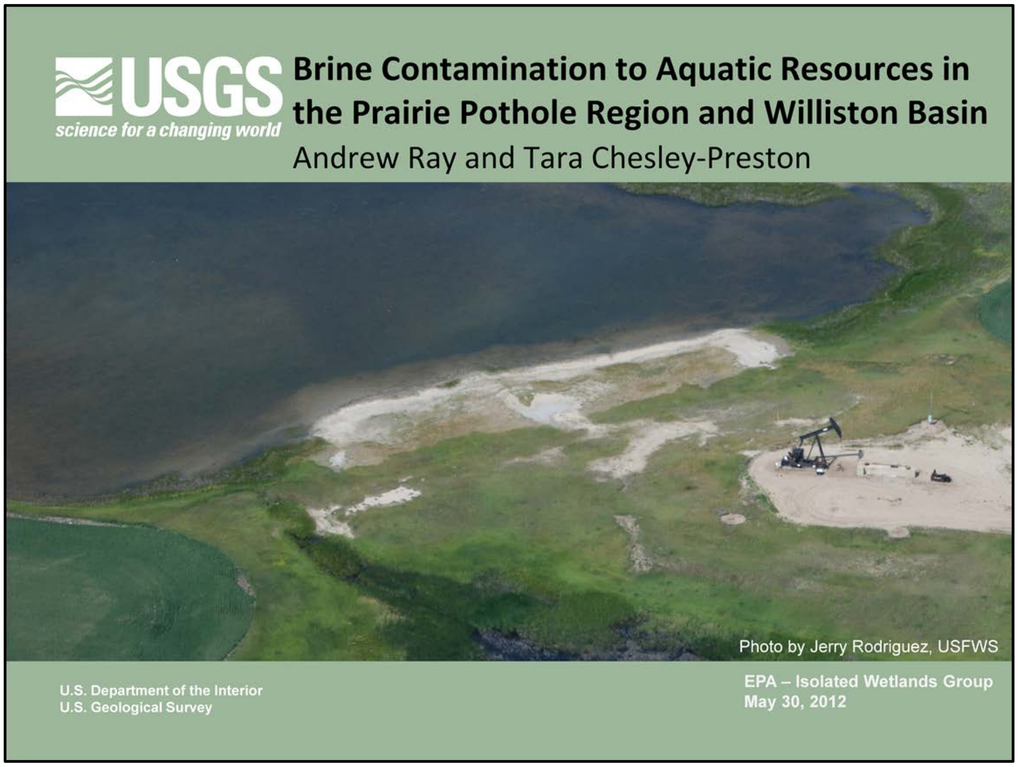

Today we will be presenting our results of an ongoing USGS project that addresses brine contamination to aquatic resources in the Prairie Pothole Region and Williston Basin.

Science Team about Energy and Prairie Pothole Environments - STEPPE

- **Andy Ray**, USGS, Northern Rocky Mountain Science Center
- **Tara Chesley-Preston**, Institute on Ecosystems at Montana State University, Northern Rocky Mountain Science Center
- **Todd Preston**, Parallel Inc., USGS Northern Rocky Mountain Science Center
- **Joanna Thamke**, USGS, Montana Water Science Center
- **Robert Gleason**, USGS, Northern Prairie Wildlife Research Center
- **Seth Haines**, USGS, Crustal Geophysics and Geochemistry Science Center
- **Max Post van der Burg**, USGS, Northern Prairie Wildlife Research Center
- **Bruce Smith**, USGS, Crustal Geophysics and Geochemistry Science Center
- **Richard Sojda**, USGS, Northern Rocky Mountain Science Center
- **Brian Tangen**, USGS, Northern Prairie Wildlife Research Center

http://steppe.cr.usgs.gov

The USGS has a large diversity of research and knowledge. The Science Team about Energy and Prairie Pothole Environments, or STEPPE, is strengthened by a multi-disciplinary approach to holistically understand the effects of brine contamination. STEPPE is composed of USGS scientists throughout in North Dakota, Montana, and Colorado with backgrounds in biology, hydrology, geophysics, ecology, and geology.

Andy Ray (aray@usgs.gov) – Aquatic Ecologist
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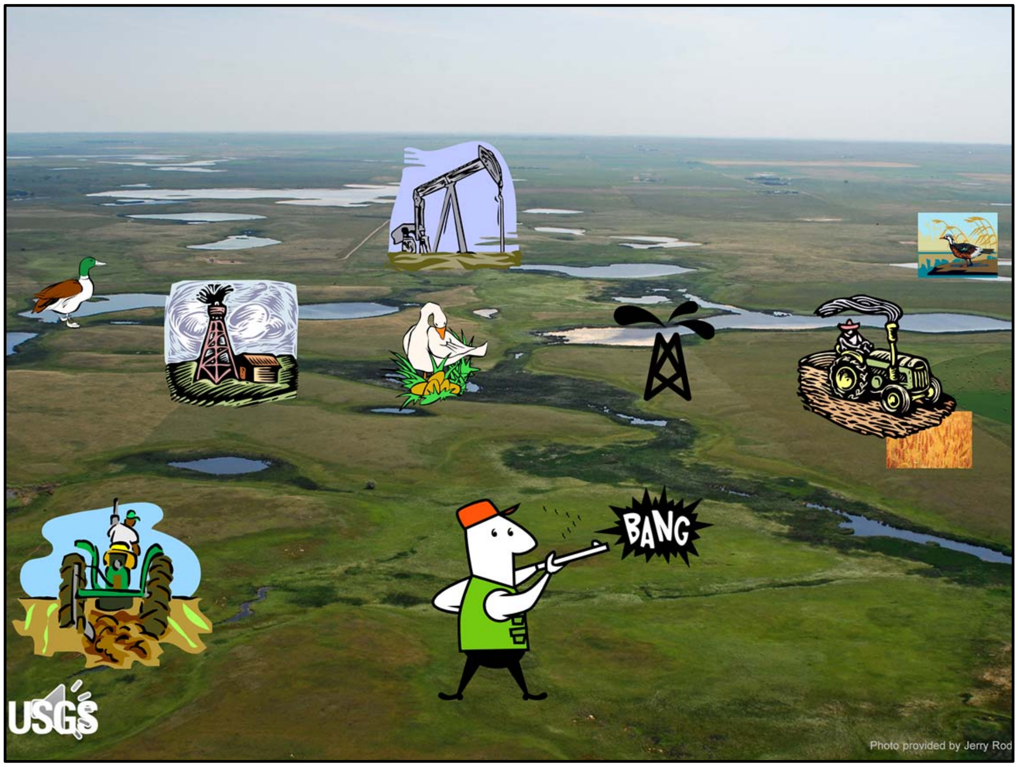
Brian Tangen (btangen@usgs.gov) – Wetland Ecologist

The project also benefitted from a strong multi-agency collaboration with the Montana Bureau of Mines and Geology, Sheridan County Conservation District, US Fish and Wildlife Service, Medicine Lake National Wildlife Refuge, and Montana State University.

