Prepared in cooperation with the Office of Environmental Protection of the Fort Peck Tribes

Borehole Geophysical Data for the East Poplar Oil Field Area, Fort Peck Indian Reservation, Northeastern Montana, 1993, 2004, and 2005

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Conversion Factors

SI to Inch/Pound

Multiply	By	To obtain
meter (m)	3.281	foot (ft)
centimeter (cm)	0.3937	inch (in)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:
°F=(1.8×°C)+32
Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:
°C=(°F–32)/1.8
Vertical coordinate information is referenced to the North American Vertical Datum of 1927 (NAD 27).
Horizontal coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29).
Altitude, as used in this report, refers to distance above the vertical datum.
*Transmissivity: The standard unit for transmissivity is cubic foot per day per square foot times foot of aquifer thickness [$(ft^3/d)/ft^2$]ft. In this report, the mathematically reduced form, foot squared per day (ft^2/d), is used for convenience. Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25°C). Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

Acronyms and Initialisms

FPOEP	Fort Peck Assiniboine and Sioux Tribes Office of Environmental Protection
LAS	Log ASCII Standard
LAW	Land and Water Consulting, Inc.
MOC	Murphy Oil Company
PNR	Pioneer Natural Resources USA, Inc.
USGS	U.S. Geological Survey

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By Bruce D. Smith,[1] Joanna N. Thamke,[2] and Christa Tyrrell[3]

Abstract

Areas of high electrical conductivity in shallow aquifers in the East Poplar oil field area were delineated by the U.S. Geological Survey (USGS), in cooperation with the Fort Peck Assiniboine and Sioux Tribes, in order to interpret areas of saline-water contamination. Ground, airborne, and borehole geophysical data were collected in the East Poplar oil field area from 1992 through 2005 as part of this delineation. This report presents borehole geophysical data for thirty-two wells that were collected during 1993, 2004 and 2005 in the East Poplar oil field study area. Natural-gamma and induction instruments were used to provide information about the lithology and conductivity of the soil, rock, and water matrix adjacent to and within the wells. The well logs were also collected to provide subsurface controls for interpretation of a helicopter electromagnetic survey flown over most of the East Poplar oil field in 2004. The objective of the USGS studies was to improve understanding of aquifer hydrogeology particularly in regard to variations in water quality.

Introduction

The East Poplar oil field study area includes the city of Poplar, the East Poplar oil field, and most of the Northwest Poplar oil field (fig. 1). The Poplar River flows generally southward through the study area. Throughout most of the study area, shallow Quaternary deposits (up to 30 m thick) that directly overlie the relatively thick (about 300 m) Upper Cretaceous Bearpaw Shale are the sole developed source of groundwater for local residents. Land uses in the study area include dry-land farming, livestock ranching, oil production, and residential development. Thamke and Craigg (1997) summarized previous investigations on geologic structure, stratigraphy, and hydrogeology in the East Poplar oil field study area.

Studies conducted by the U.S. Geological Survey (USGS) and the Fort Peck Assiniboine and Sioux Tribes of the Fort Peck Indian Reservation began in 1976 and have focused on the assessment and mapping of groundwater resources. Results of these studies have demonstrated that groundwater quality has been adversely affected by various land-use practices in some areas of the Reservation (Thamke and Midtlyng, 2003). Groundwater plumes of saline water were identified by

[1] U.S. Geological Survey, Denver, Colorado
[2] U.S. Geological Survey, Helena, Montana
[3] Office of Environmental Protection of the Fort Peck Tribes, Poplar, Montana; currently Geosyntec Consultants, Seattle, Washington

Thamke and Craigg (1997) based on water-well sampling, ground geophysical surveys, and borehole logs. The sources of these plumes are related to oil production from the East Poplar oil field (Thamke and Midtlyng, 2003).

