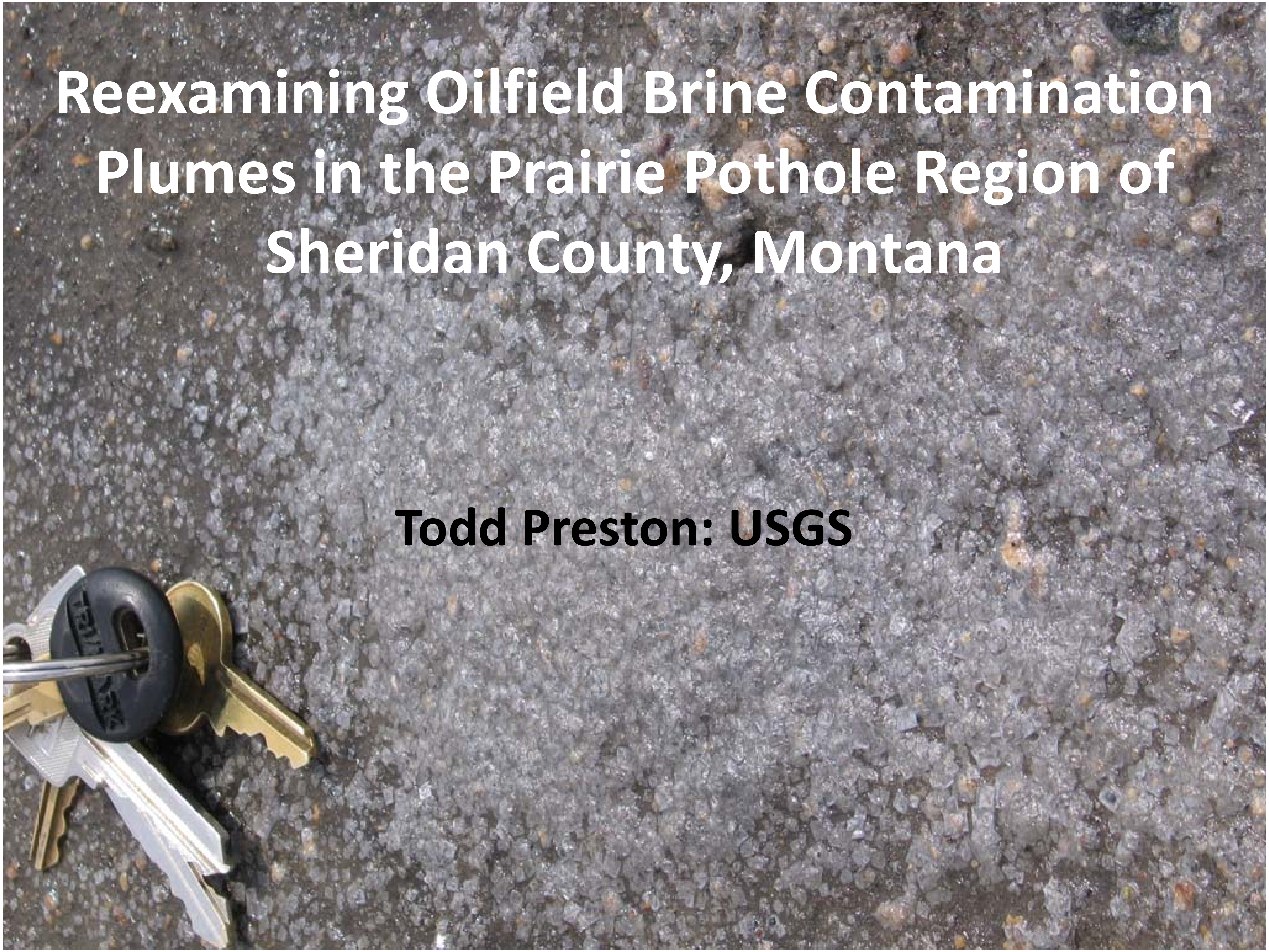
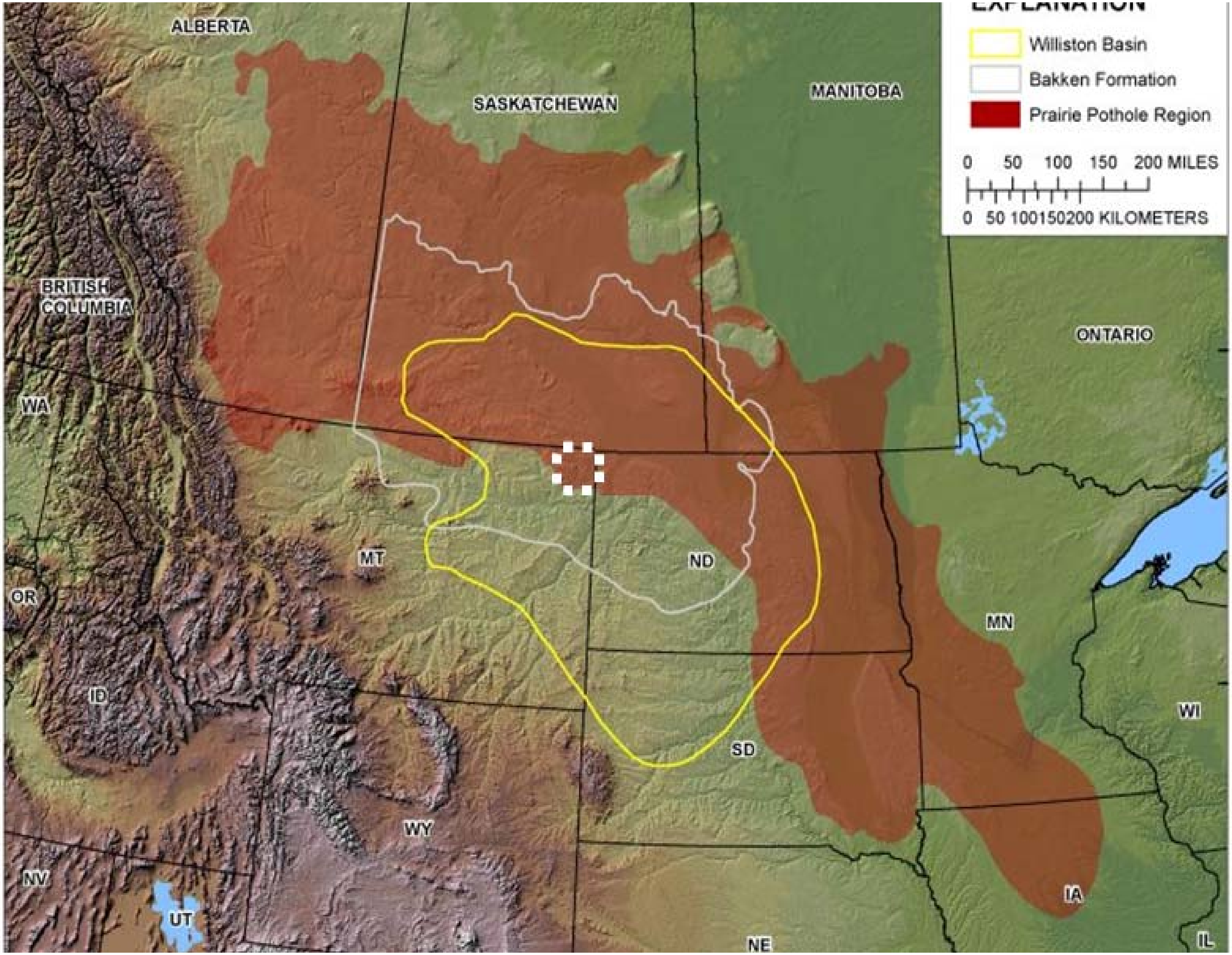
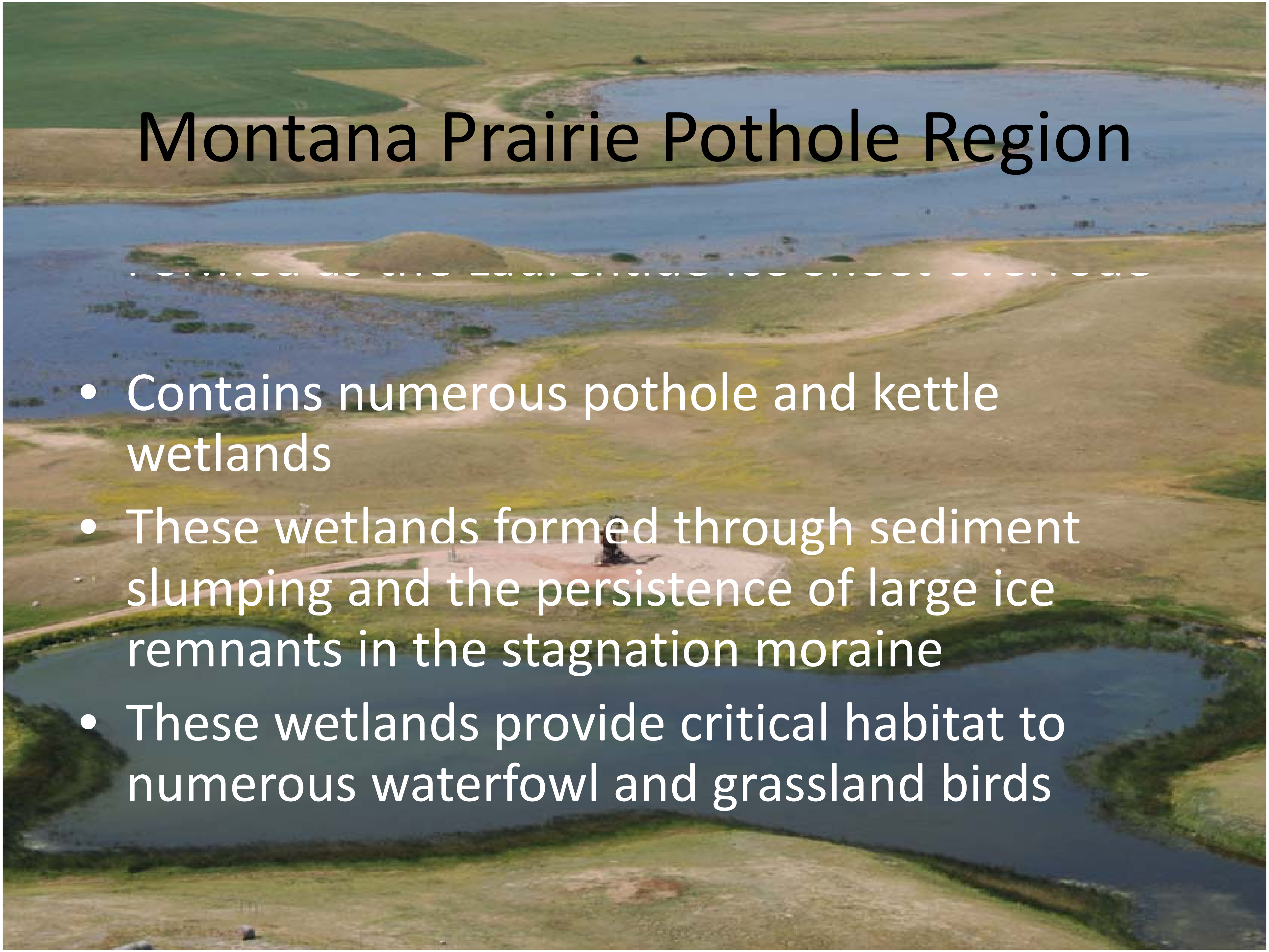
Reexamining Oilfield Brine Contamination Plumes in the Prairie Pothole Region of Sheridan County, Montana

