[PS]Multi-Disciplinary Approach to Site Characterization and Remediation of Contamination from Oilfield Produced Waters, East Poplar Oil Field, Roosevelt County, Montana--Part 2*

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(http://www.searchanddiscovery.net/documents/2009/80040jacobs/ndx_jacobs.pdf)

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Abstract

Previous studies conducted by the United States Geological Survey (USGS) and the Fort Peck Indian Tribes, Office of Environmental Protection indicated that the shallow Quaternary aquifer in this region has been heavily impacted by historical oil and gas operations.

An investigation conducted by Pioneer in late 1999 and early 2000, revealed that a previously plugged and abandoned well, the Mesa Biere #1-22 acquired through acquisition, was leaking outside of the casing at approximately 1000 feet below ground and that brine was channeling upwards into the shallow aquifer approximately 40 feet below the ground surface. The well was plugged in 2000. From 2001-2005 Pioneer conducted further delineation drilling and aqueous geochemical analyses of the area around the Mesa Biere #1-22 well.

Beginning in mid-2006, Pioneer initiated an integrated approach to characterize both the regional setting of the oilfield contamination, including a detailed study of the geological, hydrological, aqueous-geochemical, and geophysical setting of the Biere #1-22 contaminant plume area. The results of the detailed study of the Biere #1-22 plume area revealed that the contaminant plume was located within an isolated, well-defined channel of fine- to coarse-grained gravels of glacio-fluvial origin. Site and aquifer characterization studies were conducted with numerous pump and slug tests. The data was input into a 3-D groundwater model, and plume-capture scenarios utilizing different recovery well placements and pumping rates were run to evaluate the feasibility of undertaking remedial actions of the Biere #1-22 plume.

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Pioneer proactively and voluntarily committed more than $6 million to design and build a plume-capture and remediation system. The system consists ten “brine”, groundwater removal wells, five crude oil recovery wells, and Pioneer drilled a deep 7800-foot, USEPA Class V, injection well into the Mississippian, Mission Canyon, and Devonian, Nisku formations. The brine-remediation system became operational in August, 2008. The designed system will remove the most contaminated portion of the plume at a rate of approximately 250,000 gallons per day and will significantly reduce any potential threat to the City of Poplar.

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Introduction

Previous studies conducted by the United States Geological Survey (USGS) and the Fort Peck Indian Tribes, Office of Environmental Protection indicated that the shallow Quaternary aquifers in this region have been heavily impacted by historical oil and gas operations. These Quaternary aquifers are the primary and sole source of groundwater for the residents of the area.

In 1999 Pioneer Natural Resources was notified that a plugged and abandoned well, the Mesa Biere #1-22 (now Pioneer), operated by Mesa Petroleum and plugged in 1986, appeared to have been improperly plugged and had released chloride-rich oilfield brine into the shallow aquifer.

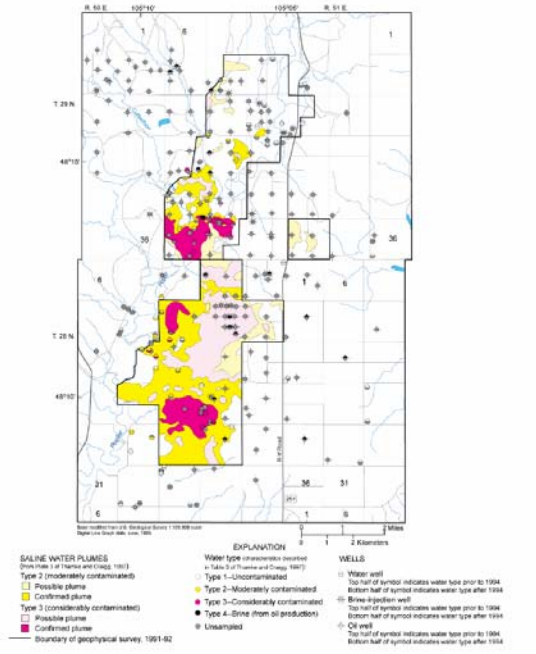

Figure 1. Interpretation of the regional saline water pollution in the East Poplar oil field study from surface geophysical electromagnetic (EM-34) surveys area 1991-1992 (Thamke and Craigg, 1997)

