A GIS BASED VULNERABILITY ASSESSMENT OF CONTAMINATION TO AQUATIC RESOURCES FROM OIL AND GAS DEVELOPMENT IN EASTERN SHERIDAN COUNTY, MT

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INTRODUCTION AND PREVIOUS RESEARCH

Abstract

There is growing public concern over the environmental risks associated with saline water co-produced with oil during development and production in the Williston Basin in the Northern Great Plains. Superimposed over this landscape is the Prairie Pothole Region (PPR), a region characterized by glacial deposits and numerous wetlands and grasslands that are the major waterfowl production areas of North America. Previous studies have identified co-produced water contamination to wetlands and groundwater resources in the Williston Basin and PPR. The Montana Bureau of Mines and Geology and the U.S. Fish and Wildlife Service developed a contamination index (CI), defined as the ratio of chloride concentration to specific conductance in a water sample, to delineate the magnitude of co-produced water contamination in eastern Sheridan County, Montana. Although the PPR has aquatic resources with high salinity and TDS concentrations, these values are primarily driven by sulfate, not chloride, salts. In eastern Sheridan County, which lies within the PPR, a CI value greater than 0.035 indicates contamination by co-produced water.

Evaluating co-produced water contamination in the Williston Basin and PPR, U.S. Geological Survey (USGS) researchers conducted a GIS-based vulnerability assessment of aquatic resources to saline contamination at the county level. The vulnerability assessment was based on the age and density of oil wells, proximity of oil wells to wetlands and streams, and type of glacial deposits. A GIS-based analysis using a similar protocol, but at the section level, was conducted to validate the larger vulnerability assessment in eastern Sheridan County, Montana. The section level vulnerability assessment assigned a value from a possible low of 2.5 to a high of 100 to all 780 sections in the study area. Ten sections were selected across the range of values (7.5 – 82), with two wetland and two groundwater samples collected from each section in September 2011 to determine the magnitude of co-produced water contamination based on the CI. CI values ranged from 0.002 to 0.409, and nineteen of the forty water samples had CI values greater than 0.035. CI values generally increased with vulnerability assessment values, with this correlation being stronger for groundwater samples than surface water samples.

Study Area

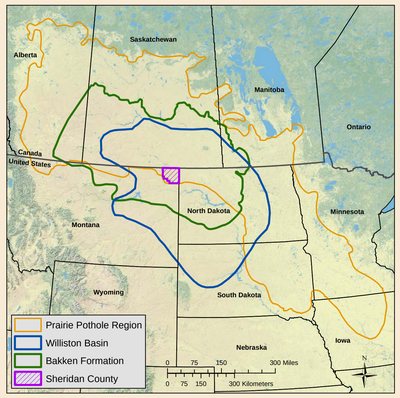
The Prairie Pothole Region (PPR) covers 770,000 km² in the northern Great Plains and Canada and contains millions of wetlands that are critically important to waterfowl

The Williston Basin has been a leading domestic source of oil and gas for decades

The Bakken Formation is experiencing rapid oil development due to advances in hydraulic fracturing and lateral drilling

Sheridan County, Montana has a long history of oil and gas production with new development in the Bakken Formation

Contamination from co-produced water has been documented in aquatic resources throughout the PPR and Williston Basin



Water Quality and Contamination Index

Naturally High TDS Water

- 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
- Chloride ranges from < 10 to 350 mg/L

Co-Produced Water

- Enriched in Na and Cl
- Co-produced waters in the Williston Basin have TDS ranging from 100,000 to 525,000 mg/L
- Chloride ranges from 30,000 to 350,000 mg/L[1]

The Contamination Index (CI) can differentiate naturally high TDS waters from those contaminated with co-produced water, with CI values greater than 0.035 indicating contamination in eastern Sheridan County, Montana[2].

$$CI = \frac{\text{Chloride (mg/L)}}{\text{Specific Conductance } (\mu S/cm)}$$

County Level GIS Assessment

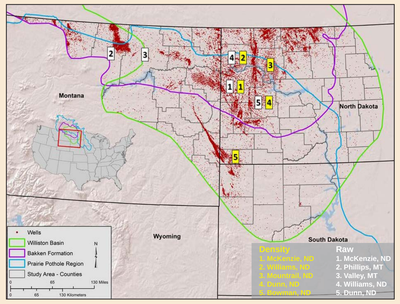
USGS Science Team about Energy in Prairie Pothole Environments (STEPPE) completed a multi-year study on saline contamination to aquatic resources from oil and gas development in the PPR and Williston Basin

