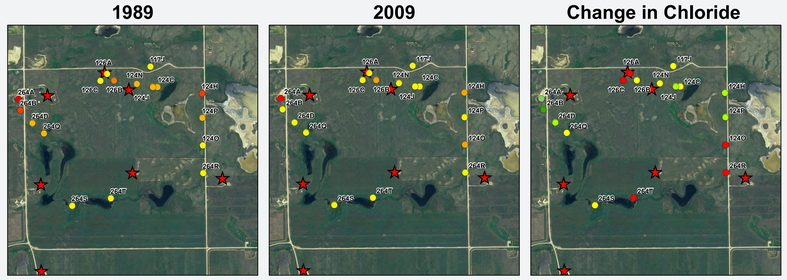
Produced Waters

- Enriched in Na and Cl
- Alkali chlorides and alkali earth chlorides comprise 90-99% of TDS
- Impacted wetlands are chloride dominated

This region contains many naturally saline wetlands with elevated Total Dissolved Solids (TDS). Jon Reiten has developed a Chloride Index (CI) to detect brine contamination as the ratio of chloride (mg/L) to the specific conductance (uS/cm) of water. Water samples in the study region with a CI above 0.035 are considered to be contaminated by produced waters.

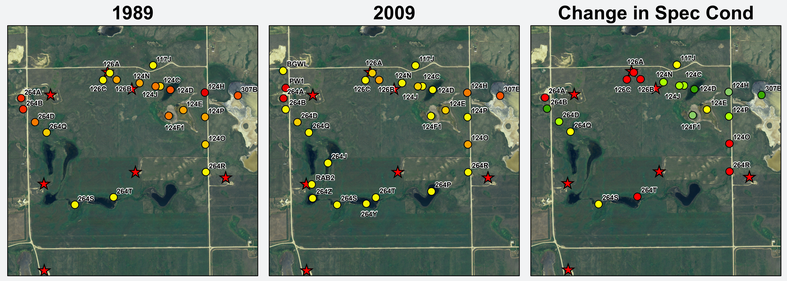
Changes in Water Chemistry

Chloride (mg/L as Cl)



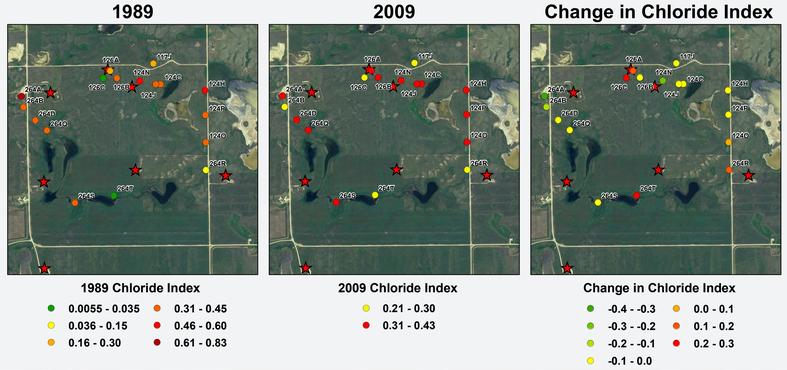
The chloride concentration maps clearly show that despite a general cleansing of the system the area remains highly contaminated. To the West, there are substantial decreases in the chloride concentrations of almost all sampled sites compared with chloride increases in sampled sites along the eastern road boundary. In addition, two sites in the East-West center line of the section, 126A, 126C and 264T, show large increases in chloride concentrations. For reference, the chloride concentration of seawater is 19,400 mg/L. Red stars in all panels are oil field sites.

Specific Conductance (uS/cm)



From the above maps, it can be seen that the majority of the sampling sites have experienced a decrease in specific conductance. However, there are several wells along the East-West center line and in the southeast that show increased conductance values. Of the seven wells that show an increase in specific conductances, only five are accompanied by increased chloride concentrations, illuminating the problem of relying solely on this parameter to determine the presence of contamination from produced waters.