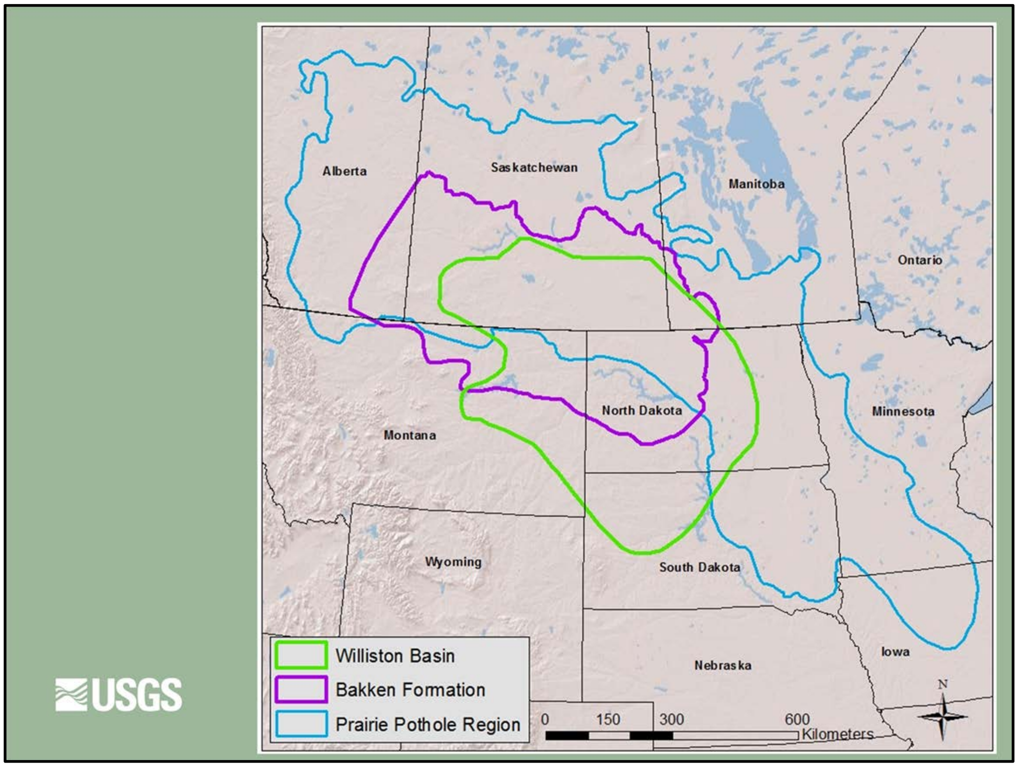


The focus of this talk is on the Prairie Pothole Region.

Once the largest expanse of grassland in the world

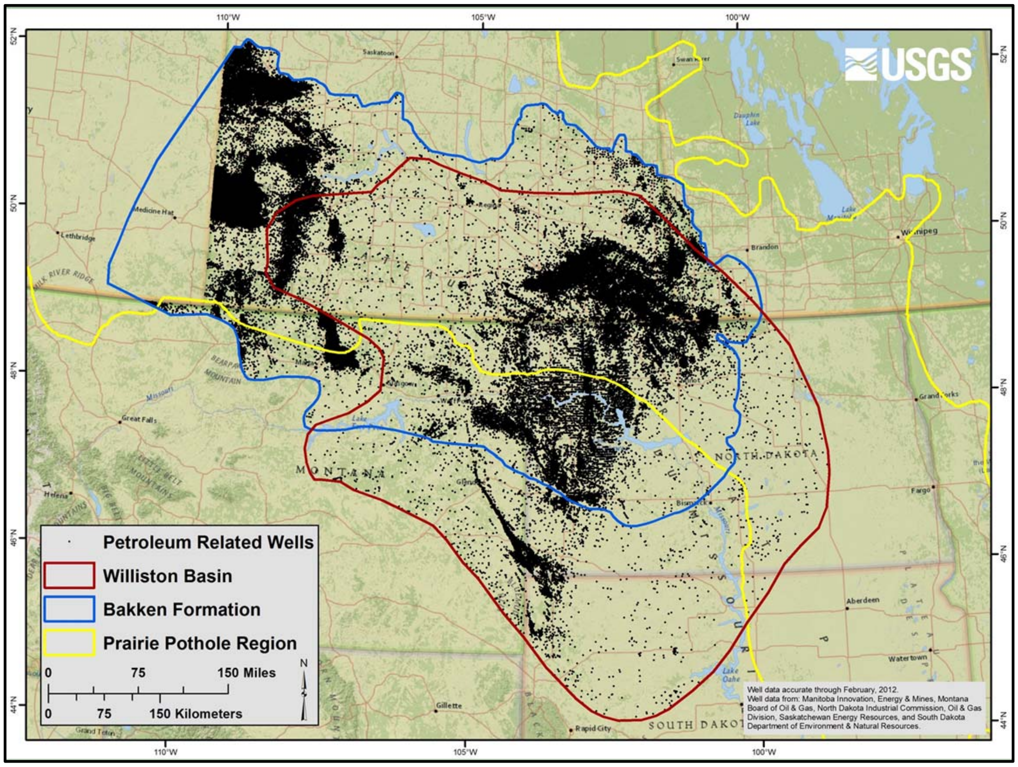
Over 50% of wetlands in U.S. part and 70% of Canada's wetlands in the PPR have been drained for agriculture.

Still this region still produces approximately 50% of NA ducks
Carbon sequestration – approx. 850 Tg stored in wetlands
Nutrient transformations and sequestration equally important



The Prairie Pothole Region is outlined in blue is the core of what was once the largest expanse of grassland in the world. When the last glaciers receded about 10,000 years ago, they left behind millions of shallow depressions that are now wetlands, known as prairie potholes. These potholes support globally significant populations of breeding waterfowl and are rich in plant and aquatic life.

