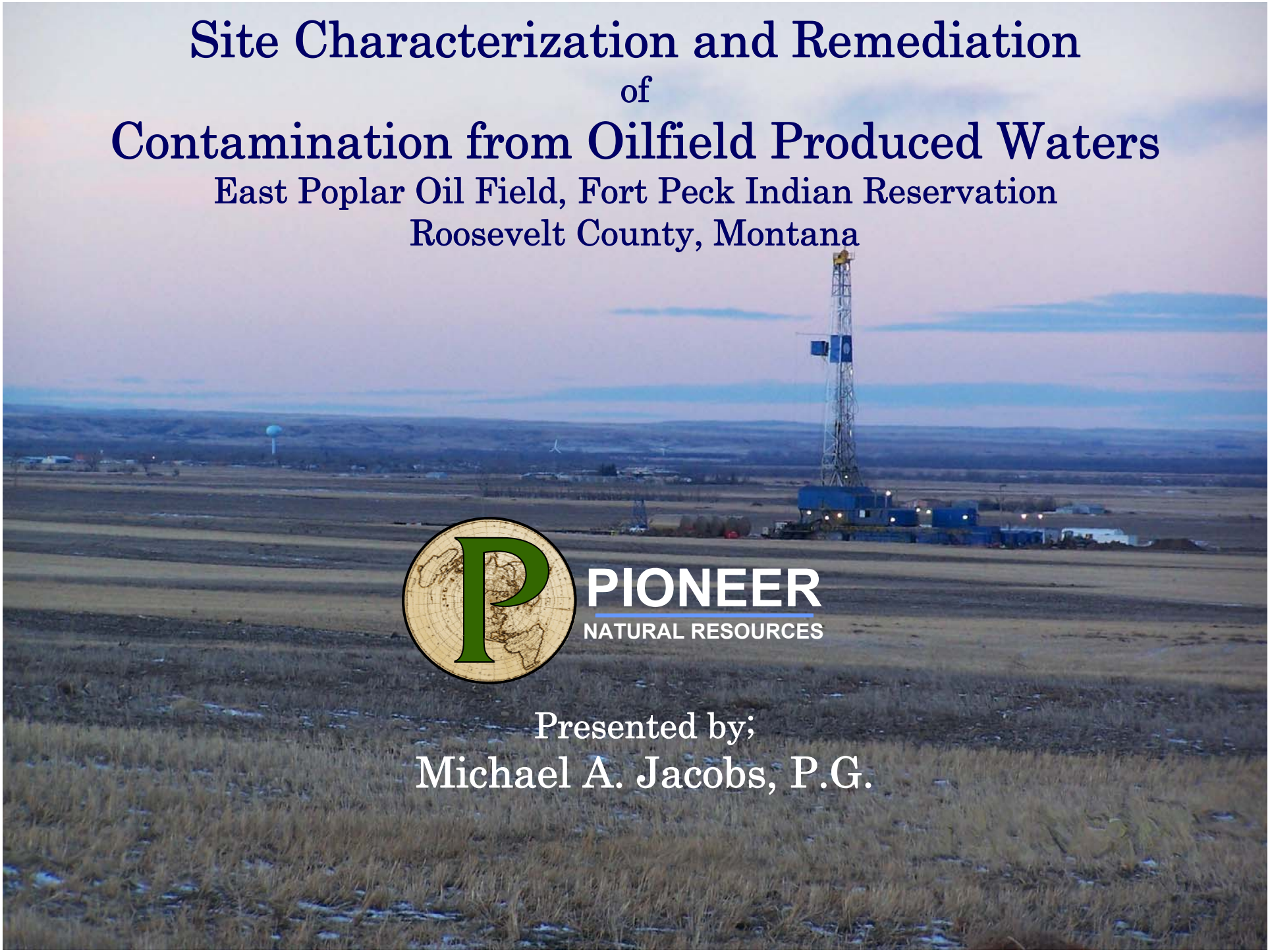
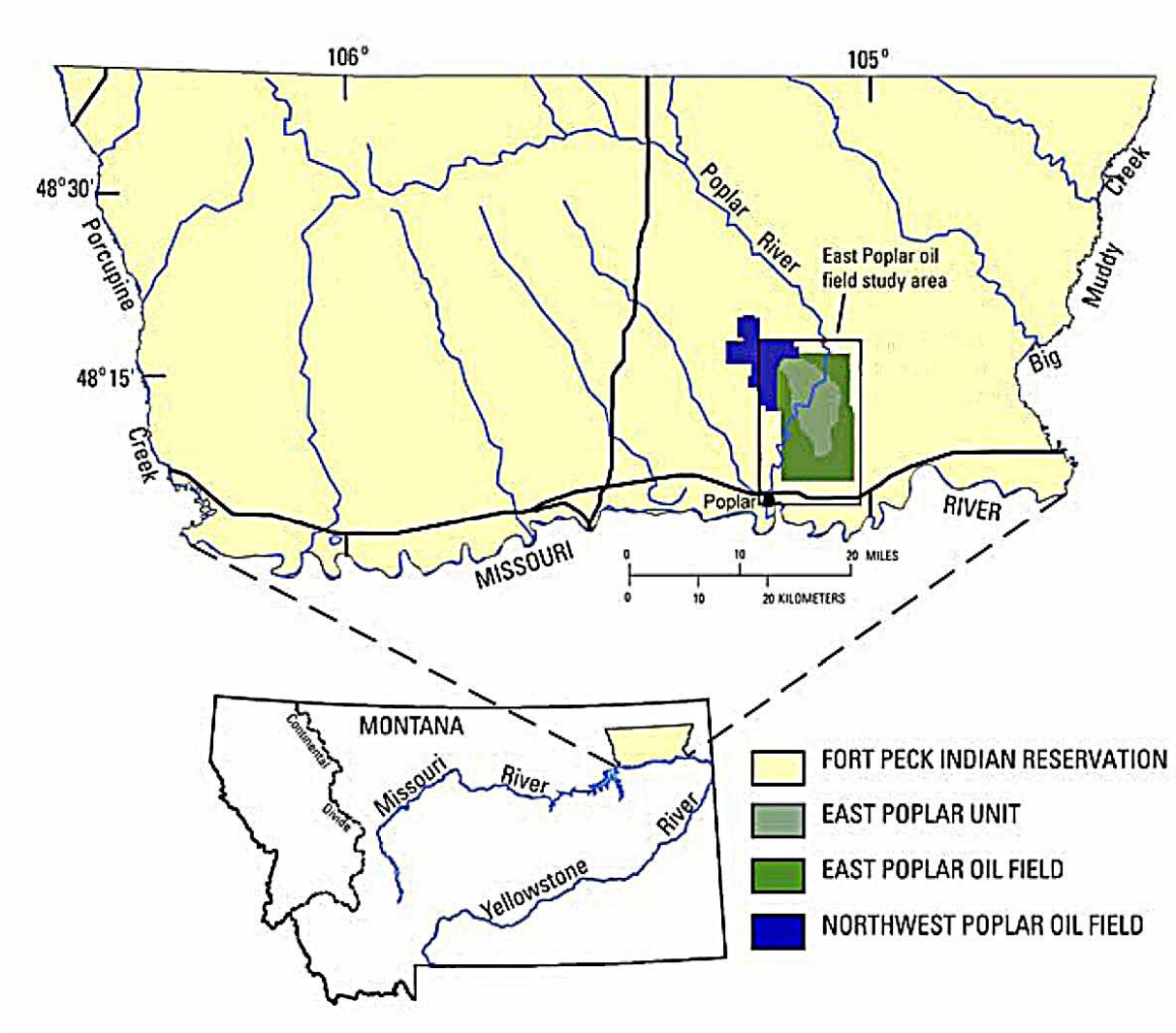
# Site Characterization and Remediation
of
# Contamination from Oilfield Produced Waters
## East Poplar Oil Field, Fort Peck Indian Reservation
## Roosevelt County, Montana



PIONEER
NATURAL RESOURCES

Presented by;
Michael A. Jacobs, P.G.

# East Poplar oil field location map




Bruce Smith - USGS

# Early Studies of Oilfield Contamination

by

United States Geological Survey

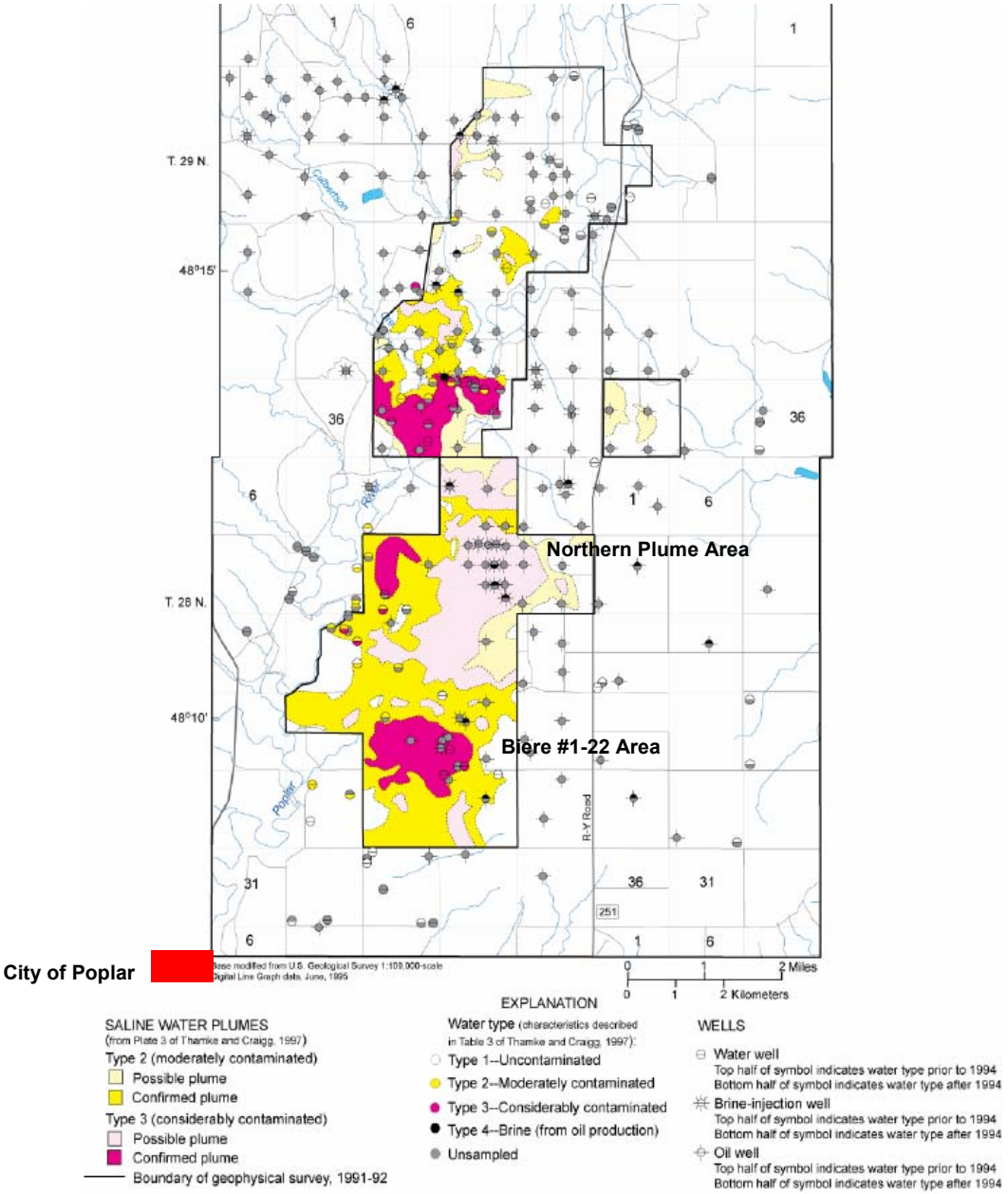
&

Fort Peck Tribes – Office of Environmental Protection

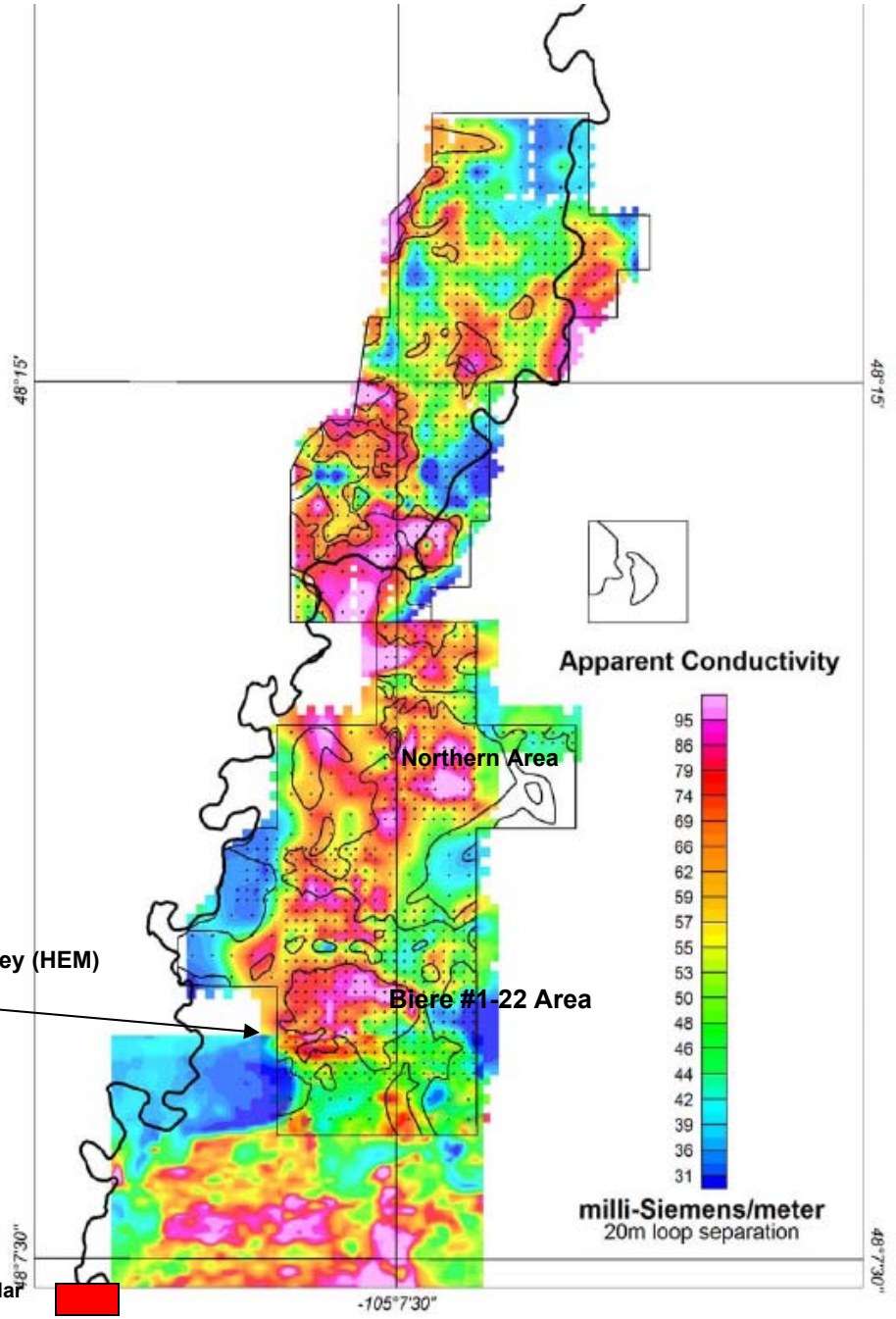
Interpreted location of saline water plumes in the East Poplar oil field study area 1991-1992

**From USGS Ground EM-34 Survey**

(Thamke and Craigg, 1997)



# Re-interpretation of Ground EM 34 Survey (Apparent Conductivity)




Boundary of 2004 Helicopter Electromagnetic Survey (HEM)


Bruce Smith
USGS

# 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

## Common Produced Water Handling Practices

SWD's

- Cretaceous Judith River Formation **≈ 1,000 depth**
- **Cretaceous Dakota SS ≈ 3,300' depth**
- **Devonian Nisku Formation ≈ 7,300' depth (1 well)**

**Shallow open unlined pits at surface**

Pioneer was notified by the EPA in late 1999, following several local landowner complaints about “salty” water in their wells, that a well previously owned and operated by Mesa Petroleum, the Mesa Biere #1-22, and plugged in 1986 was believed to be improperly plugged and leaking brine into the shallow aquifer

An investigation by PNR in late 1999 – 2000 confirmed that the well was leaking from around 1,000 feet below the surface into the shallow Aquifer.

# Regulatory Agencies Involved

## *Primary Agencies Responsible*

USEPA – Denver Region

Fort Peck Tribes – Office of Environmental Protection – Poplar Mt.
Christa Tyrrell, Director of Water Protection Division

### *Support Agency*

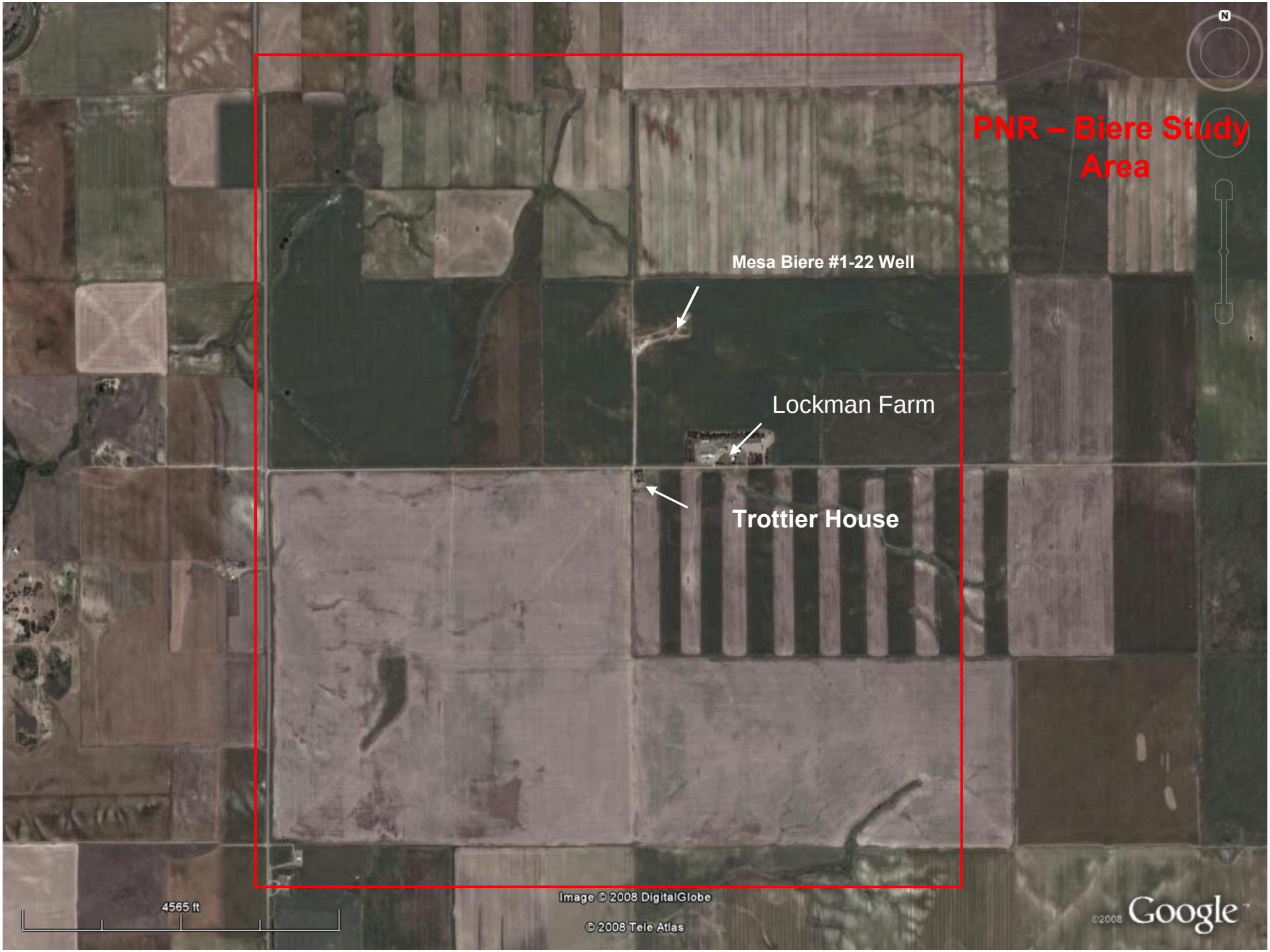
**USGS – Joanna Thamke - Helena, Montana**
**Bruce Smith – Denver, Colorado**

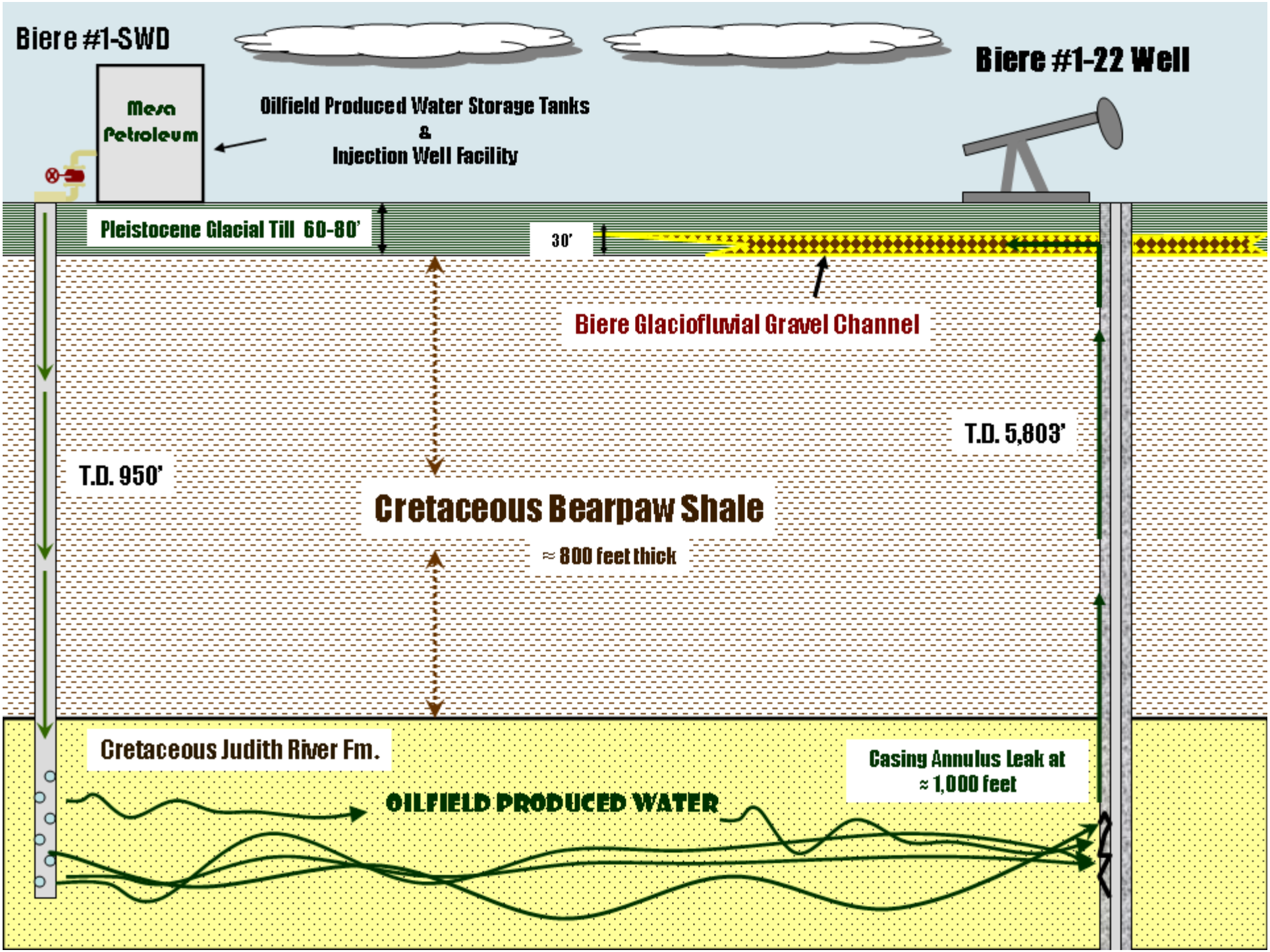
### *Courtesy Involvement*

Montana Department of Environmental Quality – Helena, MT

Montana Department of Natural Resources & Conservation – Helena, MT


Area of Widespread Regional Contamination
Mesa Biere #1-22 Well
Poplar River
PNR – Biere Study Area
City of Poplar
Skinners Island
White Shield Island
Missouri River
3.95 mi
Image © 2008 DigitalGlobe
© 2008 Tele Atlas
© 2008 Europa Technologies
©2008 Google


PNR – Biere Study Area
Mesa Biere #1-22 Well
Lockman Farm
Trottier House
4565 ft
Image © 2008 DigitalGlobe
© 2008 Tele Atlas
©2008 Google


Biere #1-SWD
Mesa Petroleum
Oilfield Produced Water Storage Tanks
&
Injection Well Facility
Biere #1-22 Well
Pleistocene Glacial Till 60-80'
30'
Biere Glaciofluvial Gravel Channel
T.D. 5,803'
T.D. 950'
Cretaceous Bearpaw Shale
≈ 800 feet thick
Cretaceous Judith River Fm.
Casing Annulus Leak at
≈ 1,000 feet
OILFIELD PRODUCED WATER