Todd Preston: USGS



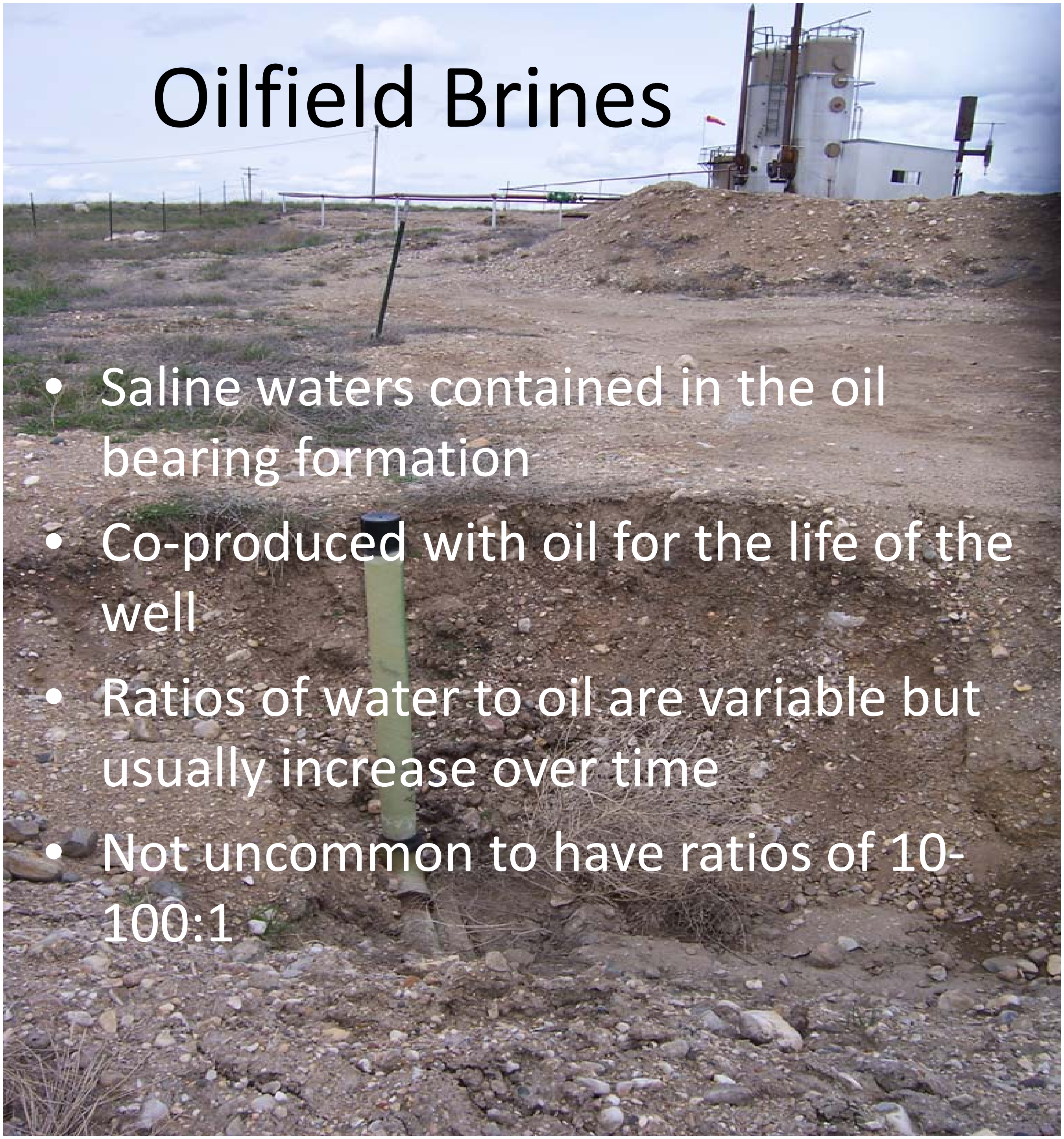

EXPLANATION
Williston Basin
Bakken Formation
Prairie Pothole Region
0 50 100 150 200 MILES
0 50 100150200 KILOMETERS
ALBERTA
SASKATCHEWAN
MANITOBA
ONTARIO
BRITISH COLUMBIA
WA
OR
ID
MT
ND
SD
MN
WI
WY
NV
UT
NE
IA
IL



Montana Prairie Pothole Region

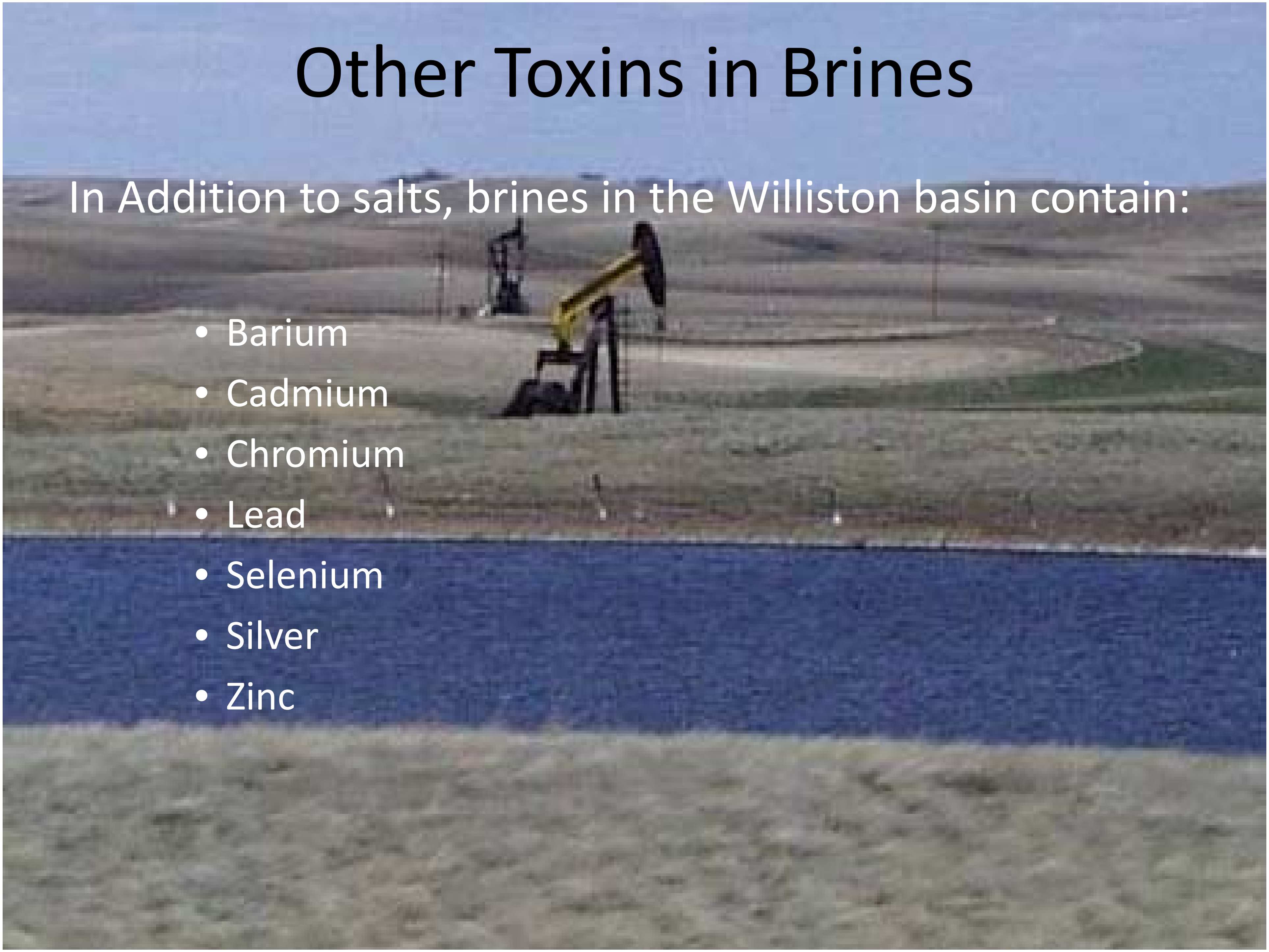
- Contains numerous pothole and kettle wetlands
- These wetlands formed through sediment slumping and the persistence of large ice remnants in the stagnation moraine
- These wetlands provide critical habitat to numerous waterfowl and grassland birds

Oilfield Brines



- Saline waters contained in the oil bearing formation
- Co-produced with oil for the life of the well
- Ratios of water to oil are variable but usually increase over time
- Not uncommon to have ratios of 10-100:1

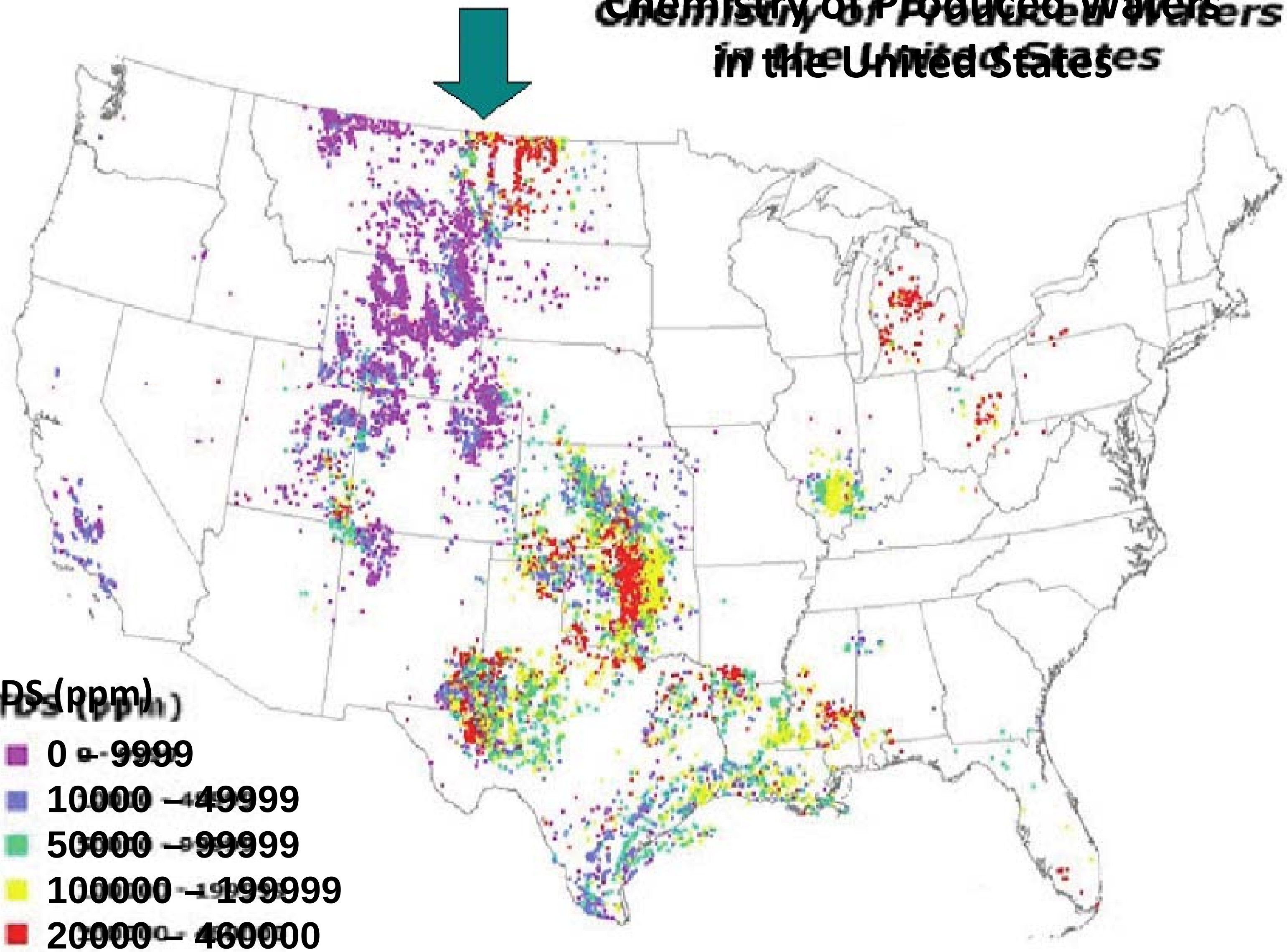
Other Toxins in Brines



In Addition to salts, brines in the Williston basin contain:

- Barium
- Cadmium
- Chromium
- Lead
- Selenium
- Silver
- Zinc

Chemistry of Produced Waters in the United States

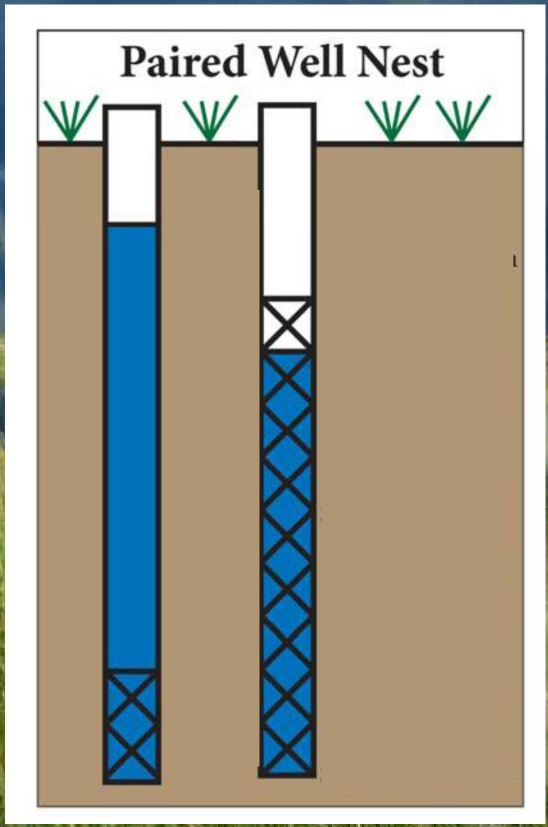


Sources of Brine Contamination

- Pipeline Leaks and Breaks
- Injection Well Failure
- Old Reserve Pits
- Typical reserve pit:
  - 150 x 60 x 10 ft
  - Contains roughly 260 tons of salt
  - Prior to the mid 70’s these pits were unlined

Wetland Characterization

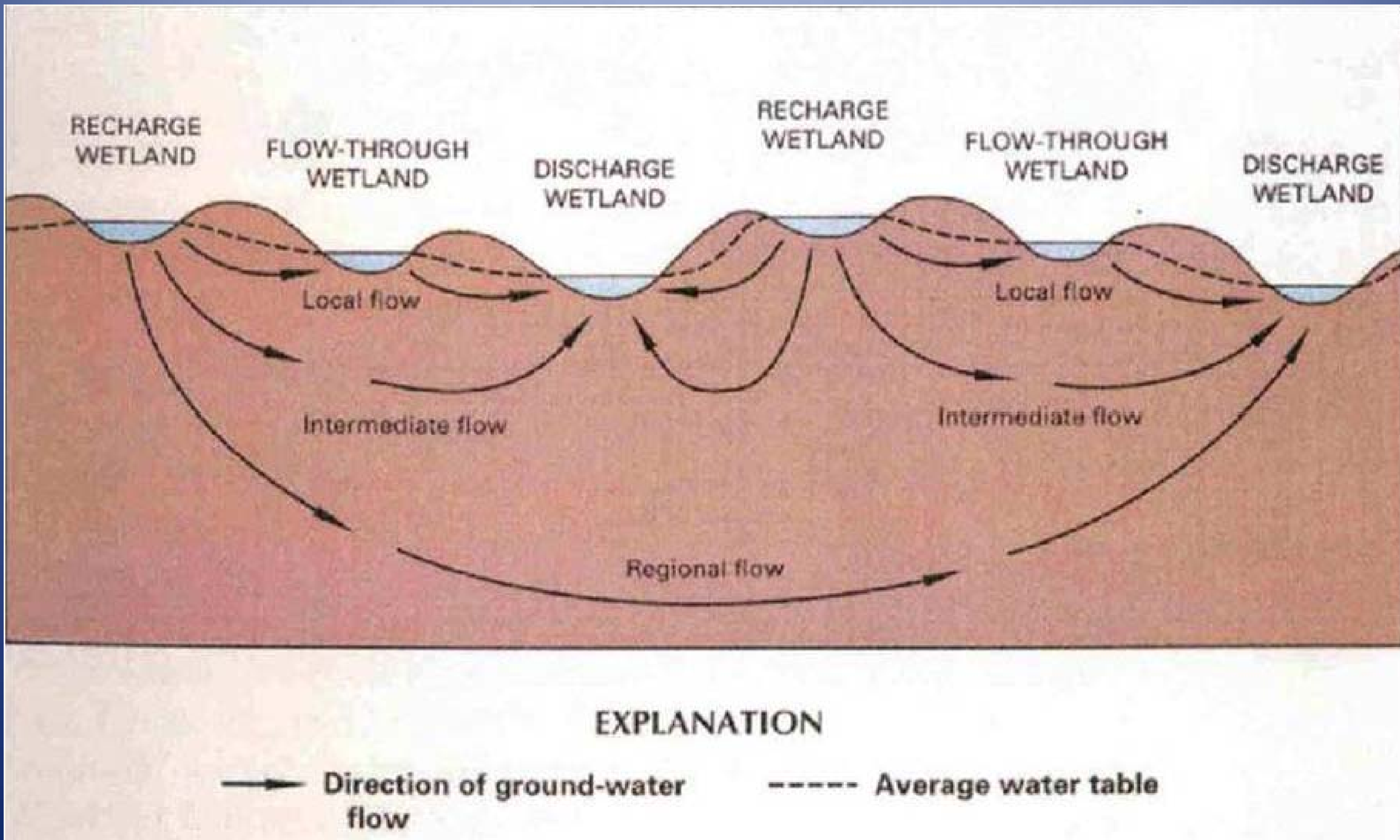
- 30 wetlands were randomly selected from the population of wetlands in Sheridan County, MT
- A piezometer and stilling well were installed at each site
- Capacitance rods were deployed in each well
- Slug tests were performed to determine lateral hydraulic conductivity
- Capacitance rod data is used to determine vertical hydraulic gradient



