Risk Assessment of Brine Contamination to Aquatic Resources from Energy Development in the Williston Basin

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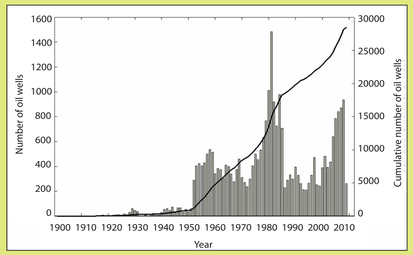
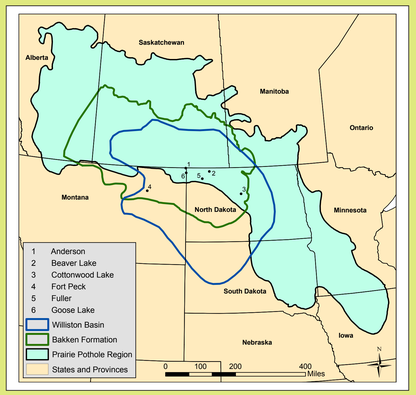
Spatial Analysis

Objective: Evaluate the spatial extent and potential risk to natural resources of past and ongoing energy development in the Williston Basin using Geographic Information System (GIS) analyses

Overview/Study Area

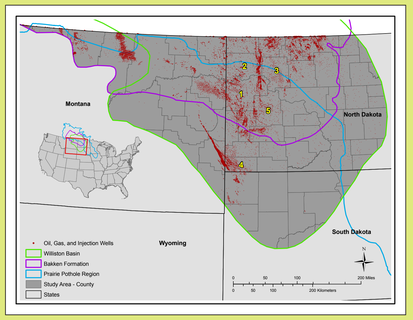
- Energy development in the Williston Basin and Bakken Formation has grown rapidly since 1950
- The Prairie Pothole Region (PPR), characterized by critical wetland habitats vulnerable to brine contamination, overlays the Williston Basin and Bakken Formation





County-Level Assessment

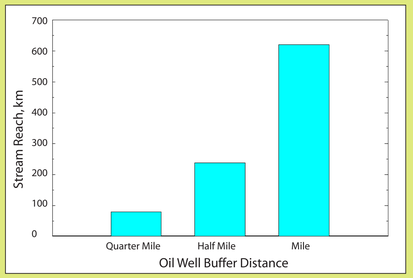
- Spatial assessment to identify the counties with greatest potential for brine contamination of aquatic resources
- "Risk" based on assumption that areas with the greatest density of wells, wetland area, and stream length have greatest potential for contamination
- Counties were ranked based on densities of wells, wetlands, and streams/rivers
- 5 counties with the highest mean rank are:
  - (1) McKenzie, ND
  - (2) Williams, ND
  - (3) Mountrail, ND
  - (4) Bowman, ND
  - (5) Dunn, ND

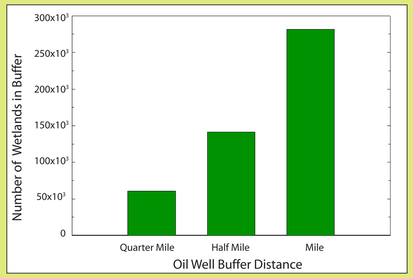


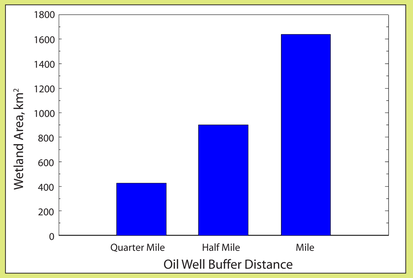
The 5 Counties (yellow numbers correspond to overall rank) with the overall greatest density of wells, wetland area, and river length.