In August of 2004, a helicopter electromagnetic survey was conducted over the oil field in order to better define possible subsurface plumes (Smith and others, 2006a,b). Electrical induction conductivity and natural-gamma logging was done during 1993, 2004, and 2005 on selected boreholes to aid in interpretation of the airborne geophysical survey and to characterize electrical parameters of the lithology and groundwater. Water-quality samples were collected from wells during 2003 to 2005 to correlate geophysical measurements with the chemical composition of water from shallow aquifers.

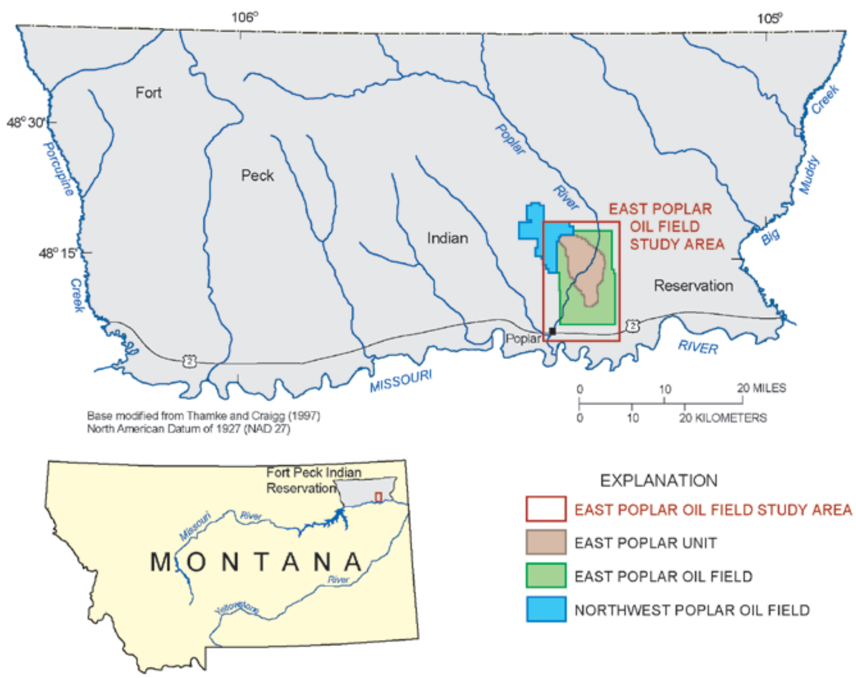

Figure 1. Location of the study area.

Purpose and Scope

This report presents borehole geophysical data that were collected by the USGS and Fort Peck Assiniboine and Sioux Tribes Office of Environmental Protection (FPOEP) during 1993, 2004, and 2005 in the East Poplar oil field study area (fig. 1). Natural-gamma and induction logging measurements were used to provide information about the lithology and conductivity of the soil, rock, and water matrix adjacent to and within the wells. Thirty-two wells were selected throughout the study area to tie-in the vertical conductivity and lithology of the earth at these sites (table 1). Information from the digital logs has been used in interpretation of an airborne electromagnetic survey of the study area (Smith and others, 2006a,b).

Site-Identification and Well-Naming Systems

Site numbers are used to identify wells in the same manner as used in previous investigations (Thamke and Midtlyng, 2003; Thamke and Craigg, 1997; Thamke and others, 1996; Levings, 1984). Site numbers are based on the rectangular Public Land Survey System (fig. 2). The number consists of as many as 14 characters and is assigned according to the location of a site within a given township, range, and section. The first three characters specify the township and its position north (N.) of the Montana Base Line, whereas the next three characters specify the range and its position east (E.) of the Montana Principal Meridian. The next two characters indicate the section; the next four characters indicate the position of the site within the section. The first letter denotes the quarter section (160-acre tract), the second letter denotes the quarter-quarter section (40-acre tract), the third letter denotes the quarter-quarter-quarter section (10-acre tract), and the fourth letter denotes the quarter-quarter-quarter-quarter section (2.5-acre tract). These lettered subdivisions of the section are indicated as A, B, C, and D in a counter-clockwise direction beginning in the northeast quadrant. The last two characters form a sequence number based on the order that a site was located in that tract. For example, site number 28N51E22CBAC02 represents the second well identified in the SW¼ of the NE¼ of the NW¼ of the SW¼ in sec. 22, T. 28 N., R. 51 E.

