Site Characterization and Remediation of Contamination from Oilfield Produced Waters, East Poplar Oil Field, Fort Peck Indian Reservation Roosevelt County, Montana*

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Search and Discovery Article #80040 (2009)
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Abstract

The shallow aquifer(s) in this region has been heavily impacted by produced water from historical oil and gas operations. One identified point source of contamination was a plugged and abandoned production well operated by Mesa Petroleum, the Mesa Biere #1-22. The well was originally plugged in 1986 but appeared to have been improperly plugged and had released chloride-rich oilfield brine into the shallow aquifer. Parker and Parsley Oil and Gas Company merged with Mesa Petroleum in August 1997 to form Pioneer Natural Resources USA, Inc (PNR). PNR was first notified of this well in 1999.

The results of an investigation conducted by PNR in 1999-2000, indicated that the wellbore was leaking outside of the casing in the Cretaceous Judith River Formation at around 1000 feet below ground and was channeling into the shallow aquifer at approximately 40 feet below the ground surface. Some evidence of this was that in this area the natural ambient groundwater temperature is around 45 degrees Fahrenheit. However, in the immediate vicinity of the Biere #1-22 well the groundwater temperature was as high as 200 degrees Fahrenheit with chloride concentrations as high as 44,700 mg/L. PNR drilled three relief wells adjacent to the old wellbore and successfully sealed the wellbore.

In 2006 PNR began a detailed study to characterize both the regional geological and hydrological setting of the oilfield contamination as well as the contaminant plume from the Biere #1-22 well. Importantly, the study showed that the Biere #1-22 contaminant plume was located within a discrete, coarse-grained, gravel channel directly overlying the Cretaceous Bearpaw Shale that is separated both geologically and hydraulically from the other contaminant plumes in the area.

Site Characterization and Remediation
of
Contamination from Oilfield Produced Waters

East Poplar Oil Field, Fort Peck Indian Reservation
Roosevelt County, Montana

Presented by;

Michael A. Jacobs, P.G.

PIONEER
NATURAL RESOURCES

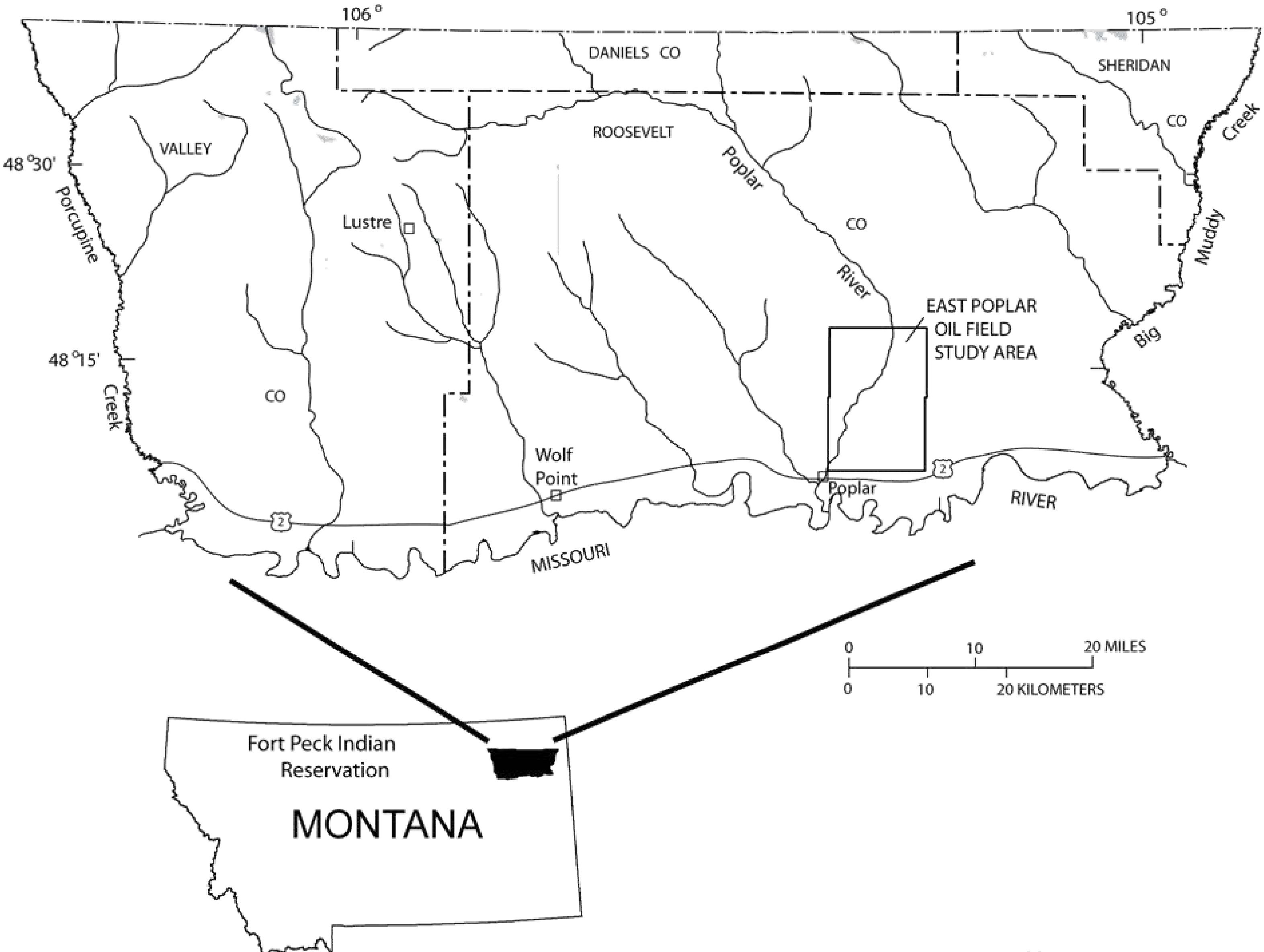
Dr. Bruce Smith, USGS, Denver

USGS
science for a changing world

Christa Tyrrell, Fort Peck Office of Environmental Protection

FT. PECK TRIBES ASSINIBOINE · SIOUX

East Poplar oil field location map



Bruce Smith - USGS

Brief Overview

of

East Poplar Field

Brief Summary of Petroleum Production of East Poplar Field

- ➪First oil discovered in 1951 by Murphy Oil Corp.
- ➪Production primarily from the Mississippian Madison Group - Charles Limestone at ≈ 5,300' depth.
- ➪Cumulative Production > 47 MM/bbls
- ➪Current Annual Production ≈ 66 M/bbls

Produced Water Disposal Zones and Practices

- ➪**Cretaceous Judith River Formation ≈ 1,000 depth**
- ➪**Cretaceous Dakota SS ≈ 3,300' depth**
- ➪**Devonian Nisku Formation ≈ 7,300' depth (1 well) - PNR-#1WD Disposal Zone**
- ➪**Shallow open unlined pits at surface**

Surface Geology of East Poplar Oil Field

T/Fort Union Fm

K/Hell Creek FM

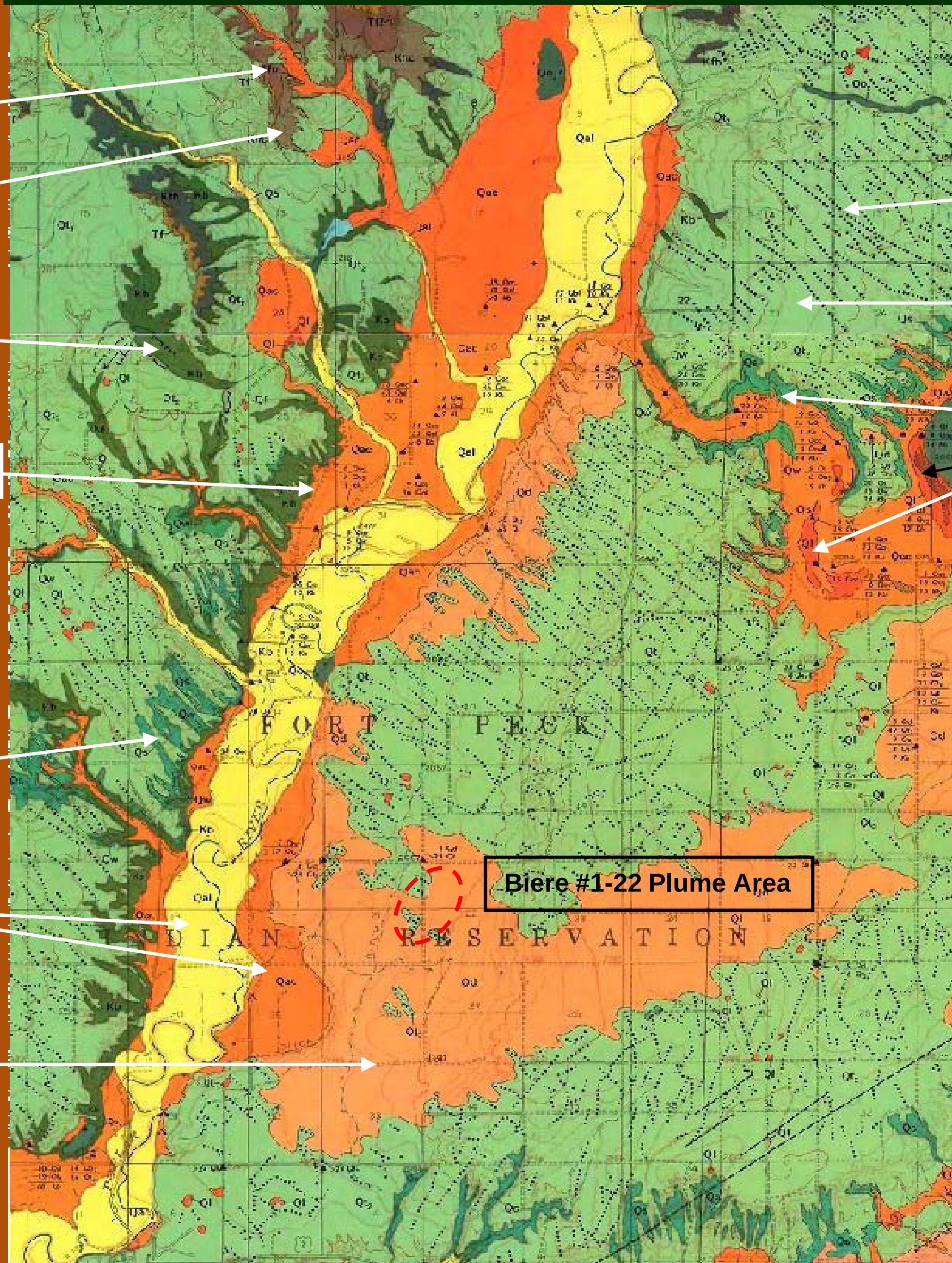
K/Bearpaw Shale

T-Q/ Wiota Gravels – Aquifer

Q/Silts (up to 30m)

Q/Alluvium and Colluvium

Q/Dune Sands



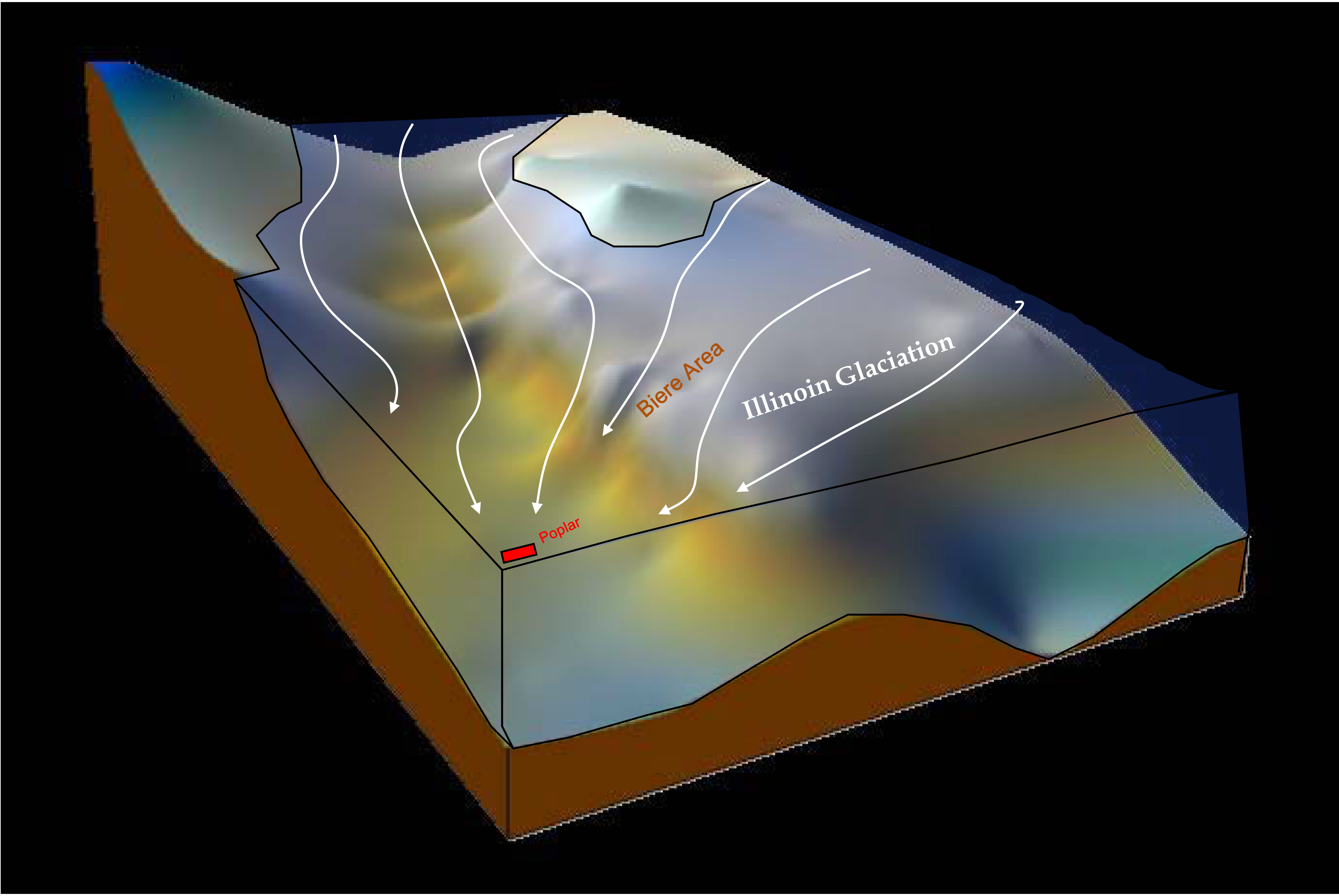
Ice-crack Moraines

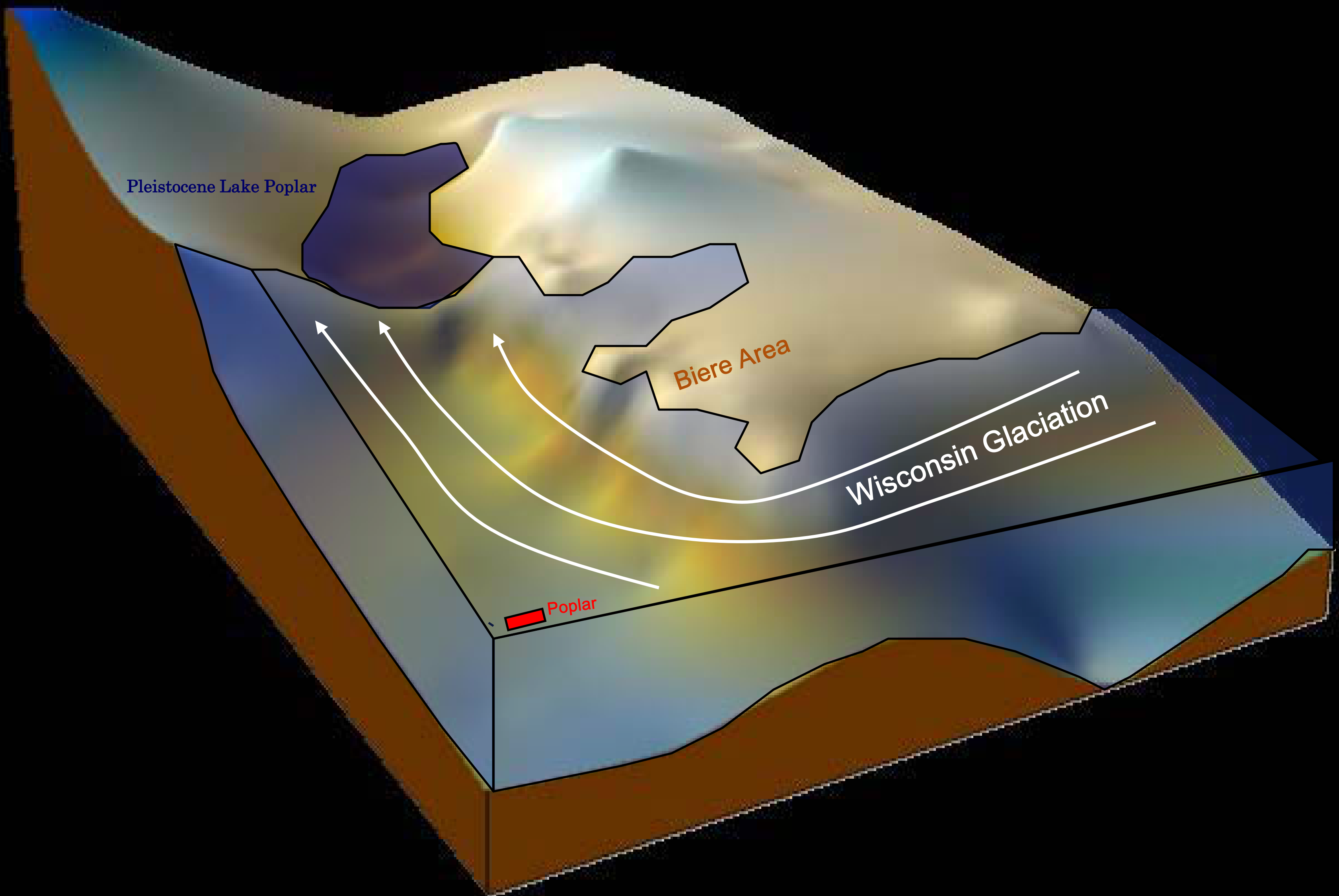
Q/Sprole Silt - Till
(mostly clay to boulders)

Q/Silts (up to 30m)

Q/Lake Sediments
(clays)

1000 0 1000 2000
metres


Biere Area
Illinoin Glaciation
Poplar


Pleistocene Lake Poplar
Biere Area
Wisconsin Glaciation
Poplar

Early Studies of Oilfield Contamination

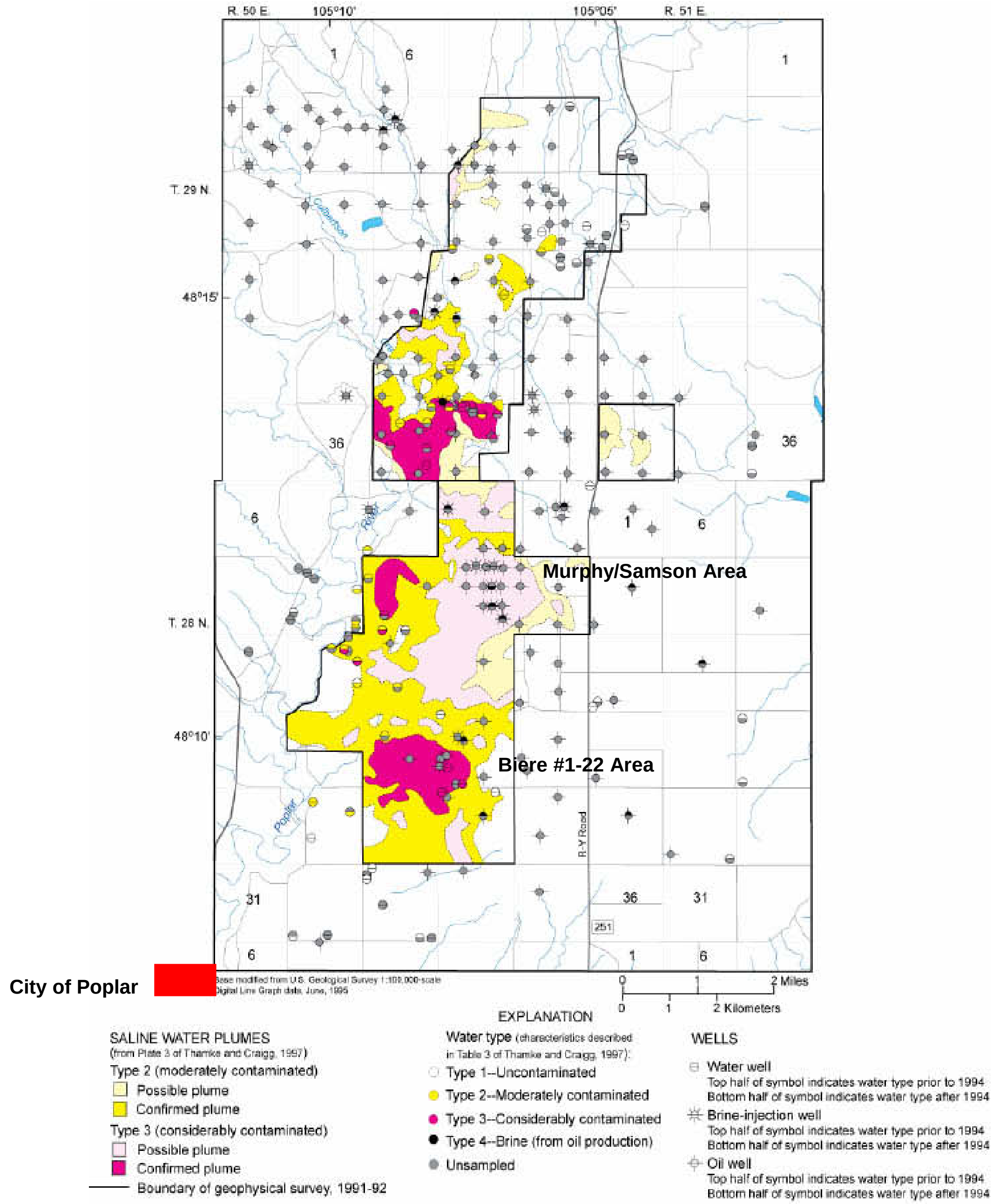
by

United States Geological Survey

&

Fort Peck Tribes – Office of Environmental Protection

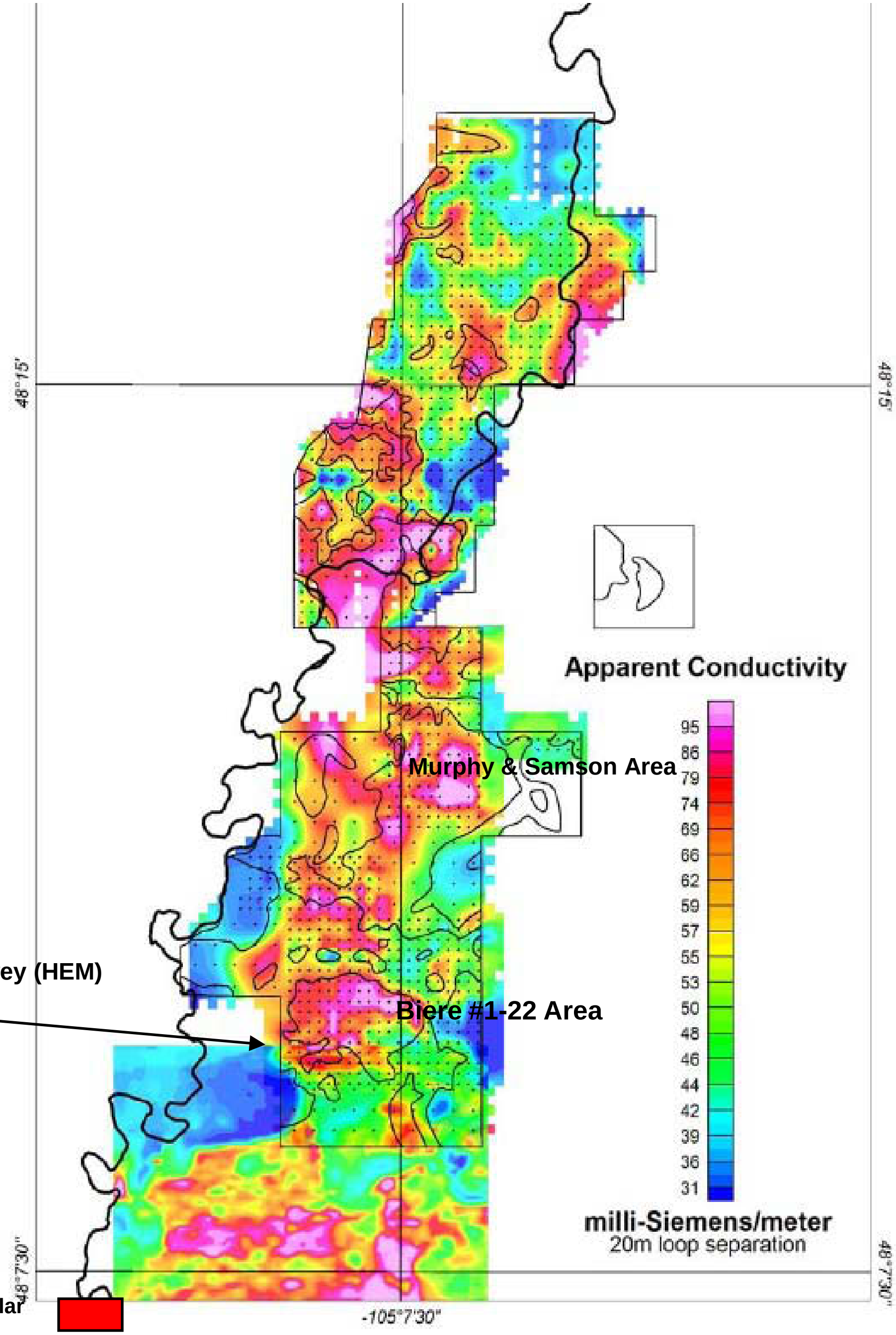
Interpreted location of saline water plumes in the East Poplar oil field study area 1991-1992 (Thamke and Craigg, 1997)



Bruce Smith
USGS

Apparent Conductivity – Ground EM 34 Survey

Boundary of 2004 Helicopter Electromagnetic Survey (HEM)

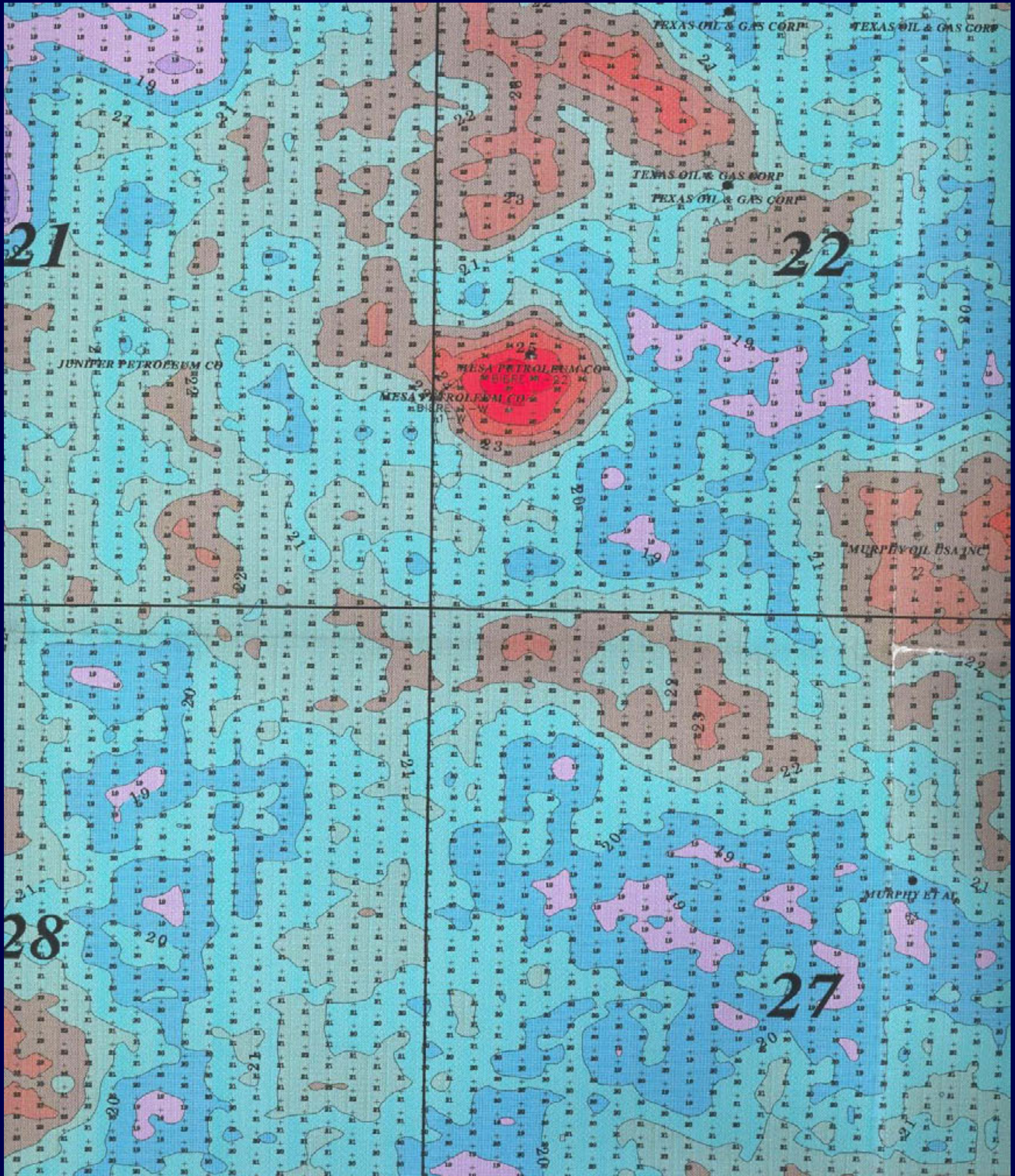


City of Poplar

Apparent Surface Temperature Degrees Celsius

Surface Range

C°	F°
27	81
14	57



Survey Data - 11/10/99

From LandSat Band 6 Thematic Imagery

Brief Overview of Initial Work & Investigations

&

Regulatory Framework

Regulatory Agencies Involved

Primary Agencies Responsible

USEPA – Denver Region

Fort Peck Tribes – Office of Environmental Protection – Poplar Mt.