Sodium Sulfate (Na_2SO_4) Wetlands

Sodium Chloride (NaCl) Impacted Wetlands

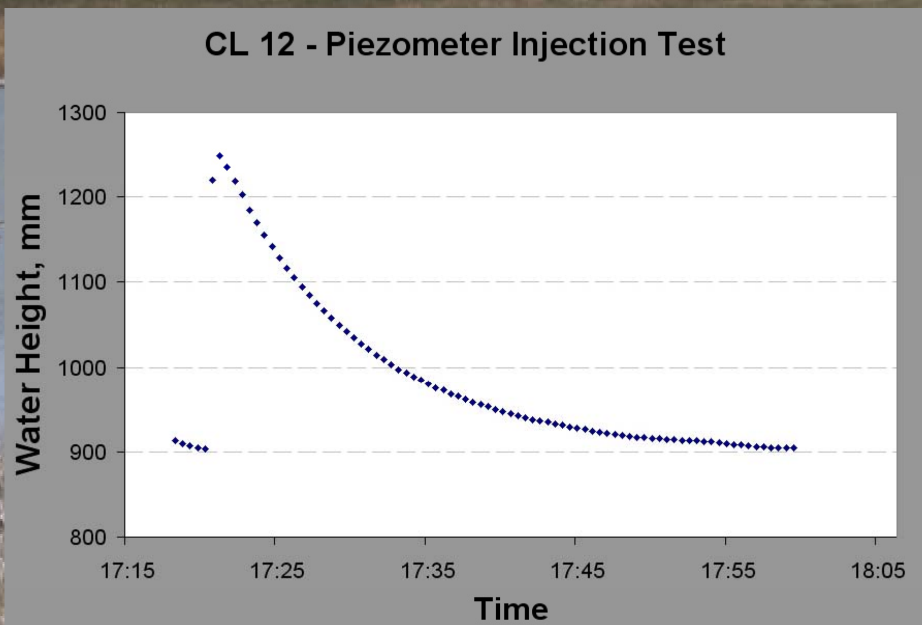
Wetland Hydrology

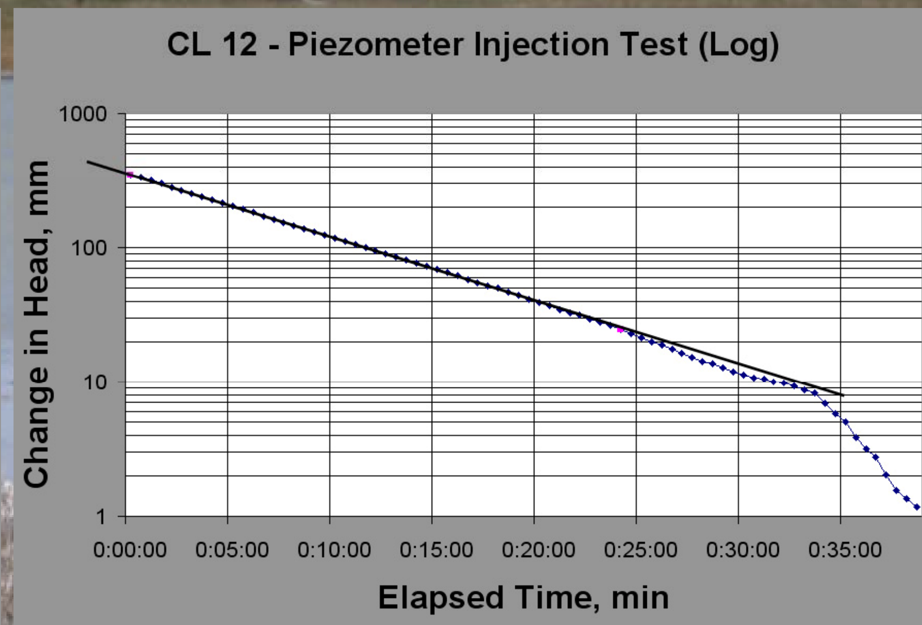


Hydraulic Conductivity

Raw Data

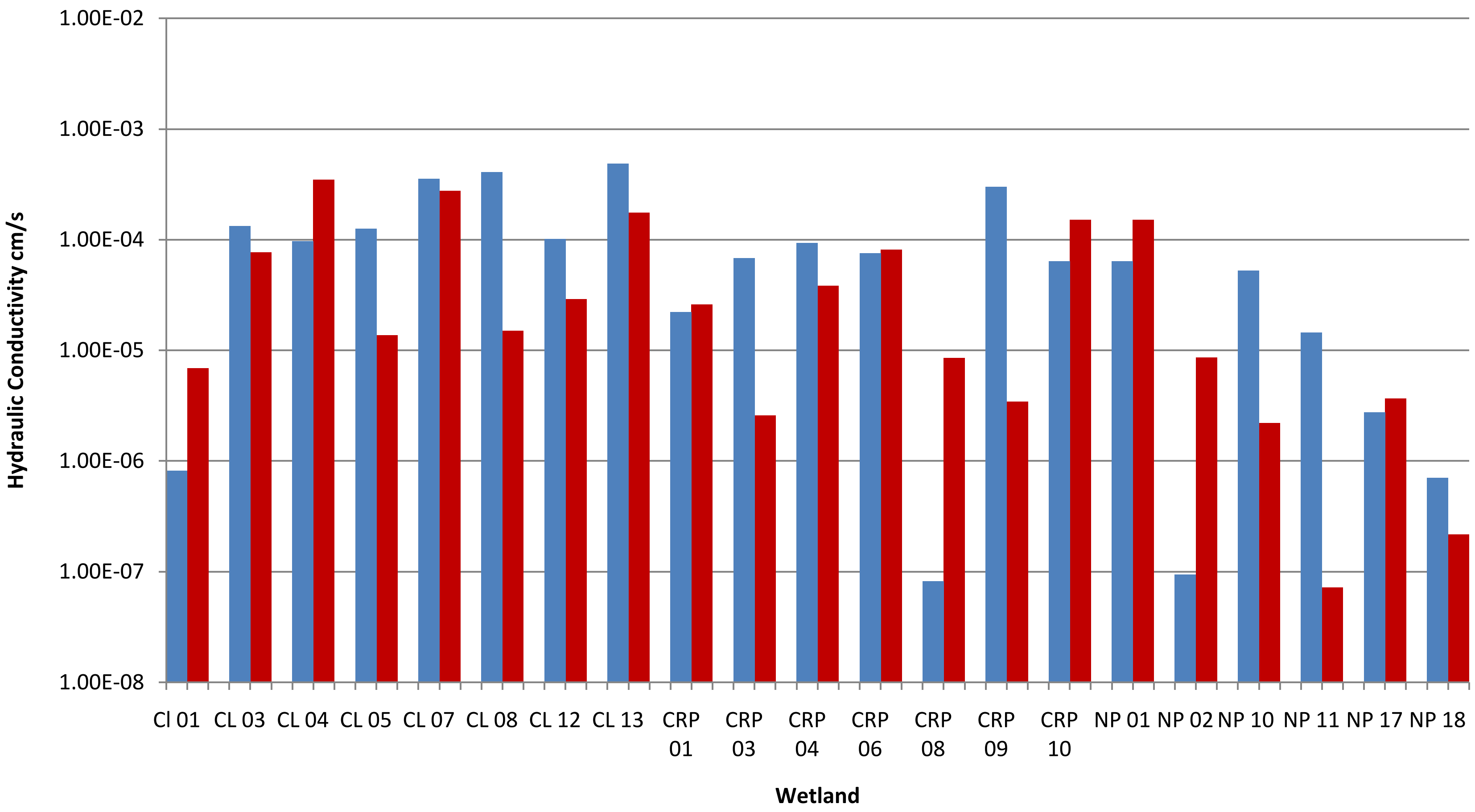
Logged Data





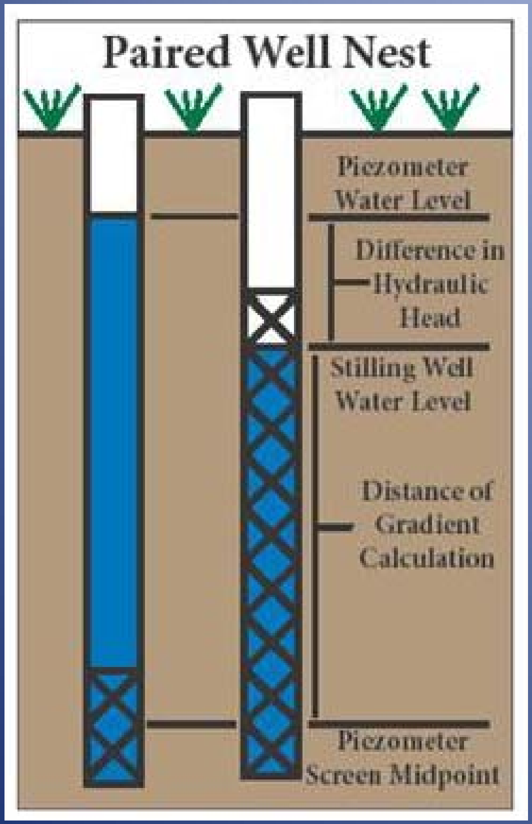
Slug tests are used to determine the lateral hydraulic conductivity of the sediments in and adjacent to monitored wetlands . Two tests are run on each well, a falling head and rising head slug test.

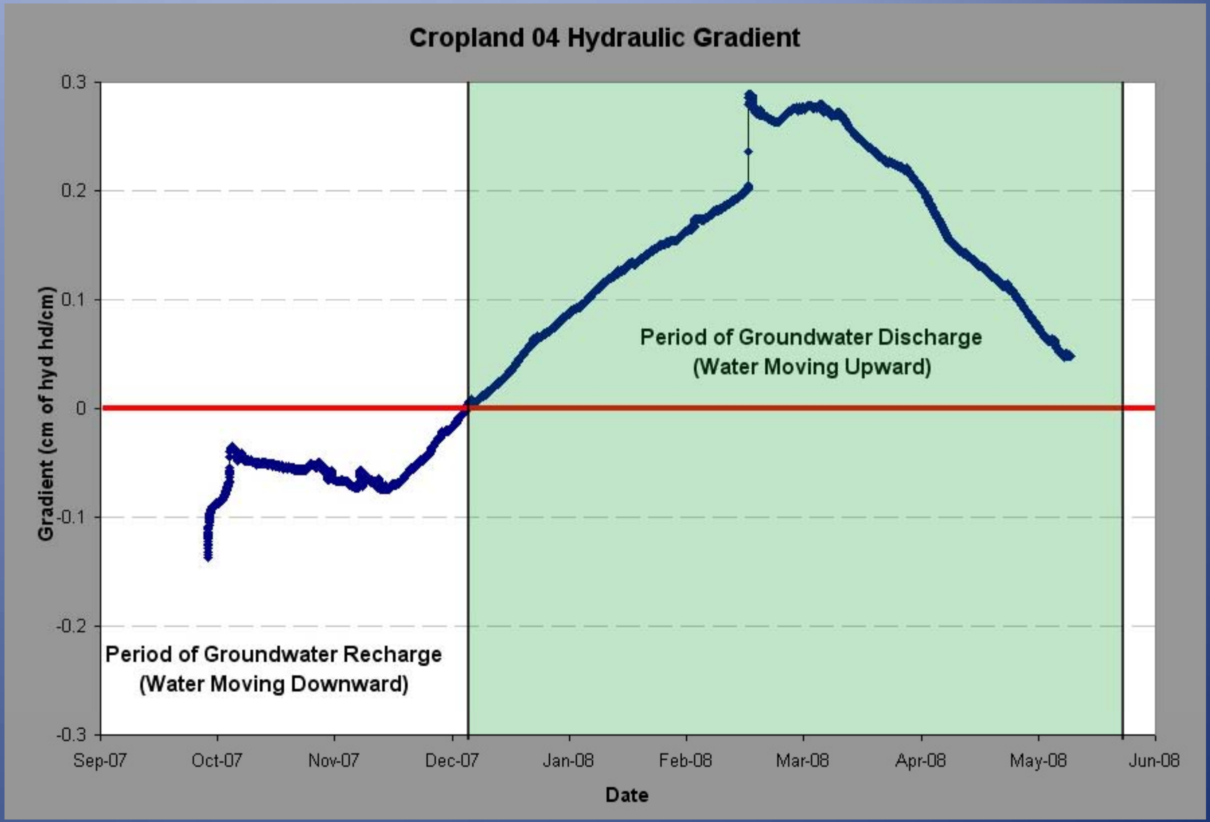
Paired Rising Head Slug Tests



Minimum - 7.23E-08 Average - 9.25E-05 Maximum - 4.85E-04

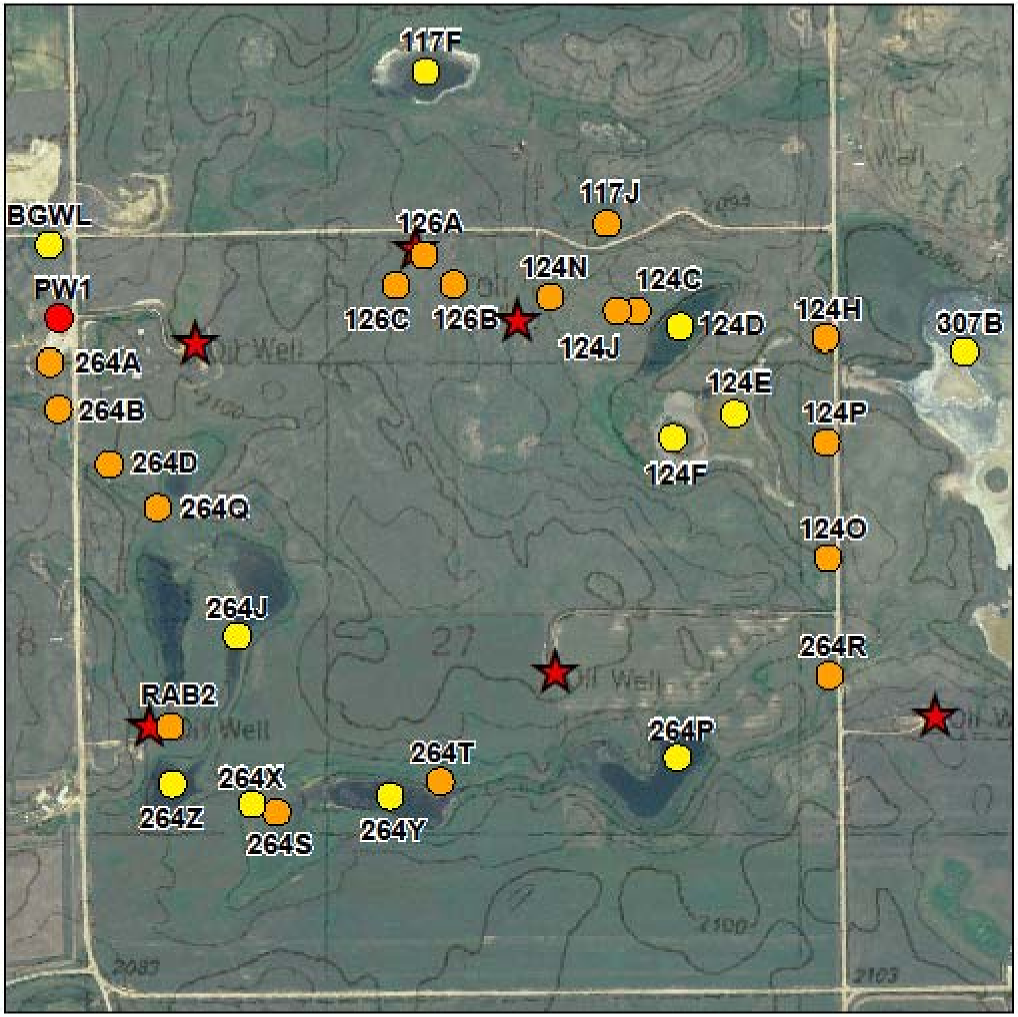
Hydraulic Gradients





Vertical hydraulic gradients are calculated by the difference in water heights between the two wells