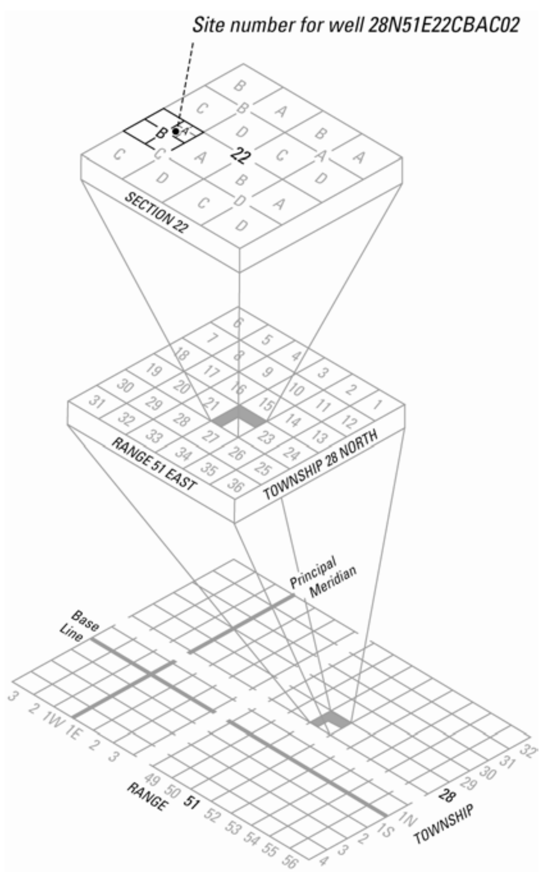

Figure 2. Diagram showing site-numbering system.

Wells are also identified by an alpha-numeric well name allowing for ease of cross reference between wells plotted on the illustrations and tables in this report and on illustrations and tables in numerous previous reports by the USGS and other agencies. The well name consists of as many as four alpha characters and four numeric characters. The alpha characters denote the well type: “LAW”—monitoring well installed for Land and Water Consulting, Inc.; “MOC”’—monitoring well installed for Murphy Oil Company; “PNR”—monitoring well installed for Pioneer Natural Resources USA, Inc.; “USGS”—monitoring well installed by the USGS. The first two numeric characters for USGS monitoring wells denote the year that the well was drilled. The last two numeric characters for USGS monitoring wells denote the sequence that the wells were drilled each year.

Borehole-Geophysical Data

Thirty-two wells, selected by the USGS and FPOEP, were logged using electromagnetic induction and natural-gamma (fig. 3 and table 1) geophysical methods. Pertinent information for wells such as site name, well name, location, altitude, total depth, and casing/well construction was obtained from previous investigations (Thamke and others, 1996; CH2M Hill, 2000; HKM Engineering, Inc., 2001; Land and Water Consulting, Inc., 2003; Jane Holzer, Montana Salinity Control Association, written commun., 2003; Montana Bureau of Mines and Geology, 2004). All wells were completed with polyvinylchloride (PVC) casing and various lengths of PVC screen.

The combination of induction and natural-gamma logs provide estimates of physical properties (electrical conductivity and gamma activity) of the earth. These geophysical logs can be used in interpretation of the presence of electrically conductive pore fluids indicative of brine contamination. (In the following discussion the term conductivity, or conductive, is used for electrical conductivity unless otherwise described.) High conductivity is associated with high total dissolved solids found in areas of contamination. The combination of gamma and conductivity logs provides information to distinguish high conductivity due to silt and clay, which has a high gamma signature, from conductive pore fluid. The gamma log measures the natural-gamma activity of sediments, differentiating relatively clay-free, quartz-rich sands and gravels (low gamma count) from clay-rich till and shale (high gamma count) lithologies. The induction log measures bulk formation conductivity, which is a function of both the electrical conductivity of the sediment grains and of the pore water filling interstices between grains. This response is usually modeled (Keys, 1990) as conduction along two parallel current paths, so that the measured conductivity of the formation is given as the sum of the conductivity along the mineral-grain and pore-fluid “circuits.” Therefore, the induction log alone cannot be used to infer the presence of saline fluid in the formation, because formation conductivity can indicate the presence of saline pore water, electrically conductive clays, or some combination of the two. Even if anomalously high formation conductivities can be unambiguously attributed to saline pore water saturating an otherwise nonconductive mineral matrix, other information about formation properties, such as lithologic logs, is needed to relate the measured formation electrical conductivity to the pore-water conductivity.