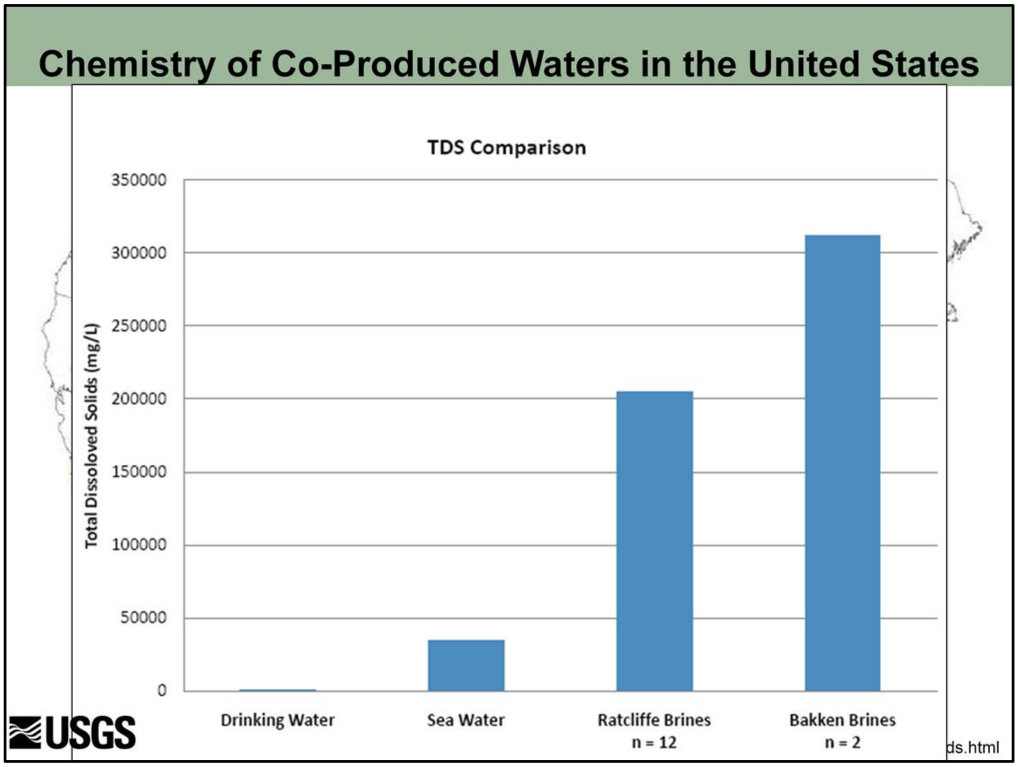
The Williston Basin, outlined in green, is a large structural basin known for its rich deposits of petroluem. Oil was first found in the Williston Basin in the 1920s with peak production in the mid-1980s. Production is increasing in the Williston Basin due to hydraulic fracturing techniques to remove oil and gas form the Bakken Formation, outlined in purple.



Tens of thousands of oil and gas wells have been drilled throughout the Williston Basin during the past half century. In 2008, the USGS estimated more than 3 ½ billion barrels of undiscovered recoverable oil is in the Bakken. Current estimates are nearly 2,000 new wells per year in the Williston basin.

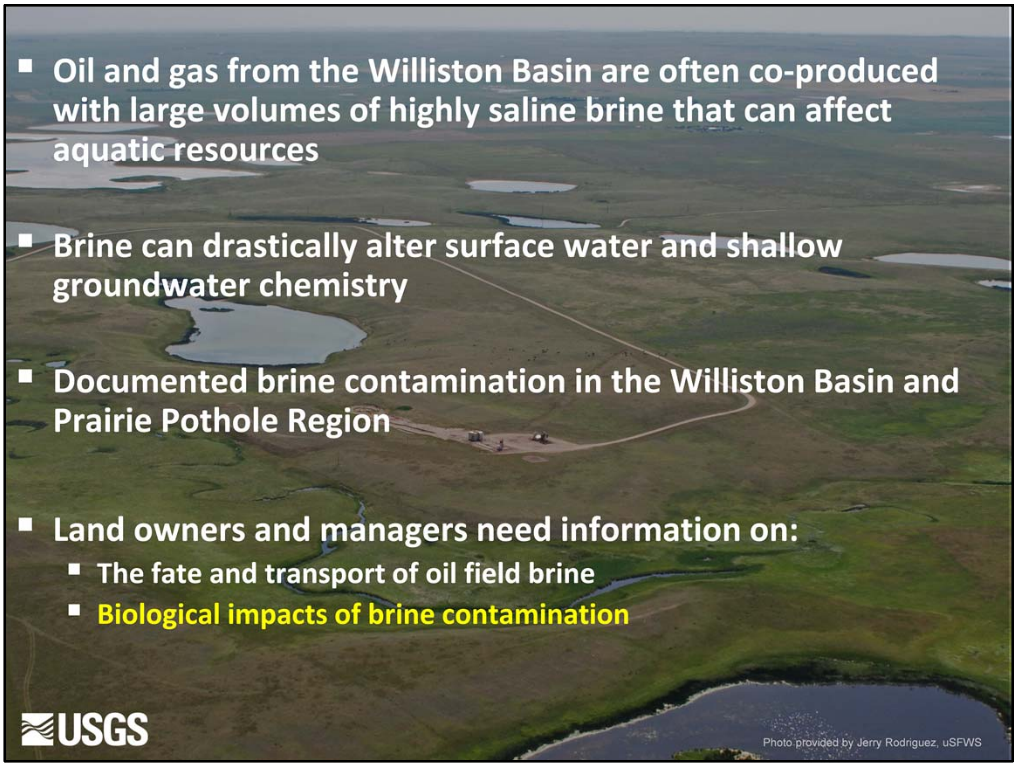
Production is increasing in the Williston Basin due to hydraulic fracturing techniques to remove oil and gas form the Bakken Formation.

During 2009-11, we focused much of our work in Sheridan County in northeastern Montana where MBMG and USFWS had previously documented brine contamination to wetlands and shallow groundwater.



It is important to know that co-produced waters associated with energy development in the Williston Basin are some of the most saline waters in the Nation, 5-10 times more saline than seawater.

These extremely saline waters pose an environmental risk to the sensitive aquatic resources of the Prairie Pothole Region.



Our project work was conducted because of the very saline co-produced waters and the sensitive aquatic resources that both exist in the Williston Basin. Previous work had identified that brine contamination had already occurred in the Williston Basin and PPR.

We are beginning to look at the relationship between well densities, water quality and biological assemblages

Documented sources of brine from conventional oil and gas development include reserve and evaporation pits.

In addition, well casing and pipeline failures are also documented sources of brine contamination.