Goose Lake Oil Field Site



Legend

- Oil Tank Battery
- Groundwater Well
- Sampled Wetland
- Oil Well

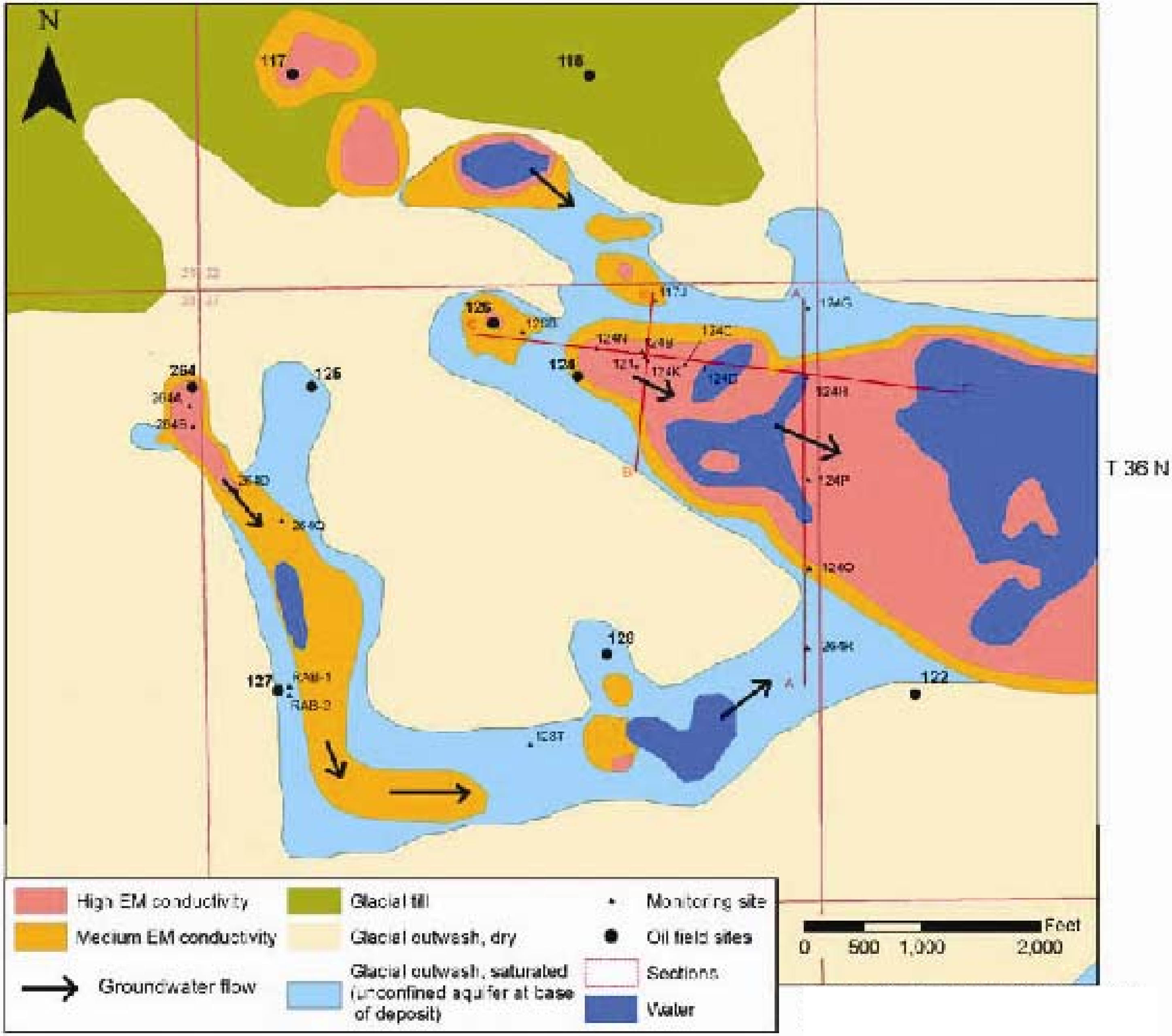
N

0 0.5

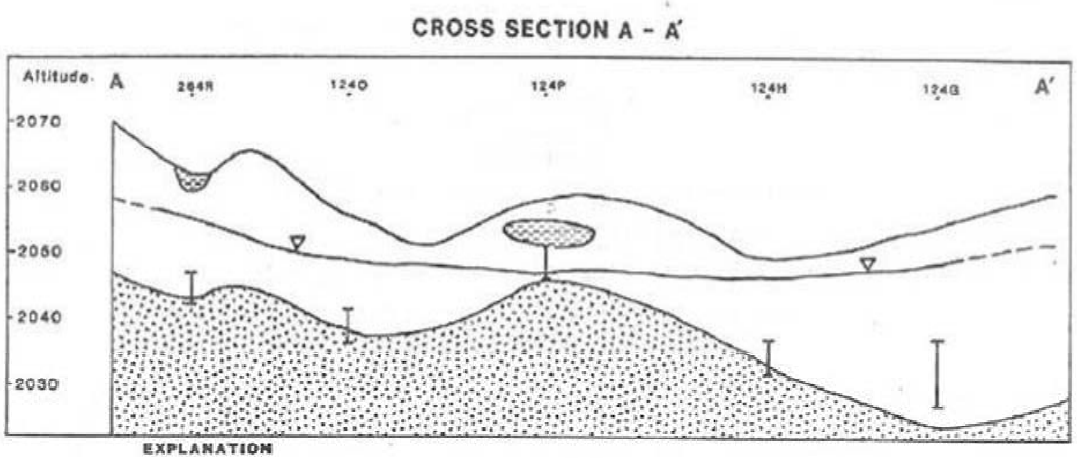
Miles

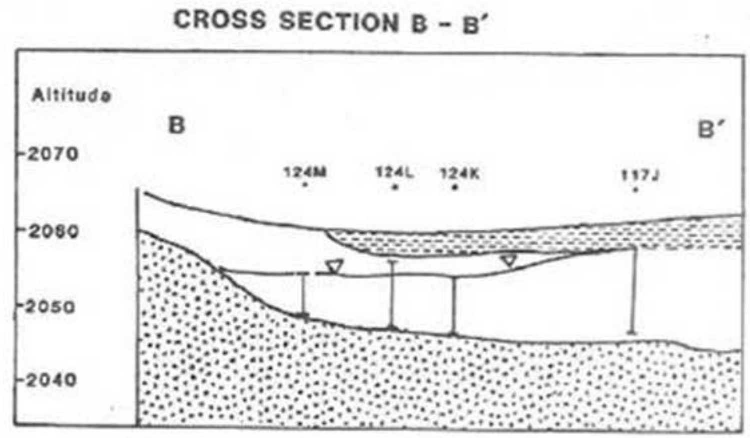
Contour Interval = 10 ft

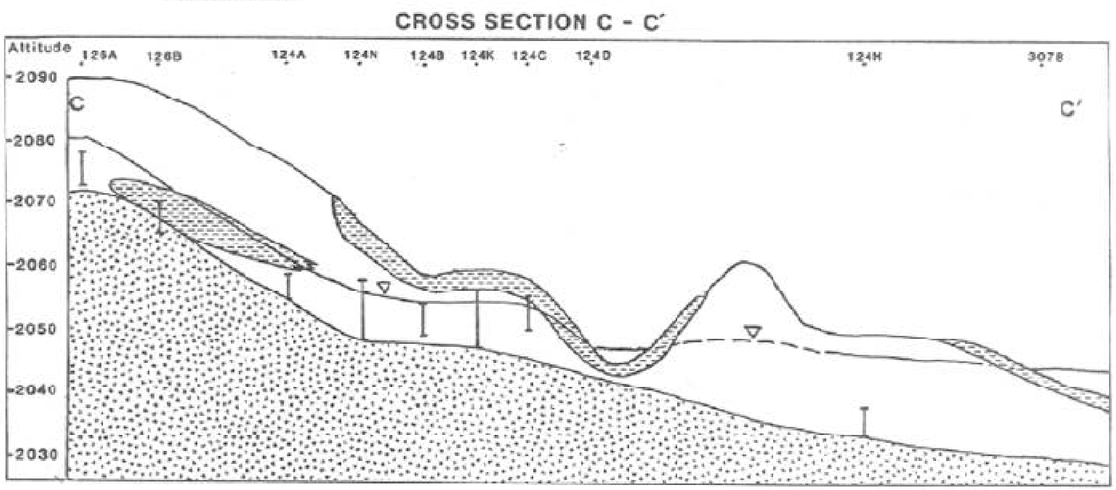
Goose Lake Field Hydrogeology

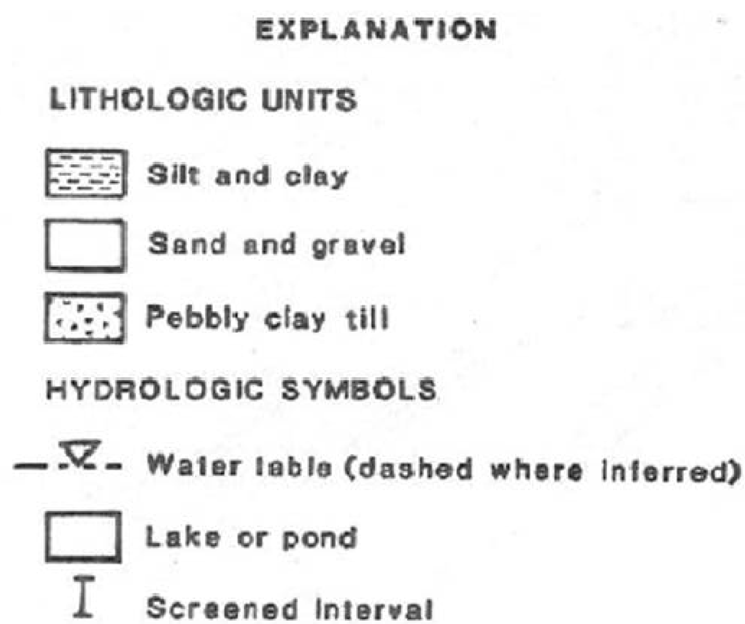


Cross Sections

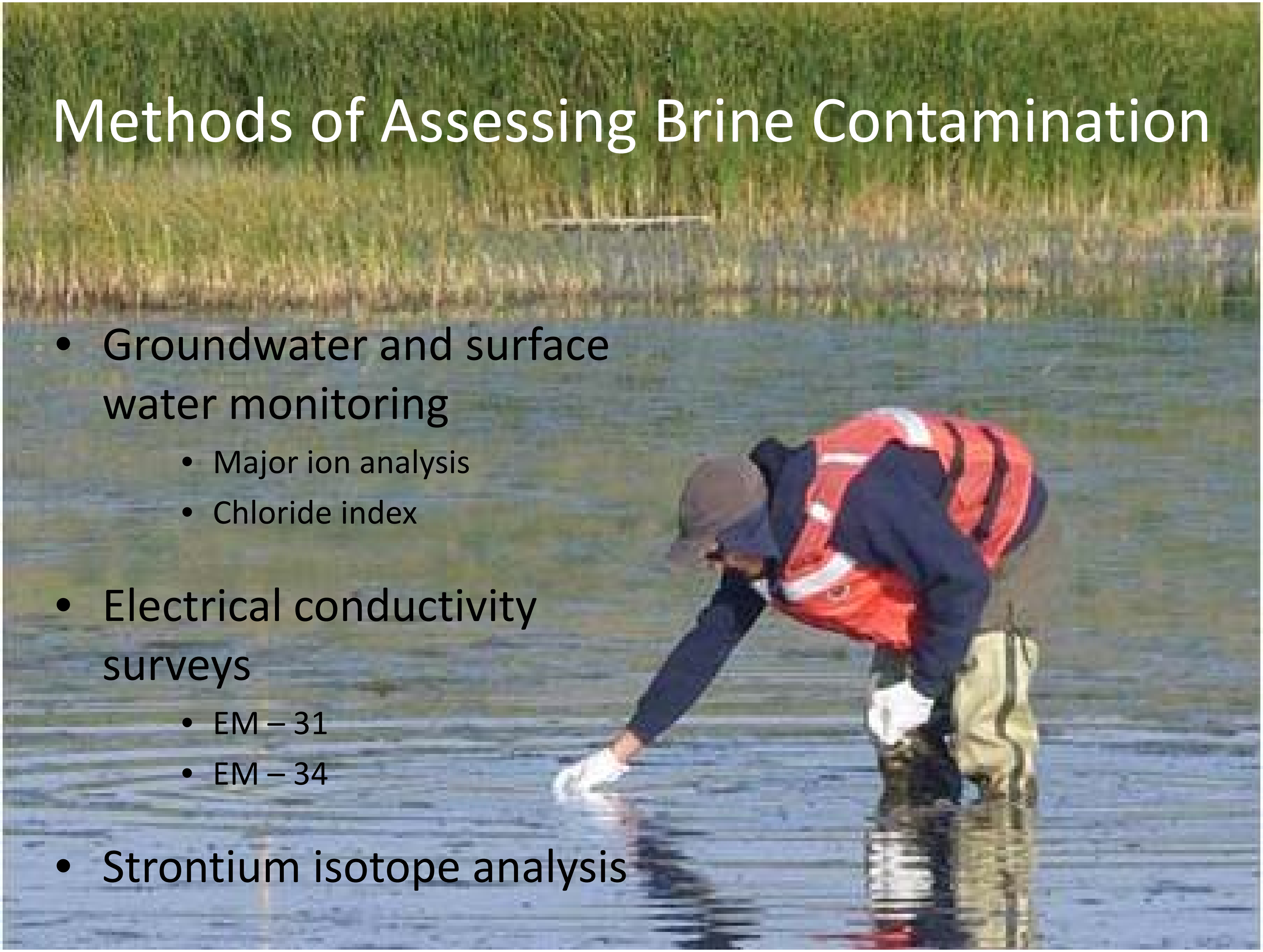








Methods of Assessing Brine Contamination



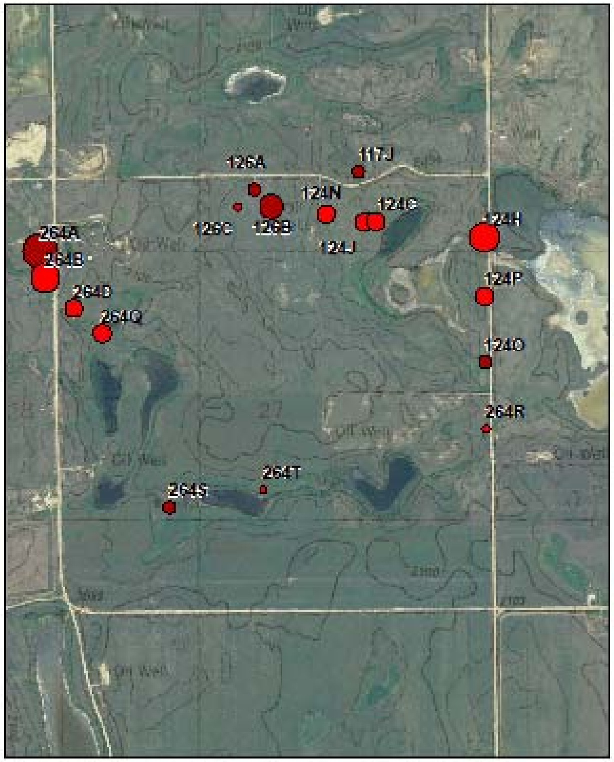
- Groundwater and surface water monitoring
  - Major ion analysis
  - Chloride index
- Electrical conductivity surveys
  - EM – 31
  - EM – 34
- Strontium isotope analysis

