Hydrogeology and Leachate Plume Delineation at a Closed Municipal Landfill, Norman, Oklahoma

Water-Resources Investigations Report 01–4168

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By C.J. Becker

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CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATIONS

Multiply	By	To obtain
Length		
centimeter (cm)	0.3937	inch
millimeter (mm)	0.03937	inch
meter (m)	3.281	foot
meter per second (m/s)	3.281	foot per second
meter per day (m/d)	3.281	foot per day
kilopascal (kPa)	0.1450	pound per square inch

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:

$$°C=(°F-32)/1.8$$

Sea level: In this report "sea level" refers to the North American Vertical Datum of 1988--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada.

Altitude, as used in this report, refers to distance above sea level.

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 ˚C).

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ABSTRACT

The City of Norman operated a solid-waste municipal landfill at two sites on the Canadian River alluvium in Cleveland County, Oklahoma from 1970 to 1985. The sites, referred to as the west and east cells of the landfill, were originally excavations in the unconsolidated alluvial deposits and were not lined. Analysis of ground-water samples indicate that leachate from the west cell is discharging into an adjacent abandoned river channel, referred to as the slough, and is migrating downgradient in ground water toward the Canadian River. The report describes the hydrogeologic features at the landfill, including the topography of the bedrock, water-level changes in the alluvial aquifer, and delineates the leachate plume using specific conductance data.

The leading edge of the leachate plume along the 35–80 transect extended over 250 meters downgradient of the west cell. The leading edge of the leachate plume along the 40–SOUTH transect had moved about 60 meters from the west cell in a south-southwesterly direction and had not moved past the slough as of 1997. Specific conductance measurements exceeding 7,000 microsiemens per centimeter at site 40 indicate the most concentrated part of the plume remained in the upper half of the alluvial aquifer adjacent to the west cell.

The direction of ground-water flow in the alluvial aquifer surrounding the landfill was generally north-northeast to south-southwest toward the river. However, between the west cell and the slough along the 40–SOUTH transect, head measurements indicate a directional change to the east and southeast toward a channel referred to as the sewage outfall. Near the 35–80 transect, at 0.5 meter below the water table and at the base of the aquifer, the direction of ground-water flow was south-southeast with a gradient of about 30 centimeters per 100 meters.

Generally, ground-water levels in the alluvial aquifer were higher during the winter months and lower during summer months, due to a normal decrease in precipitation and increased evapotranspiration in the summer. Hydrographs show temporal water-level changes in ground water and the slough, indicating a hydrologic connection between the alluvial aquifer and the slough.

INTRODUCTION

The City of Norman operated a solid-waste municipal landfill at two sites on the Canadian River alluvium in Cleveland County, Oklahoma from 1970 to 1985. The sites, referred to as the west and east cells of the landfill, were originally excavations in the unconsolidated alluvial deposits and were not lined. Operations stopped in 1985 and the west and east cells were closed and covered with a clay cap (Dixon and Popoola, 1992, p. 8). Analysis of ground-water samples indicate that leachate from the west cell is discharging into an adjacent abandoned river channel, referred to as the slough, and is migrating downgradient in ground water toward the Canadian River (fig. 1) (Schlottmann, 2001). See Schlottmann (2001) for a description of waste disposal practices before 1970 on

