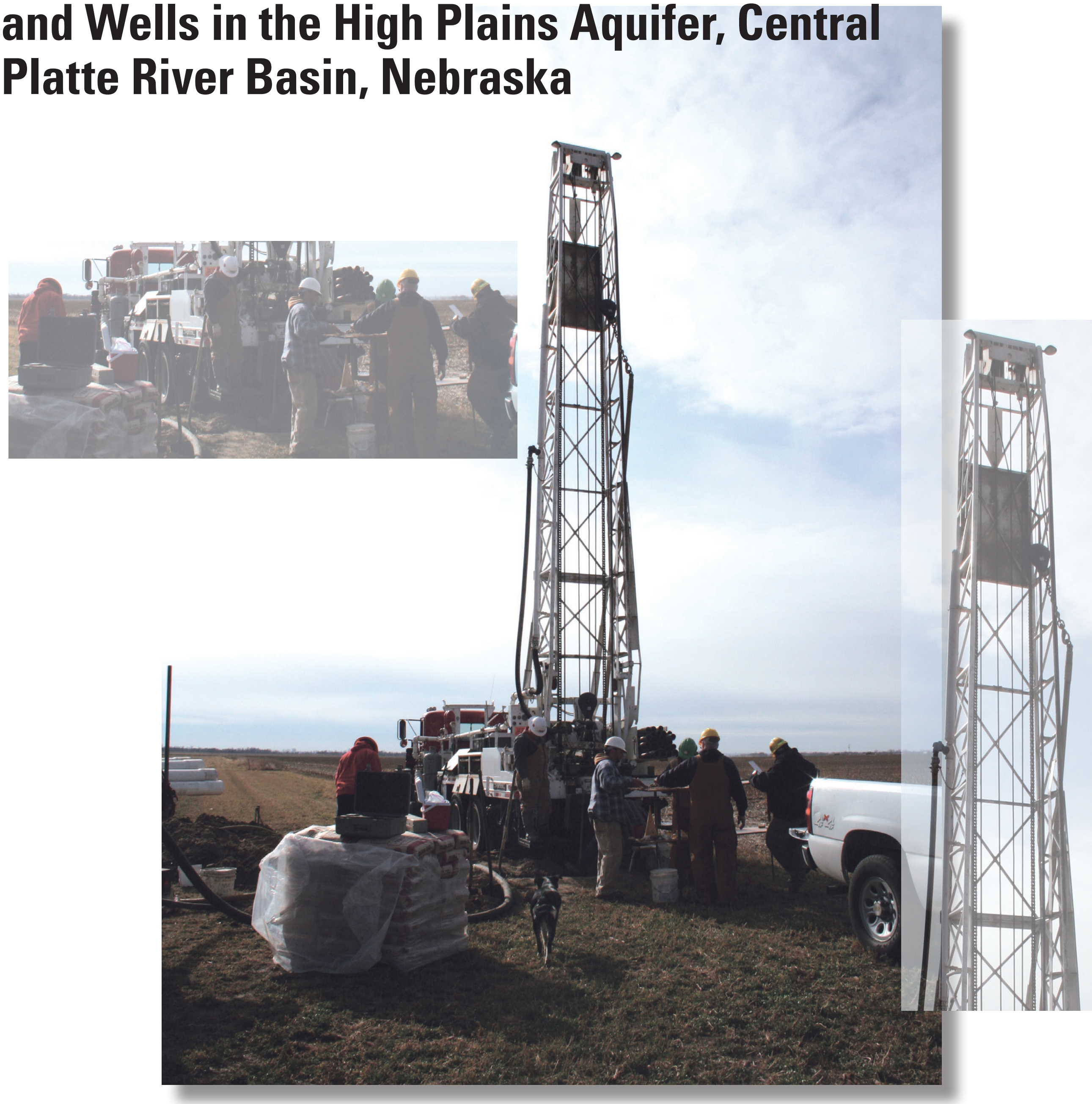
Prepared in cooperation with the Central Platte Natural Resources District

Geophysical Log Analysis of Selected Test Holes and Wells in the High Plains Aquifer, Central Platte River Basin, Nebraska



Scientific Investigations Report 2009–5033

U.S. Department of the Interior
U.S. Geological Survey

Geophysical Log Analysis of Selected Test Holes and Wells in the High Plains Aquifer, Central Platte River Basin, Nebraska

By J. Alton Anderson, Roger H. Morin, James C. Cannia, and John H. Williams

Prepared in cooperation with the Central Platte Natural Resources District

Scientific Investigations Report 2009–5033

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
KEN SALAZAR, Secretary

U.S. Geological Survey
Suzette M. Kimball, Acting Director

U.S. Geological Survey, Reston, Virginia: 2009

For more information on the USGS—the Federal source for science about the Earth, its natural and living resources, natural hazards, and the environment, visit http://www.usgs.gov or call 1-888-ASK-USGS

For an overview of USGS information products, including maps, imagery, and publications, visit http://www.usgs.gov/pubprod

To order this and other USGS information products, visit http://store.usgs.gov

Suggested citation:
Anderson, J.A., Morin, R.H., Cannia, J.C., and Williams, J.H., 2009, Geophysical log analysis of selected test holes and wells in the High Plains aquifer, Central Platte River basin, Nebraska: U.S. Geological Survey Scientific Investigations Report 2009–5033, 16 p.

Contents

Abstract..1
Introduction..1
Description of Test Holes and Wells...3
Methods..3
Description of Geophysical Logs 3
Caliper and Deviation Logs 3
Electromagnetic-Induction Conductivity Log..3
Normal-Resistivity Logs...3
Magnetic-Susceptibility Log..4
Nuclear Logs 4
Spontaneous-Potential Log...4
Sonic Log..4
Flow and Fluid-Property Logs 6
Geophysical Log Analysis..6
Stratigraphy and Lithology 6
Hydrostratigraphy 13
Summary...13
References Cited...15
Appendix—Geophysical Logging Tools and Their Design Specifications.........................16

Figures

1. Study site with locations of test holes and wells 2
2. Stratigraphic, lithologic, and hydrostatigraphic column of the High Plains aquifer and confining units 2
3. Composite of stratigraphic and geophysical logs for test holes: (A) 58, (B) 71, (C), 71A, (D) 72, (E) 72A, and (F) 72B..7
4. Composite of flow and fluid-property logs for test well 72A and production well 72A-430..14

Tables

1. Location, elevation, and depth of test holes and selected wells 4
2. Types of logs collected from the test holes and wells; locations are shown in figure 1...5

Conversion Factors and Datums

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
	Flow rate	
gallon per minute (gal/min)	0.06309	liter per second (L/s)
	Specific capacity	
gallon per minute per foot [(gal/min)/ft)]	0.2070	liter per second per meter [(L/s)/m]

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F = (1.8 \times °C) + 32$$

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Fluid conductivity (Fl cond) in microsiemens per centimeter (uS/cm) is calculated from fluid resistivity in ohm meters (ohm-m) as follows: uS/cm = 10,000/ohm-m

Geophysical Log Analysis of Selected Test Holes and Wells in the High Plains Aquifer, Central Platte River Basin, Nebraska

By J. Alton Anderson, Roger H. Morin, James C. Cannia, and John H. Williams

Abstract

The U.S. Geological Survey in cooperation with the Central Platte Natural Resources District is investigating the hydrostratigraphic framework of the High Plains aquifer in the Central Platte River basin. As part of this investigation, a comprehensive set of geophysical logs was collected from six test holes at three sites and analyzed to delineate the penetrated stratigraphic units and characterize their lithology and physical properties. Flow and fluid-property logs were collected from two wells at one of the sites and analyzed along with the other geophysical logs to determine the relative transmissivity of the High Plains aquifer units. The integrated log analysis indicated that the coarse-grained deposits of the alluvium and the upper part of the Ogallala Formation contributed more than 70 percent of the total transmissivity at this site. The lower part of the Ogallala with its moderately permeable sands and silts contributed some measureable transmissivity, as did the fine-grained sandstone of the underlying Arikaree Group, likely as a result of fractures and bedding-plane partings. Neither the lower nor the upper part of the siltstone- and claystone-dominated White River Group exhibited measurable transmissivity. The integrated analysis of the geophysical logs illustrated the utility of these methods in the detailed characterization of the hydrostratigraphy of the High Plains aquifer.

Introduction

In 2004, the Nebraska State Legislature passed Bill 962, which calls for the development of an integrated surface-water and groundwater management plan for areas that have been declared fully appropriated. The U.S. Geological Survey in cooperation with the Central Platte Natural Resources District (CPNRD) is investigating the hydrostratigraphic framework of the High Plains aquifer in the Central Platte River basin to provide information that will be included in ongoing groundwater flow modeling efforts to aid water-resource management. As part of the overall investigation, a comprehensive set of geophysical logs was collected and analyzed from selected test holes and wells. This part of the investigation was undertaken to better define the hydrostratigraphy in the area, to provide ground-truth and calibration parameters for previously collected surface-geophysical surveys, and to assist in the design of aquifer tests. This report describes the geophysical logging methods used in this investigation and presents the logs and their analysis within the context of the lithologic, stratigraphic, and hydrostratigraphic characterization of the High Plains aquifer in the study area.