Prairie Pothole Region Assessment

- Created buffers at a quarter, half, and one-mile distances around each oil well in the PPR portion of study area
- Determined total length of stream reaches and the number and area of wetlands within each buffer
- Buffers were based on guidance provided by USGS researchers using geophysical techniques to evaluate brine plume movement (next column)
- Wetland area includes area of entire wetland; stream reach includes only portion within buffer







Oil Field Investigations

Objective: Reassess brine contamination movement in pilot areas

Natural vs. Produced Water Chemistry

Naturally High TDS Waters

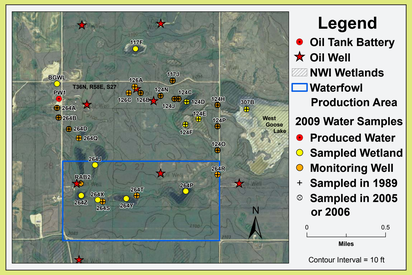
- Enriched in Na, Mg, SO_4 and HCO_3
- TDS of surface and shallow groundwaters vary by landscape position but are usually < 100,000 mg/L
- Cl- ranges from < 10 - 350 mg/L

Produced Waters (Oil Field Brines)

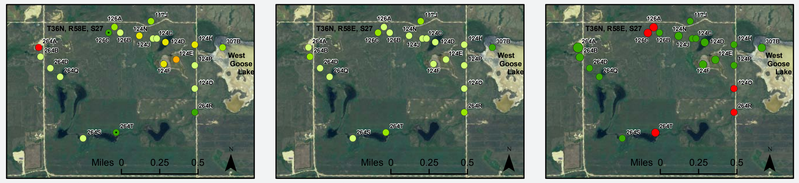
- Enriched in Na and Cl
- Produced waters in the Williston Basin have TDS ranging from 100,00 - 525,000 mg/L
- Cl- ranges from 30,000 - 350,000 mg/L

Goose Lake Detailed Study Site, MT

- The PPR has three main surficial deposits: clay-rich glacial till, coarse-grained fluvial outwash deposits, and fine grained lacustrine deposits
- Goose Lake is characteristic of outwash deposits in the PPR as surficial geology is a thin (5-40 ft.) layer of collapsed outwash mantling a pebbly-clay till
- Detailed hydrological investigations, involving water chemistry analysis and geophysical surveys, were conducted in 1989, 2005, and 2009
- All studies found extensive chloride contamination in surface and groundwaters from oil field brines



1989, 2009, and Temporal Changes in Contamination Index Values, Goose Lake Field, MT



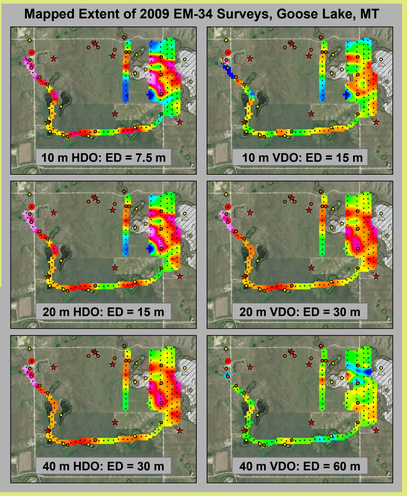
1989 Contamination Index		2009 Contamination Index	Change in Contamination Index	
0.01 - 0.15	0.46 - 0.60	0.06 - 0.15	- 0.30 - - 0.40	0.01 - 0.15
0.16 - 0.30	0.61 - 0.75	0.16 - 0.30	- 0.15 - - 0.29	0.16 - 0.26
0.31 - 0.45	0.76 - 0.83	0.31 - 0.43	0.00 - - 0.14	

The Prairie Pothole Region (PPR) contains naturally saline water resources with elevated Total Dissolved Solids (TDS). Reiten and Tischmak (1993) created a Contamination Index (CI) to detect produced water contamination in high TDS waters in eastern Sheridan County, Montana. The CI is the ratio of chloride (mg/L) to specific conductance (uS/cm) in a water sample. Values above 0.035 indicate contamination from produced waters. Symbols with black dots in center indicate CI values below 0.035.

