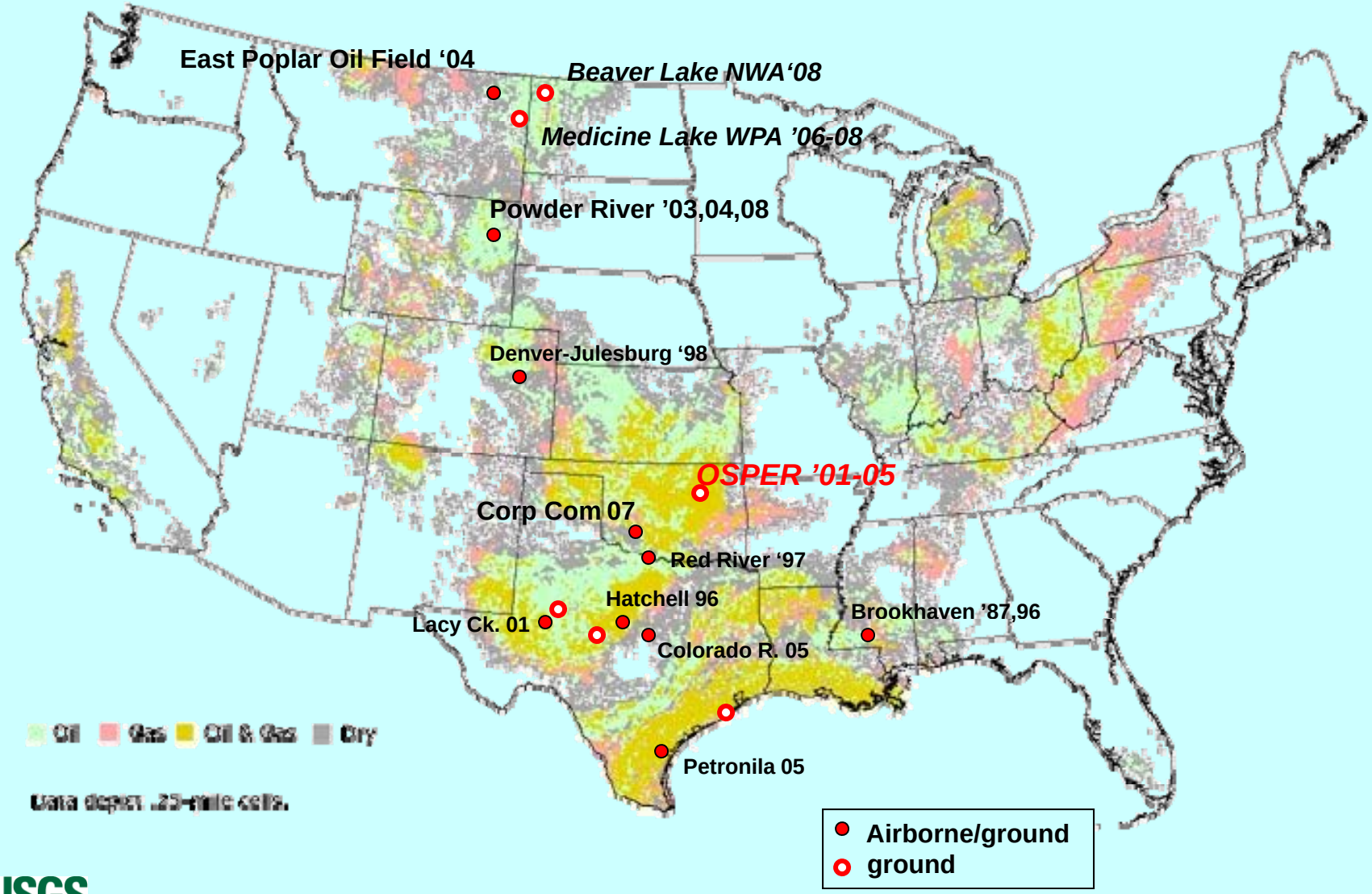
Terrain Conductivity Measurements of Brine-affected Oil Production Sites on U.S. Fish and Wildlife Lands, Williston Basin, Montana and North Dakota

Bruce D. Smith[1], Kevin M. Johnson[2], Karen Nelson[2], Robert Gleason[1], Richard Sojda[1], Joanna N. Thamke[1], Mickey McCall[3], and Jon C. Reiten[4]

(1) U.S. Geological Survey
(2) U.S. Fish and Wildlife Service
(3) Sheridan County Conservation District, Montana
(4) Montana Bureau of Mines and Geology

Electrical Conductivity Geophysical Surveys in Energy Environmental Studies



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Background for Study:

U.S. Geological Survey has conducted electrical geophysical surveys over the last 20 years to map and characterize subsurface produced waters in a number of different hydrogeologic environments including:

- **Perched ground water setting – Brookhaven MS – impacts on water supply**
- **Semi Arid vadose zone - OK Osage study area research study area**
- **Semi Arid vadose and ground water in Powder River Basin – disposal and use of CBNG water**

Described in this talk

- ***Glacial terrain ground water controlled by gravel channels- Ft. Peck MT – impact city water supply***
- ***Prairie Pot Hole wet lands Williston Basin – – impact on wildlife areas (under study)***

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Physical Basis of Electrical Geophysical Subsurface Imaging

- Electrical properties of fluids
- Properties of matrix (porosity, permeability, and conductivity)
- Rock-Water Interactions (redox-natural potentials)
- Conductive (saline) plumes both below water table (saturated zone) and above (vadose zone)

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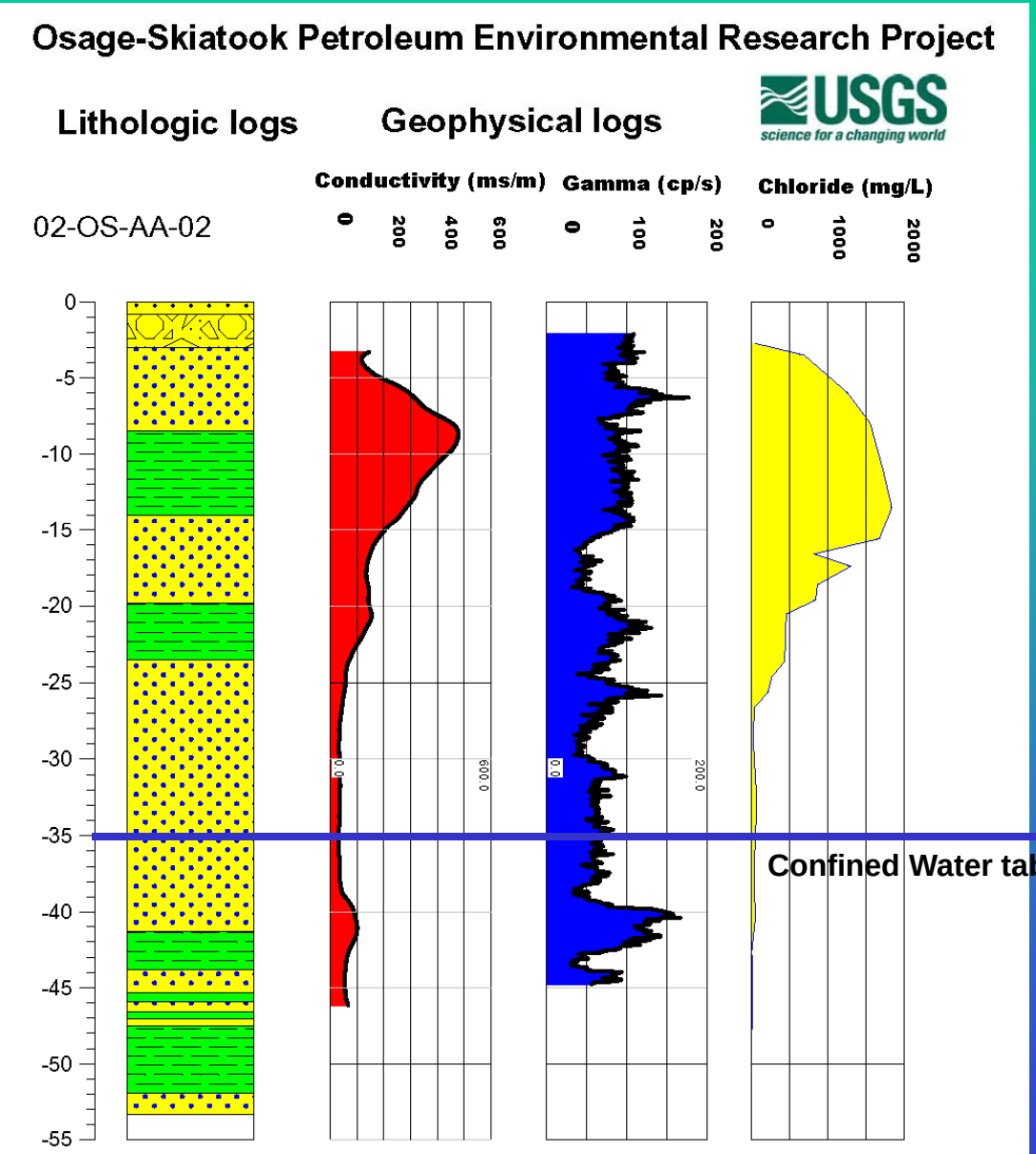
Osage Skiatook Petroleum Environmental Research Site (OSPERS)