Water Quality Monitoring

- In 1989 18 groundwater wells were installed and sampled at the Goose Lake study site
- Numerous surface water samples were also collected and analyzed
- Samples collected in 2009
  - 18 groundwater wells
  - 11 Wetlands
  - 1 produced water
- Sampled for major ion chemistry and Strontium isotopes

Chloride (mg/L as Cl)

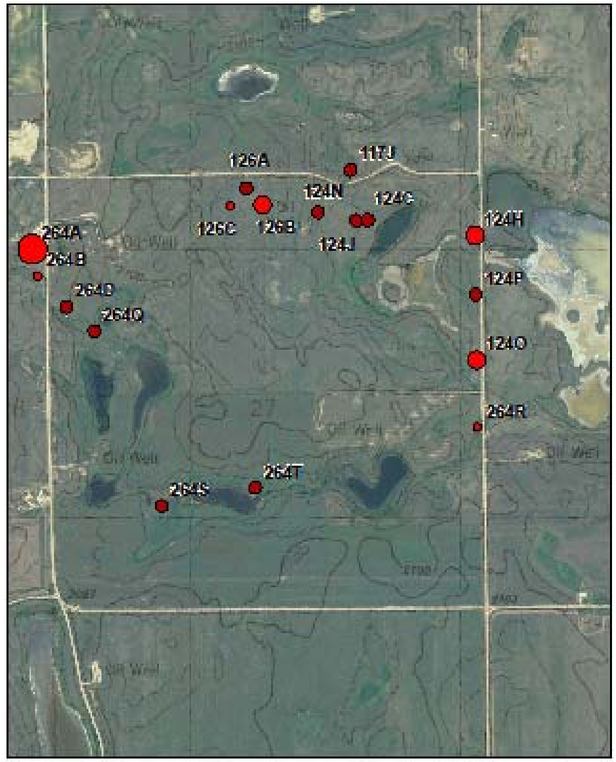
1989



Chloride (mg/L)

7 - 1000	20001 - 30000
1001 - 10000	30001 - 40000
10001 - 20000	40001 - 66900

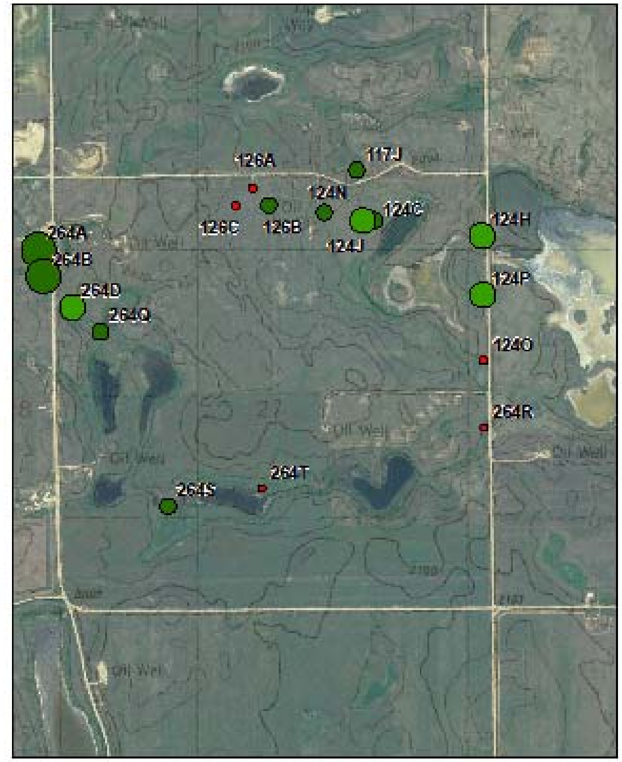
2009



Chloride (mg/L)

732 - 1000	20001 - 30000
1001 - 10000	30001 - 40000
10001 - 20000	40001 - 6900

Change in Chloride

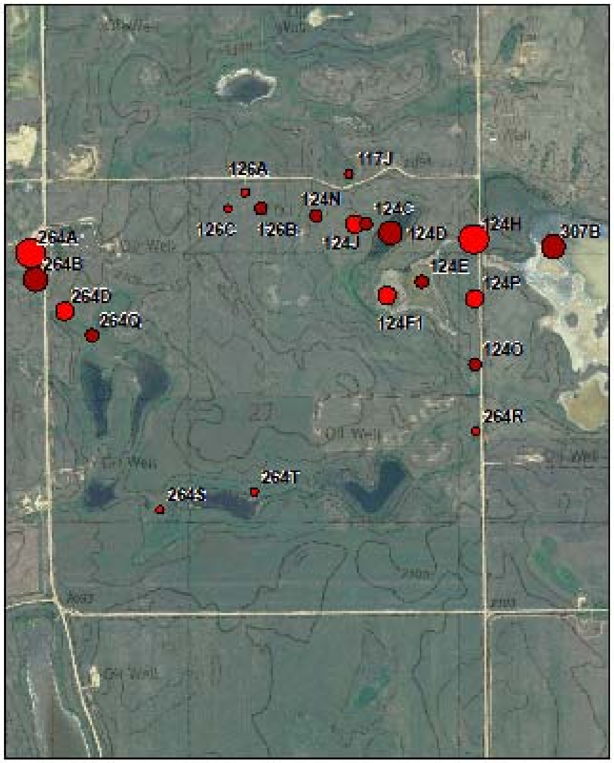


Change in Chloride (mg/L)

-32038 - -22000	-10999 - 0
-21999 - -11000	1 - 10000

Specific Conductance (uS/cm)

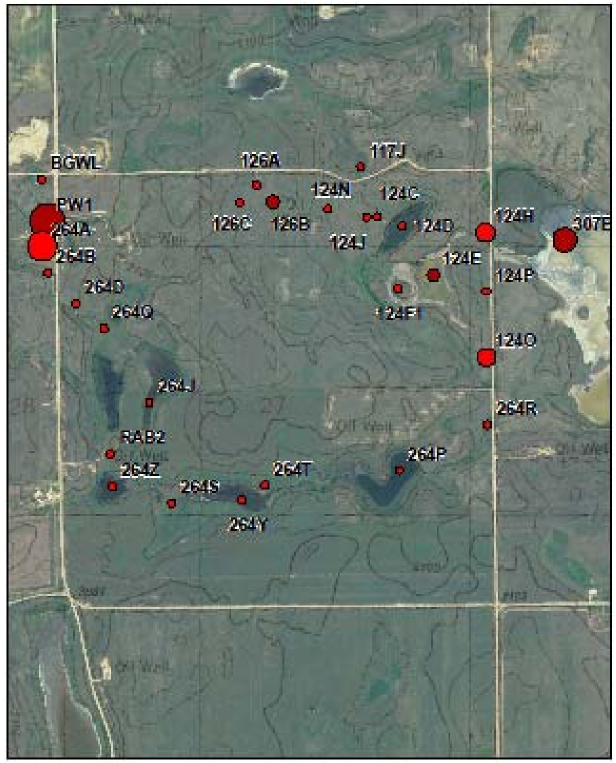
1989



Specific Conductance (uS/cm)

- 760 - 20000
- 20001 - 40000
- 40001 - 60000
- 60001 - 80000
- 80001 - 100000

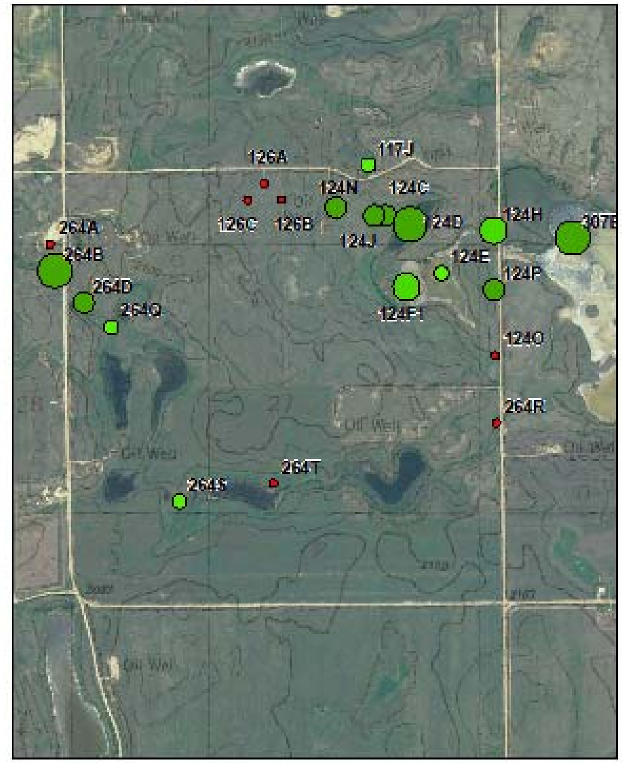
2009



Specific Conductance (uS/cm)

- 378 - 20000
- 20001 - 40000
- 40001 - 60000
- 60001 - 80000
- 80001 - 100000
- 291400

Change in Spec Cond

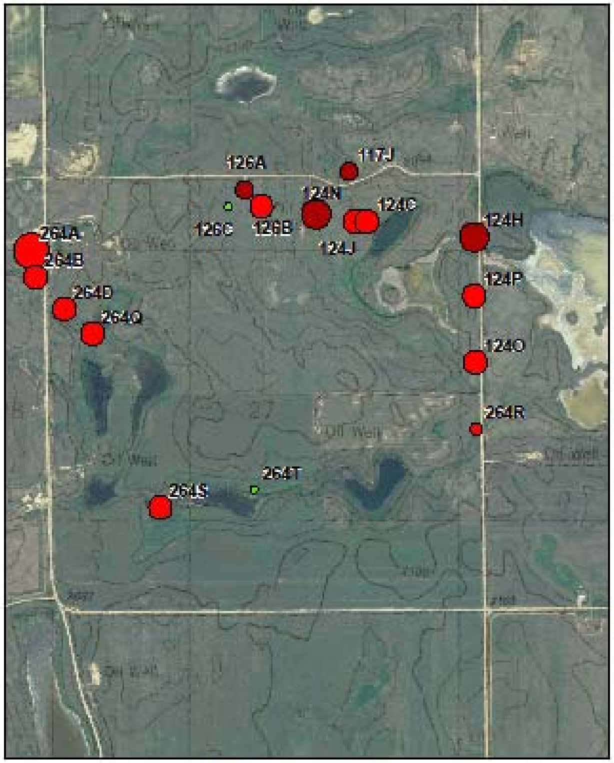


Change in Specific Conductance (uS/cm)

- -75355 - -60000
- -59999 - -40000
- -39999 - -20000
- -19999 - 0
- 1 - 19008

Chloride Index (Cl/S.C.)