The study site lies within a broad floodplain north of the Platte River in Dawson County, Nebr. (fig. 1). The High Plains aquifer as described by Pettijohn and Chen (1983) and Gutentag and others (1984) consists of hydraulically connected deposits of Tertiary and Quaternary age (fig. 2). The Tertiary deposits include the upper part of the White River Group, the Arikaree Group, and the Ogallala Formation, whereas the Quaternary deposits include alluvium and eolian sands. The upper White River Group forms the basal unit of the High Plains aquifer and consists primarily of siltstone with some sandstone beds. Zones of higher permeability in the upper White River are typically associated with densely spaced fractures and bedding-plane partings (Barrash and Morin, 1987). The High Plains aquifer is underlain by confining units composed of the Cretaceous-age Pierre Shale and Tertiary-age claystone and siltstone of the lower part of the White River Group (Schultz and Stout, 1955).

The Arikaree Group overlies the White River Group and is composed of massive, very fine to fine-grained sandstone with some beds of volcanic ash, siltstone, claystone, and marl. Fracture permeability similar to that of the upper White River occurs in the Arikaree. The Ogallala Formation, which overlies the Arikaree, forms the principal unit in the High Plains aquifer and is made up of unconsolidated gravel, sand, silt, and clay with some zones of caliche. Laterally extensive alluvial deposits of gravel, sand, and silt blanket the Ogallala. The alluvium locally is overlain by eolian deposits of dune sand and loess. The most permeable zones in the Ogallala and alluvium are associated with the coarse-grained sands and gravels.

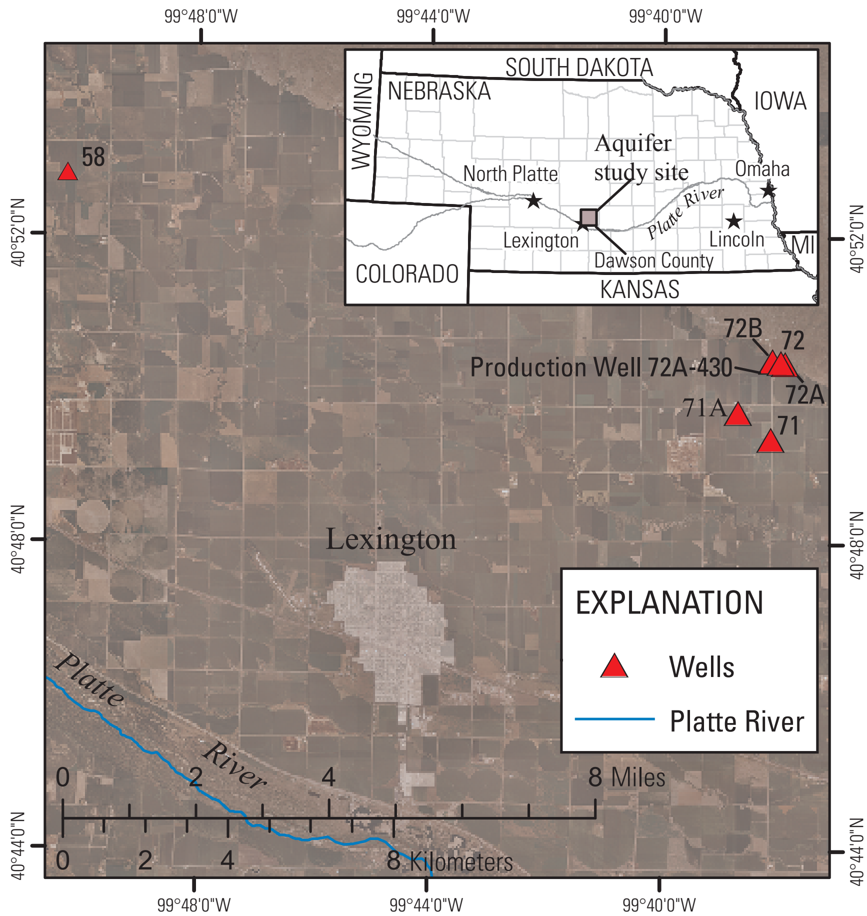


Figure 1. Study site with locations of test holes and wells.

Age	Stratigraphy		Lithology	Hydrostratigraphy
Quaternary	Alluvium and eolian deposits		Gravel, sand, silt, and clay	High Plains aquifer
Tertiary	Ogallala Formation		Gravel, sand, silt, and clay	
	Arikaree Group		Fine-grained sandstone	
	White River Group	Upper	Siltstone with sandstone	
		Lower	Claystone and siltstone	Confining unit
Cretaceous	Pierre Shale		Shale	

Modified from Gutentag and others, 1984

Figure 2. Stratigraphic, lithologic, and hydrostratigraphic column of the High Plains aquifer and confining units.

Description of Test Holes and Wells

Six test holes (CPNRD_MRS-58, -71, -71A, -72, -72A, and -72B) were drilled at three sites within the study area (fig. 1). Each of these was drilled as an 8-inch-diameter open hole that penetrated the entire High Plains aquifer and extended into the Pierre Shale. The test holes were filled with a viscous bentonite-water drilling fluid to prevent them from collapsing during drilling and subsequent collection of geophysical logs. After logging operations were completed, all of the test holes except hole 72A were allowed to collapse under the inherently unstable conditions and were then properly abandoned to the surface using a bentonite seal. Test hole 72A was completed as a test well in the alluvium, Ogallala, Arikaree, and White River units with a 4-inch-diameter casing that had multiple screened intervals from 60 to 425 feet (ft) below land surface (BLS). A 16-inch-diameter test hole was drilled adjacent to this test well and completed as production well 72A-430 in the Ogallala, Arikaree, and White River deposits with 12-inch-diameter casing that was continuously screened from the base of the alluvium at 85 to 430 ft BLS. The USGS and CPNRD directed and supervised the test-hole drilling and well completion. Further information regarding each test hole and well is presented in table 1.

Methods

Description of Geophysical Logs

Geophysical logs were collected in test holes 58, 71, 71A, 72, 72A, and 72B. The types of logs collected in each borehole are presented in table 2. The logs included caliper, deviation, electromagnetic-induction conductivity, normal resistivity, magnetic susceptibility, natural gamma, neutron, gamma-gamma density, spontaneous potential, and full-waveform sonic. These geophysical logs were collected in the test holes when the holes were filled with drilling fluid. Flow and fluid-property logs were collected in test well 72A and production well 72A-430 after the wells had been completed with screens and developed. The geophysical logs are briefly described below, and information on individual probes and manufacturers' specifications are presented in the Appendix. Additional information regarding these tools and their principles of operation can be found in Hearst and others (2000) and in Keys (1990).

Caliper and Deviation Logs

The caliper log measures borehole diameter and is collected with a spring-loaded, three-arm averaging probe. Changes in borehole diameter may be correlated to drilling and construction procedures, competency of lithologic units, and fractures and solution features. The caliper log was typically the first log run to evaluate hole stability and to confirm total depth before proceeding with other logs.

The deviation log measures the vertical deviation and spatial trajectory of a borehole with two inclinometers and a three-component magnetometer. The deviation logs are not presented in this report, because each of the test holes and wells were deviated less than two degrees from vertical, which is within the range of measurement error of the tool.

Electromagnetic-Induction Conductivity Log

The electromagnetic-induction conductivity log measures the electrical conductivity of rocks and water surrounding the borehole. In this study, the logs were collected at a frequency of 40 kilohertz (kHz). The electromagnetic-induction tool has a vertical resolution of about 2 ft and primarily samples volumes out to roughly 18 inches (in.) radially from the well. As such, it generally is not influenced by the electrical properties of the wellbore fluid for diameters less than 8 in. Electrical conductivity measurements are affected by the argillaceous content and porosity of the rocks and by the dissolved-solids concentration of the pore fluid. Electromagnetic-induction conductivity logs are most effective in formations having high electrical conductivities (low resistivities).

Normal-Resistivity Logs

The normal-resistivity log measures the electrical resistivity of the rocks and water surrounding the borehole. Electrical resistivity measurements consist of short-normal (16 in.) and long-normal (64 in.) resistivities, or near and far resistivities, respectively, that have two different volumes of investigation. Electrical resistivity measurements are similarly affected by the argillaceous content and porosity of the rocks and by the dissolved-solids concentration of the pore fluid (Archie, 1942). However, unlike the electromagnetic-induction logs, normal-resistivity logs are most effective in formations having high electrical resistivities (low conductivities). A lower resistivity corresponds to higher porosity and (or) smaller grain size because the surface area associated with fine particles promotes the transmission of electric current (Biella and others, 1983; Kwader, 1985). Due to the smaller area of investigation sampled by the near measurement, short-normal logs are more affected by drilling fluid and the filter cake that develops along the borehole wall than are the far measurements. Correspondingly, the long-normal logs have a greater volume of investigation beyond the borehole, and are proportionally less influenced by drilling fluid than is the near measurement. Intervals where these two logs diverge substantially, typically indicate permeable zones where drilling fluid has invaded the formation.