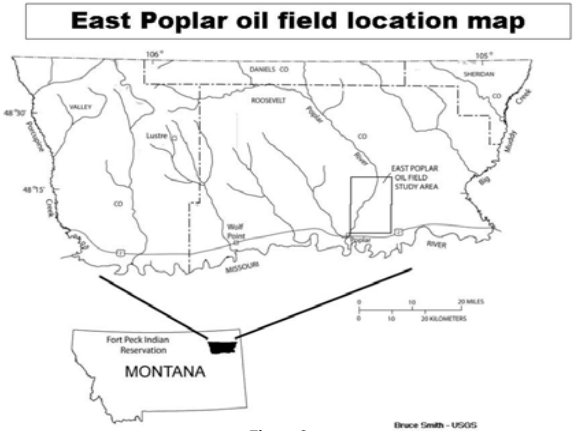

Figure 2

An investigation conducted by Pioneer Natural Resources (PNR) in late 1999 and early 2000, revealed that the Biere #1-22 wellbore was still leaking outside of the casing in the Cretaceous, Judith River Formation at approximately 1000 feet below ground and that brine, and some crude oil, was channeling upwards into the shallow aquifer approximately 40 feet below the ground surface. PNR successfully plugged the well in 2000. From 2001-2005 Pioneer conducted delineation studies of the contamination from the Biere #1-22 well with monitor well drilling and aqueous geochemical analyses of the groundwater around the Mesa Biere #1-22 well. In 2006, PNR began a detailed study of the geological, geophysical, geochemical, and hydrological setting of the regional and Biere #1-22 areas. Below is an outline describing the major work done during this study.

Development of Site-Specific Geological, Geophysical & Hydrological Conceptual Model

- Detailed Regional & Site Specific Geological, Hydrogeological, Geochemical and Geophysical Surveying and Mapping
  - Structure Maps
  - X-Sections
  - Isopach Maps
  - Constituent Isopleth Plume Maps
  - Construction and standardization of lithological & well completion logs
  - Downhole geophysical surveys in selected wellbores
  - Surface geophysical electro-magnetic (EM-34) survey

Aquifer Testing & Aquifer Characterization

- Drilling of four additional wells (three 5" pumping wells and one observation well
- Conducted Three Aquifer Tests
  - Test #1 - Gravels in Main Biere #1-22 Plume Area
  - Test #2 - Downgradient Gravel Channel Area
  - Test #3 - Upgradient Gravel Channel
- Conducted 16 Slug Tests

Groundwater Flow and Contaminant Transport Model

- Build Model - input geological, hydrogeological, hydraulic head data, pump & slug test data, initial head data and well completion data
- Perform Capture Zone Analysis
- Perform Total Pumping Rate Analysis
- Determine Location of Pumping Wells & Number of Wells Needed

Quaternary Geology of Area Aquifers

As shown in Figure 3, below, 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 1) early to middle Pleistocene pre-glacial and interglacial 2) middle to late Pleistocene glacial outwash, 3) late Pleistocene ice-contact deposits, 4) Holocene, post-glacial alluvium and 5) Holocene alluvium-colluvium.