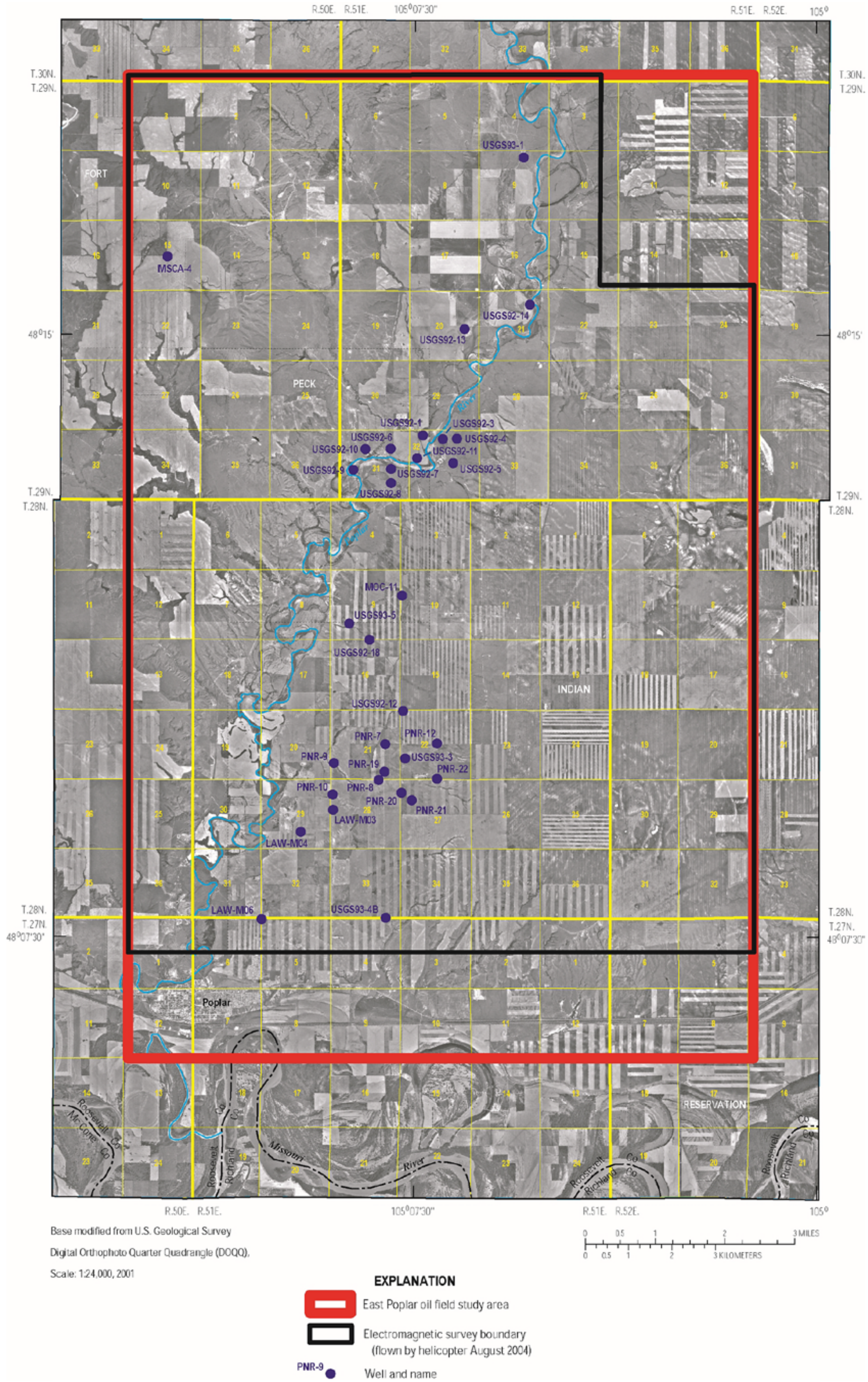

Figure 3. Index map showing locations and names of groundwater wells described in this report.