Table 1. Location, elevation, and depth of test holes and selected wells.

Well ID[1]	Field identification	Latitude[2]	Longitude[2]	Land-surface elevation[3]	Test hole/well depth[4]
405249099501601	CPNRD-MRS-58	40 52 49.4	099 50 16.4	2,475[5]	520
404923099380901	CPNRD-MRS-71	40 49 23.2	099 38 08.7	2,389	440
404943099384201	CPNRD-MRS-71A	40 59 40.1	099 38 42.5	2,368	400
405023099375901	CPNRD-MRS-72	40 50 23.5	099 37 59.1	2,438	477
405024099380801	CPNRD-MRS-72A	40 50 23.8	099 38 07.2	2,400	460
405024099380802	CPNRD-MRS-72B	40 50 24.6	099 38 07.4	2,419	390
405024099380801	CPNRD-MRS-72A-430	40 50 23.7	099 38 07.3	2,420	430

[1]Site identification number assigned by USGS.

[2]Degrees, minutes, seconds, and tenths of seconds; North American Datum 1983.

[3]Land-surface elevation surveyed in feet above National Geodetic Vertical Datum of 1929; elevations to the nearest foot.

[4]Depth of well, in feet below land surface (BLS).

[5]Test hole elevation estimated to nearest half contour (5 ft) from USGS 1:24,000 topographic map.

Magnetic-Susceptibility Log

The magnetic-susceptibility log measures the concentration of magnetite and other magnetic minerals present in the rocks surrounding the borehole. When the magnetic susceptibility log is combined with other logs that also respond to mineral composition, such as natural gamma and electrical logs, it can help detect subtle variations in lithology.

Nuclear Logs

The natural gamma log measures the natural gamma radiation being emitted by the rocks surrounding the borehole. Clays tend to accumulate radioisotopes through adsorption and ion-exchange processes, and zones of high gamma activity are typically interpreted as being clay rich. Shale, feldspathic sandstones, phosphatic limestones, organic-rich sediments, and glauconitic sands also are associated with high gamma responses.

The neutron log measures the number of neutrons received at a detector from a neutron source in the probe after the neutrons have interacted with the formation surrounding the borehole. The majority of the neutron interactions are in response to the amount of hydrogen present, which, in groundwater environments, is largely a function of the water content of the rocks. The neutron probe is calibrated in specially designed test pits, and the response of the neutron detector, in counts per second, can be accurately converted to quantitative values of total porosity provided the formation is saturated. Data often correlate with natural gamma logs and indicate high porosities (low count rates) associated with bound water on clay surfaces. In the test holes, conversion of neutron data to porosity was problematic because of the presence of drilling fluid and a highly variable borehole diameter. Thus, neutron logs are presented in the original units of counts per second to provide a qualitative measure of rock porosity, where high count rates represent low porosity and vice versa.

The gamma-gamma density log measures the radiation received at each of two detectors from a gamma source in the probe after the energy has been attenuated by rocks and water surrounding the borehole. The probe's two detectors (near and far) are located at precise distances, 7.9 and 14.1 in., from a radioactive source. The probe is calibrated in test pits and on calibration blocks of known densities, and a separate density value is determined from each detector response. The ratios of these values are subsequently processed to minimize errors due to borehole enlargements and drilling-fluid invasion, and the result provides a reliable estimate of formation density. Density logs typically display a gradual increase with depth due to compaction.

Spontaneous-Potential Log

The spontaneous-potential log (sometimes referred to as SP or self-potential) measures the electrical potentials that develop in a borehole at lithologic and water-quality interfaces. Spontaneous potential is largely a function of chemical reactions that occur within the wellbore fluids and the type and quantity of clay present. Electrochemical effects tend to result from the migration of ions from more concentrated to less concentrated fluids.

Sonic Log

The full-waveform sonic log measures the amplitude and travel time of acoustic waves transmitted through rocks and water surrounding a borehole. The probe is equipped with a variable frequency transmitter and three receivers spaced 3, 4, and 5 ft away from the transmitter. In this study, logs were

Table 2. Types of logs collected from the test holes and wells; locations are shown in figure 1.

[Dash indicates log not collected]

Well ID	CALIPER[1]	DEV[2]	COND[3]	RES (16N)[4]	RES (64N)[5]	MAG SUSCEP[6]	GAMMA[7]	NEUTRON[8]	DENSITY[9]	SP[10]	FWF SONIC[11]	Flow[12]	Fl Cond[13]	Fl Temp[14]
MRS-58	X	X	-	X	X	-	X	X	X	X	X	-	-	-
MRS-71	X	X	X	X	X	X	X	X	-	X	X	-	-	-
MRS-71A	X	X	X	X	X	X	X	-	X	X	X	-	-	-
MRS-72	X	X	X	X	X	X	X	X	X	X	X	-	-	-
MRS-72A	X	X	X	X	X	X	X	-	X	X	-	X	X	X
MRS-72B	X	X	X	X	X	X	X	-	-	X	-	-	-	-
MRS-72-430	-	-	-	-	-	-	-	-	-	-	-	X	X	X

[1]3-arm caliper, [2]deviation, [3]electromagnetic-induction conductivity, [4]16-in. resistivity (short normal), [5]64-in. resistivity (long normal), [6]magnetic susceptibility, [7]natural gamma, [8]neutron, [9]compensated gamma-gamma density, [10]spontaneous potential, [11]full-waveform sonic, [12]flow, [13]fluid conductivity, [14]fluid temperature

collected at a frequency of 15 kHz. The waveforms recorded by each receiver were digitized and processed by means of a semblance technique (Paillet and Cheng, 1991) to arrive at estimates of the compressional-wave slowness, in units of microseconds per foot (the inverse of velocity), and to provide image logs of the acoustic amplitude data. Values of slowness are affected primarily by rock elastic properties and often correlate with density. Slowness also increases substantially when rocks are highly fractured.

Flow and Fluid-Property Logs

The flow log measures the vertical direction (up or down) and rate of flow in a borehole. Flow logs commonly are collected under ambient and pumped conditions. Flow occurs under ambient conditions in boreholes that penetrate multiple zones having different hydraulic heads. An electromagnetic flowmeter (Molz and Young, 1993) was used in this study. The operation of the electromagnetic flowmeter is based upon Faraday's Law, which states that the flow of an electrically conductive fluid through an induced magnetic field generates a voltage gradient that is proportional to its velocity. The calibrated measurement range of the electromagnetic flowmeter when equipped with a fully fitted diverter is 0.05 to 15 gallons per minute (gal/min). A flexible rubber diverter focuses the borehole flow through the instrument's sensor. It is typically fitted to the nominal borehole diameter after inspection of the caliper log. To measure flows greater than the measurement range of the probe, flow logs may be collected with an underfit or with no diverter to allow some flow to bypass the sensor.

The fluid-conductivity log measures the electrical conductivity of the borehole fluid, a property directly related to the concentration of dissolved solids. Changes in the slope of the fluid conductivity profile may indicate zones of fluid exchange between the well and the surrounding formation. In this study, fluid conductivity logs were used to identify water level, evaluate water quality, and delineate possible flow patterns in wells. The fluid conductivity logs were calculated from the measured fluid resistivity.

The temperature log records the temperature of air and water in the borehole. Fluid temperature gradients that are variable with respect to depth may indicate the presence of vertical flow within the borehole. Temperature logs were used to locate water level and identify possible flow zones.

Geophysical Log Analysis

Stratigraphy and Lithology

The statigraphy, lithology, and physical properties of the High Plains aquifer and confining units penetrated by the test holes primarily were characterized through an analysis of the normal-resistivity, electromagnetic-induction conductivity, and nuclear logs. Composites of the geophysical logs for test holes 58, 71, 71A, 72, 72A, and 72B are presented with their interpreted stratigraphy in figures 3*A* to 3*F*. The Pierre Shale was recognized as having the lowest electrical resistivity/highest conductivity, highest gamma activity, lowest neutron counts, and lowest gamma-gamma density, all reflecting the elevated clay content and associated bound water associated with this unit. The overlying claystone and siltstone of the lower White River Group (fig. 2) were characterized by slightly higher resistivity/lower conductivity, with generally lower gamma activity, higher neutron counts, and higher gamma-gamma density than the Pierre Shale. The contact between the Pierre Shale and the White River Group was typically marked by an inflection in the SP log. This contact was penetrated in test holes 58, 71, 72, and 72A at 500, 391, 431, and 427 ft BLS, respectively.

The contact between the claystone and siltstone of the lower White River and the siltstone of the upper White River was characterized by an increase in resistivity and corresponding decrease in conductivity, lower gamma and higher neutron counts, and an increase in the gamma-gamma density. This contact between the lower and upper units of the White River Group was penetrated in test holes 58, 71, 72, 72A, and 72B at 476, 368, 400, 395, and 393 ft BLS, respectively.