These sources are common to conventional (vertical) wells and unconventional (horizontal or hydraulic fractured) wells

Many of the shallow aquifers and wetlands in the Prairie Pothole Region are naturally saline. The locals like to call this summer snow. The anion that composes the salinity is sulfate and the vegetation and macroinvertebrates have adapted to life in these naturally saline environments.

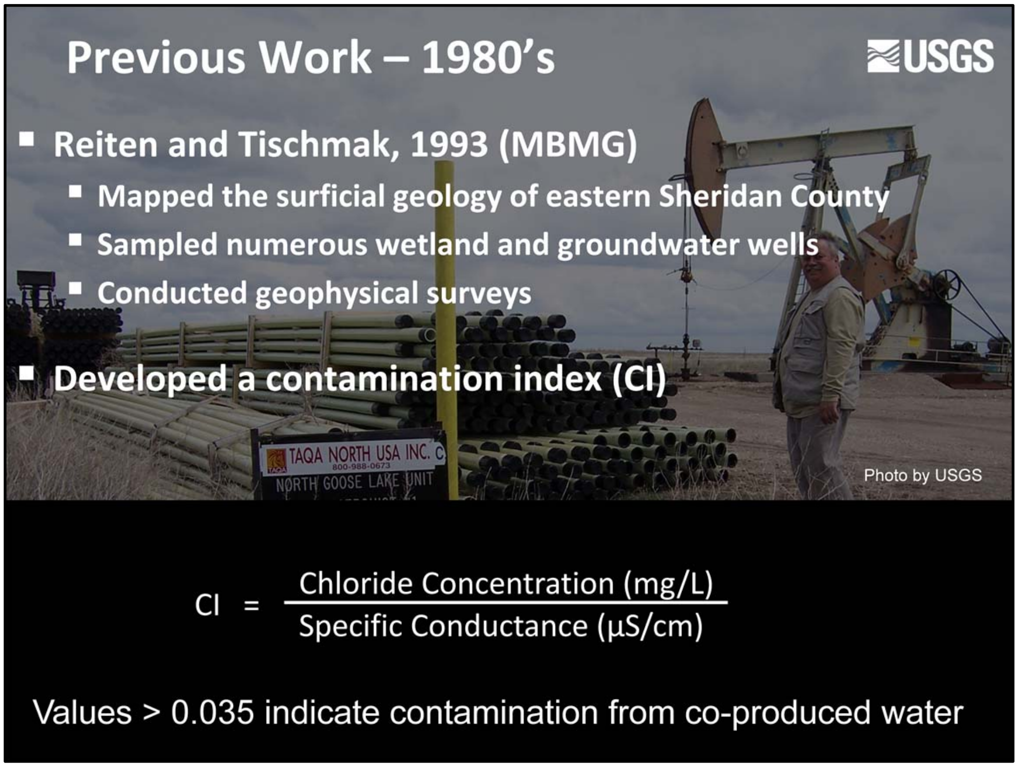
The brine that is co-produced in the Williston basin is from deep sources that are also naturally saline—at great depth. The anion that composes the salinity is chloride. When this chloride-rich water mixes with the shallow sulfate-rich waters, the responses of vegetation and macroinvertebrates are not well understood.

Several tools are useful to identify brine contamination to shallow water resources.

Water-chemistry results. As mentioned earlier the primary anions are different for the water that is produced with energy development from the water that is in the shallow groundwater and wetlands.

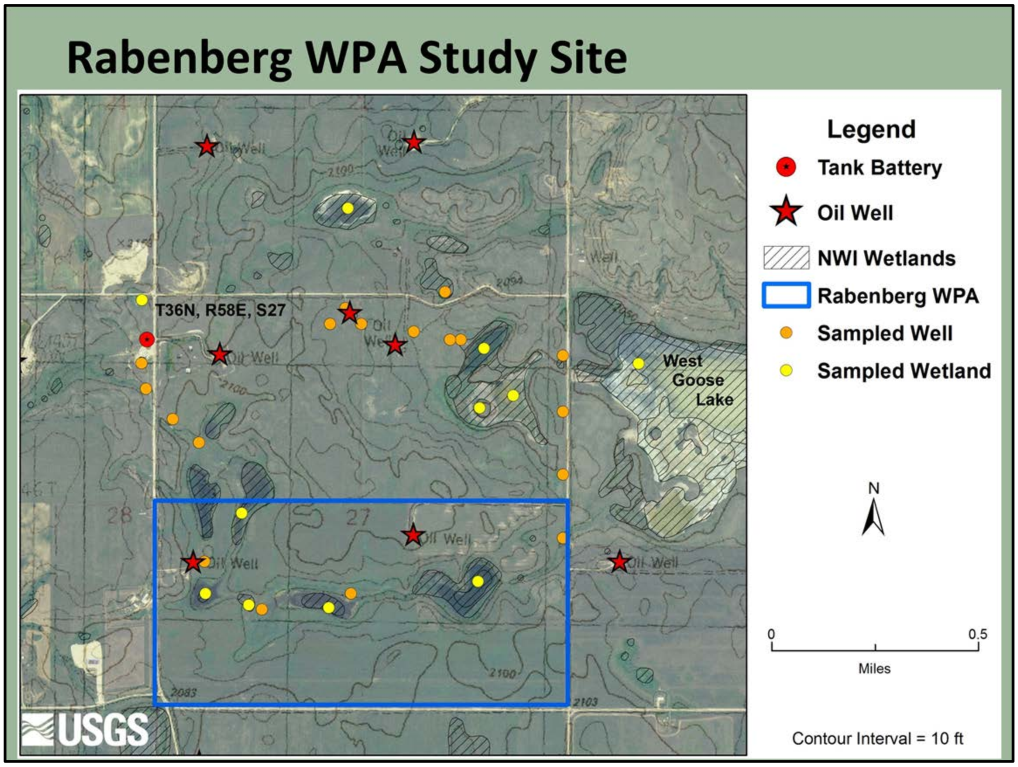
Brine also contains much larger concentrations of total dissolved solids than the water in the shallow aquifers and wetlands. This difference in major-ion chemistry is useful to identify brine from energy production.

Geophysical methods that measure electromagnetic resistivity are also useful at mapping areas of high salinity.