# *Apparent Surface Temperature Degrees Celsius*

Surface Range

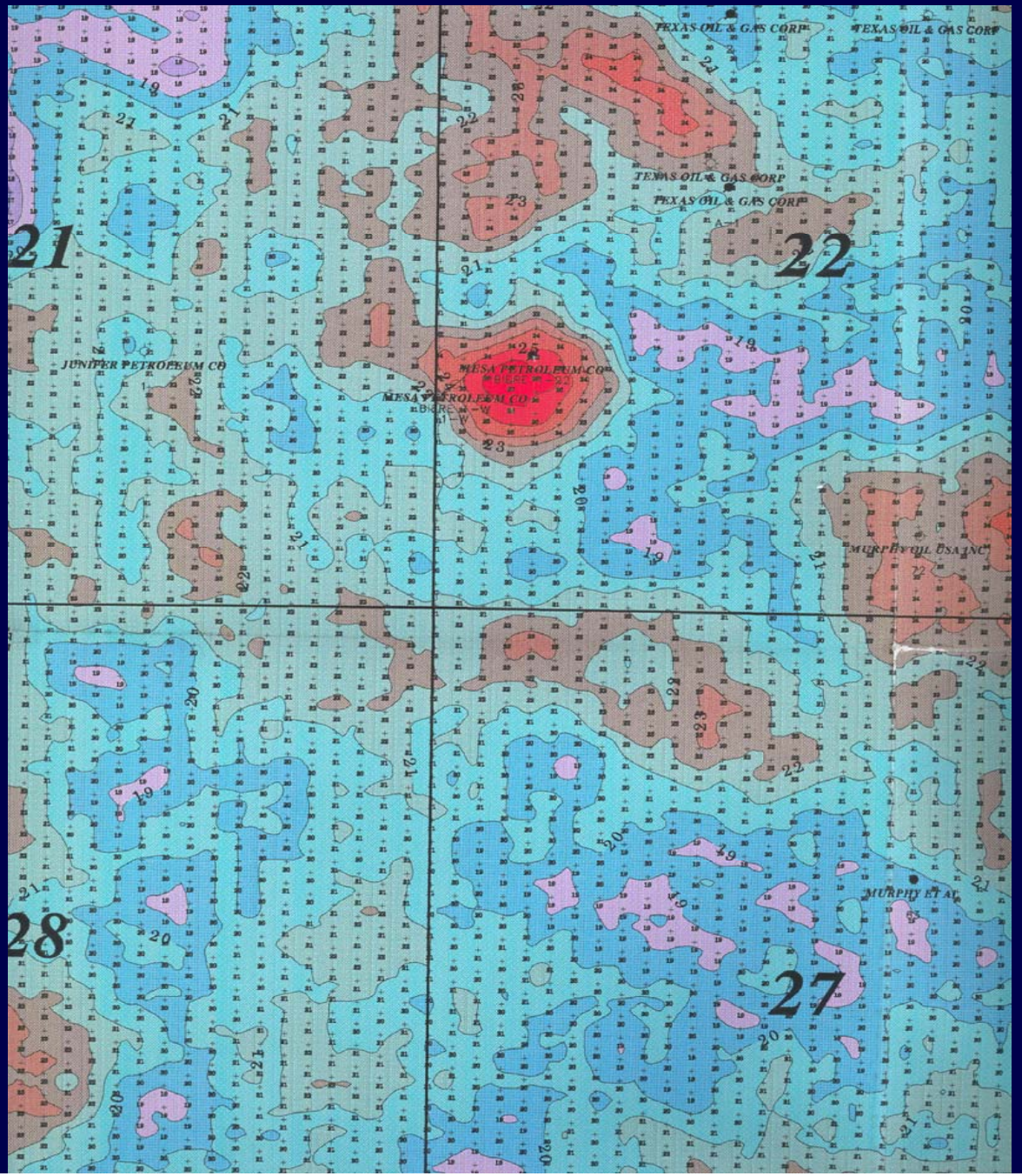
C° F°

27 81

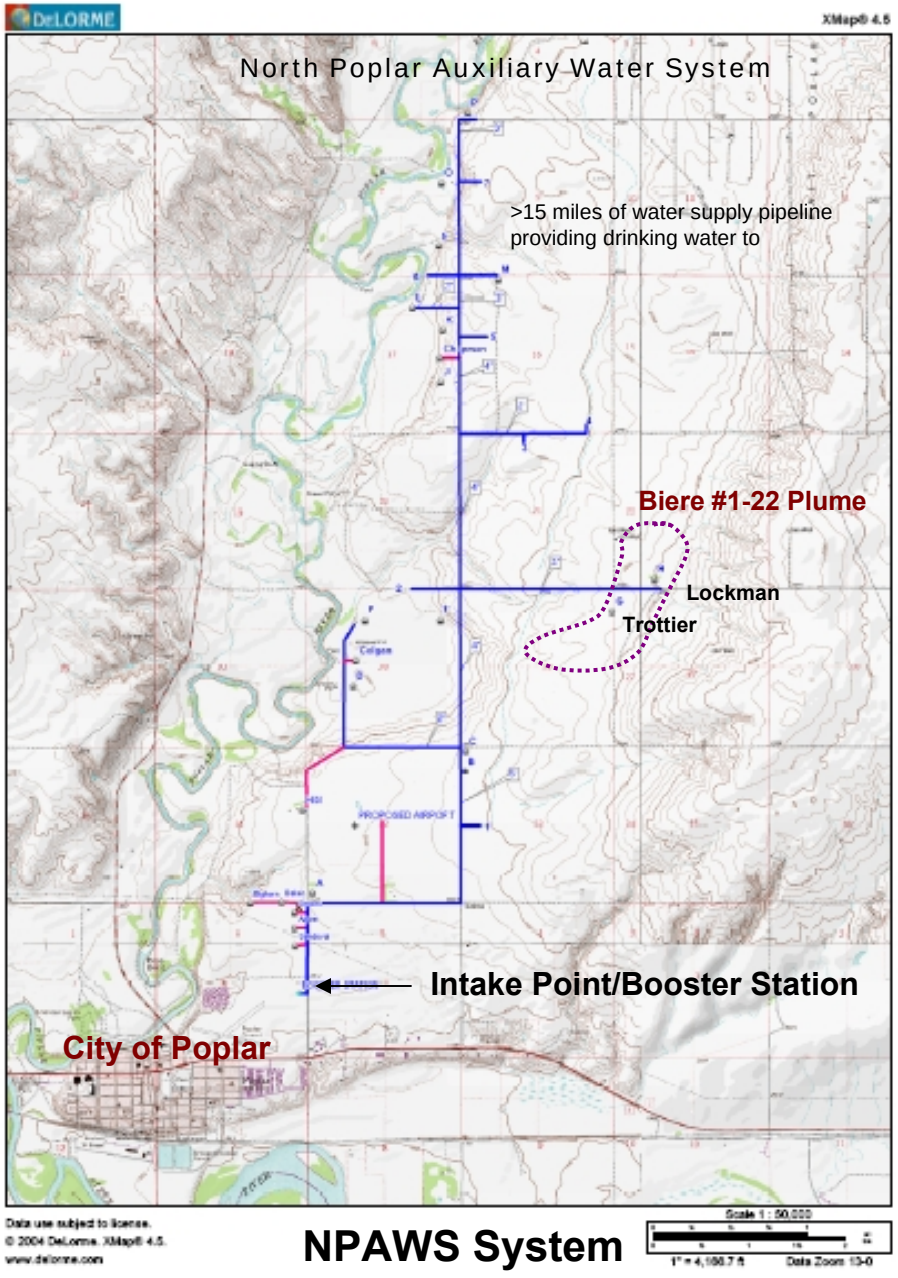
14 57

Survey Data - 11/10/99

From LandSat Band 6 Thematic Imagery



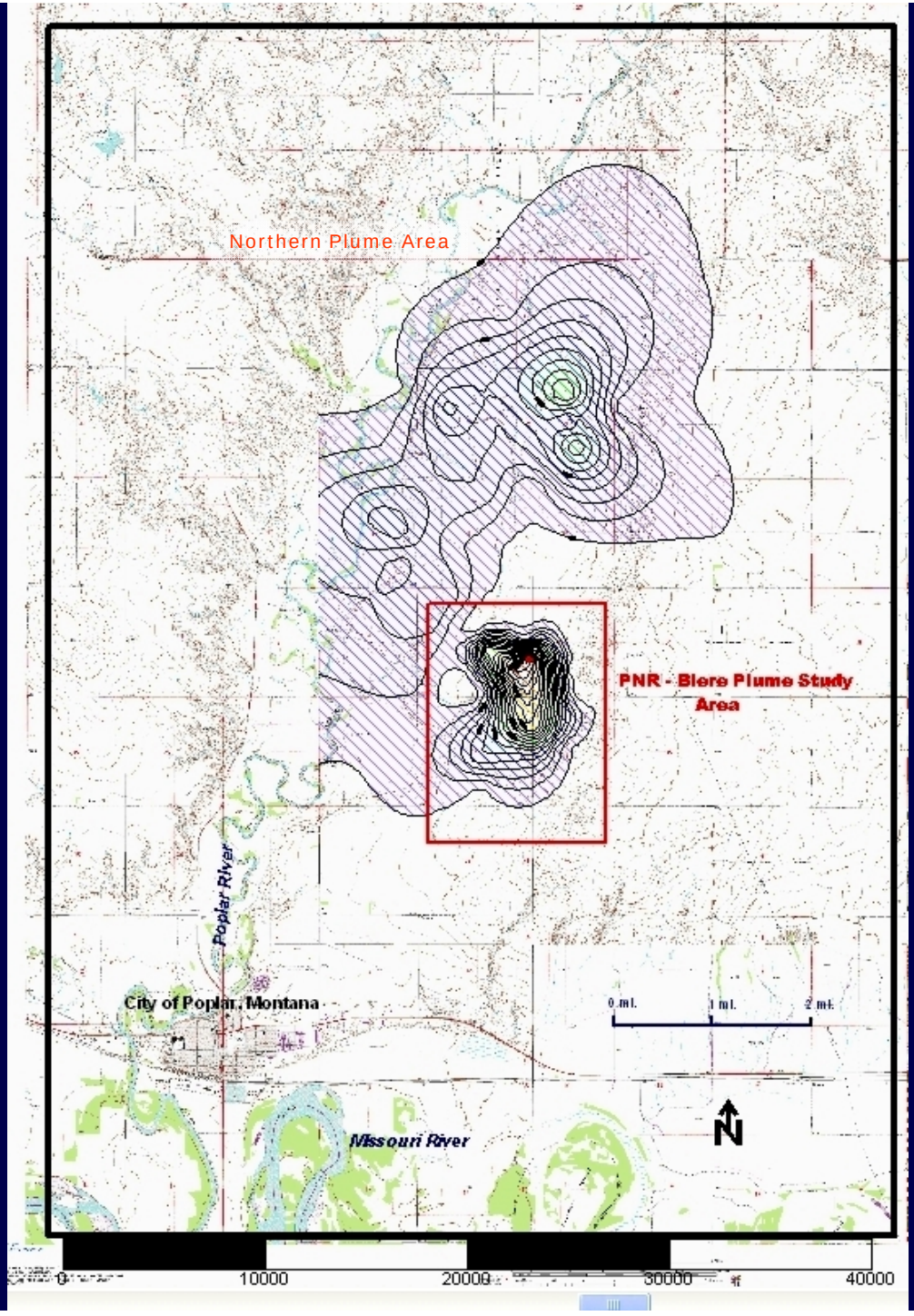

Relief Wells used to Plug
Biere #1-22 well
Biere #1-22 Cellar & Well


DeLORME
XMap® 4.5
North Poplar Auxiliary Water System
>15 miles of water supply pipeline
providing drinking water to
Biere #1-22 Plume
Lockman
Trottier
Colgan
PROPOSED AIRPORT
Intake Point/Booster Station
City of Poplar
Data use subject to license.
© 2004 DeLorme. XMap® 4.5.
www.delorme.com
NPAWS System

# PNR Work Conducted from Late 1999 to Mid-2006

(and continuing to present)

- *Plugging of Biere #1-22* – accomplished early 2000
  - *Biere #1-22 Wellbore Monitoring* – Conduct Bi-Annual pressure & temperature surveys in the three Mesa Biere #1-22 relief wells from 1,000 feet to surface
  - *Monitor Well Installation & Sampling* – PNR samples 63 wells total; 49 bi-annually & 14 annually


Northern Plume Area
PNR - Biere Plume Study Area
Poplar River
City of Poplar, Montana
0 mi.
1 mi.
2 mi.
Missouri River
N
0
10000
20000
30000
40000
ft

# 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**

# *The Most Critical Step to Success is*
# *"Understanding the Geology"*

**Step 1 - Construct Geochemical 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 (164 Wells)**

- ♠ Create and Standardize Lithological and Well Completion Logs – 164 wells
- ♠ Bedrock Structure Map –
  Cretaceous Bearpaw Shale
- ♠ Geological Isopach Maps –
  Biere Upper Bench Gravel/Lower Alluvial Aquifer – Thickness Isopach
- ♠ Construct Geological Cross Sections

## Step 3 - Conduct Geophysical Surveys

- Re-interpretation of 1,094 linear miles of Helicopter-Borne Electromagnetic Data – Conductivity Depth Sections
- Downhole Geophysics (Gamma Ray, Induction Logs) – 20 wells
- > 16 linear miles of Surface EM-34 Geophysical Conductivity Survey

# Geological History of Biere Site

The more it snows
"Tiddly Pom"
The more it goes
"Tiddly Pom"
The more it goes
"Tiddly Pom"
On snowing

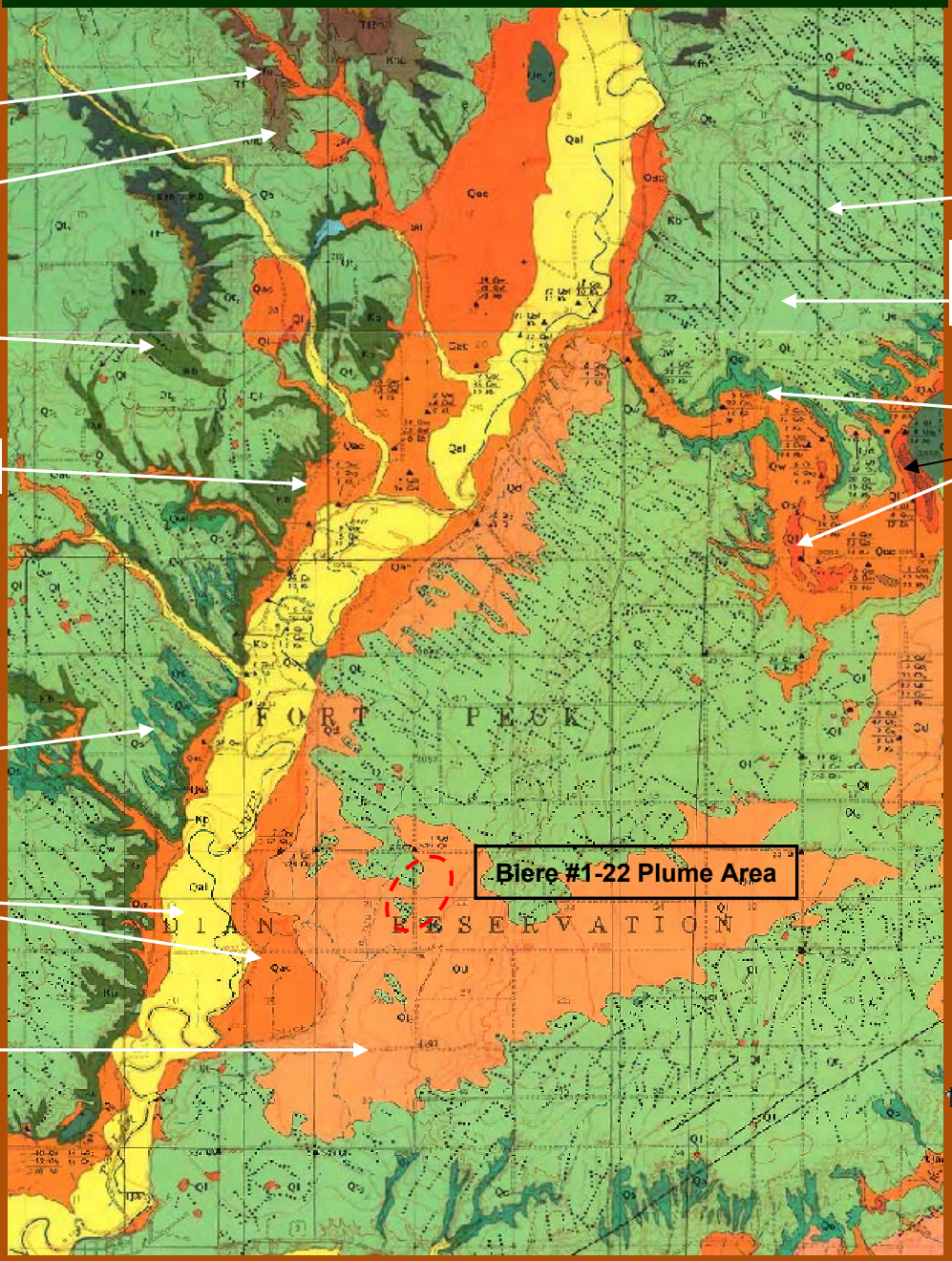
*A.A. Milne – The House on Pooh Corner*

## ***Quaternary deposits of Pleistocene age and younger cover more than 90% of the study area***

All of the aquifers in this study area are found in sands and gravels that are mainly

- Early to middle Pleistocene pre-glacial and interglacial
- Middle to late Pleistocene glacial outwash,
- Late Pleistocene ice-contact deposits,
- Holocene, post-glacial alluvium and
- Holocene alluvium-colluvium

# 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)

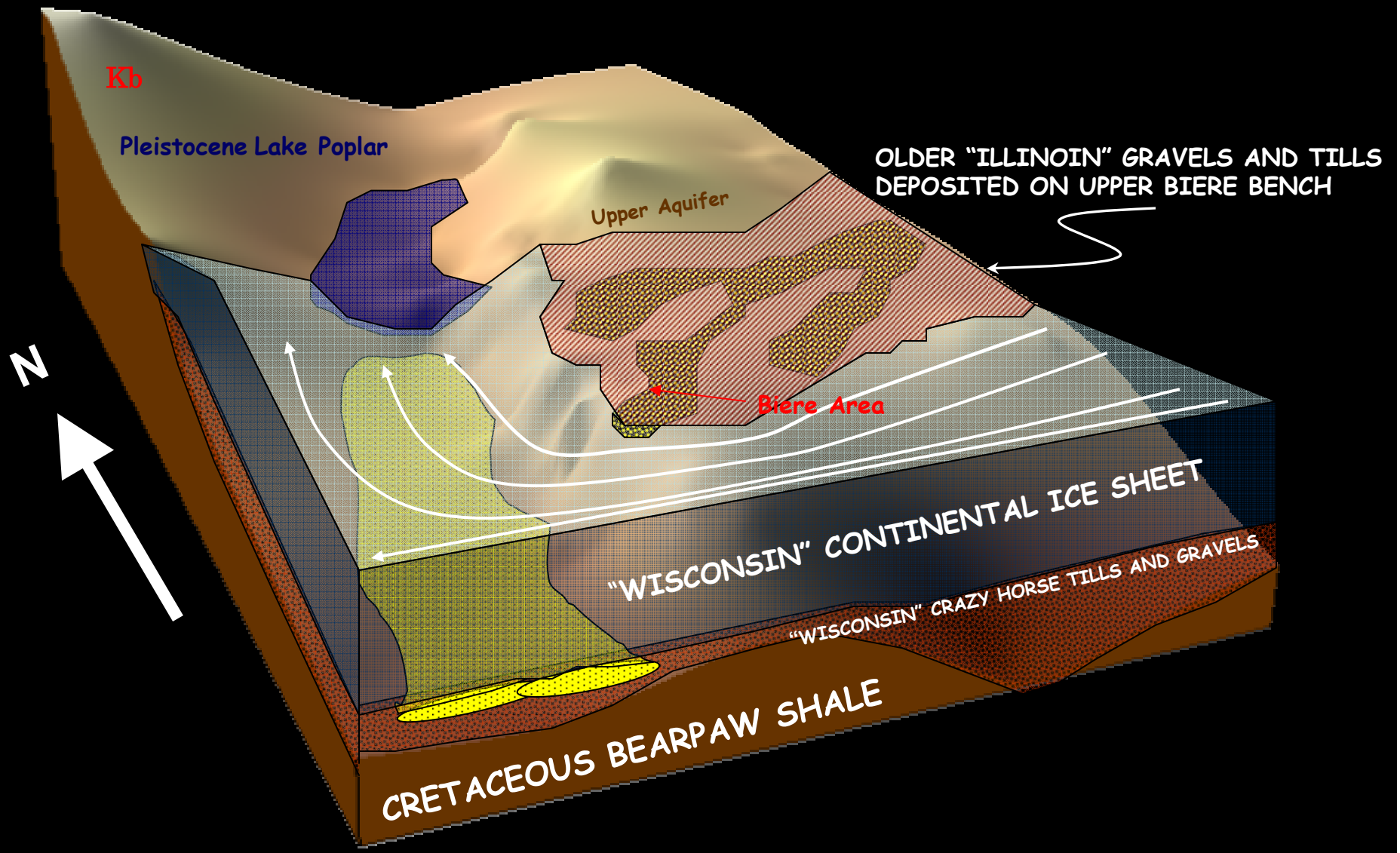
Q/Silts (up to 30m)

Q/Lake Sediments
(clays)

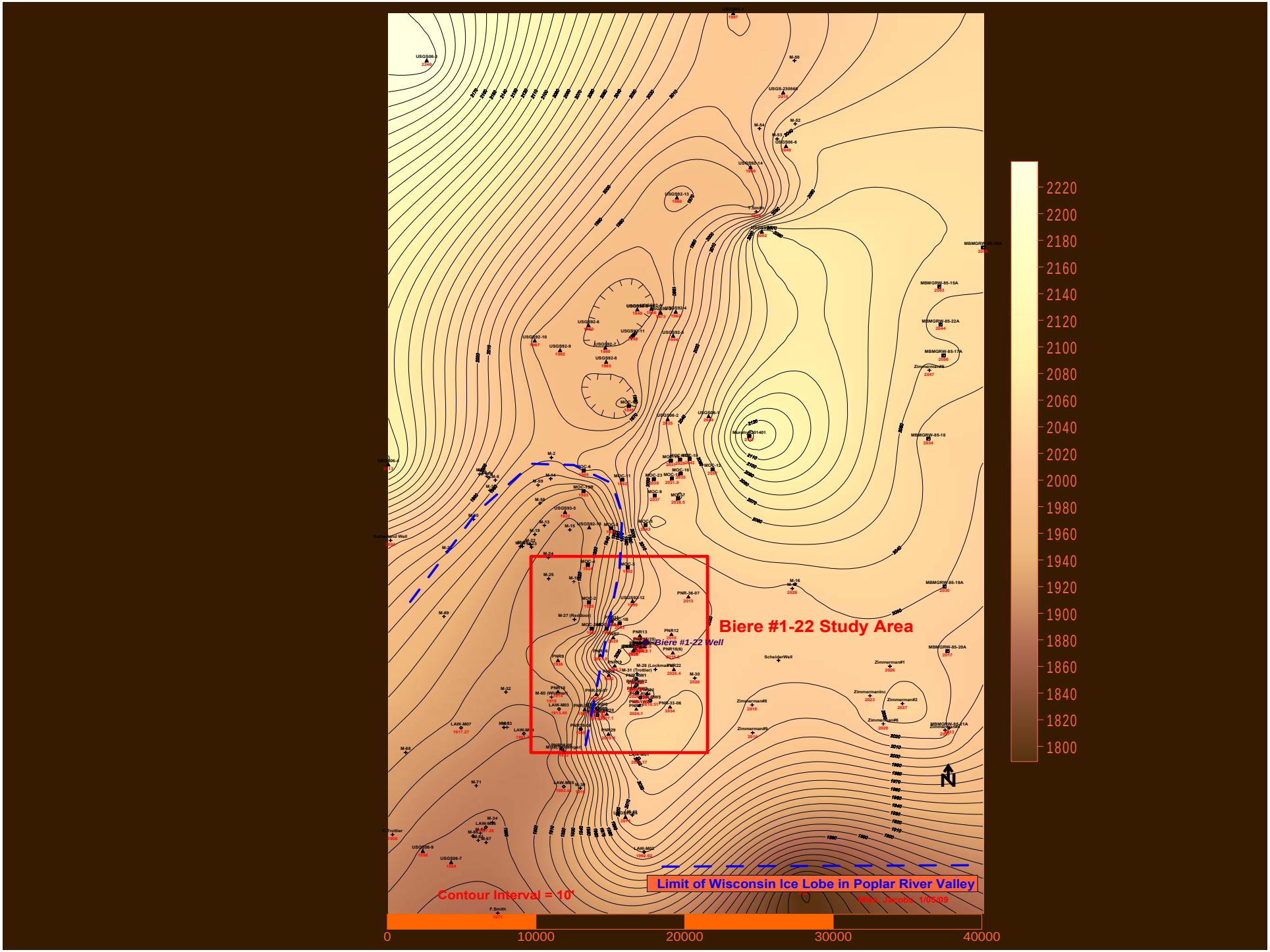
# Conceptualized Drawing of "Illinoin" Glaciation & Pleistocene Geological History


Mike Jacobs

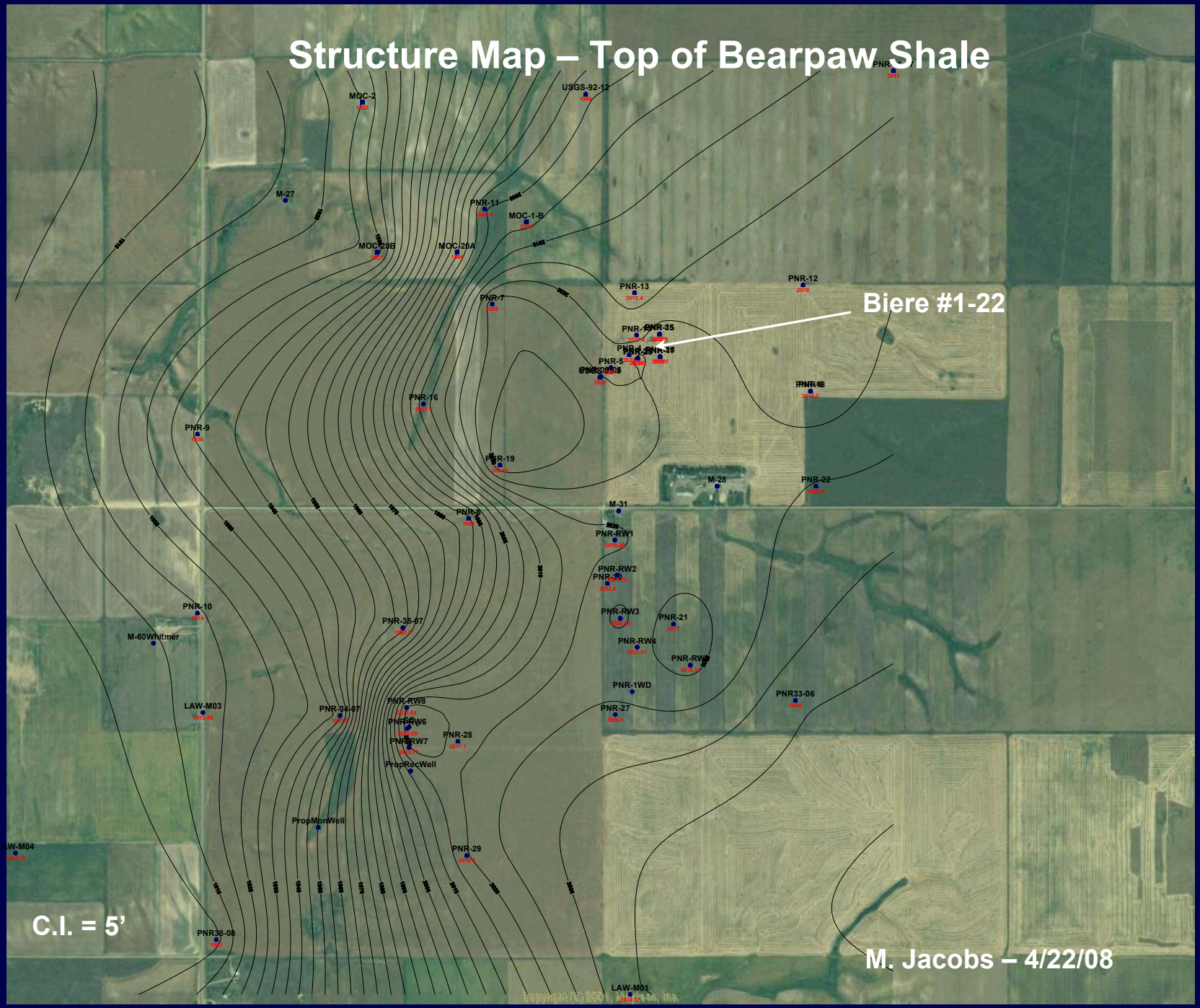
# Conceptualized Drawing of "Wisconsin" Glaciation