Other Agencies – Limited Involvement

Montana Department of Environmental Quality – Helena, MT

Montana Department of Natural Resources & Conservation – Helena, MT

Support Agency

USGS – Helena, Mt & Denver, Co.

PIONEER WORK - 1999 to Mid 2006

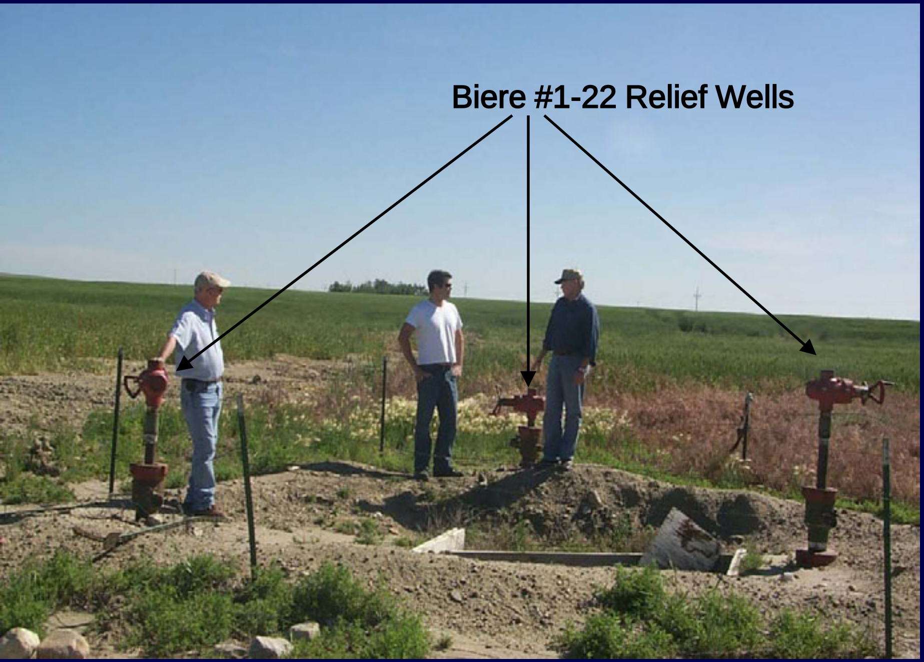
- ☞Plugging of Biere #1-22
- ☞Biere #1-22 Wellbore Monitoring
- ☞Monitor Well Installation & Sampling

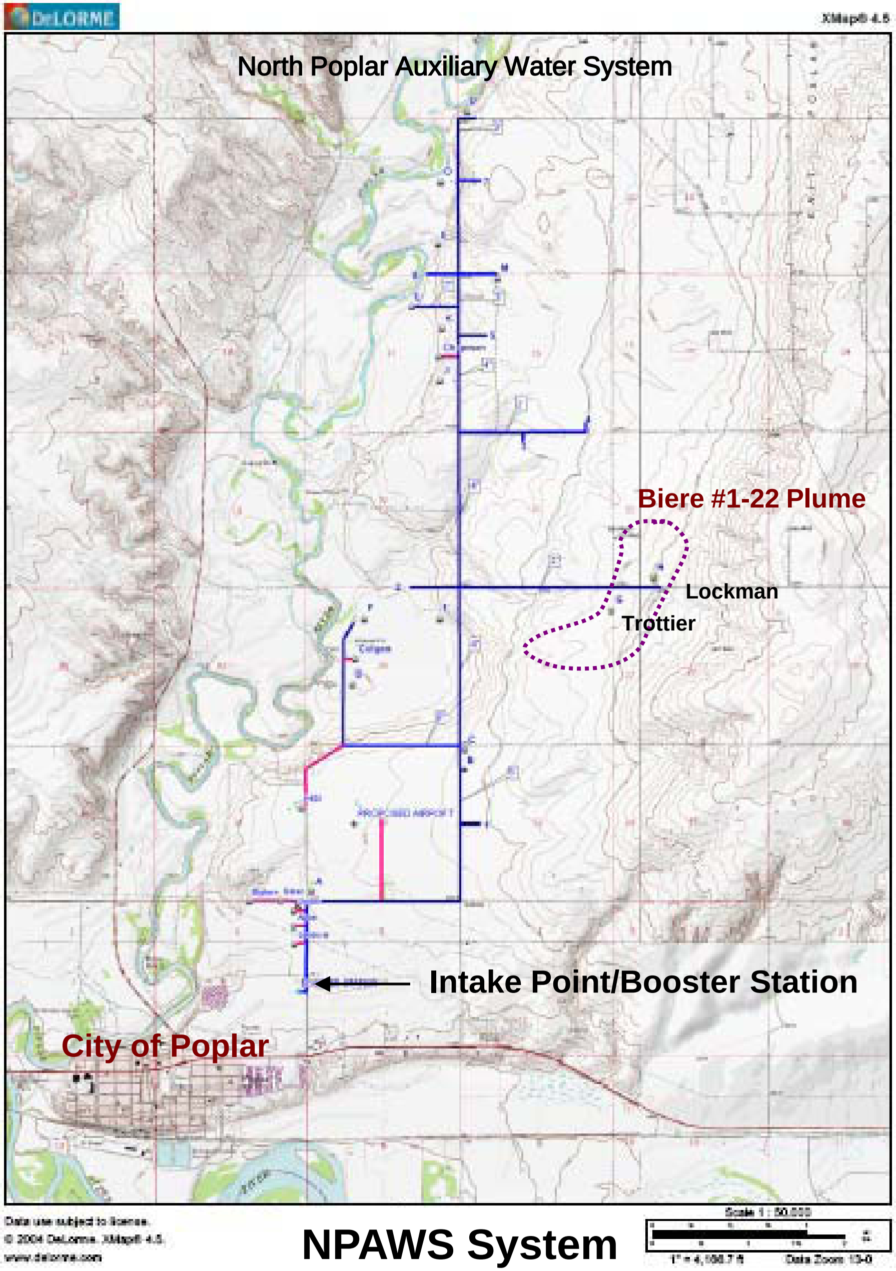
Biere#1-22 Well Testing

(Pressure & Temperature Surveys)

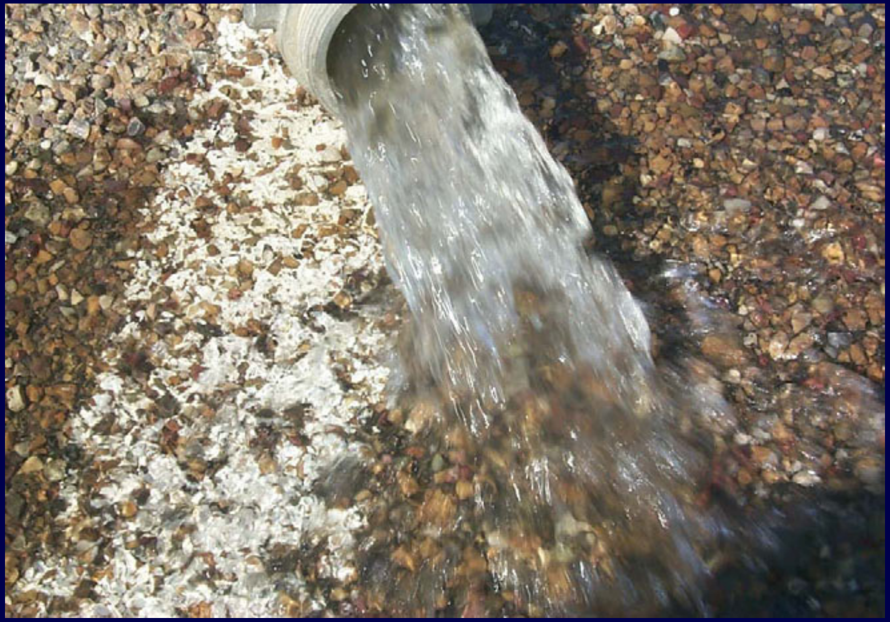
&

Monitor Well Sampling Programs





NPAWS System



Monitor Well Sampling and Analysis Program

Key Elements

PNR/HKM Engineering, Billings samples ≈ 44 groundwater monitoring and private landowner water wells on a bi-annual basis*

PNR, Sampson & Murphy samples an additional 16 wells on an annual basis – as required by Consent Order – "PBS&J Threat Study"

Wells analyzed for the following constituents:

- BTEX – Benzene, Toluene, Ethylbenzene, Xylene
- Inorganic Ions – HCO^3, Ca, CO^3, Cl, Mg, N, K, Si, Na, SO^4, F
- Other Parameters - CaCO3 (Alkalinity), pH, Conductivity, TDS
- Field Parameters – Conductivity, Temperature, pH

*In June the sampling frequency was changed from quarterly to bi-annual. Est. cost per sampling event was $35K/event; thereby, by reducing the frequency to bi-annual PNR saves ≈ 70K/year.

Pioneer Natural Resources

Program

Mid 2006 to Present

Integrated Hydrogeological and Engineering Study

1. ***Development of Site-Specific Geological & Hydrogeological Conceptual Model***

   (Pioneer - Midland ED)

   - **Detailed Regional & Site Specific Geological, Hydrogeological & Geochemical Mapping**
     - ✓ **Structure Maps**
     - ✓ **X-Sections**
     - ✓ **Isopach Maps**
     - ✓ **Constituent Plume Maps**
     - ✓ **Construction of Lithologic and Well Completion Logs**

2. ***Aquifer Testing including additional Well Completions (Pioneer – Midland ED & HKM Engineering)***
   - **Drilling of three additional wells (two 5" pumping wells and one observation well**
   - **Three Aquifer Tests**
     - ✓ **Test #1 - "Ground - Zero" Main Plume Area**
     - ✓ **Test #2 - Wiota Gravel "Choke Point" Area**
     - ✓ **Test#3 – Upgradient Gravel Channel**
   - **Conducted 15 Slug Tests**

3. ***Groundwater Flow and Contaminant Transport Model – Visual MODFLOW***

   (Pioneer – Midland ED & Daniel B. Stephens & Associates, Albuquerque, NM)

   - **Build Model including input of Geological, Hydrogeological and Hydraulic Data (aquifer pump & slug test data - initial head data – lithological and well completion data)**
   - **Perform Capture Zone Analysis**
   - **Perform Total Pumping Rate Analysis**
   - **Determine Location of Pumping Wells & Number or Wells Needed**

Develop Regional & Site-Specific Geological & Hydrogeological Conceptual Model

Step 1 – Construct Contaminant Plume Maps - 6 ½ years (26 quarters) of geochemical water analyses data

- **Chlorides**
- **Crude Oil Thickness/LNAPL**
- **Dissolved Phase BTEX/Benzene – Dissolved Phase**

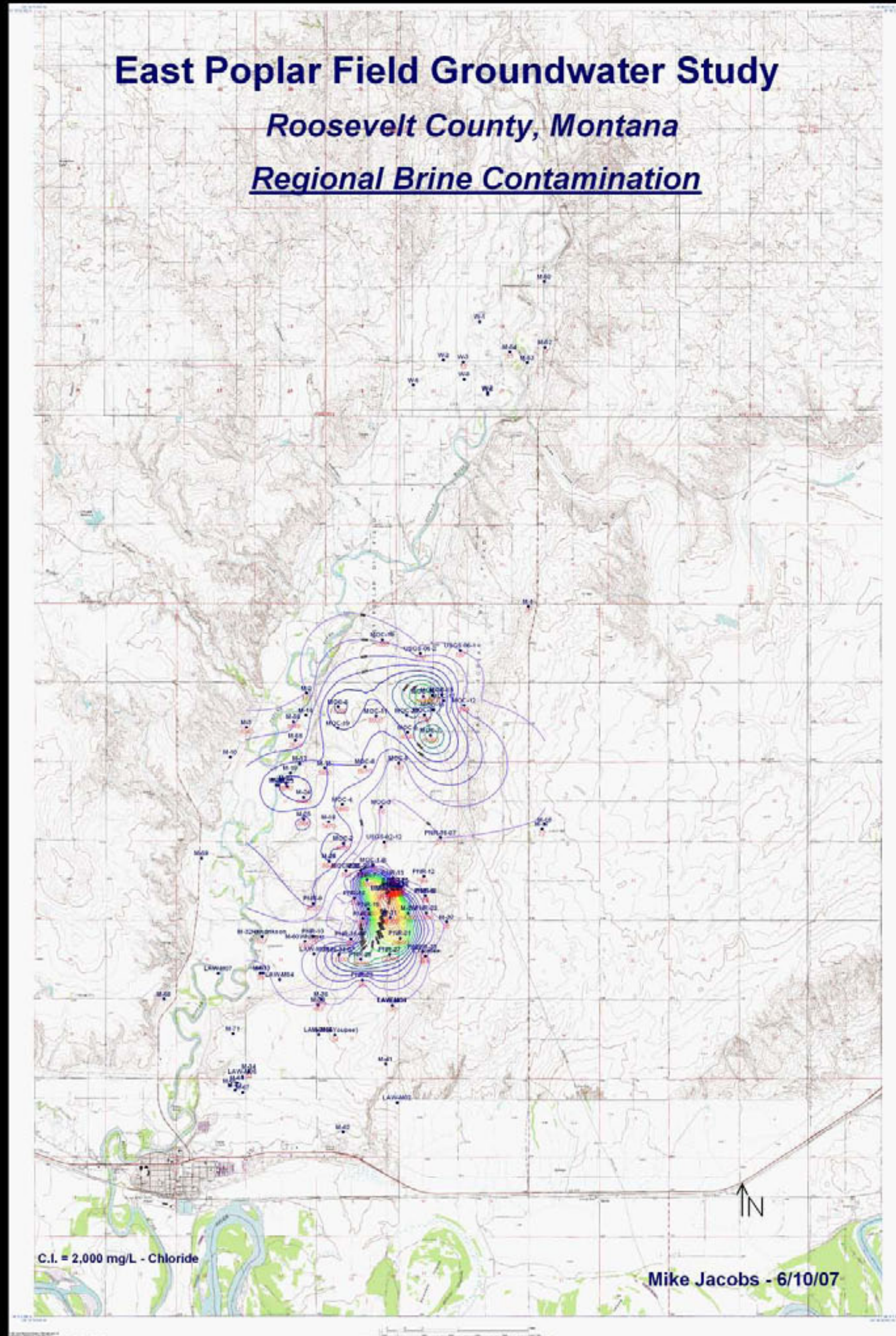
Step 2 - Perform Detailed Geological Mapping and Geophysical Analyses (164 Wells, 1,094 linear miles of Helicopter-Borne Electromagnetic Data, Downhole Geophysics (Gamma Ray, Induction Logs)

Create and Standardize Lithological and Well Completion Logs

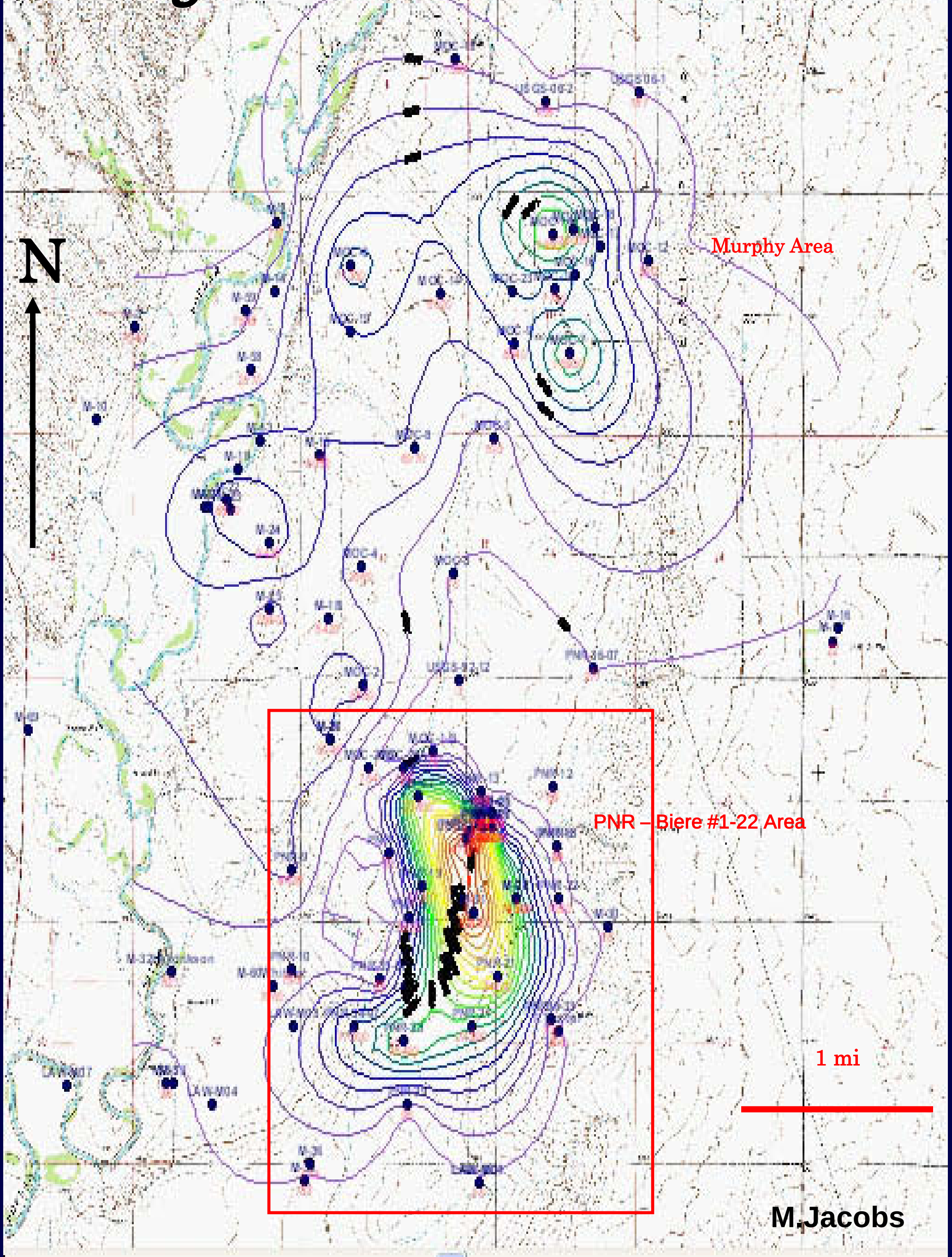
Bedrock Structure Map –
Cretaceous Bearpaw Shale

Geological Isopach Maps –
Wiota Gravel/Lower Alluvial Aquifer - Thickness

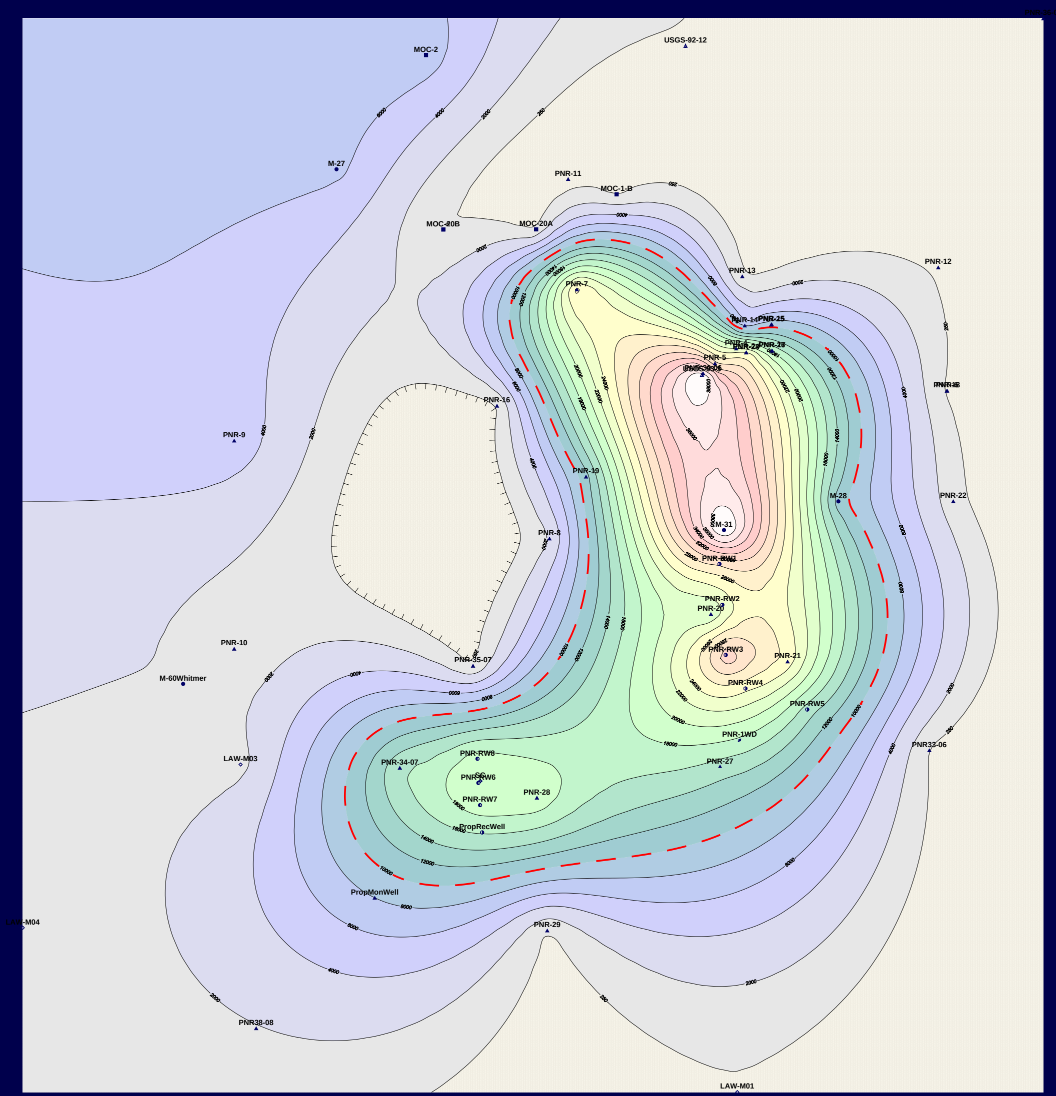
Construct Geological Cross Sections


East Poplar Field Groundwater Study
Roosevelt County, Montana
Regional Brine Contamination
N
C.I. = 2,000 mg/L - Chloride
Mike Jacobs - 6/10/07

Regional Brine Contamination



Detailed Data– Biere #1-22 Plume



Areall extent of Plume > 10,000 mg/L ≈ 426 acres

Average Aquifer Thickness ≈ 19’

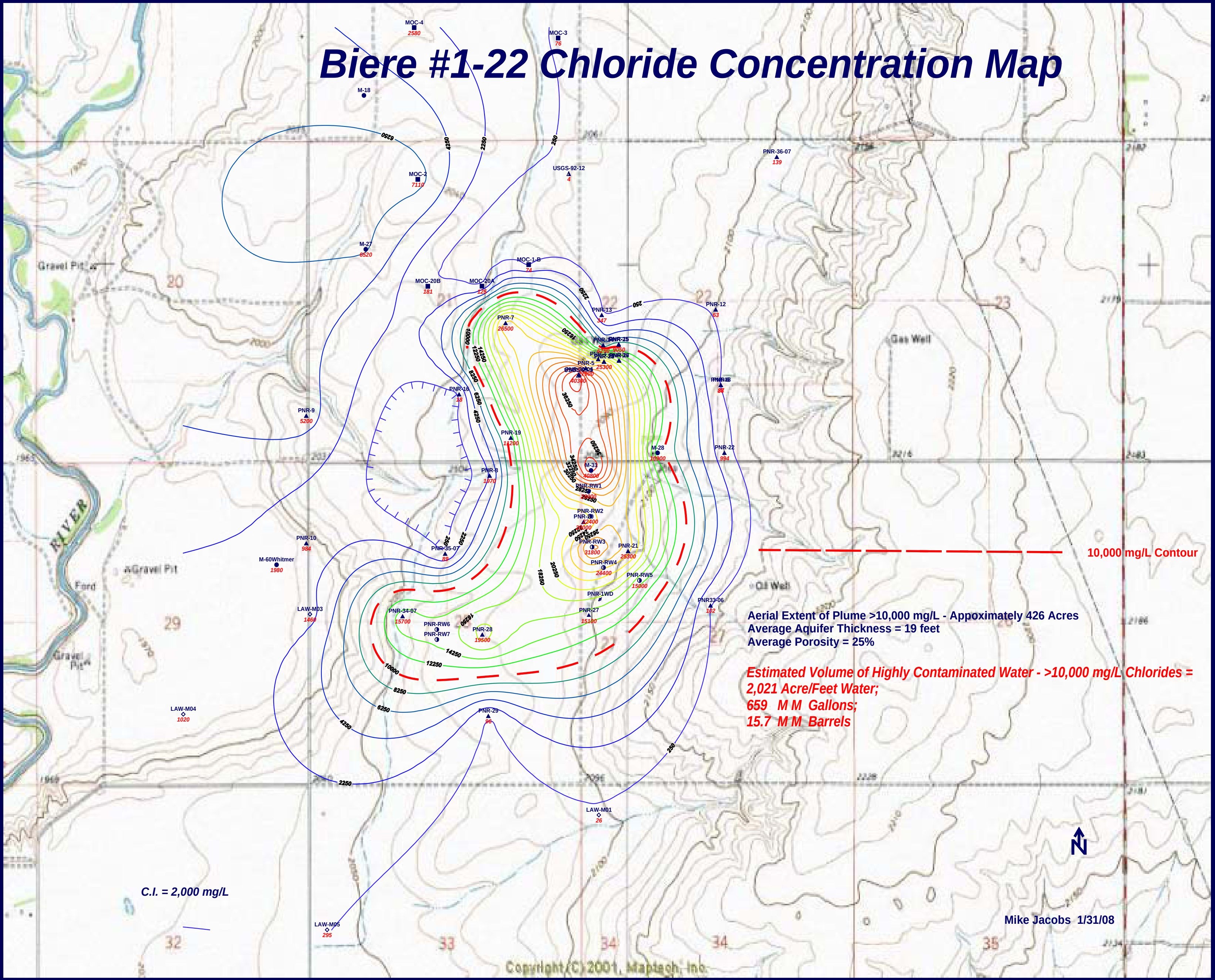
Average Porosity ≈ 25%

≈ 2,021 Acre Feet Water:

659 MM/Gallons
15.7 MM/bbls

Biere PNR-WD1 Disposal Rate
6,000 bbls/day

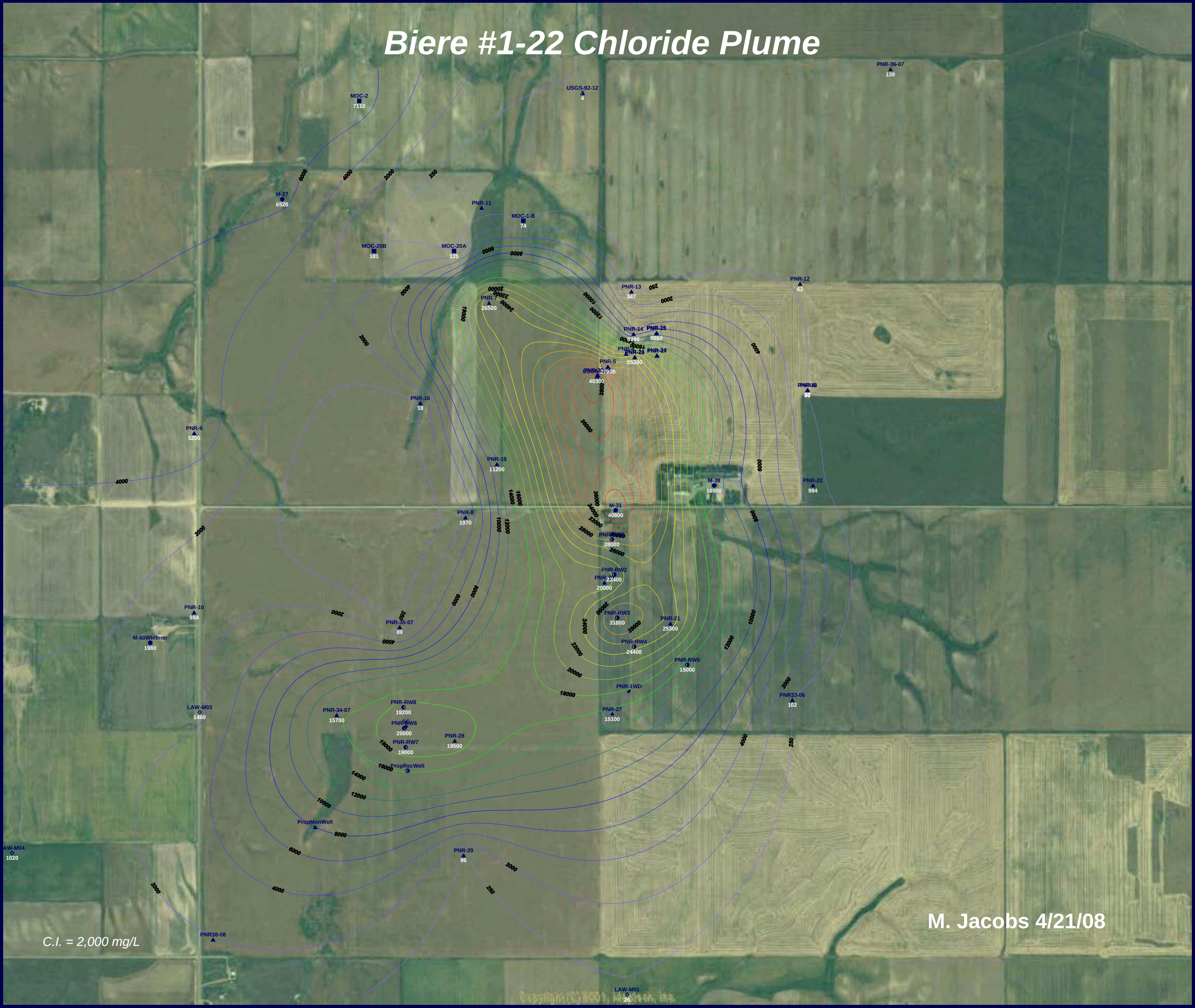
Biere #1-22 Chloride Concentration Map



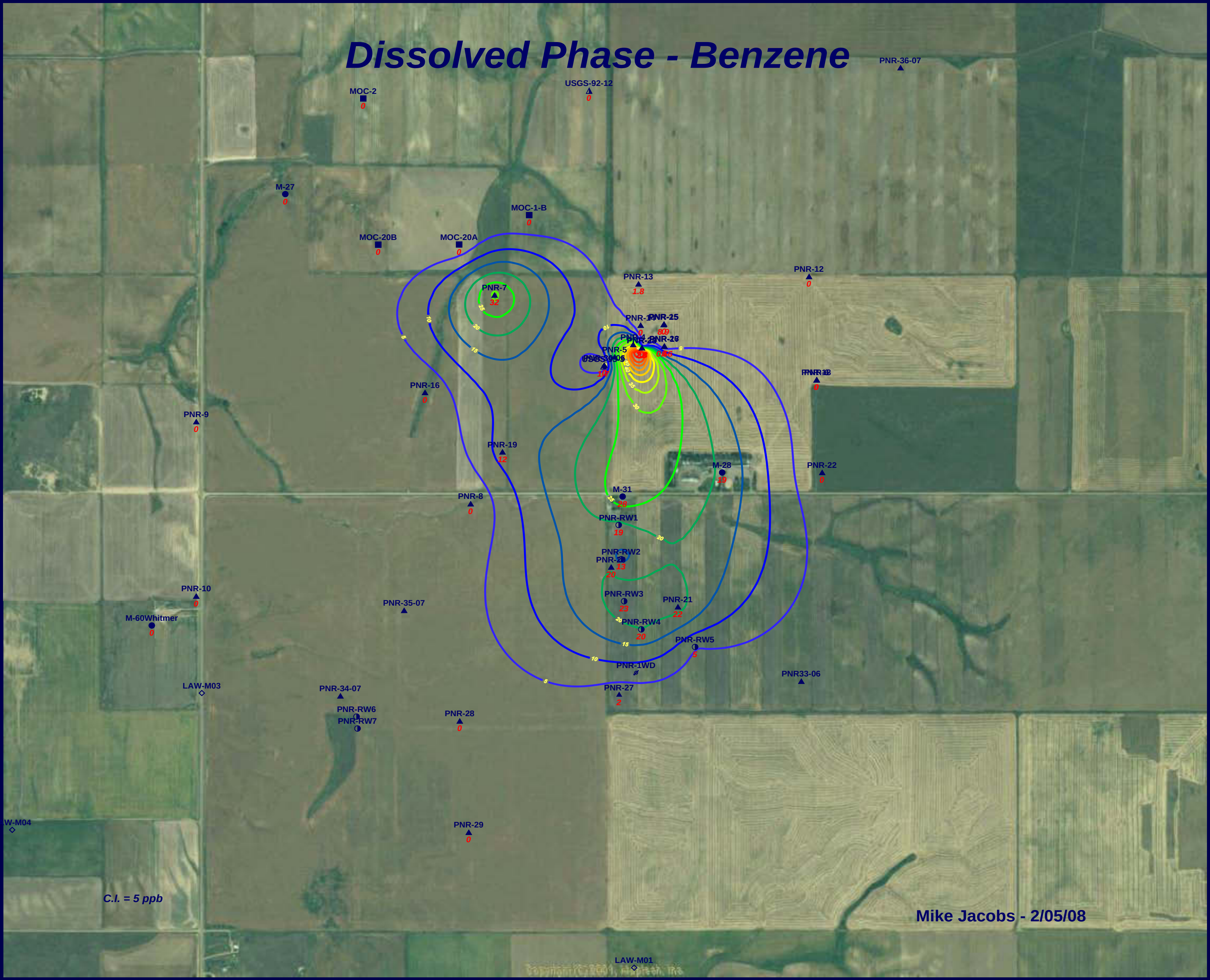
Aerial Extent of Plume >10,000 mg/L - Appoximately 426 Acres
Average Aquifer Thickness = 19 feet
Average Porosity = 25%

Estimated Volume of Highly Contaminated Water - >10,000 mg/L Chlorides = 2,021 Acre/Feet Water;
659 M M Gallons;
15.7 M M Barrels

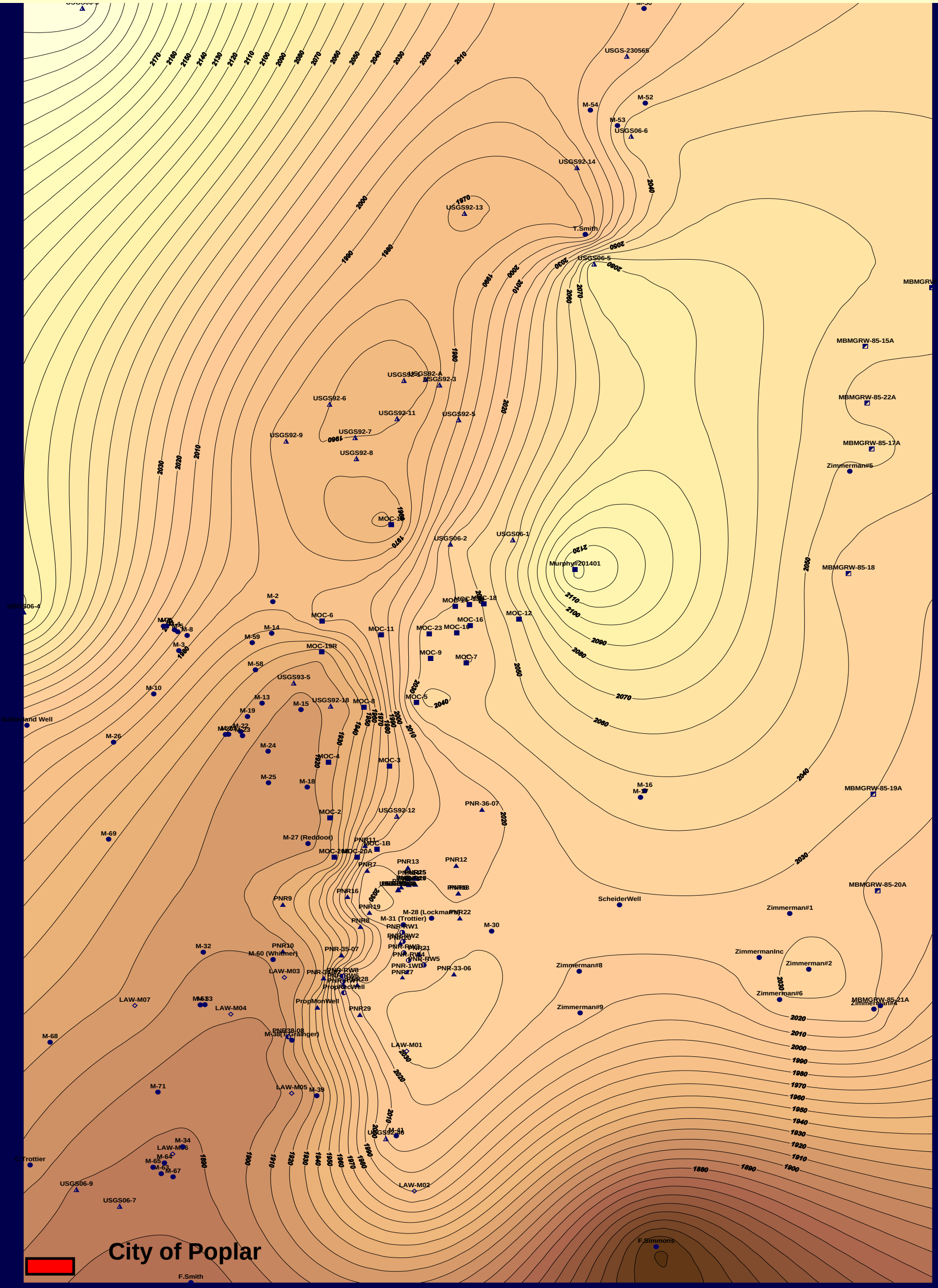
Biere #1-22 Chloride Plume



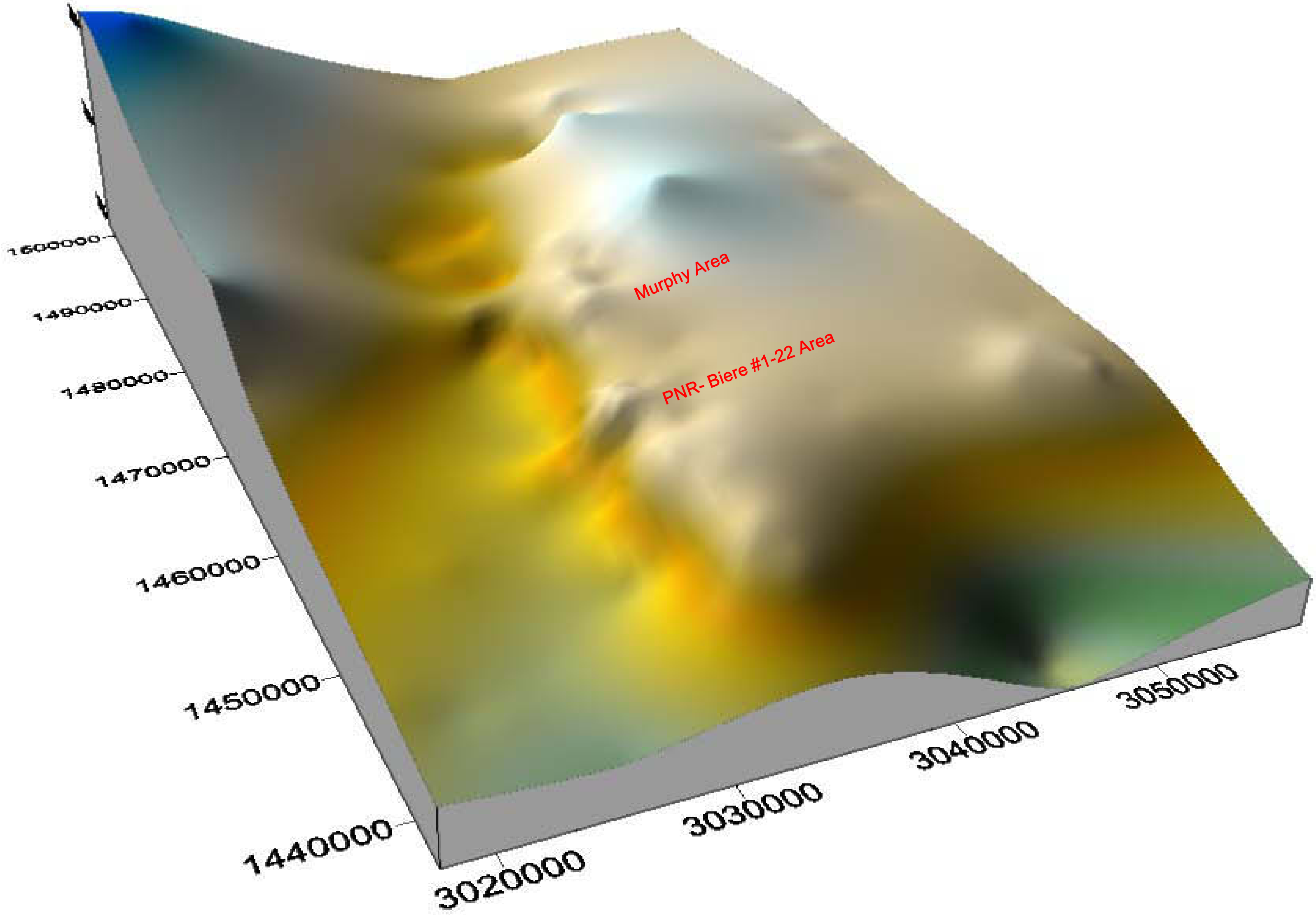
Dissolved Phase - Benzene



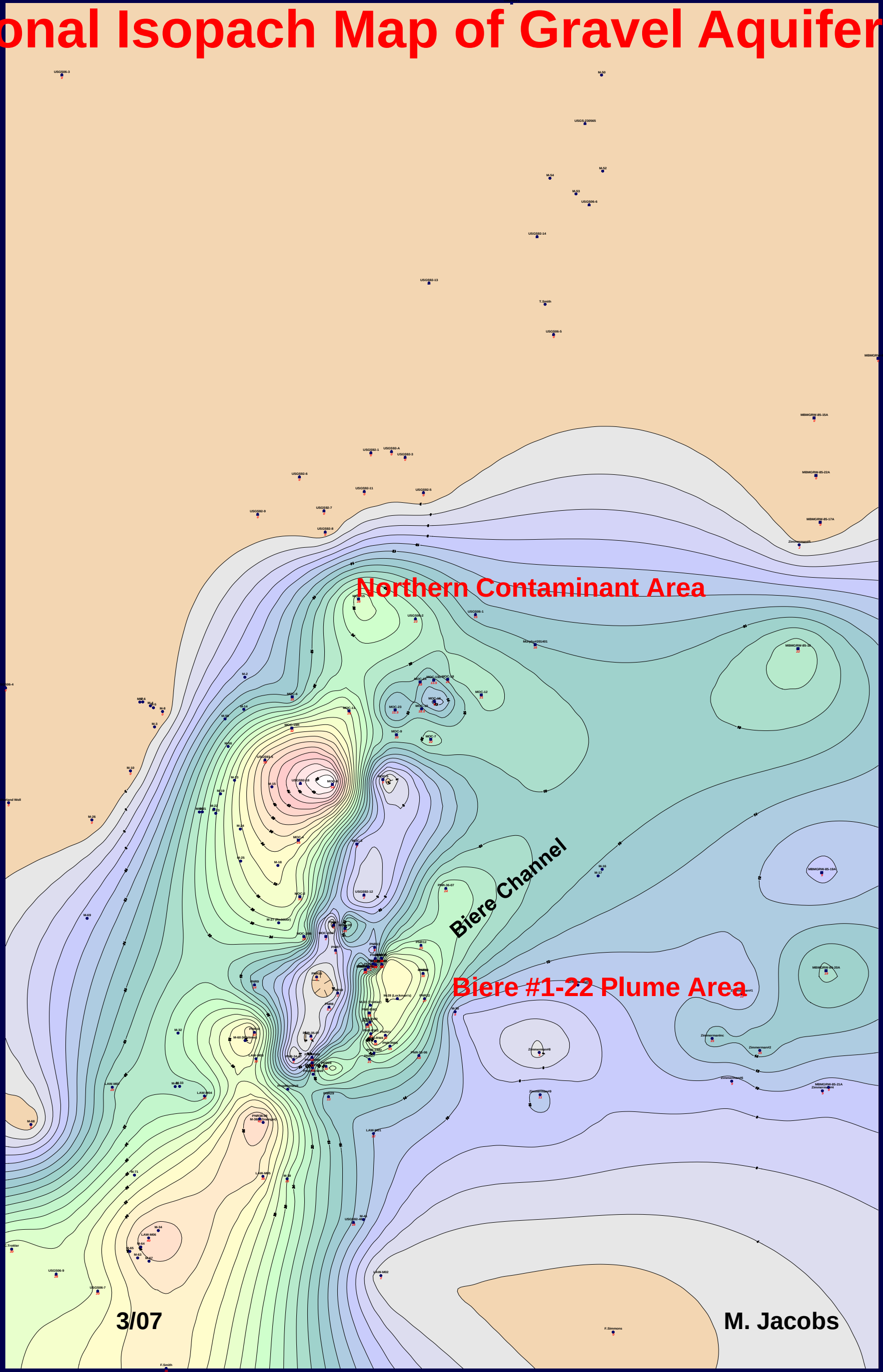
Regional Structure Map on Top of Bearpaw Shale – Base Aquifer



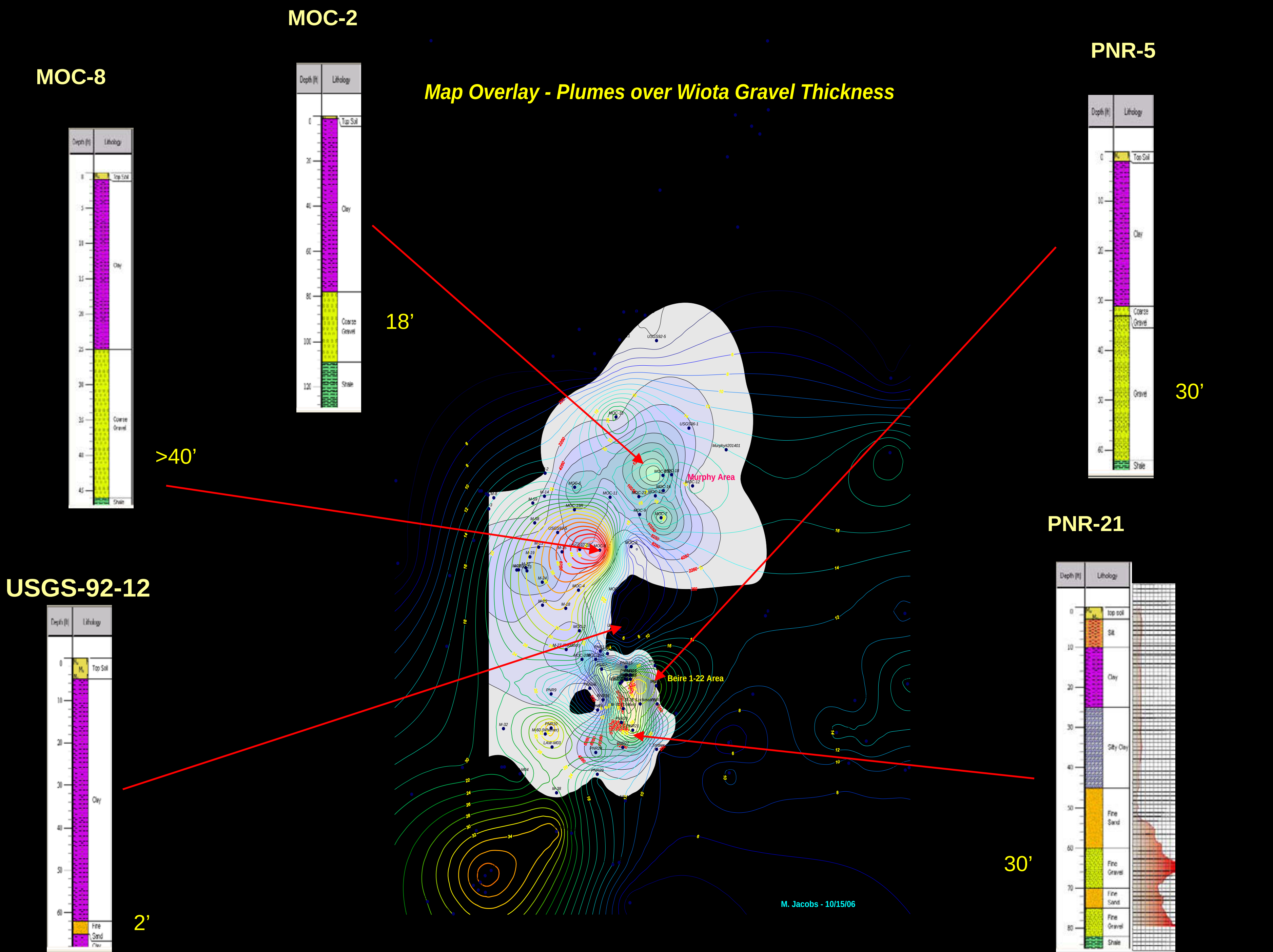
3-D View of T/Bearpaw Shale



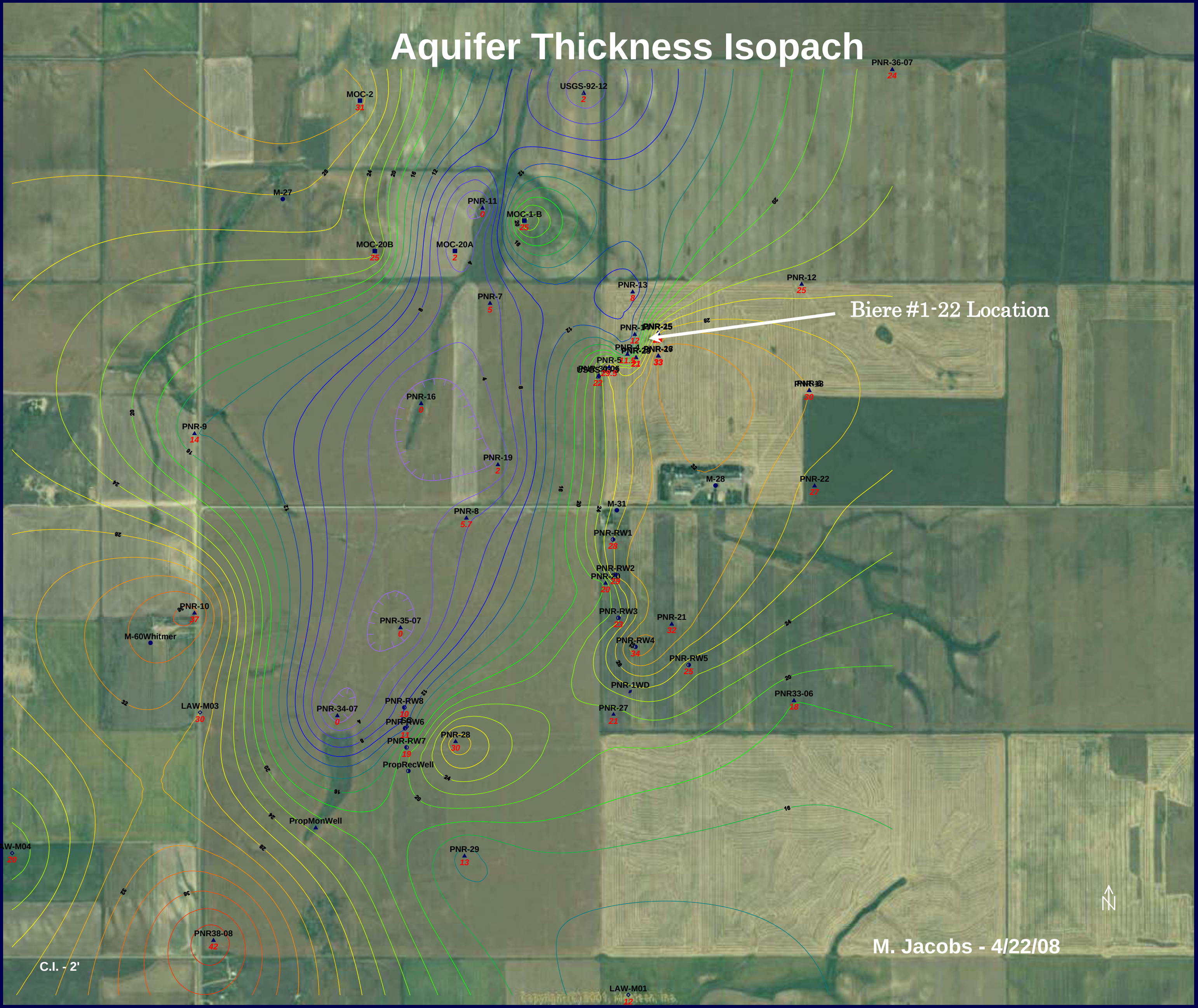
Regional Isopach Map of Gravel Aquifer(s) Thickness