Drill Hole AA02

Comparison of borehole log and core extract geochemistry

Water = 12,000 mg/l TDS



Green -- shale units

Yellow Sandy units

Total depth: 53.35 ft

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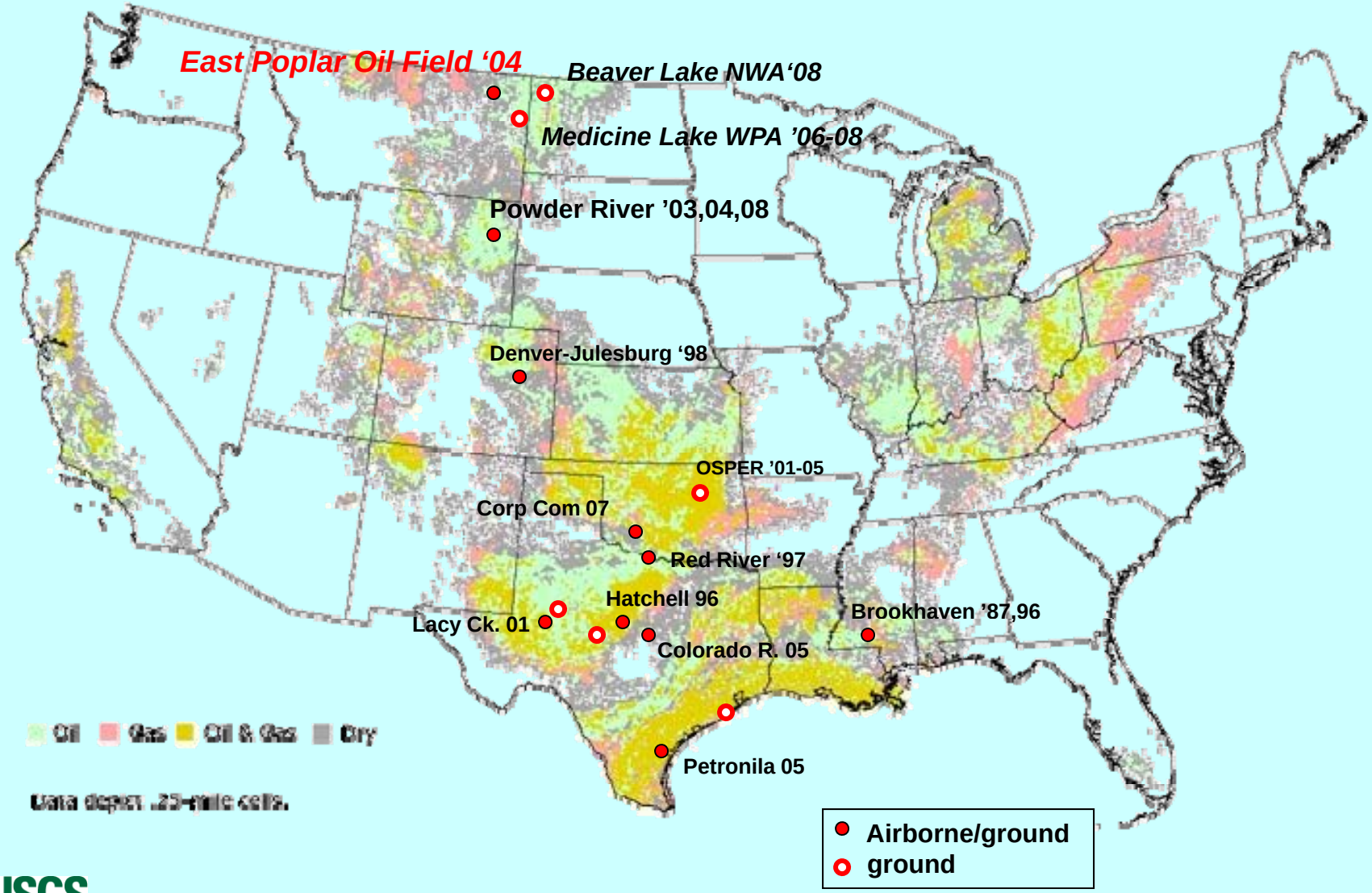

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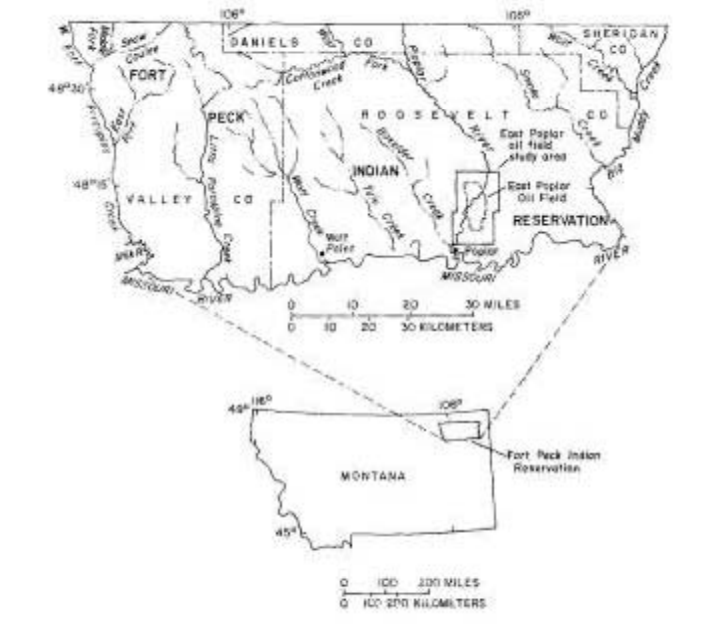
USGS – Ft. Peck History of activity



Joanna Thamke (USGS MT)

Crista Tyrell (Ft Peck Tribe)

Mike Jacobs (Pioneer Natural Resources)

- **1980s, first documented contamination**
- **1990s, mapped contamination**
  - **Ground shallow conductivity profiling**
  - **Identified source areas (much larger than suspected)**
  - **Borehole logging (93)**
- **2004 Helicopter EM survey summer**
- **2005 Ground-water studies and borehole logging continue**
- **2006 Pioneer Natural Resources begins remediation program southern part of field (pump and inject > $2mil)**
- **2008 As a result of USGS nomination, DOI Environmental Awareness Award made to project in recognition of excellence in environmental work**

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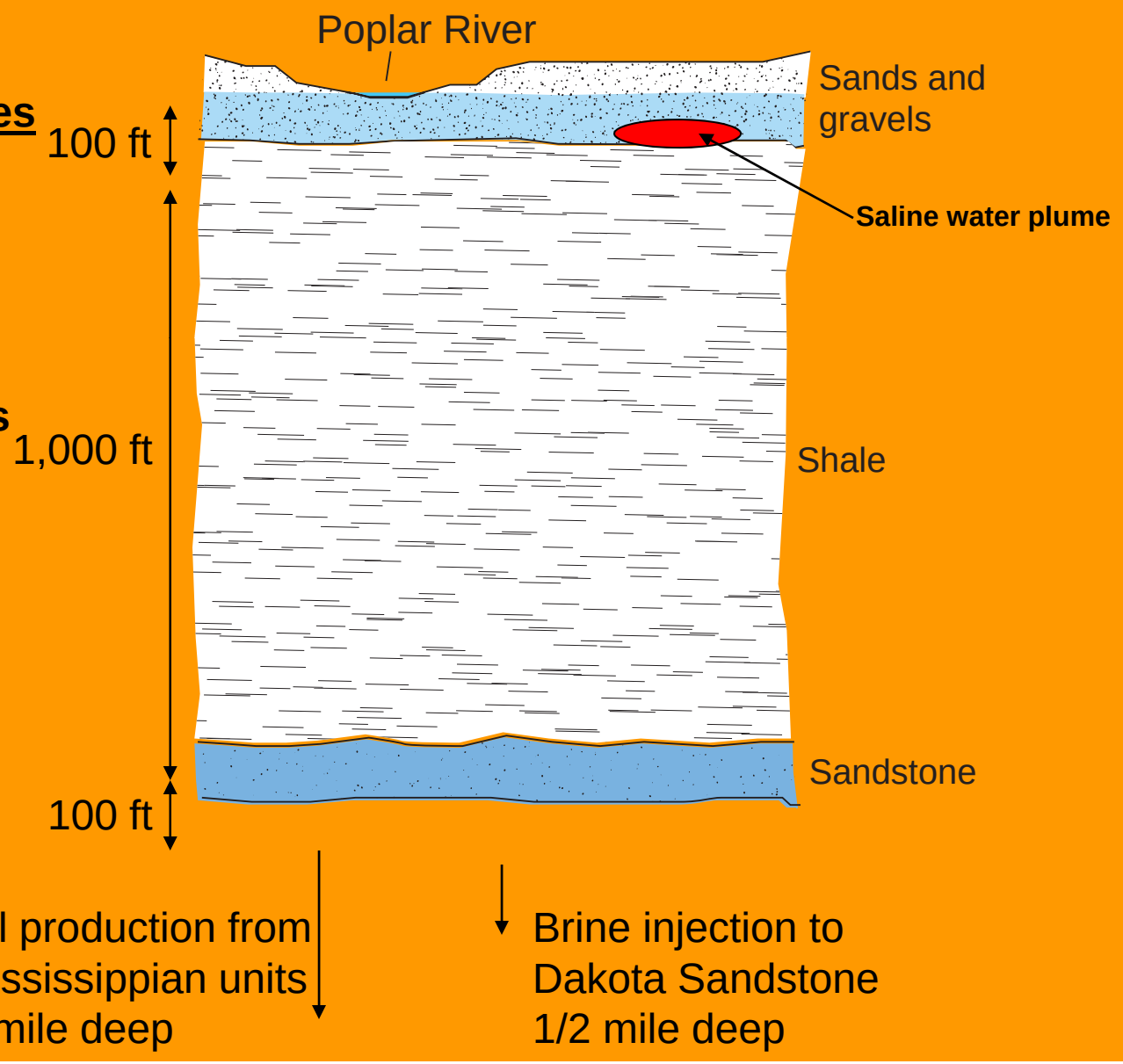
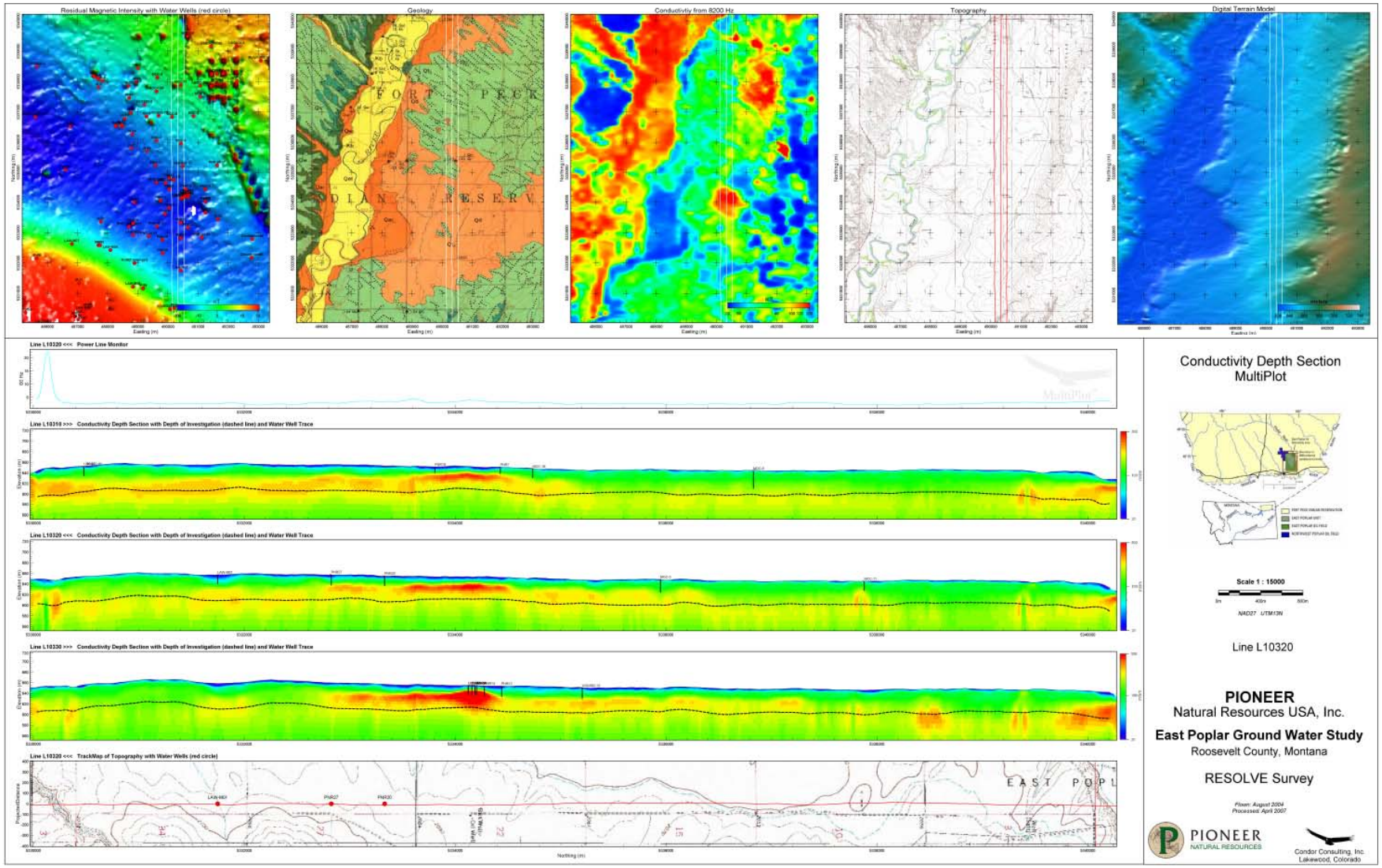
East Poplar Oil Field General Geology