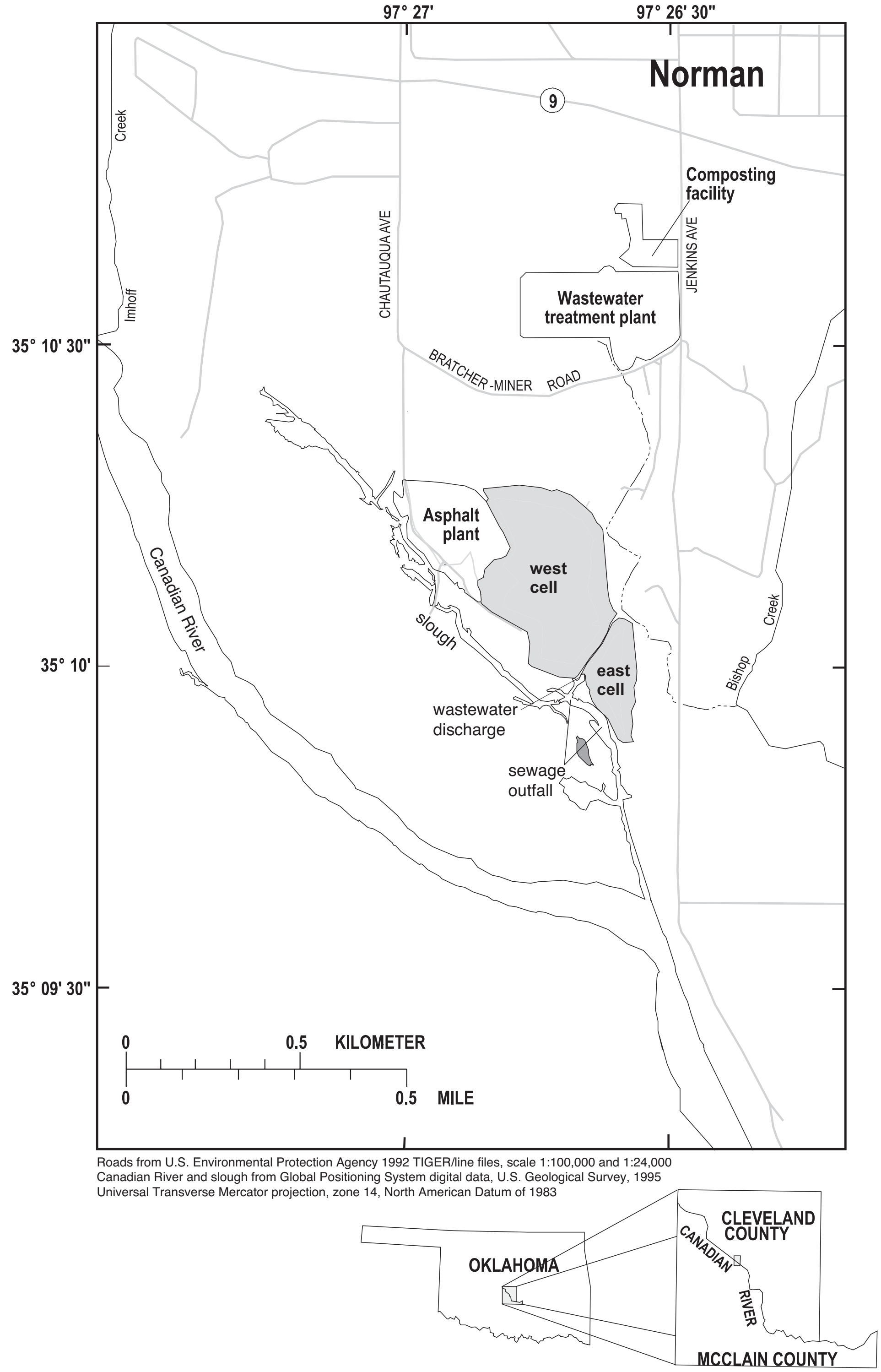


Figure 1. Locations of the study area and the Canadian River near Norman, Oklahoma (modified from Schlottmann, 2001).

the Canadian River alluvium near the west and east cells.

This landfill is similar to thousands of abandoned landfills situated on sandy river bank deposits in Oklahoma and nationwide. Such sites are common locations for landfills because they are easy to excavate; however, they also typically contain alluvial aquifers that can be important sources of drinking water. This landfill was selected for study in 1994 as part of the Toxic Substances Hydrology Program of the U.S. Geological Survey and provides scientists the opportunity to study ground-water contamination resulting from a typical older municipal landfill. One objective of the study is to describe the site hydrogeology and the leachate plume distribution in the shallow alluvial aquifer at the landfill.