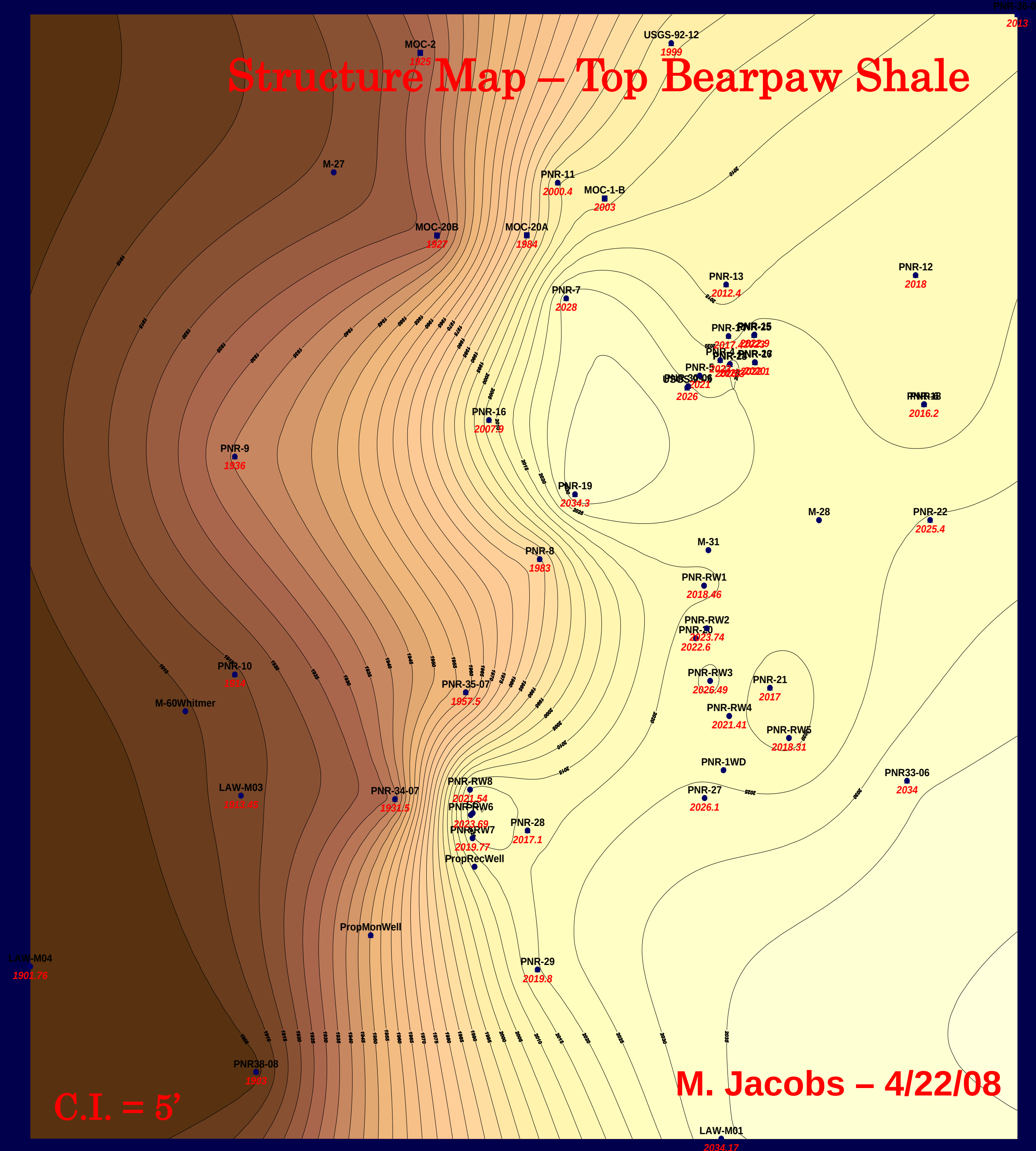
Map Overlay - Plumes over Wiota Gravel Thickness



Aquifer Thickness Isopach



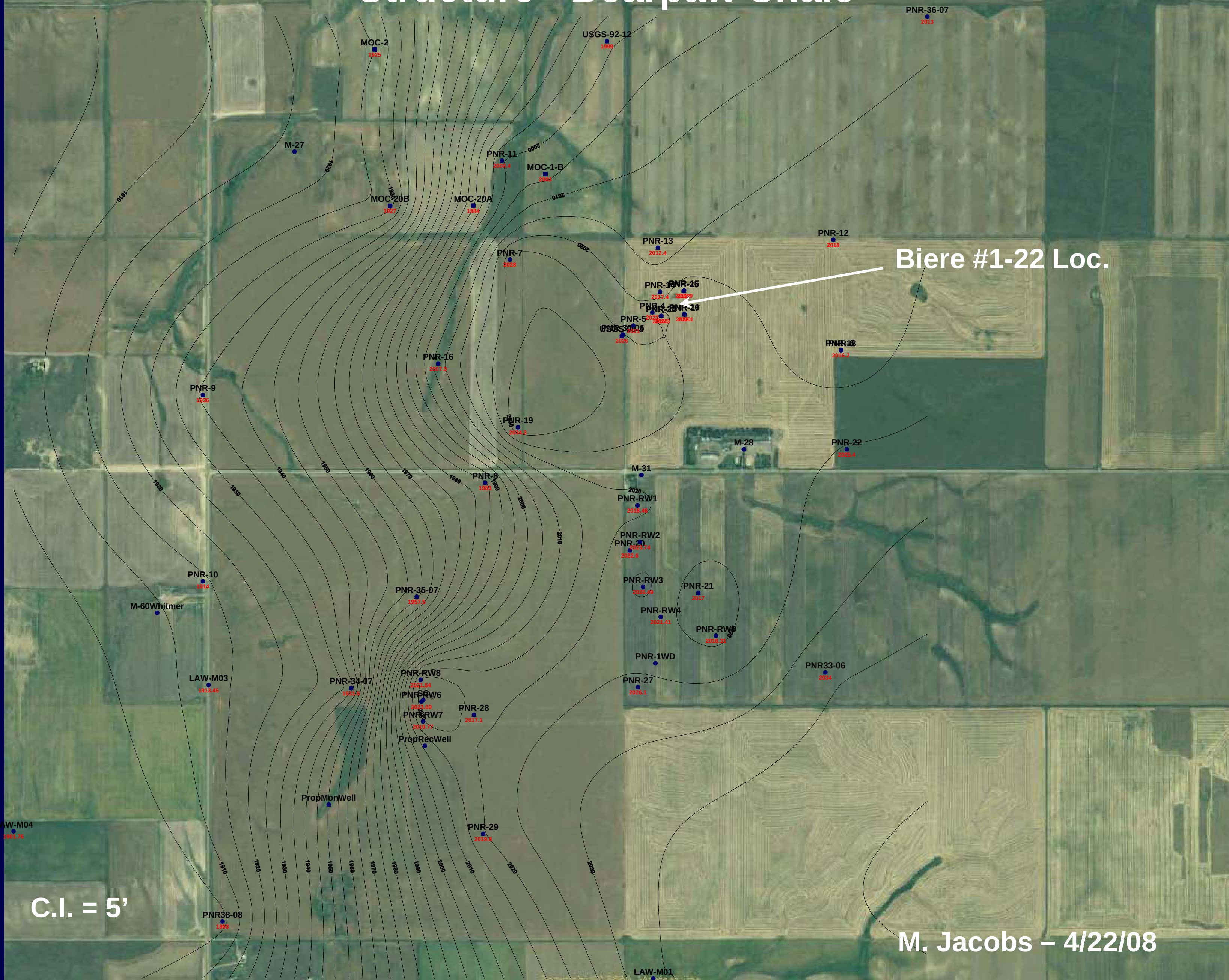
Structure Map – Top Bearpaw Shale

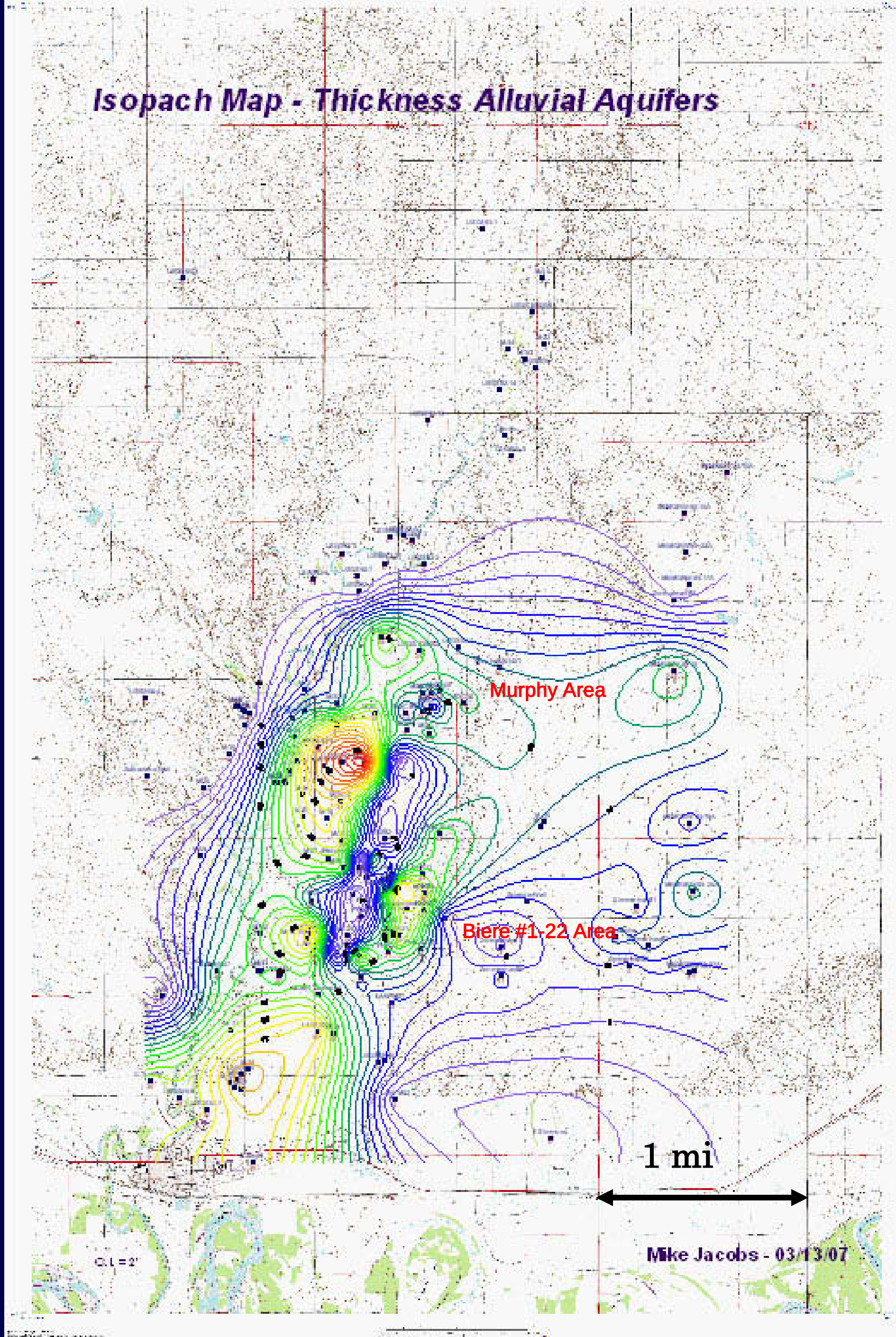


C.I. = 5’

M. Jacobs – 4/22/08

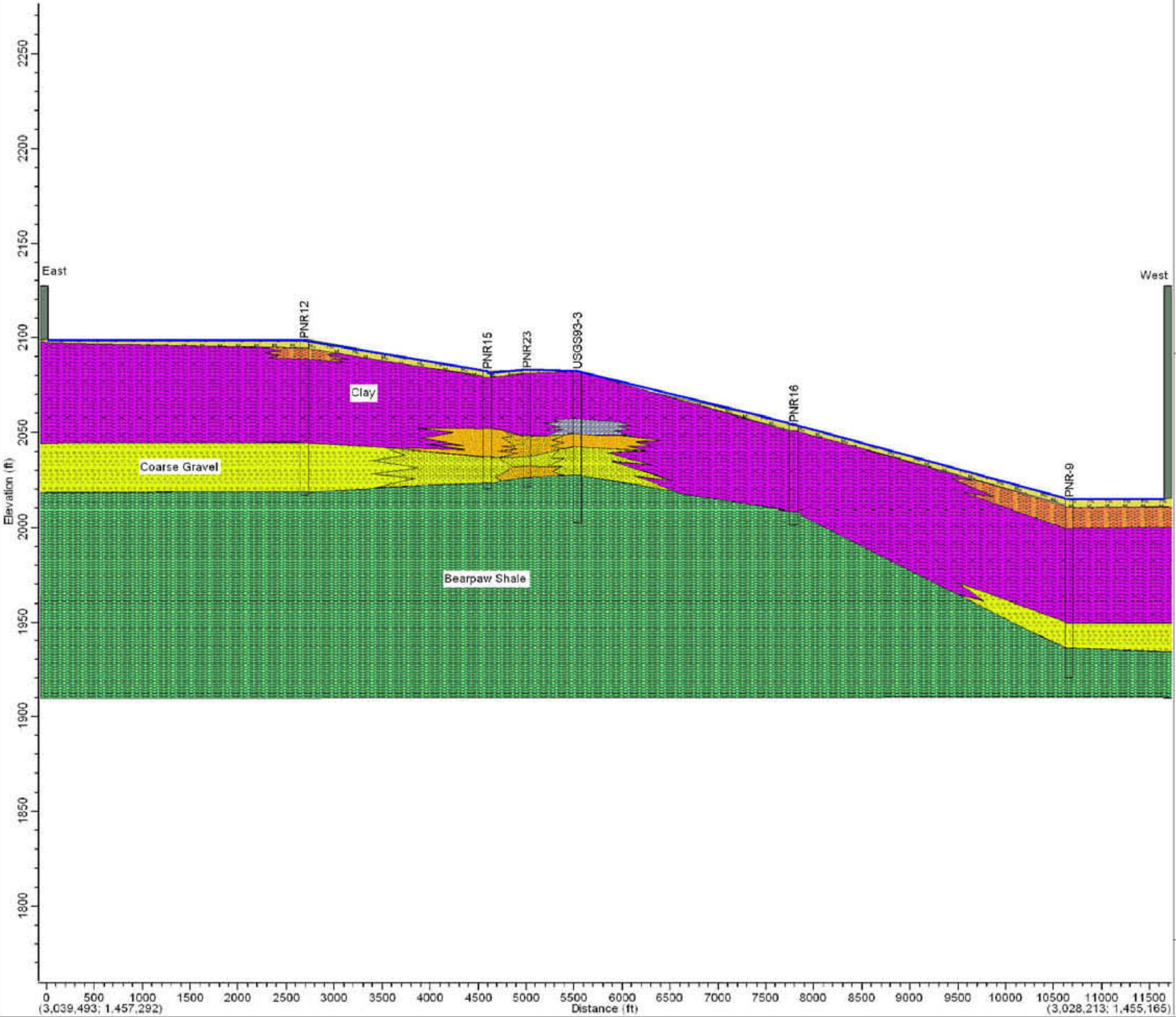
Structure - Bearpaw Shale




Isopach Map - Thickness Alluvial Aquifers
Murphy Area
Biere #1-22 Area
1 mi
Mike Jacobs - 03/13/07

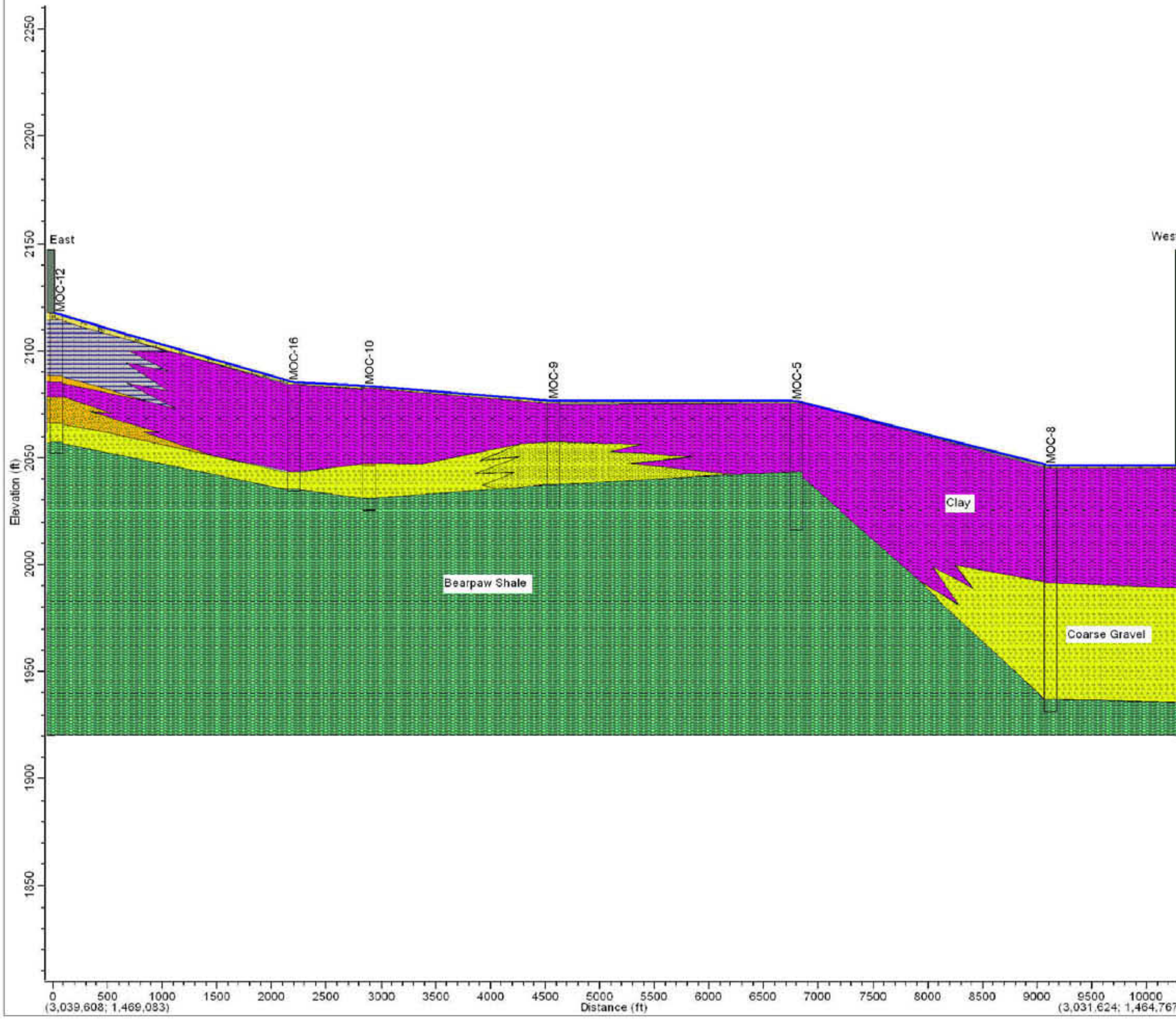
Geological Cross Sections
&
Recent
Geophysical Work

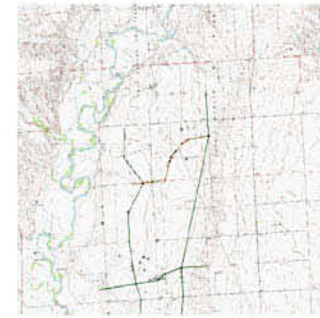
Pioneer Natural Resources	303 West Wall St., Suite Midland, Texas 79701	Project: East Poplar Groundwater Location: Poplar, Montana



Cross-Section E-W 1
Vertical Exaggeration: 20

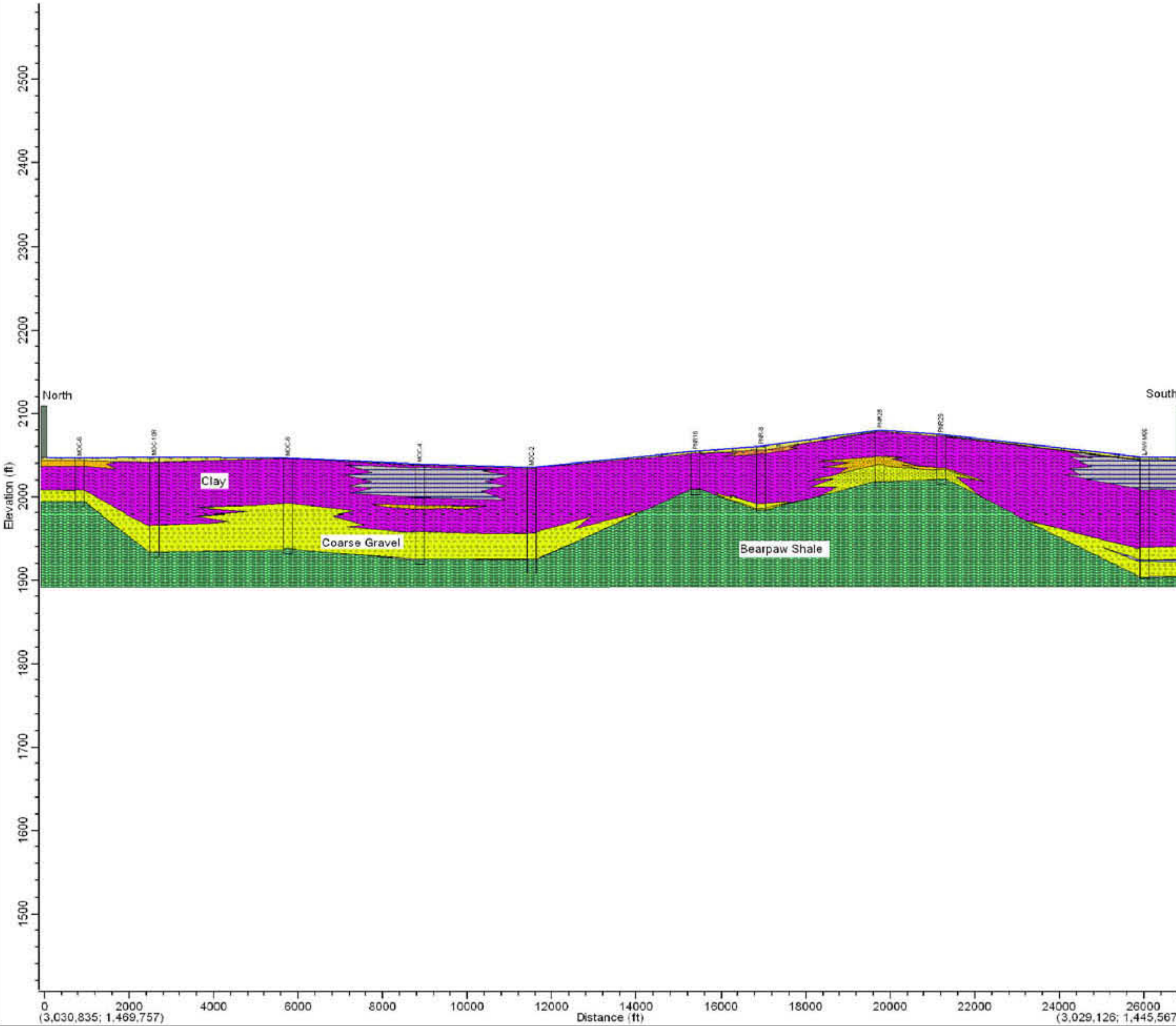
Pioneer Natural Resources | 303 West Wall St., Suite Midland, Texas 79701 | Project: East Poplar Groundwater Location: Poplar, Montana





Cross-Section E-W 2
Vertical Exaggeration: 20

Pioneer Natural Resources	303 West Wall St., Suite Midland, Texas 79701	Project: East Poplar Groundwater Location: Poplar, Montana



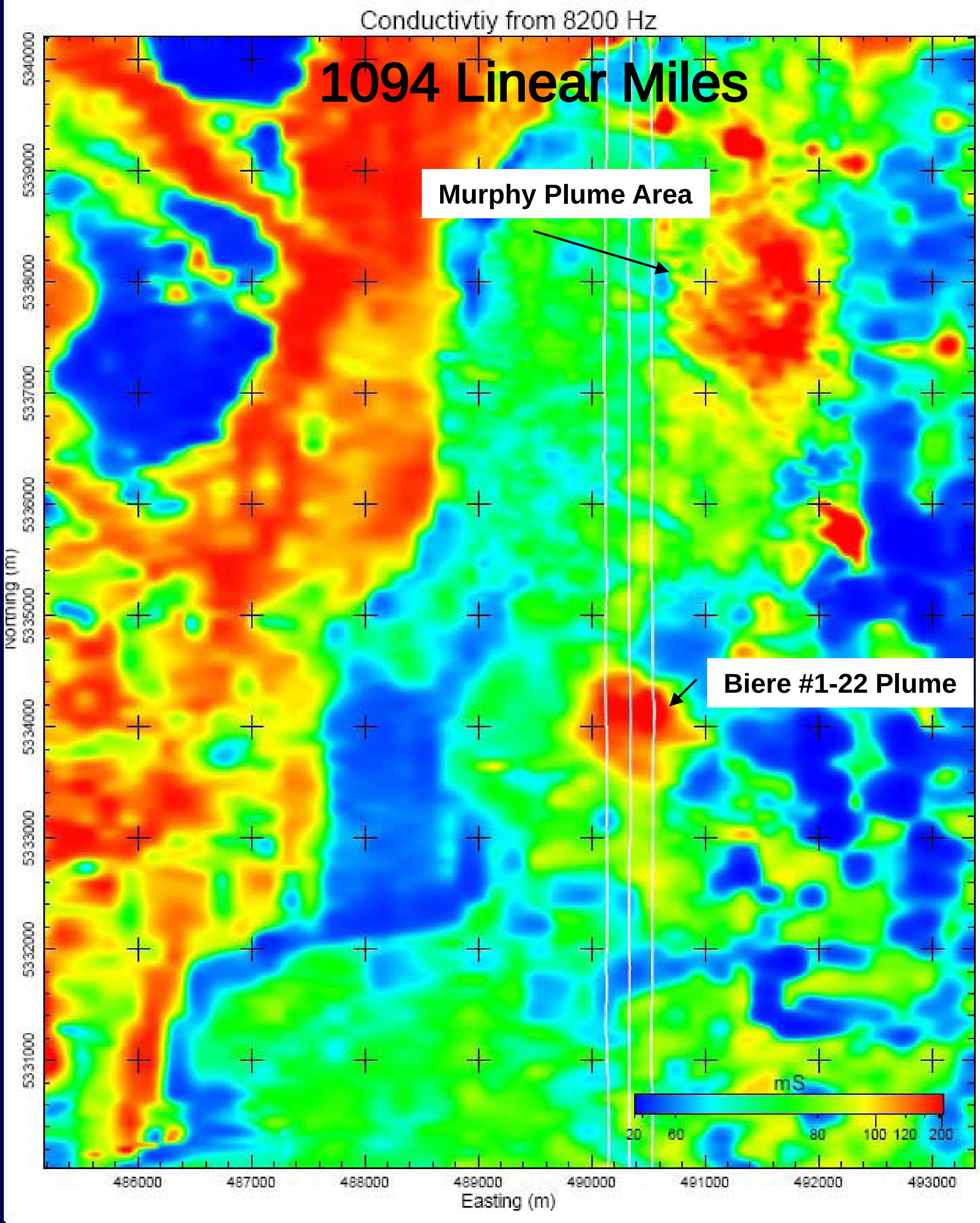
Legend

- Topography
- Top Soil
- Clay
- Sandy Clay
- Silty Sandstone
- Silt
- Fine Sand
- Medium Sand
- Coarse Sand
- Fine Gravel
- Gravel
- Coarse Gravel
- Bearpaw Shale