Geophysical Challenges

- ✓ **clays in glacial sediments**
- ✓ **Bearpaw Shale**
- ✓ **salinization from agriculture**
- ✓ **power and pipe lines**



Ft Peck Poplar Oil Field Plume



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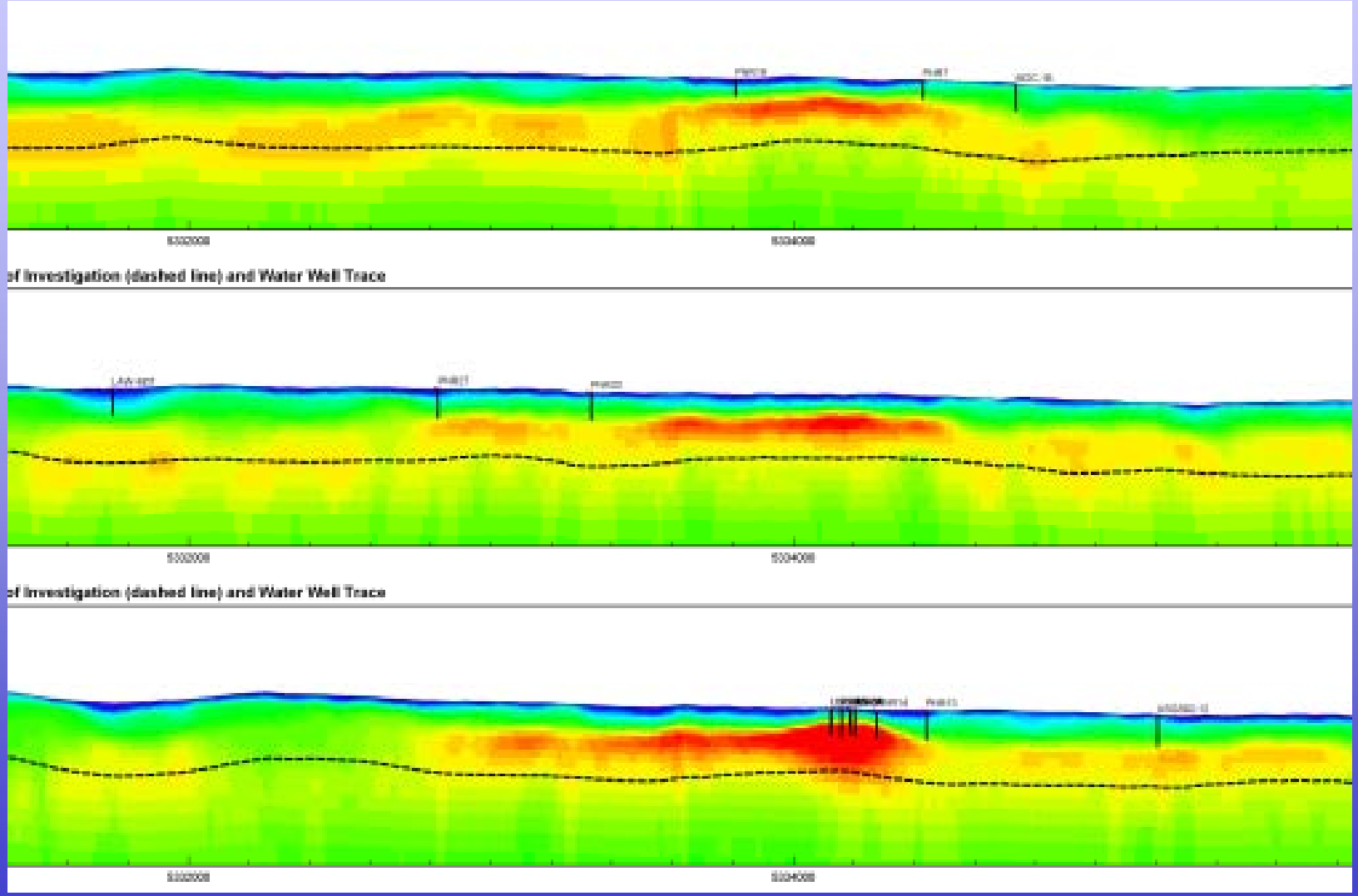
Ft Peck Poplar Oil Field Plume Zoom



Dotted line is approximate max resolution

Poplar Oil Field Lessons Learned

- Integration of all data critical in separation of subsurface sources high electrical conductivity
- Conductivity depth images (CDI) created from earth electrical models critical in separation of sources
- Areas can be prioritized for remediation in terms of ground-water resource management
- Use of CDI for modeling ground-water flow and bedrock topography
- Possible application for identification of areas of salinization from other sources such as agricultural

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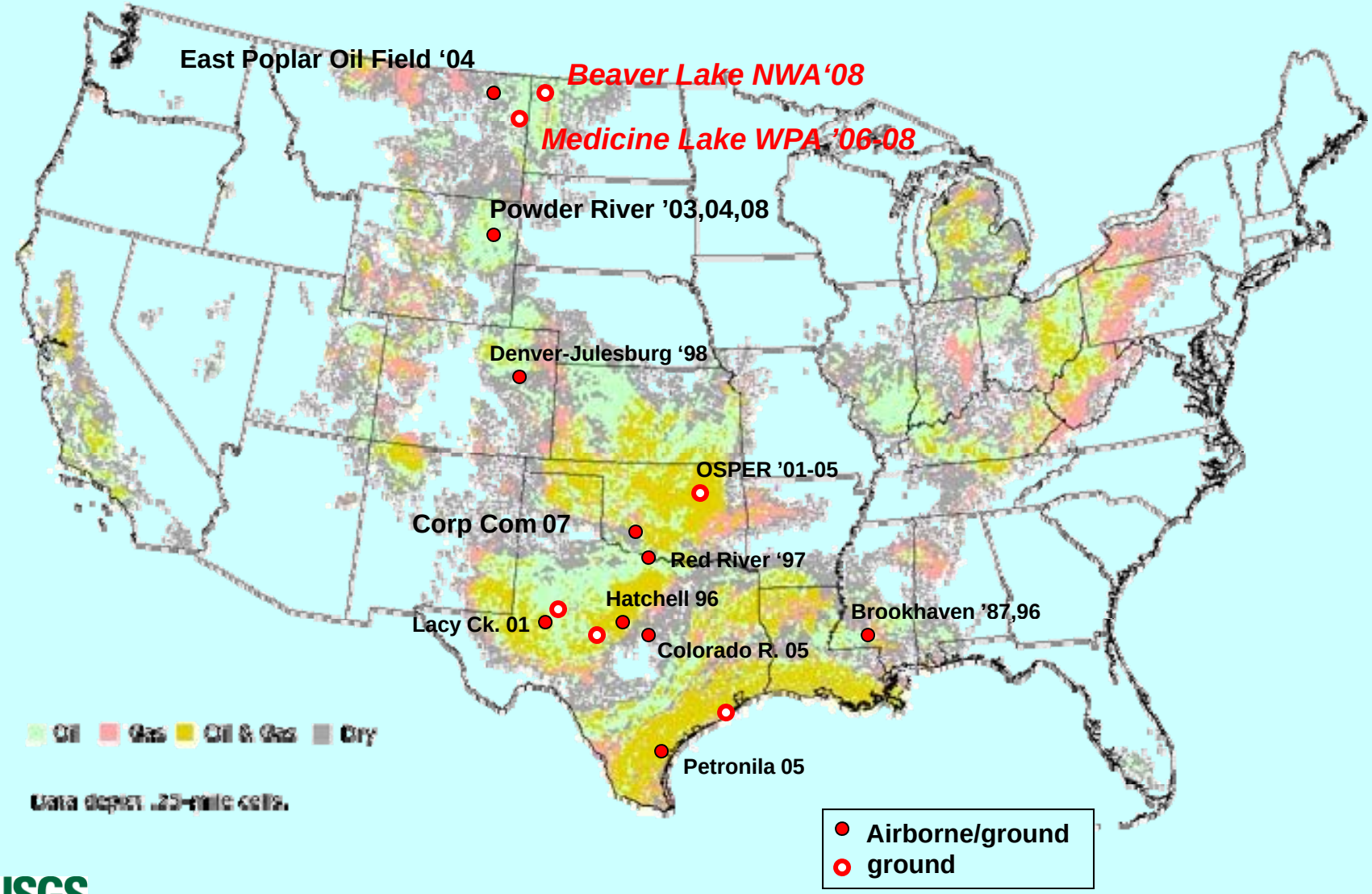