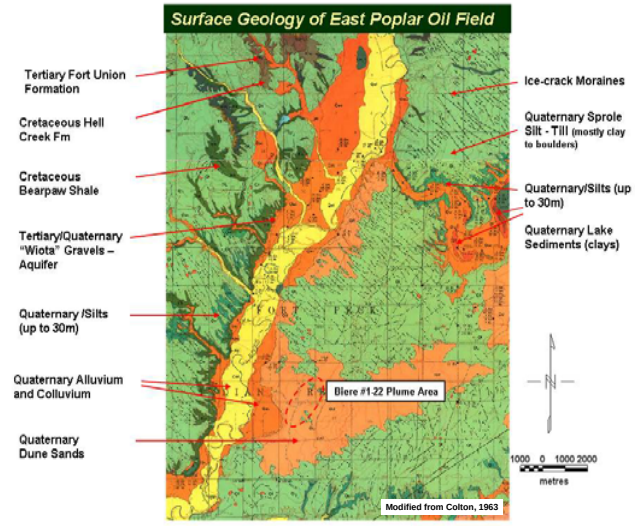

Figure 3 Surface Geology of the East Poplar Oil Field Area

In the area there have been at least two major advances of Pleistocene continental ice-sheets. It is difficult to unravel the entire glacial history as younger glaciations tend to obscure the evidence of older glaciation. The youngest advances occurred during the Illinoin age, 130-200 ka, and during the Wisconsin, 12-110 ka. The Illinoin glaciation was more extensive and covered most of the area under a thick ice-sheet, whereas the Wisconsin ice sheet advanced from the northeast and traveled southwest to about the position occupied by the current Missouri River channel, just a few miles to the south of the city of Poplar. This ice sheet advanced up the Missouri River valley with a smaller lobe pushing up into the Poplar River valley.

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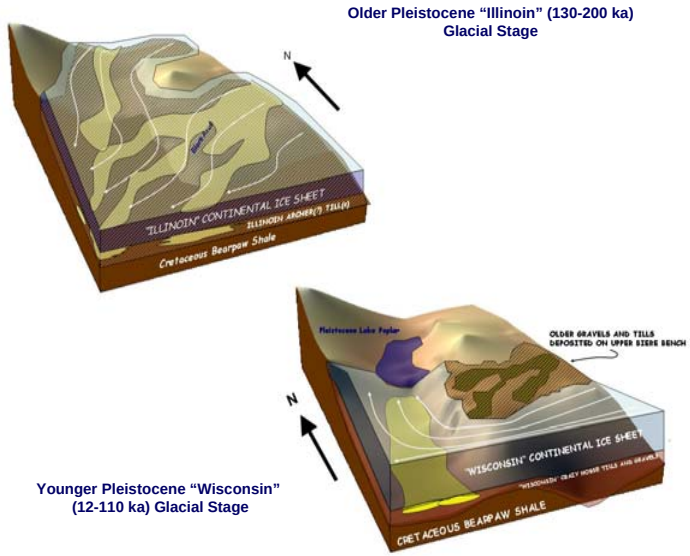
Figure 4, below, is an illustration showing the complex nature of the various depositional environments of the aquifers. Aquifers occur in thick gravel and sand outwash channels, subglacial flow channels on benches and terraces, as well as thick pre-glacial and post-glacial gravels and sands in the alluvial valleys. Dramatic differences in water level elevations from east to west across the area indicate that the older, upper bench "Biere Aquifer", east of the Poplar River Valley, is distinct with no apparent hydraulic connection to aquifers in the Poplar River Valley. The hydrogeological characteristics of the separate aquifers vary.

The aquifers vary in thickness and range from 10 to 30 feet on the upper benches, such as in the Biere #1-22 area, to over 40 feet thick in the Poplar River alluvial valley. In the Missouri River Valley the aquifer may be over 350 feet thick.