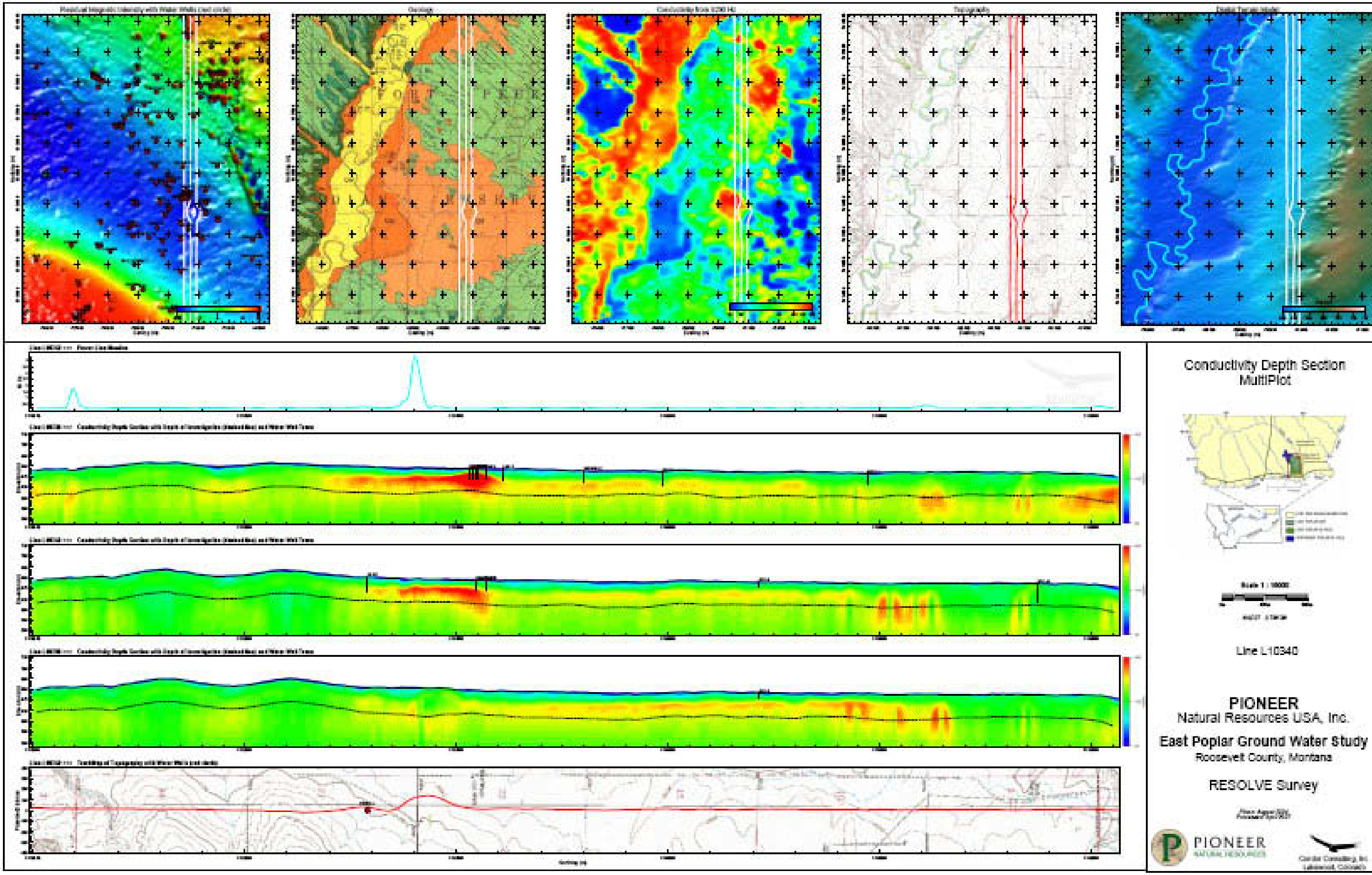
Cross-Section N-S 1
Vertical Exaggeration: 20

Conduct Reprocessing of 2004 USGS Helicopter Electromagnetic (HEM) Survey for Conductivity Depth Sections

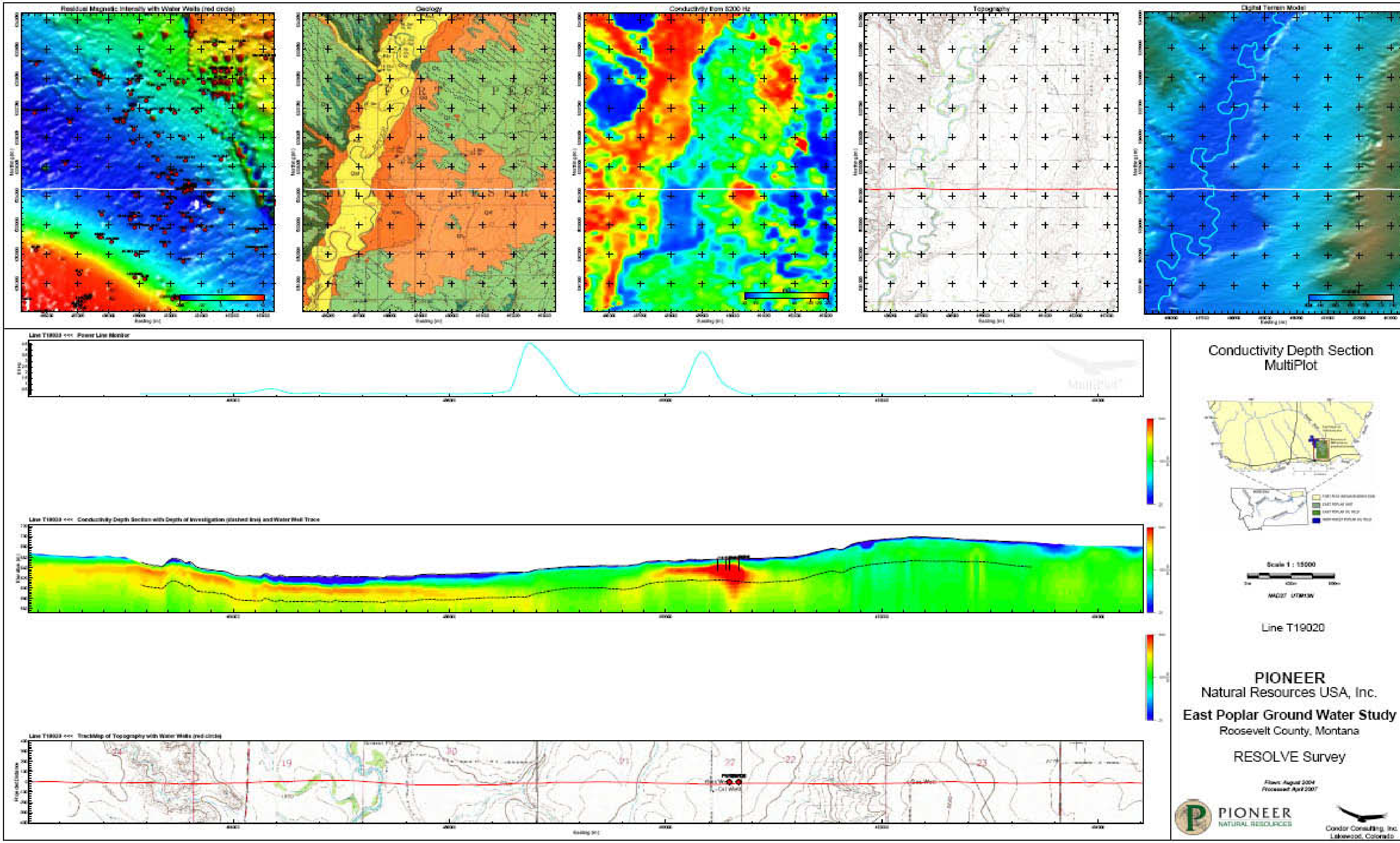
(Dr. Bruce Smith - USGS, Denver, Co., Condor Consulting, Lakewood, Co., and Mike Jacobs-PNR)

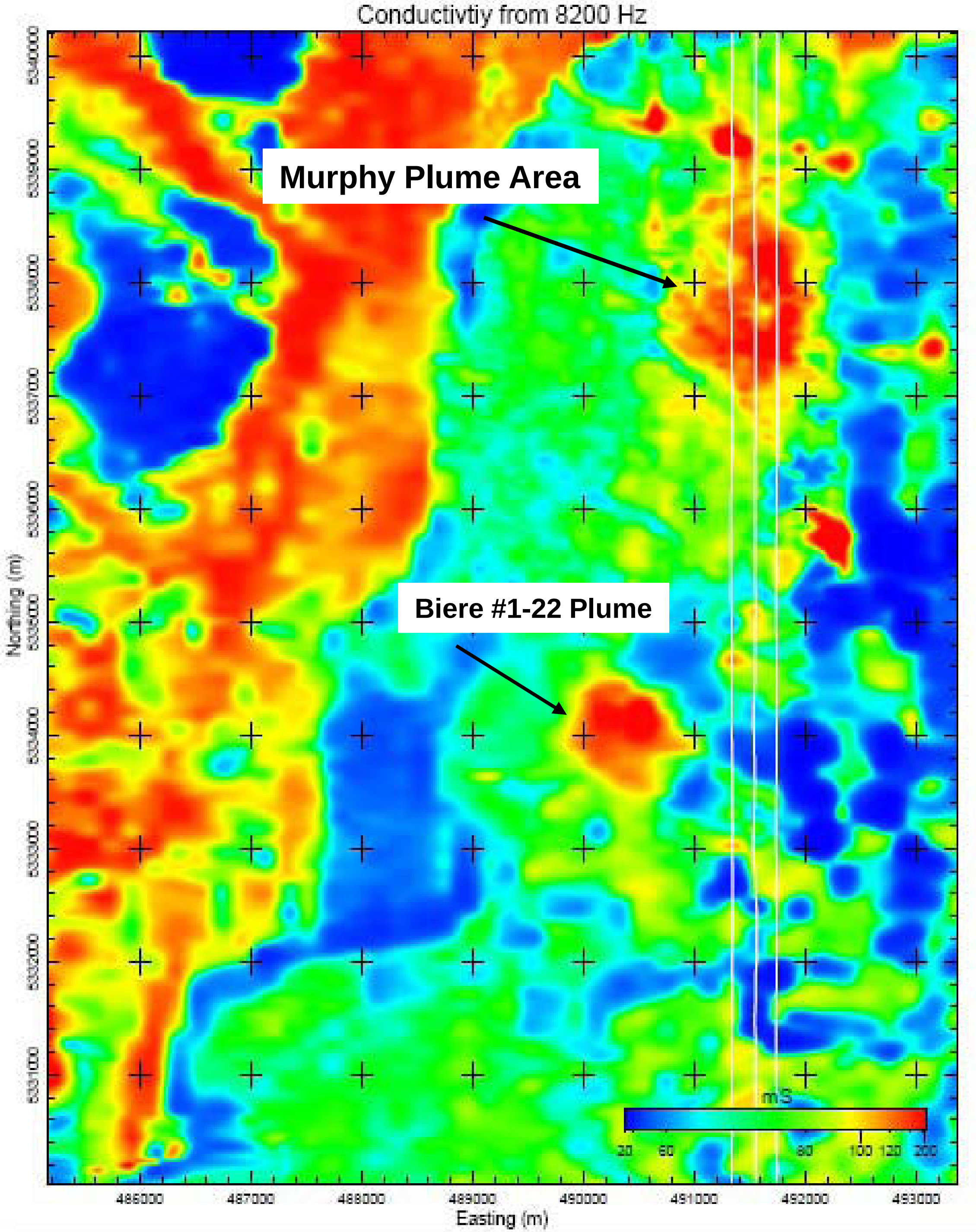


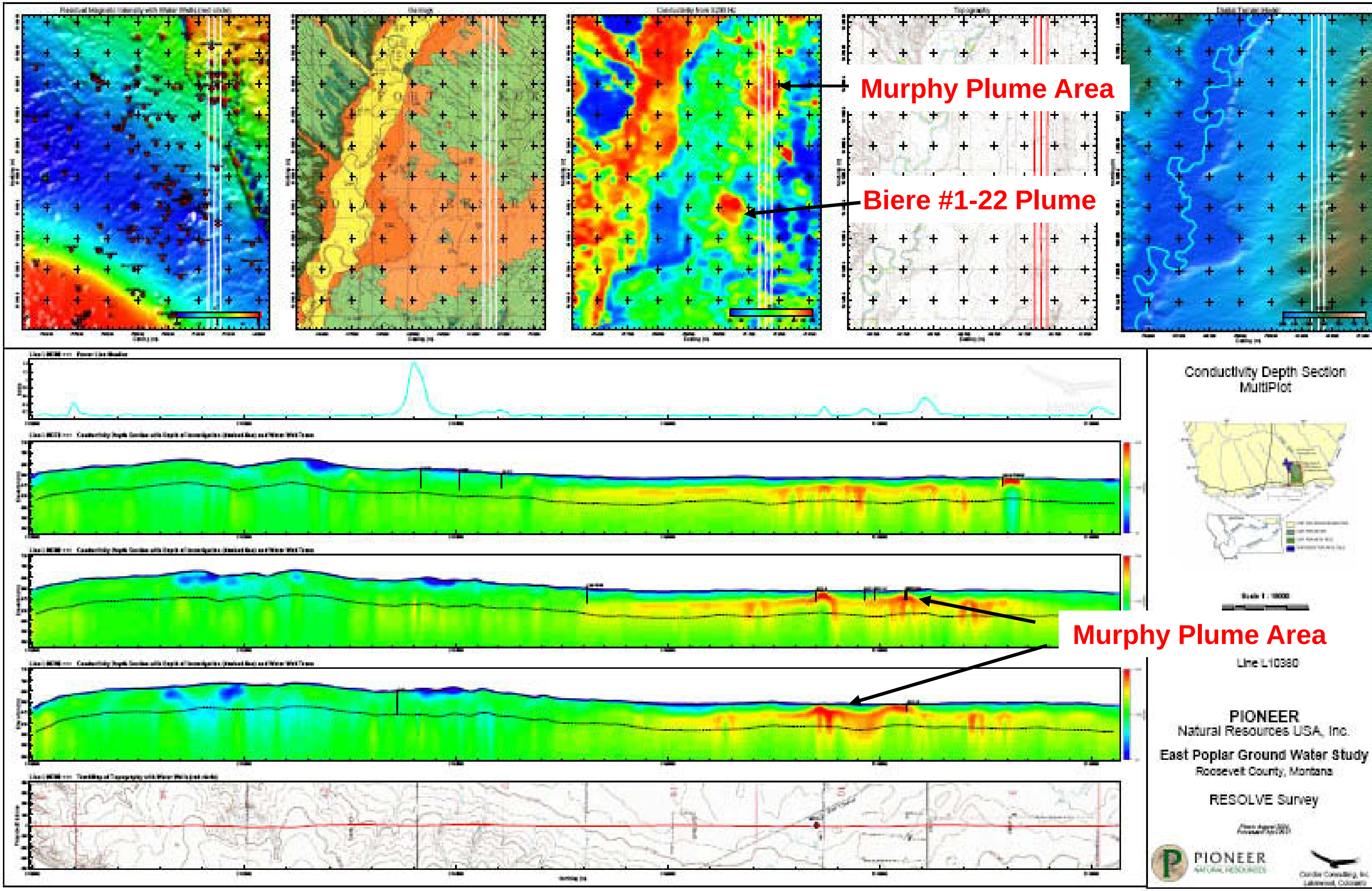
Conductivtiy from 8200 Hz
1094 Linear Miles
Murphy Plume Area
Biere #1-22 Plume
Northing (m)
Easting (m)
mS
20
60
80
100
120
200
486000
487000
488000
489000
490000
491000
492000
493000
5340000
5339000
5338000
5337000
5336000
5335000
5334000
5333000
5332000
5331000



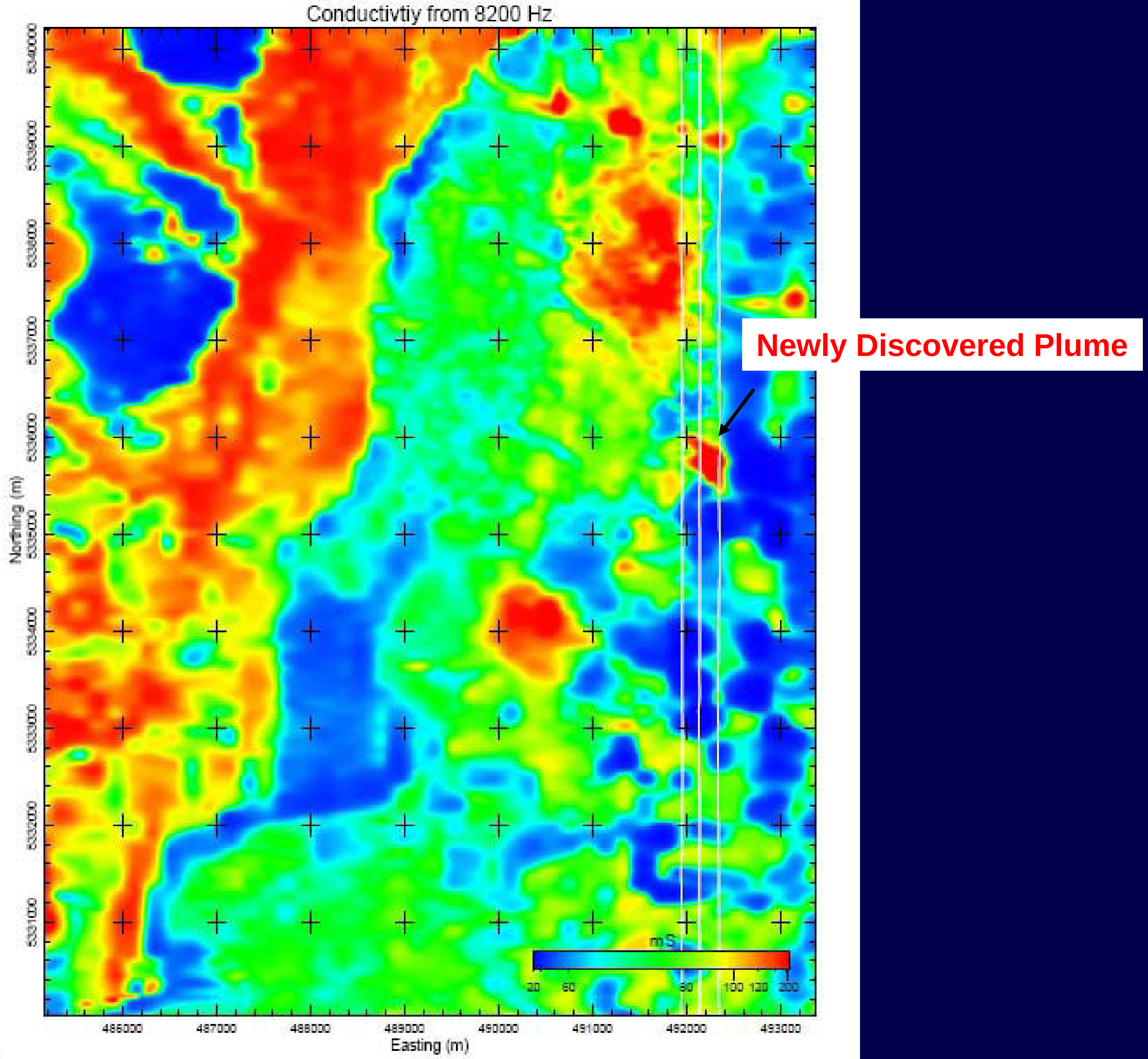
Conductivity Depth Section
MultiPlot
Line L10340
PIONEER
Natural Resources USA, Inc.
East Poplar Ground Water Study
Roosevelt County, Montana
RESOLVE Survey
PIONEER
NATURAL RESOURCES

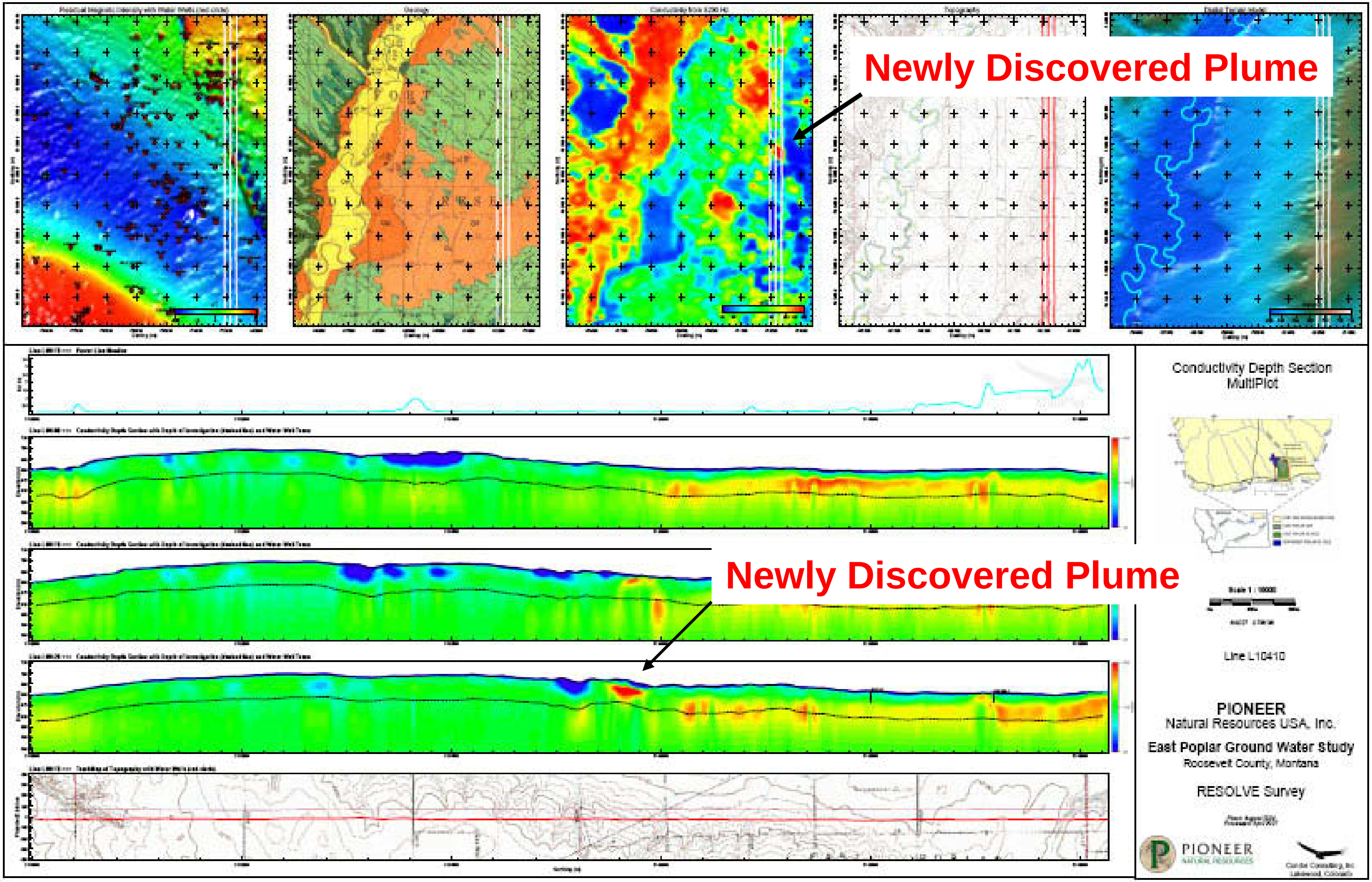

Residual Magnetic Intensity with Water Wells (red circle)
Geology
Conductivity from 5200 Hz
Topography
Digital Terrain Model
Power Line Monitor
Conductivity Depth Section with Depth of Investigation (dashed line) and Water Well Trace
Conductivity Depth Section
MultiPlot
Scale 1 : 15000
NAD27 UTM13N
Line T19020
PIONEER
Natural Resources USA, Inc.
East Poplar Ground Water Study
Roosevelt County, Montana
RESOLVE Survey
Flown: August 2004
Processed: April 2007
PIONEER
NATURAL RESOURCES
Condor Consulting, Inc.
Lakewood, Colorado


Conductivtiy from 8200 Hz
Murphy Plume Area
Biere #1-22 Plume
Northing (m)
mS
20
60
80
100
120
200
486000
487000
488000
489000
490000
491000
492000
493000
Easting (m)



Murphy Plume Area
Biere #1-22 Plume
Murphy Plume Area
Conductivity Depth Section
MultiPlot
Line L10380
PIONEER
Natural Resources USA, Inc.
East Poplar Ground Water Study
Roosevelt County, Montana
RESOLVE Survey
PIONEER


Conductivtiy from 8200 Hz
Northing (m)
Easting (m)
486000
487000
488000
489000
490000
491000
492000
493000
mS
20
60
80
100
120
200
Newly Discovered Plume