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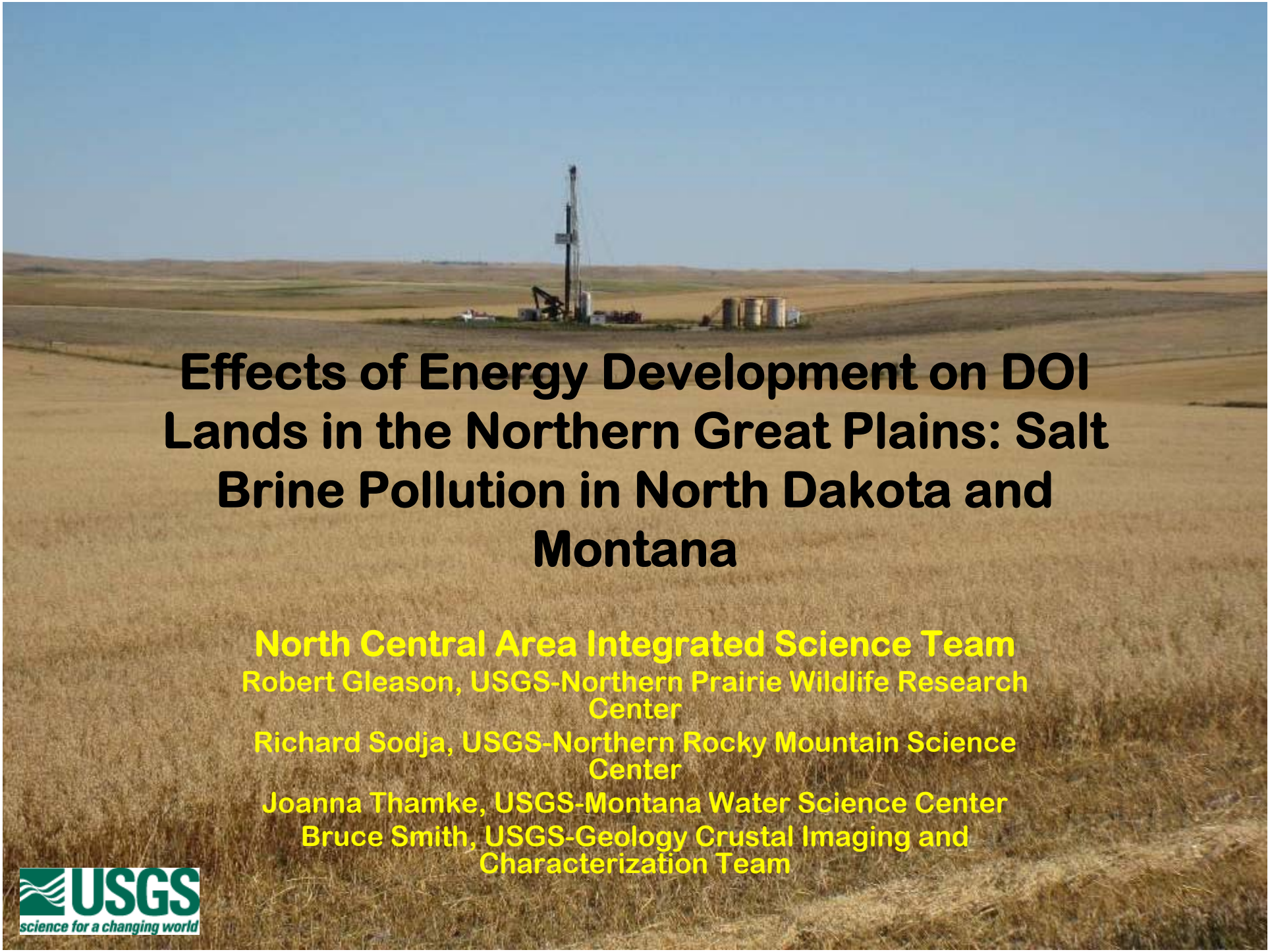

Effects of Energy Development on DOI Lands in the Northern Great Plains: Salt Brine Pollution in North Dakota and Montana

North Central Area Integrated Science Team

Robert Gleason, USGS-Northern Prairie Wildlife Research Center

Richard Sodja, USGS-Northern Rocky Mountain Science Center

Joanna Thamke, USGS-Montana Water Science Center

Bruce Smith, USGS-Geology Crustal Imaging and Characterization Team

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National Assessment of Oil and Gas Fact Sheet

Assessment of Undiscovered Oil Resources in the Devonian-Mississippian Bakken Formation, Williston Basin Province, Montana and North Dakota, 2008

Using a geology-based assessment methodology, the U.S. Geological Survey estimated mean undiscovered volumes of 3.65 billion barrels of oil, 1.85 trillion cubic feet of associated/dissolved natural gas, and 148 million barrels of natural gas liquids in the Bakken Formation of the Williston Basin Province, Montana and North Dakota.

Introduction

The U.S. Geological Survey (USGS) completed an assessment of the undiscovered oil and associated gas resources of the Upper Devonian–Lower Mississippian Bakken Formation in the U.S. portion of the Williston Basin of Montana and North Dakota and within the Williston Basin Province (fig. 1). The assessment is based on geologic elements of a total petroleum system (TPS) that include (1) source-rock distribution, thickness, organic richness, maturation, petroleum generation, and migration; (2) reservoir-rock type (conventional or continuous), distribution, and quality; and (3) character of traps and time of formation with respect to petroleum generation and migration. Detailed framework studies in stratigraphy and structural geology and the modeling of petroleum geochemistry, combined with historical exploration and production analyses, were used

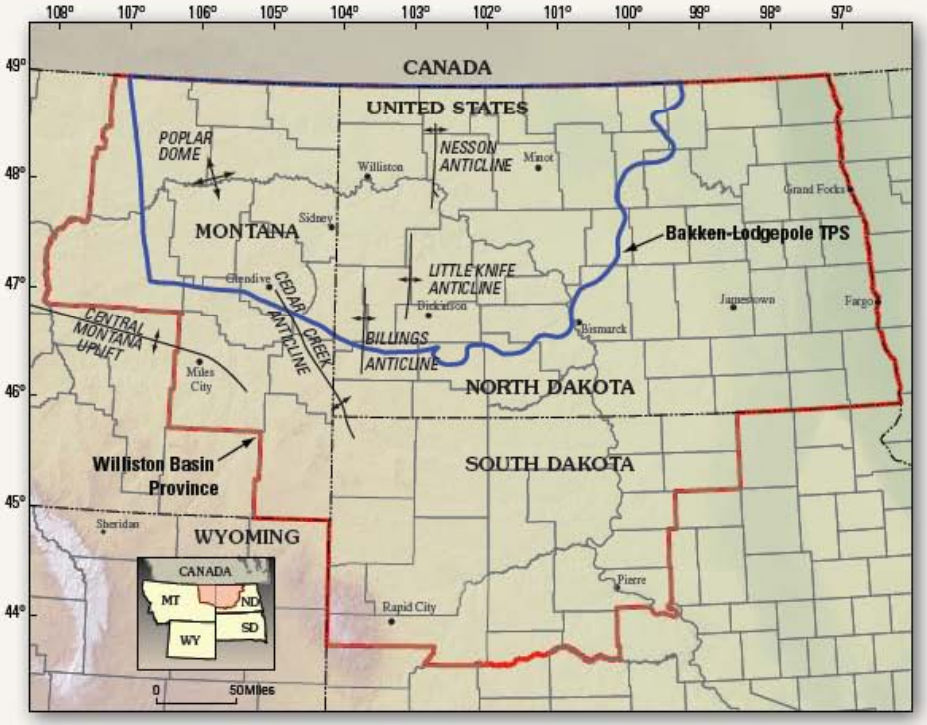
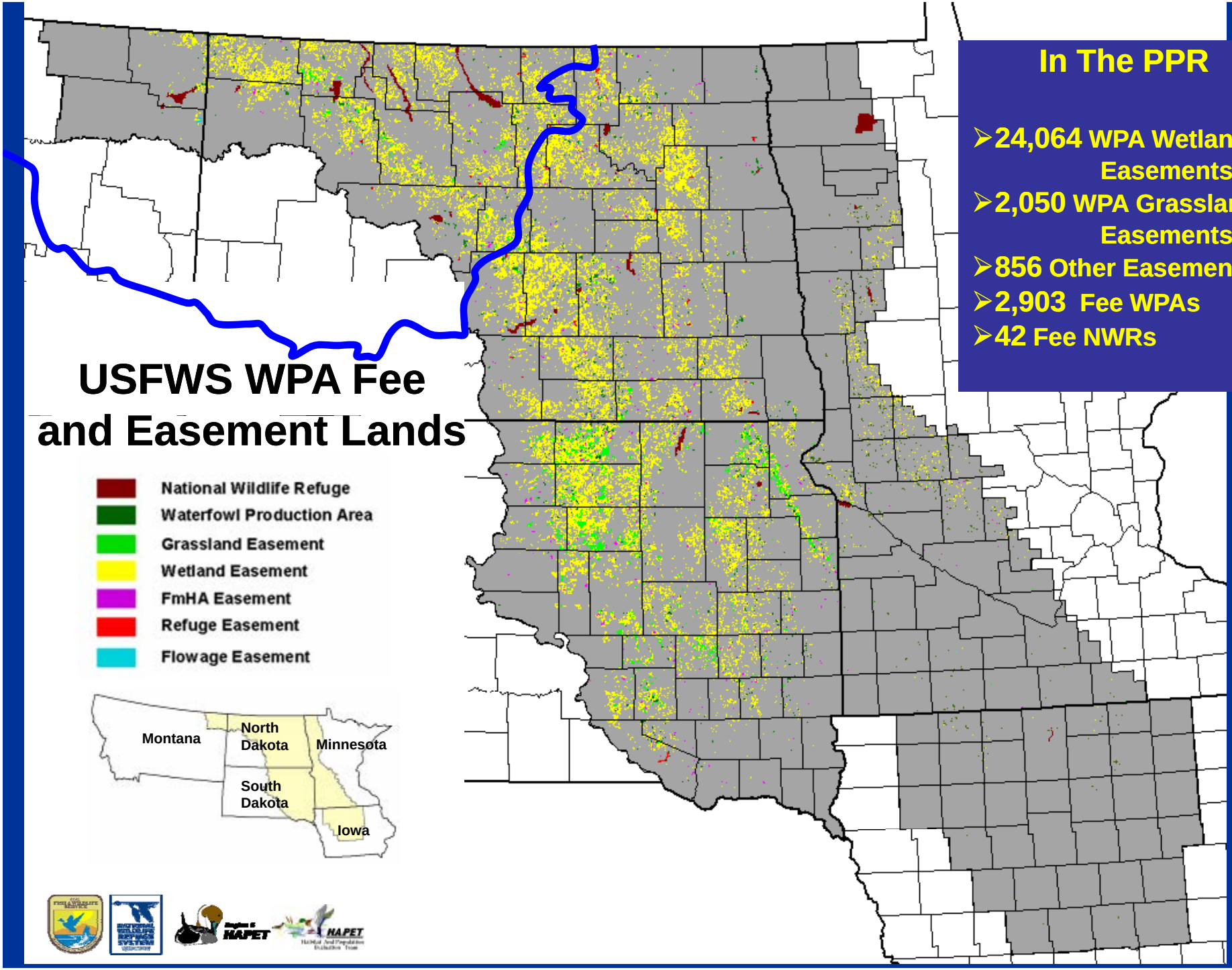


Figure 1. *Map showing Williston Basin Province boundary (in red), Bakken-Lodgepole Total Petroleum System (TPS) (in blue), and major structural features in Montana, North Dakota, and South Dakota.*