As part of this study, we conducted a county-level assessment on the potential for saline contamination to aquatic resources

The map shows the five counties with the highest number of oil wells, wetlands, and stream reaches in the PPR by both density and raw total

For more information on the STEPPE project go to:

http://steppe.cr.usgs.gov



METHODS AND ANALYSIS

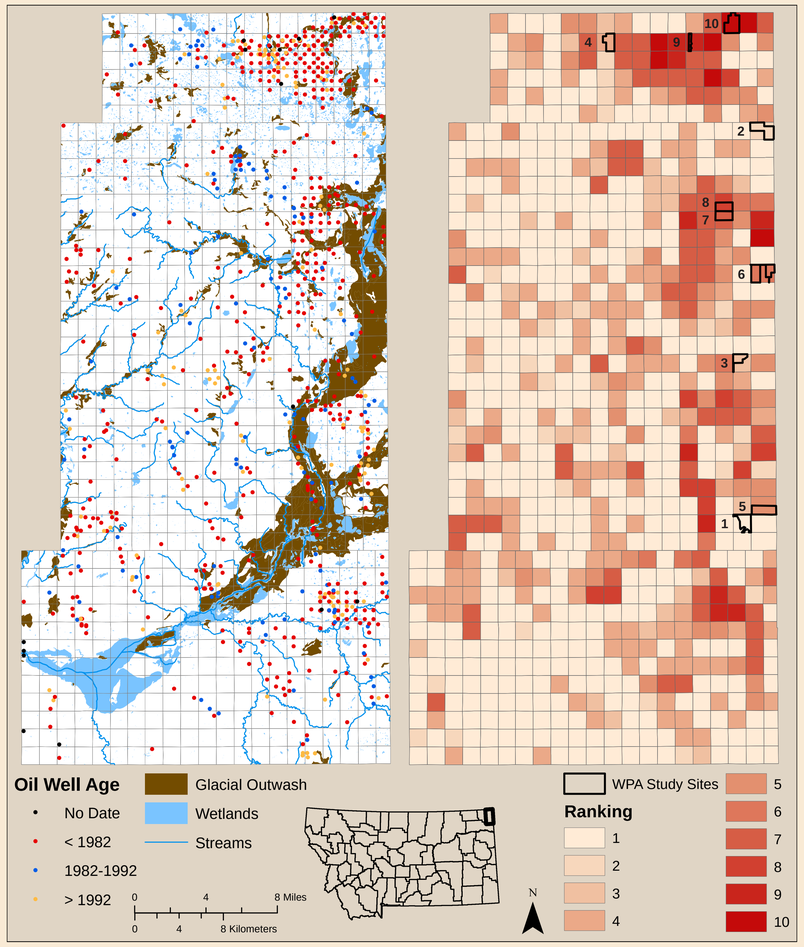
Vulnerability Assessment Criteria

The vulnerability assessment included five criteria, shown in columns A-E, with the total score calculated by (A+B+C+D)*E

Criteria weights and total score calculation were based on previous research and STEPPE expertise

A		B		C		D		E	
Oldest Oil Well		% Glacial Outwash (GO)		% Wetland (W)		Stream Reach (SR)		Number of Wells (TW)	
Date	Score	%	Score	%	Score	Length (km)	Score	Number	Score
Pre 1982	15	GO ≥ 75	5	W ≥ 75	5	SR ≥ 5	3	TW ≥ 7	4
1982-1992	10	50 ≤ GO < 75	4	50 ≤ W < 75	4	4 ≤ SR < 5	2.5	3 ≤ TW < 7	3
Post 1992	5	25 ≤ GO < 50	3	25 ≤ W < 50	3	3 ≤ SR < 4	2	1 ≤ TW < 3	2
		10 ≤ GO < 25	2	10 ≤ W < 25	2	2 ≤ SR < 3	1.5	TW < 1	1
		GO < 10	1	W < 10	1	1 ≤ SR < 2	1		
						SR < 1	0.5		

Site Ranking and Selection



We generated a value for all 780 sections in the study area based on the ranking criteria. Resulting values were binned into ten equal interval ranks from 1 to 10. The Waterfowl Production Area (WPA) with the greatest acreage in each rank was selected to ensure sampling access. The study area matched the extent of the MT Bureau of Mines and Geology surficial geologic map[2].