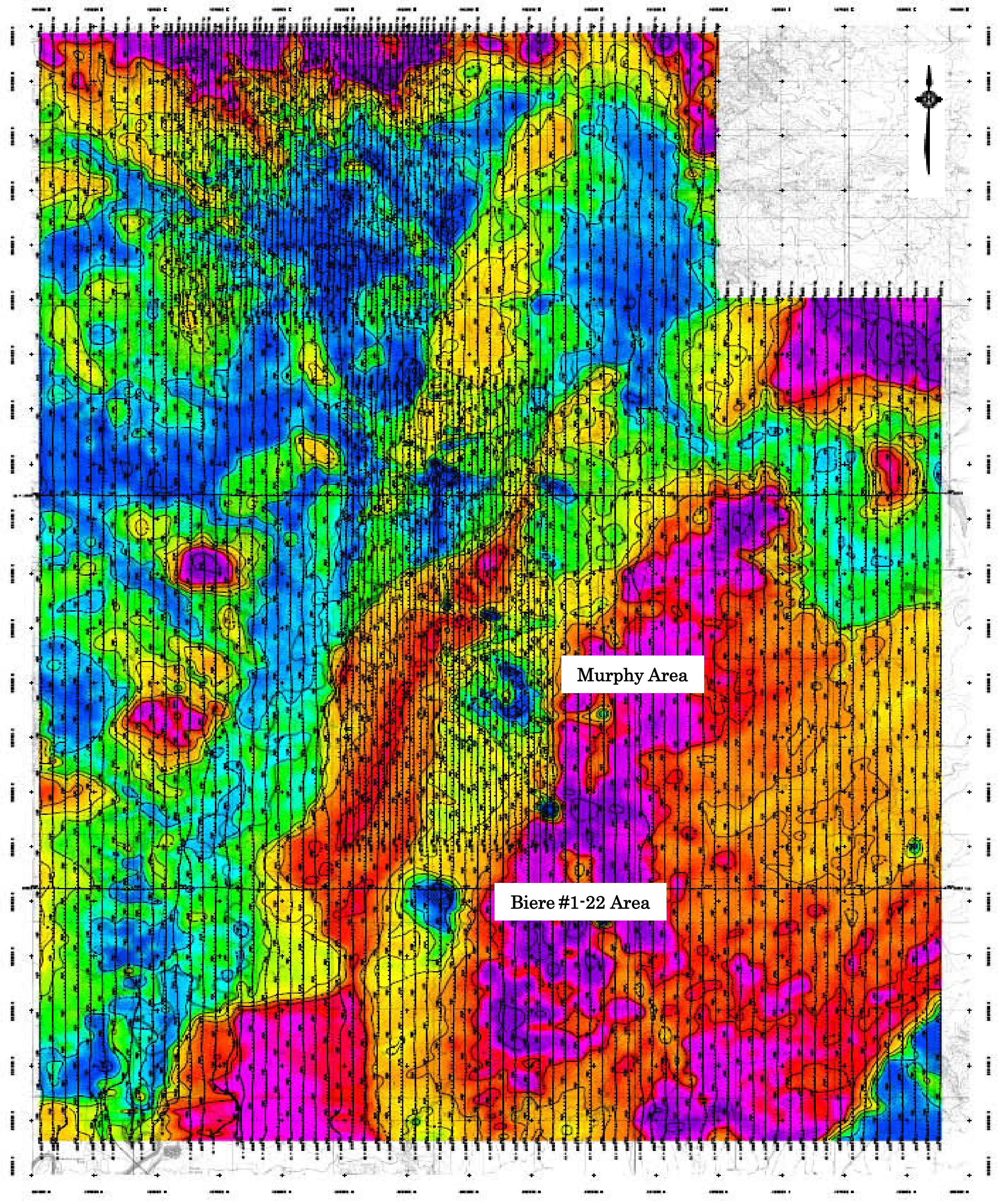


Newly Discovered Plume
Conductivity Depth Section
MultiPlot
Newly Discovered Plume
Line L10410
PIONEER
Natural Resources USA, Inc.
East Poplar Ground Water Study
Roosevelt County, Montana
RESOLVE Survey
PIONEER

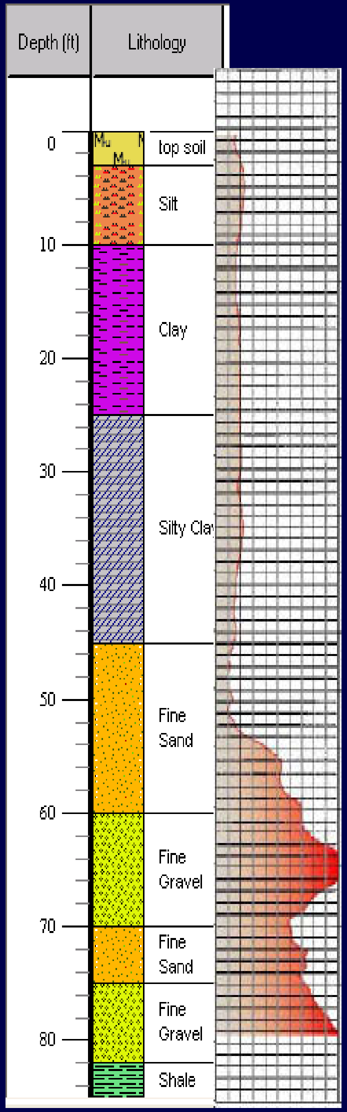
APPARENT RESISTIVITY MAP

1800 Hz Coplanar

USGS 2004 Resolve Survey



Downhole Geophysical Logging



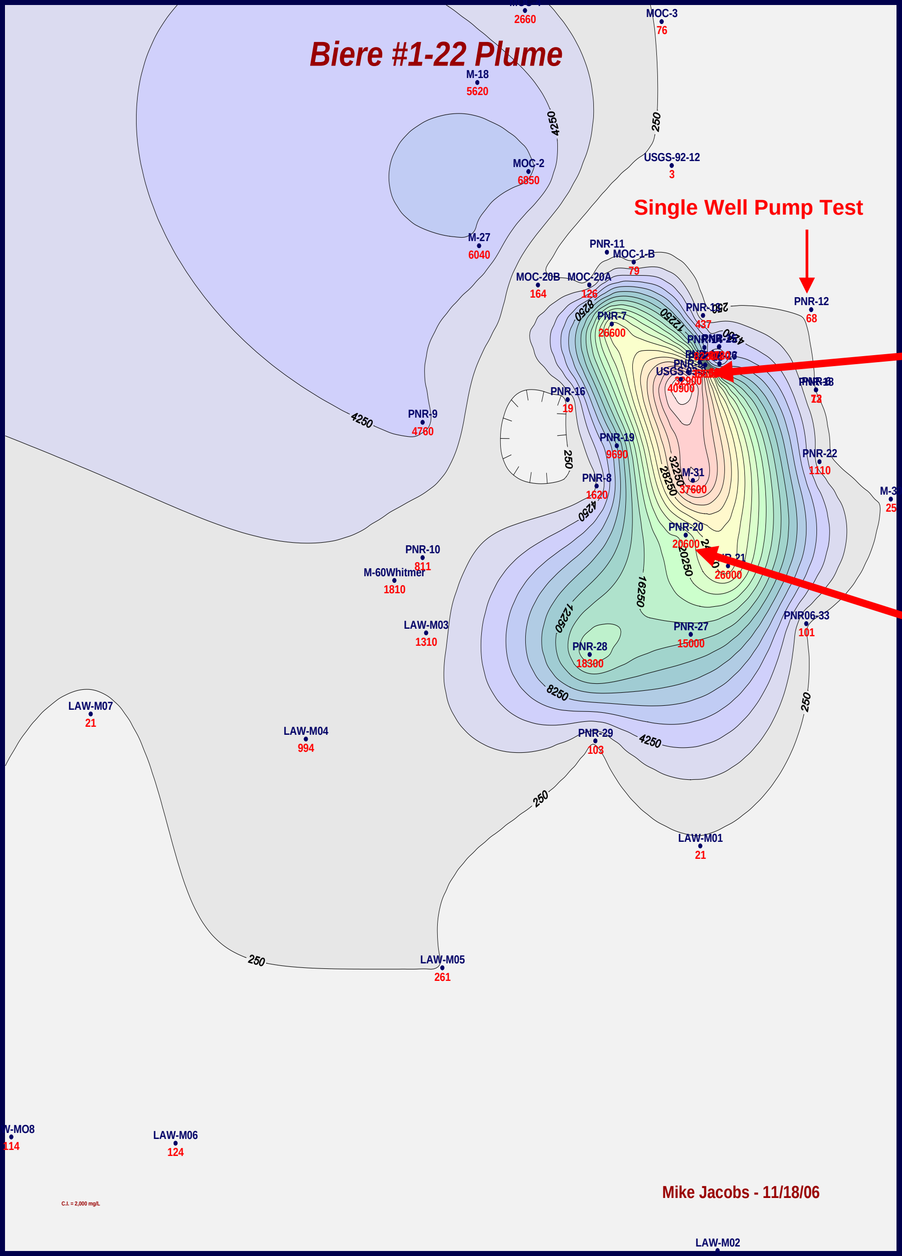
Aquifer Testing – Aquifer Characterization
(Pioneer – Midland ED & HKM Engineering)

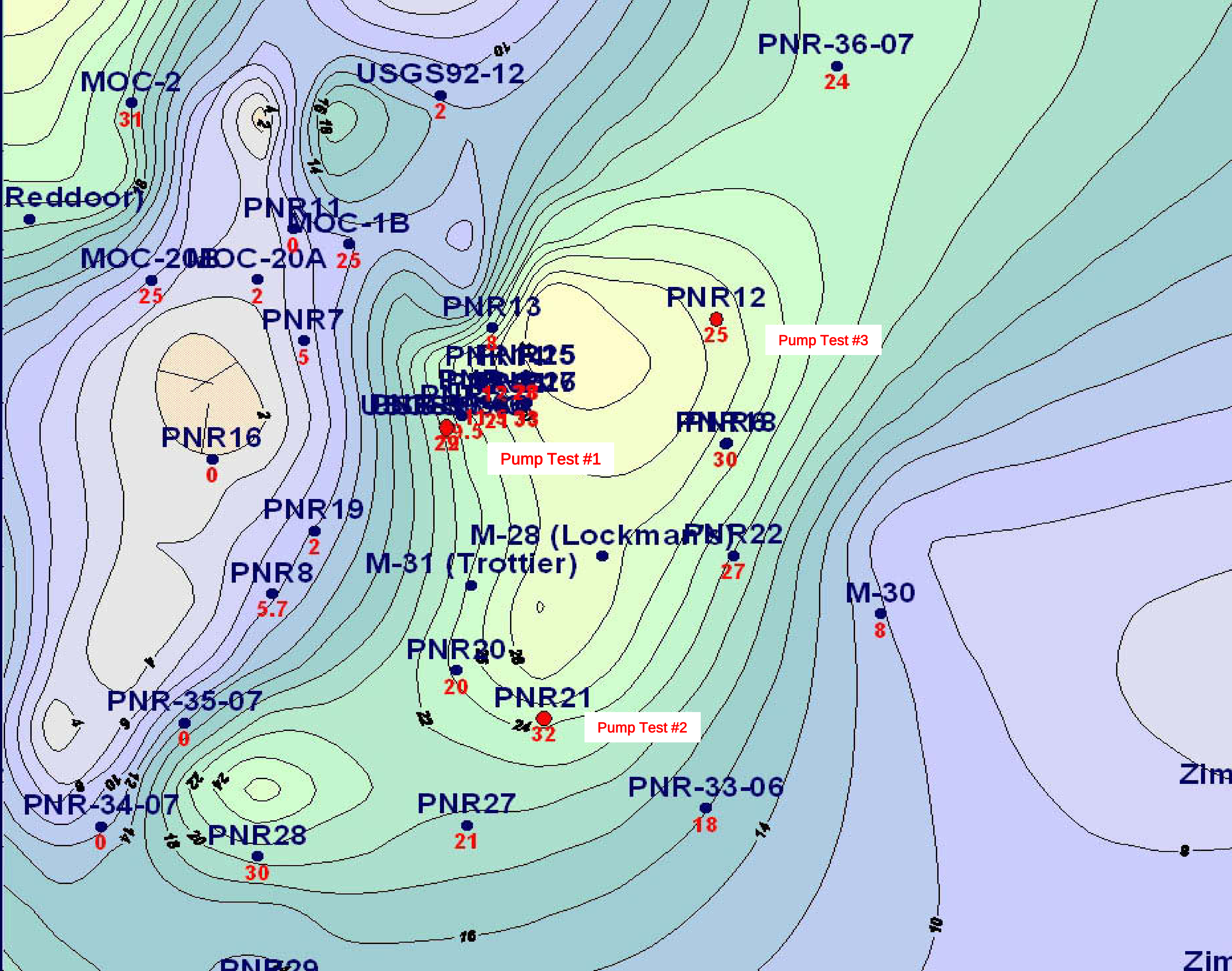
- **Drilling of three additional wells (two 5” pumping wells and one 5” observation well**
- **Conducted Three Aquifer Tests**
  - ✓ **Test #1 - Main Plume Area – 18 hour pump test (1,000 minutes)**
  - ✓ **Test #2 - Wiota Gravel “Choke Point” Area – 18 hours pump test (1,000 minutes)**
  - ✓ **Test#3 – Upgradient Gravel Channel (8 hour pump test)**
- **Conducted 15 Slug Tests**

Hydrogeologic and Hydraulic Parameters Important for Aquifer Characterization, Modeling, & Cleanup

Parameter	*Importance To Groundwater Cleanup*
Hydraulic Conductivity K	Ease with which water can move through a formation and influences the rate at which groundwater can be pumped for treatment. Influences the total flow rate of the system.
Hydraulic gradient *U*	Influences the direction of contaminant movement based upon the elevation and pressure differences.
Transmissivity T	Influences the rate at which groundwater can be pumped and, thus, influences the total flow rate of the system.
Groundwater velocity V_i	Influences the direction and velocity of dissolved contaminant movement - important when designing a containment system.
Porosity θ	Pores store water and contaminants. Influences the hydraulic conductivity and impacts the fate of the contaminants due to various physical, chemical, and biological processes that take place in the saturated zone.
Effective porosity θ_e	Has an impact on the groundwater velocity.
Storage coefficient S	Influences the quantity of groundwater that can be obtained by pumping
Specific yield S_y	Fraction of total pore volume released as water by gravity drainage during pumping of an unconfined aquifer and influences the quantity of groundwater that can be obtained by pumping.

Aquifer Tests to Obtain Hydraulic Parameters

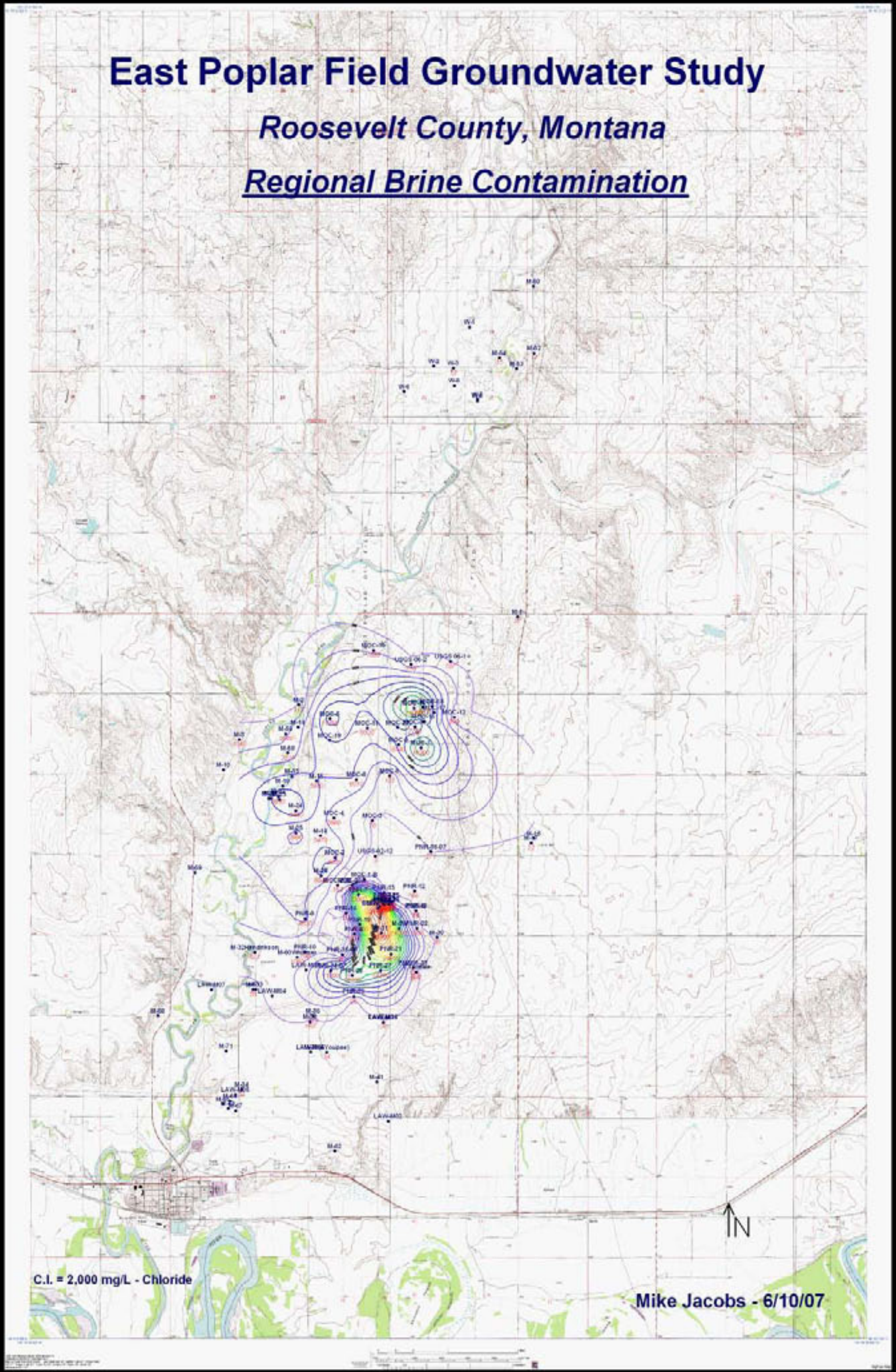



PNR-36-07
24
MOC-2
31
USGS92-12
2
Reddoor)
PNR11
0
MOC-1B
25
MOC-20B
25
MOC-20A
2
PNR7
5
PNR13
8
PNR12
25
Pump Test #3
PNR16
0
PNR18
30
Pump Test #1
PNR19
2
M-28 (Lockman's)
PNR22
27
M-31 (Trottier)
PNR8
5.7
M-30
8
PNR20
20
PNR21
32
Pump Test #2
PNR-35-07
0
PNR-33-06
18
PNR-34-07
0
PNR27
21
PNR28
30

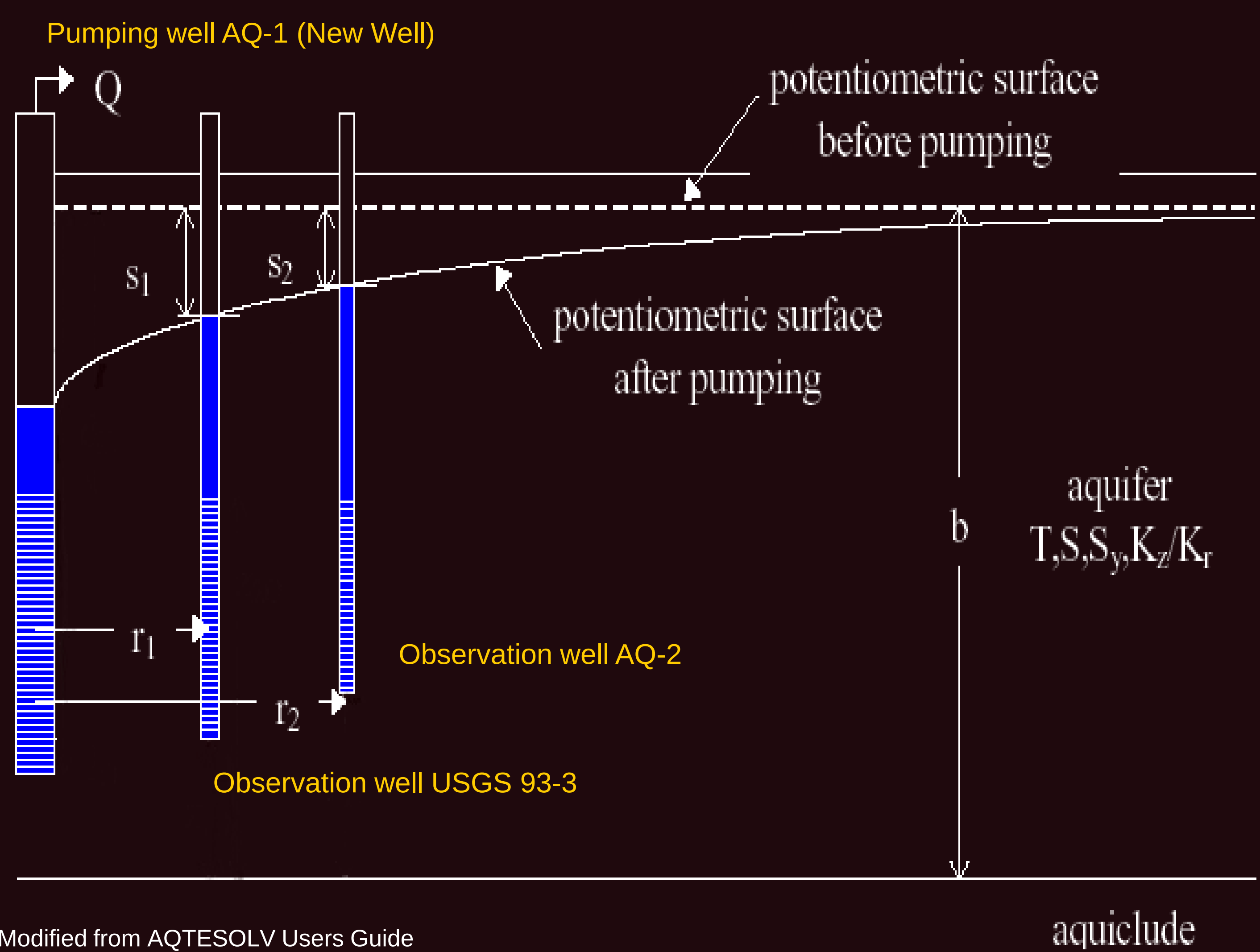
East Poplar Field Groundwater Study

Roosevelt County, Montana

Regional Brine Contamination



Aquifer Testing



Modified from AQTESOLV Users Guide

PNR-30-06 Pumping Test Results - Northern Channel - Plume "Hot Spot"

WELL	DISTANCE (feet)	PUMPING RATE (gpm) hh:mm:ss	MAXIMUM DRAWDOWN (feet)
PNR-30-06 *Pumping Well*	0.0	29 gpm for 19:17:12	1.96
USGS-93-3A	14	0	0.92
USGS-93-3	24	0	0.86
PNR-5	162	0	0.34
PNR-14	682	0	0.24

Avg. K = 285 ft/day

PNR-31-06 Pumping Test Results – Southern Channel – Plume Front Area

WELL	DISTANCE (feet)	PUMPING RATE (gpm) (hh:mm:ss)	MAXIMUM DRAWDOWN (feet)
PNR-31-06 *Pumping Well*	0.0	80 gpm for 00:12:46 60 gpm for 00:56:35 53 gpm for 18:30:47	16.22
PNR-21	20		1.16
PNR-32-06	65		0.54
PNR-20	970		0

Avg. K = 205 ft/day

Hydraulic Conductivities (K) - Derived From Slug Test Data

Well	Hydraulic Conductivity (ft/day)		Average Hydraulic Conductivity = K
Well	Falling Head Test	Rising Head Test	
USGS 92-12	.075 ft/day	.012 ft/day	.098 ft/day
PNR-8	.0039 ft/day	.044 ft/day	.024 ft/day
PNR-13	.31 ft/day	.30 ft/day	,305 ft/day
PNR-16	.0045 ft/day	.0034 ft/day	.004 ft/day
PNR-34-07	1.96 ft/day	11.35 ft/day	6.66 ft/day
PNR-35-07	1.28 ft/day	2.28 ft/day	1.78 ft/day
PNR-22 Upper Alluvial Aquifer	12.03 ft/day	17.03 ft/day	16.15 ft/day
MOC- 3	0.42 ft/day	0.45 ft/day	0.43 ft/day
MOC- 2	5.22 ft/day	7.01 ft/day	6.01 ft/day
LAW-MO3 Lower Alluvial Aquifer	59.83 ft/day	100.20 ft/day	98.01 ft/day
LAW-MO4 Lower Alluvial Aquifer	41.42 ft/day	45.92 ft/day	48.53 ft/day
PNR-9	1.01 ft/day	3.96 ft/day	2.55 ft/day
PNR-12	0.38 ft/day	0.29 ft/day	0.36 ft/day
PNR-18	2.52 ft/day	1.54 ft/day	2.06 ft/day
PNR-36-07	14.56 ft/day	5.89 ft/day	9.26 ft/day

Integrated Hydrogeological and Engineering Study

Groundwater Flow and Contaminant Transport Model – Visual MODFLOW

(Daniel B. Stephens & Associates, Albuquerque, NM & Pioneer Midland ED)

- **Build Model including input of Hydrogeological and Hydraulic (aquifer pump & slug test and initial head data), Geological and Well Completion data**
- **Perform Capture Zone Analysis**
- **Perform Total Pumping Rate Analysis**
- **Determine Location of Pumping Wells & Number or Wells Needed**

Groundwater Flow and Contaminant Transport Model – Visual MODFLOW

(Daniel B. Stephens & Associates, Albuquerque, NM & Pioneer Midland ED)

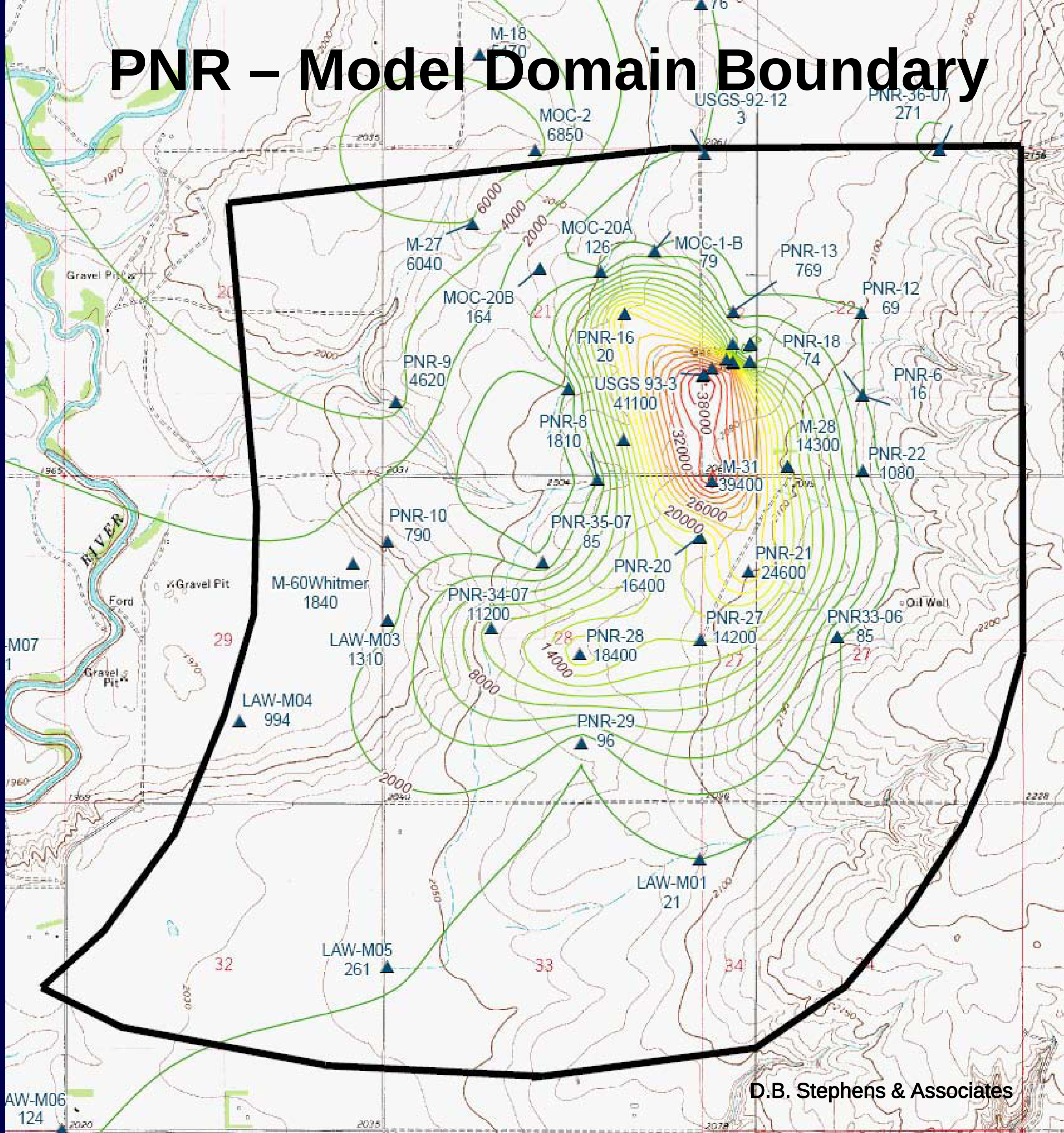
1. **Build Model**
   - **Input of Hydrogeological & Hydraulic Data**
     - ***Input Initial Head Data – 47 Wells***
     - ***Define Hydrogeological Layers & Aquifer Thickness***
       - **Elevation of Top of Hydrostratigraphic Layers**
       - **Elevation of Bedrock (Bearpaw Shale)**
     - ***Assign K from Pump and Slug Test Data to Layers***
     - ***Input Geological Data***
       - **Lithology Logs**
     - ***Well Completion data***
       - **Elevation of T/Screen Interval**
       - **Screened Interval**
       - **Size of Casing**
       - **Screen Slot Size**