The fine-grained sandstone of the Arikaree Group exhibited relatively uniform log responses and was characterized by intermediate to high electrical resistivity, intermediate to low conductivity, low gamma activity, high neutron counts, and high gamma-gamma density. The upper White River-Arikaree contact was penetrated in test holes 58, 71, 72, 72A, and 72B at 437, 344, 369, 365, and 365 ft BLS, respectively.

The contact between the Arikaree sandstone and the unconsolidated Ogallala Formation was typically delineated by a sharp decrease in the electrical resistivity, slightly higher gamma activity, lower neutron counts, and a marked inflection in the SP log. The Arikaree-Ogallala contact was penetrated in test holes 58, 71, 72, 72A, and 72B at 336, 254, 287, 280, and 284 ft BLS, respectively.

Due to the wide range of lithologies that make up the Ogallala Formation, log responses were variable among test holes. In test hole 58, the Ogallala, which consisted of interbedded coarse- and fine-grained deposits, was coarser in the lower part and finer grained in the upper part (fig. 3*A*). The lower part between 216 and 337 ft BLS generally had higher resistivity, and lower gamma but higher neutron counts. The upper part between 81 and 216 ft BLS generally had lower resistivity, with higher gamma and lower neutron counts; these responses are typical of finer grained materials. At test holes 71 and 71A (figs.3*B* and 3*C*), logs recorded in the Ogallala consisted of alternating zones of higher and lower electrical resistivity/conductivity, gamma activities, and neutron counts, all indicative of interbedded fine- and coarse-grained deposits.

At test holes 72, 72A, and 72B (figs. 3*D*, 3*E*, and 3*F*), the lower part of the Ogallala Formation between 185 and 285 ft BLS appeared to be finer grained than the upper part with a few coarser grained beds; it was characterized by generally lower resistivity/higher conductivity, higher gamma activity, and lower neutron counts. The middle part of the Ogallala

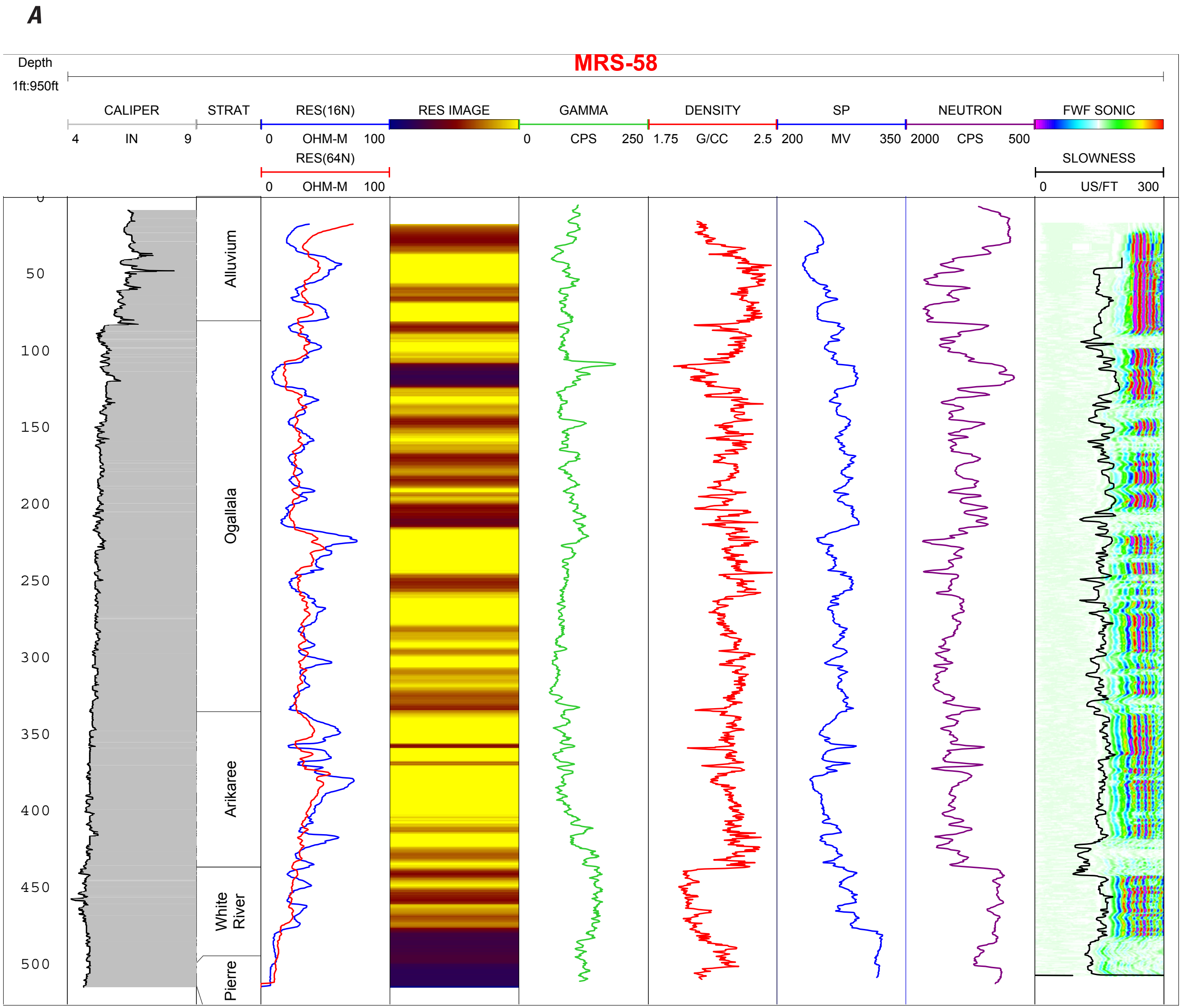


Figure 3*A*. Composite of stratigraphic and geophysical logs for test hole 58. CALIPER-IN (caliper, in inches); STRAT (stratigraphic units); RES (16N)-OHM-M (short-normal resistivity, in ohm-meters); RES (64N)-OHM-M (long-normal resistivity, in ohms per meter); RES IMAGE (color-scale representation of the short-normal resistivity, darker colors are less resistive, whereas lighter colors are more resistive); GAMMA-CPS (gamma, in counts per second); DENSITY-G/CC (density, in grams per cubic centimeter); SP-MV (spontaneous-potential, in millivolts); NEUTRON-CPS (neutron, in counts per second); FWF SONIC (image of the compressional wave amplitude with color scale showing red as representing the largest amplitude in the full waveform); and SLOWNESS-US/FT (first arrival time of the compressional wave, in microseconds per foot).