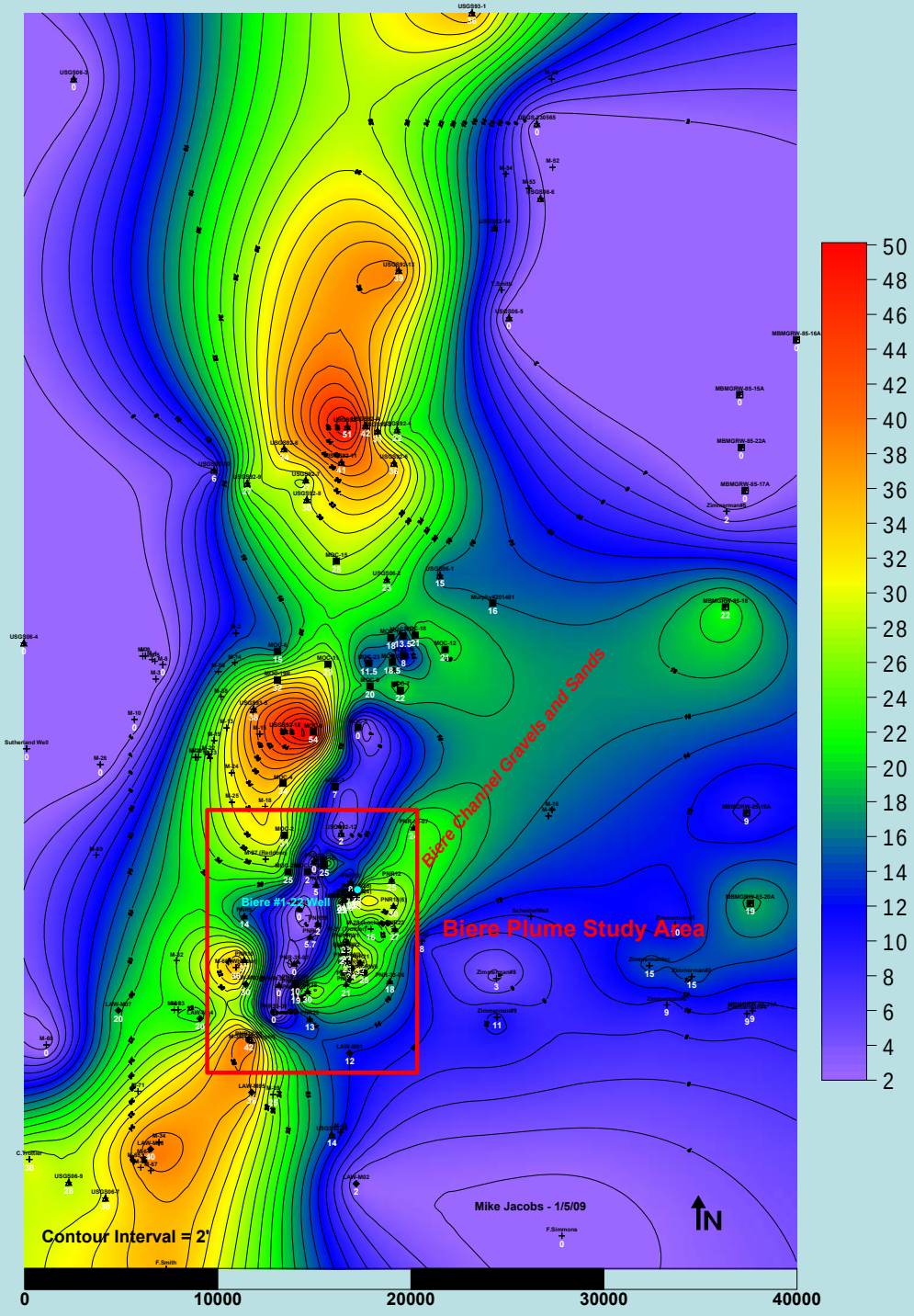


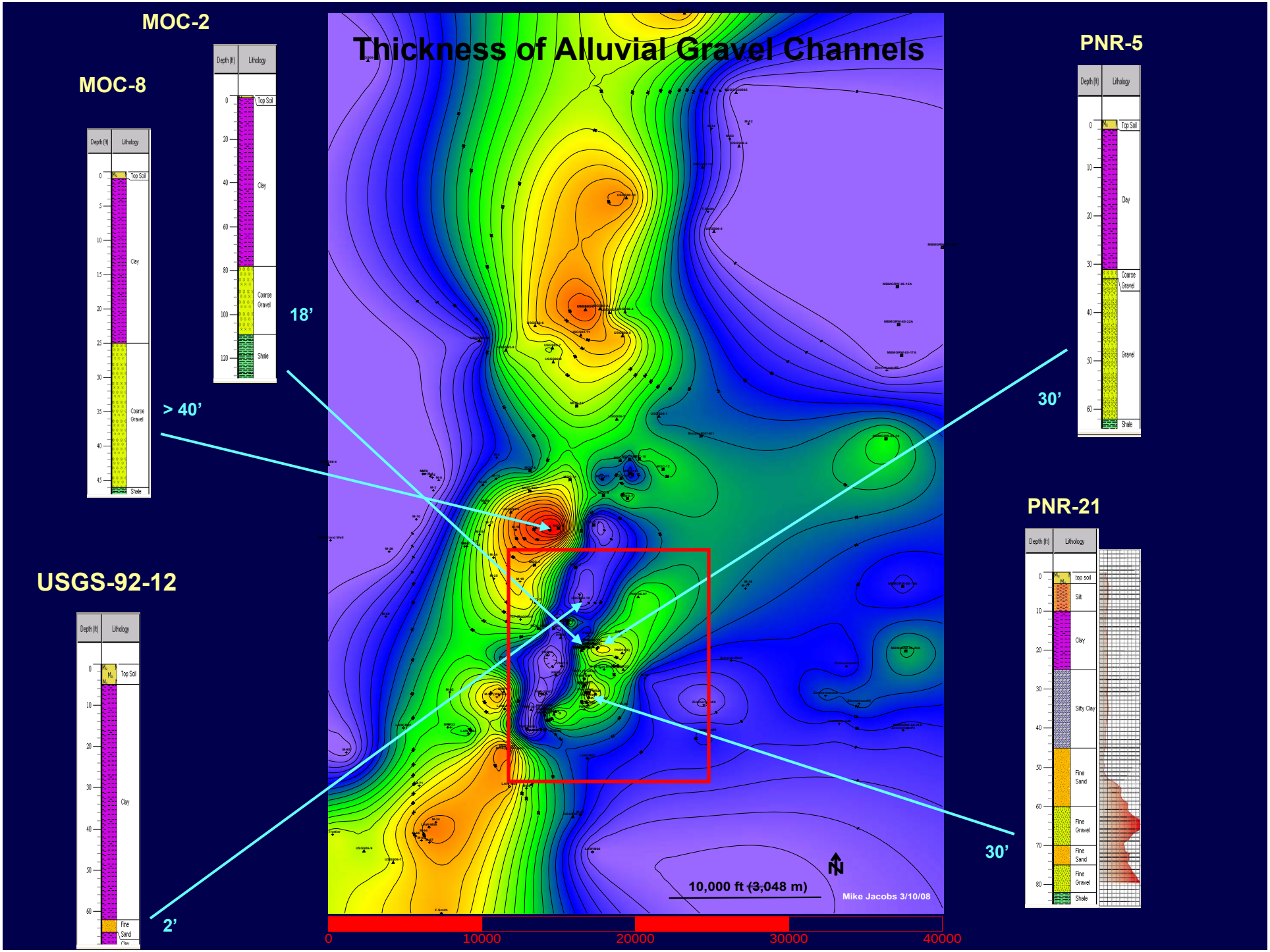

Mike Jacobs


Biere #1-22 Study Area
Biere #1-22 Well
Limit of Wisconsin Ice Lobe in Poplar River Valley
Contour Interval = 10'
2220
2200
2180
2160
2140
2120
2100
2080
2060
2040
2020
2000
1980
1960
1940
1920
1900
1880
1860
1840
1820
1800
N
0
10000
20000
30000
40000

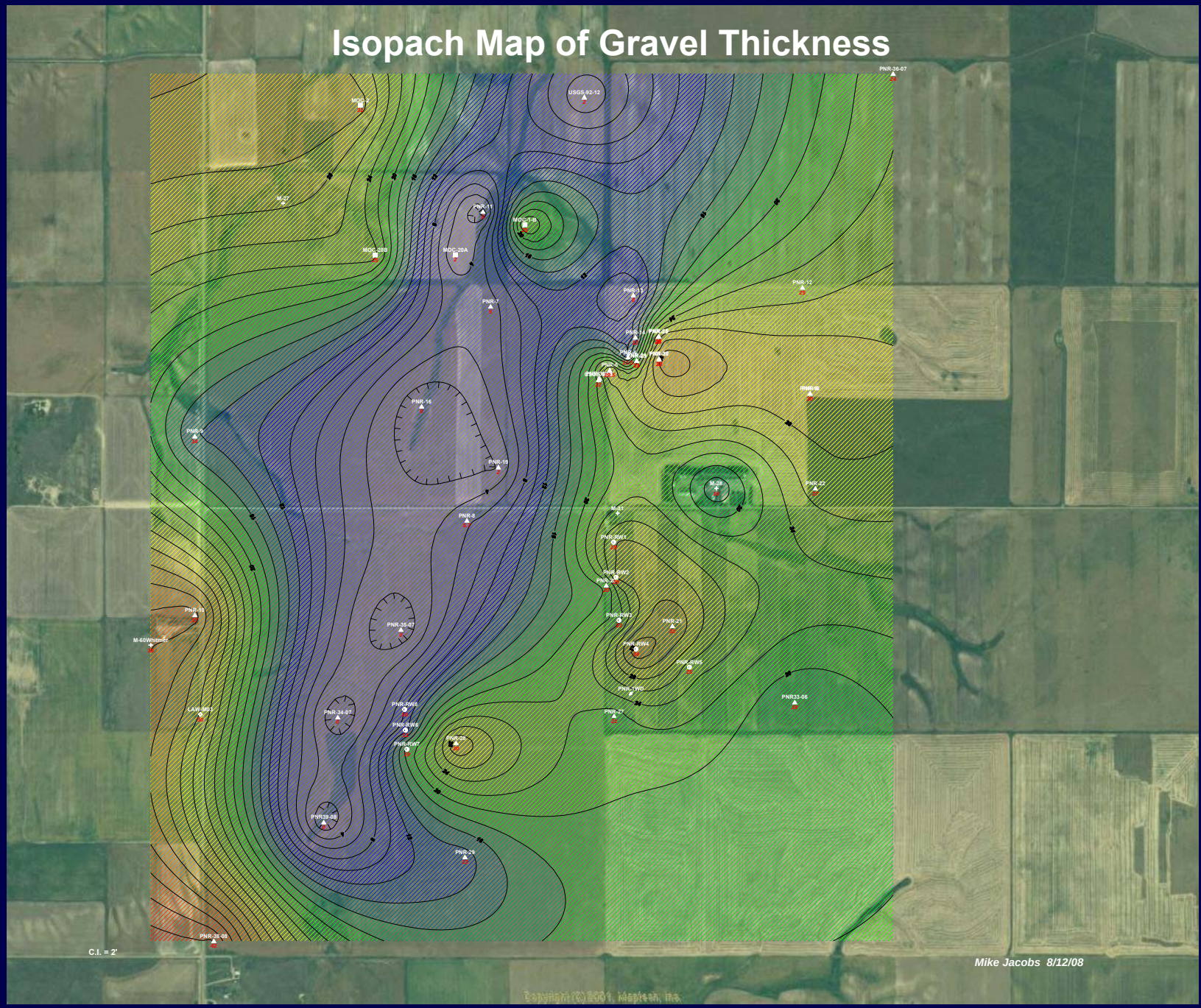
# Structure Map – Top of Bearpaw Shale

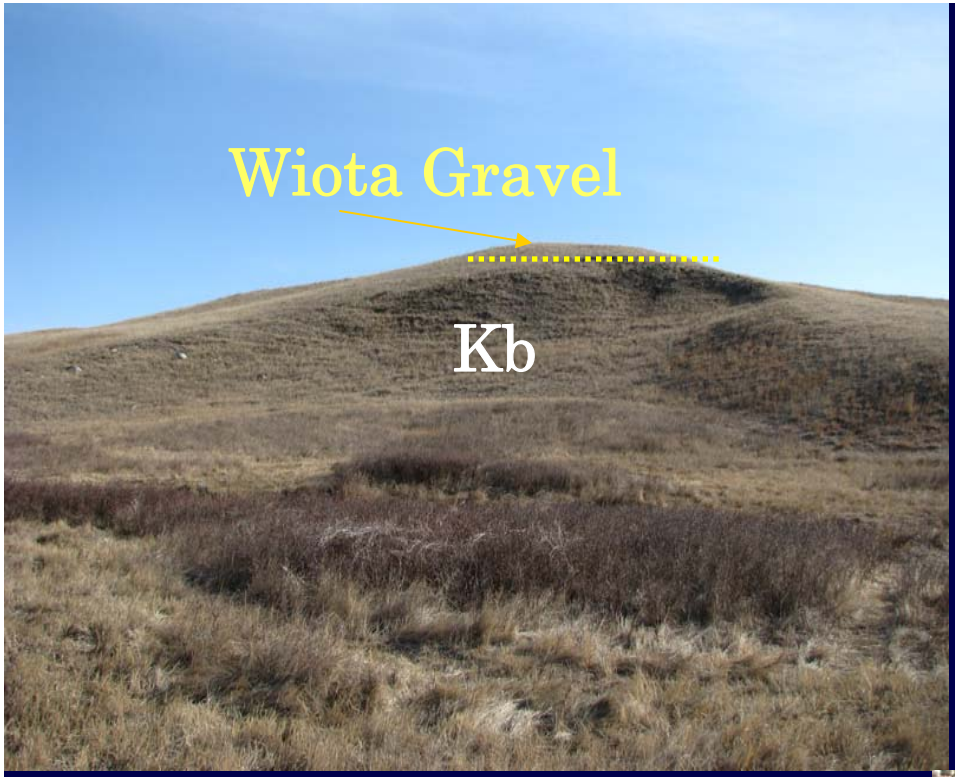



Biere Channel Gravels and Sands
Biere #1 Test Well
Biere Plume Study Area
Mike Jacobs - 1/5/09
Contour Interval = 2'
N
0
10000
20000
30000
40000
50
48
46
44
42
40
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2


Thickness of Alluvial Gravel Channels
MOC-2
MOC-8
PNR-5
PNR-21
USGS-92-12
18'
> 40'
30'
30'
2'
Depth (ft)
Lithology
Top Soil
Clay
Coarse Gravel
Shale
top soil
Silt
Silty Clay
Fine Sand
Fine Gravel
Gravel
10,000 ft (3,048 m)
Mike Jacobs 3/10/08
0
10000
20000
30000
40000

# Isopach Map of Gravel Thickness

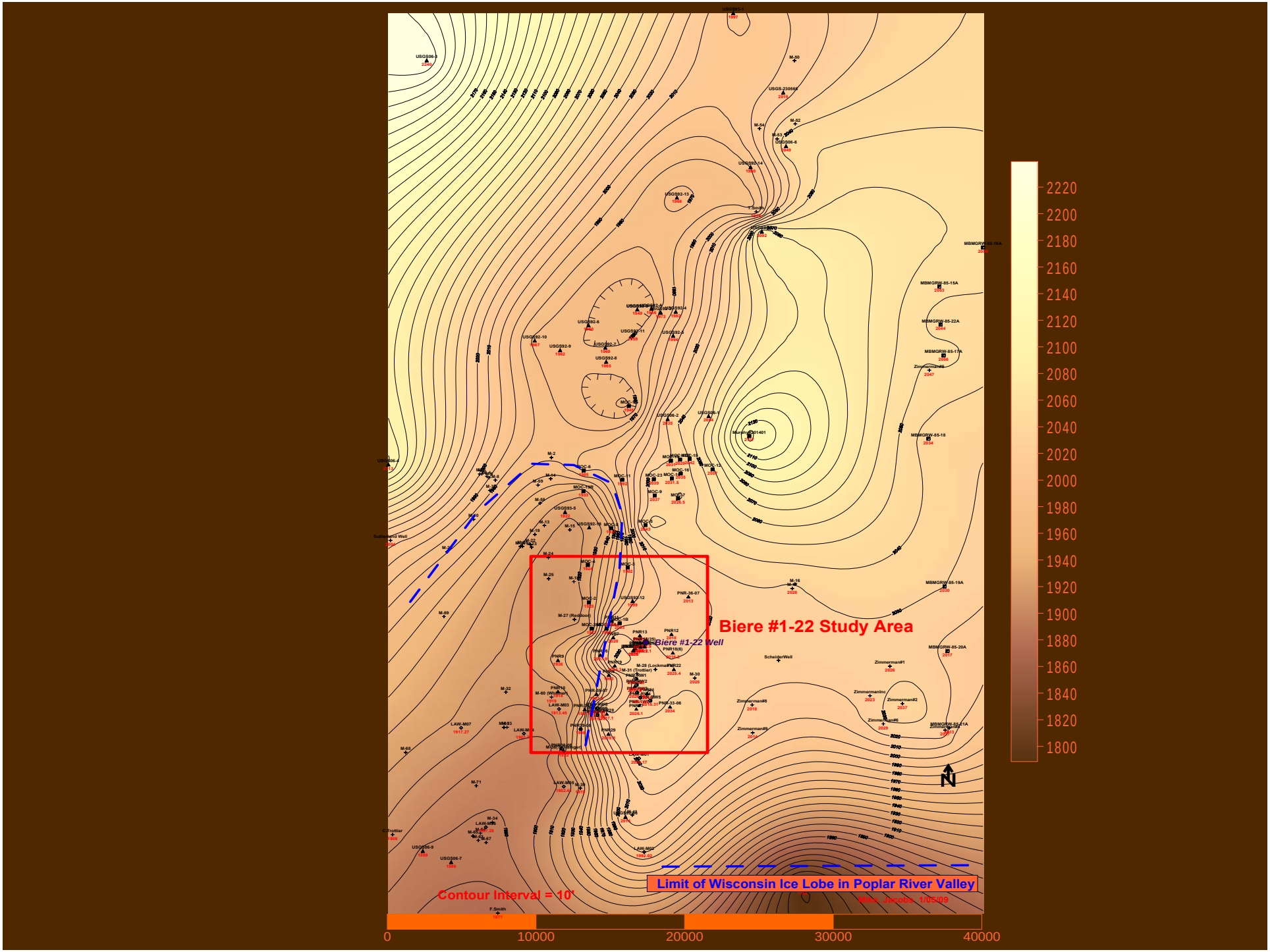



Wiota Gravel
Kb

Hard compact “Fat Clay” of the overlying Sprole Till and inter-channel clay deposits


Loose, coarse-grained gravel of the Wiota Gravel - Aquifer

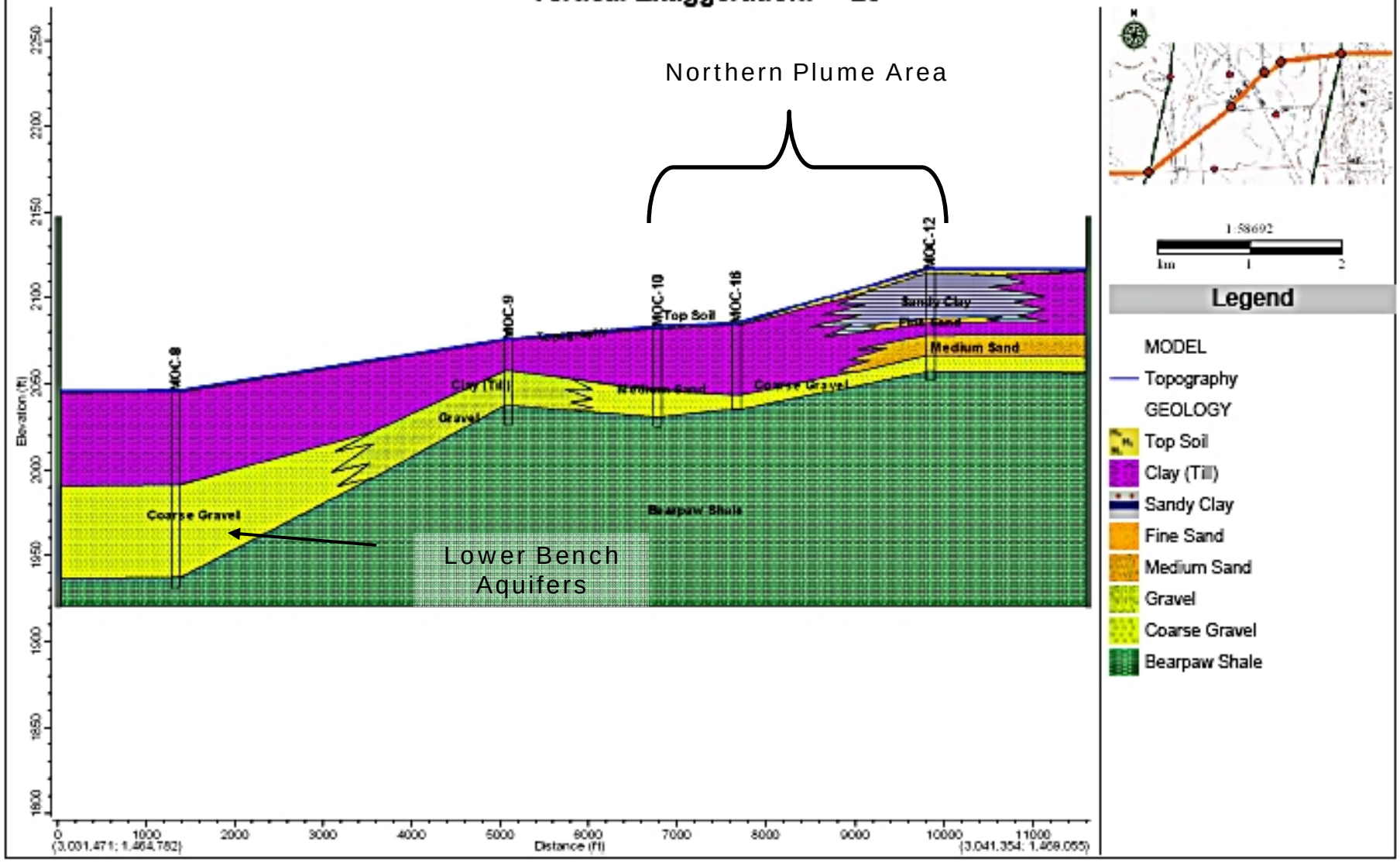
# Geological Cross Sections

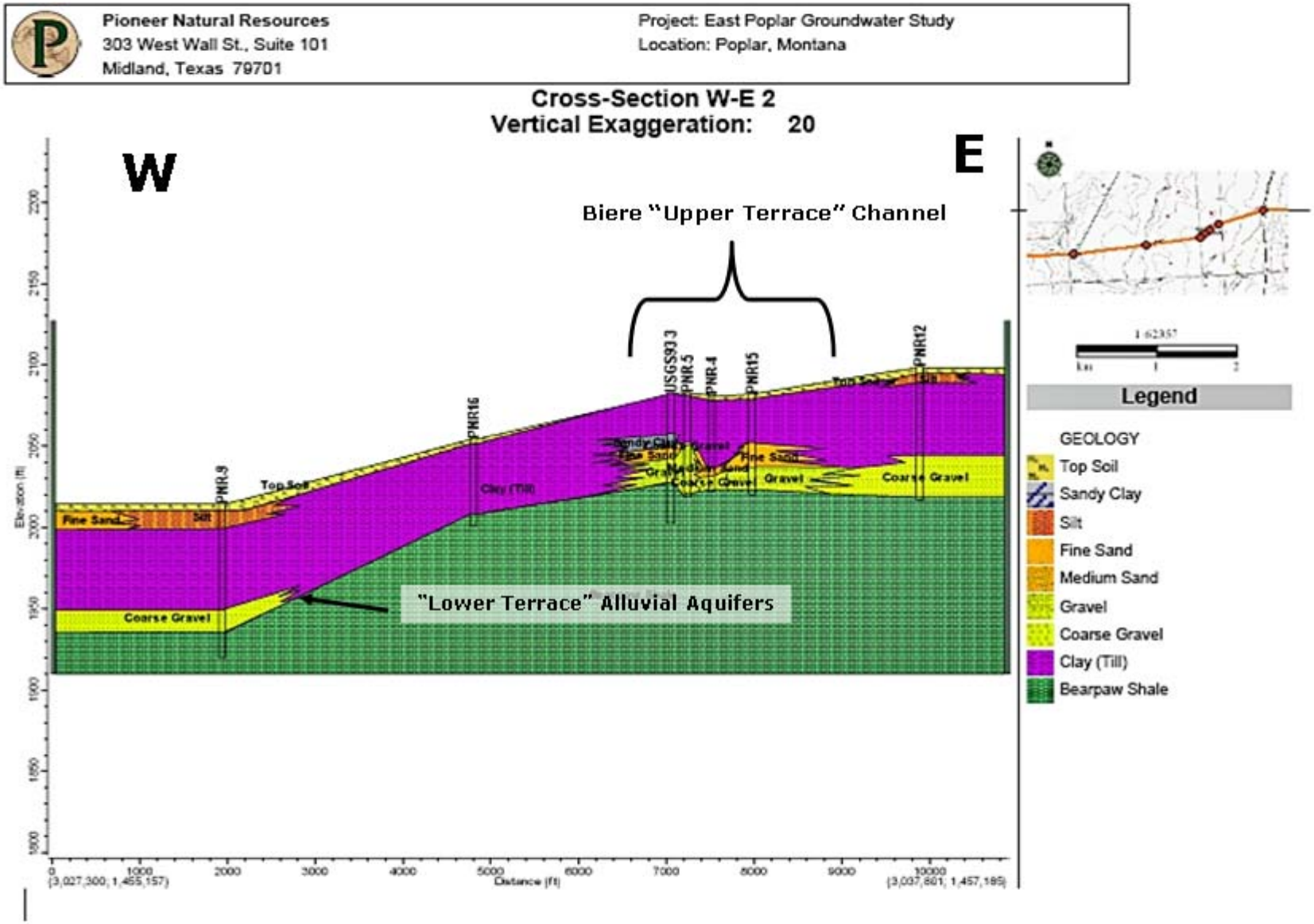

Biere #1-22 Study Area
Biere #1-22 Well
Limit of Wisconsin Ice Lobe in Poplar River Valley
Contour Interval = 10'
MBG 2/6/2009 1/05/09
N
2220
2200
2180
2160
2140
2120
2100
2080
2060
2040
2020
2000
1980
1960
1940
1920
1900
1880
1860
1840
1820
1800
0
10000
20000
30000
40000