Purpose and Scope

The purpose of this report is to describe hydrogeologic features at the landfill, including the topography of the bedrock, and water-level changes in the alluvial aquifer, and to delineate the leachate plume using specific conductance data.

Data used in this report include drilling information, shallow seismic data, continuous ground-water level measurements in six wells, continuous surface-water measurements in the slough, daily precipitation, potentiometric head measurements near the water table and at the base of the alluvial aquifer in 15 wells, and specific conductance of ground water from October 1995 to November 1997 (figs. 2 and 3).

Site Description

The closed landfill is located on the northeast side of the Canadian River on Quaternary alluvium in Cleveland County, Oklahoma. The west and east cells are about 186,000 square meters in area and rise 12 to 15 meters above the alluvium. A buried wastewater discharge pipe separates the cells and discharges effluent from the Norman Wastewater Treatment Plant into a stream referred to as the sewage outfall (fig. 1). The sewage outfall is a channel that has been eroded into the alluvial aquifer by the wastewater effluent and discharge from the slough. The slough does not have an obvious source of water and is presumed to be fed by ground-water discharge and precipitation (Schlottmann, 2001). The combined waters in the sewage outfall flow south to the Canadian River (fig. 1). The Canadian River flows in a southeasterly direction and is about 600 meters southwest of the cells. In the mid-1980s, the river flowed in the slough along the southwest edge of the landfill. The river moved to its present channel after a flood in 1986.

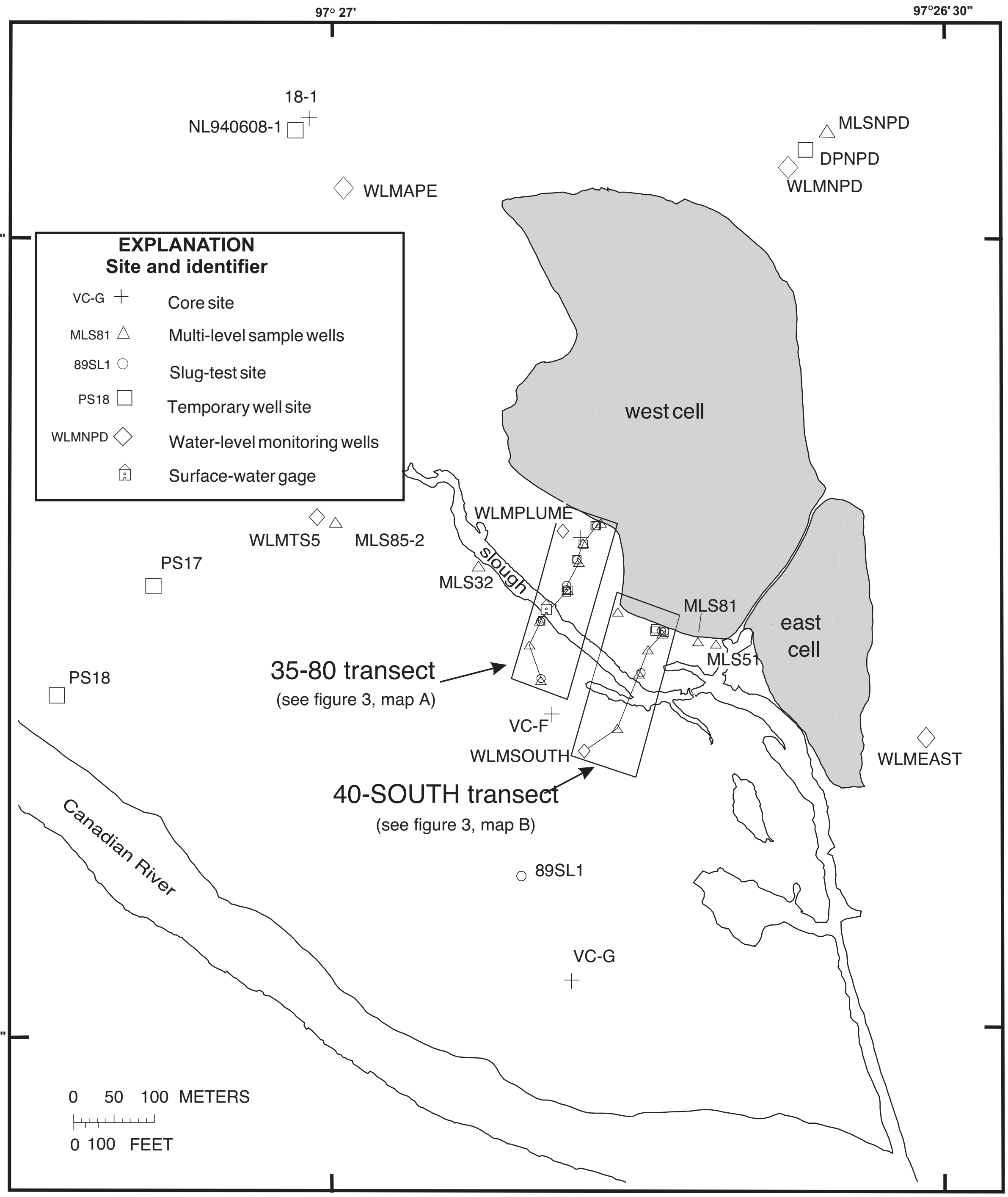
The Canadian River alluvial aquifer supplies ground water for many purposes in Cleveland County; however, there are no wells near the landfill that produce water for human consumption (Scott Christenson, U.S. Geological Survey, oral commun., 2001).