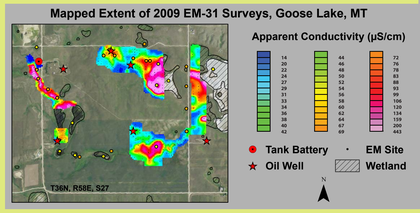
Geophysical Surveys

- Used Geonics EM-31 and EM-34 systems to record apparent electrical conductivity (EC) which reflects the subsurface electrical properties of soils and pore fluids. High EC can be caused by saline pore fluid or conductive silts. Geochemical data for this area suggests high CI correlates with high EC.
- The estimated exploration depth (ED) of the EM-31 is ~6 m and ranges from 7.5 to 60 m for the EM-34, depending on coil orientation and separation.
- Contamination plumes have complex lateral and vertical geometries, controlled by a variety of hydrogeologic parameters.

Mapped Extent of 2009 EM-34 Surveys, Goose Lake, MT



Mapped Extent of 2009 EM-31 Surveys, Goose Lake, MT



Conclusions

Spatial Analysis

- Counties were ranked based on the density of wells, wetland area, and stream length. The five counties that ranked highest were all located in western North Dakota, and portions of two of these counties fall within the PPR.
- These ranks can be used to identify areas with greatest potential of brine contamination and can be used by land-management agencies such as the U.S. Fish and Wildlife Service to prioritize limited monitoring and mitigation resources.
- We identified nearly 300,000 wetlands and greater than 600 km of streams within 1 mile of oil wells in the PPR of the study area. Over 60,000 of these wetlands and nearly 80 km of streams were within a quarter mile of oil wells.
- The high number of aquatic resources in close proximity to oil wells demonstrates the greater risk of brine contamination from energy development in the Williston Basin and PPR.

Oil Field Investigations

- The Goose Lake detailed study site remains highly impacted from produced waters, with CI values above 0.035 for all surface and groundwater samples collected in 2009 with the exception of BGWL.
- Temporal analysis of CI data from 19 surface and groundwater samples that had been identified as contaminated by produced water in 1989 showed significant reductions in CI values(two-sided p-value = 0.0080 from a paired t-test with a t-stat of 2.98 and 18 degrees of freedom). It is estimated that the mean reduction in CI values is 0.095, with a 95% confidence interval from 0.028 – 0.162.
- Two groundwater wells that were uncontaminated in 1989 had CI values in 2009 indicative of impacts from produced waters. The reduction in CI values in contaminated sites and increases in previously uncontaminated groundwater wells shows that saline contaminated groundwater plumes have continued to migrate within the Goose Lake detailed study site.
- Geophysical survey results show wide spread saline groundwater contamination within the shallow sand and gravel aquifer underlying the study site, evidenced by the high apparent conductivities recorded in the EM-31 and EM-34 HDO surveys.
- Apparent conductivity readings were lower in the vertical dipole orientation and also showed decreases with increased intercoil spacing in the horizontal dipole orientation. This is interpreted as the result of saline contaminated groundwater plumes moving laterally within the shallow sand and gravel aquifer overlying the Goose Lake detailed study site, with minimal penetration into the underlying till.

Future Work

- Similar hydrogeological investigations were completed in 2010 at sites representative of clay-rich till and lacustrine environments. Two of the three study sites were locations of previous hydrogeological studies. Comparing our analytical chemical and geophysical data to past studies will allow characterization of the spatial and temporal effects of brine contamination to surface and groundwater resources in the most common surficial glacial deposits in the PPR.
- Results from oil field investigations will then be extrapolated to similar surficial deposits, identified from soil surveys and geological maps, to assess the potential for brine contamination and migration throughout the PPR.
- Recent assessments of oil and gas resources and improved recovery technology have increased development within the Bakken Formation. Site investigations and available spatial data will be used to guide a user-needs workshop to frame and develop a decision support tool for resource-management decisions designed to help locate oil field facilities in the least environmentally sensitive areas.
- Additionally, we are currently conducting a more detailed "proximity analysis " to identify specific parcels of U.S. Fish and Wildlife Service lands that have oil wells adjacent to wetlands to help land managers identify potential monitoring sites.

Additional Project Information

http://steppe.cr.usgs.gov

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