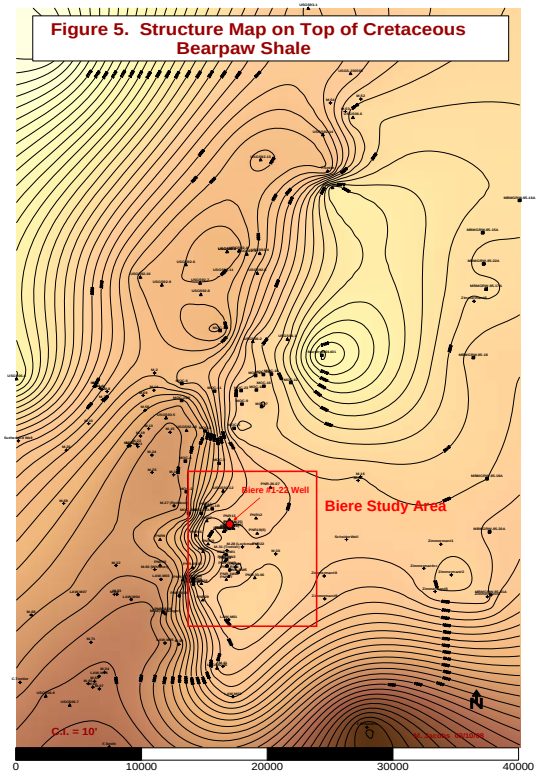
Figure 4. Illustrated Pleistocene History of the Study Area



Regional Geological Setting and Groundwater Contaminant Distribution

Over 160 private oil company, USGS, and Montana Bureau of Mines monitor wells as well as many private water wells were used to construct structure maps, isopach, geochemical isopleth maps, and cross-sections. Figure 6, shows the regional bedrock elevation of the Bearpaw Shale which in this area represents the base of most of the aquifers. The Bearpaw Shale is a highly impermeable formation, over 900 feet thick in this area.

The steep dip in the bedrock from the Biere area westward to the Poplar River Valley is interpreted to be due to deep scouring of the bedrock by glaciers during Wisconsin time. This scouring is interpreted to have truncated the older "Biere" channel gravels in this area (Figure 4) separating the Biere aquifer from younger Poplar River alluvial aquifers to the west. Separation of the aquifers is demonstrated on the East-West cross section, Figure 6, and the aquifer thickness isopach map (Figure 7). The isopach map shows thick gravels and sands occupying bedrock lows and shows the correlation of the contaminant plumes occupying and preferentially traveling along these gravel and sand channels.



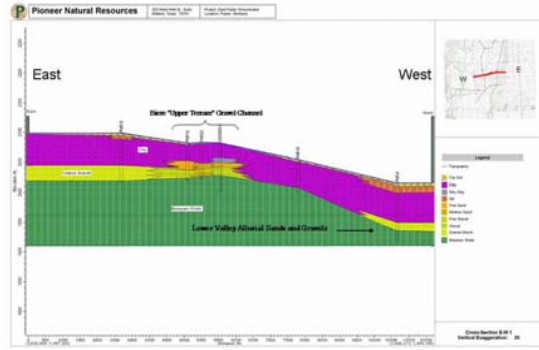
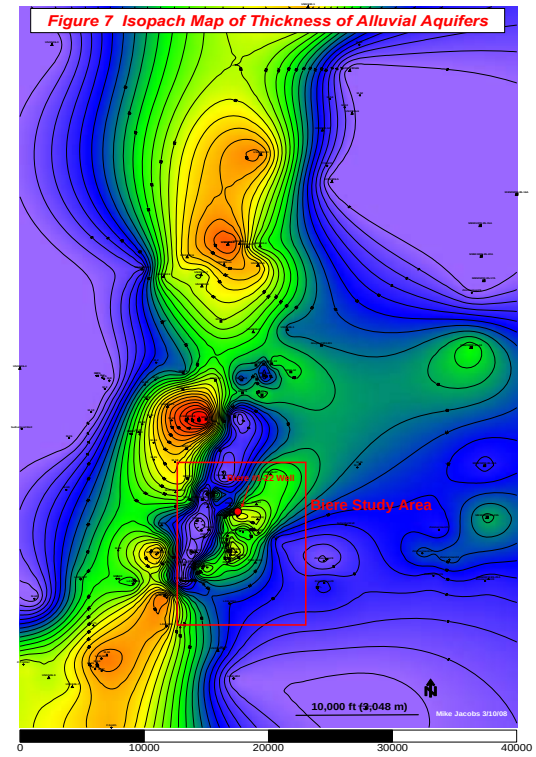
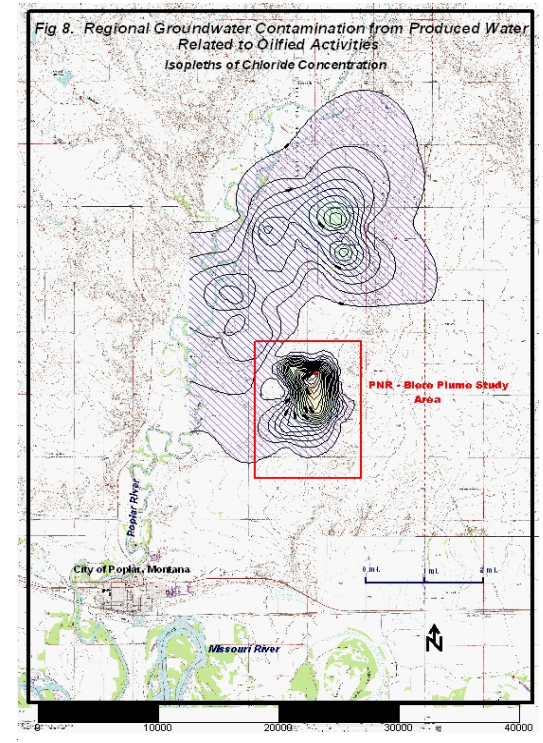