The alluvial aquifer generally consists of unconsolidated lenticular beds of clay, silt, sand, and gravel overlain by dune sand and is highly permeable. Hydraulic conductivity of the alluvium, excluding clayey layers, ranges from 8.4×10^{-7} to 2.8×10^{-4} meter per second (7.3×10^{-2} to 24.2 meters per day), with a median value of 6.6×10^{-5} meter per second (5.7 meters per day) (Scholl and Christenson, 1998, p. 18). Underlying the alluvium is the Permian Hennessey Group, which consists of red-brown blocky shale containing layers of orange-brown siltstone and fine-grained sandstone (Bingham and Moore, 1975). The thickness of the Hennessey Group is about 61 meters at Norman (Wood and Burton, 1968, p. 22). The Hennessey Group is considered a confining unit because the primarily shale and siltstone beds have relatively low hydraulic conductivity.

The alluvial plain between the landfill and the river is relatively flat, with small sand dunes covered with willow and cottonwood trees, shrubs, and grasses (Schlottmann, 2001). An asphalt plant operates at the western edge of the west cell. The eastern edge of the landfill is undeveloped and heavily wooded.

Acknowledgments

The author thanks Gary and Chris Lohne with the Norman Asphalt Company for allowing access to the landfill and John Potts for allowing access to his property and wells. The author thanks Jim Berry, Director of Public Works for the City of Norman, David St. John with the Norman Police Department, and Ralph Arnet, Debra Smith, and Lyle Milby with the Norman Wastewater Treatment Plant for their ongoing assistance with the Norman Landfill investigation.



Global positioning system digital data, U.S. Geological Survey, 1995
Universal Transverse Mercator projection, zone 14, North American Datum of 1983

Figure 2. Locations of west and east cells and selected wells at a closed municipal landfill, Norman, Oklahoma.