Water Samples

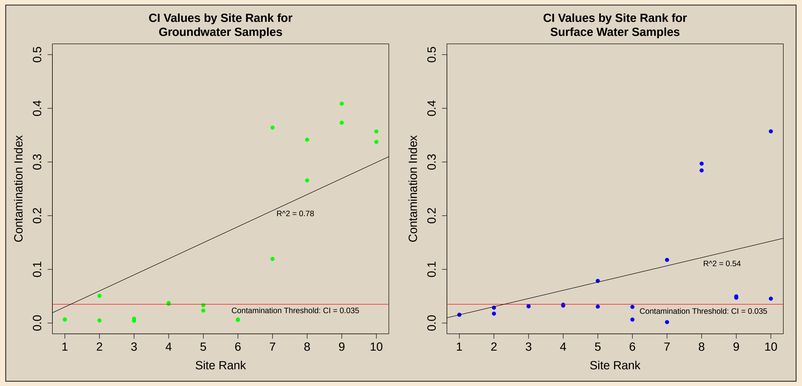
Two groundwater wells were installed in each WPA at the locations with the highest apparent conductivity readings from electromagnetic (EM) surveys

Groundwater wells were purged of at least three well volumes of water and field parameters (pH, temp., and specific conductance) had stabilized prior to sampling

The two wetlands within the WPA in closest proximity to oil well sites were sampled using a discrete sampling method modified from Knapton[3]

Samples were analyzed for major ions and selected halides at the USGS Strontium Isotope Laboratory using methods described by Fishman and Friedman[4]

RESULTS



At least one sample from seven of the ten study sites, and nineteen of the forty total samples, had CI values indicating co-produced water contamination.

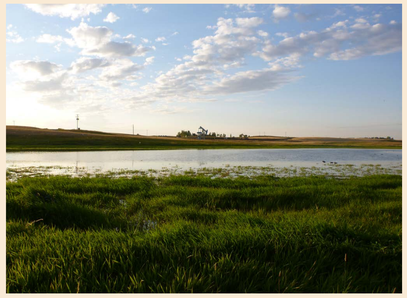
Only one sample had a CI value indicating contamination in sites ranked 1 - 3. A total of 445 sections, or 57% of our selected study area, had ranks of 1 - 3.

In sites ranked 4 - 6, three samples had CI values indicating contamination; however, five samples had values greater than 0.030. A total of 239 sections, or 31% of the study area, had ranks of 4 - 6.

Fifteen of the samples had CI values indicating contamination in sites ranked 7 - 10. A total of 96 sections, or 12% of the study area, had ranks of 7 - 10.

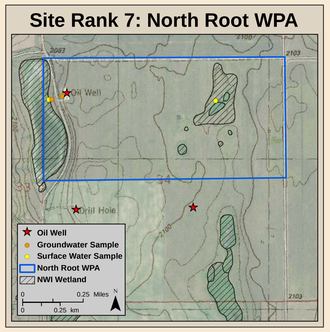
The correlation between increased CI value and increased site rank was stronger for groundwater samples than surface water samples.

CI values have greater variability in sites with higher ranks



The winter of 2010/2011 was unusually wet which led to abnormally high water levels continuing through the fall when we collected the samples.

CONCLUSIONS



The parameters selected did well at identifying the potential for co-produced water contamination.

However, sampling locations confined within the WPA boundaries likely reduced detection of the full extent of contamination at some sites.

Contamination is possible in areas with a low rank (1 - 3), but is unlikely.

Contamination is probable in areas with medium rankings (4 - 6).

Contamination is likely widespread in areas with a high rank (7 - 10).

Groundwater wells were located by EM surveys and were generally closer to oil well sites than sampled wetlands. This likely explains the better correlation for groundwater samples and the higher CI values for groundwater samples in the higher ranked sites.

Validates our county-level vulnerability assessment.

Provides land managers a cost effective tool to identify areas most susceptible to contamination in the PPR and Williston Basin.

FUTURE WORK

Water Chemistry Characterization:

Sample 100 wetlands in North Dakota during 2012

Provide baseline data on trace element, cation, and anion chemistry across the PPR

Document the extent and magnitude of co-produced water contamination across the PPR

Salinity Effects On Wetland Biota:

Laboratory based experiments on wetland plants and macroinvertabrates

Subject wetland soils and seed banks to varying levels of chloride in aquatic tanks to simulate different water qualities

Monitor species and abundance of wetland biota in the tanks

ACKNOWLEDGEMENTS AND REFERENCES

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