Text to accompany slide show entitled "Reexamining Oilfield Brine Contamination Plumes in the Prairie Pothole Region of Sheridan County, Montana"

Slide 1: Halite (NaCl) crystals precipitating from surface water contaminated with oilfield brines near the Hammer Tank Battery located northwest of Rabenberg WPA. This site is part of our detailed study site within the Goose Lake Oil Field.

Slide 2: Map showing the location of the Williston Basin, Bakken Formation, Prairie Pothole Region, and approximate location of Sheridan County (dashed white line).

Slide 3: General information on Montana's Prairie Pothole Region**.** Note close proximity of oil wells in the background to wetland.

Slide 4: General information on oilfield brines. Photo shows transport line leading to the Hammer Tank Battery near Rabenberg WPA.

Slide 5: Other toxins associated with oilfield brines in the Williston Basin. Note close proximity of oil wells in the background to wetland.

Slide 6: Chemistry of produced waters in the USA, note extremely high TDS values in the Williston Basin.

Slide 7: Sources of brine contamination. Large and inset photos show a lined reserve pit and leaking oil transport line near Rabenberg WPA, respectively.

Slide 8: General information on studied wetlands and nature of determining their hydrological characteristics. Inset shows schematic of paired piezometer (right) and stilling wells (left) with X pattern representing the length of the screen.

Slide 9: Sodium sulfate dominated wetlands. The large image shows typical white ring of thenardite (sodium sulfate salt, also called summer snow) surrounding these wetlands. Lower left image shows thenardite coated vegetation near wetland edge. Lower right image shows single grain of thenardite.

Slide 10: Sodium chloride impacted wetlands. The large image shows typical grey coloration of wetlands impacted by sodium chloride. Lower left image shows desiccation cracks lined by halite crystals. Lower right image shows halite crystals precipitated out of solution at former shore line of wetland. Note the penny in both lower images for scale.

Slide 11: Image showing wetland hydrology and the development of local, intermediate and regional flow paths.

Slide 12: Slide shows raw and logged water height data for a slug test. These test determine the horizontal hydraulic conductivity of the sediments beneath and adjacent to the wetland. Tests were performed using the method of Bouwer and Rice (1989).

Slide 13: Bar graph showing results from the rising head slug test for the piezometer and stilling wells at each site. Note the high variability between all values and variability between the two wells at each site.

Slide 14: Schematic of paired piezometer and stilling wells showing how vertical hydraulic gradients are calculated for periods of no standing water. The difference in water levels between the two wells is divided by the distance of gradient calculation (distance from the water level in the stilling well to the midpoint of the screen in the piezometer). For periods of standing water the differences in water height are divided by the depth to the midpoint of the piezometer screen. The graph on the right illustrates how many of these wetlands alternate between sources of groundwater recharge and groundwater discharge throughout the year.

Slide 15: Overview map of the detailed study site within the Goose Lake Oil Field. The map shows potential sources of brine contamination and the locations of groundwater monitoring wells and sampled wetlands. The southern half of the section (bounded by roads) is the Rabenberg WPA.

Slide 16: Illustration showing the hydrogeology of our detailed study site and extent of contamination in 1989. Also shown are surficial deposits including saturated and unsaturated outwash and glacial till and lines of cross sections shown in the next slide.

Slide 17: Cross sections through various parts of the detailed study sites.

Slide 18: Text outlines our 3 different methods used to determine the presence of brine contamination. Photo shows surface water sampling of a wetland within the detailed study site.

Slide 19: History of groundwater monitoring well installation and description of water samples collected in 2009. Large photo shows sampling of groundwater well for preparation in a USGS mobile hydrology laboratory. Inset shows the four sample bottles prepared in the mobile laboratory for analysis.

Slide 20: Due to the naturally occurring high sodium sulfate salt concentrations of these wetlands, a chloride index has been developed to determine the degree of brine contamination of sampled waters. The chloride index is defined as the ratio of the chloride concentration to the specific conductance. This slide is the chloride concentration, the following slide is specific conductance and the next slide is the chloride index.
Temporal maps showing the chloride concentration of sampled waters in 1989, 2009 and the change in chloride concentrations over the last twenty years. Green and red dots in the third panel indicate decreased and increased chloride concentrations in 2009 compared to 1989 respectively.

Slide 21: Temporal maps showing the specific conductance of sampled waters in 1989, 2009 and the change in specific conductance over the last twenty years. Green and red dots in the third panel indicate decreased and increased specific conductance in 2009 compared to 1989 respectively.

Slide 22: Temporal maps showing the chloride index of sampled waters in 1989, 2009 and the change in chloride index over the last twenty years. Green and red dots in the third panel indicate decreased and increased chloride indexes in 2009 compared to 1989 respectively. For this region a chloride index greater than 0.035 indicates contamination by oil field brines.

Slide 23: Overview of electrical conductivity surveys. Background image shows testing of surface water for electrical conductivity, using a handheld YSI probe, below the Hammer Tank Battery.

Slide 24: Overview of the Geonics EM-31. Both images show field surveying with this equipment.

Slide 25: Overview of the Geonics EM-34. Upper image shows all the components of the EM-34. Lower image shows field surveying with this equipment.

Slide 26: Basic description of glacial outwash deposits. Upper left image shows upper weathered (red coloration) and lower unweathered zone. Lower right image is a close up, showing weathering contact and increased texture, of first image. Note the high abundance of coarse clasts within the outwash.

Slide 27: Basic description of glacial till deposits. Upper left image shows trench dug in road cut. Other two images show slump slide observed in the same road cut. Note the absence of coarse clasts within the dug trench.

Slide 28: Overview and rationale for conducting the 1989 EM surveys within the detailed study site in the Goose Lake Oil Field and selected results. The inset image shows the extent of contamination associated with the Hammer Tank Battery.

Slide 29: Overview and selected results of 2009 EM surveys within the detailed study site in the Goose Lake Oil Field. Inset image shows data from selected surveys in 2009. Cool colors represent low conductivities while warm colors represent high conductivity. Narrow band of EM survey data in the upper left is in the same location as inset map in the previous slide.

Slide 30: Rationale and overview of strontium isotope principles illustrating why their relative abundances are an effective method for determining contamination from oil field brines.

Slide 31: Selected strontium isotopes results and regional characterization of brines. Inset graph shows binary mixing curves for oil field brines.

Slide 32: Results from strontium isotope studies proving their effectiveness at determining contamination from oil field brines.

Slide 33: Conclusions.

Slide 34: Future work.

Slide 35: Acknowledgements.

Slide 36: Questions.