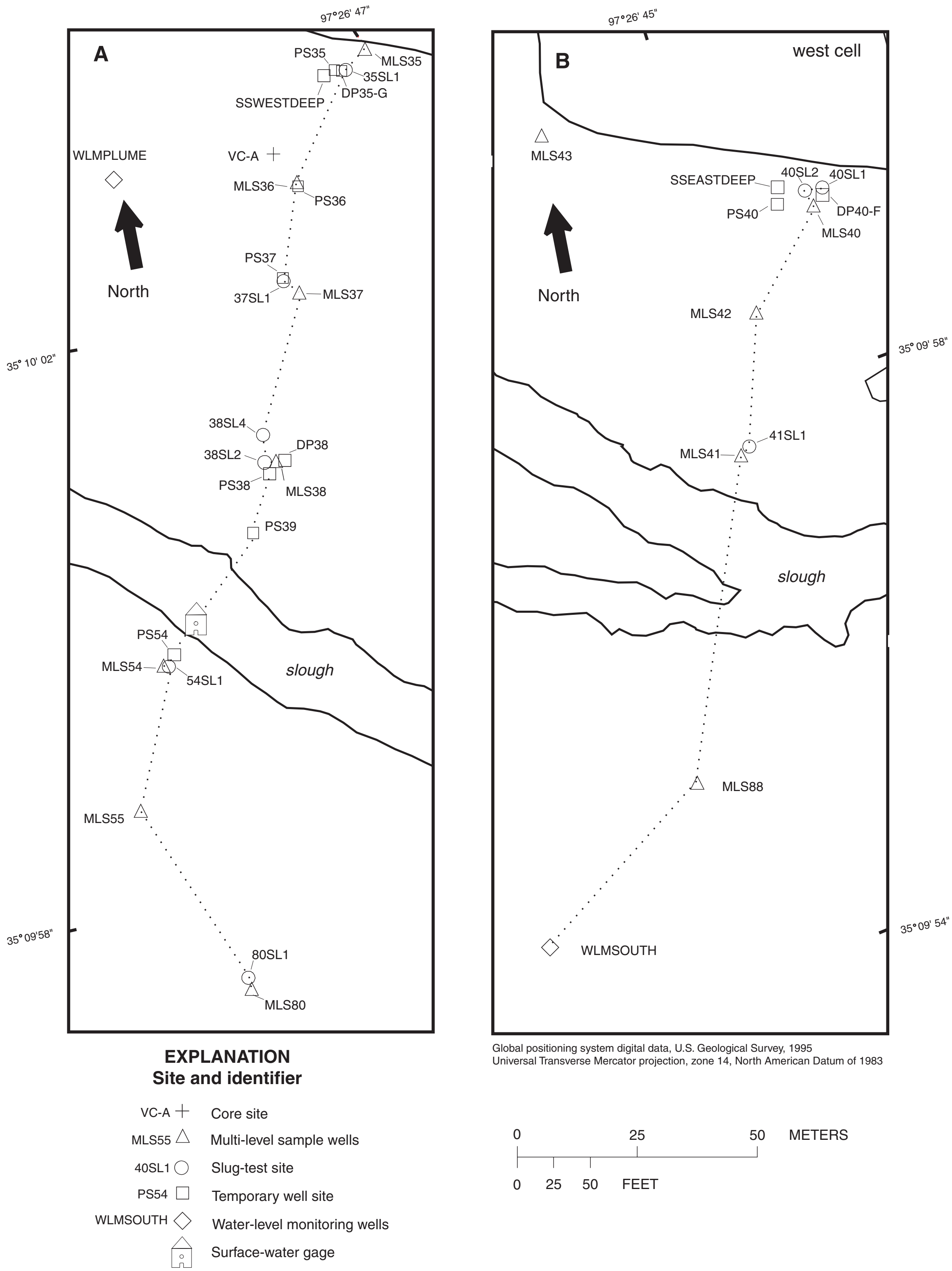


Figure 3. Well sites along 35–80 transect (A) and 40–SOUTH transect (B).

HYDROGEOLOGY

The hydrogeology of the alluvial aquifer at the landfill was characterized by a map showing the altitude of the underlying bedrock surface and by hydrographs showing changes in ground-water levels. Graphs show changes in surface-water levels in the slough and daily precipitation at the landfill.