2. **Perform Capture Zone Analysis**

3. **Perform Total Pumping Rate Analysis**

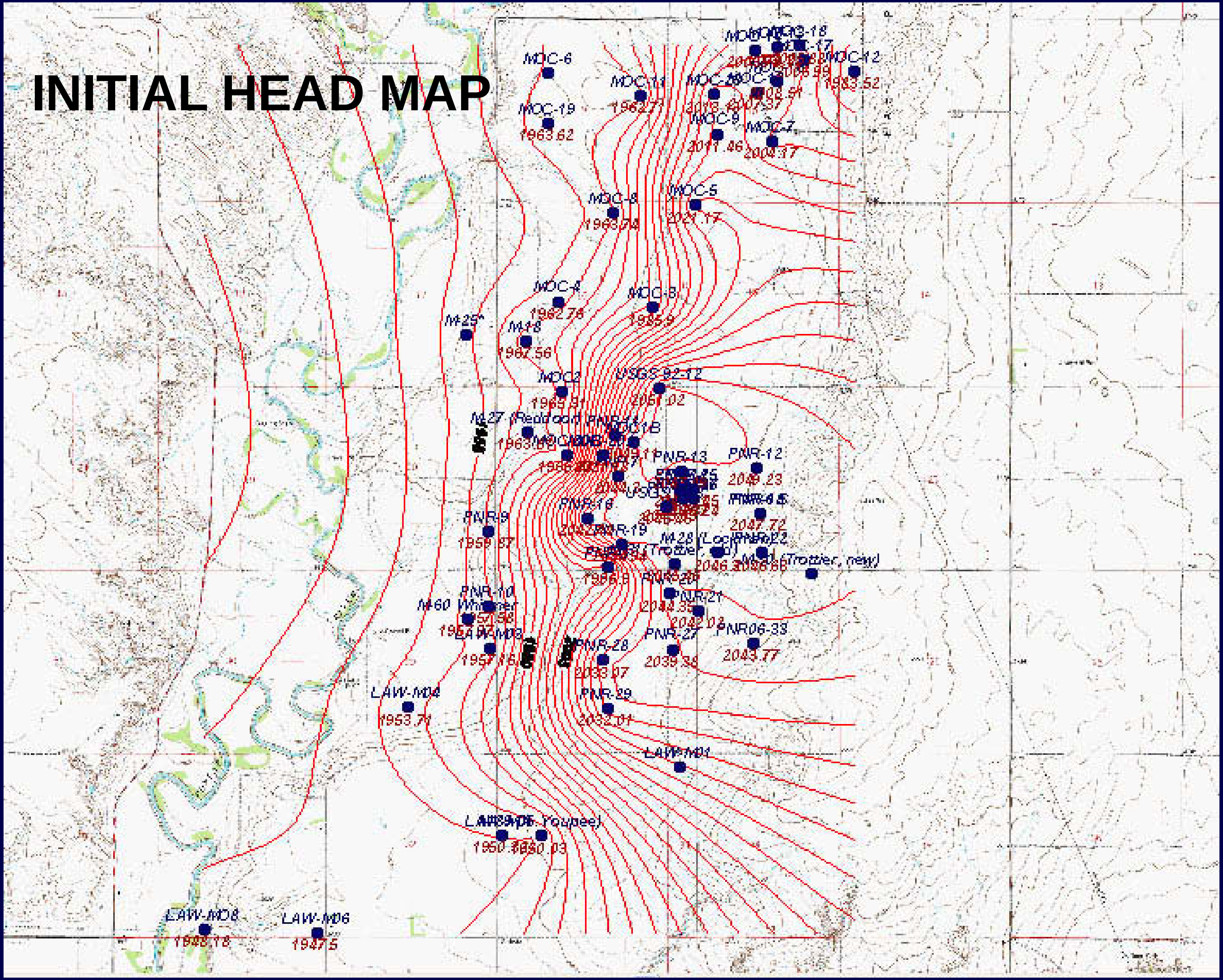
4. **Determine Location of Pumping Wells & Number or Wells Needed**

PNR – Model Domain Boundary

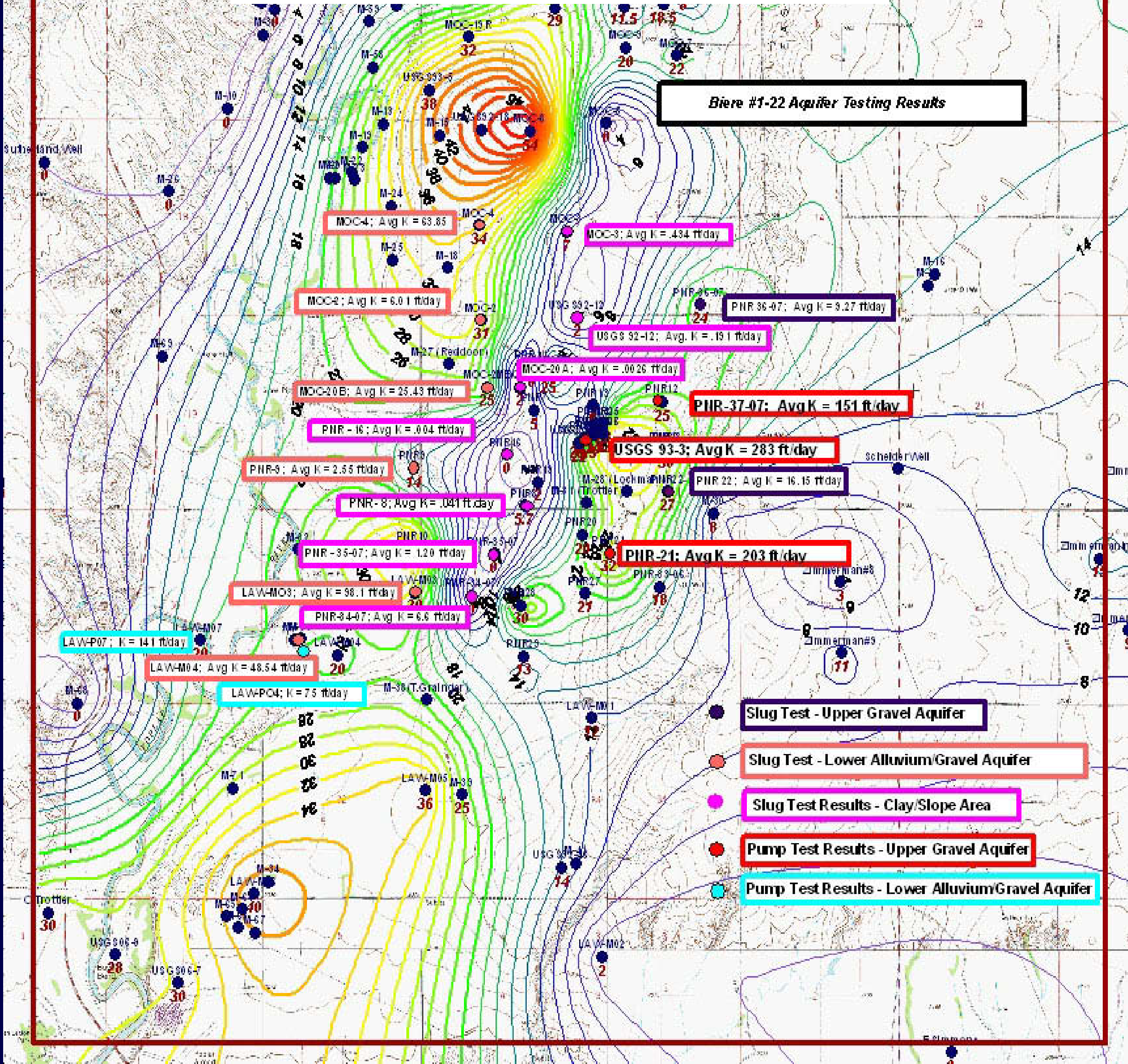


D.B. Stephens & Associates

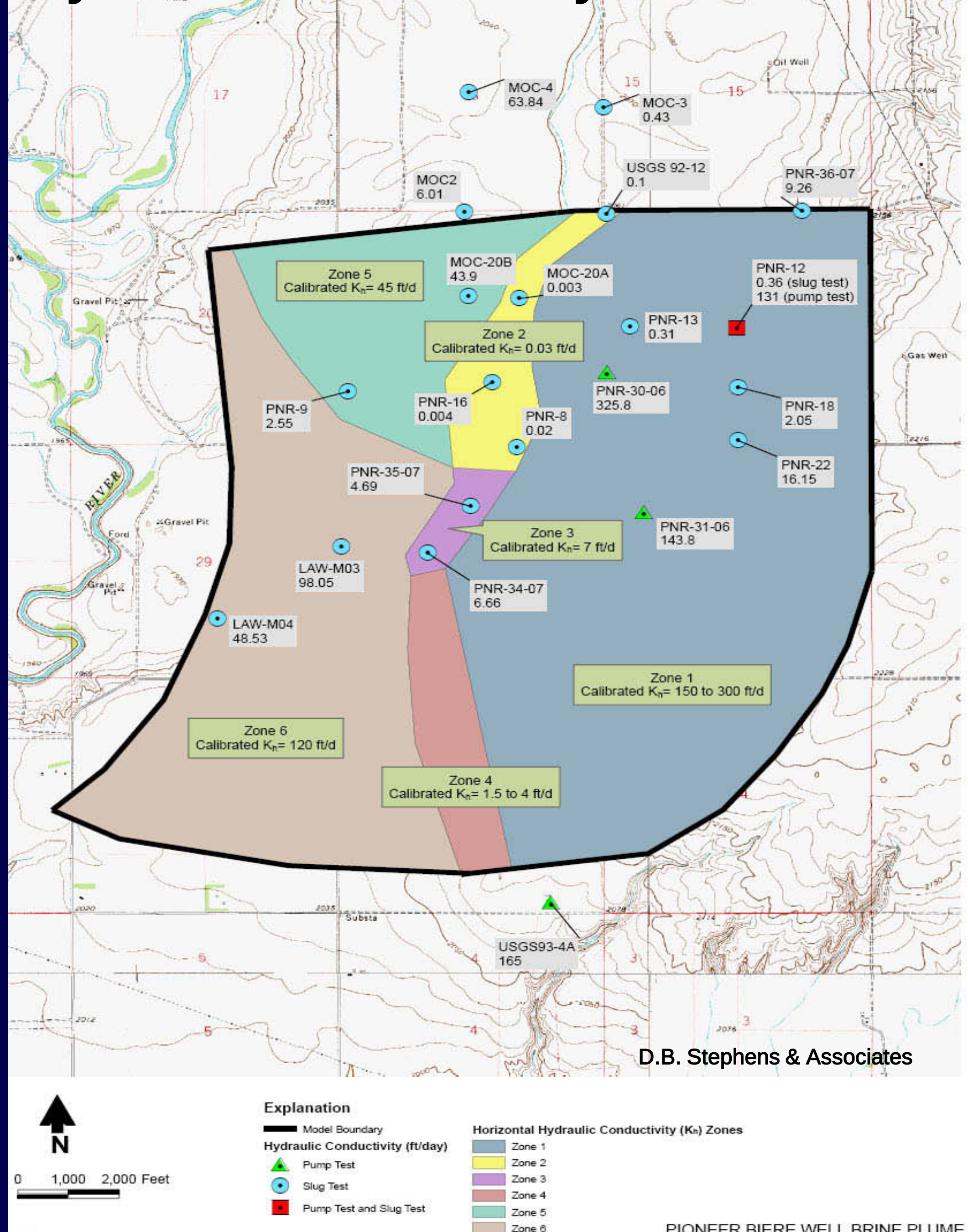
INITIAL HEAD MAP

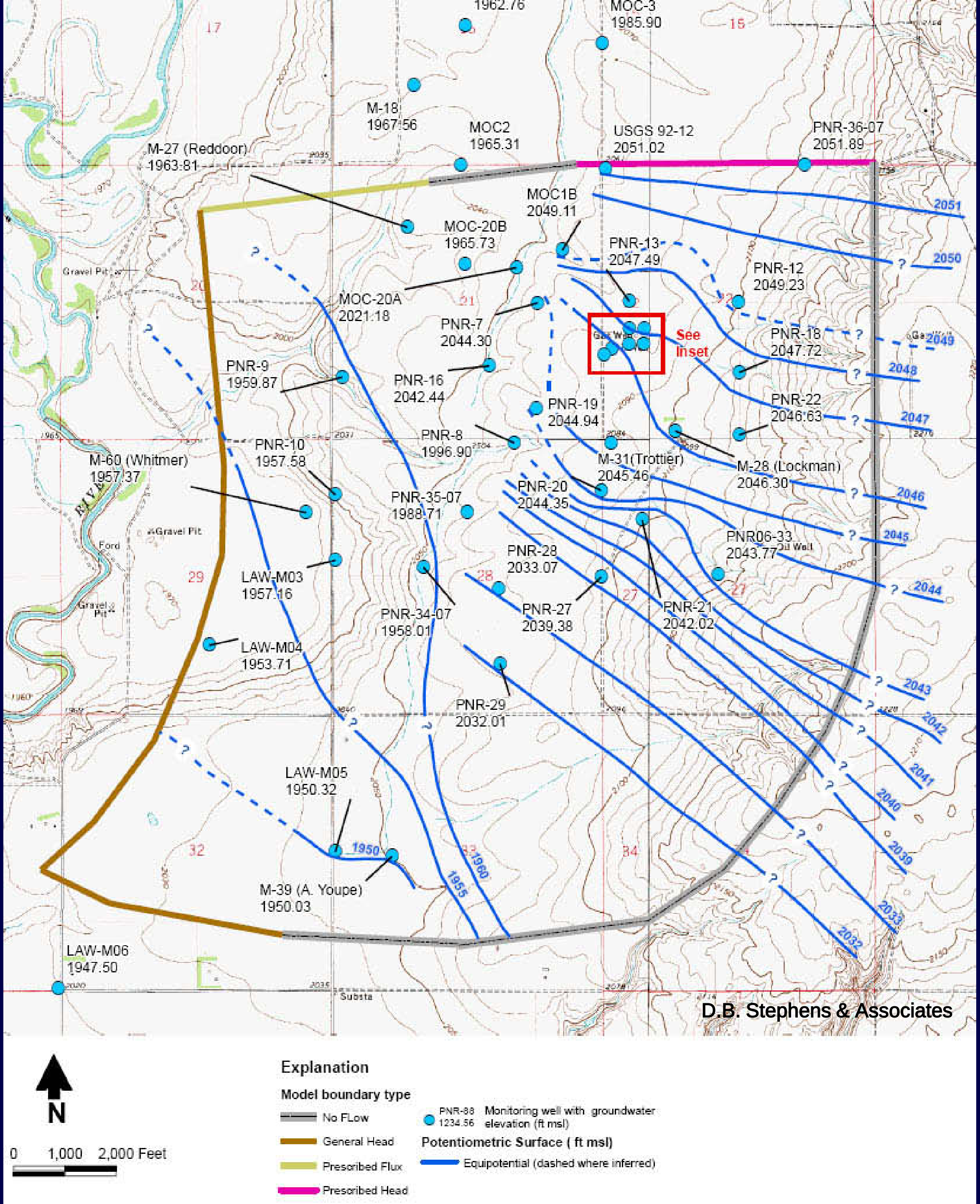


Pump & Slug Test Results

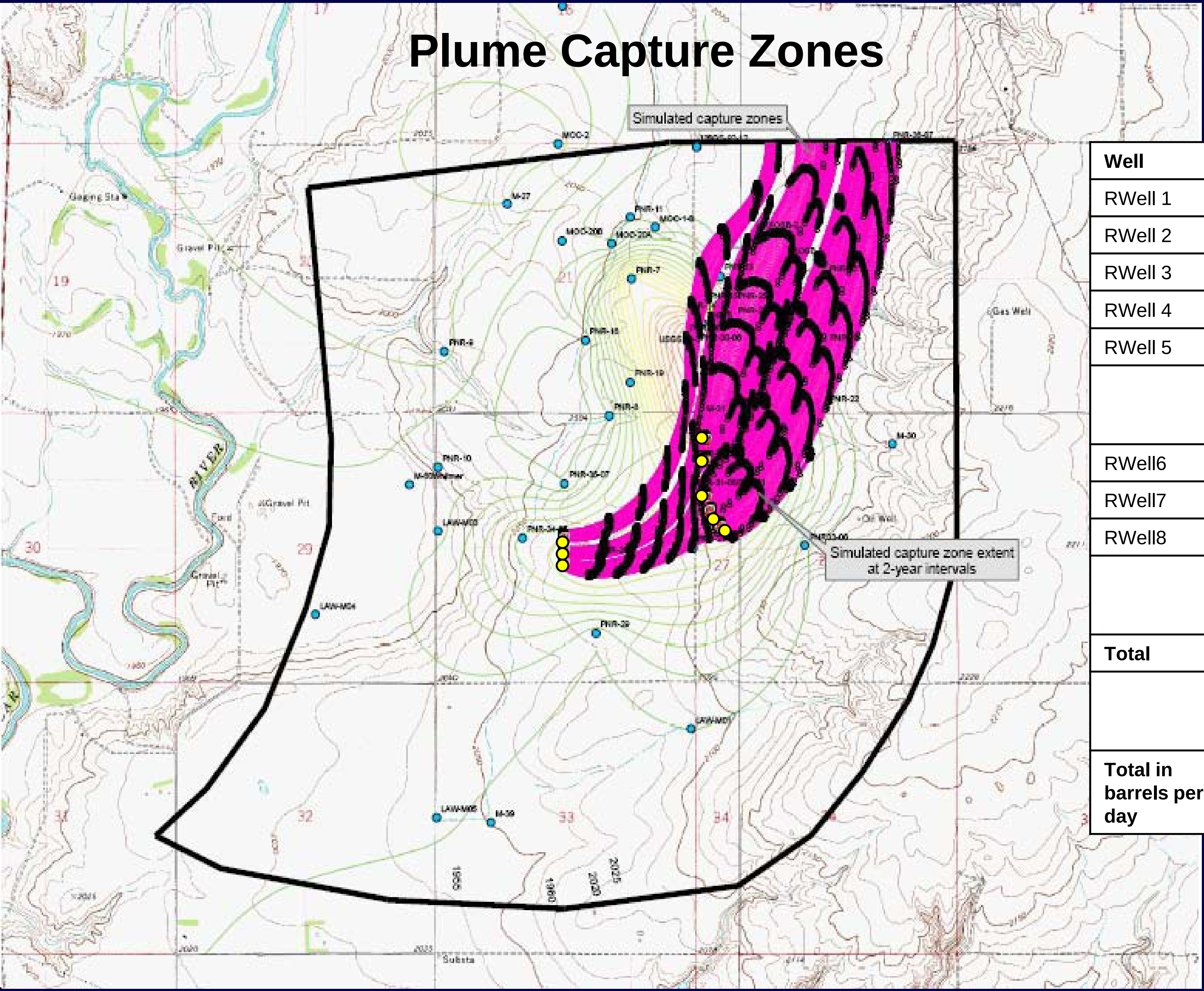


Hydraulic Conductivity Distribution



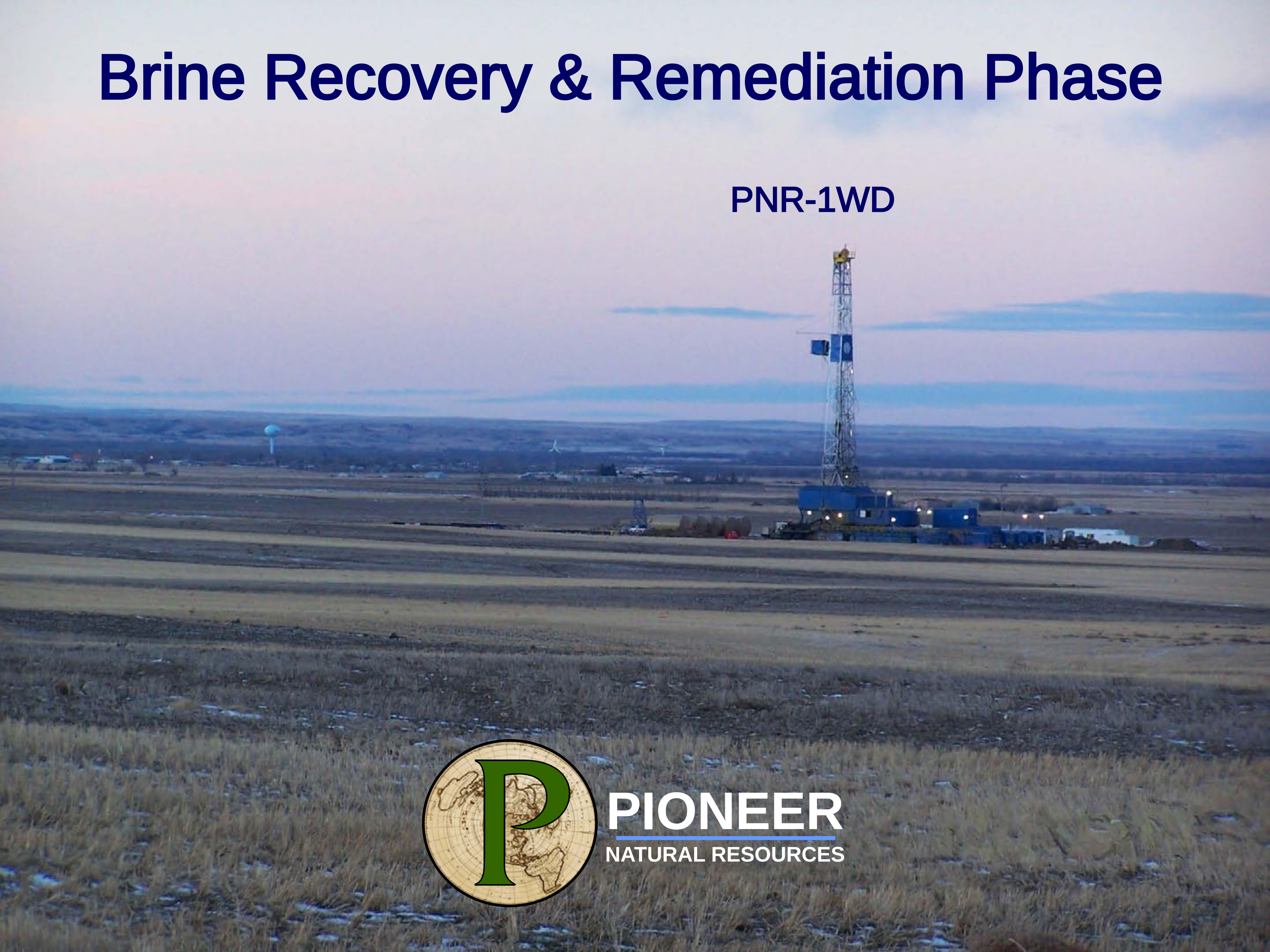

M-27 (Reddoor) 1963.81
M-18 1967.56
MOC2 1965.31
MOC-3 1985.90
USGS 92-12 2051.02
PNR-36-07 2051.89
MOC1B 2049.11
MOC-20B 1965.73
MOC-20A 2021.18
PNR-13 2047.49
PNR-12 2049.23
PNR-7 2044.30
PNR-18 2047.72
PNR-9 1959.87
PNR-16 2042.44
PNR-19 2044.94
PNR-22 2046.63
PNR-8 1996.90
PNR-10 1957.58
M-60 (Whitmer) 1957.37
M-31 (Trottier) 2045.46
M-28 (Lockman) 2046.30
PNR-35-07 1988.71
PNR-20 2044.35
PNR06-33 2043.77
LAW-M03 1957.16
PNR-28 2033.07
PNR-34-07 1958.01
PNR-27 2039.38
PNR-21 2042.02
LAW-M04 1953.71
PNR-29 2032.01
LAW-M05 1950.32
M-39 (A. Youpe) 1950.03
LAW-M06 1947.50
See Inset
Gravel Pit
Ford
D.B. Stephens & Associates
Explanation
Model boundary type
No FLow
General Head
Presribed Flux
Presribed Head
PNR-88 1234.56 Monitoring well with groundwater elevation (ft msl)
Potentiometric Surface (ft msl)
Equipotential (dashed where inferred)
N
0 1,000 2,000 Feet