Table 1. List of well names and dates logged with induction and gamma methods by the U.S. Geological Survey in the East Poplar oil field area, 1993, 2004, and 2005; additional well information is given in table 1-1 in appendix 1.

[MOC, monitoring well installed for Murphy Oil Company; PNR, monitoring well installed for Pioneer Natural Resources USA, Inc.; USGS, monitoring well installed by the U.S. Geological Survey; LAW, monitoring well installed for Land and Water Consulting, Inc.]

1.	Well MOC-11, August 14, 2004
2.	Well USGS93-5, August 7, 2004
3.	Well USGS92-18, September 8, 1993
4.	Well PNR-9, August 13, 2004
5.	Well PNR-7, September 29, 2005
6.	Well PNR-19, September 28, 2005
7.	Well PNR-12, September 28, 2005
8.	Well USGS92-12, September 8, 1993, and August 7, 2004
9.	Well USGS93-3, September 8, 1993, and August 7, 2004
10.	Well PNR-22, August 13, 2004
11.	Well PNR-21, September 29, 2005
12.	Well PNR-20, September 28, 2005
13.	Well PNR-8, August 13, 2004
14.	Well PNR-10, September 28, 2005
15.	Well LAW-M03, September 29, 2005
16.	Well LAW-M04, September 29, 2005
17.	Well LAW-M06, September 29, 2005
18.	Well USGS93-4B, September 8, 1993
19.	Well MSCA-4, August 8, 2004
20.	Well USGS93-1, September 9, 1993, and August 11, 2004
21.	Well USGS92-13, August 12, 2004
22.	Well USGS92-14, August 8, 2004
23.	Well USGS92-6, September 9, 1993, and August 11, 2004
24.	Well USGS92-10, September 9, 1993, and August 11, 2004
25.	Well USGS92-9, September 9, 1993, and August 11, 2004
26.	Well USGS92-7, September 9, 1993, and August 11, 2004
27.	Well USGS92-8, September 9, 1993, and August 11, 2004
28.	Well USGS92-4, August 11, 2004
29.	Well USGS92-5, August 11, 2004
30.	Well USGS92-3, September 9, 1993
31.	Well USGS92-1, September 9, 1993, and August 11, 2004
32.	Well USGS92-11, August 11, 2004

Collection Methods

Electromagnetic induction and natural gamma probes were used to log boreholes and interfaced to surface instrumentation through a 0.626-cm (0.25-in) diameter two-conductor wireline log acquisition system. The induction probe was calibrated before logging each borehole using manufacturer's recommended procedures (Geonics Limited, 1992) at temperatures within the range expected in the boreholes. To attain a stable temperature, the probe was suspended in a well for at least 15 minutes prior to calibration and logging while the logging system was being setup. A two-point calibration process was used where the probe was calibrated to a (1) zero-conductivity environment (held above the earth) and (2) calibration coil of known conductivity with the bottom of the probe at least 2.7 m (9 ft) above the ground. The calibration values also were checked periodically in a zero-conductivity environment between full calibrations at borehole logging sites. Any changes in calibration factors were input into the acquisition system prior to logging.

Logs were recorded digitally while moving the probe in downward and upward directions. Only the upward direction logs were processed because slack in the wireline was eliminated, which aided in maintaining proper depth control (fig. 4). Probes were depth referenced to the top of casing during acquisition. Logging speed did not exceed 3.2 m (10 ft) per minute. The depth that water wells were originally drilled differs from the depth that logging measurements are made because the logging tools have different lengths and measurement points (Mount Sopris Instrument Company Inc., 2002).