Altitude of the Bedrock Surface

A map of the altitude of the bedrock surface (Hennessey Group) surrounding the closed landfill was constructed using drilling information at 42 sites (fig. 4 and Appendix 1) and shallow seismic data collected along 19 survey lines (L1-L9, L33-L42) (fig. 4). Forty sites were drilled by the U.S. Geological Survey as multi-level sample wells, slug test sites, temporary wells, and core sites. Information from two wells at the City of Norman Composting Facility was used (fig. 1). Seismic data were collected by a shallow seismic shear-wave refraction method using a modified delay-time interpretation program (Jeffrey Lucius and Wilfred Hasbrouck, U.S. Geological Survey, written commun., 1998).

Water Levels and Precipitation

Six ground-water level monitoring wells (WLMAPE, WLMEAST, WLMNPD, WLMPLUME, WLMSOUTH, and WLMTS5), installed during 1997, continuously measured ground-water levels around the east and west cells. Each well had a well screen 1.39 meters in length and was positioned to intersect the water table throughout the year. The ground-water levels in the wells were measured by a vibrating-wire vented transducer, which recorded ground-water levels at 30-minute intervals with an accuracy of 3.5 centimeters. The measuring point elevations of the wells were measured to an accuracy of about 1 centimeter. Hydrographs in figures 5 and 6 show changes in ground-water levels for part of 1997 and all of 1998.

Surface-water levels at the slough were recorded at 30-minute intervals by use of a gas-purge transducer with an accuracy of 0.061 centimeter. Graphs in figure 7 show surface-water levels measured in the slough from May 1996 to December 1998. Graphs in figure 8 show daily precipitation measured at the landfill near the slough from May 1996 to September 1998.

Ground-water levels

Generally, ground-water levels in the alluvium were higher during the winter months and lower during summer months, due to a normal decrease in precipitation and increased evapotranspiration in the summer (figs. 5 and 6). Change of ground-water levels from evapotranspiration were recorded as small, less than 5 centimeters, daily fluctuations during the growing season (fig. 6). Well WLMEAST and well WLMNPD had the largest change in ground-water levels recorded in 1998, varying more than 2 meters. Well WLMTS5 had the smallest change, 1.68 meters. Hydrographs show ground-water levels generally rise within 24 hours of a precipitation event, which indicates the alluvium has high infiltration rates, confirming the high permeabilities measured.

Water levels in the slough were similar to ground-water levels; water in the slough generally was 0.5 to more than 1.0 meter higher during winter months and decreased during summer months (fig. 7). The slough was dry during part of the summer of 1998. Hydrographs show temporal water-level changes in ground water and the slough, indicating a hydrologic connection between the alluvial aquifer and the slough (fig. 8). Beaver dams at the southeast end of the slough may have affected water levels. During March 1997, an instantaneous drop in the water level of about 0.25 meter may have been the result of a beaver dam breaking.

Precipitation

Daily precipitation was measured near the surface-water gage at the slough by a tipping-bucket rain gage (fig. 9). The total precipitation from January 1 to December 31, 1997, was 107 centimeters, about 18 percent above the 30 year (1961-90) average annual precipitation of 91 centimeters (Johnson and Duchon, 1994).

LEACHATE PLUME DELINEATION

Maps showing the direction of leachate plume movement were constructed using potentiometric head measurements near the water table and at the base of the aquifer. Specific conductance was used to differentiate leachate-contaminated water from uncontaminated ground water in background wells upgradient from the west cell. Two transects and two areal maps