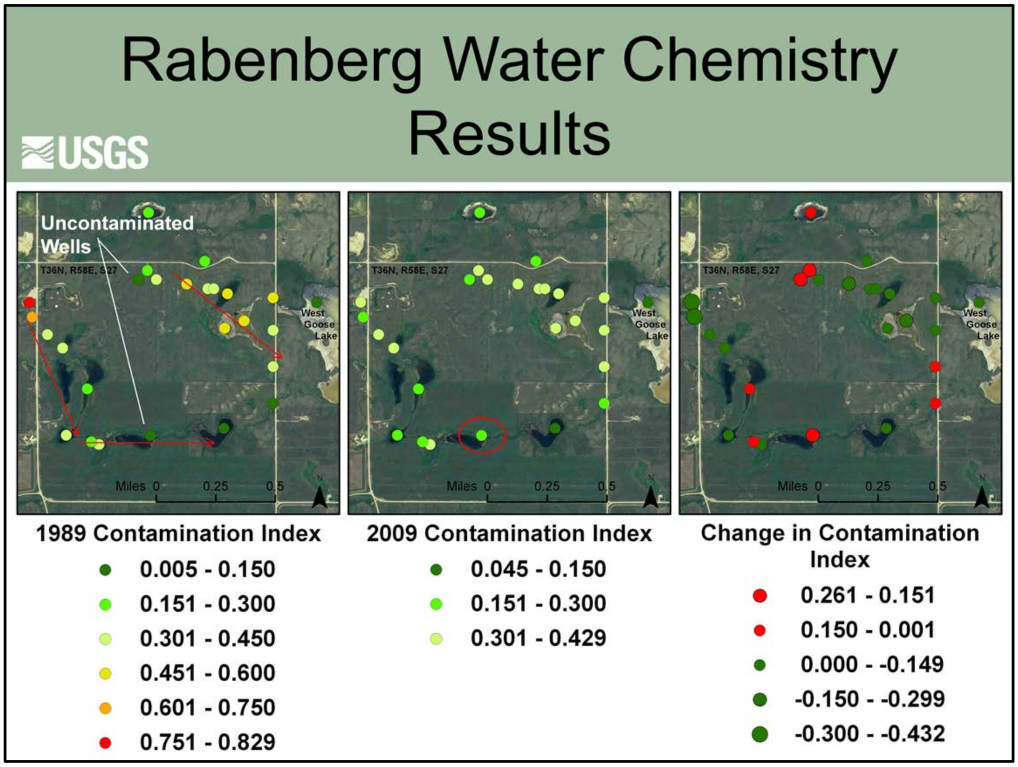
The Montana Bureau of Mines and Geology had mapped the geology and identified areas in eastern Sheridan county that had been affected by brine contamination. They also developed a contamination index using chloride and specific conductance to quickly identify if water was affected by brine.

Working with MBMG and the US Fish and Wildlife Service, we re-visited these sites to determine changes with time.



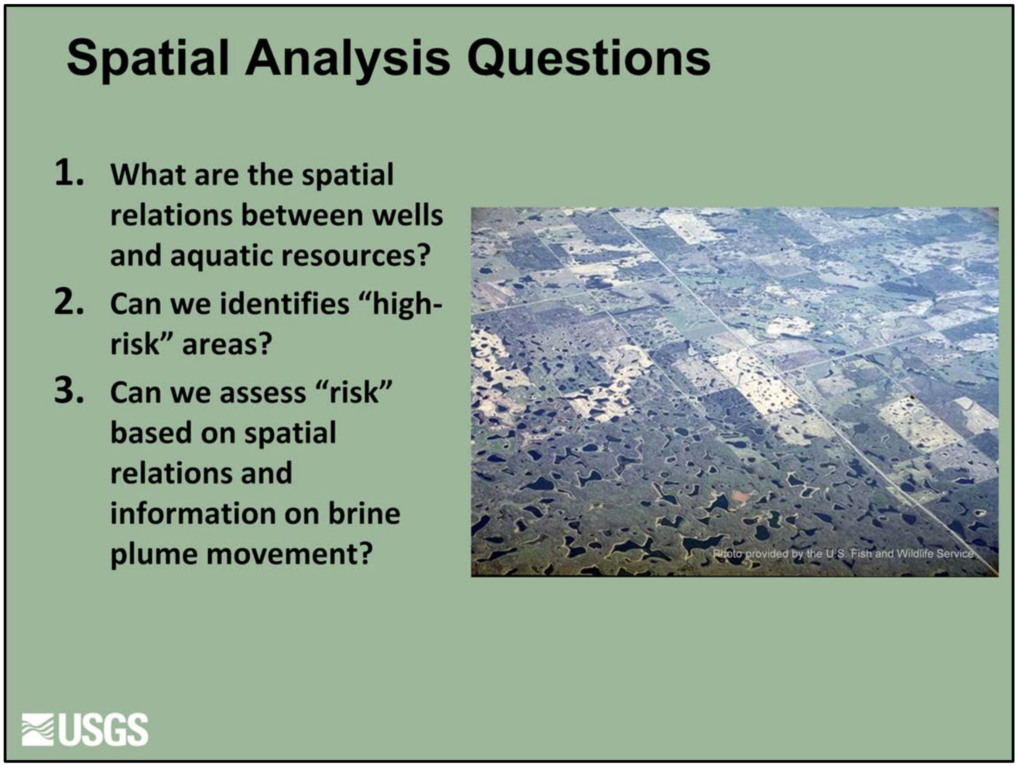
We are going to present results from a case study at the Rabenberg WPA study site.

There are several "isolated" wetlands, oil wells and a tank battery. Monitoring wells and wetlands were sampled in 1989 by MBMG, and revisited by USGS 20 years later. You can see the distribution of wells and wetlands on this map.



At the Rabenberg WPA study site, the contamination index at 8 of the monitoring sites increased between 1989 and 2009, the remaining 19 remained the same or decreased. Contamination index values during 2009 at all of the sites indicated brine contamination (>0.035).