B

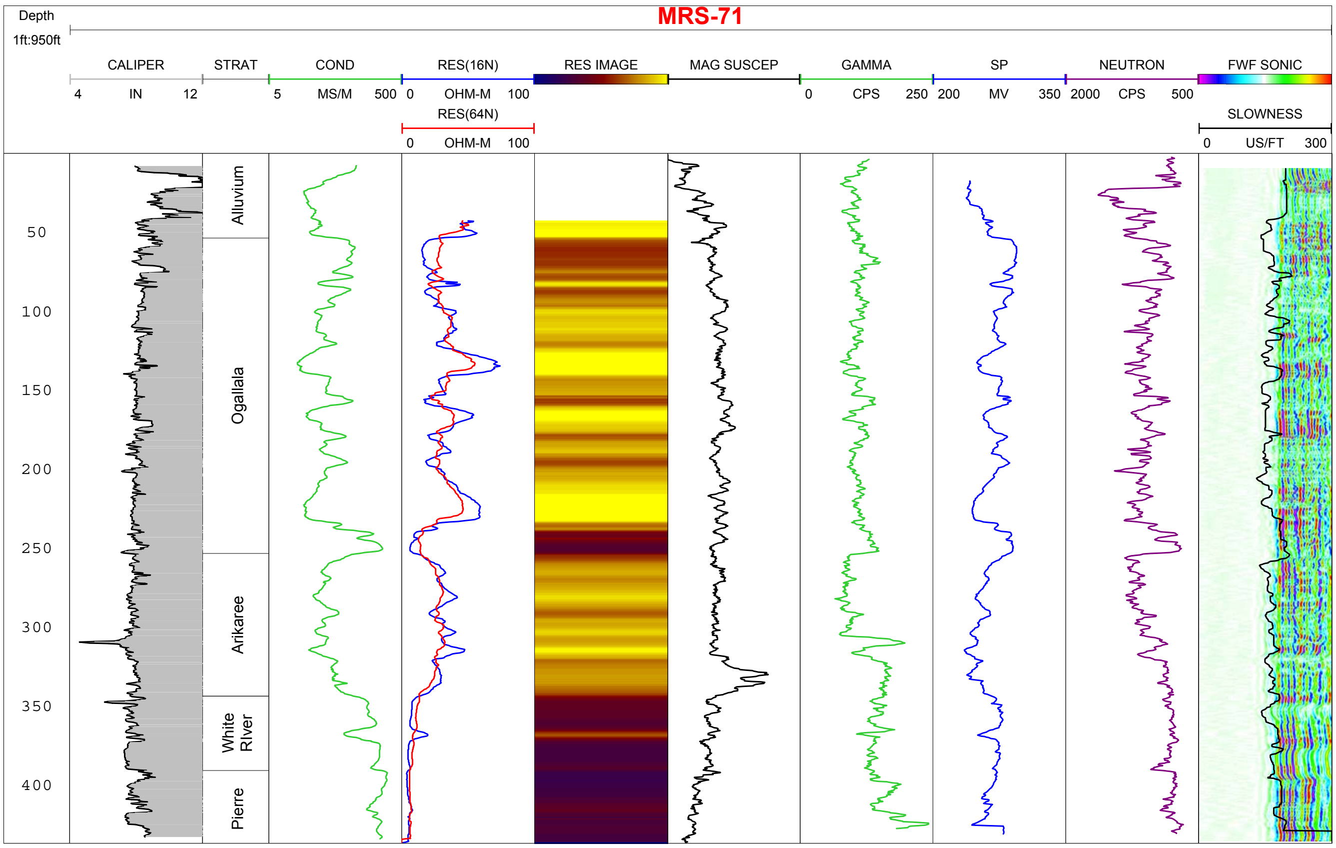


Figure 3*B*. Composite of stratigraphic and geophysical logs for test hole 71. CALIPER-IN (caliper, in inches); STRAT (stratigraphic units); COND-MS/M (conductivity, in millisiemens per meter); RES (16N)-OHM-M (short-normal resistivity, in ohm-meters); RES (64N)-OHM-M (long-normal resistivity, in ohm-meters); RES IMAGE (color-scale representation of the short-normal resistivity, darker colors are less resistive, whereas lighter colors are more resistive); MAG SUSCEP (magnetic susceptibility shown on a relative scale with increasing susceptibility to the right); GAMMA-CPS (gamma, in counts per second); SP-MV (spontaneous-potential, in millivolts); NEUTRON-CPS (neutron, in counts per second); FWF SONIC (image of the compressional wave amplitude with color scale showing red as representing the largest amplitude in the full waveform); and SLOWNESS-US/FT (first arrival time of the compressional wave, in microseconds per foot).

C

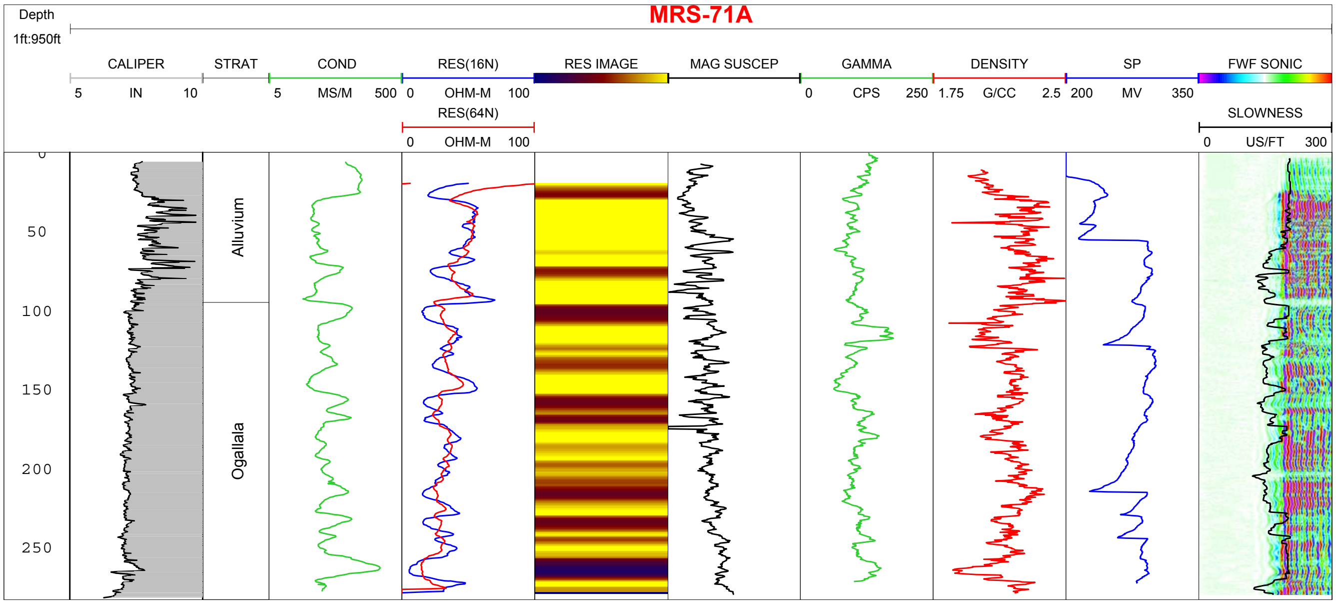


Figure 3*C*. Composite of stratigraphic and geophysical logs for test hole 71A. CALIPER-IN (caliper, in inches); STRAT (stratigraphic units); COND-MS/M (conductivity, in millisiemens per meter); RES (16N)-OHM-M (short-normal resistivity, in ohm-meters); RES (64N)-OHM-M (long-normal resistivity, in ohm-meters); RES IMAGE (color-scale representation of the short-normal resistivity, darker colors are less resistive, whereas lighter colors are more resistive); MAG SUSCEP (magnetic susceptibility shown on a relative scale with increasing susceptibility to the right); GAMMA-CPS (gamma, in counts per second); DENSITY-G/CC (density, in grams per cubic centimeter); SP-MV (spontaneous-potential, in millivolts); FWF SONIC (image of the compressional wave amplitude with color scale showing red as representing the largest amplitude in the full waveform); and SLOWNESS-US/FT (first arrival time of the compressional wave, in microseconds per foot).