Pioneer Natural Resources
303 West Wall St., Suite 101
Midland, Texas 79701

Project: East Poplar Groundwater Study
Location: Poplar, Montana

# Cross-Section W-E 1
## Vertical Exaggeration: 20

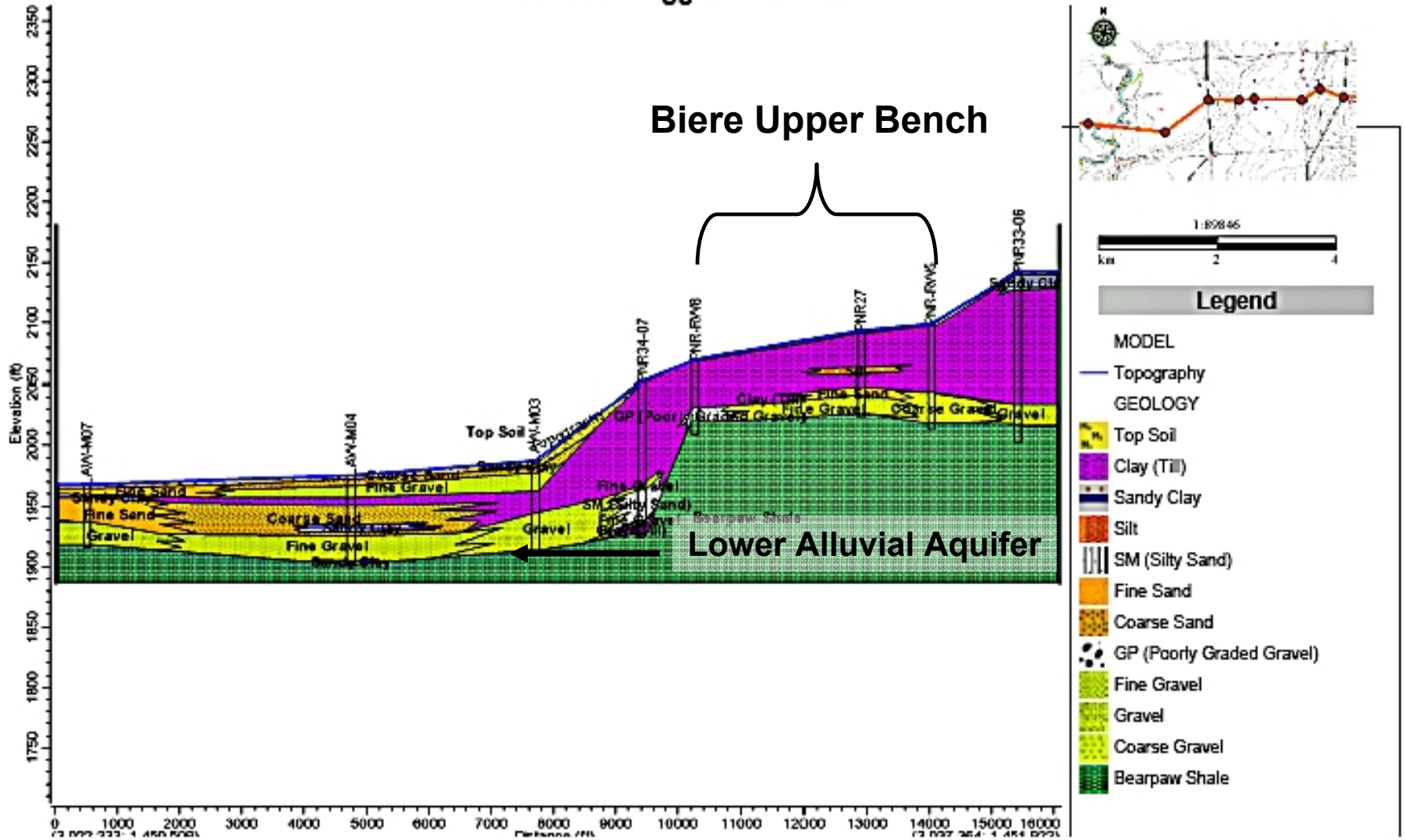



Pioneer Natural Resources
303 West Wall St., Suite 101
Midland, Texas 79701
Project: East Poplar Groundwater Study
Location: Poplar, Montana
Cross-Section W-E 2
Vertical Exaggeration: 20
W
E
Biere "Upper Terrace" Channel
"Lower Terrace" Alluvial Aquifers
PNR9
PNR16
USGS933
PNR5
PNR4
PNR15
PNR12
Top Soil
Fine Sand
Silt
Clay (Till)
Coarse Gravel
Gravel
Elevation (ft)
Distance (ft)
(3,027,300; 1,465,157)
(3,037,801; 1,457,185)
Legend
GEOLOGY
Top Soil
Sandy Clay
Silt
Fine Sand
Medium Sand
Gravel
Coarse Gravel
Clay (Till)
Bearpaw Shale

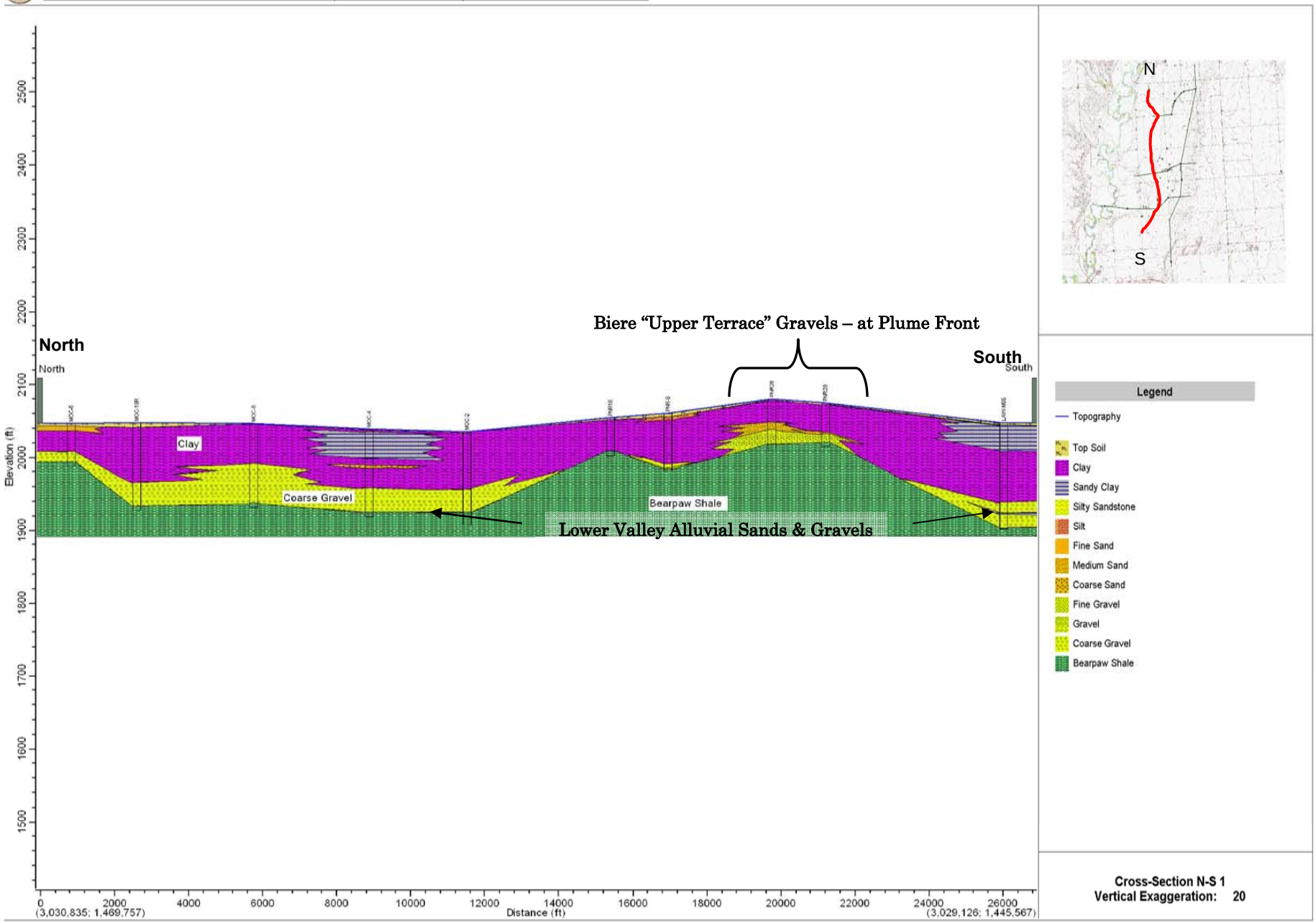
Pioneer Natural Resources
303 West Wall St., Suite 101
Midland, Texas 79701

Project: East Poplar Groundwater Study
Location: Poplar, Montana

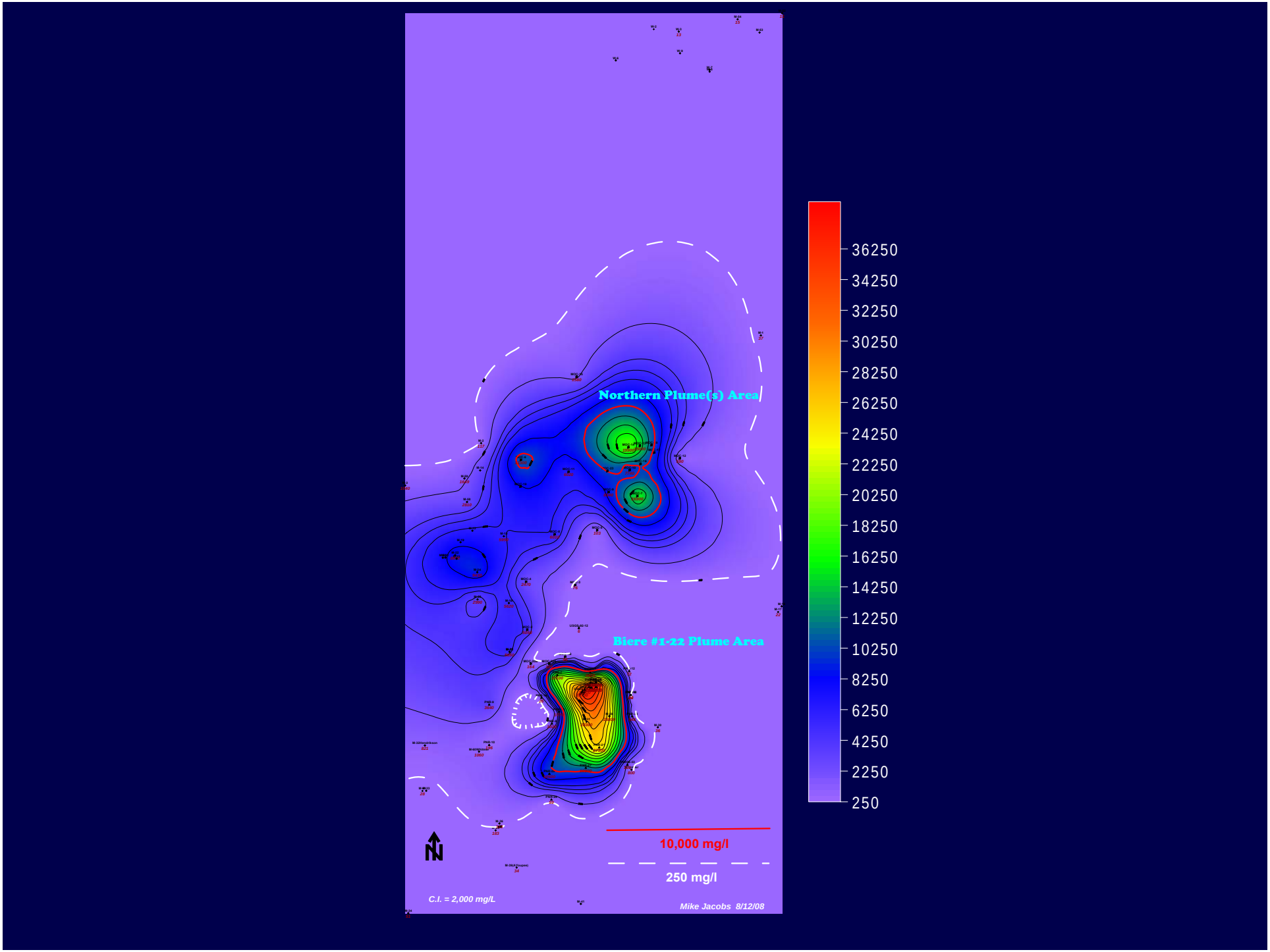
# Cross-Section W-E3
## Vertical Exaggeration: 20

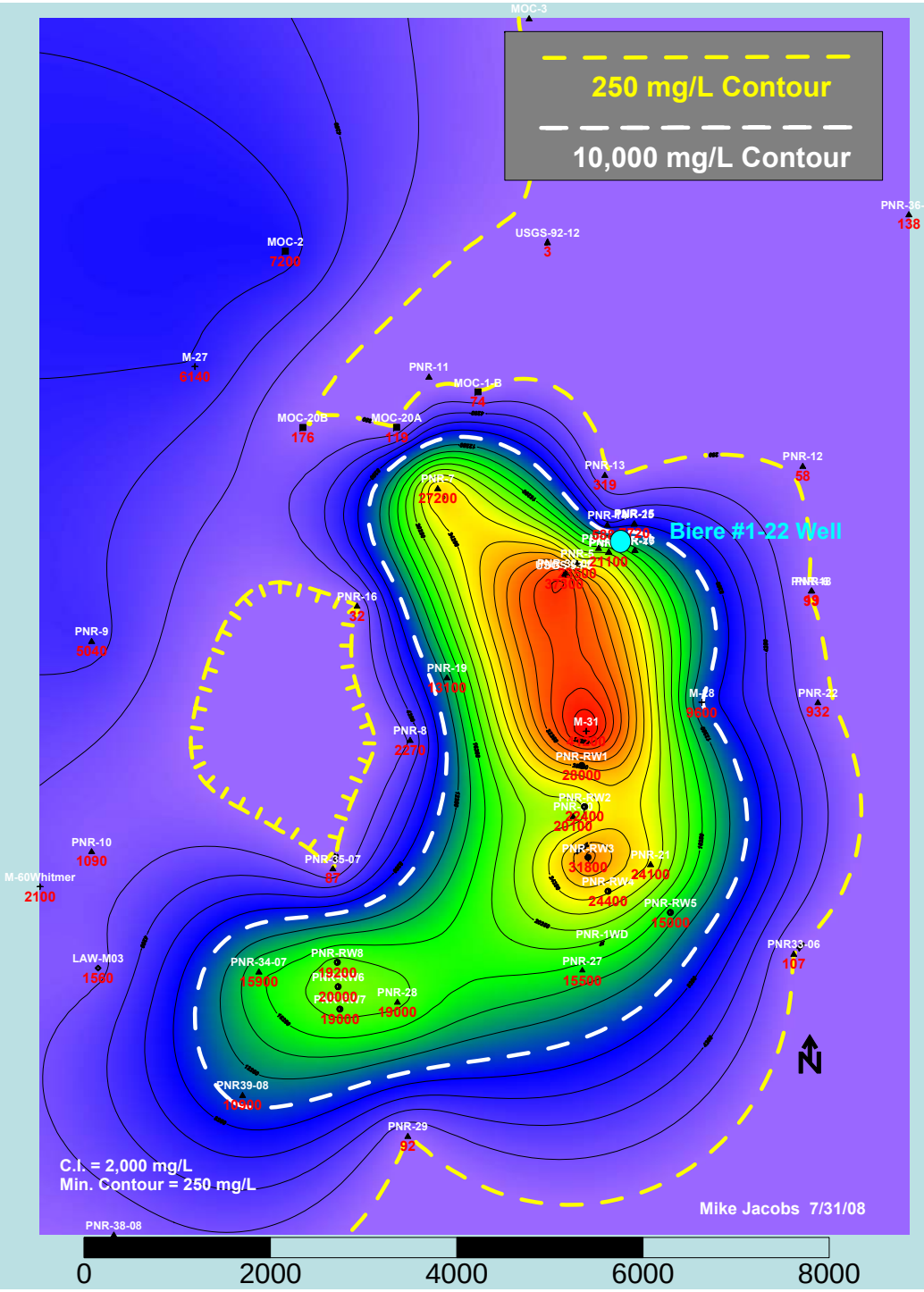


**Pioneer Natural Resources** | 303 West Wall St., Suite Midland, Texas 79701 | Project: East Poplar Groundwater Location: Poplar, Montana



# Contaminant Plume Mapping


Northern Plume(s) Area
Biere #1-22 Plume Area
36250
34250
32250
30250
28250
26250
24250
22250
20250
18250
16250
14250
12250
10250
8250
6250
4250
2250
250
10,000 mg/l
250 mg/l
C.I. = 2,000 mg/L
Mike Jacobs 8/12/08




## PLUME STATISTICS

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

Average Aquifer Thickness ≈ 19’

Average Porosity ≈ 25%

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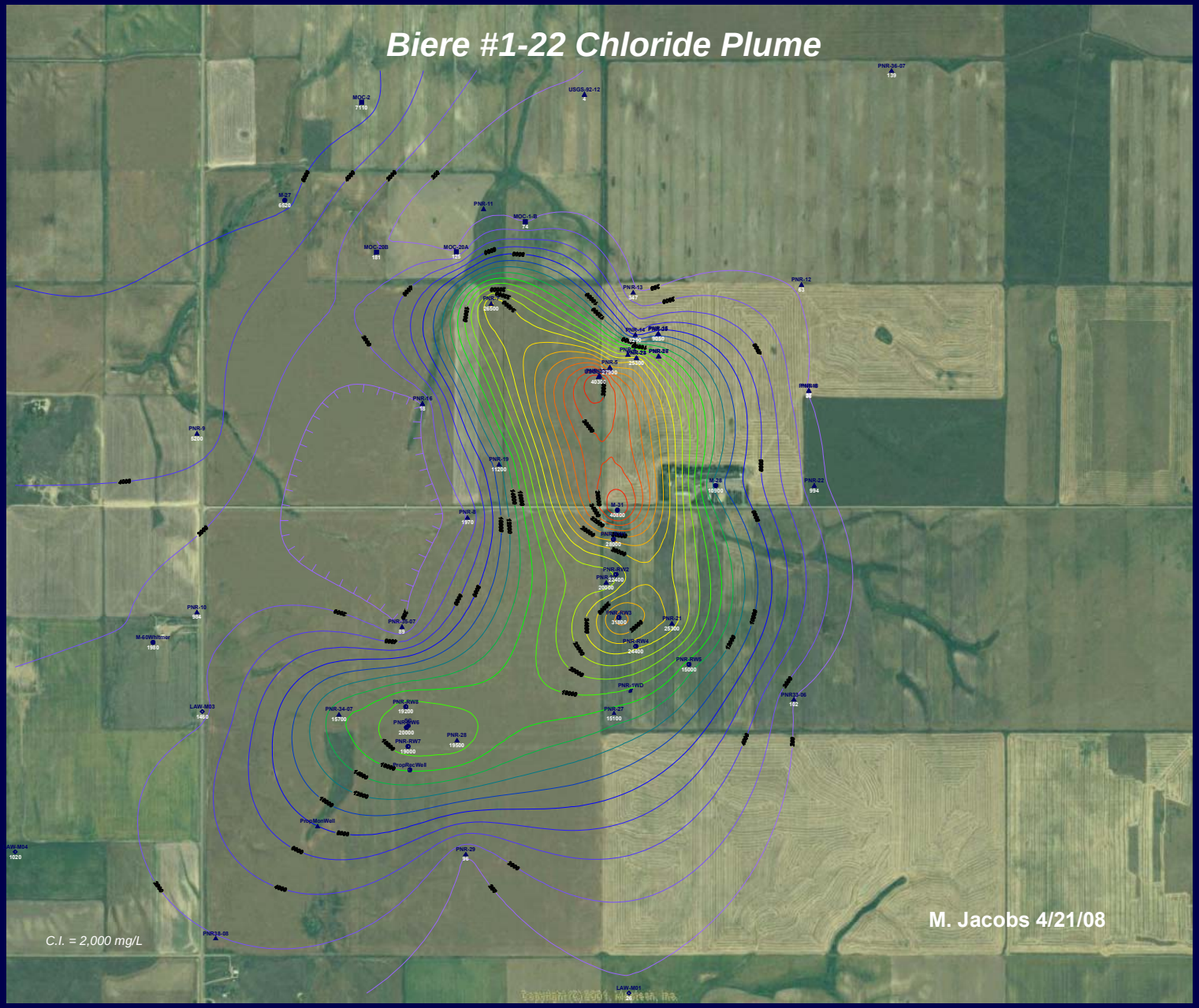
**One Pore Volume**
**≈ 2,021 Acre Feet Water:**
**= 659 MM/Gallons/15.7 MM/bbls**

**Biere PNR-WD1 Disposal Rate**
**6,000 bbls/day;252,000 gallons/day**

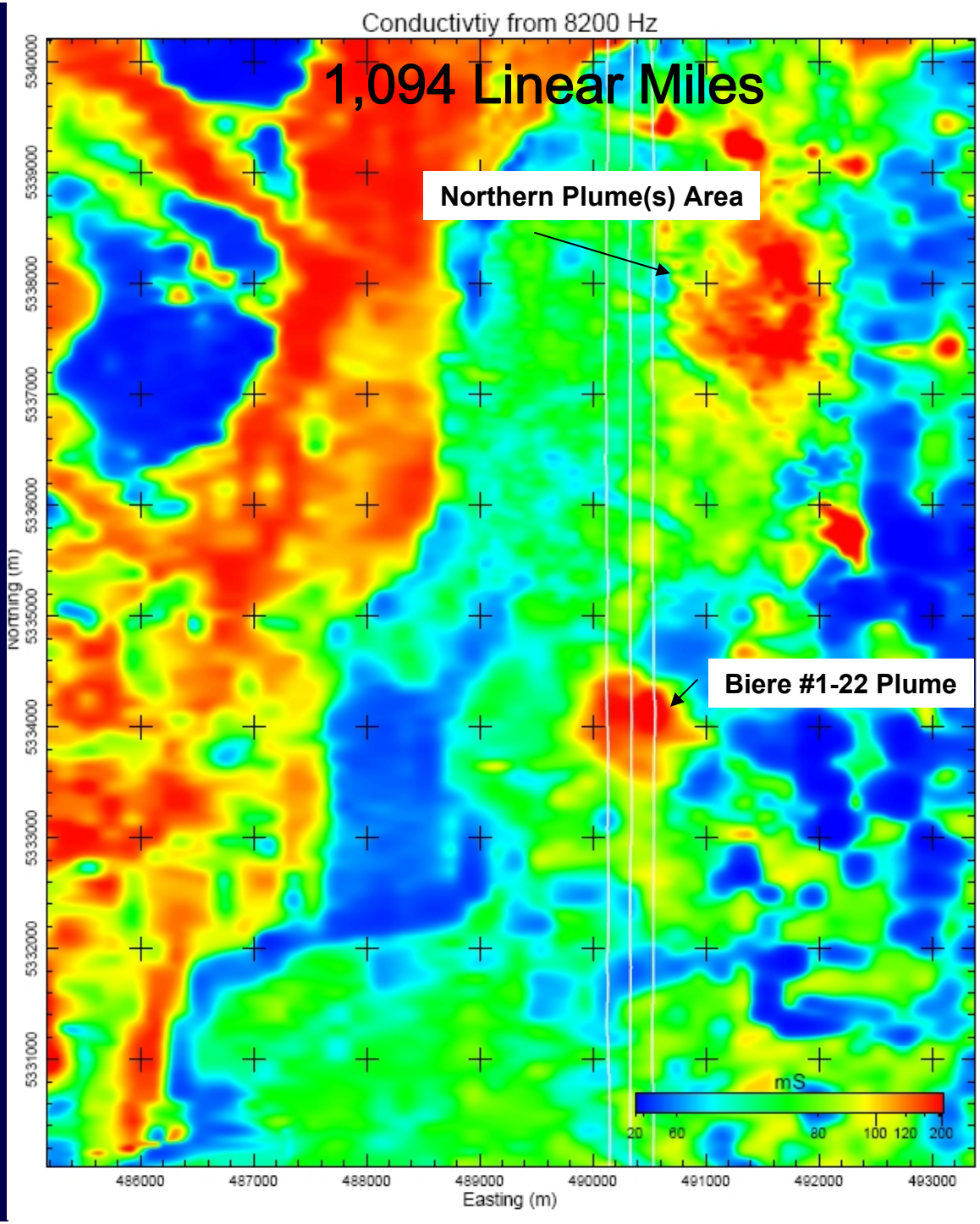

Biere #1-22 Chloride Plume
C.I. = 2,000 mg/L
M. Jacobs 4/21/08

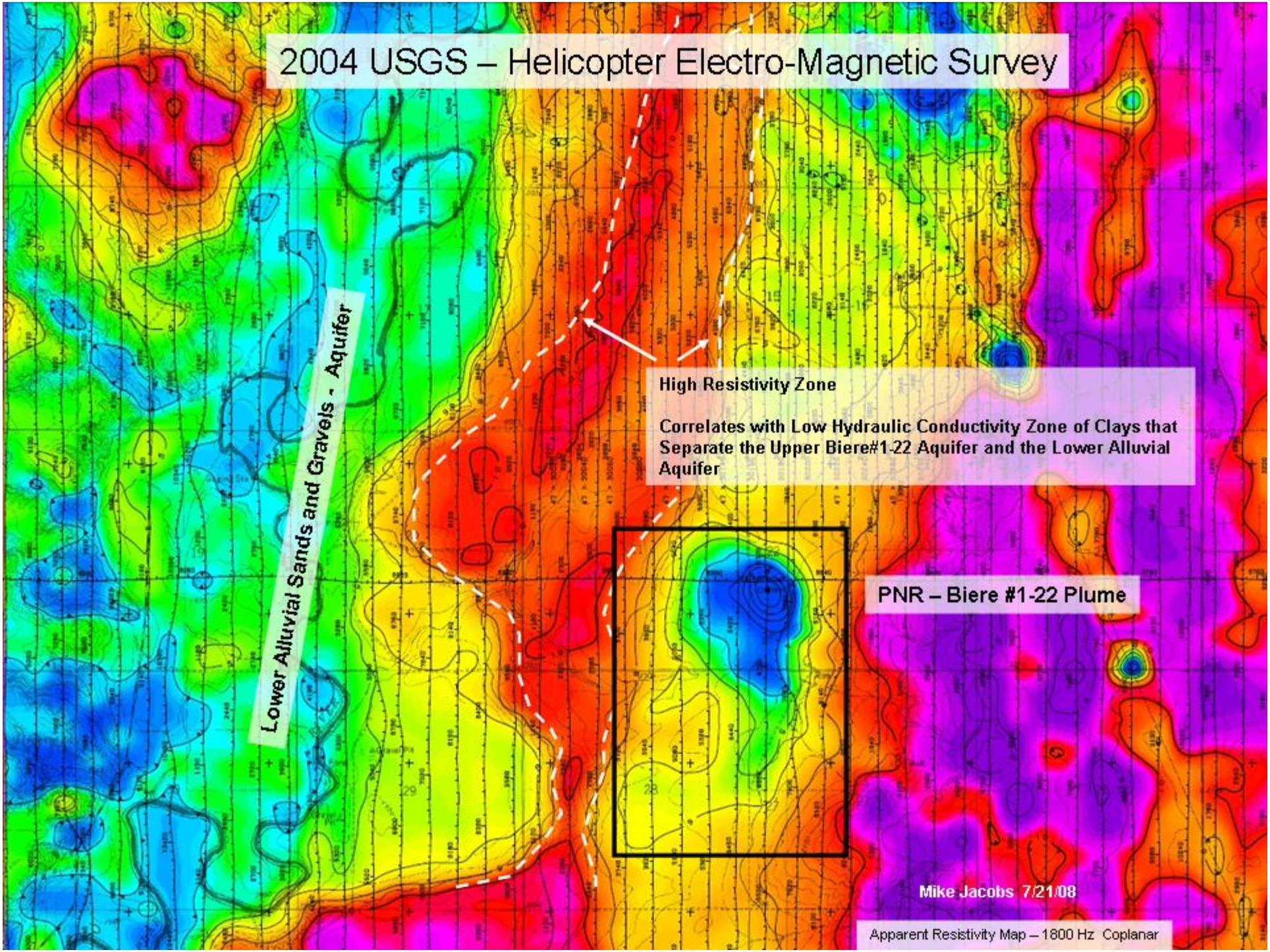
# Interpretation of 2004 USGS Helicopter Electromagnetic (HEM) Survey