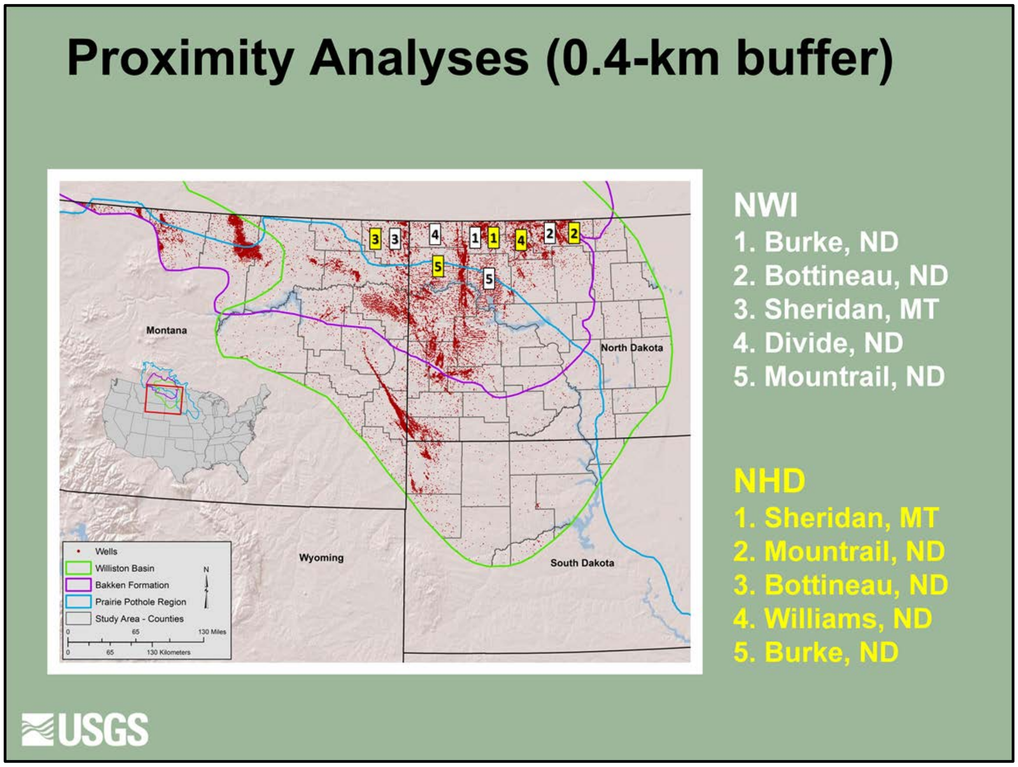
Statistical results indicated that contamination duration could be as much as 140 years.



Another component of our work was to apply our site-specific information to the regional study area of the Prairie Potholes. Questions we had heard from other natural resource managers were:

What are spatial relations between energy development and aquatic resources?
Can ‘high-risk’ areas be identified?
Can risk be assessed using spatial relations and knowledge about brine plume movement?

This work was based on surface features only.



Counties with waterbodies close to O&G development are primarily in NW North Dakota and NE Montana.

We applied a proximity analysis to compare locations of O&G wells to aquatic resources, such as wetlands, lakes, and streams on USFWS lands within the Prairie Pothole Region. We used several buffer extents and analyzed older wells, prior to 1980, and the entire network of wells.

Proximity Analysis (PPR)

Wetland distribution

<u>All years (10,361 wells)</u>

- **33% of wetlands within 1 mile buffer**
- **17% of wetlands within ½ mile buffer**
- **7% of wetlands within ¼ mile buffer**

<u>Pre-1980 (5,446 wells)</u>

- **23% of wetlands within 1 mile buffer**
- **11% of wetlands within ½ mile buffer**
- **4% of wetlands within ¼ mile buffer**

USGS

In this area of the Prairie Pothole Region, almost 5,500 wells were drilled prior to 1980. 23% of all wetlands were within 1-mile of energy development, 11% were within half-mile of energy development, and 4% were within quarter-mile of energy development.
After 1980, the total number of O&G wells in this area doubled. The number of wetlands close to energy development also increased.

Andy – if you remember a few slides back… streams & interconnectivity of wetlands

Biological Impacts of Salinity on the PPR Lacking

Elsewhere, impacts of salinity on wetlands include:

- **affects seed germination**
- **alters biotic composition**
  - **selects for salt tolerant species**
- **reduces productivity**

USGS

The previous work shows that brines can move long distances and enter pothole ecosystems. Moreover, the spatial analysis shows that many wetlands (and streams) have the potential to be impacted by O&G development.

The lingering question, is ***what are the potential biological impacts of brine or chloride salt contamination***?

Salinity studies have shown that NaCl differentially effects salt intolerant species. Specifically, salinity impacts germination of some seeds leading to a shift in composition towards salt tolerant species (e.g. Hordeum jubatum – squirrel tail barley).

In a greenhouse experiment using species common to the PPR, biomass of vegetation is reduced from 29 to 75% depending on the salinity dose. And, importantly these reductions in productivity related to NaCl far exceeded reductions associated with moisture stress for these same plants.

Interactions Between Salinity and Plant Nutrition

Salinity Impacts Primary Production

- Ca; sodium salts reduce Ca availability, transport, and mobility
- K; sodium salts interfere with K acquisition by plant roots
- NO_3; chloride competes strongly with NO_3 and readily taken up by plants
- PO_4; tissue P reduced by 20 to 50% under elevated salinity
- Combined effects lead to a reduction in primary productivity and alteration of nutrient standing stocks

USGS

From laboratory work and research on agronomic species, we know that NaCl reduces productivity. There are several important mechanisms but importantly, introductions of chloride salts affects calcium, potassium, nitrogen (NO3), and phosphorus (PO4) uptake.

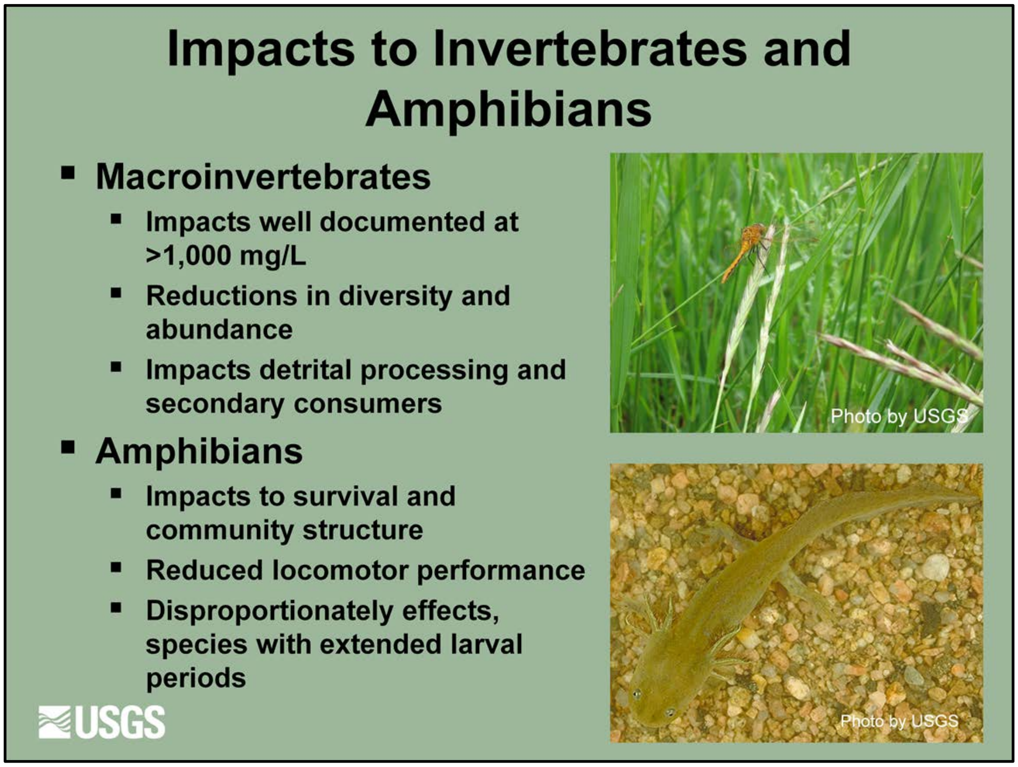
Interactions between salinity and plant macro-nutrients is complex but the combined effects lead to a reduction in primary production and an alteration of nutrient standing stocks. These impacts could have deleterious impacts on food webs and ecosystem services in this region.