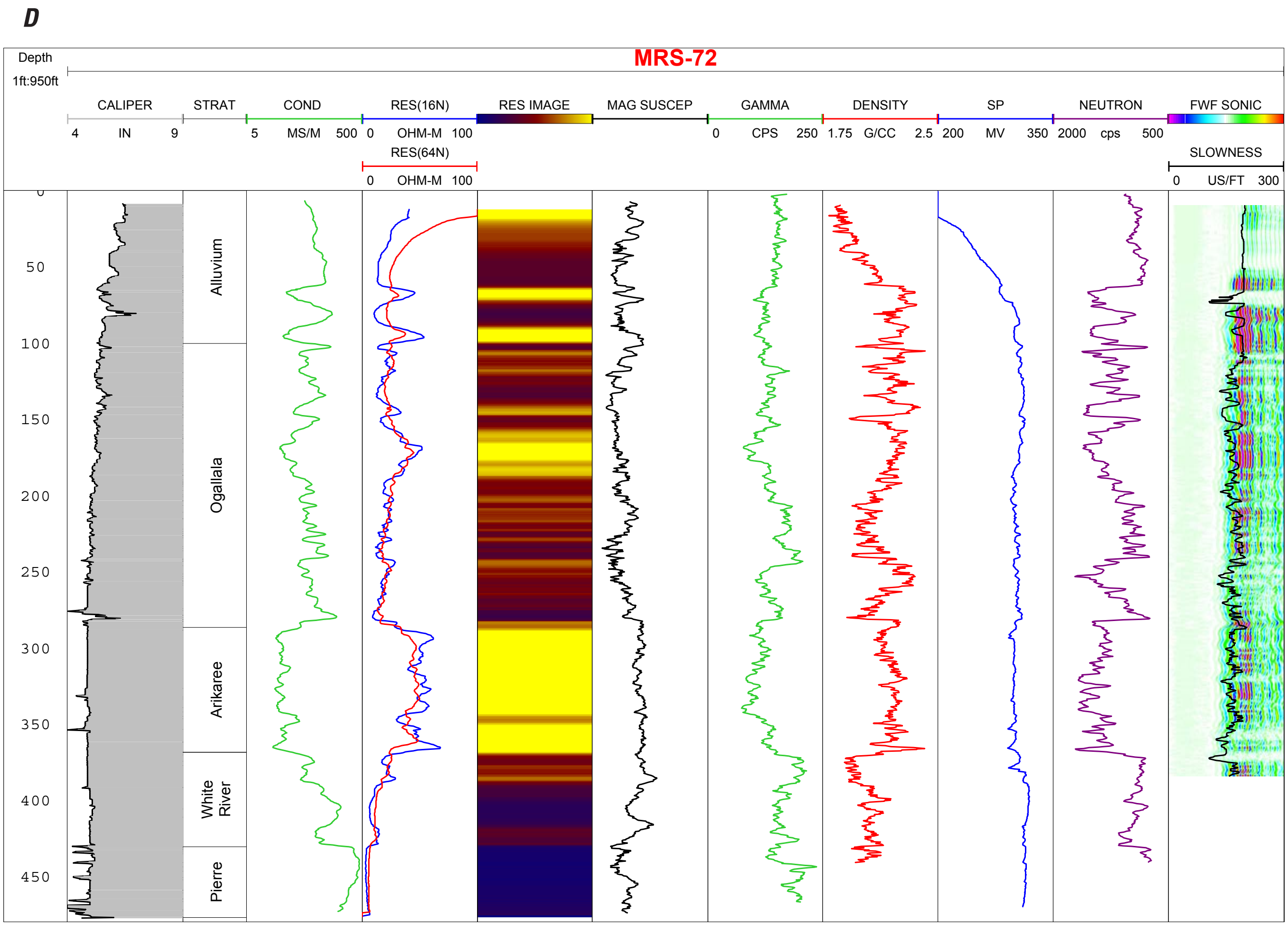


Figure 3*D*. Composite of stratigraphic and geophysical logs for test hole 72. CALIPER-IN (caliper, in inches); STRAT (stratigraphic units); COND-MS/M (conductivity, in millisiemens per meter); RES (16N)-OHM-M (short-normal resistivity, in ohm-meters); RES (64N)-OHM-M (long-normal resistivity, in ohm-meters); RES IMAGE (color-scale representation of the short-normal resistivity, darker colors are less resistive, whereas lighter colors are more resistive); MAG SUSCEP (magnetic susceptibility shown on a relative scale with increasing susceptibility to the right); GAMMA-CPS (gamma, in counts per second); DENSITY-G/CC (density, in grams per cubic centimeter); SP-MV (spontaneous-potential, in millivolts); NEUTRON-CPS (neutron, in counts per second); FWF SONIC (image of the compressional wave amplitude with color scale showing red as representing the largest amplitude in the full waveform); and SLOWNESS-US/FT (first arrival time of the compressional wave, in microseconds per foot).

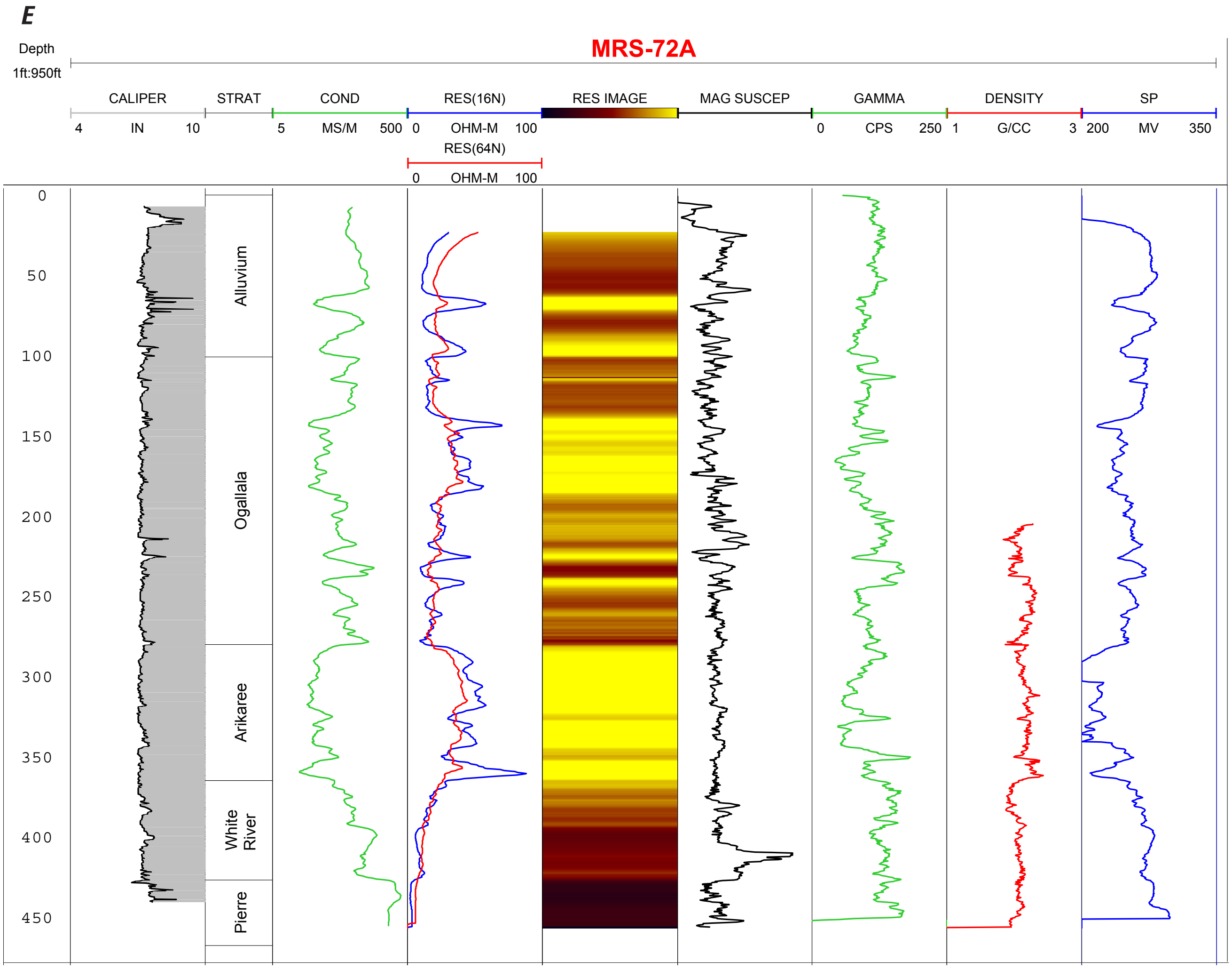


Figure 3*E*. Composite of stratigraphic and geophysical logs for test hole 72A. CALIPER-IN (caliper, in inches); STRAT (stratigraphic units); COND-MS/M (conductivity, in millisiemens per meter); RES (16N)-OHM-M (short-normal resistivity, in ohm-meters); RES (64N)-OHM-M (long-normal resistivity, in ohm-meters); RES IMAGE (color-scale representation of the short-normal resistivity , darker colors are less resistive, whereas lighter colors are more resistive); MAG SUSCEP (magnetic susceptibility shown on a relative scale with increasing susceptibility to the right); GAMMA-CPS (gamma, in counts per second); DENSITY-G/CC (density, in grams per cubic centimeter); and SP-MV (spontaneous-potential, in millivolts).