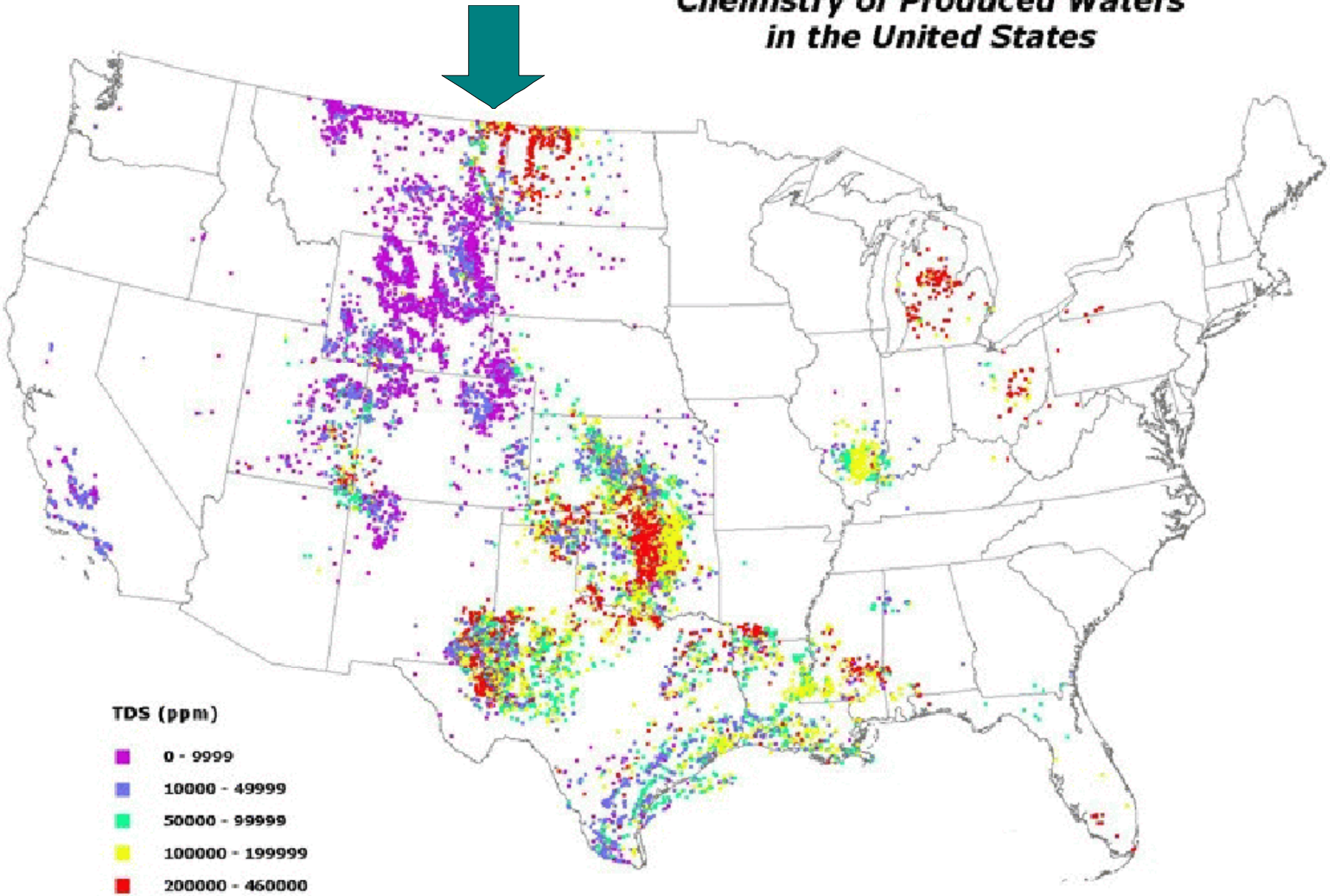
USFWS WPA Fee and Easement Lands



In The PPR

- 24,064 WPA Wetland Easements
- 2,050 WPA Grassland Easements
- 856 Other Easements
- 2,903 Fee WPAs
- 42 Fee NWRs

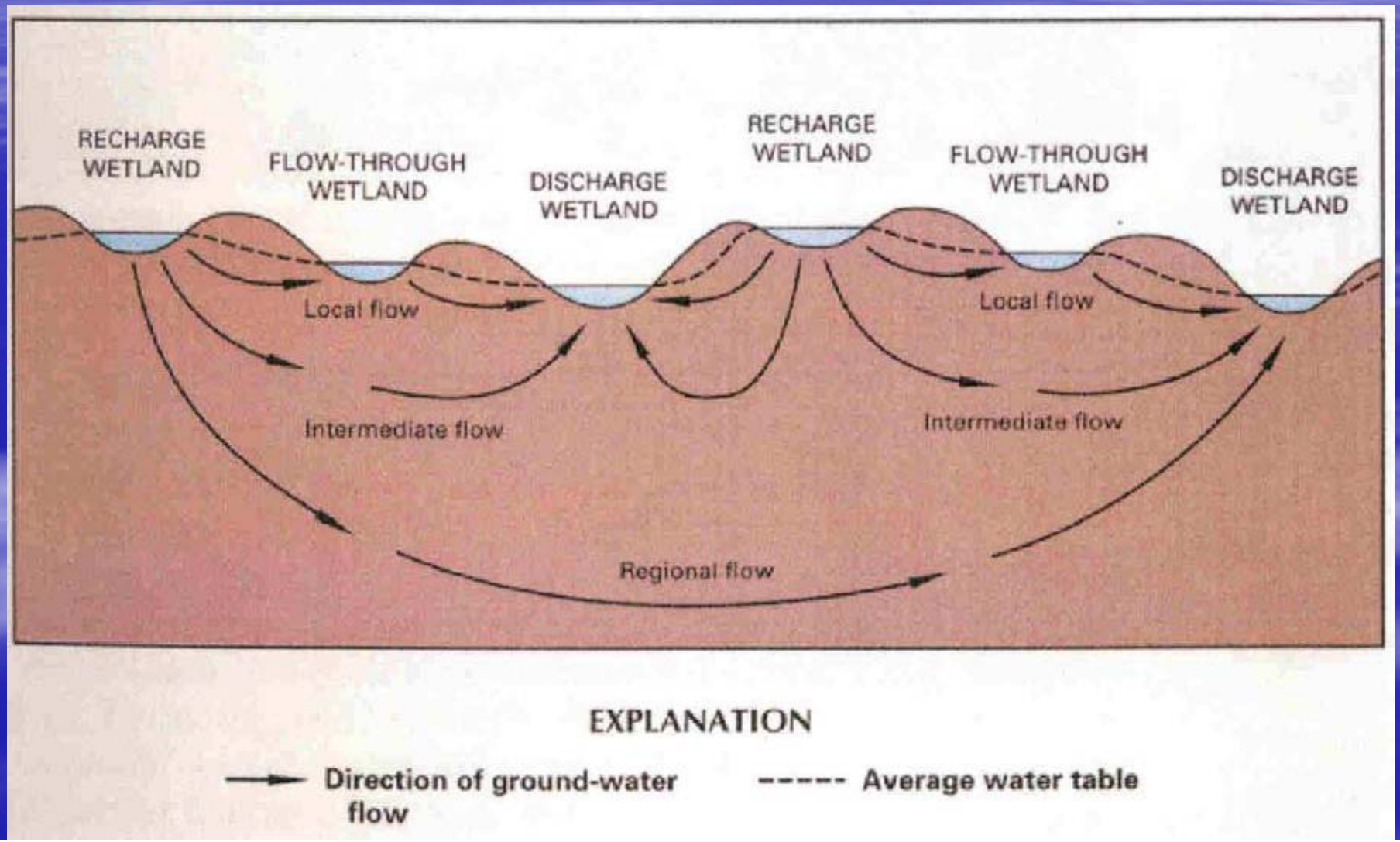
Chemistry of Produced Waters in the United States



MT - Impacts of Oil Exploration and Production to the U.S. Fish and Wildlife Service's Northeast Montana Wetland Management District

Karen J. Nelson, USFWS, Helena MT, Jon C. Reiten, MBMG, Billings MT, and Mike Rabenberg, USFWS, Medicine Lake, MT

Natural geochemical diversity created by: Groundwater flow path, aquifer mineralogy, evaporation rates….



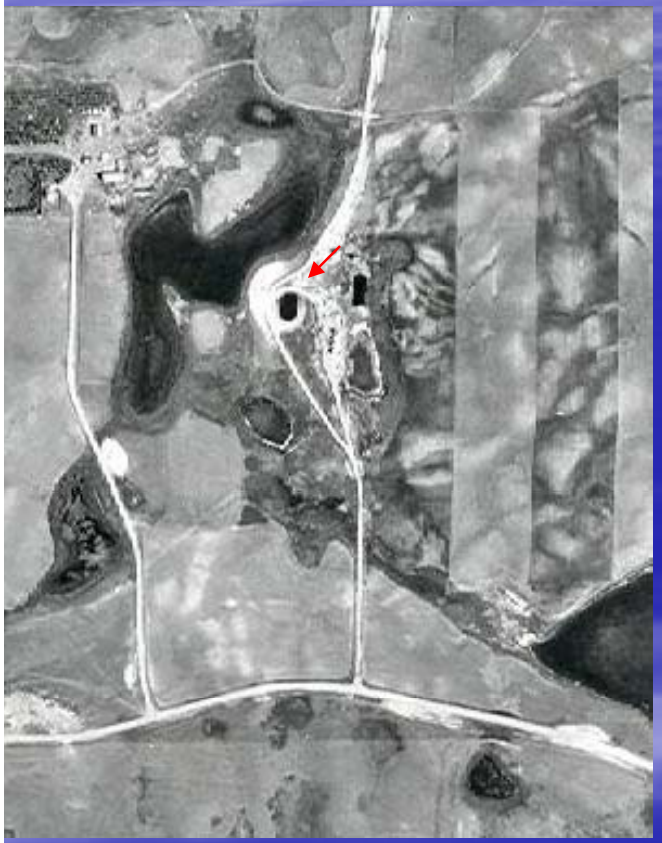
Assessment Methods

- Produced water contamination index
- NORM surveys (not discussed here)
- EM-31 Soil Conductivity Surveys
- Groundwater sampling in identified plumes
- Hydrocarbon sampling and plume delineation
- Toxicity Testing (not discussed here)
- Invertebrate sampling and identification (not discussed here)

Contaminant Pathways in the Williston Basin

Infiltration pits for produced water disposal

Produced waters sampled at reinjection sites contained barium, cadmium, chromium, lead, selenium, silver, and zinc