Chloride Index (Cl/S.C.)



From the Chloride Index maps, two major temporal changes can be observed. First, in 1989 there were two groundwater wells, 126C and 264T, that were classified as uncontaminated. These wells exhibited contamination from produced waters in 2009. Second, sampled areas to the West generally show decreases in the Chloride Index while sampled areas to the East show a general increase. This is interpreted as a flushing of the system as the highly saline water moves down gradient through the underlying shallow sand and gravel aquifer towards the East.

Geophysical Methods

Electrical Conductivity

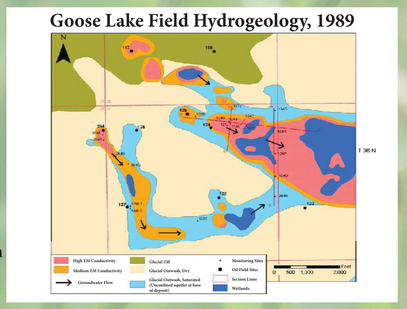
- Measures electrical properties of soils and pore fluids
- Measures conductivity of the saturated and vadose zones
- Excellent tool for delineation of contaminated groundwater plumes due to the high conductivity of salts
- The EM-31 can determine the lateral extent of contaminant plumes, but is limited to an exploration depth of 3-4 meters
- EM-34 utilizes multiple coil orientations and spacings to provide lateral extent data and three exploration depths between 7-60 meters, providing depth profiles of plumes

Jon Reiten collecting EC data with a Geonics EM-31 in 2004

Todd Preston, Joanna Thamke and David Rouse collecting EC data with a Geonics EM-34 in September of 2009

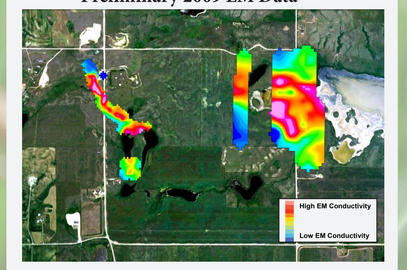
1989 EC Survey

- Elevated chloride levels were reported in 1975 in surface waters 1/2 mile below the Hammer Battery
- EM-31 & shallow EM-34 surveys in 1989 detected plumes in the slough below the Hammer Battery and emanating from sites 117, 124, 126 and 128
- Areas below the Hammer Battery and within the section were surveyed, while plume boundaries and EC values were extrapolated East of the section
- 18 wells were installed based on EM survey data



2009 EC Survey

- EM-31 Surveys of previously monitored areas for correlation between 1989, 2004 and 2009 data
- Selected portions of the Goose Lake Field study site were resurveyed with a Geonics EM-34
- Repeat surveying will allow temporal comparative analyses to determine rates of brine movement
- It is hypothesized that the increased depth profile will illuminate the potential for density driven flow of saline contaminated groundwater



Conclusions and Future Research

- Water quality and electrical conductivity surveys of the Goose Lake Field study site show the area has become less contaminated from produced waters in the last 20 years as the max CI decreased from 0.83 to 0.43. However, two groundwater wells that were uncontaminated in 1989 have now been affected.
- Despite an overall cleansing of the shallow sand and gravel aquifer, the surface water and groundwater resources in the area are still highly contaminated as evidenced by the 2009 Chloride Index data
- Water quality data indicates the heart of the contamination plume in the southern half section has migrated down gradient towards the West Arm of Goose Lake (water body on eastern margin of maps)
- Additional EM-31 surveys are planned for the beginning of October 2009 to determine the current extent of the contamination plume in the southern half section
- EM-31 transects will also be conducted to determine the location of the upper limit of the contamination plume in the northern half section
- After mapping of the 2009 data is completed, a correlation framework between the different instruments will need to be created to quantify the temporal changes observed in the electrical conductivity data

Acknowledgements

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[1]Murphy, E., Kehew, A., Groenewold, G., Beal, W. 1988. Leachate generated by an oil-and-gas brine pond site in North Dakota. Groundwater 26(1) p. 31-38