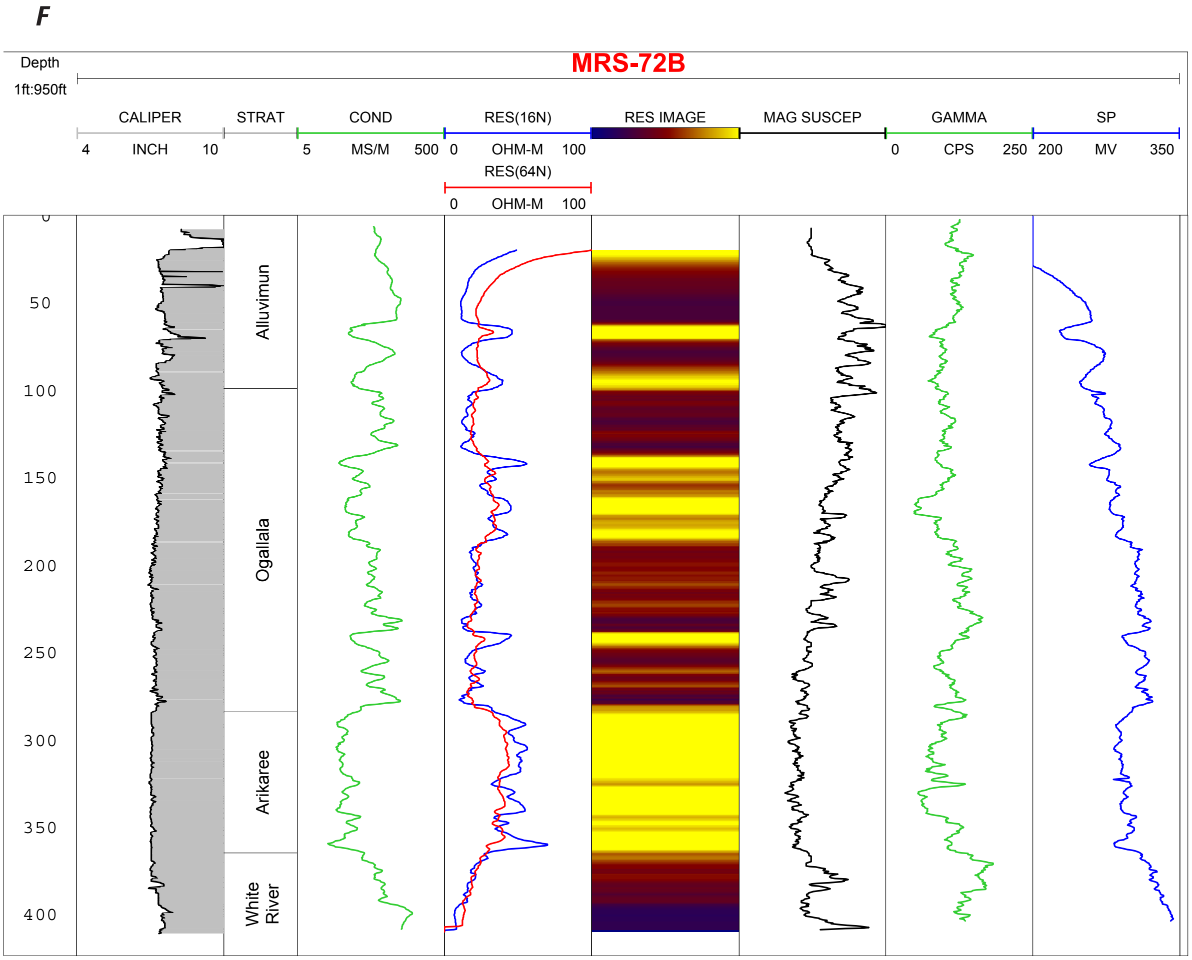


Figure 3*F*. Composite of stratigraphic and geophysical logs for test hole 72B. CALIPER-IN (caliper, in inches); STRAT (stratigraphic units); COND-MS/M (conductivity, in millisiemens per meter); RES (16N)-OHM-M (short-normal resistivity, in ohm-meters); RES (64N)-OHM-M (long-normal resistivity, in ohm-meters); RES IMAGE (color-scale representation of the short-normal resistivity, darker colors are less resistive, whereas lighter colors are more resistive); MAG SUSCEP (magnetic susceptibility shown on a relative scale with increasing susceptibility to the right); GAMMA-CPS (gamma, in counts per second); and SP-MV (spontaneous-potential, in millivolts).

between 140 and 185 ft BLS was coarser grained and identified by higher resistivity/lower conductivity, lower gamma activity, and higher neutron counts. The upper part of the Ogallala was fine grained and characterized by generally lower resistivity/higher conductivity, and higher gamma and lower neutron counts, except for sporadic coarse-grained zones that exhibited higher resistivity/lower conductivity and lower gamma activity.

The contact between the Ogallala Formation and the overlying alluvium was identified by a marked increase in electrical resistivity and a corresponding decrease in conductivity, along with lower gamma counts. The Ogallala-alluvium contact was penetrated in the various test holes at depths ranging from 58 to 101 ft BLS.

Hydrostratigraphy

The hydrostratigraphy of the High Plains aquifer penetrated by test well 72A and production well 72A-430 was characterized through an analysis of the flow and fluid-property logs. The flow and fluid-property logs for the test well and production well are presented with the resistivity image and interpreted stratigraphy at the site in figure 4. In the test well, the flow and fluid-property logs were collected under ambient and pumped conditions with the flowmeter equipped with a fully fitted diverter. In the production well, the ambient flow and fluid-property logs were collected with the flowmeter equipped with an undersize diverter, whereas the pumped flow and fluid-property logs were collected with the flowmeter equipped with no diverter. In the test well, the ambient flow was downward from the alluvium and upper Ogallala to the lower Ogallala and Arikaree, which indicates a downward hydraulic gradient with higher heads in the alluvium and upper Ogallala (source) and lower heads in the lower Ogallala and Arikaree (sink). Finer grained beds in the middle Ogallala apparently act as a semi-confining unit between the upper and lower parts of the High Plains aquifer at this site. No measurable ambient flow was detected in the production well. This was not unexpected considering the large amount of flow bypass, which would occur with the undersize-diverter-equipped flowmeter in the large diameter well, in relation to the small ambient flow rate measured in the test well.

In the test well, flow and fluid-property logs were collected under quasi-steady-state conditions while pumping at a rate of 15 gal/min. The quasi-steady-state drawdown during logging was 2.1 ft, which corresponds to a specific capacity for the well of 7.1 (gal/min)/ft. In the production well, flow and fluid-property logs were collected under quasi-steady-state conditions while pumping at a rate of 730 gal/min. The quasi-steady-state drawdown during logging was 44 ft, which corresponds to a specific capacity for the well of 17 (gal/min)/ft. In the production well, the position of the pump precluded collection of the logs above 135 ft BLS.

Based on the interpreted stratigraphy and lithology in relation to the pumped flow and fluid-property logs, the High Plains aquifer at the well site was divided into a series of aquifer zones (fig. 4). The inflow that resulted from the pumped stresses was calculated for each of these zones by differencing the pumped-induced flow above and below the given zone. In the test well, the pumped-induced flow was determined by subtracting the ambient flow measurements from the pumped flow measurements. In the production well, the pumped-induced flow above and below each zone was equal to the pumped flow measurements because the ambient flow was insignificant compared to the pumped flow. The pumped-induced inflows for the test well and the production well displayed similar distributions. The relative transmissivity of the aquifer zones was estimated from these pumped-induced flows through application of the proportion method as described by Molz and Young (1993).

The upper and lower parts of the White River Group displayed negligible transmissivity, indicating a lack of significant primary or secondary permeability in this siltstone- and claystone-dominated interval. Fractured zones in the sandstone of the Arikaree Group contributed about 8 percent of the total transmissivity, and coarse-grained beds in the dominantly fine-grained lower zone of the Ogallala Formation contributed another 4 percent. Coarse-grained beds in the middle zone of the Ogallala contributed about 16 percent of the transmissivity. Coarse-grained beds in the upper Ogallala and in the alluvium contributed more than 70 percent of the transmissivity, representing the predominant aquifer zones in the High Plains aquifer at the site.

Summary

The U.S. Geological Survey in cooperation with the Central Platte Natural Resources District is investigating the hydrostratigraphic framework of the High Plains aquifer in the Central Platte River basin. As part of this investigation, a comprehensive set of geophysical logs was collected from six test holes at three sites and analyzed to delineate the penetrated stratigraphic units and characterize their lithology and physical properties. Flow and fluid-property logs were collected from two wells at one of the sites and analyzed along with the other geophysical logs to determine the relative transmissivity of the High Plains aquifer units.

The geophysical logs systematically recorded in the test holes drilled at six sites as part of this study help to identify the lithology and stratigraphy and help to provide some specific information regarding physical properties of the High Plains aquifer. The flow and fluid-property logs collected in the test well and in the production well constructed at one of the sites were analyzed with the geophysical logs to determine the hydrostratigraphy of the High Plains aquifer.