Figure 6. East-West X-Section across Biere "Upper Bench" Gravel Channel and Lower Alluvial Aquifer





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Local Geological Controls on the Biere Contaminant Plume

The "Biere" channel is separated geologically and hydraulically, both laterally and vertically, from the other contaminant plumes in the region by very dense, compact, "fat" glacial till clays and silts. Shown in Figure 9, the "Biere" gravel channel exhibits a very high hydraulic conductivity (K) values, >250 ft/day. The dense, compact, "fat" clays and silts (glaciolacusrine) of glacial till exhibit very low corresponding hydraulic conductivity (K) values ranging from .004 to 6.6 ft/day. As might be expected, the more porous gravel and sand channels are acting as preferential pathways for contaminant flow controlling both the direction of contaminant flow as well as total flow rate of the system. Groundwater velocity estimates within the channel are around 2-2.5 ft/day.

Photo #1 - Loose, coarse glaciofluvial gravels within the "Biere" Channel

Photo #2 - "Fat" clay of overlying and inter-channel glacial till material

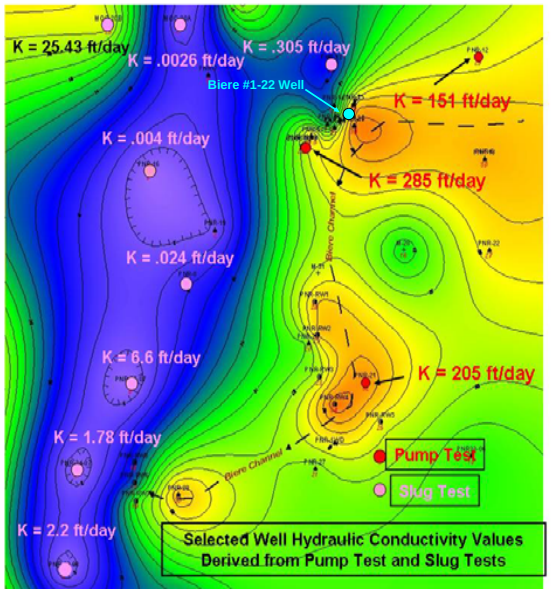

Figure 9. Isopach map of thickness of "Biere Channel" gravels showing hydraulic conductivity values of gravels and adjacent "fat" clays and silts