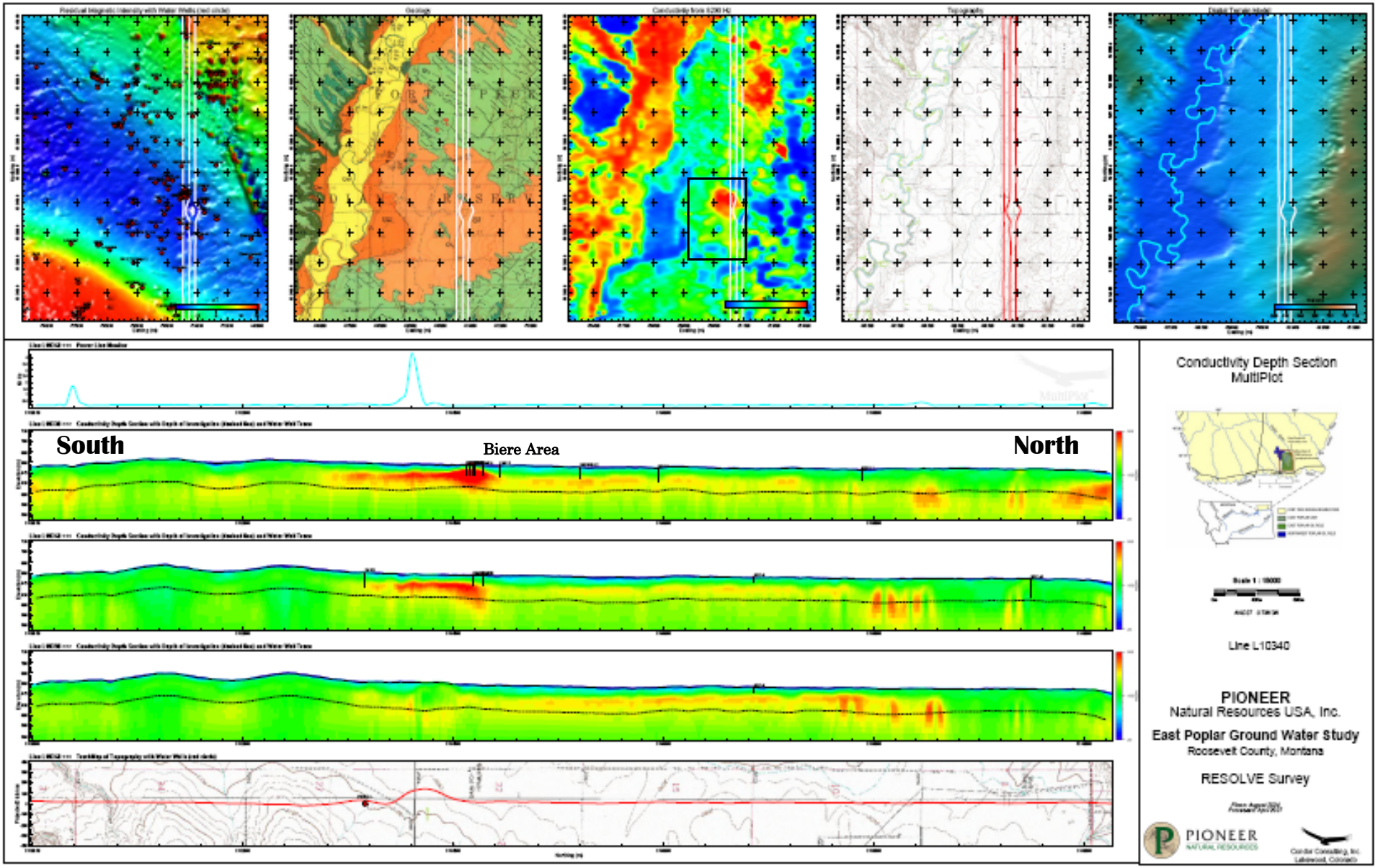
&

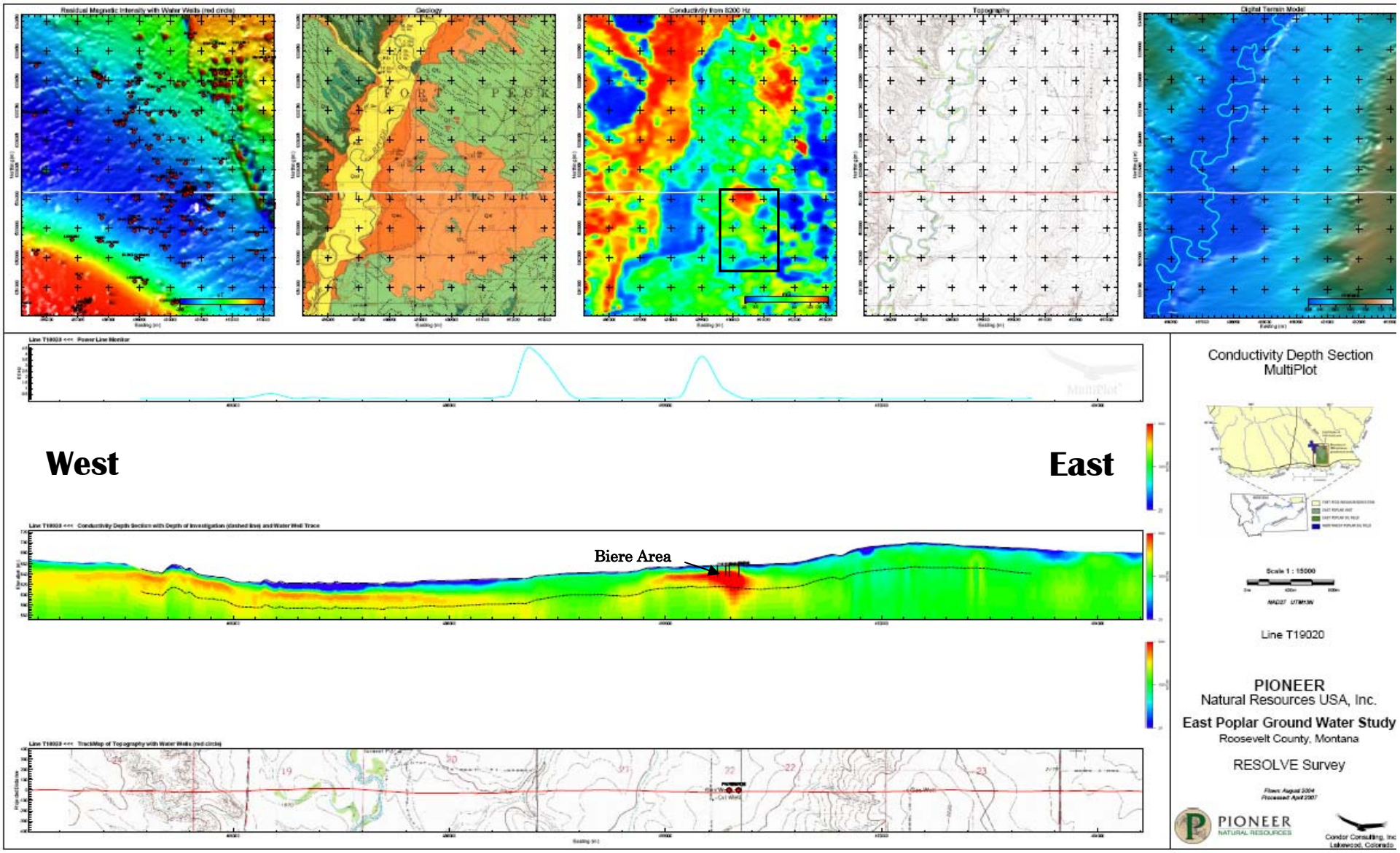
# Conductivity Depth Sections

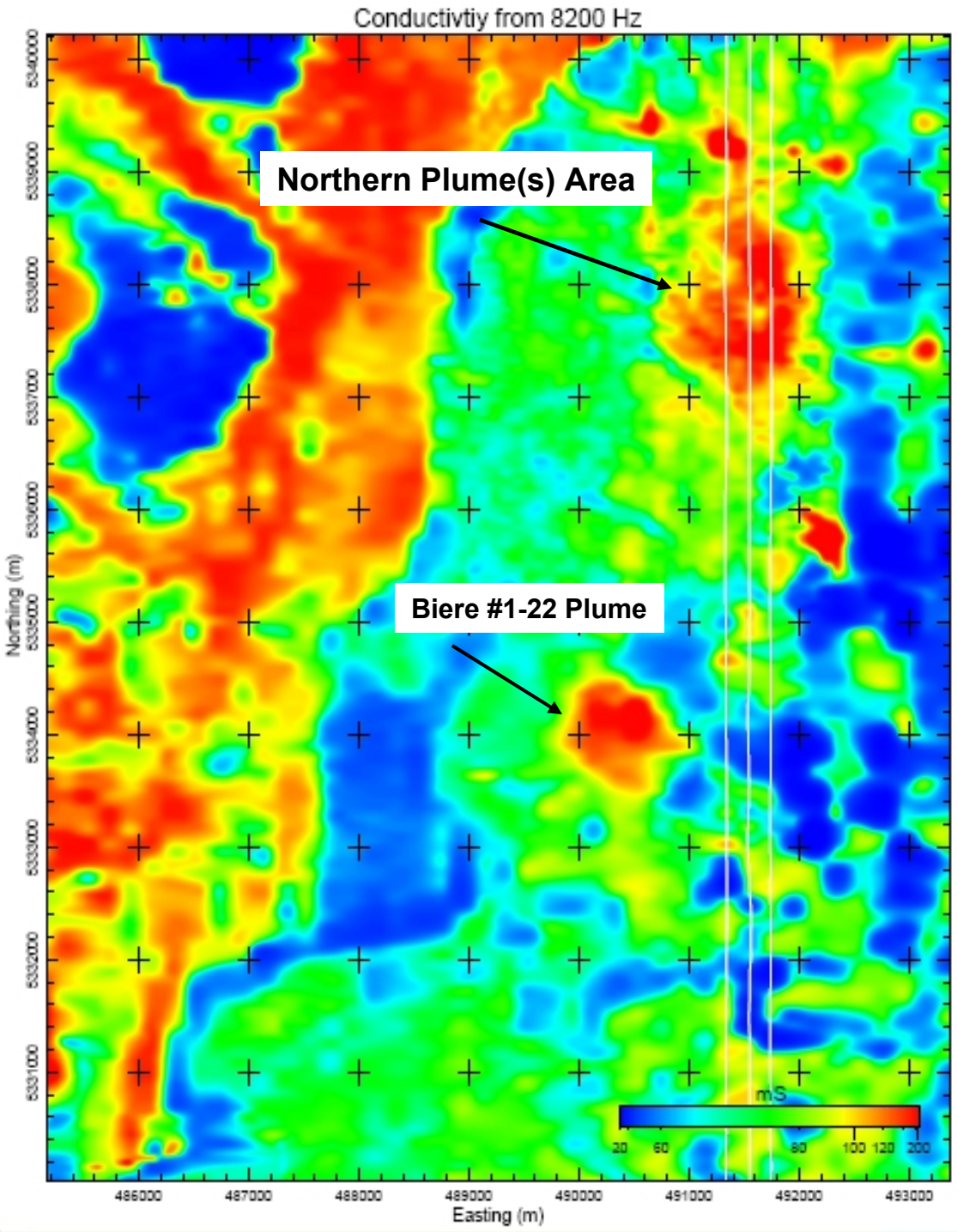
***(Dr. Bruce Smith - USGS, Denver, Co., Condor Consulting, Lakewood, Co., and Mike Jacobs-PNR)***

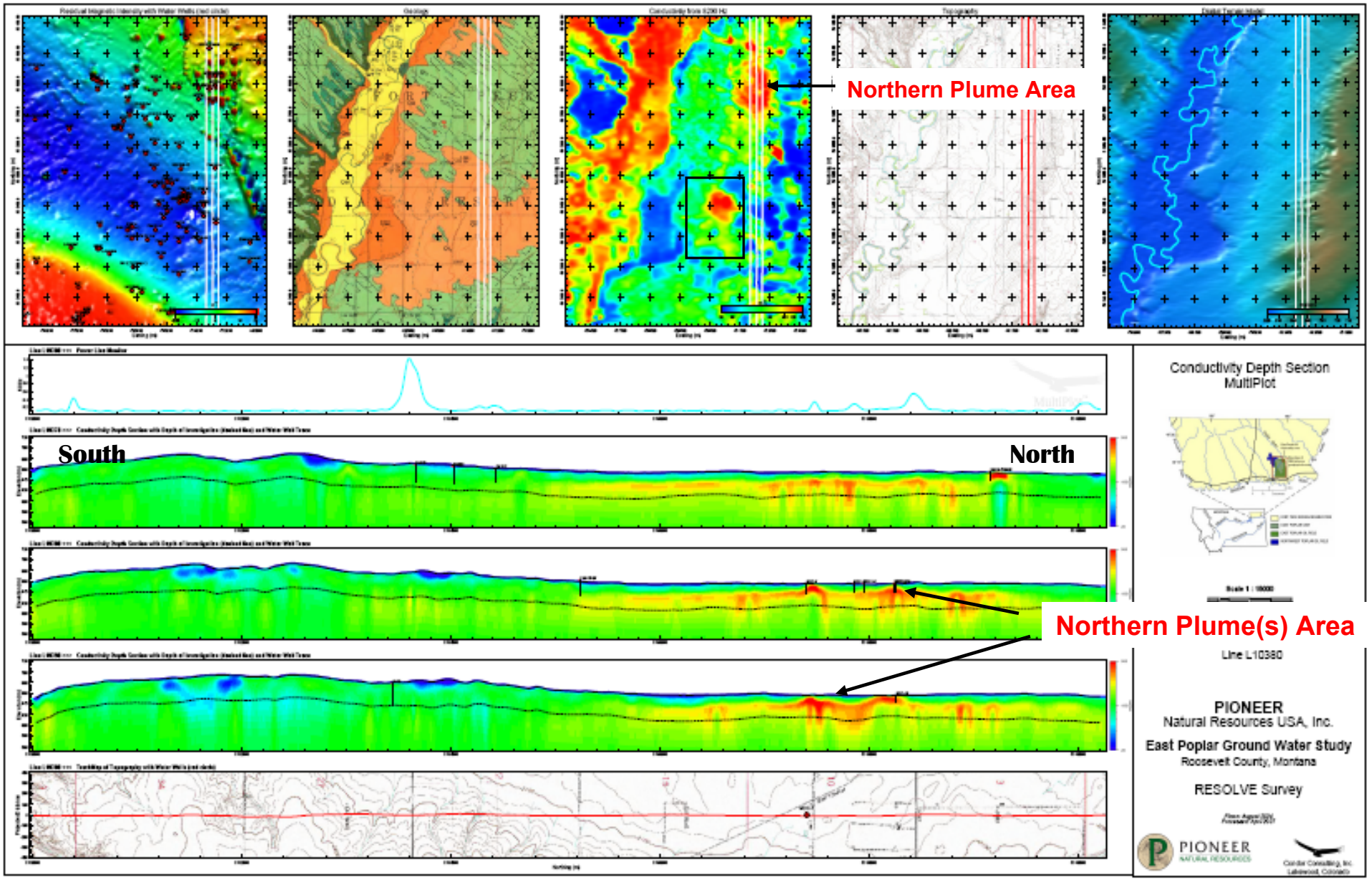

Conductivtiy from 8200 Hz
1,094 Linear Miles
Northern Plume(s) Area
Biere #1-22 Plume
mS
20
60
80
100
120
200
Northing (m)
5340000
5339000
5338000
5337000
5336000
5335000
5334000
5333000
5332000
5331000
486000
487000
488000
489000
490000
491000
492000
493000
Easting (m)


2004 USGS – Helicopter Electro-Magnetic Survey
Lower Alluvial Sands and Gravels - Aquifer
High Resistivity Zone
Correlates with Low Hydraulic Conductivity Zone of Clays that Separate the Upper Biere#1-22 Aquifer and the Lower Alluvial Aquifer
PNR – Biere #1-22 Plume
Mike Jacobs 7/21/08
Apparent Resistivity Map – 1800 Hz Coplanar


South
Biere Area
North
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 8200 Hz
Topography
Digital Terrain Model
Line T19020 <<< Power Line Monitor
West
East
Line T19020 <<< Conductivity Depth Section with Depth of Investigation (dashed line) and Water Well Trace
Biere Area
Line T19020 <<< TrackMap of Topography with Water Wells (red circle)
Conductivity Depth Section
MultiPlot
Scale 1 : 15000
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
Northern Plume(s) Area
Biere #1-22 Plume
mS
20
60
80
100
120
200
Northing (m)
Easting (m)
486000
487000
488000
489000
490000
491000
492000
493000


Northern Plume Area
South
North
Northern Plume(s) Area
Conductivity Depth Section
MultiPlot
Line L10380
PIONEER
Natural Resources USA, Inc.
East Poplar Ground Water Study
Roosevelt County, Montana
RESOLVE Survey
PIONEER

# Aquifer Testing

## (Pioneer – Midland ED & HKM Engineering)

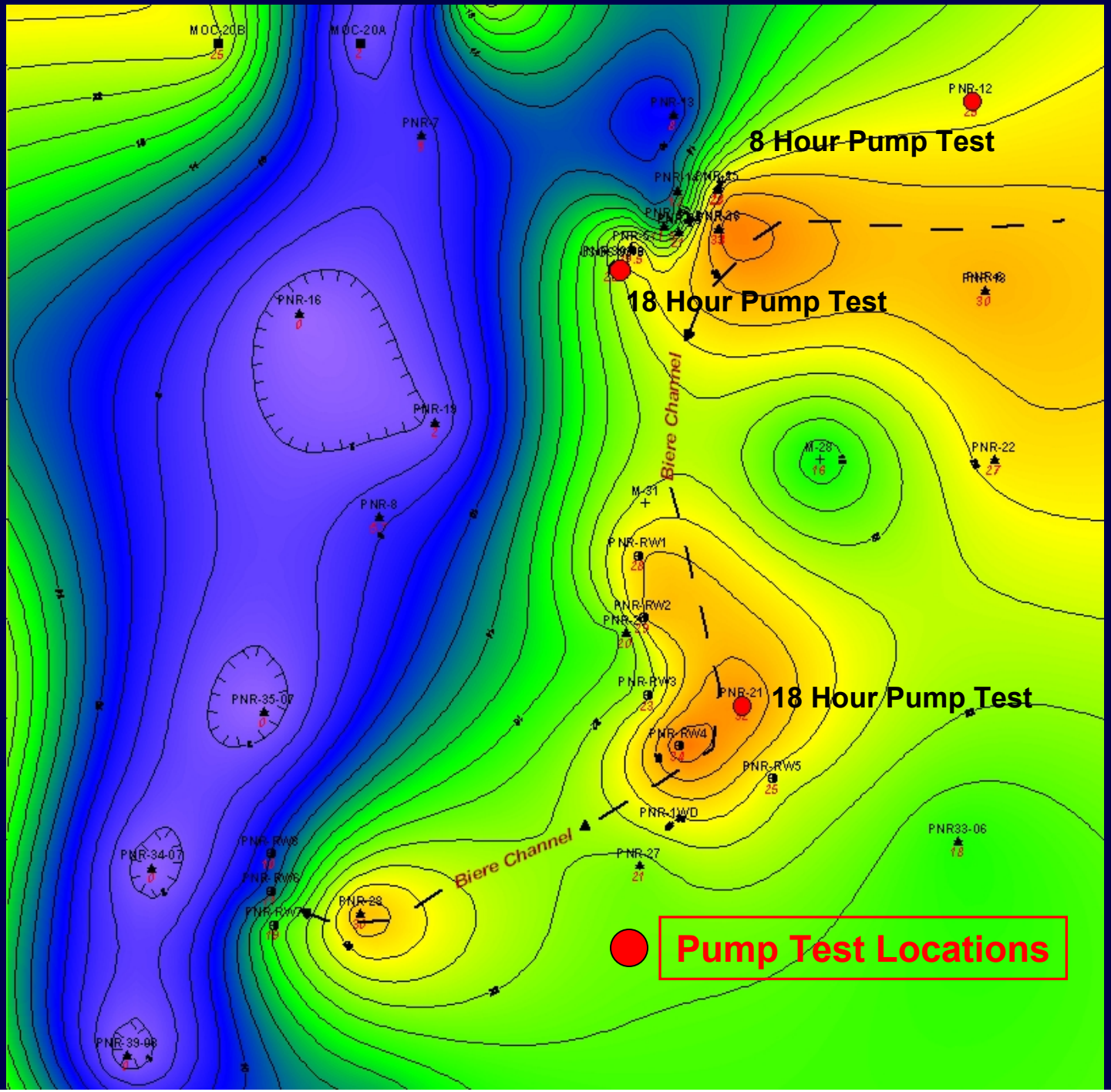
- Drilled three new wells - two 5” pumping wells and one observation well
- Conducted Three Aquifer Pump Tests

  Test #1 - Northern Main Plume Area – 18 hour pump test
  Test #2 – Southern Plume Area – 18 hour pump test
  Test#3 – Upgradient Gravel Channel – 8 hour pump test

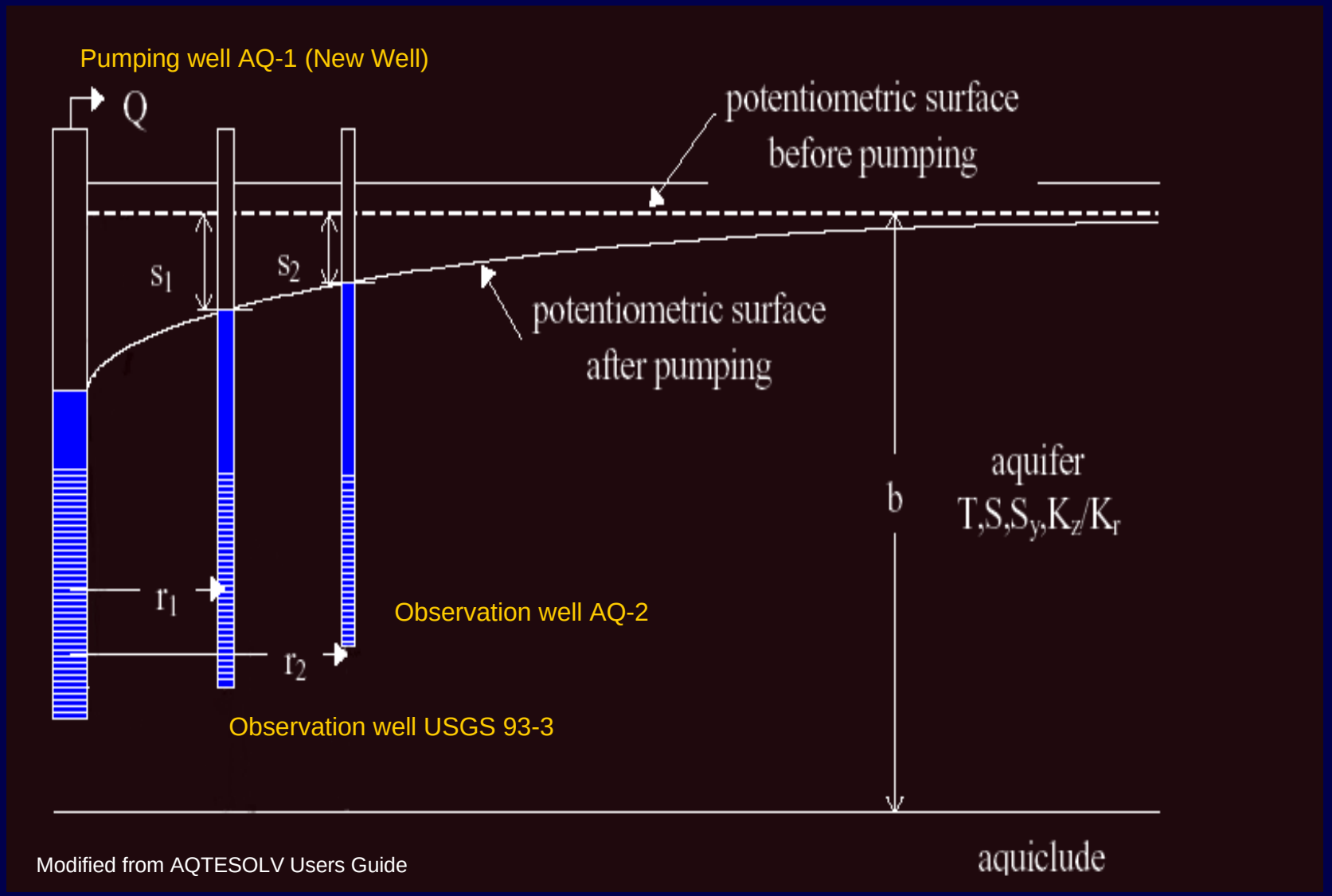
- Conducted Slug Tests on 14 wells

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

| *Parameter* | *Importance To Groundwater Cleanup* |
|---|---|
| Hydraulic Conductivity<br>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<br>$i$ | Influences the direction of contaminant movement based upon the elevation and pressure differences. |
| Transmissivity<br>T | Influences the rate at which groundwater can be pumped and, thus, influences the total flow rate of the system. |
| Groundwater velocity<br>$V_i$ | Influences the direction and velocity of dissolved contaminant movement - important when designing a containment system. |
| Porosity<br>$\theta$ | 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<br>$\theta_e$ | Has an impact on the groundwater velocity. |
| Storage coefficient<br>S | Influences the quantity of groundwater that can be obtained by pumping |
| Specific yield<br>$S_y$ | 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. |


8 Hour Pump Test
18 Hour Pump Test
18 Hour Pump Test
Biere Channel
Biere Channel
Pump Test Locations
MOC-20B
MOC-20A
PNR-7
PNR-13
PNR-12
PNR-16
PNR-19
PNR-8
PNR-35-07
PNR-34-07
PNR-39-08
PNR-RW8
PNR-RW6
PNR-RW7
PNR-28
PNR-RW1
PNR-RW2
PNR-RW3
PNR-RW4
PNR-RW5
PNR-1WD
PNR-21
PNR-27
PNR-22
M-28
M-31
PNR33-06