July, 1967

July, 1974

Infiltration pit location 2004

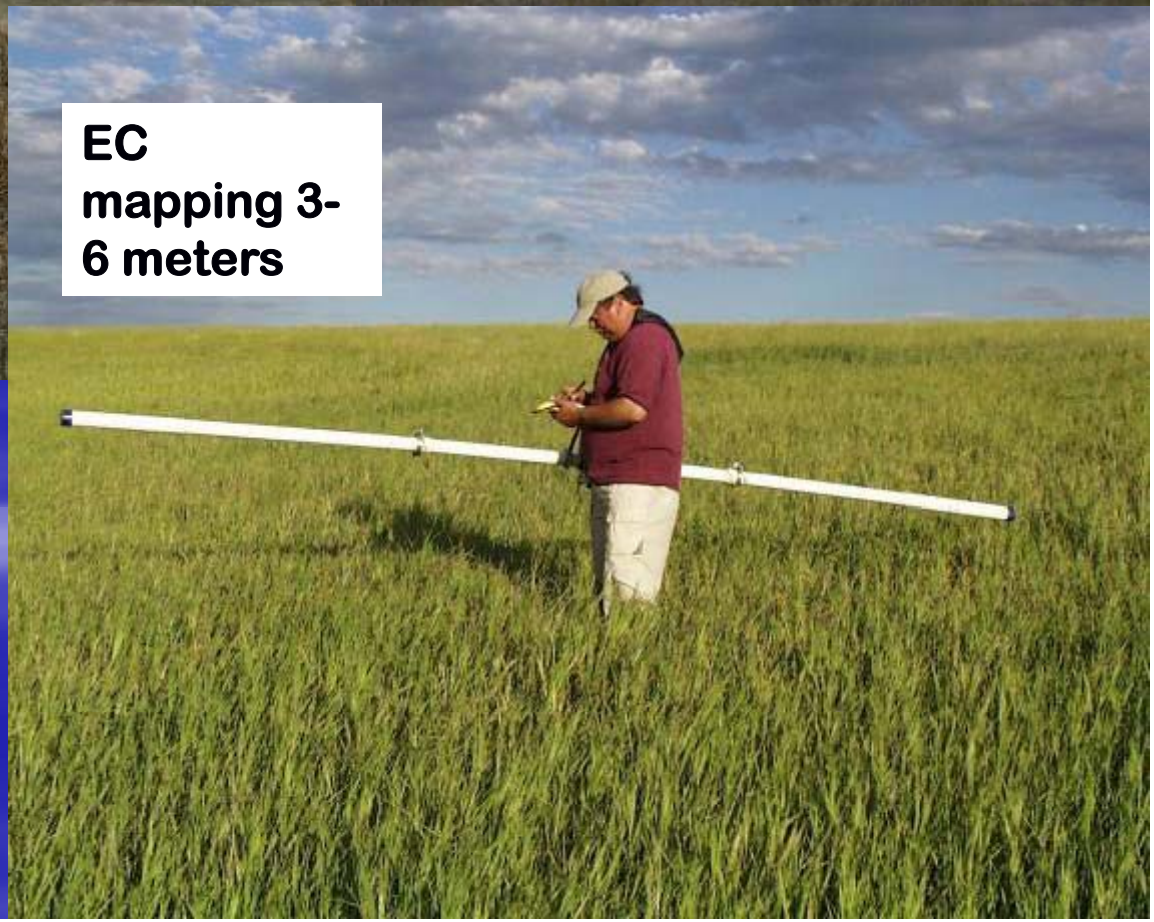
Produced Water Contamination Index

SC µs/cm:Cl mg/L >0.034 Produced water impacts

Surface water samples collected from 80 wetlands and lakes

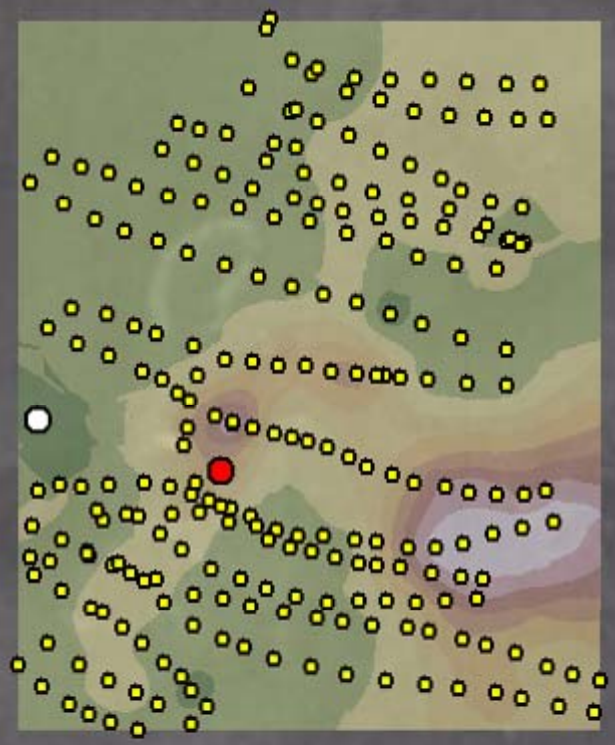
50 % revealed impacts from produced water

WPA/NWR	Site	SC µs/cm	Cl mg/L	CI
Parry	PAR1	4902	53	0.0108
Parry	PAR1E	4680	53	0.0113
Parry	PAR2	55185	1547	0.0280
Parry	PAR3	4351	61	0.0140
Parry	PAR3	5928	84	0.0142
Parry	PAR4	2669	27	0.0101
Parry	PAR4	3396	30.5	0.0090
Rabenberg	RABE1	22480	8362	0.3720
Rabenberg	RABE2A	4130	953	0.2308
Rabenberg	RABE2	5150	1485	0.2883
Rabenberg	RABE3	4011	908	0.2264
Rabenberg	RABE3A	2731	650	0.2380
Rabenberg	RABE4	8658	3145	0.3632
Rabenberg	RABE5	7509	2420	0.3223
Rabenberg	RABE5	8126	2690	0.3310
Rabenberg	RABE5+	8437	2908	0.3447
Rabenberg	RABE6	8812	2614	0.2966



Soil Conductivity Surveys

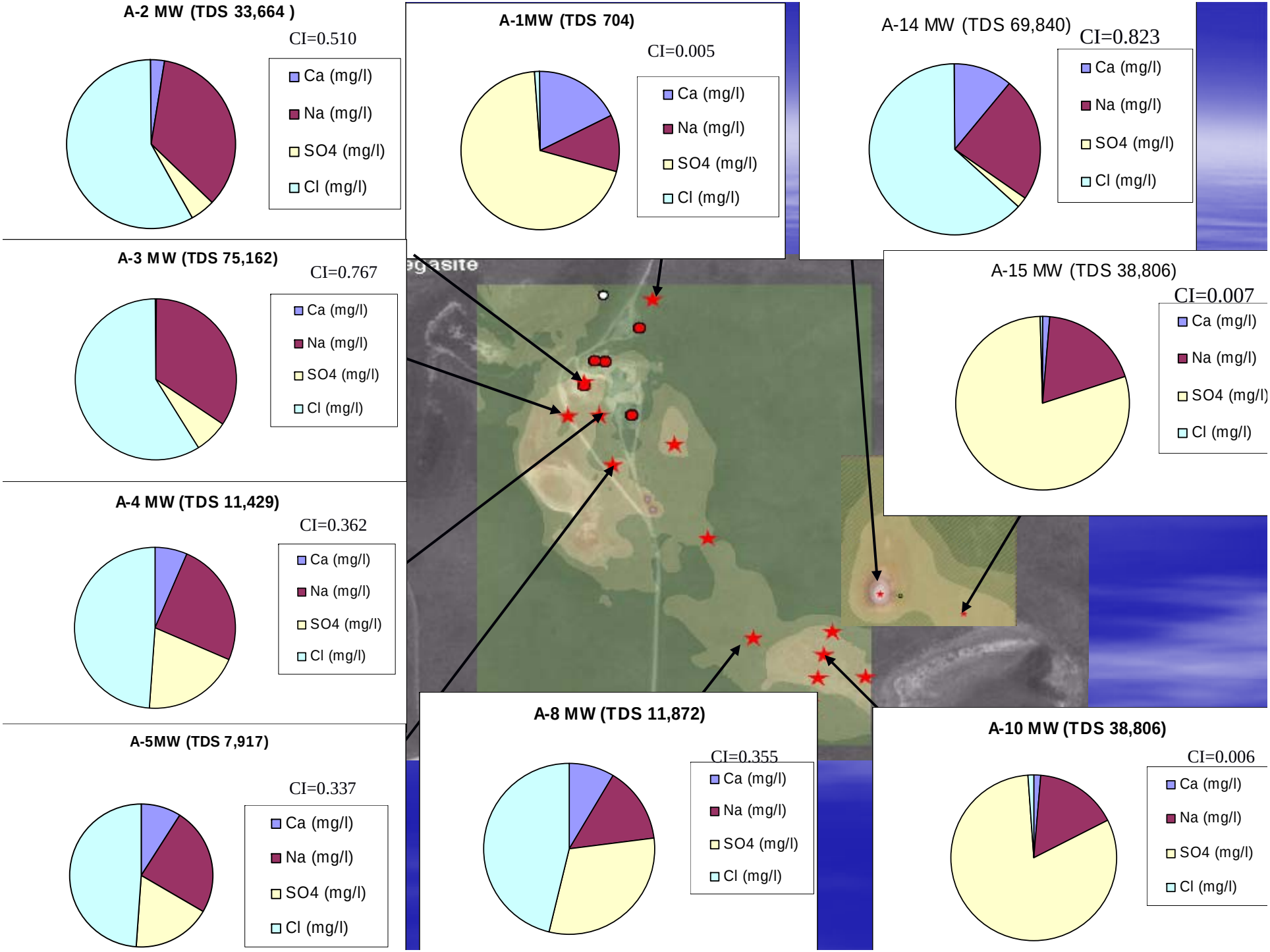
- Conducted using an EM-31 and a Trimble GeoXT
- Completed on 30 sites, on or near Service owned land
- High EC (Plumes) delineated at all but one survey location



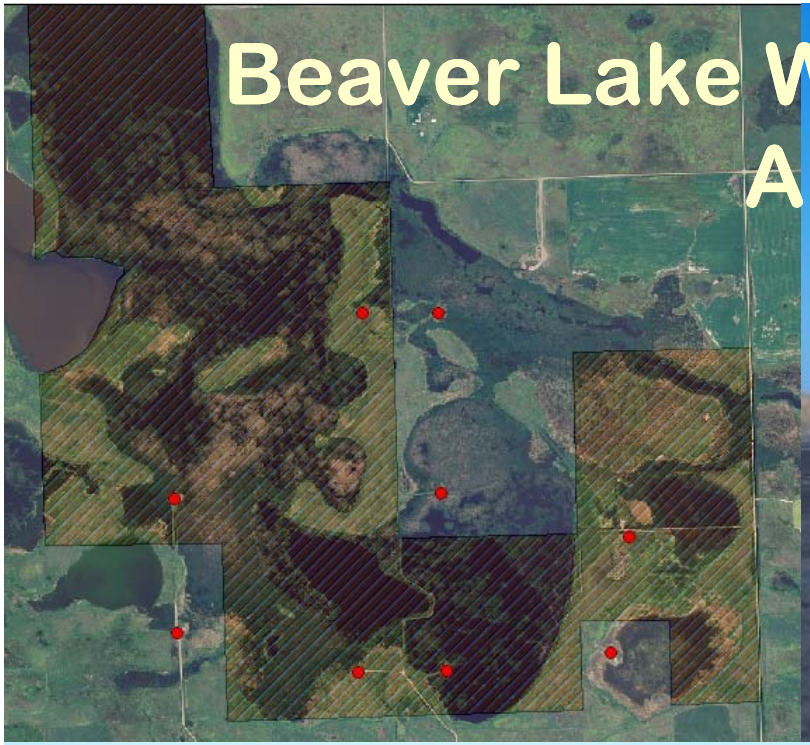
- Trimble files containing EM-31 data were used to create plume maps utilizing Kreiging
- Monitoring well locations selected based on plume maps

Installation of Monitoring wells

- 33 wells established on 6 WPAs and 2 ML NWR locations
- Sampled for major ions, trace element, and TPH