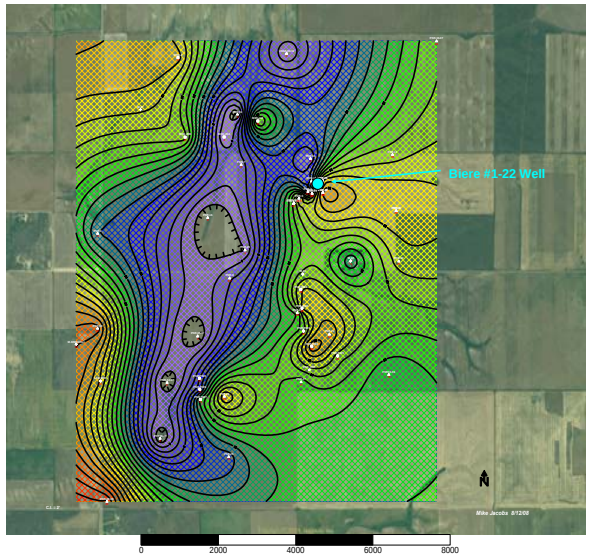

Figure 10. Aerial view with overlay of Isopach map of thickness of "Biere Channel" gravels and adjacent "fat" clays and silts

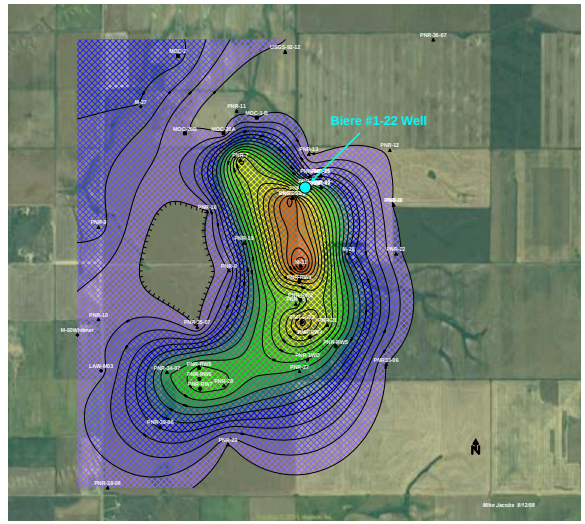

Figure 12. Aerial view with overlay of isopleth map of Chloride Concentration – mg/L

Biere #1-22 Brine Contaminant Plume

The following maps show the areal extent of the brine plume. Below are some estimates of plume area and volume.

- *Areal extent of Plume >10,000 mg/L Chlorides ≈ 1,76 km²*
- *Average Aquifer Thickness ≈ 5.8 meters (19 feet)*
- *Average Porosity ≈ 25%*
- *Estimated Groundwater Velocity within Biere Channel ≈ .6- .72 m/day (2-2.5 ft/day*
- *One Pore Volume ≈ 2,021 Acre Feet Water; 2.5 MM m³ (659 MM/Gallons/15.7 MM/bbls)*