Ca: Salinity dominated by Na (e.g. NaCl) reduces calcium availability, transport, and mobility with the plant. However many factors influence Ca nutrition in plants. These Factors include the total Ca2
supply, the nature and species of counter-ions, substrate pH, and the ratio of Ca to other cations in the substrate solution. When soils are saturated with Na this cation ratio is strongly offset.

K: Numerous studies with a wide variety of horticultural crops have shown that K concentration in plant tissue, expressed on a dry mass basis, declines as the Na-salinity or as the Na/Ca2. In brief, high levels of external Na interfere with K acquisition by the roots, but also may disrupt the integrity of root membranes and alter their selectivity. The selectivity of the root system for K over Na must be sufficient to meet the levels of K required for metabolic processes, for the regulation of ion transport, and for osmotic adjustment.

NO3-: Cl is readily taken up by plants and its accumulation occurs concomitant with a reduction shoot tissue NO3 concentrations. Numerous studies show that NaCl treated plants contain less tissue N than plants growing in the absence of salinity. Chloride competes strongly with NO3 for binding sites on the plasma membrane and can suppress the transport of NO3 from the external solution.

PO4-: Like nitrogen, increased salinity decreases P in plant tissues; commonly tissue P reduced by 20 to 50%; Phosphate availability is reduced in saline soils not only because of ionic strength effects that reduce the activity of phosphate but also because phosphate concentrations in soil solution are tightly controlled by sorption processes and by the low-solubility of Ca±P minerals. Therefore, it is understandable that phosphate concentrations in field-grown agronomic crops decreased as salinity (NaCl . CaCl2) increased (Sharpley et al., 1992).



Introductions of brines may not only impact vegetation but also other wetland assemblages.

Macroinvertebrate responses to salinity have been documented above 1,000 mg/L. Above this level, diversity of macroinvertebrate communities decreases rapidly.

Changes in macroinvertebrate communities can have dramatic impacts on detrital processing and secondary consumers including: fish, amphibians, and waterfowl. For example, Ca needed by waterfowl for eggshell formation during laying is met by feeding on invertebrates.

Impacts of elevated salinity on amphibian assemblages have been documented. High salt concentrations reduce speed and movement of tadpoles (Denoel et al 2010). Increases in surface water salinity may disproportionately affect amphibians with extended larval periods (e.g. *Ambystoma tigrinum*). Multiple bouts of poor or unsuccessful recruitment due to elevated salinity could ultimately lead to local extinctions (Karraker et al. 2008) and reduce amphibian diversity over several years.

Assessing Biological Impacts

- **Rapid BioAssessment Approaches**
  - Primary goal of bioassessments is to *identify the impacts of anthropogenic disturbance to the biotic integrity of wetlands*
- **Assessment Indicators (Adamus 1996)**
  - Microorganisms
  - Algae
  - Vascular plants
  - Macroinvertebrates
  - Amphibians
  - Birds

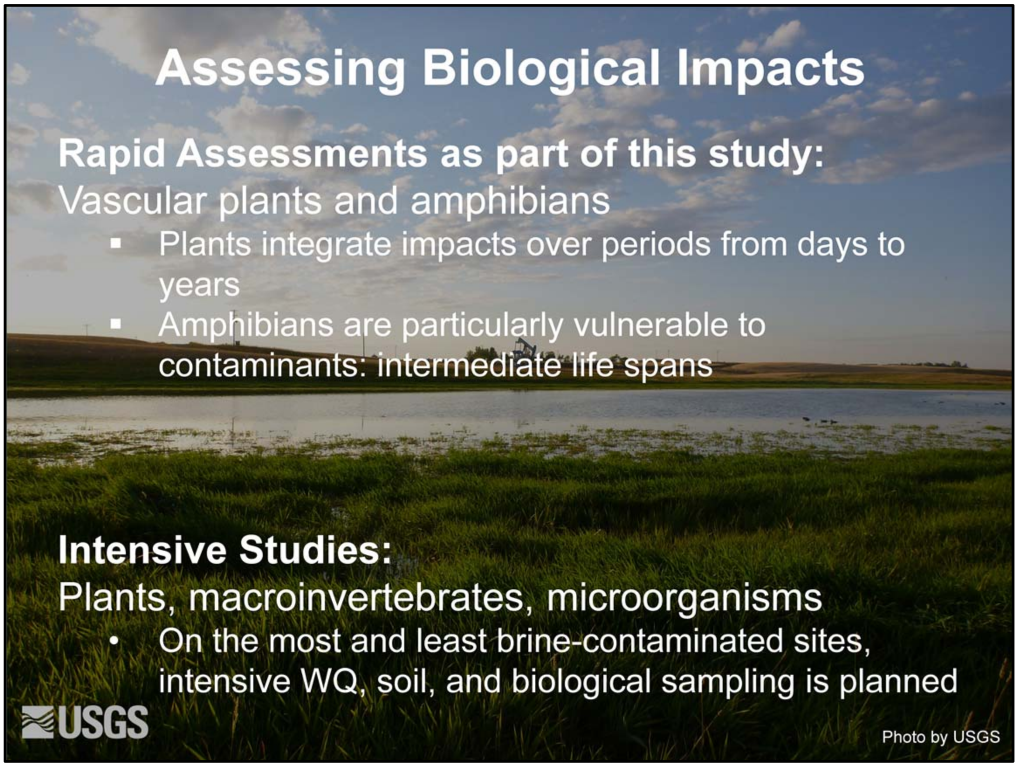
USGS

Given the scale and rate of oil and gas development in this region, the mobility of released brine in groundwater resources, and the magnitude of risk to PP wetlands, the need for comprehensive monitoring and assessment of wetlands in the Willston Basin is high.