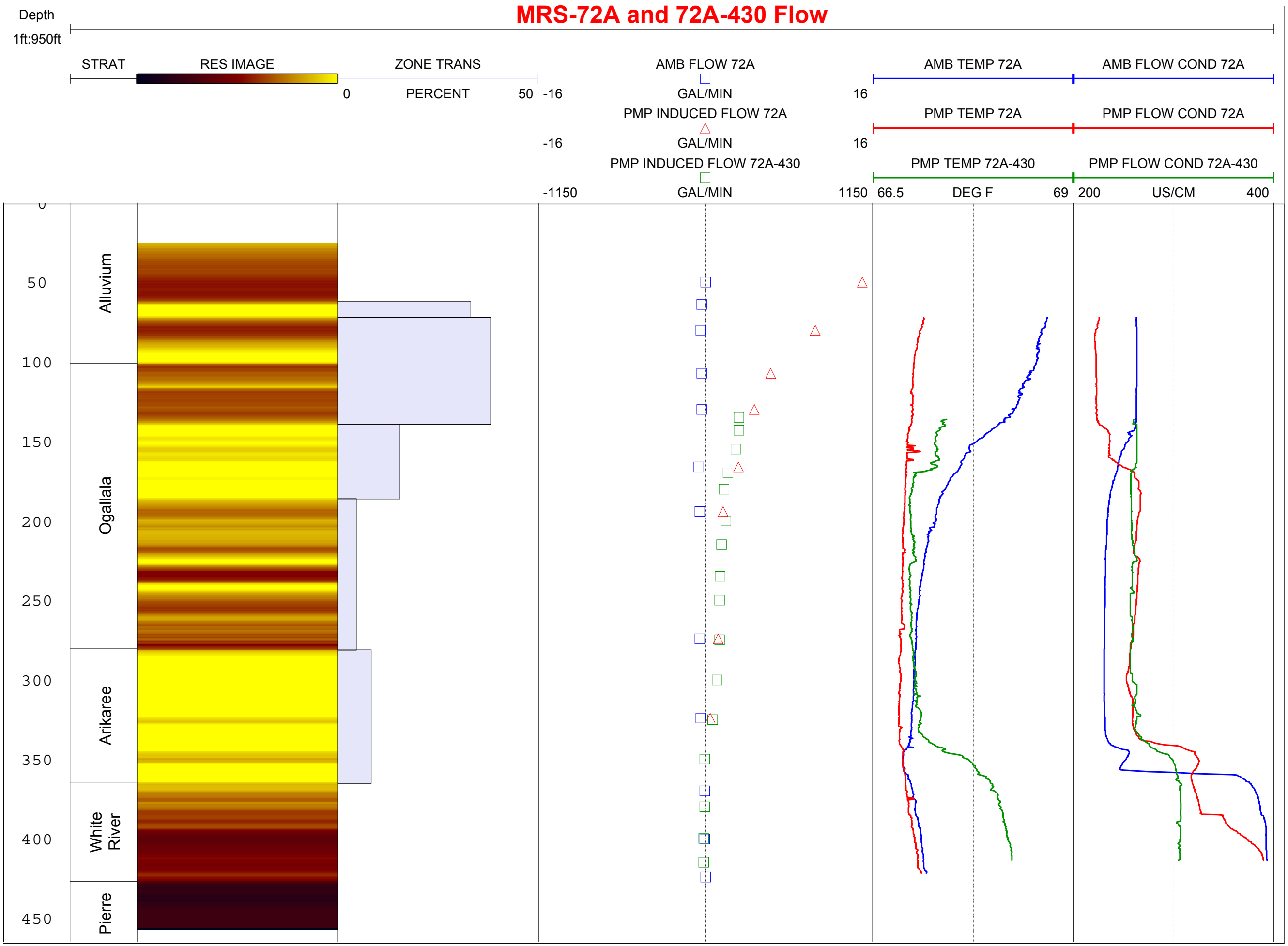


Figure 4. Composite of flow and fluid-property logs for test wells 72A and production well 72A-430. STRAT (stratigraphic units); RES IMAGE (color-scale representation of short-normal resistivity; darker colors are less resistive, whereas lighter colors are more resistive); ZONE TRANS-PERCENT (calculated percent contribution of flow); AMB FLOW 72A-GAL/MIN (ambient flow measured in well 72A in gallons per minute; negative values indicate downward flow and positive values indicate upward flow); PMP INDUCED FLOW-GAL/MIN (Net pumped flow calculated after removing the ambient flow effect in well 72A in gallons per minute); PMP INDUCED FLOW 72A-430-GAL/MIN (pumped flow measured in well 72A-430 in gallons per minute); AMB TEMP 72A (ambient temperature in well 72A in degrees Fahrenheit); PMP TEMP 72A (pumping temperature in well 72A in degrees Fahrenheit); PMP TEMP 72A-430-DEG F (pumping temperature in well 72A-430 in degrees Fahrenheit); AMB FLOW COND 72A (ambient fluid conductivity in well 72A in microsiemens per centimeter); PMP FLOW COND 72A (pumping fluid conductivity in well 72A in microsiemens per centimeter); and PMP FLOW COND 72A-430-US/CM (pumped fluid conductivity in well 72A-430, in microsiemens per centimeter).

The Pierre Shale and the White River Group exhibited low electrical resistivity/high conductivity and the highest gamma activities and lowest neutron counts. These responses indicated the presence of clays with large amounts of bound water. No measurable transmissivity was detected in the lower or upper parts of the White River Group at the well site.

The Arikaree Group displayed the lowest gamma activity, intermediate to high electrical resistivity, high neutron counts, and high gamma-gamma density. These responses indicated clean sandstones with relatively few fines. Fractures in these competent rocks likely contribute roughly 8 percent of the total transmissivity at the well site.

Normal-resistivity and gamma logs separated the Ogallala Formation into a lower, finer grained zone (lower resistivity and higher gamma activity), a middle coarser grained zone (higher resistivity and lower gamma activity), and an upper, finer grained zone with sporadic coarse-grained beds. The lower zone does not appear to be very permeable and may contribute less than the underlying Arikaree Group to the total transmissivity at the well site. The middle zone is characterized by fewer fine-grained beds and contributed a larger percent of the transmissivity than the underlying units combined. The upper zone is more permeable and, in combination with the overlying alluvium, accounts for more than 70 percent of the total transmissivity at the well site.

References Cited

Archie, G.E., 1942, The electrical resistivity log as an aid in determining some reservoir characteristics: Transactions, American Institute of Mining, Metallurgical and Petroleum Engineers, v. 146, p. 54–62.

Barrash, W., and Morin, R.H., 1987, Hydrostratigraphy and distribution of secondary permeability in the Brule Formation, Cheyenne County, Nebraska: Geological Society of America Bulletin, v. 99, p. 445–462.

Biella, G., Lozej, A., and Tabacco, I., 1983, Experimental study of some hydrogeophysical properties of unconsolidated porous media: Ground Water, v. 21, no. 6, p. 741–751.

Gutentag, E.D., Heimes, F.J., Krothe, N.C., Luckey, R.R., and Weeks, J.B., 1984, Geohydrology of the High Plains aquifer in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming: U.S. Geological Survey Professional Paper 1400-B, 63 p.

Hearst, J.R., Nelson, P.H., and Paillet, F.L., 2000, Well logging for physical properties, 2nd ed.: New York, Wiley, 442 p.

Keys, W.S., 1990, Borehole geophysics applied to groundwater investigations: U.S. Geological Survey Techniques of Water-Resources Investigations, book 2, chap. E2, p. 49–82, 109–113.

Kwader, T., 1985, Estimating aquifer permeability from formation resistivity factors: Ground Water, v. 23, no. 6, p. 762–766.

Molz, F.J., and Young, S.C., 1993, Development and application of borehole flowmeters for environmental assessment: The Log Analyst, v. 34, no. 1, p. 13–23.

Paillet, F.L., and Cheng, C.H., 1991, Acoustic waves in boreholes: Boca Raton, Fla., CRC Press, 264 p.

Pettijohn, R.A., and Chen, H.H., 1983, Geohydrology of the High Plains aquifer system in Nebraska: U.S. Geological Survey Open-File Report 82–502, 3 sheets, scale 1:750,000.

Schultz, C.B., and Stout, T.M., 1955, Classification of Oligocene sediments in Nebraska: University of Nebraska State Museum Bulletin, v. 4, no. 2, p. 17–52.

Appendix—Geophysical Logging Tools and Their Design Specifications

[in., inch; API, American Petroleum Institute; °C, degrees Celsius; mv, millivolts; mmho/m, millimhos per meter; cgs, centimeter-gram-second; g/cc, grams per cubic centimeter; kHz, kilohertz; microsec/ft, microseconds/foot; <, less than]

3-arm caliper	
Manufacturer	Century Geophysical Corporation
Model	9065
Specifications	Diameter range: 2.0–30.0 in. Accuracy: ± 0.15 in.
Multifunction	
Manufacturer	Century Geophysical Corporation
Model	8144
Specifications	Natural gamma activity Range: 0–400,000 API units. Accuracy: ± 5 percent 16N and 64N normal resistivity Range: 0–2,000 ohm-meters. Accuracy: ± 5 percent Temperature Range: 0–70°C. Accuracy: ± 5 percent Fluid resistivity Range: 1–100 ohm-meters. Accuracy: ± 5 percent Spontaneous potential Range: –400 to +400 mv. Accuracy: ± 5 percent
Electromagnetic–induction conductivity	
Manufacturer	Century Geophysical Corporation
Model	9512
Specifications	Conductivity Range: 5–3,000 mmho/m. Accuracy: ± 5 percent Natural gamma activity Range: 0–10,000 API units. Accuracy: ± 5 percent
Magnetic susceptibility/deviation	
Manufacturer	Century Geophysical Corporation
Model	9620
Specifications	Magnetic susceptibility Range: 0–90,000 cgs. Accuracy: ± 5 percent Natural gamma activity Range: 0–10,000 API units. Accuracy: ± 5 percent X-Y inclinometers Range: 0–90°. Accuracy: ± 0.5° Azimuth Range: 0–360°. Accuracy: ± 2°
Compensated density	
Manufacturer	Century Geophysical Corporation
Model	9239
Specifications	Near density Range: 0.5–3.5 g/cc. Accuracy: ± 0.05 g/cc Far density Range: 0.5–3.5 g/cc. Accuracy: ± 0.05 g/cc Caliper Range: 2.0–14.0 in. Accuracy: ± 0.25 in.
Neutron	
Manufacturer	Mount Sopris Instrument Company
Model	2NUA-1000
Specifications	Detector HE-3 tube Range: 0–100,000 counts per second. Accuracy: ± 0.5 percent
Full-waveform sonic	
Manufacturer	Mount Sopris Instrument Company
Model	2SAA-1000/F
Specifications	Multi-frequency (1–30 kHz) wide-band transducer Accuracy: ± 1 percent. Resolution: <1microsec/ft

Branch of Regional Research

Publishing support provided by:
Denver Publishing Service Center

For more information concerning this publication, contact:
USGS Central Region Geospatial Information Office
Federal Center
Box 25286
Denver, CO 80225
1-888-ASK-USGS

USGS

Anderson and others—**Geophysical Log Analysis of Selected Test Holes in the Central Platte River Basin, Nebraska—SIR 2009–5033**

Printed on recycled paper