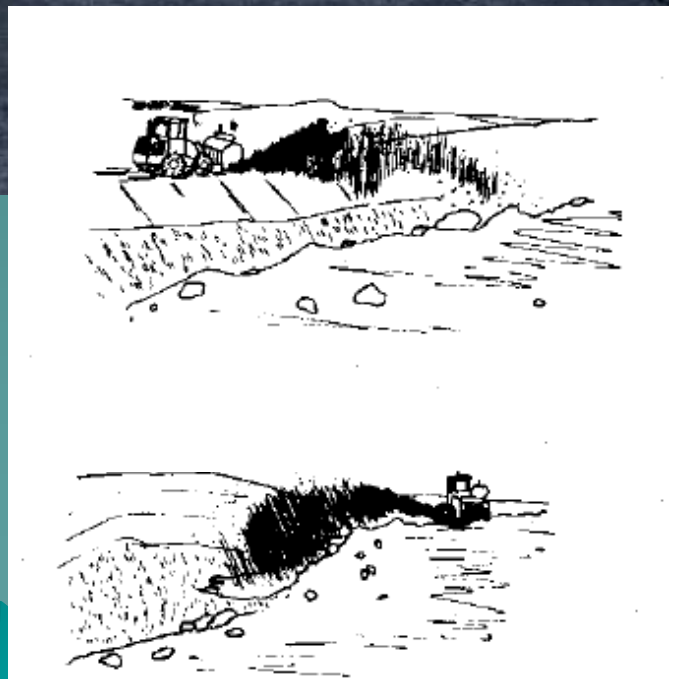

A-2 MW (TDS 33,664)
CI=0.510
Ca (mg/l)
Na (mg/l)
SO4 (mg/l)
Cl (mg/l)
A-1MW (TDS 704)
CI=0.005
Ca (mg/l)
Na (mg/l)
SO4 (mg/l)
Cl (mg/l)
A-14 MW (TDS 69,840)
CI=0.823
Ca (mg/l)
Na (mg/l)
SO4 (mg/l)
Cl (mg/l)
A-3 MW (TDS 75,162)
CI=0.767
Ca (mg/l)
Na (mg/l)
SO4 (mg/l)
Cl (mg/l)
A-15 MW (TDS 38,806)
CI=0.007
Ca (mg/l)
Na (mg/l)
SO4 (mg/l)
Cl (mg/l)
A-4 MW (TDS 11,429)
CI=0.362
Ca (mg/l)
Na (mg/l)
SO4 (mg/l)
Cl (mg/l)
A-5MW (TDS 7,917)
CI=0.337
Ca (mg/l)
Na (mg/l)
SO4 (mg/l)
Cl (mg/l)
A-8 MW (TDS 11,872)
CI=0.355
Ca (mg/l)
Na (mg/l)
SO4 (mg/l)
Cl (mg/l)
A-10 MW (TDS 38,806)
CI=0.006
Ca (mg/l)
Na (mg/l)
SO4 (mg/l)
Cl (mg/l)

Beaver Lake Waterfowl Protection Area, ND



Kevin Johnson USFW Bismark ND
Bruce Smith, USGS Denver
Ryan Tompkins, USGS Nebraska