This year we will begin rapid assessments of wetlands across this region.

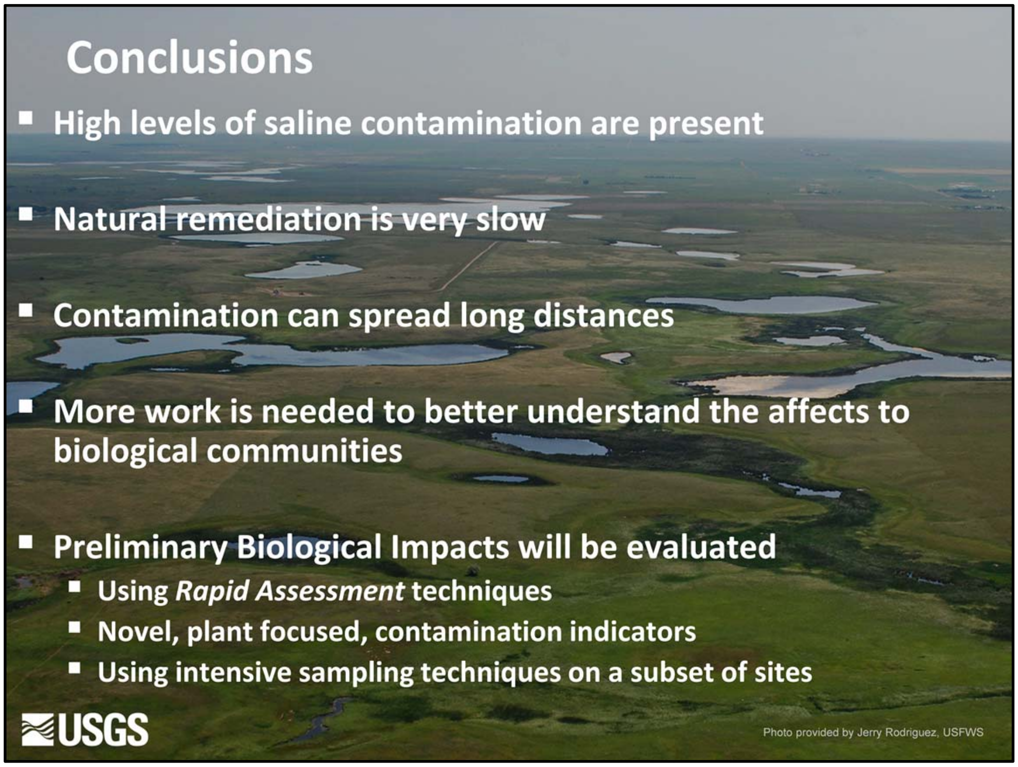
To be useful, rapid assessments must be *statistically valid* and *environmentally relevant* to a defined region (USEPA 2012).

Because of their recognized role as biological indicators, Paul Adamus recommended six potential indicators for this region: microorganisms, algae, vascular plants, macroinvertebrates, amphibians, and birds.



This year we will used a modified version of the MT Natural Heritage Programs Level 2 Assessment. We wil include measures of water quality, vascular plants, and amphibians.

In addition we will use intensive field studies on a subset of sites. These surveys will focus on characterization of surface and groundwater chemistry, soil type, organic matter content, bulk density, and descriptions of the composition and estimates of biomass of vegetation and macroinvertebrates.



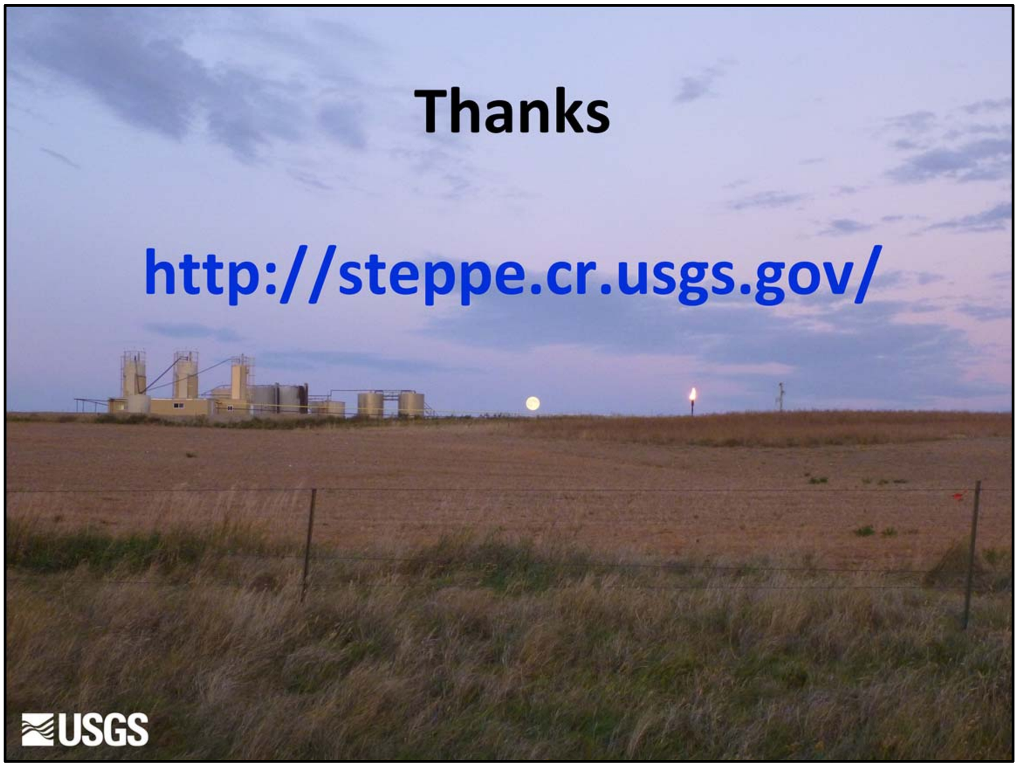
Based on the site studies, we observed that the brine contamination from energy development that occurred as long as 2 decades ago is still persistent in the shallow aquifers and wetlands.

Natural remediation is very slow.

Contamination is mobile on the surface and in the shallow subsurface.

There is a growing need to understand biological impacts.

Studies this year will….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