# Aquifer Testing




Modified from AQTESOLV Users Guide

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

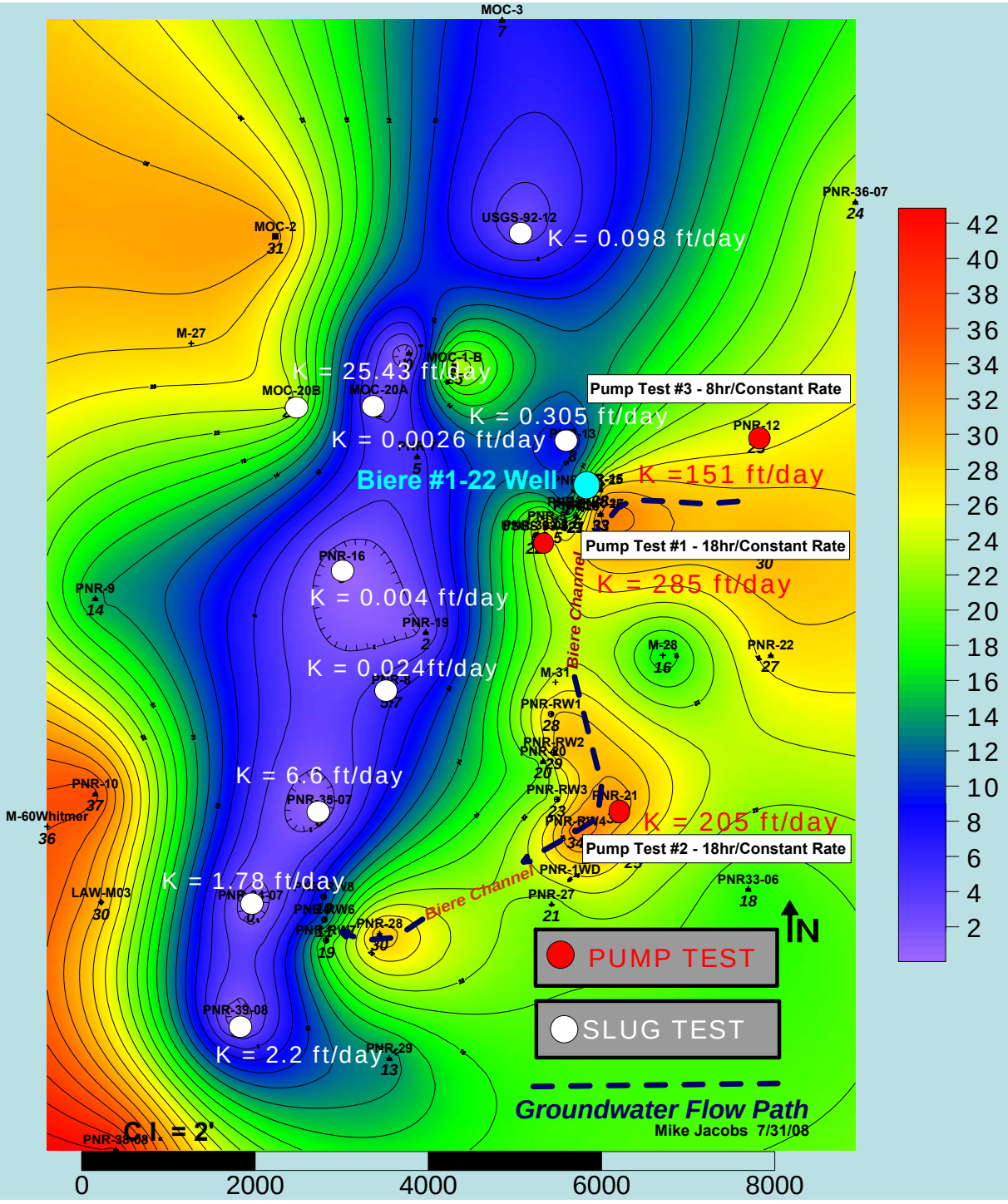
| WELL | DISTANCE (feet) | PUMPING RATE (gpm) hh:mm:ss | MAXIMUM DRAWDOWN (feet) |
|---|---|---|---|
| PNR-30-06 *Pumping Well* | 0.0 | 29 gpm for 19:17:12 | 1.96 |
| USGS-93-3A | 14 | 0 | 0.92 |
| USGS-93-3 | 24 | 0 | 0.86 |
| PNR-5 | 162 | 0 | 0.34 |
| PNR-14 | 682 | 0 | 0.24 |

**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<br>60 gpm for 00:56:35<br>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**


MOC-3
7
USGS-92-12
K = 0.098 ft/day
PNR-36-07
24
MOC-2
31
M-27
MOC-1-B
MOC-20B
MOC-20A
K = 25.43 ft/day
K = 0.305 ft/day
K = 0.0026 ft/day
Biere #1-22 Well
Pump Test #3 - 8hr/Constant Rate
PNR-12
K =151 ft/day
Pump Test #1 - 18hr/Constant Rate
K = 285 ft/day
PNR-16
K = 0.004 ft/day
PNR-9
14
PNR-19
2
K = 0.024ft/day
Biere Channel
M-28
16
PNR-22
27
M-31
PNR-RW1
28
PNR-RW2
PNR-40
29
20
K = 6.6 ft/day
PNR-10
37
PNR-35-07
M-60Whitmer
36
PNR-RW3
PNR-21
PNR-RW4
K = 205 ft/day
Pump Test #2 - 18hr/Constant Rate
PNR-1WD
PNR33-06
18
LAW-M03
30
K = 1.78 ft/day
PNR-27
21
PNR-28
PNR-39-08
K = 2.2 ft/day
PNR-29
13
PUMP TEST
SLUG TEST
Groundwater Flow Path
Mike Jacobs 7/31/08
C.I. = 2'
N
0
2000
4000
6000
8000
42
40
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2

Hard compact “Fat Clay” of the overlying Sprole Till and inter-channel clay deposits


Loose, coarse-grained gravel of the Wiota Gravel - Aquifer


Slug Test Evaluation ( -28° F)

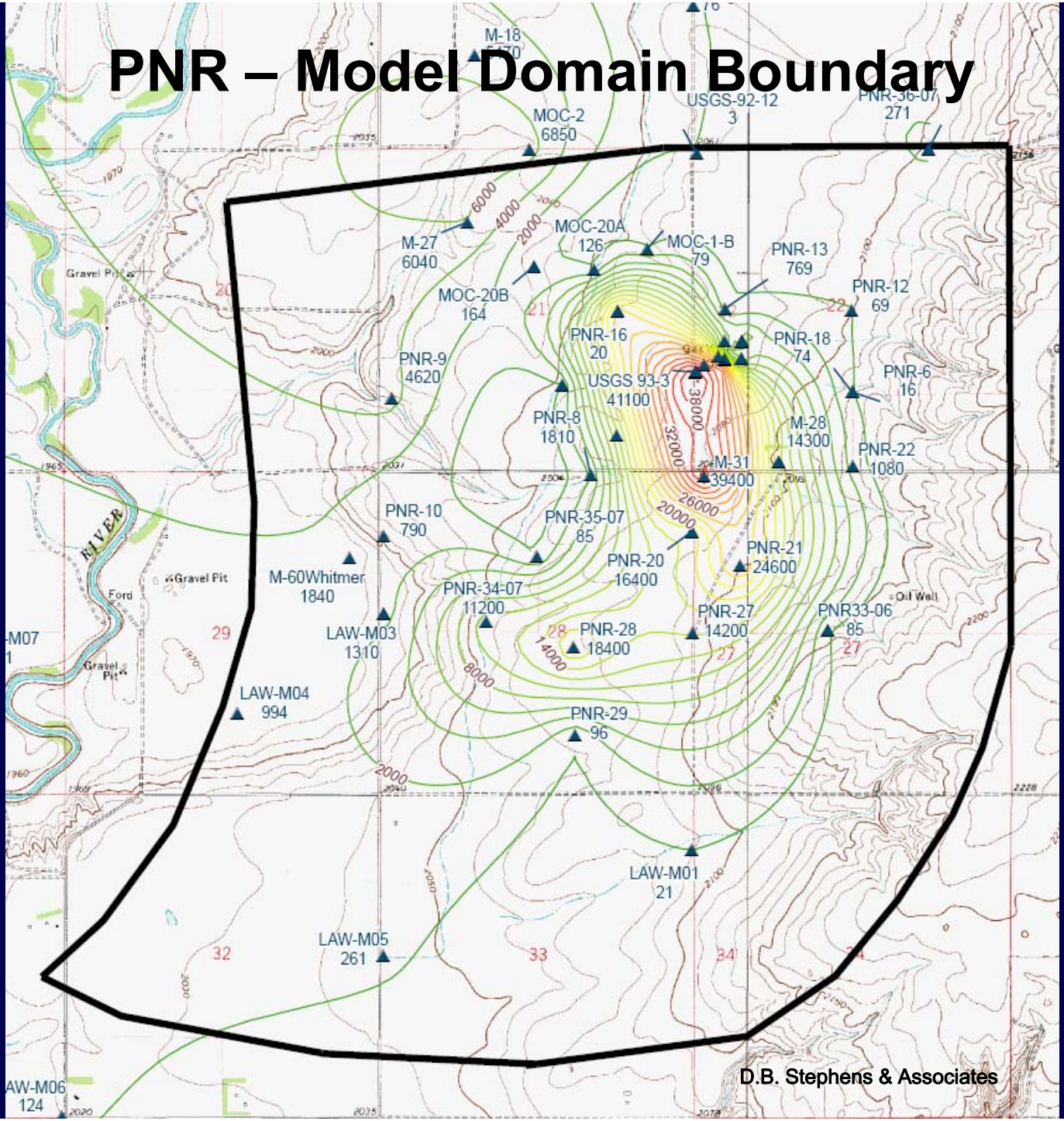
# *Later that Day – Still Smiling*

# Groundwater Flow and Contaminant Transport Model – Visual MODFLOW

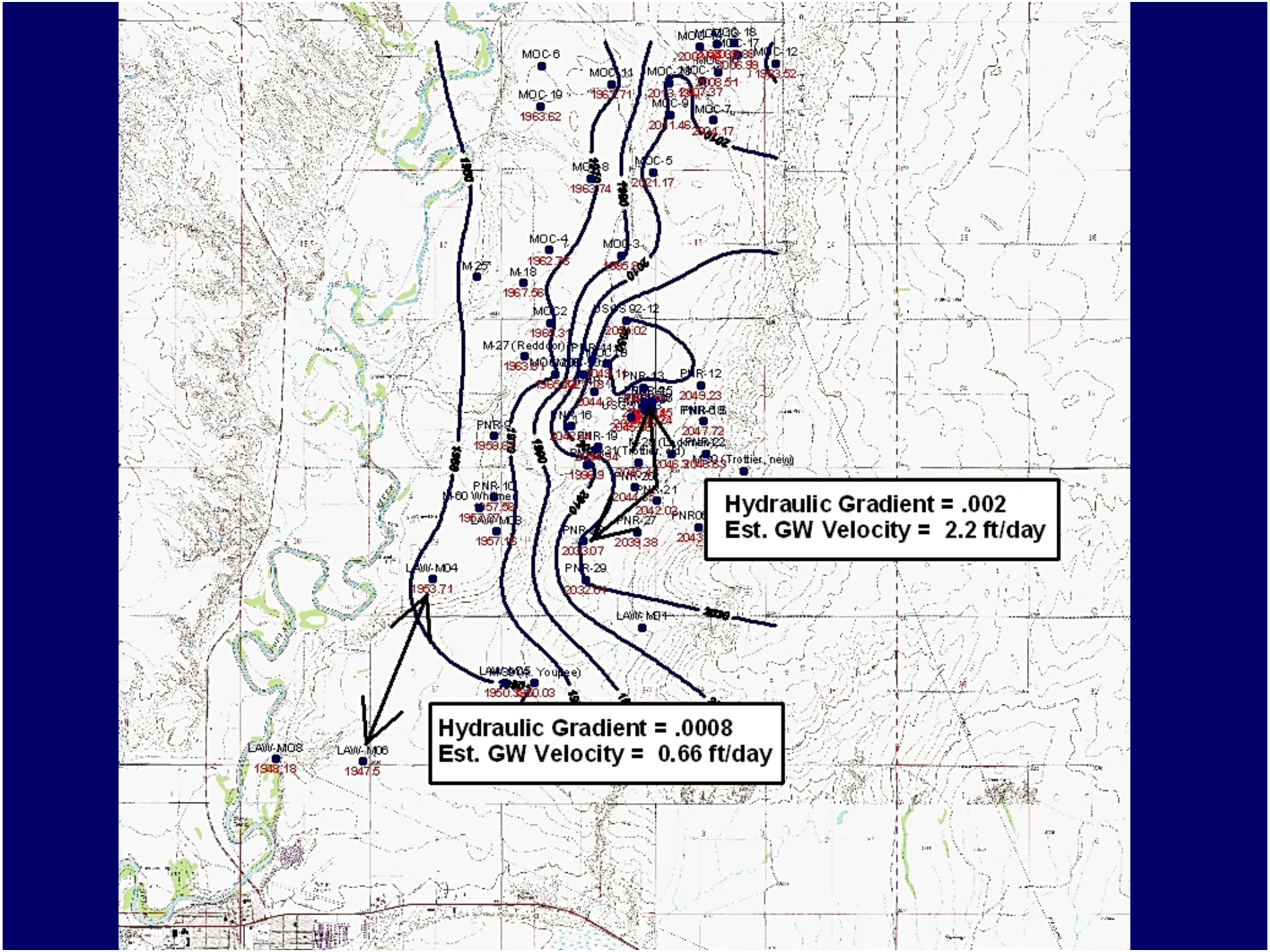
(Daniel B. Stephens & Associates, Albuquerque, NM & Pioneer Midland ED)

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**

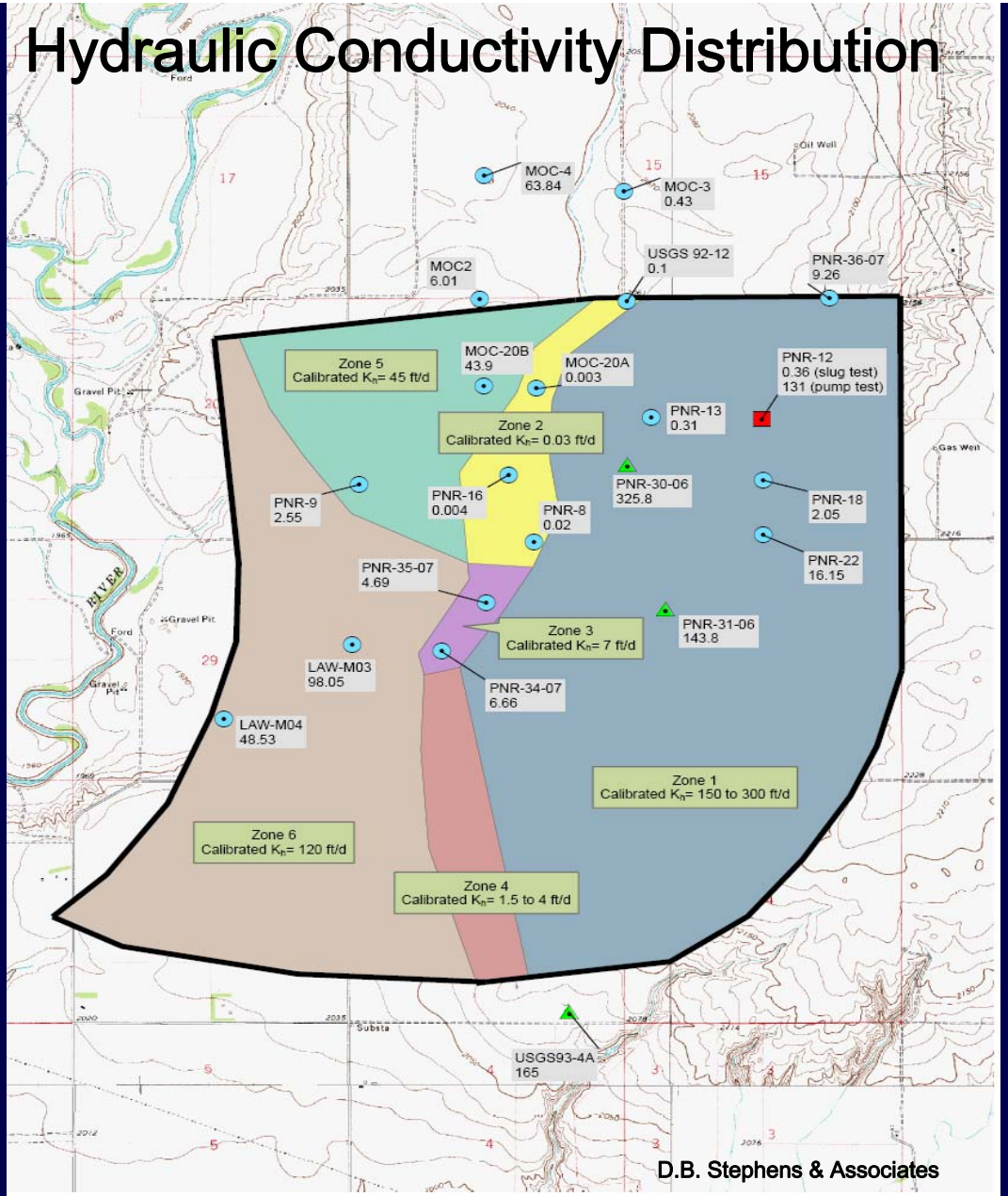
# PNR – Model Domain Boundary




D.B. Stephens & Associates


Hydraulic Gradient = .002
Est. GW Velocity = 2.2 ft/day
Hydraulic Gradient = .0008
Est. GW Velocity = 0.66 ft/day
MOC-6
MOC-19
1963.62
MOC-11
1962.71
MOC-18
MOC-12
MOC-9
MOC-7
MOC-5
2021.17
MOC-8
1963.74
MOC-4
1962.76
MOC-3
M-25
M-18
1967.56
MOC2
1962.31
USGS 92-12
M-27 (Reddor)
PNR-13
PNR-12
2049.23
PNR-16
PNR-19
PNR-22
PNR-10
M-60 Whitmer
1957.56
LAW-M03
1957.16
PNR-27
2039.38
PNR-29
LAW-M04
1953.71
LAW-M01
LAW-M05 Youpee)
LAW-M08
1948.18
LAW-M06
1947.5

# Hydraulic Conductivity Distribution




D.B. Stephens & Associates

N

0 1,000 2,000 Feet

**Explanation**

Model Boundary

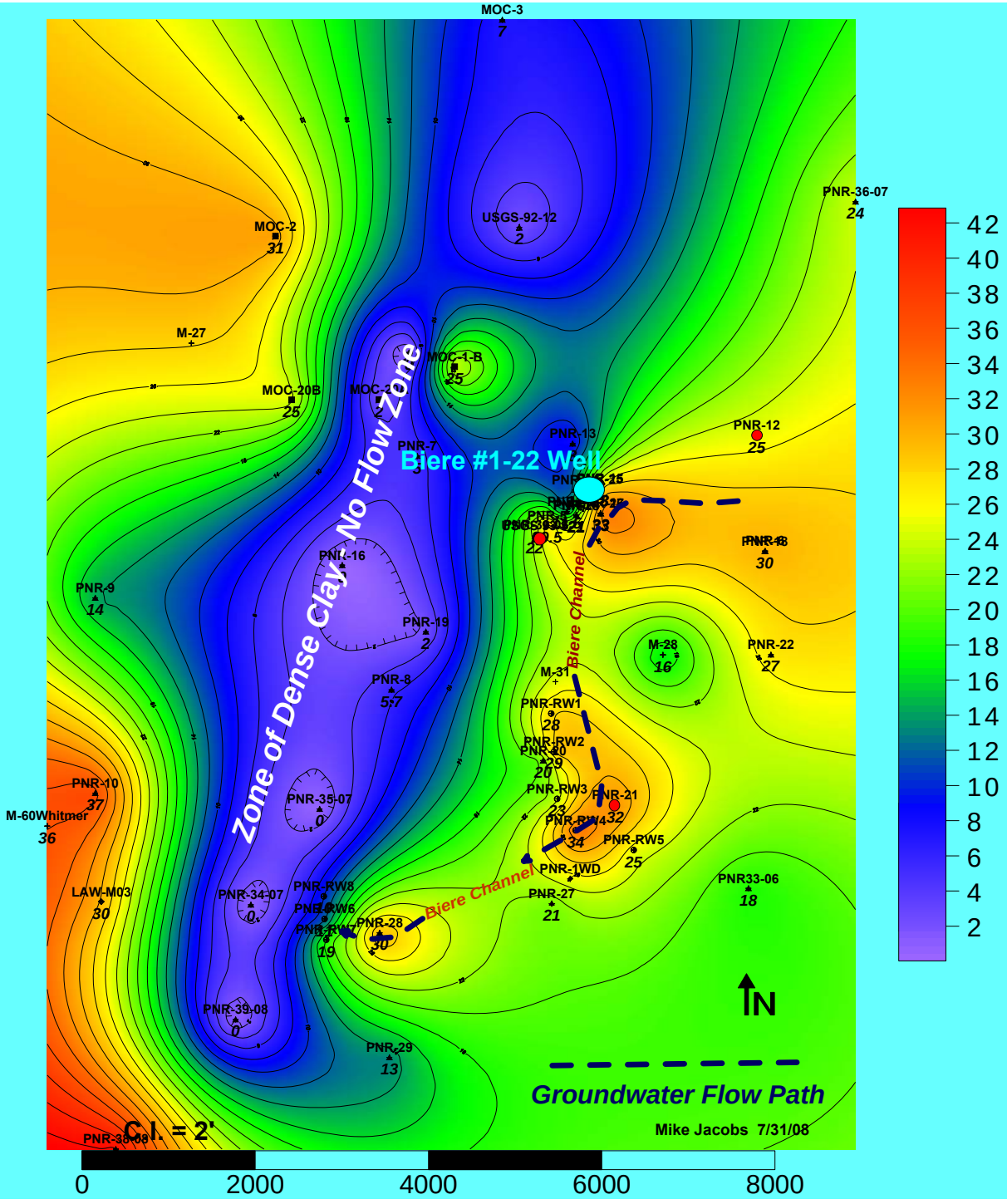
**Hydraulic Conductivity (ft/day)**

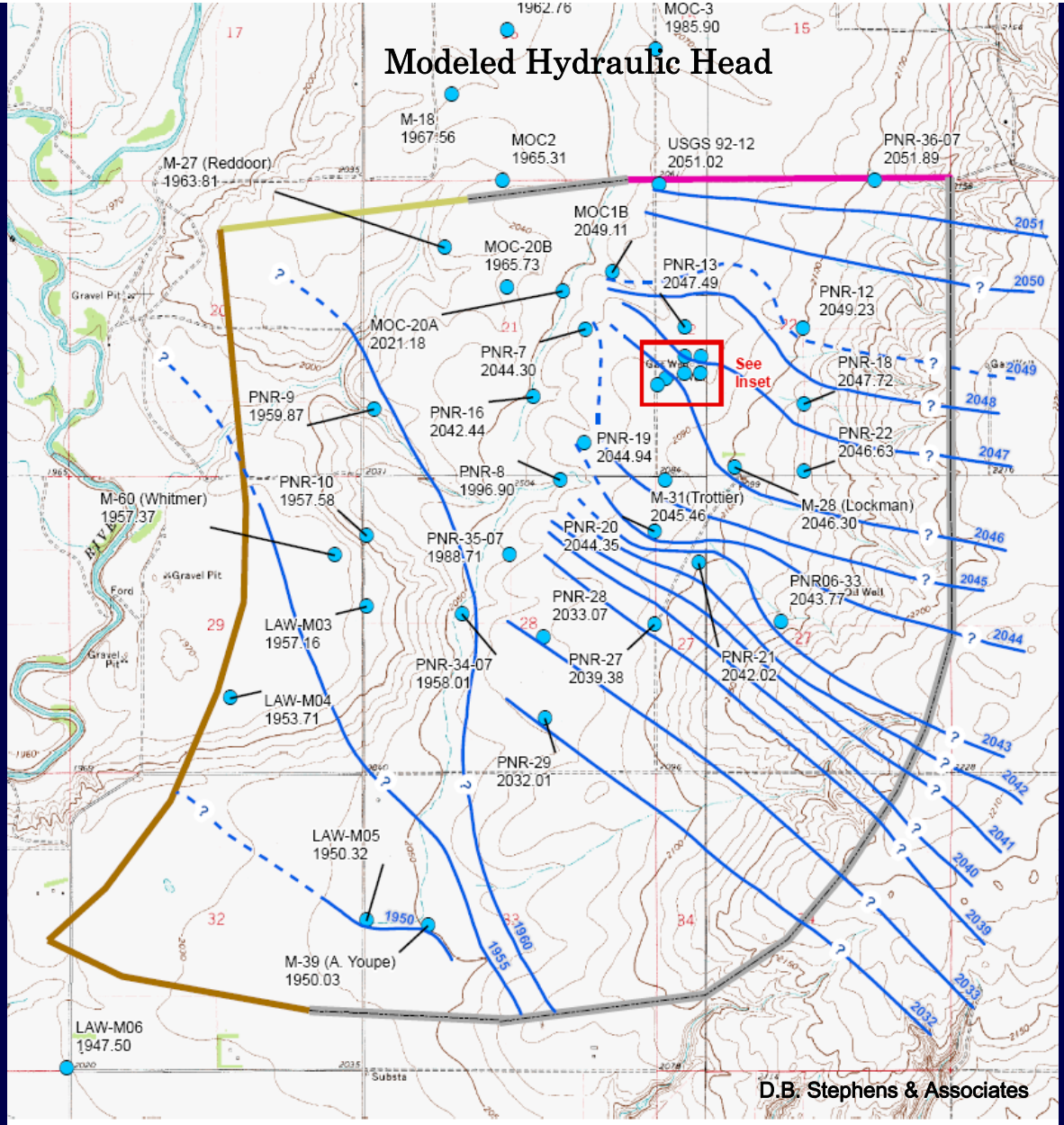
- Pump Test
- Slug Test
- Pump Test and Slug Test

**Horizontal Hydraulic Conductivity ($K_h$) Zones**

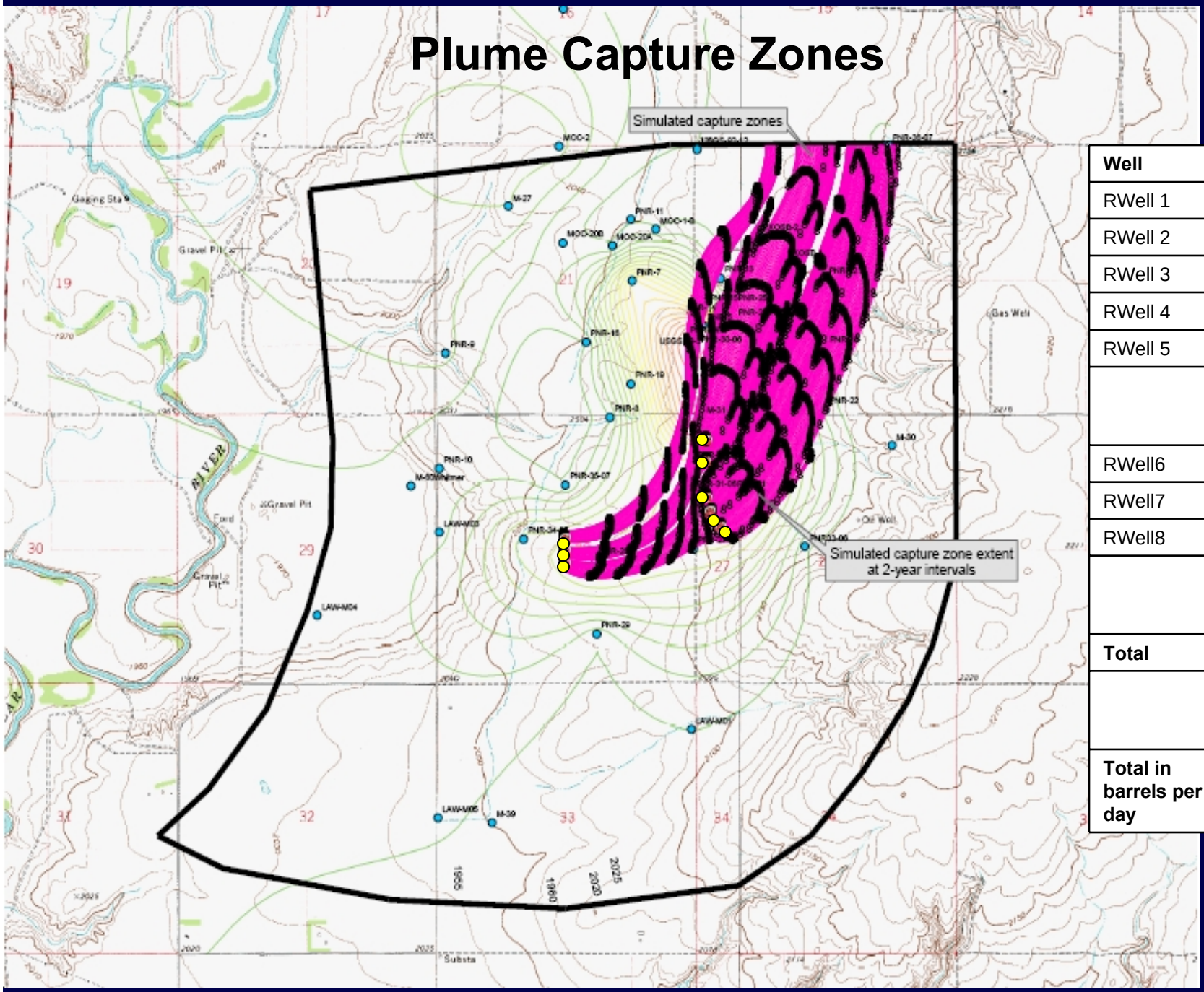
- Zone 1
- Zone 2
- Zone 3
- Zone 4
- Zone 5
- Zone 6