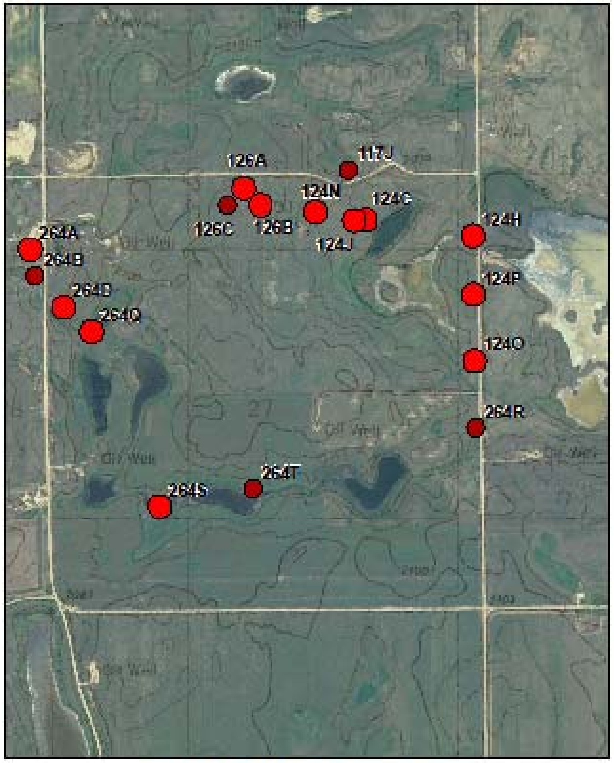
1989



1989 Chloride Index

- < 0.035
- 0.036 - 0.15
- 0.16 - 0.30
- 0.31 - 0.45
- 0.46 - 0.60
- 0.83

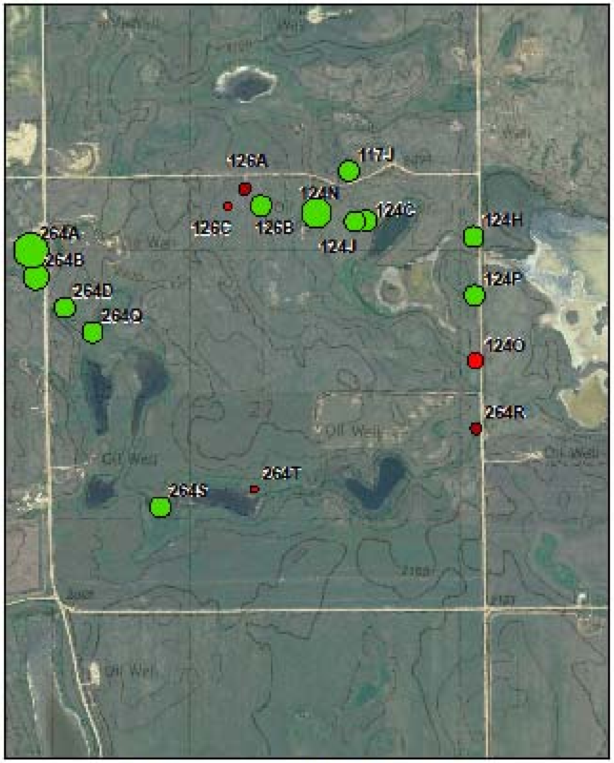
2009



2009 Chloride Index

- 0.21 - 0.30
- 0.31 - 0.43

Change in Chloride Index

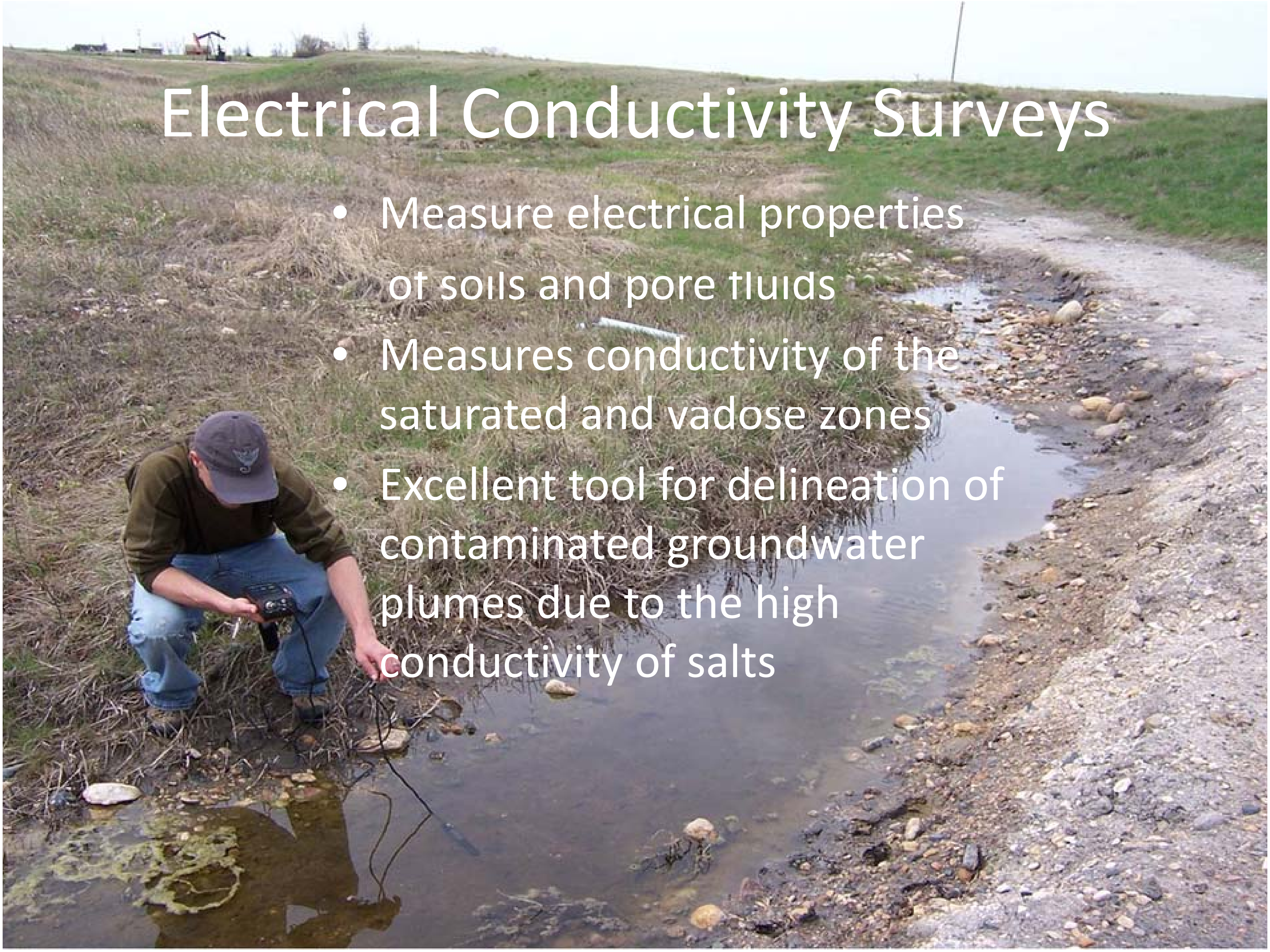


Change in Chloride Index

- -0.4 - -0.3
- -0.3 - -0.2
- -0.2 - -0.1
- -0.1 - 0
- 0 - 0.1
- 0.1 - 0.2
- 0.2 - 0.3

Electrical Conductivity Surveys

- Measure 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



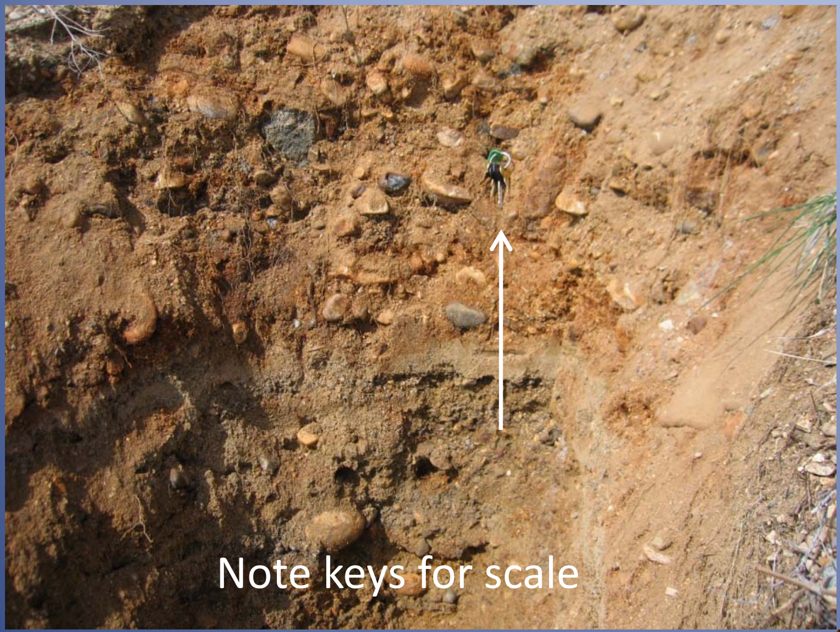
EM-31

- Excellent for determining the lateral extent of contamination but has an exploration depth of 3-4 m
- Utilizes two potential coil orientations
- Fast and straight forward allowing rapid surveying of large sites

EM-34

- Has multiple coil spacings and orientations to provide lateral extent data and exploration depths of 7-60
- Provides a depth profile of contamination plumes
- More complicated and time intensive
- May illustrate the potential for density driven flow

Glacial Outwash Deposits



- Formed by fluvial processes at the edge of the ice sheet
- Predominately sands and gravels

- Surficial deposits at Goose Lake study site are collapsed outwash
- Lenses of outwash are common in glacial tills

Glacial Till Deposits

Results form textual analysis of 66 till samples:

35.6% Sand

37.9% Silt

26.5% Clay

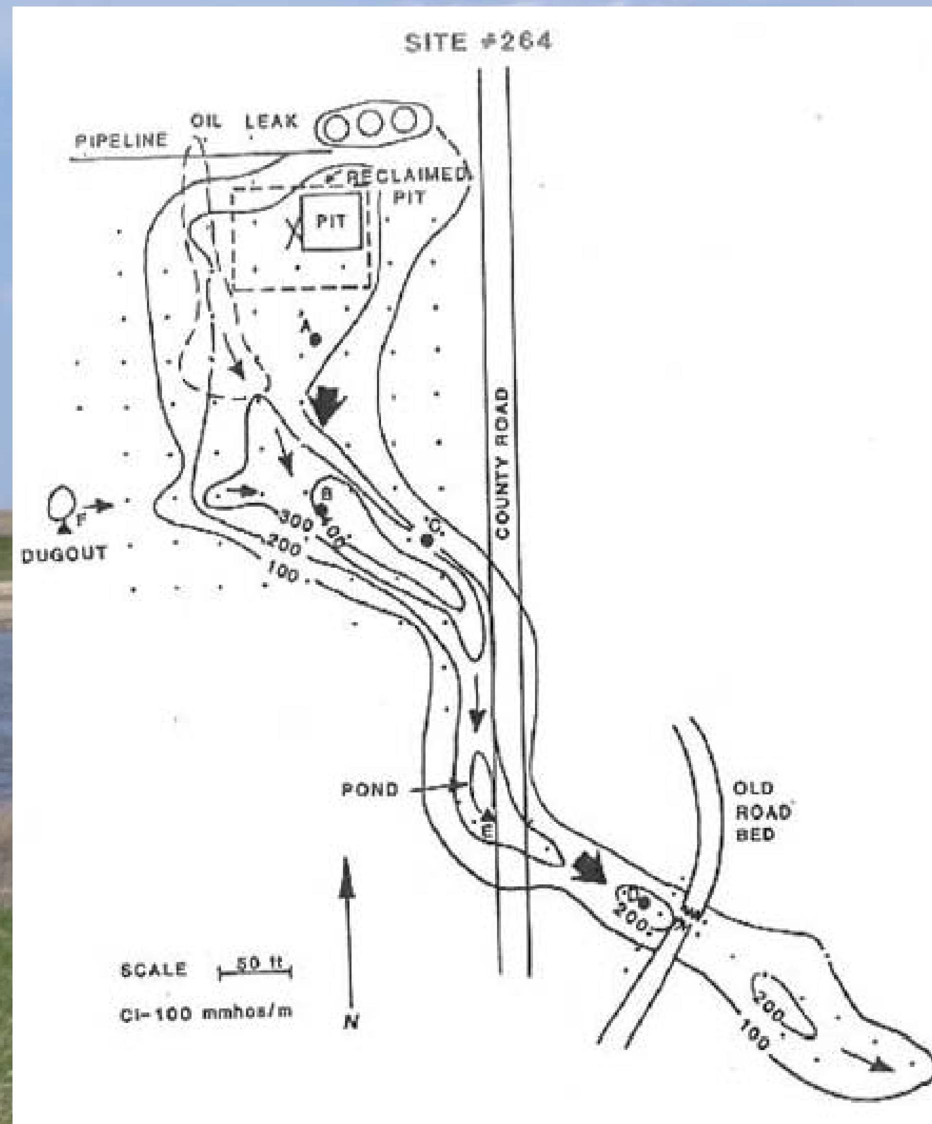
These tills are very rich in silt and clay sized particles

