Hydrological Characterization of Wetlands and Geophysical Assessment of Brine Contamination From Produced Water in the Prairie Pothole Region of Montana

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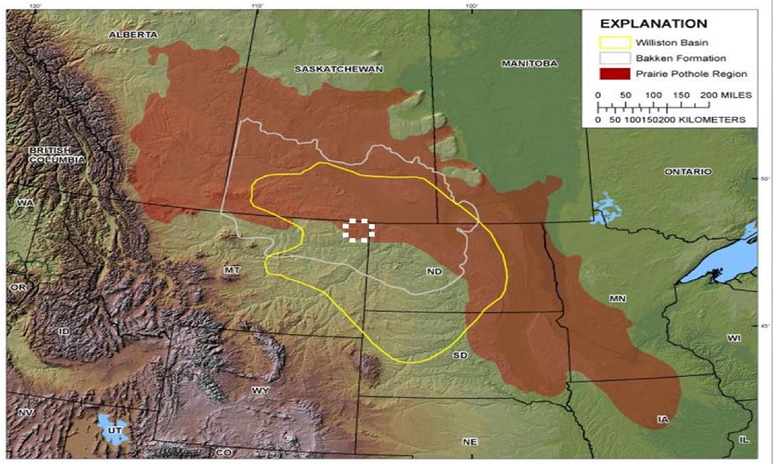
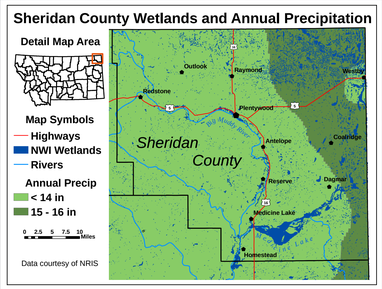
Study Area and Produced Water



The prairie pothole region of Montana is located in the northeast corner of the state, primarily in Sheridan County, and is contained within the Williston Basin. Much of the basin is underlain by the Devonian and Mississippian age Bakken Shale, which is the main oil and gas producing unit in the region. The Bakken Formation is classified as a continuous reserve, such that it lacks major structural traps, and therefore oil and gas development will require drilling thousands of wells in the region.

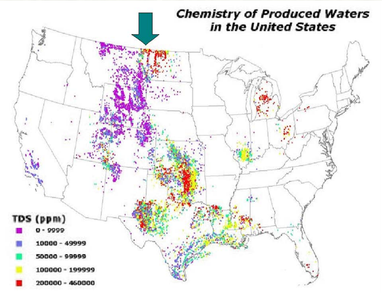
Geological Setting

- Montana's prairie pothole region is part of the larger Missouri Coteau system, which is an elevated highland covered with clay-rich Wisconsin aged 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



Hydrologic Setting

- There are over 12,000 wetlands in Sheridan County
- Region characterized by unintegrated drainage
- Local, intermediate and regional groundwater flow between wetlands
- Annual precipitation is less then 17 inches



Reserve Pits

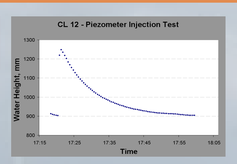
- Constructed at each well site to hold drilling muds and produced water (brine) while drilling
- Prior to mid-70's were unlined evaporation pits and now are main source of brine contamination
- Typical reserve pit measures 150 ft x 60 ft x 10 ft deep and contains roughly 260 tons of salt
- Many older reserve pits were spider legged, drained and buried upon completion of drilling
- There are approximately 900-1,000 oil well and associated reserve pit sites in Sheridan County
- 25% of all wetlands in the county are within 500 meters of an oil well, of these 80 are within 50 meters

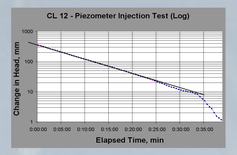
A lined reserve pit holding produced water

Hydrological Characterization

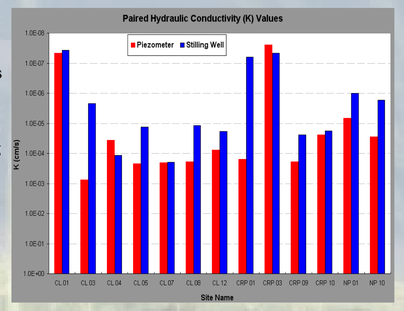
Slug Tests

- Single well slug tests were performed in stilling wells and piezometers to determine hydraulic conductivity using the Bower and Rice method
- Local hydraulic conductivity is controlled by the degree of fracturing and soil heterogeneity
- Fractures in till and lacustrine deposits increase hydraulic conductivity up to four orders of magnitude over intergranular conductivity
- Glacial outwash deposits have hydraulic conductivities four orders of magnitude greater than fractured till and lacustrine deposits
- Wetlands in Sheridan County exhibited a large variability in hydraulic conductivity, with values ranging over five orders of magnitude
- Hydraulic conductivity values from paired wells ranged from near perfect agreement to differing by several orders of magnitude
- Hydraulic conductivities showed no positive correlation with either depth or well type
- Variability makes characterizing the potential for wetlands to experience brine contamination simply by proximity to oil wells problematic