PIONEER BIERE WELL BRINE PLUME


MOC-3
7
MOC-2
31
USGS-92-12
2
PNR-36-07
24
M-27
MOC-1-B
25
MOC-20B
25
MOC-3
PNR-7
3
PNR-13
PNR-12
25
Biere #1-22 Well
PNR-15
PNR-48
30
PNR-16
PNR-9
14
PNR-19
2
Zone of Dense Clay, No Flow Zone
Biere Channel
M-28
16
PNR-22
27
PNR-8
5.7
M-31
PNR-RW1
28
PNR-RW2
PNR-20
29
20
PNR-10
37
PNR-RW3
23
PNR-21
32
M-60Whitmer
36
PNR-35-07
0
PNR-RW4
34
PNR-RW5
25
PNR-1WD
LAW-M03
30
PNR-34-07
0
PNR-RW8
PNR-RW6
PNR-RW7
19
PNR-28
10
Biere Channel
PNR-27
21
PNR33-06
18
PNR-39-08
0
PNR-29
13
N
Groundwater Flow Path
Mike Jacobs 7/31/08
C.I. = 2'
PNR-38-08
0
2000
4000
6000
8000
42
40
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2


Modeled Hydraulic Head
1962.76
MOC-3
1985.90
M-18
1967.56
MOC2
1965.31
USGS 92-12
2051.02
PNR-36-07
2051.89
M-27 (Reddoor)
1963.81
MOC1B
2049.11
MOC-20B
1965.73
PNR-13
2047.49
PNR-12
2049.23
MOC-20A
2021.18
PNR-7
2044.30
See Inset
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-31(Trottier)
2045.46
M-28 (Lockman)
2046.30
M-60 (Whitmer)
1957.37
PNR-35-07
1988.71
PNR-20
2044.35
PNR06-33
2043.77
PNR-28
2033.07
LAW-M03
1957.16
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
D.B. Stephens & Associates
N
0 1,000 2,000 Feet
Explanation
Model boundary type
No FLow
General Head
Prescribed Flux
Prescribed Head
PNR-88 1234.56 Monitoring well with groundwater elevation (ft msl)
Potentiometric Surface ( ft msl)
Equipotential (dashed where inferred)

# Plume Capture Zones

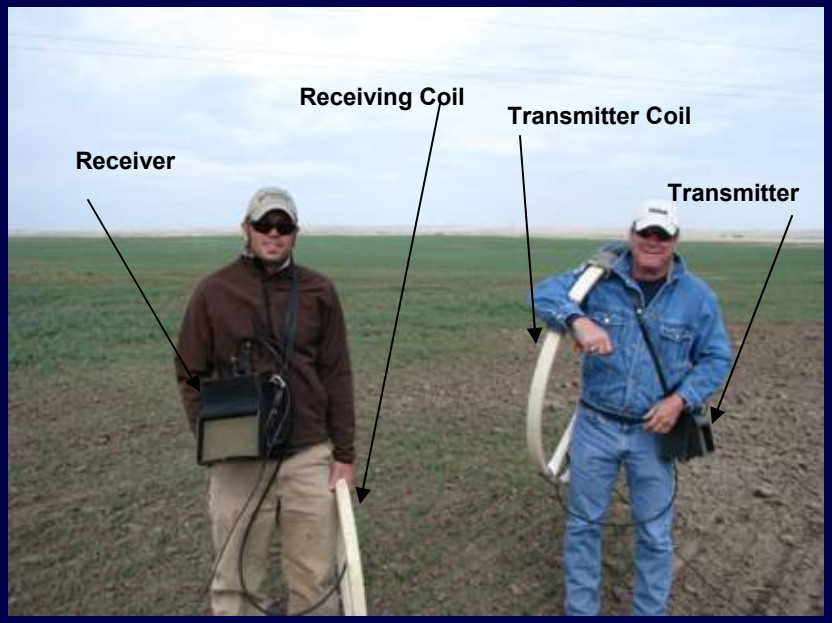



| Well | Q (gpm) |
|---|---|
| RWell 1 | 30 |
| RWell 2 | 15 |
| RWell 3 | 8 |
| RWell 4 | 25 |
| RWell 5 | 30 |
| | |
| RWell6 | 10 |
| RWell7 | 10 |
| RWell8 | 10 |
| | |
| **Total** | 138 gpm |
| | |
| **Total in barrels per day** | 4731 |

# 2008 Biere #1-22 Brine Plume - Surface EM-34 Geophysical Work

## Advantages of EM34 surveys are:

✓The equipment is relatively lightweight and portable



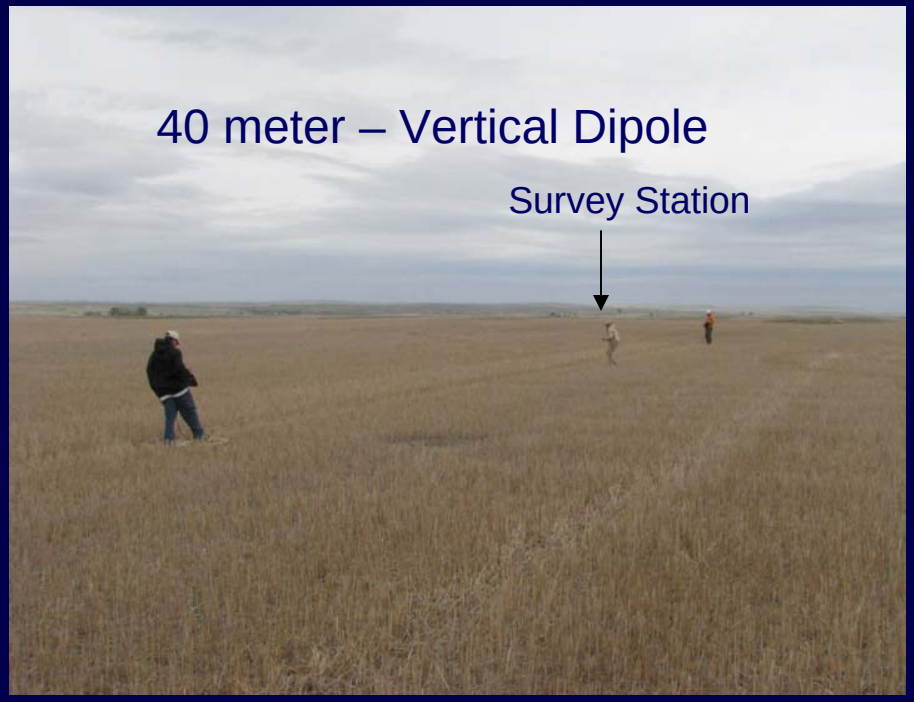

✓Measurements can be collected rapidly with a minimum number of field personnel, 2 to 3.

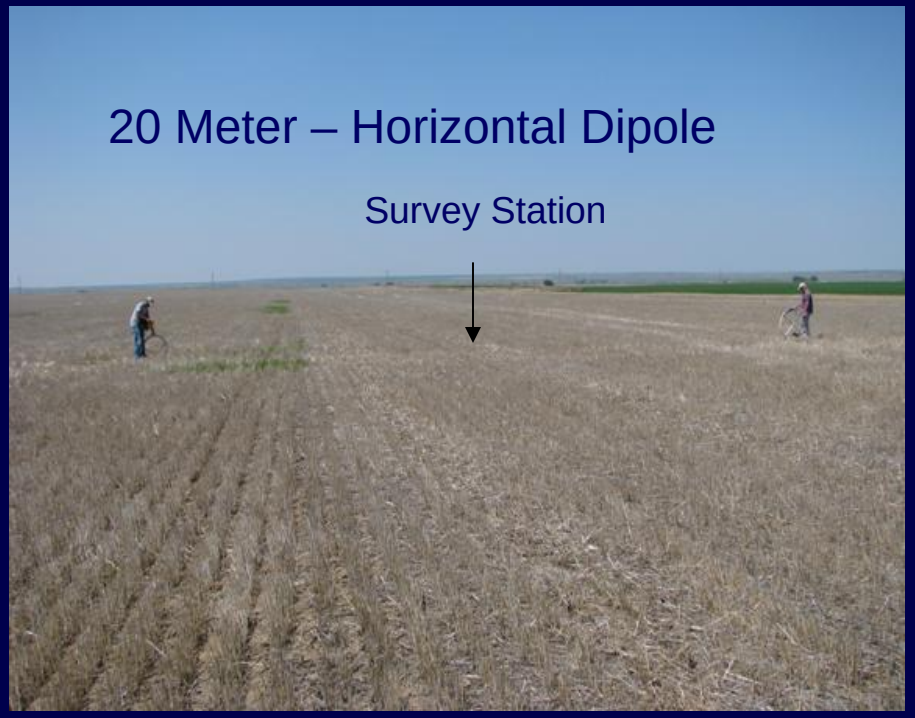
✓Is accurate and good for groundwater investigations up to 180’ in depth

- The electromagnetic (EM) geophysical method determines electrical properties of earth materials by inducing electromagnetic currents in the ground and measuring the secondary magnetic field produced by these currents.

- An alternating current is generated in a wire loop or coil above the ground's surface. Both the primary magnetic field (produced by the transmitter coil in the instrument) and the secondary field (produced by currents in the earth) induce a corresponding alternating current in the receiver coil of the instrument.

- The coils are kept at a fixed distance and orientation relative to the ground to simplify data analysis. The spacing and orientation of the EM field determines the effective depth of the investigation with good results up to depths of as much as 60 meters (180 feet) at the 40-meter spacing.

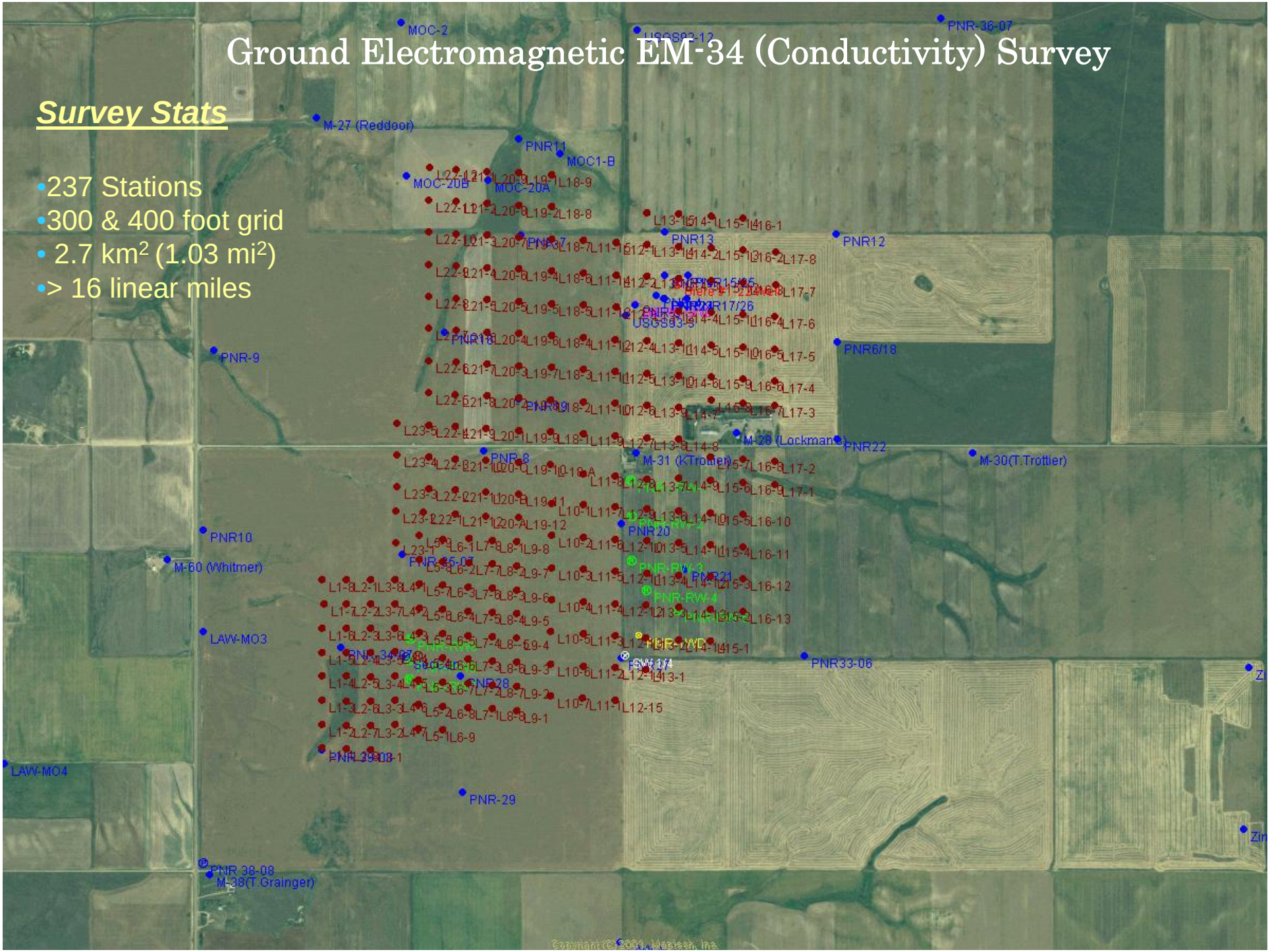


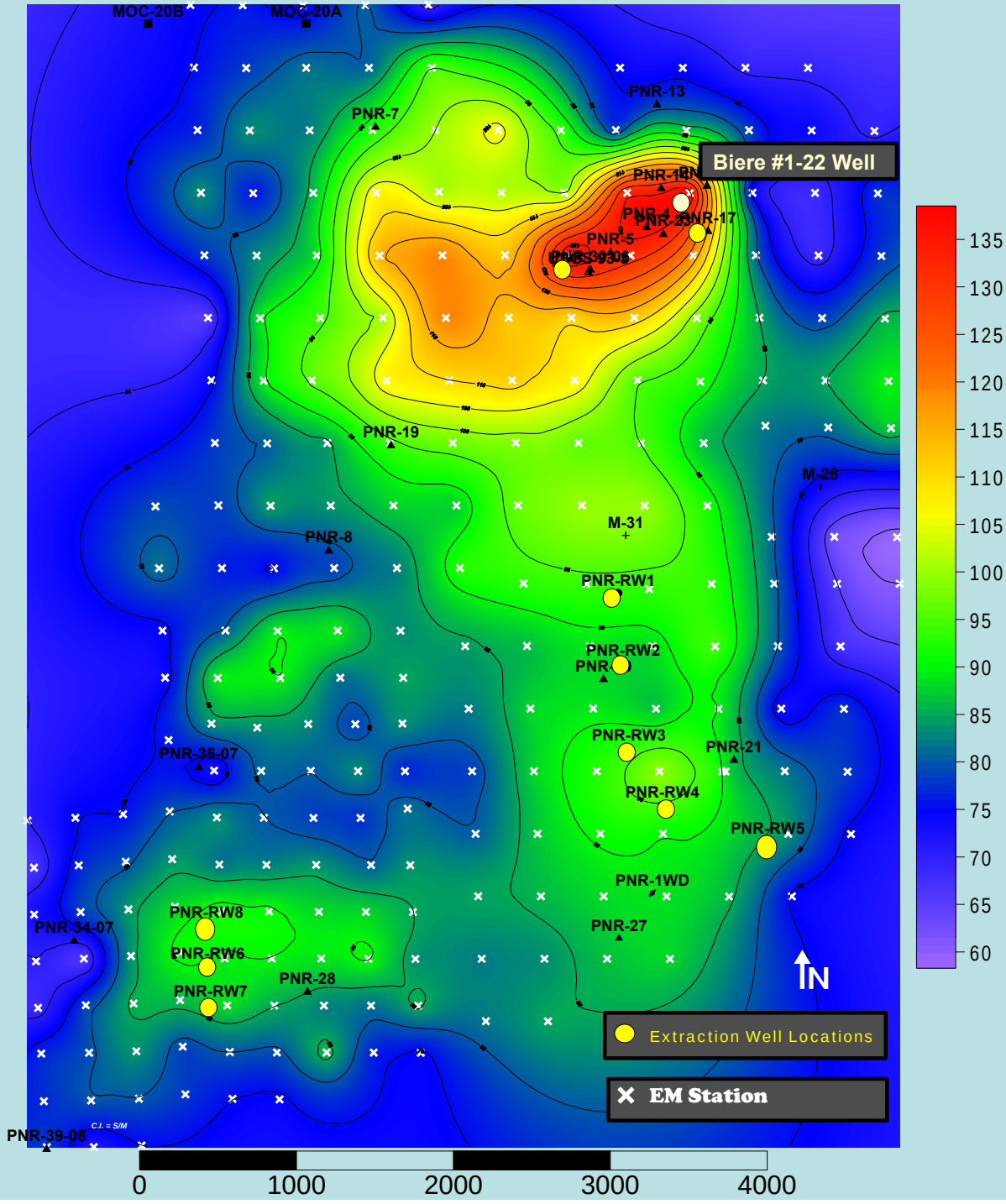



# Ground Electromagnetic EM-34 (Conductivity) Survey

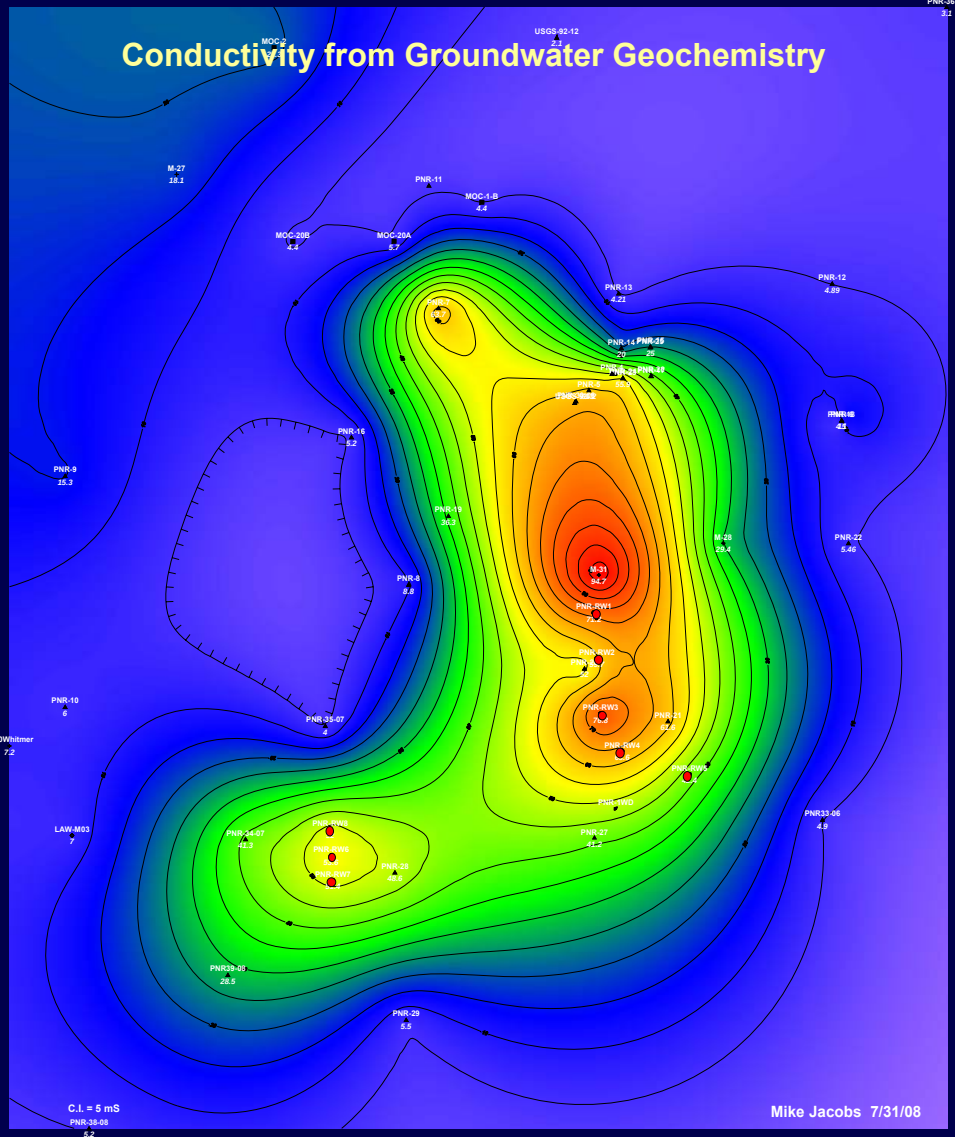
## ***Survey Stats***

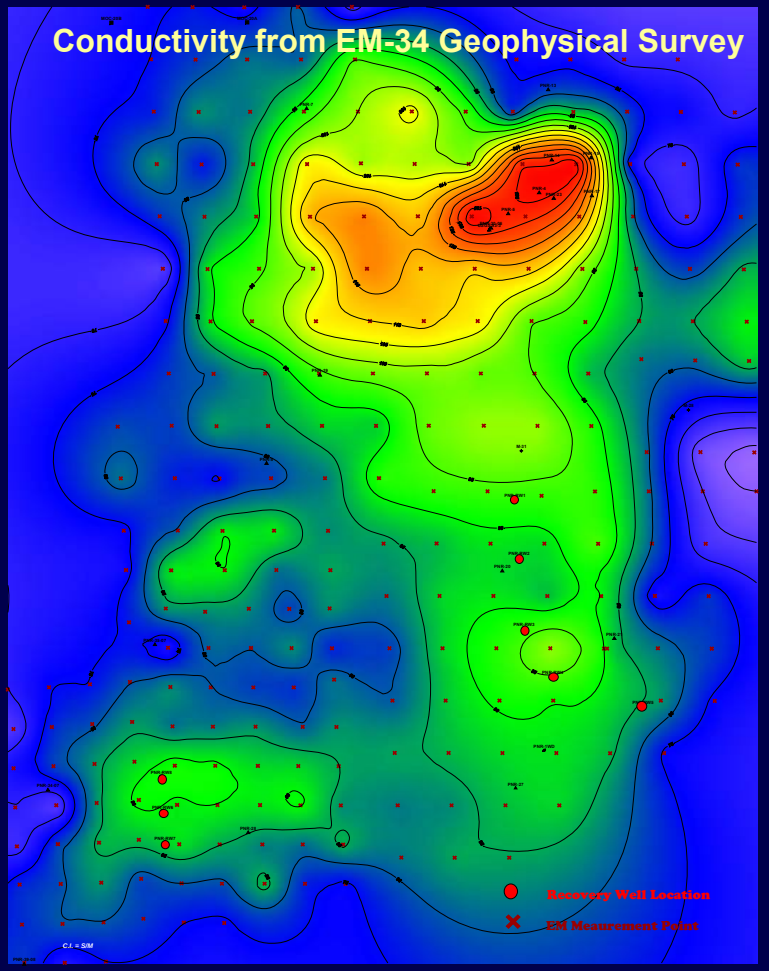
- 237 Stations
- 300 & 400 foot grid
- 2.7 km$^2$ (1.03 mi$^2$)
- > 16 linear miles




MOC-20B
MOC-20A
PNR-13
PNR-7
Biere #1-22 Well
PNR-18
PNR-4
PNR-23
PNR-17
PNR-5
PNR-19
M-28
M-31
PNR-8
PNR-RW1
PNR-RW2
PNR-RW3
PNR-21
PNR-35-07
PNR-RW4
PNR-RW5
PNR-1WD
PNR-RW8
PNR-34-07
PNR-27
PNR-RW6
PNR-28
PNR-RW7
PNR-39-08
C.I. = 5/M
Extraction Well Locations
EM Station
IN
0
1000
2000
3000
4000
135
130
125
120
115
110
105
100
95
90
85
80
75
70
65
60