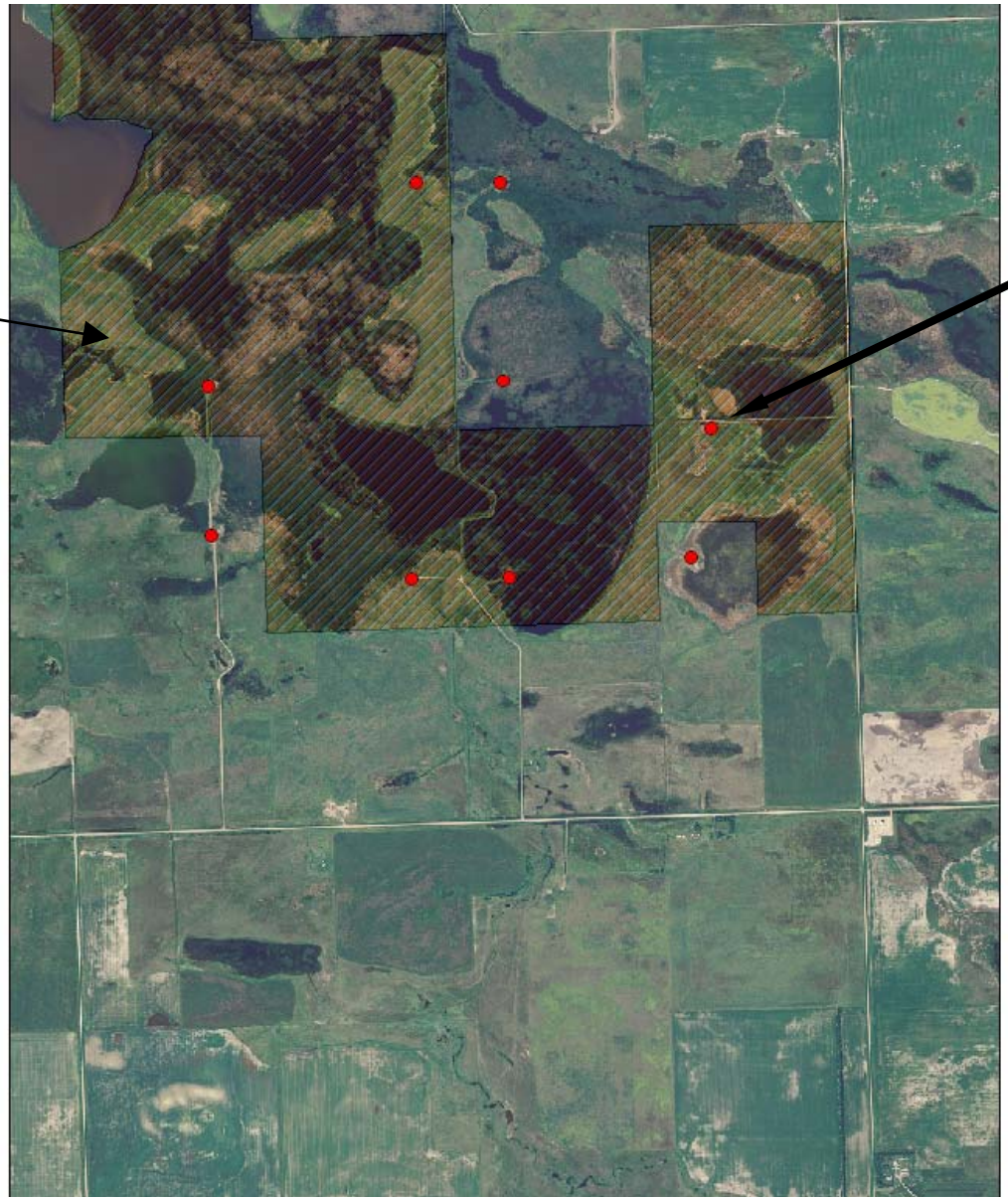
EM31 Operations February 2008



Areas of Interest
Abandoned and Active areas

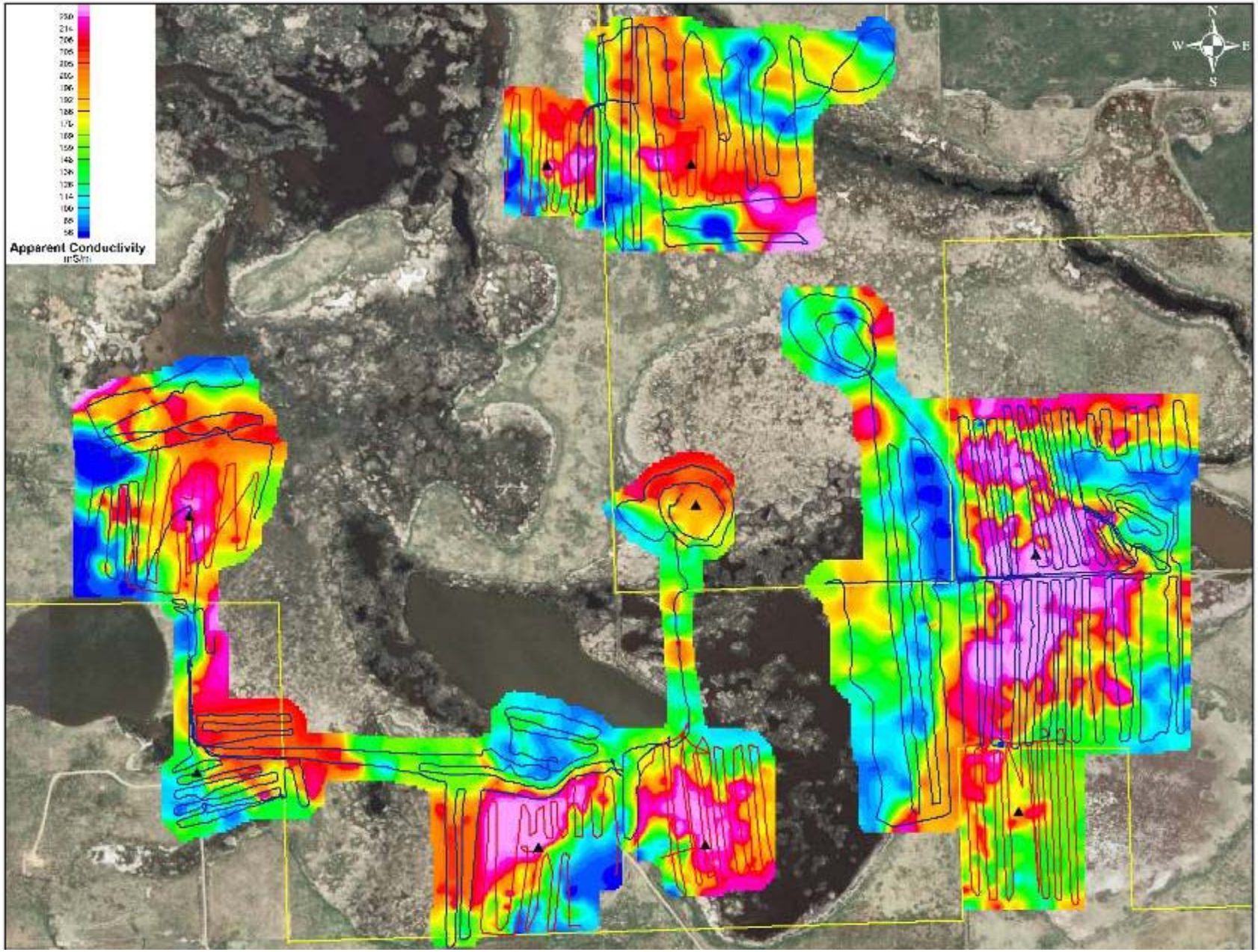
Beaver Lake

USFWS Lands

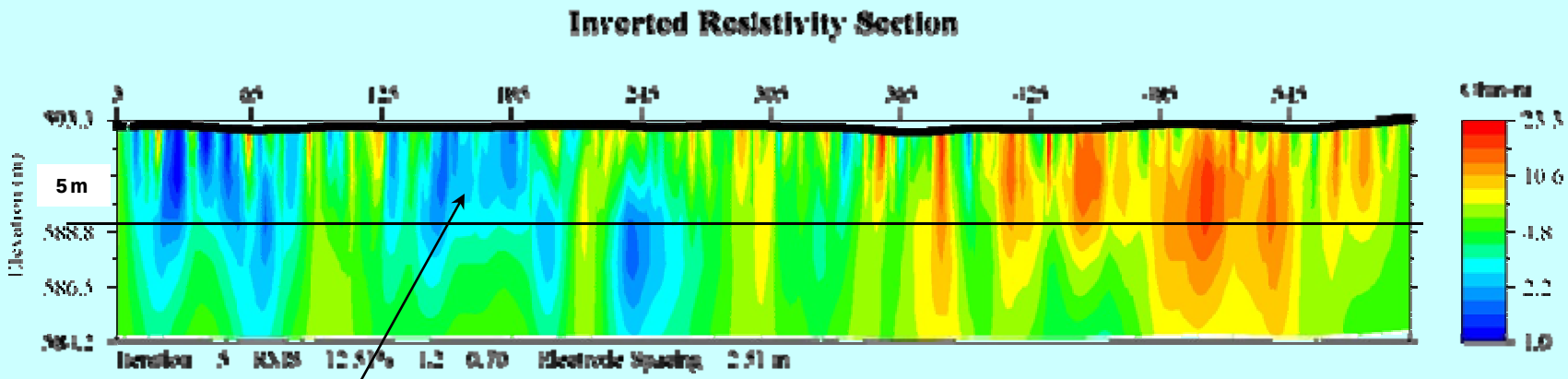


Sites of Interest

EM31 Beaver Lake WPA, Burke Co., ND



Ohm-mapper Resistivity



Light blue is low resistivity or high conductivity showing general extent of plume with depth

Conclusions

- Electrical conductivity ground and airborne geophysical methods are effective in the wetland setting of the prairie pot holes of Williston Basin – physical property contrast exists
- Shallow EM31 profiling method effective but depth limited – attenuated by lakes
- EC depth imaging needed for complete plume delineation in addition to drilling

This project was made possible by the funding, expertise, and support of the following agencies:

U.S. Fish and Wildlife Service
Division of Environmental Quality (Montana and North Dakota)
Medicine Lake National Wildlife Refuge Complex
HAPET Office, Bismarck, North Dakota
Montana Board of Oil and Gas Conservation Commission
Montana Bureau of Mines and Geology in cooperation with the Sheridan County Conservation District
Montana State University
University of Wyoming
U.S. Environmental Protection Agency
Region VIII Montana Office, Helena, MT
Office of Enforcement, Compliance, and Environmental Justice's Legal Enforcement Program, Denver, Colorado
U.S. Geological Survey, Denver, Colorado
North Dakota Department of Health
North Dakota Industrial Commission

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CI 0.0338
SC 260
CI 0.0378
SC 9681
CI 0.4631
SC 68366
CI 0.0984
SC 26286
CI 0.1443
SC 89693

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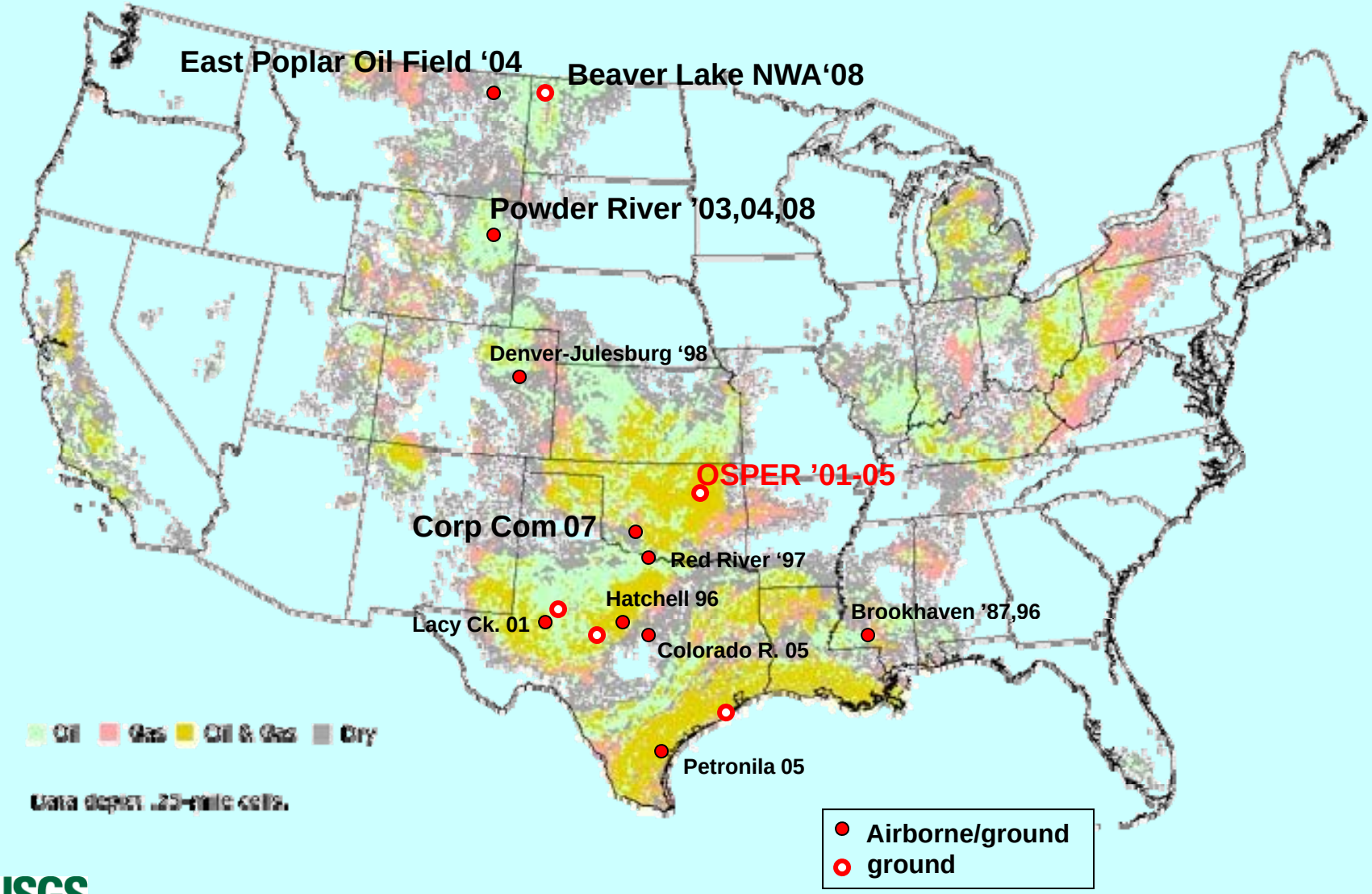

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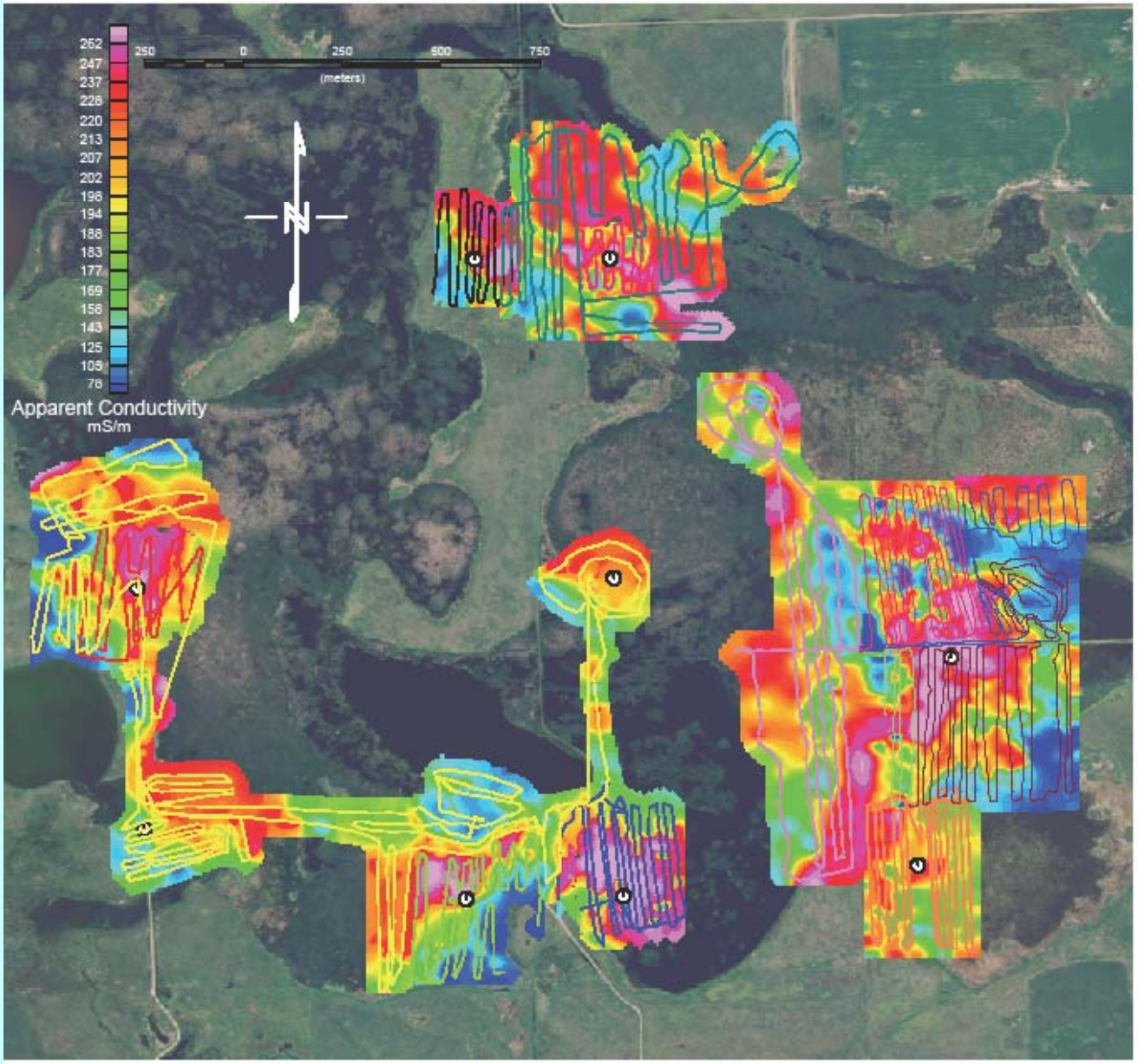
EM31 CONDUCTIVITY



Poplar Oil Field Lessons Learned

- Integration of all data critical in separation of subsurface sources high electrical conductivity
- Conductivity depth images (CDI) created from earth electrical models critical in separation of sources
- Areas can be prioritized for remediation in terms of ground-water resource management
- Use of CDI for modeling ground-water flow and bedrock topography
- Possible application for identification of areas of salinization from other sources

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