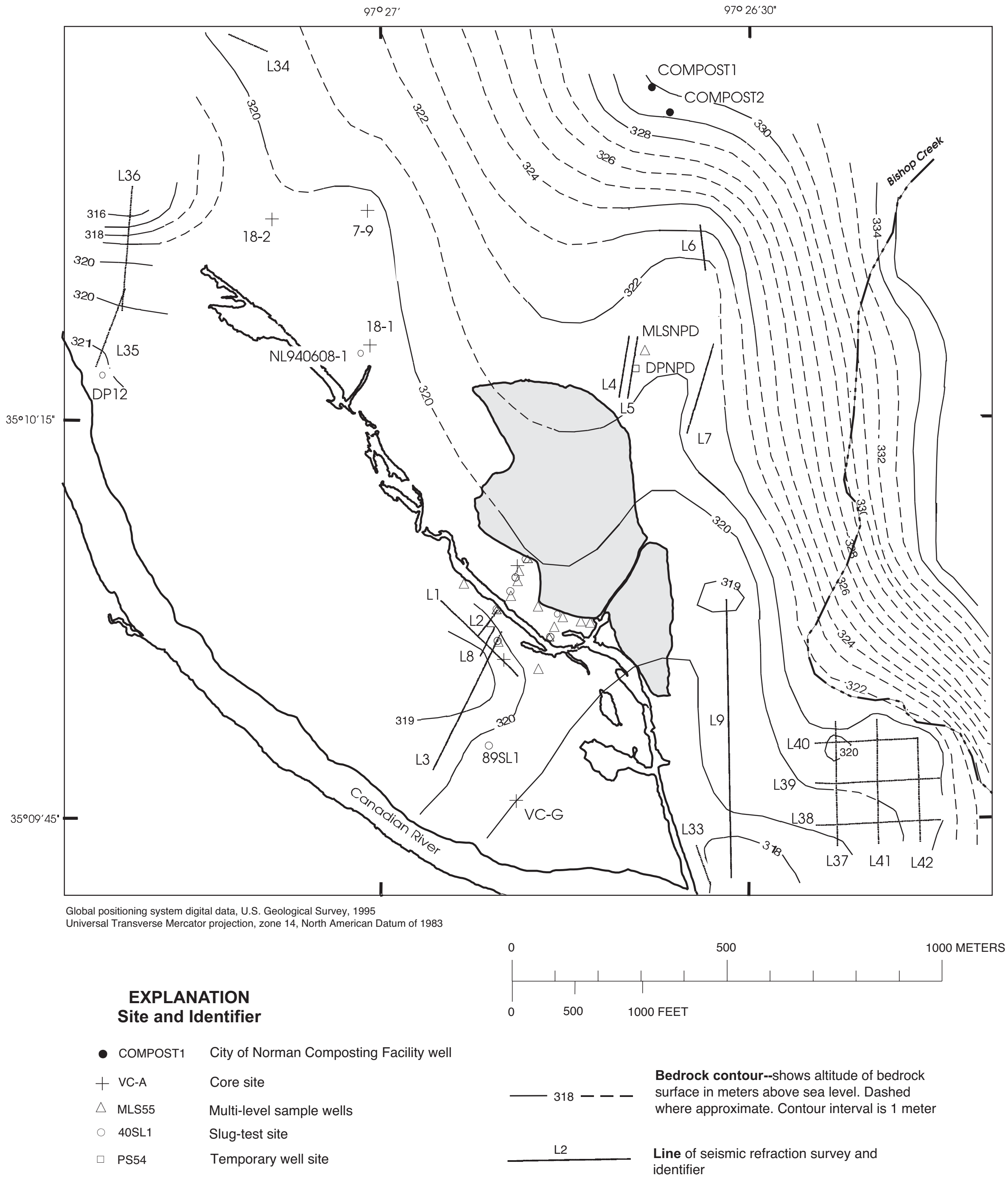


Figure 4. Altitude of bedrock (base of aquifer) near a closed municipal landfill, Norman, Oklahoma.