Borehole geophysical data were collected during September 1993 from 12 wells in the East Poplar oil field study area by the USGS (Paillet, written commun., 1994). Natural-gamma activity and electrical conductivity were measured with a Century 9510C tool (Century Geophysical LLC, Tulsa, OK). The natural-gamma and induction systems were calibrated prior to logging at each site according to Keys (1990) and procedures described by Mount Sopris Instrument Company Inc. (2002).

Following the 1993 study, additional borehole geophysical data were collected during August 2004 from 20 wells in the East Poplar oil field study area by the USGS. Natural-gamma activity was measured with a Mount Sopris 2PGA-1000 tool (Mount Sopris Instrument Company Inc., Denver, CO), which measures gamma counts per second. The electrical conductivity was measured with a Mount Sopris 2EMA-1000 induction tool. The natural-gamma and induction systems were calibrated prior to logging at each site using practices described by Keys (1990) and procedures described by Mount Sopris Instrument Company Inc. (2002). To eliminate possible cross-contamination from geophysical probes during the field work, the probes were washed (collected water was disposed of at an approved site) and wiped and dried with clean paper towels after logging at each site. Prior to logging wells PNR-8, PNR-9, PNR-22, and MOC-11, the probes were additionally scrubbed using a low-phosphate detergent and rinsed three times with distilled water. These four wells were logged in order of increasing chloride concentration based on analyses of the most recently collected water samples.

Figure 4. Photograph showing borehole geophysical equipment and setup during 2004.

Borehole geophysical data were collected from nine wells in the East Poplar oil field study area during August 2005 by the USGS. Natural-gamma activity was measured in counts per second with a Mount Sopris tool (2PGA-1000). The electrical conductivity was measured with a Geonics EM39 tool built by Mount Sopris. The natural-gamma and induction systems were calibrated prior to logging at each site according to Keys (1990) and procedures described by Mount Sopris Instrument Company Inc. (2002). To minimize possible cross-contamination from geophysical probes, the probes were scrubbed using a low-phosphate detergent and rinsed three times with distilled water, then wiped and dried with clean paper towels prior to logging at each site. Wells were logged during 2005 in order of increasing benzene and total-dissolved-solids concentration based on analyses of the most recently collected water samples.

Digital Logging Data

All logs collected were recorded digitally and archived in the Log ASCII Standard (LAS) version 2 format, which is the industry standard for borehole geophysical data storage. The digital data are available from the USGS Geolog Locator archive accessible at *https://doi.org/10.5066/F7X63KT0*. The LAS file format has been developed and promoted by the Canadian Well Logging Society (2012). The LAS files contain several lines of header data followed by columns of borehole geophysical data with depth at an interval of 0.06 m (0.2 ft). Geophysical data values of –999 for any parameter in the LAS file represent null values for that parameter. The field data are recorded with depth as the bottom of the tool used (Mount Sopris Instrument Company Inc., 2002). Digital logging data collected in the field were input into

LogPlot 2005 (Rockware Inc., Golden, CO) or WellCAD v5.2 (Advanced Logic Technology, Redange, Luxembourg); corrections were applied for tool geometry.

Borehole Log Plots

Plots of borehole geophysical logs given in appendix 1 were produced by the Fort Peck Tribes Office of Environmental Protection using LogPlot 2005 software (Rockware, 2005). Information on well construction, lithology, and water levels included in the plots were taken from tribal records but are not part of the digital data release.

Acknowledgments

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Appendix

Appendix 1. Plots of Digital Geophysical Logs (Portable Document Format)

Prepared by Christa Tyrell, Fort Peck Tribes Office of Environmental Protection

Contains .pdf files for wells listed in table 1 (open-file-report text). Details of well location and other information are given in file; 00_table1-1_LoggedWells1993_2005.xlsx. File name convention is given in 00_readme_pdf_files.doc.

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