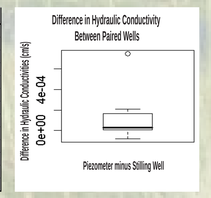


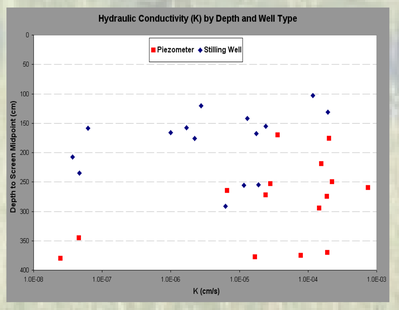
Hydraulic Conductivity Summary For Falling Head Slug Tests (cm/s)	
All Tests	
Average	1.63E-04
MAX	4.75E-03
MIN	1.77E-08
Piezometers (PZ)	
Average (16 Sites)	3.12E-04
Max	4.75E-03
Min	2.46E-08
Stilling Wells (SW)	
Average (15 Sites)	5.65E-06
Max	2.65E-05
Min	1.77E-08
Cropland	
PZ Average (8 Sites)	1.24E-04
SW Average (7 Sites)	5.61E-06
Average (8 Sites)	6.72E-05
Conservation Reserve	
PZ Average (5 Sites)	8.38E-04
SW Average (5 Sites)	7.66E-06
Average (6 Sites)	4.23E-04
Native Prairie	
PZ Average (3 Sites)	1.34E-05
SW Average (3 Sites)	1.79E-06
Average (4 Sites)	7.62E-06



Wilcoxon Signed Rank Test

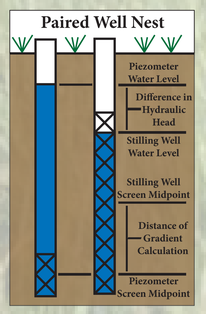
Test Description
Non-parametric hypothesis test for paired samples used when the measured values are not normally distributed
p-Value: 0.0105
95% Confidence Interval: 5.64E-06 – 1.79E-04
Estimated Median: 8.19E-05

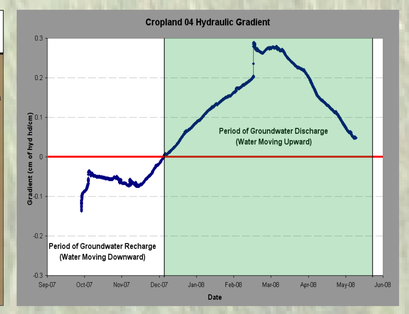




- There was a significant difference in hydraulic conductivities between the piezometer and stilling well in paired nests, with the piezometer yielding K values averaging 1.14E-04 cm/s greater than the stilling well

Hydraulic Gradients





- Hydraulic gradients were determined by comparing simultaneous water levels, which represent the hydraulic head at the midpoint of the well's screened interval, in paired stilling wells and piezometers
- Wetlands with continuous gradient calculations exhibited a seasonal reversal in gradient indicating these wetlands alternate from areas of groundwater discharge to sources of groundwater recharge
- Due to drought conditions in the summer of 2008 many of the stilling wells went dry resulting in discontinuous hydraulic gradient information

Brine Contamination Assessment

Differences in Water Chemistry

Natural Surface Waters

- Enriched in Na, Mg, SO_4 and HCO_3
- Depleted in Cl
- 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) values. Jon Reiten from the MBMG has developed a chloride Contamination Index (CI) to detect brine contamination, by determining the ratio of chloride to the specific conductance of the water. In Sheridan County wetlands with a CI above 0.035 are considered to be impacted by produced waters.

Geophysical Methods

Electrical Conductivity (EC)

- Measures electrical properties of fluids and soils
- Very effective due to high conductivity of salts
- Determines locations of contaminated ground-water plumes in the saturated and vadose zones

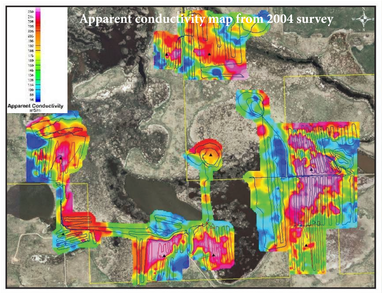
Mickey McCall performing an EC survey in 2004

2004 EC Survey

- Surveyed 30 wetlands that are within a half mile of oil well sites using a Geonics EM-31
- The EM-31 provides data on the lateral extent of contaminate plumes but reveals little about depth profile as exploration depth is 3-4 meters
- 29 of the 30 sites surveyed exhibited brine contamination from produced water

2009 EC Survey

- Selected wetlands will be resurveyed with a Geonics EM-34
- EM-34 utilizes an exploration depth of 7-60 meters to determine both lateral extent and depth profile of contamination plumes
- Repeat surveying allows temporal comparative analysis to determine rates of brine movement
- Increased depth profile will provide insight into density driven flow of impacted groundwater



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