Plume Capture Zones

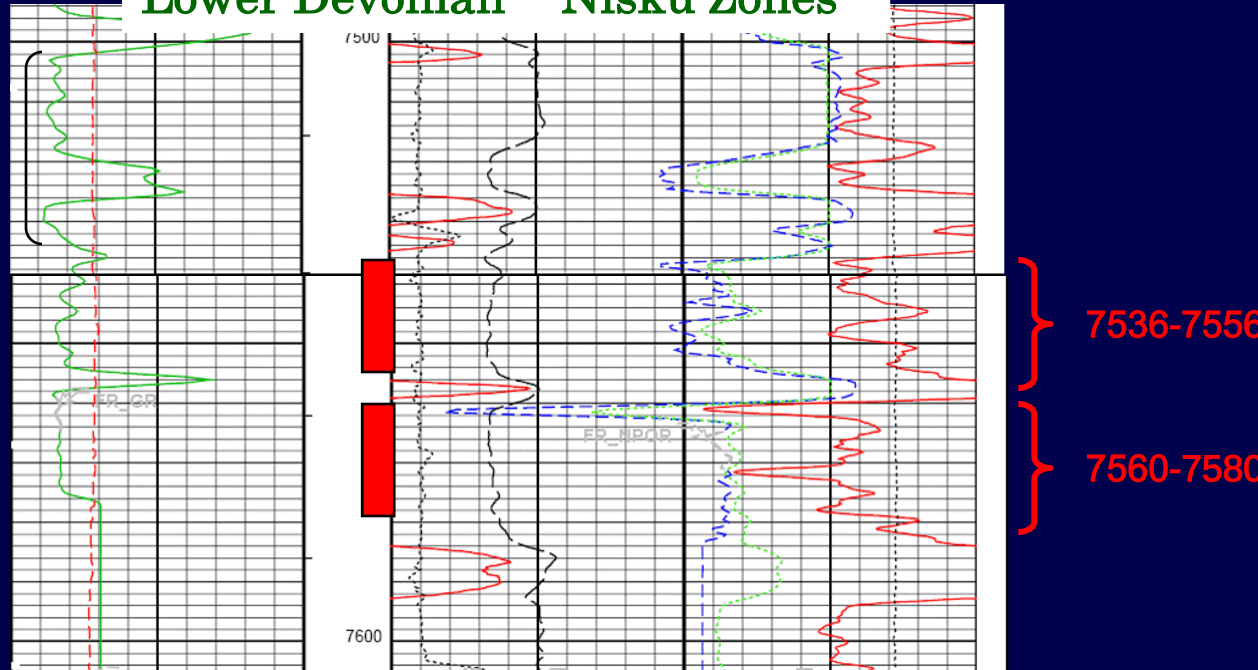


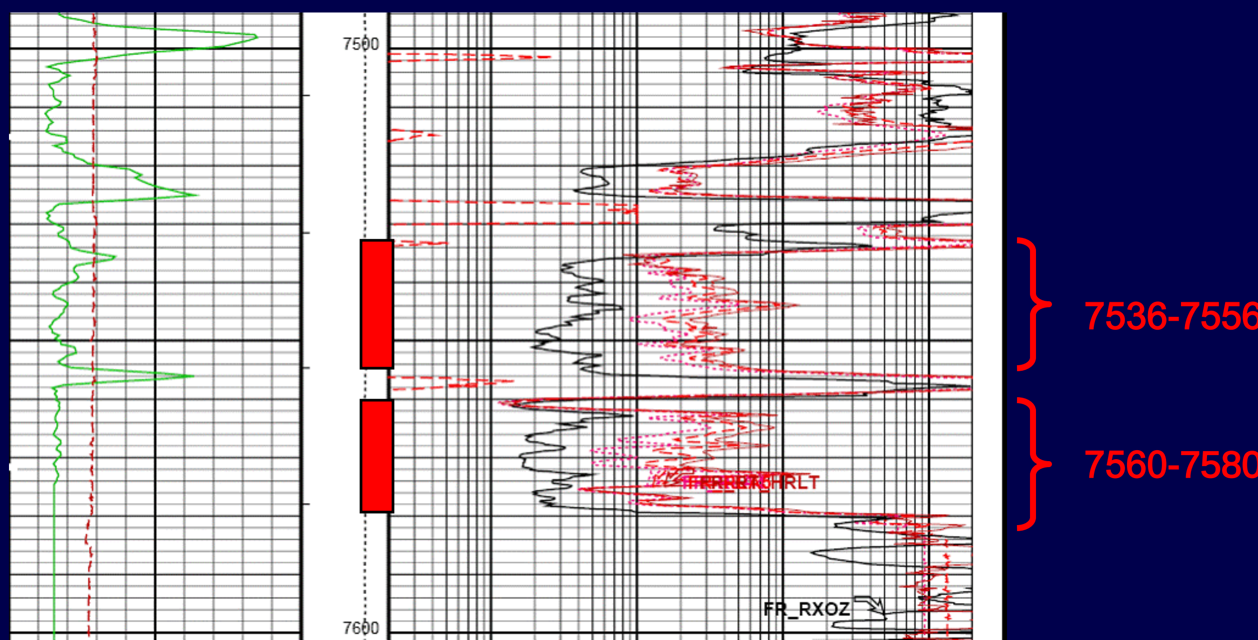
Well	Q (gpm)
RWell 1	30
RWell 2	15
RWell 3	8
RWell 4	25
RWell 5	30
RWell6	10
RWell7	10
RWell8	10
Total	138 gpm
Total in barrels per day	4731

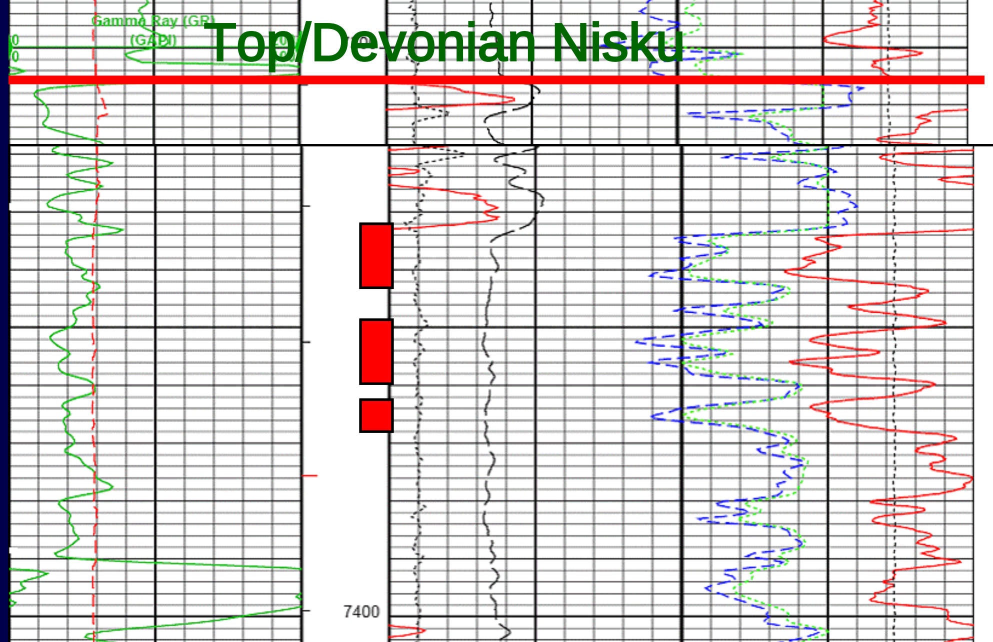
Brine Recovery & Remediation Phase



Lower Devonian - Nisku Zones



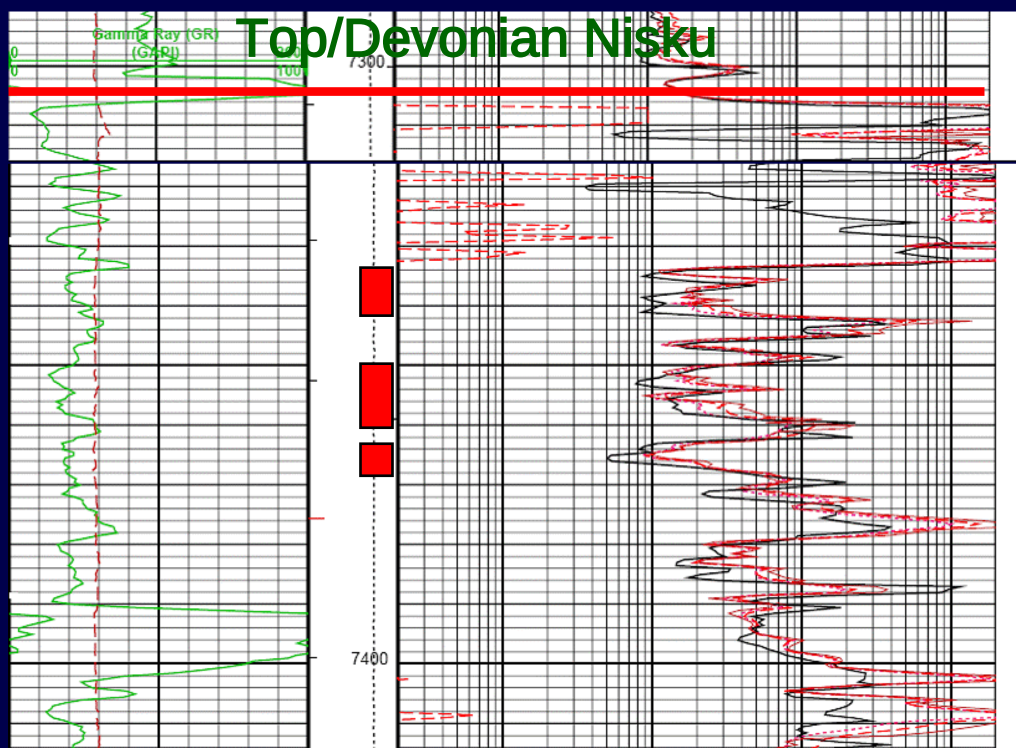




7333-7442

7350-7358

7362-7368

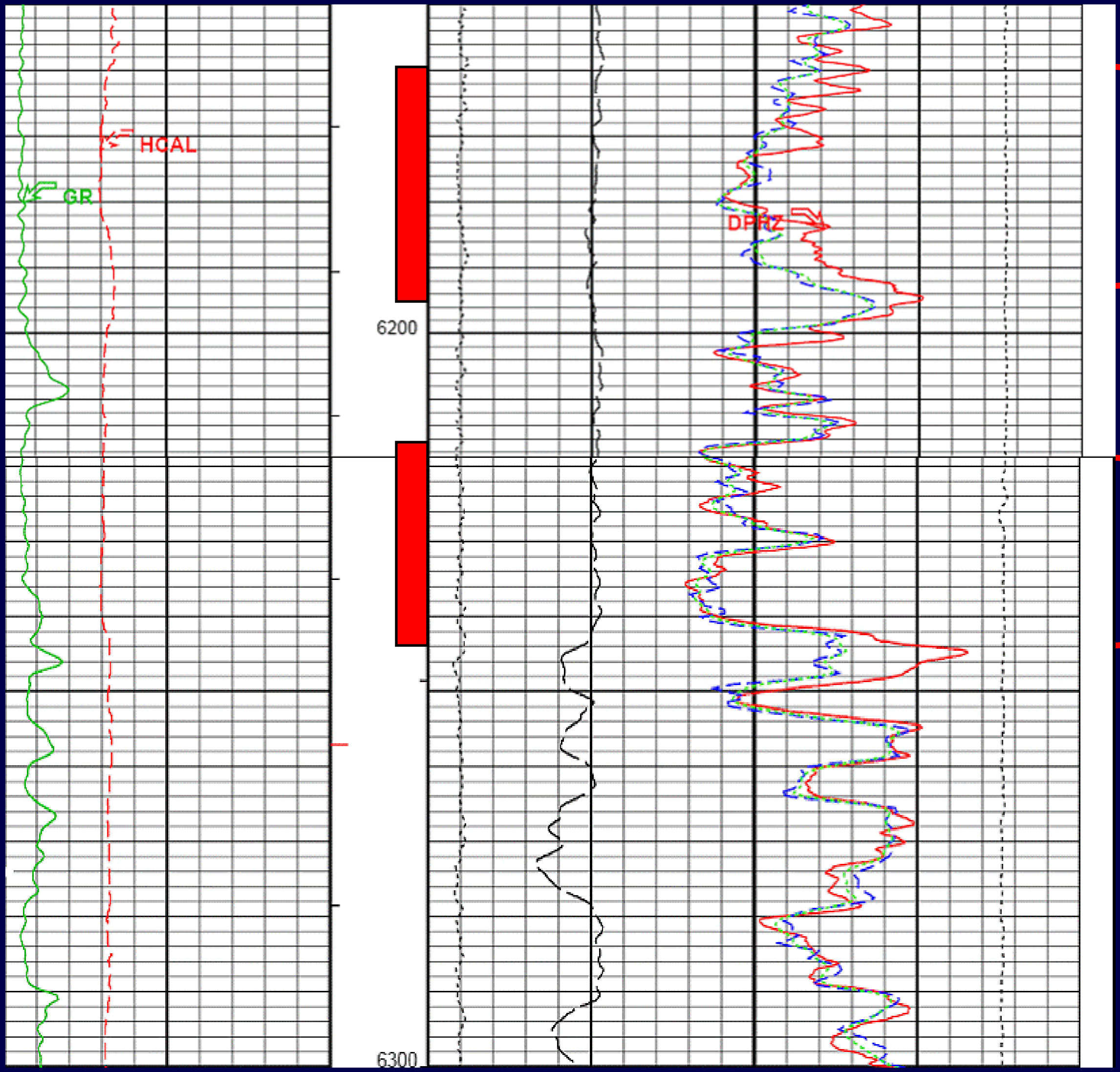


7333-7442

7350-7358

7362-7368

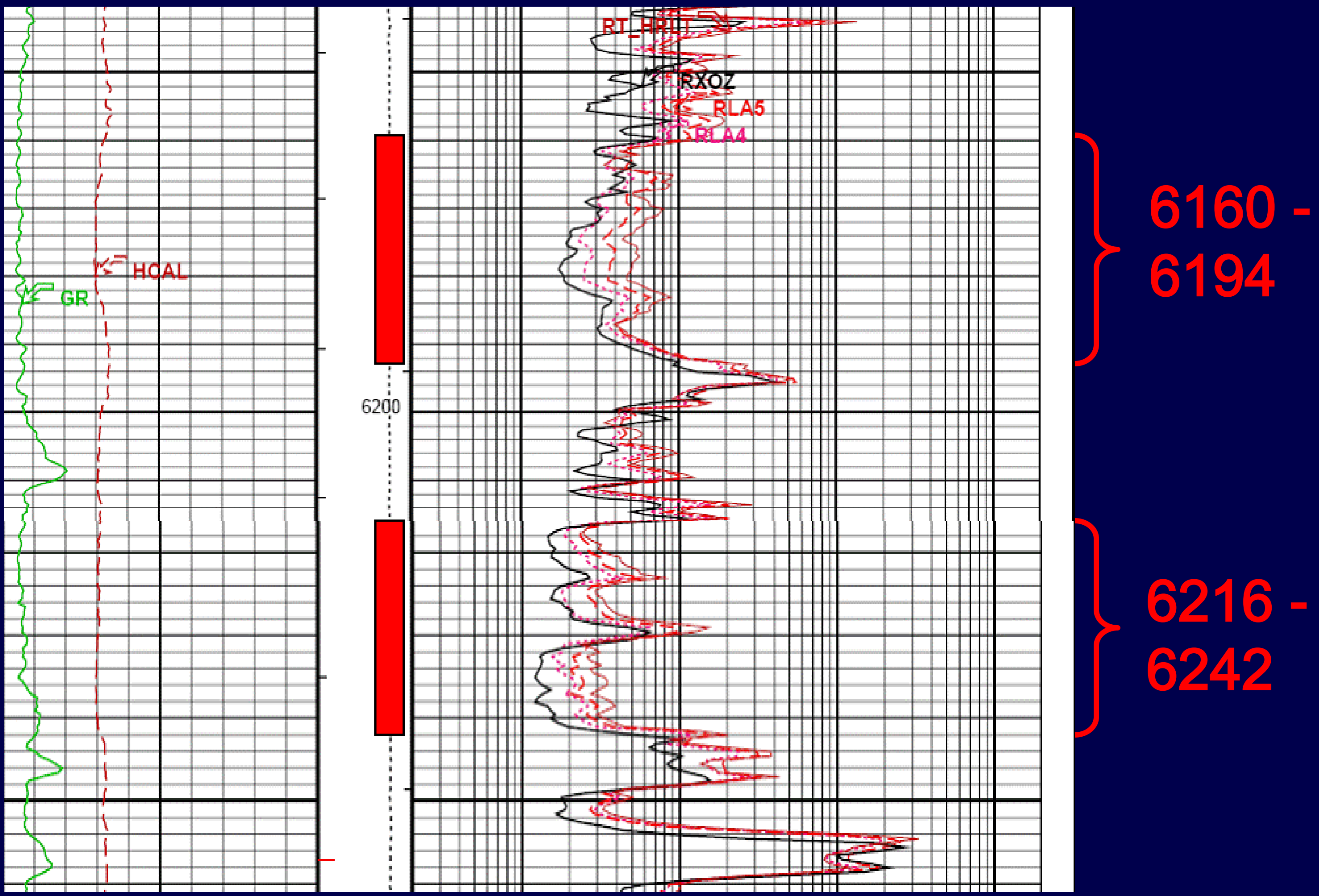
Mississippian – Mission Canyon Zones



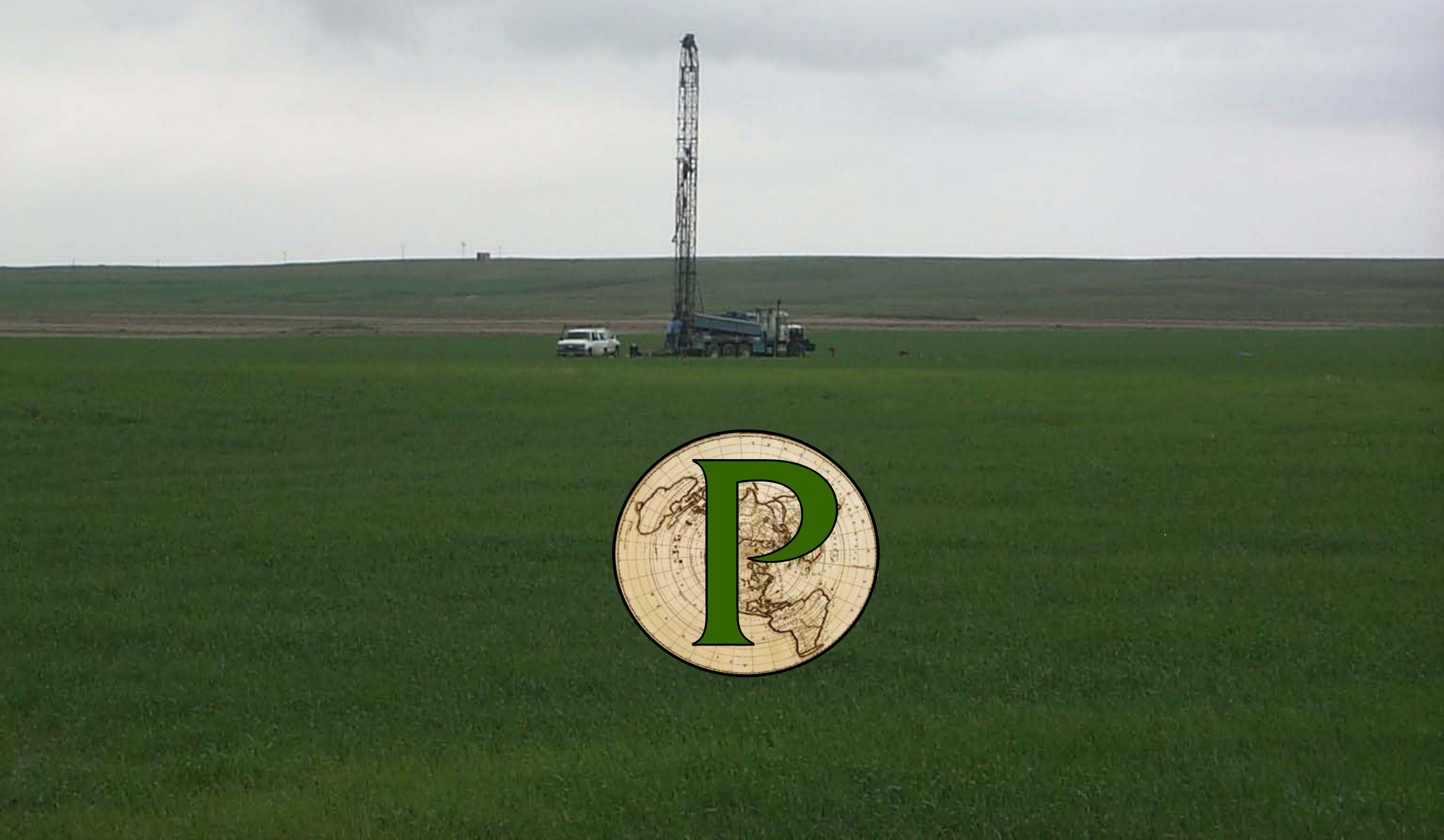
6160 - 6194

6216 - 6242

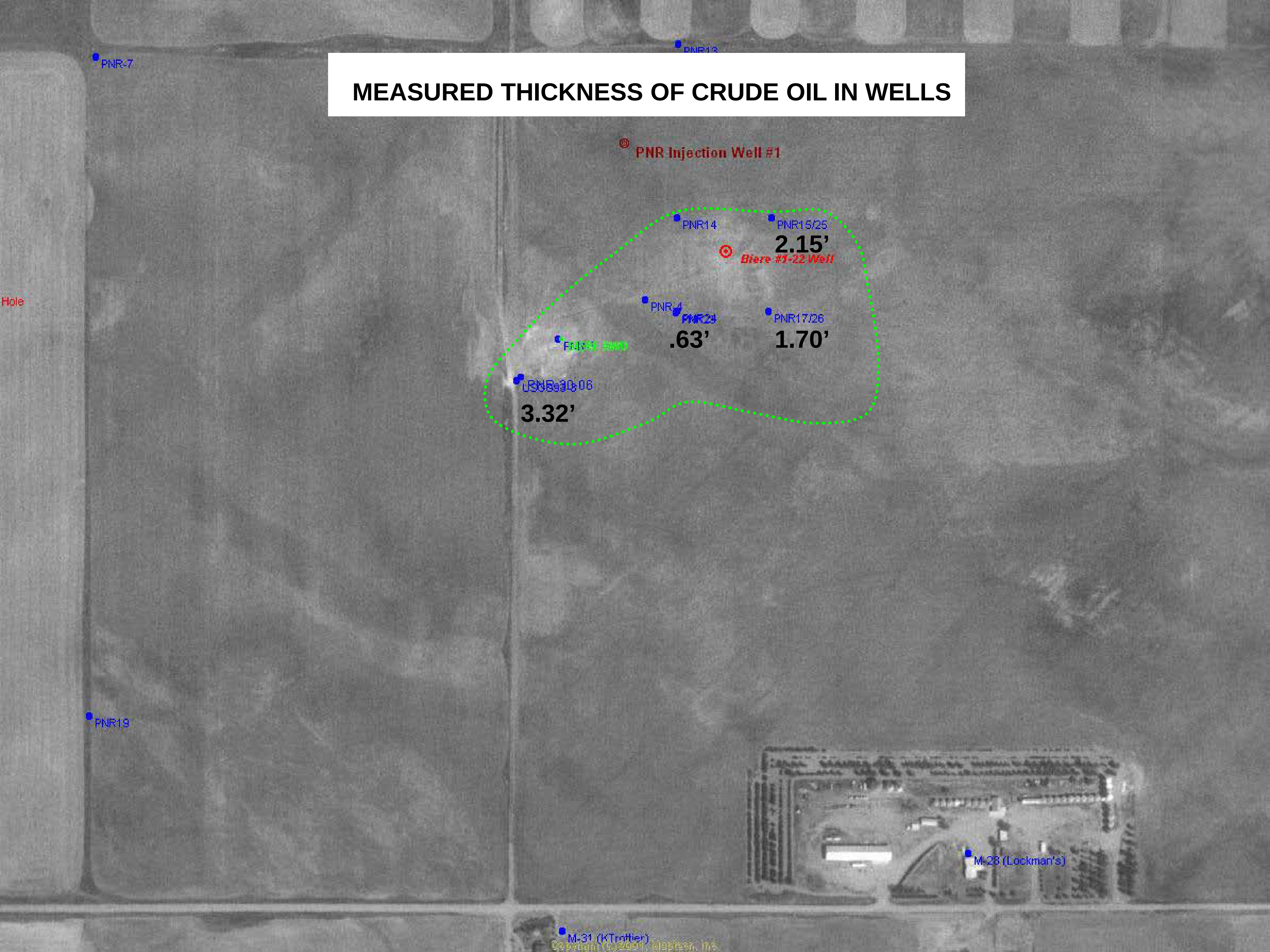
Mississippian – Mission Canyon Zones



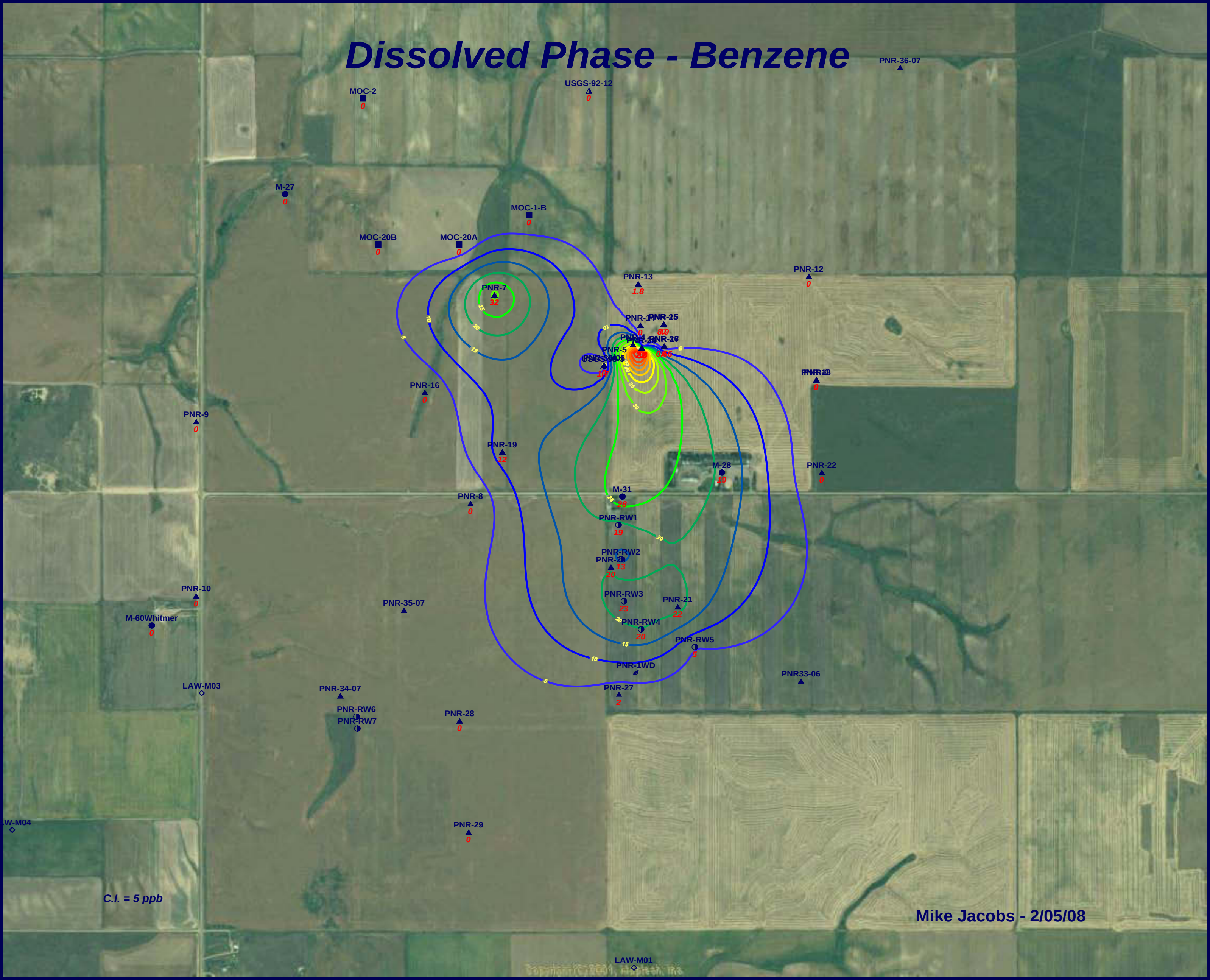
PNR – Biere #1-22 Crude Oil Recovery Project



MEASURED THICKNESS OF CRUDE OIL IN WELLS



Dissolved Phase - Benzene



Mike Jacobs - 2/05/08


Recovery Well #1 (5")
Recovery Well #2 (5")
Recovery Well #3 (8")
Recovery Well #5 (8")
PNR 30-06
Recovery Well #4 (5")
N
Current Transmission Line
New Transmission Line
Trenching for Lines (to be installed)
Product Recovery Well
System Location

References

AQTESOLV, 2008, AQTESOLV version 4.5 Users Guide: Web accessed 28 November 2008, http://www.aqtesolv.com

DeLorme, 2004, DeLorme XMap 4.5: Web accessed 28 November 2008, http://forum.delorme.com

Thamke, J.N., and S.D. Craigg, 1997, Saline-water contamination in Quaternary deposits and the Poplar River, East Poplar Oil Field, northeastern Montana: U.S. Geological Survey, Water Resources Investigations Report, #WRI, 97-4000, 37 p., 3 sheets.

U.S.G.S., 1995, U.S.Geological Survey Digital Line Graph (DLG): Web accessed 25 November 2008, http://edc.usgs.gov/guides/dlg.html