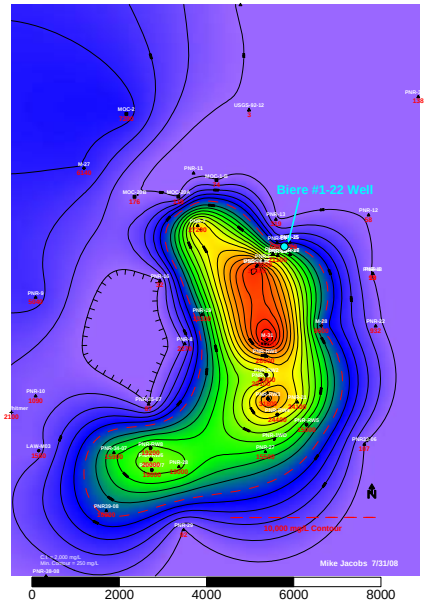

Figure 11. Isopleth map of Chloride Concentration – mg/L

Depth to groundwater in the Biere Plume averages around 30 below ground surface. The water analyses in Chart 1, below, are representative of the geochemistry of groundwater in selected monitor wells adjacent to the Biere #1-22 well and in background water wells outside the impacted area in 2001. Note that groundwater temperatures in the immediate area around the Biere well were as high as 75°C (167°F). Ambient groundwater temperatures are around 9.7°C (49°F).

Well Name	pH	Ca	Mg	Cl	SO^4	Na	TDS	SC mS @ 25 C	HCO_3	T° (C)
PNR-17	7.4	1,440	449	42,500	1,520	22,900	68,800	65.4	269	75
Background	739	318	218	74	1,890	400	3,500	4	439	9.7

Chart 1. Representative Groundwater Geochemistry - 2001

Geophysical Studies of Brine Contamination

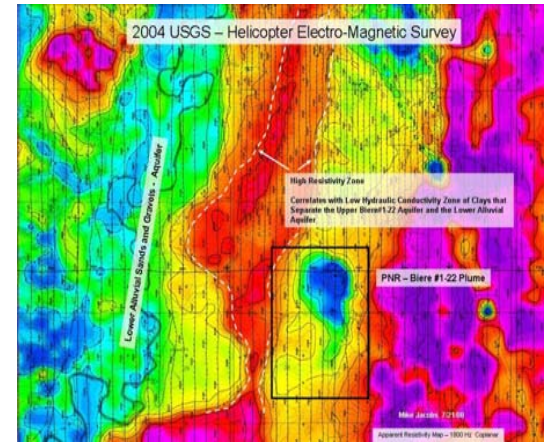

Figure 13. 1800 Hz Apparent Resistivity map of Biere Area – 2004 USGS Helicopter EM Survey

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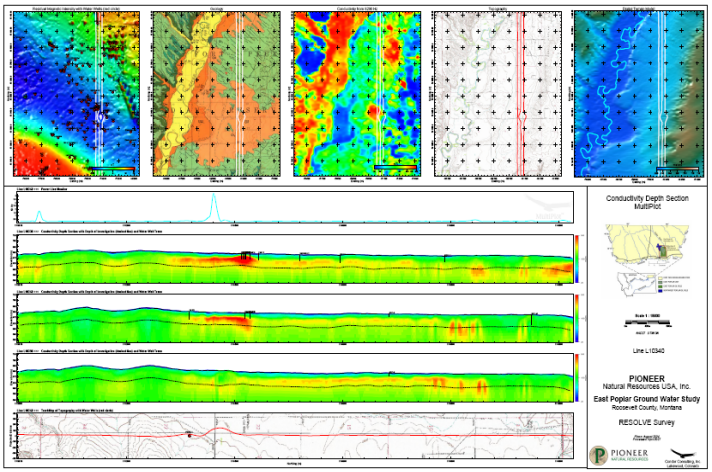

Figure 14. Conductivity X-Sections generated from 2004 EM USGS Data

Surface EM-34 Geophysical Survey of Biere Plume

In order to obtain a more detailed geophysical picture of the Biere Plume, PNR conducted a detailed electromagnetic, EM-34 survey over the plume area. The survey indicates that from the Biere #1-22 area the plume traveled westerly until it reached the low conductivity-low flow barrier (clays) and then turned south-southeasterly following the Biere gravel channel to a point where it again turns to the west where is terminates.

Periodic surveys are planned during remediation to determine the spatial and temporal changes in the plume and therefore maximize plume recovery efficiency .