Location of above photo

Slump slide in road cut through glacial till deposits

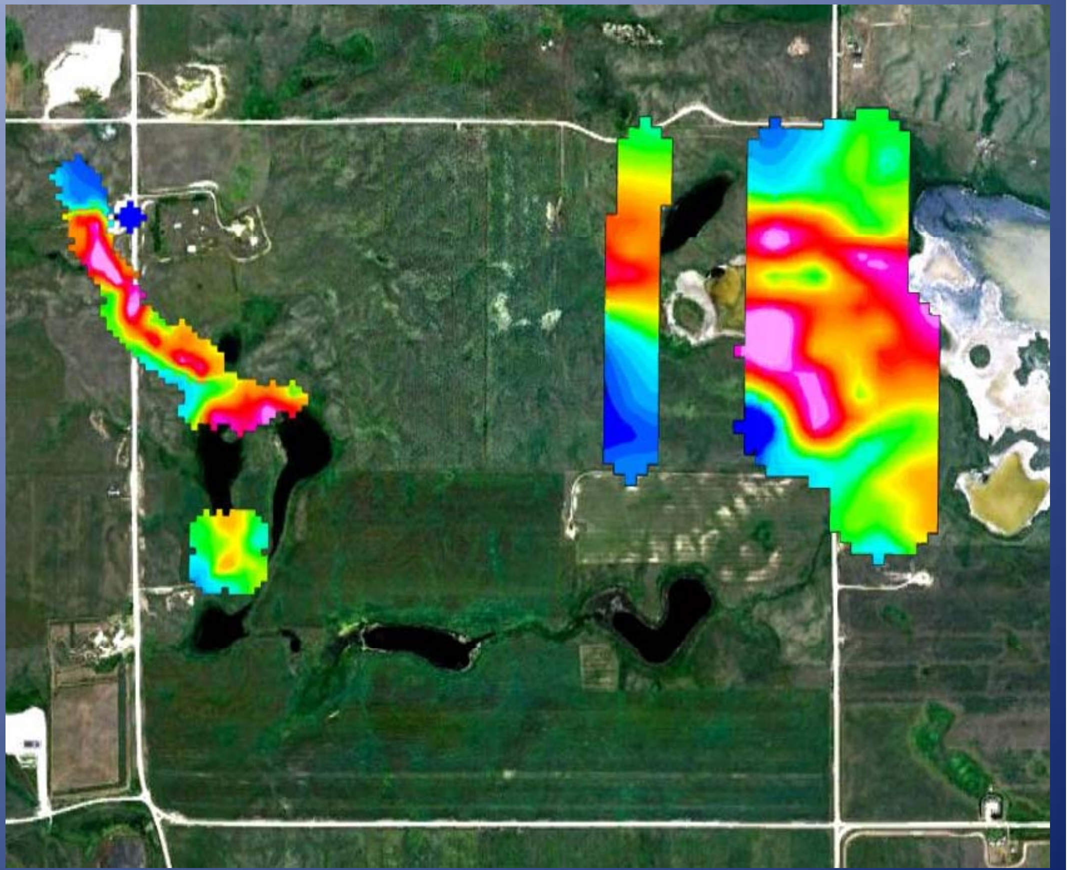
1989 EM Surveys

- Elevated chloride levels were reported in in 1975 in surface waters ½ mile below the Hammer Battery
- EM-31 & shallow EM-34 surveys detected plumes in the slough below the Hammer Battery and emanating from sites 117, 124, 126 & 128
- 18 groundwater wells were installed based on EM survey data



2009 EM Surveys

- Resurveyed areas surveyed in 1989 on and adjacent to T36N, R58N Sec 27
- Used a combination of EM-31 and EM-34 equipment
- Still showed areas of extremely high conductivity

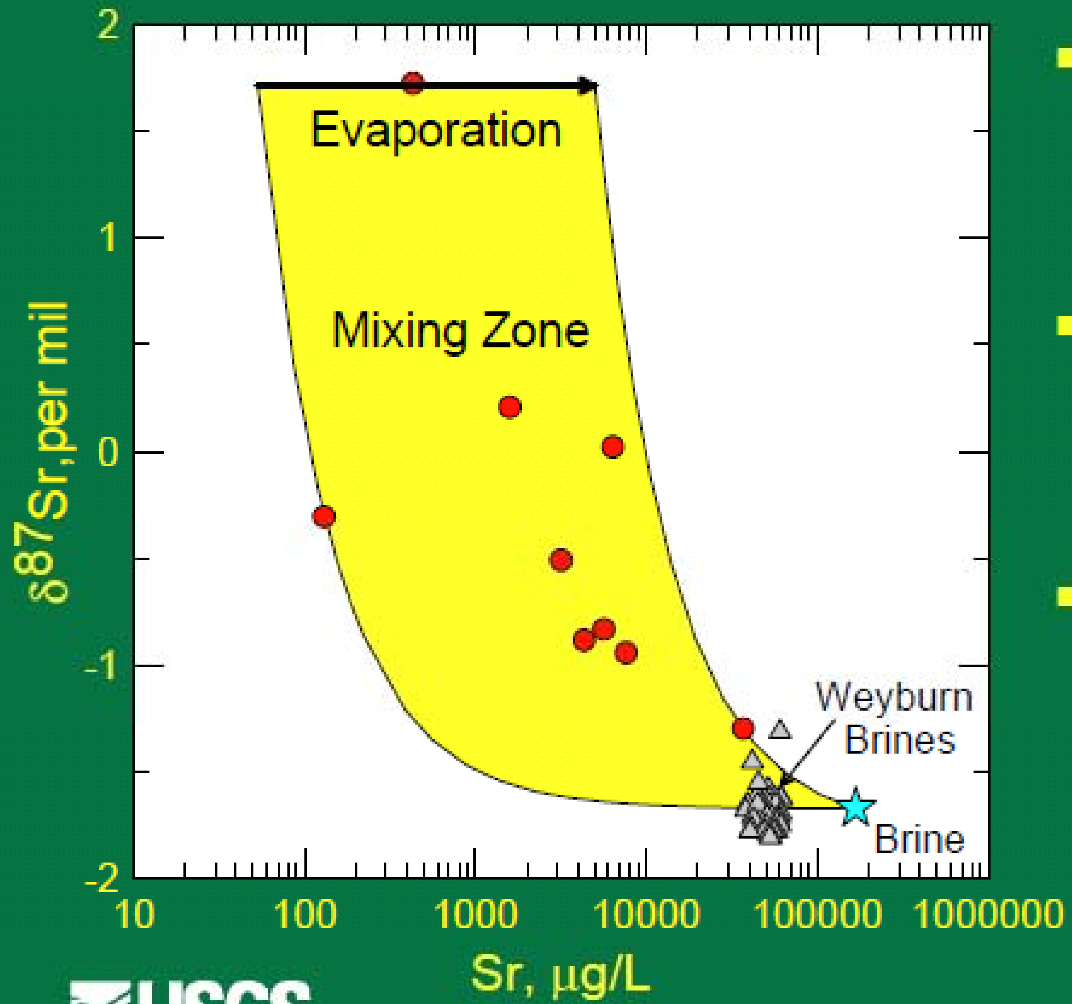


Small Amounts of Contamination Can be Detected by Sr Isotopes

- Sr contents of fresh water and produced water differ by several orders of magnitude
- Where Sr isotopic composition of fresh water and produced water differ, binary mixing trends are produced
- $^{87}Sr/^{86}Sr$ ratios are shown as $\delta^{87}Sr$ values (per mil deviation from modern sea water)

$$\delta^{87}Sr = [(^{87}Sr/^{86}Sr/0.7092)-1]*1000$$

Sr Isotope Systematics of Goose Lake Samples



- Largest $\delta^{87}Sr$ is assumed to represent uncontaminated (or least contaminated) end member
- Mixing zone is bounded by mixing lines between brine and values on evaporation line
- Weyburn brines (Quattrocchi et al, 2006) are consistent with Goose Lake brine

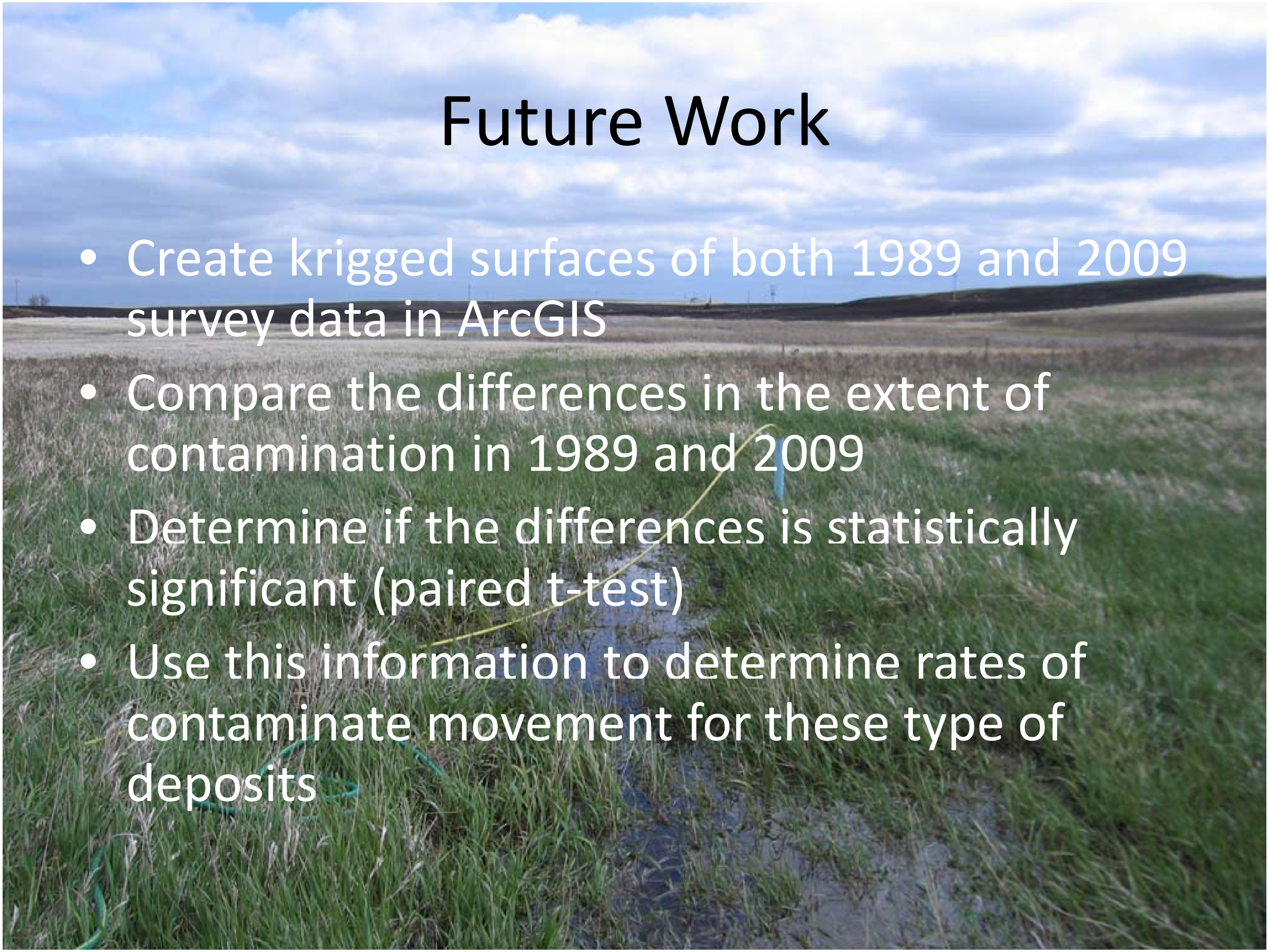
USGS

Strontium Results

- Sr Isotopes are sensitive indicators of small amounts of produced water contamination
- Ratios do not change with evaporation
- Mixing systematics allow calculation of degree of contamination

Conclusions

- 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.
- Two groundwater wells that were uncontaminated in 1989 have bow been affected
- Despite the overall cleansing of the shallow sand and gravel aquifer, the surface and groundwater resources in the area are still highly contaminated as evidenced by the 2009 chloride index data
- Water quality data indicates that the heart of the contamination plume in the southern half section has migrated down gradient towards the west arm of Goose Lake


Future Work
• Create krigged surfaces of both 1989 and 2009 survey data in ArcGIS
• Compare the differences in the extent of contamination in 1989 and 2009
• Determine if the differences is statistically significant (paired t-test)
• Use this information to determine rates of contaminate movement for these type of deposits

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Questions?
http://steppe.cr.usgs.gov