# Groundwater Conductivity (left) Vs Interpreted Conductivity from EM-34 Survey (below)

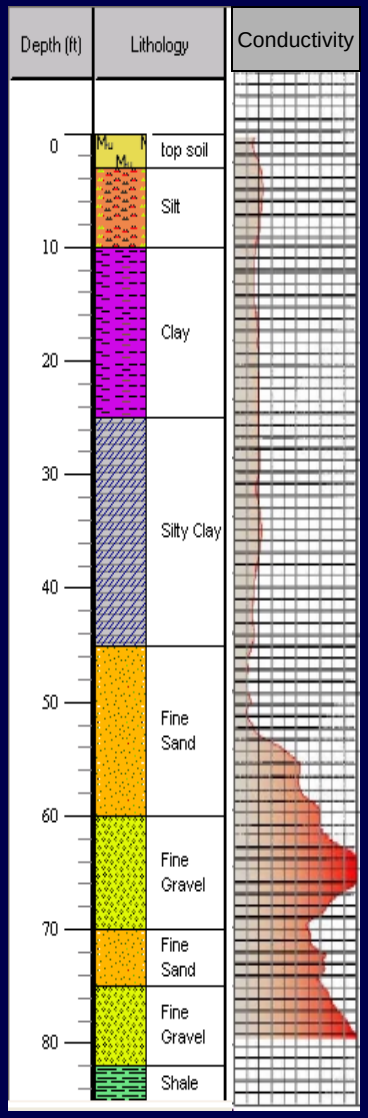


# Downhole Geophysical Logging

## Natural Gamma/Conductivity
## 20 Wells

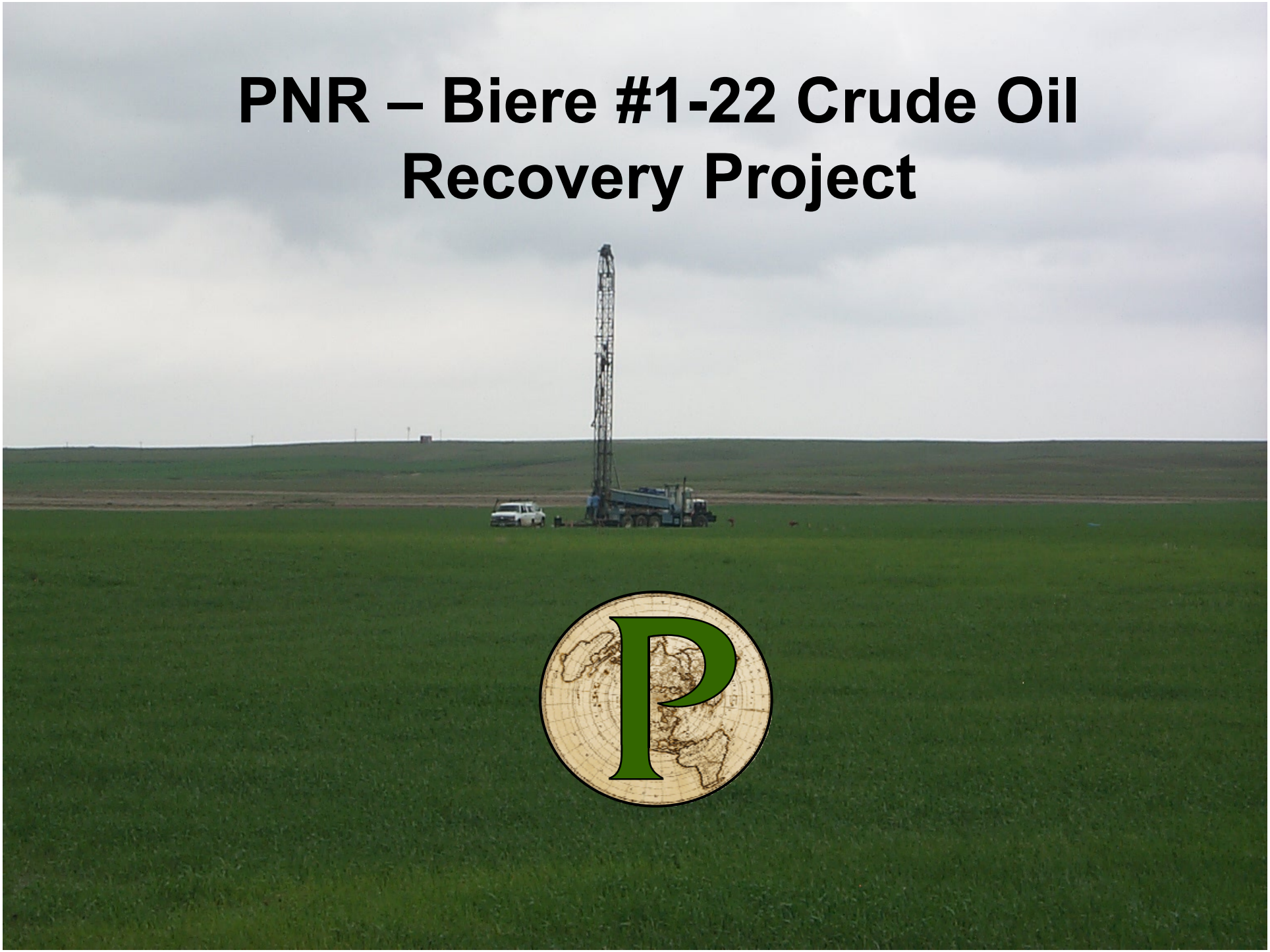
PNR-21

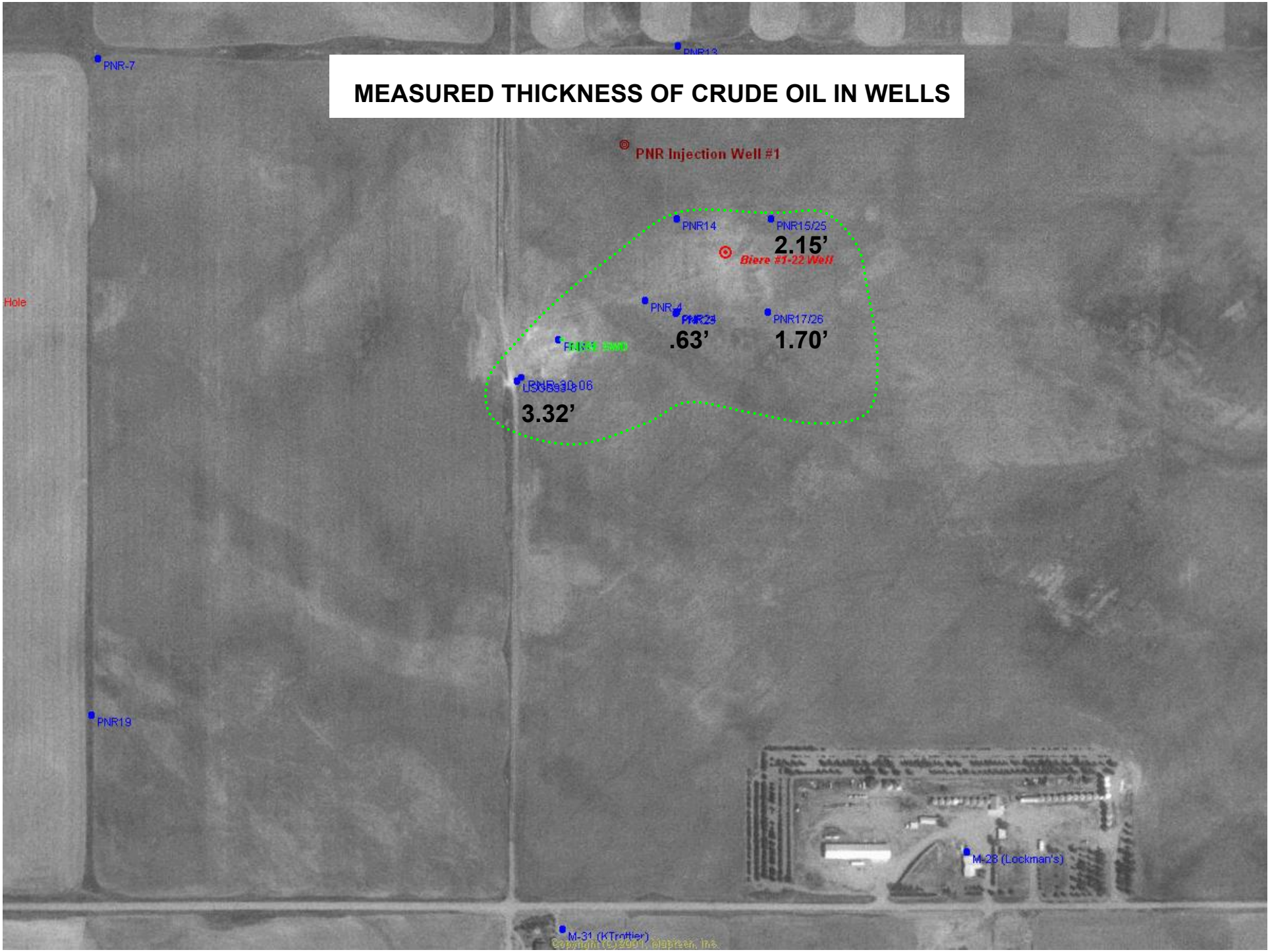


# Designing and Constructing the Biere Aquifer Restoration System

A Picture Story

# PNR – Biere #1-22 Crude Oil Recovery Project




MEASURED THICKNESS OF CRUDE OIL IN WELLS
PNR Injection Well #1
PNR-7
PNR14
PNR15/25
2.15’
Biere #1-22 Well
PNR17/26
.63’
1.70’
3.32’
PNR19
M-28 (Lockman's)
M-31 (KTrottier)


# Crude Oil Recovery “Pilot Test”


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

Trenching Electrical Line

Laying Electrical Line

# Crude Oil Recovery Project - Installation

Plumbing in Wells

8” Recovery Well


PUMA


CAUTION
HIGH VOLTAGE
CAUTION
HIGH VOLTAGE
CAUTION
HIGH VOLTAGE
HEVI-DUTY


# Pioneer's

# "Git er Dun"

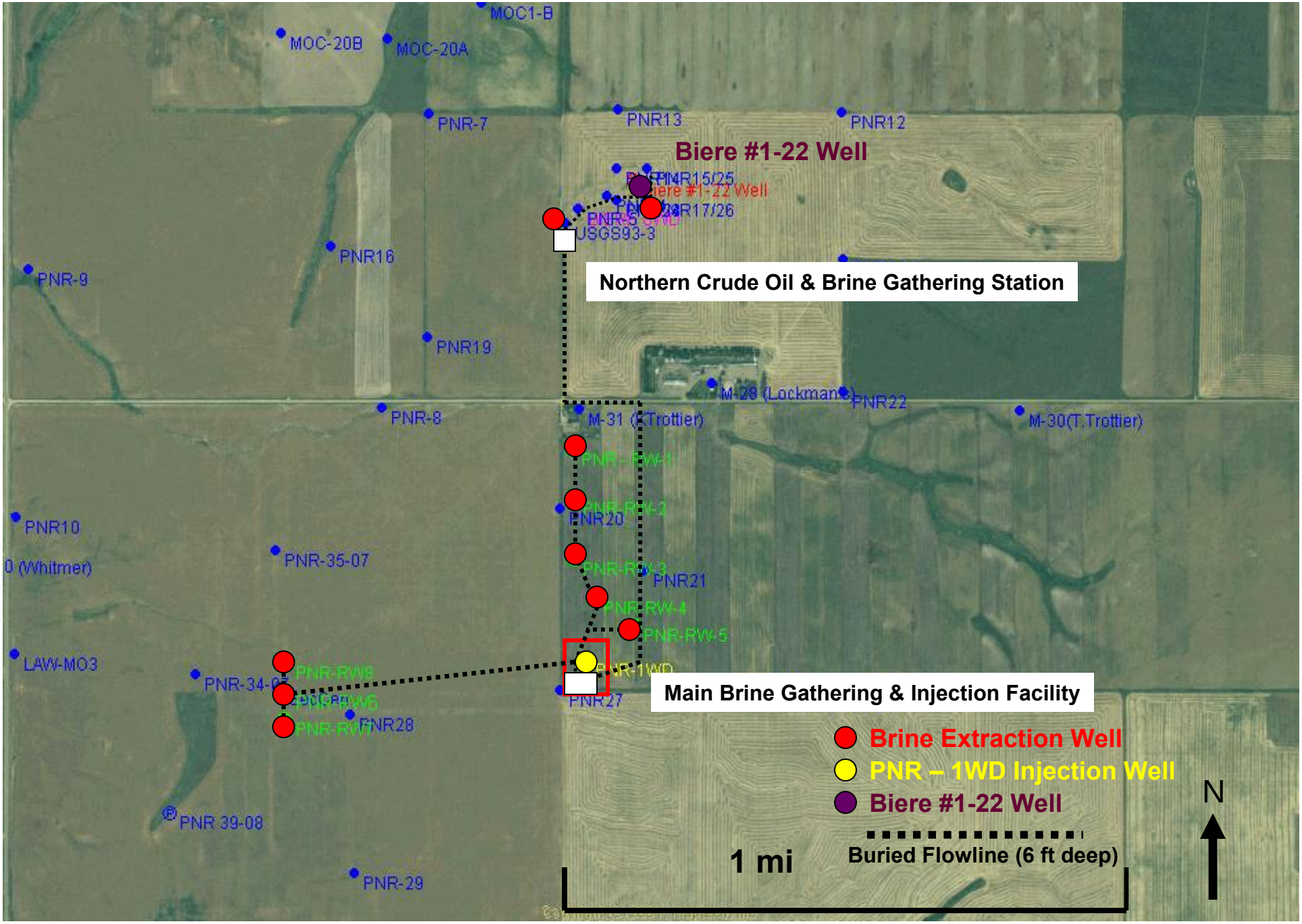
# Roustabout Crew

## (good but very costly!!!!)

Ed Hance – Former Operations Services Manager, Current Manager of Operations - Tunisia

## Recovery Rate ≈ 2.5 bbl/day
## 90 gallons/day

# NORTHERN CRUDE OIL
# AND
# BRINE RECOVERY STATION


MOC1-B
MOC-20B
MOC-20A
PNR-7
PNR13
PNR12
Biere #1-22 Well
PNR15/25
PNR17/26
PNR-5 SWD
USGS93-3
PNR16
PNR-9
Northern Crude Oil & Brine Gathering Station
PNR19
M-28 (Lockman)
PNR22
PNR-8
M-31 (T.Trottier)
M-30(T.Trottier)
PNR-RW-1
PNR-RW-2
PNR20
PNR10
0 (Whitmer)
PNR-35-07
PNR-RW-3
PNR21
PNR-RW-4
PNR-RW-5
LAW-MO3
PNR-RW8
PNR-34-07
PNR-RW6
PNR28
PNR-RW7
PNR-1WD
PNR27
Main Brine Gathering & Injection Facility
Brine Extraction Well
PNR – 1WD Injection Well
Biere #1-22 Well
Buried Flowline (6 ft deep)
1 mi
N
PNR 39-08
PNR-29

# Some Logistics of Biere Aquifer Restoration System

***Flowlines***

>15,000 ft of SDR-7, 2-inch poly flowline
>5,000 ft of SDR-7, 4-inch poly flowline

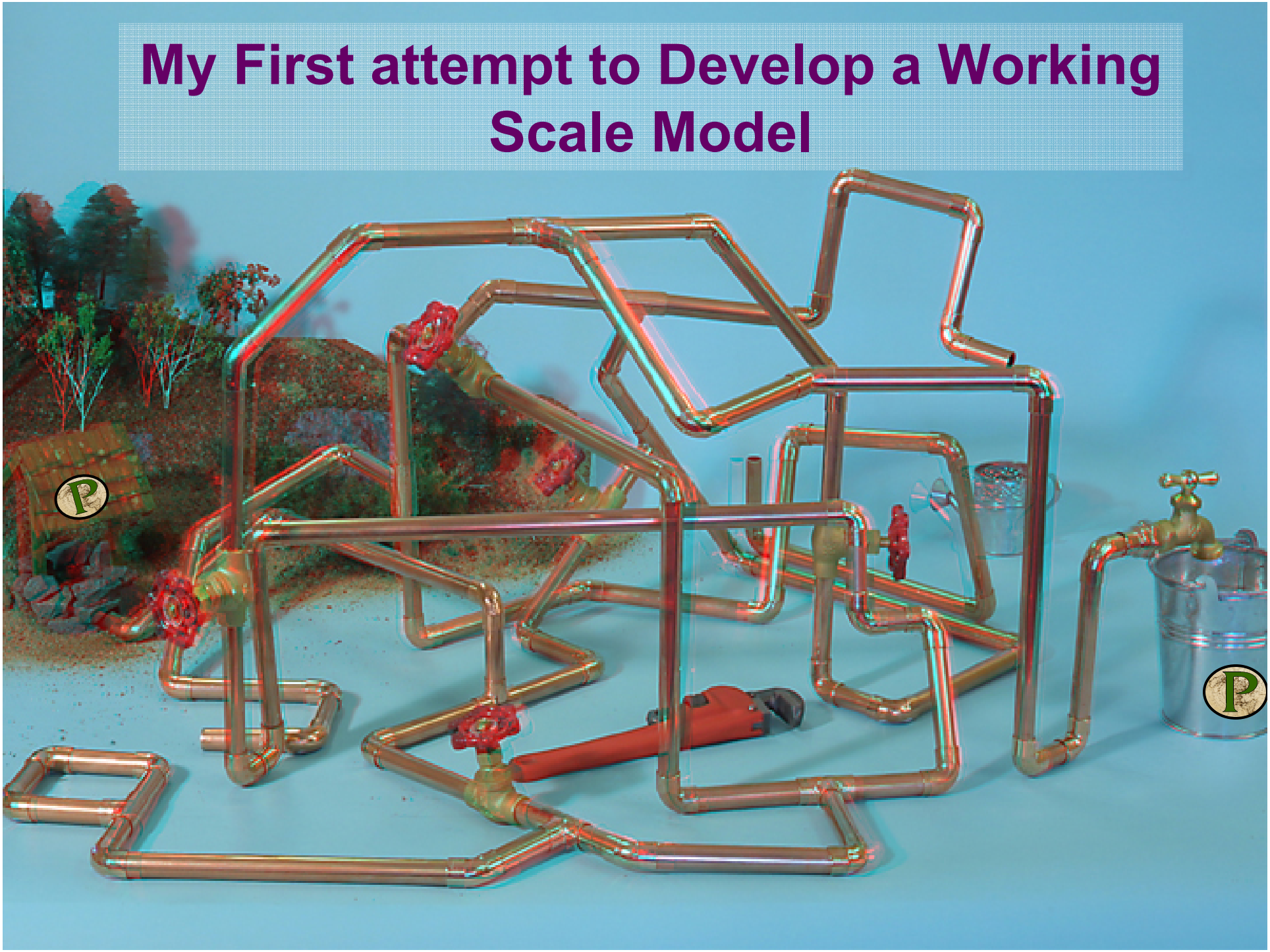
***Main Brine Collection Facility***

1 - 7,500 ft USEPA Class V Injection Well
8 - Brine Extraction Wells (with either a 5hp or a 3/4hp Stainless Steel Grundfos pump)
5 – 500 bbl Brine Storage Tanks
1 - 250 hp Tri-Plex Injection Pump
2 – Electrical Transfer Pumps
Meter Shed with flow meters and conductivity meters

***Northern Crude Oil/Brine Recovery System***

3 – Crude Oil Extraction Wells
2 – Dual Crude/Brine Extraction Wells (1, 5hp Grundfos pump and 1, 3/4hp pump)
2 – Xi-Tech Product Recovery Pumps
2 – 250 bbl Crude and Brine Storage Tanks
1- Electrical Transfer Pump

# My First attempt to Develop a Working Scale Model



# “The Wild Bunch”

# PIONEER'S TRINIDAD COLORADO CREW

# High Level - Planning and D


PNR-1WD – 7,600’ T.D in Devonian Nisku Fm.

# Injection Well - Step Rate Test


RESULTS – WELL CAPABLE OF
14,400 BBLS/DAY @ 2,000 PSI


Brine Recovery Well – "PNR-RW1"
11/26/07


Brine Recovery Well – "PNR-RW2"
11/27/07

Gravels – PNR-RW1

Gravels – PNR-RW2


Brine Storage Tanks
Injection Pump Shed


Injection Pump
Weatherford


PNR-1WD Wellhead

# System Kick off Ceremony

Pioneer Senior Management


PIONEER
Award of Appreciation
Christa Tyrell


PIONEER
NATURAL RESOURCES USA, INC.
PNR MAIN GROUNDWATER RESTORATION COLLECTION FACILITY
TOWNSHIP 28 NORTH, RANGE 51 EAST, P.M.P.
SECTION 27; SW/4 SW/4 NW/4
ROOSEVELT COUNTY, MONTANA
EMERGENCY CONTACT: 719-846-7898
NO SMOKING

# 2008 Recipient

## *United States Department of Interior*

## Environmental Achievement "Team" Award

From left to right: **Mr. Willie Taylor**; Chief of Division of Environment Compliance, DOI; **Ms. Lynne Scarlett**, Deputy Secretary of the DOI; **Ms. Joanna Thamke**, Hydrogeologist, USGS; **Mr. Nathan Wiser**, USEPA, Region 8; **Mr. Mike Jacobs**, Sr. Environmental Specialist, Pioneer Natural Resources; **Mr. Victor Labson**, Acting Chief Geologist, USGS, Washington, D.C.

PIONEER
NATURAL RESOURCES

FT. PECK TRIBES
ASSINIBOINE SIOUX

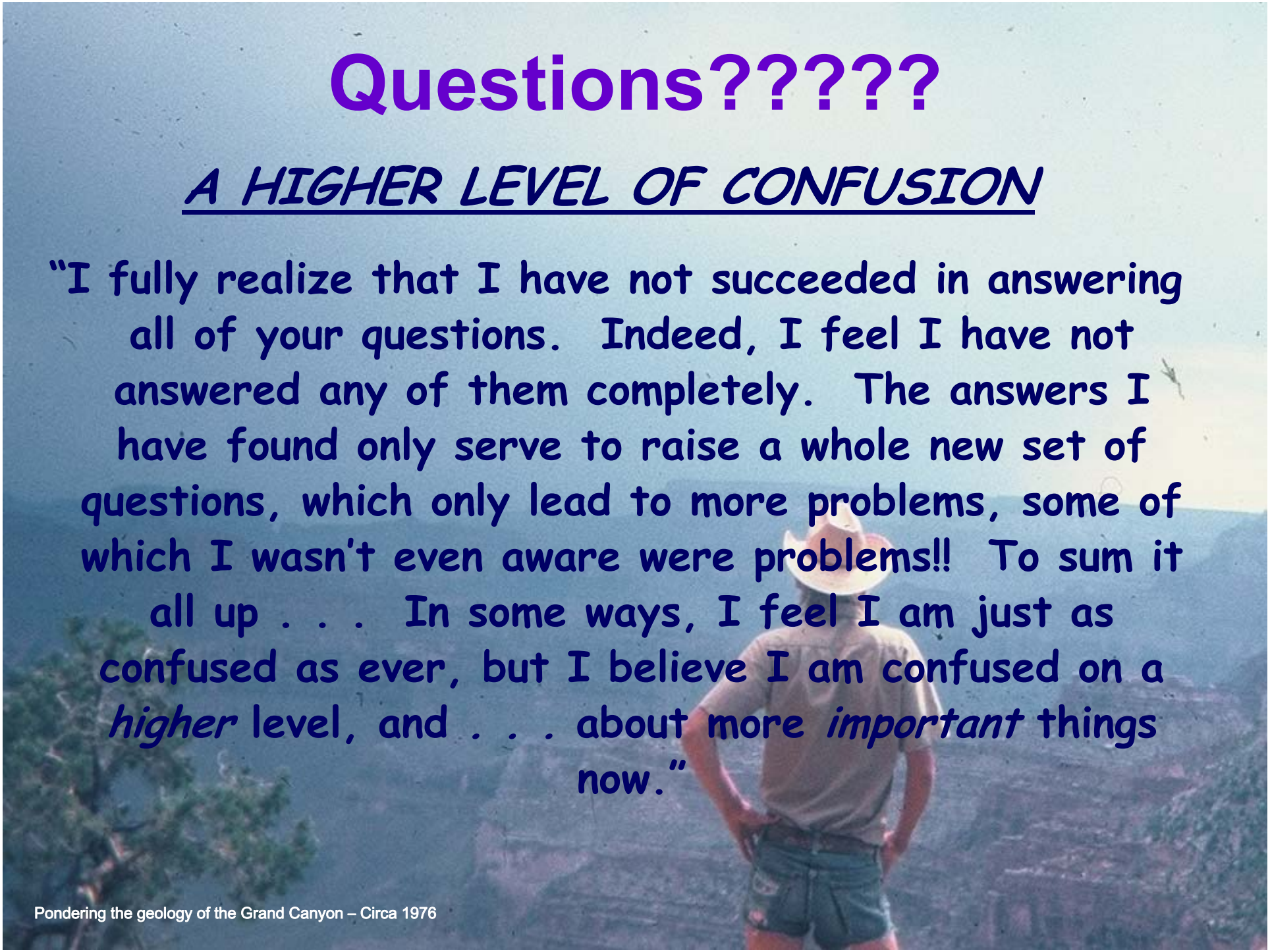
USGS
science for a changing world

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

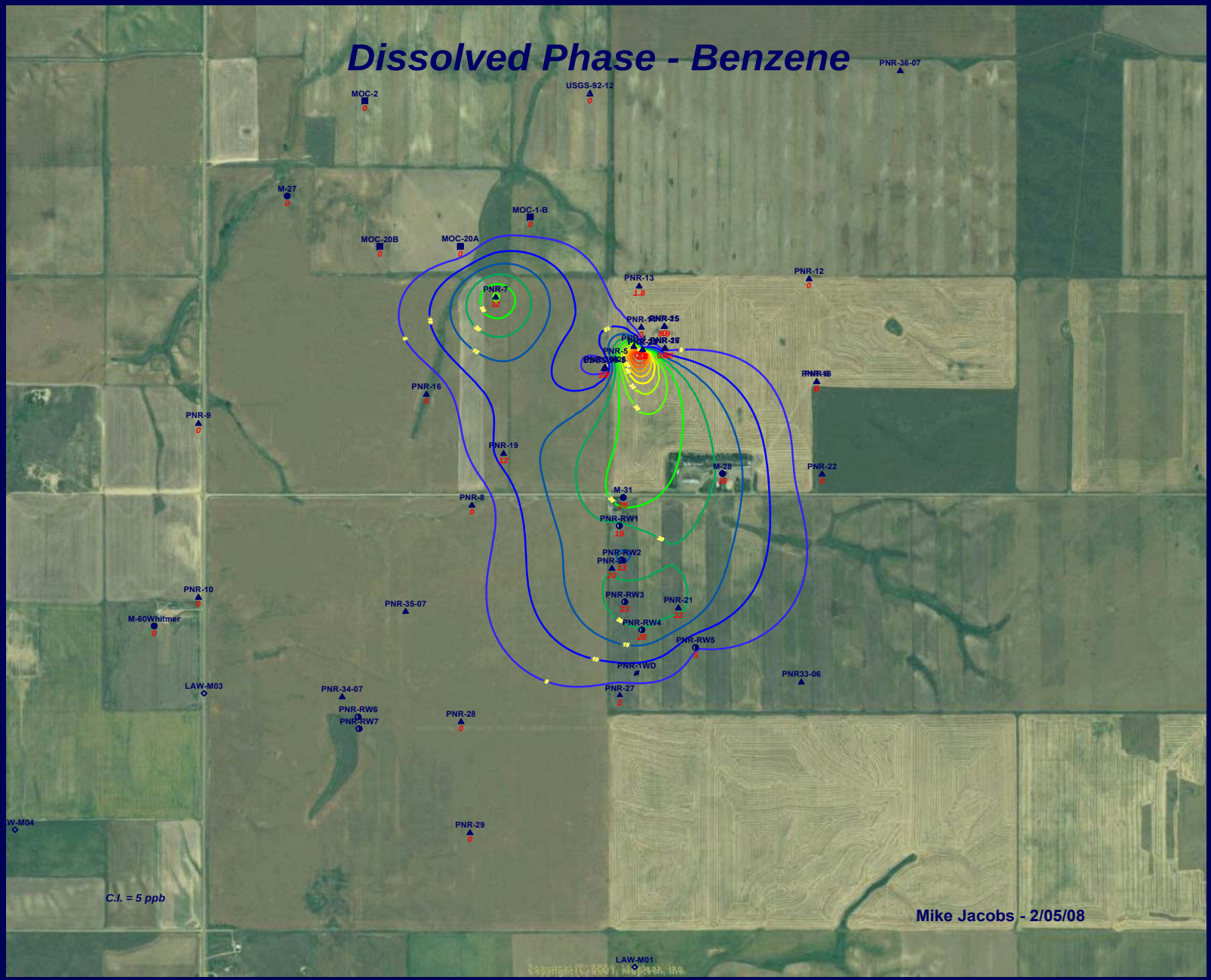
# Questions?????

## *A HIGHER LEVEL OF CONFUSION*

"I fully realize that I have not succeeded in answering all of your questions. Indeed, I feel I have not answered any of them completely. The answers I have found only serve to raise a whole new set of questions, which only lead to more problems, some of which I wasn't even aware were problems!! To sum it all up . . . In some ways, I feel I am just as confused as ever, but I believe I am confused on a *higher* level, and . . . about more *important* things now."



Pondering the geology of the Grand Canyon – Circa 1976


Dissolved Phase - Benzene
PNR-36-07
USGS-92-12
MOC-2
M-27
MOC-1-B
MOC-20B
MOC-20A
PNR-13
PNR-12
PNR-7
PNR-5
PNR-16
PNR-9
PNR-19
M-28
PNR-22
M-31
PNR-8
PNR-RW1
PNR-RW2
PNR-10
PNR-35-07
PNR-RW3
PNR-21
M-60Whitmer
PNR-RW4
PNR-RW5
PNR-1WD
PNR33-06
LAW-M03
PNR-34-07
PNR-27
PNR-RW6
PNR-RW7
PNR-28
PNR-29
C.I. = 5 ppb
Mike Jacobs - 2/05/08
LAW-M01