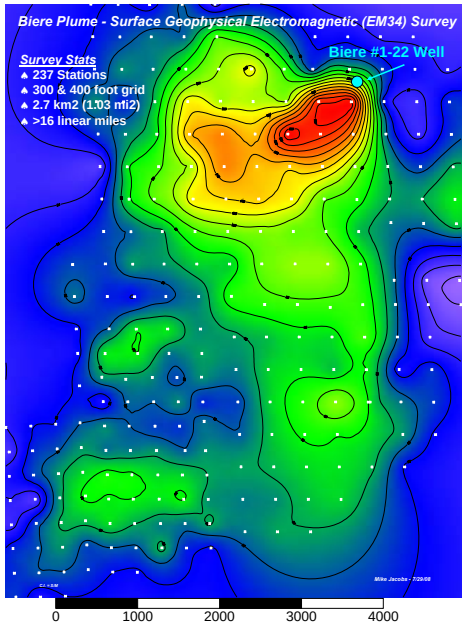

Figure 15. Interpretation of Biere Plume EM-34 Conductivity Survey

Remediation Design & Construction

The remediation design in Figure 17 is based on this study and 3-D groundwater modeling of the contaminant plume. The map below shows the results of a plume capture analyses based on the flow rates in box to the left.

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
Total in bbls/day	4731

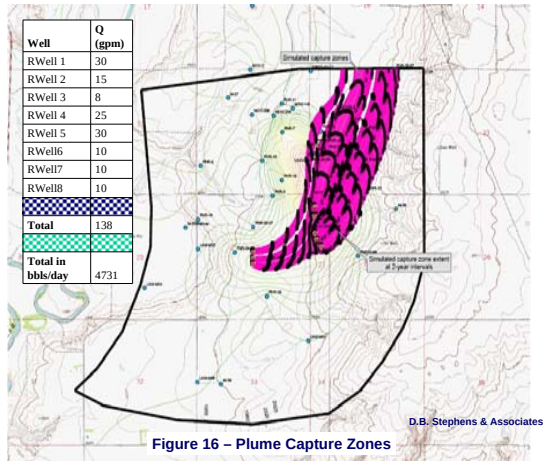

Figure 16 – Plume Capture Zones

The Diagram below shows the layout of the groundwater restoration facilities, flow lines and recovery well locations.

Figure 17

The remediation system consists of a newly drilled $1.7MM, 7600 foot Brine Disposal Well (Photo 3), ten brine-groundwater recovery wells and five crude oil recovery wells (Photo 4). The disposal well is completed in the Devonian Nisku Formation and the Mississippian Mission Canyon Formation from 6000 feet to 7600 feet. The well is designed to dispose of 6000 bbls/day (252,000 gal/day) of contaminated groundwater.

Photo 3

Photo 4

Photos 5-8, below, show some of the remediation design features. These are one of ten brine recovery wells (5), brine storage tanks (6), brine injection pump (7), PNR-1WD injection wellhead (8).

Photo 5

Photo 6

Photo 7

Photo 8

Given the volume of the contaminant plume along with the removal and disposal rates, it is anticipated to take approximately 15 to 20 years to reach a point where the system is reduced to minimal protective pumping or turned off.

Summary and Conclusions

Beginning in mid-2006, Pioneer initiated an integrated approach to characterize both the regional setting of the oilfield contamination, including a detailed study of the geological, hydrological, aqueous-geochemical, and geophysical setting of the Biere #1-22 contaminant plume area. Results of the detailed study of the Biere #1-22 plume area revealed that the contaminant plume was located within an isolated, well-defined channel of fine to coarse-grained gravels of glacio-fluvial origin. Based upon the positive results of the geological study and groundwater modeling, Pioneer began an aggressive remediation program installing five crude oil recovery wells, ten groundwater removal wells, and drilled a deep injection well capable of disposing of 6000 bbl/day of contaminated groundwater into the Mississippian, Mission Canyon, and Devonian, Nisku Formations. This system was turned on August 19, 2008 and has begun remediation and groundwater restoration of the aquifer.

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