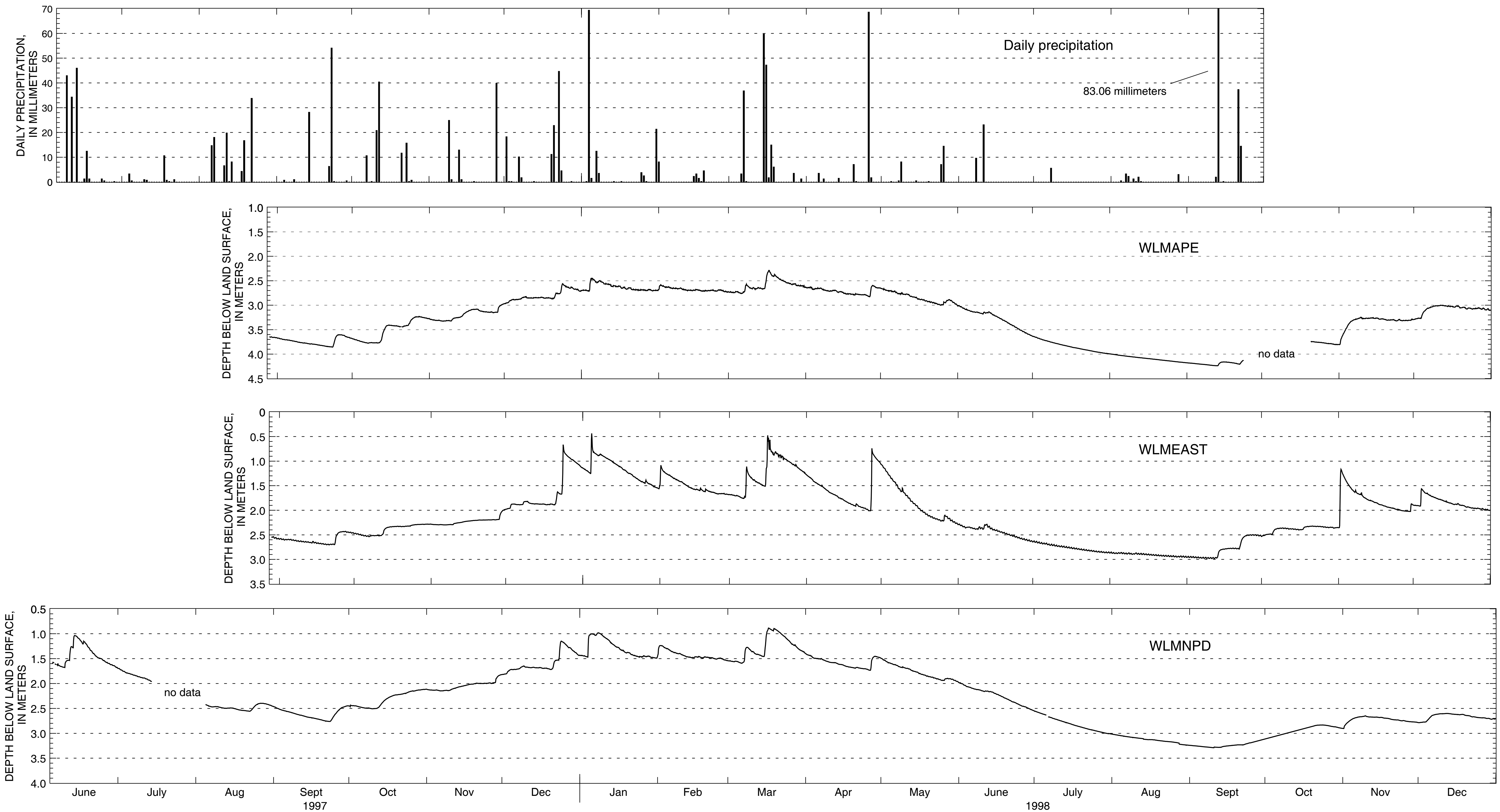


Figure 5. Changes in precipitation and ground-water levels at wells WLMAPE, WLMEAST, and WLMNPD near a closed municipal landfill, Norman, Oklahoma.

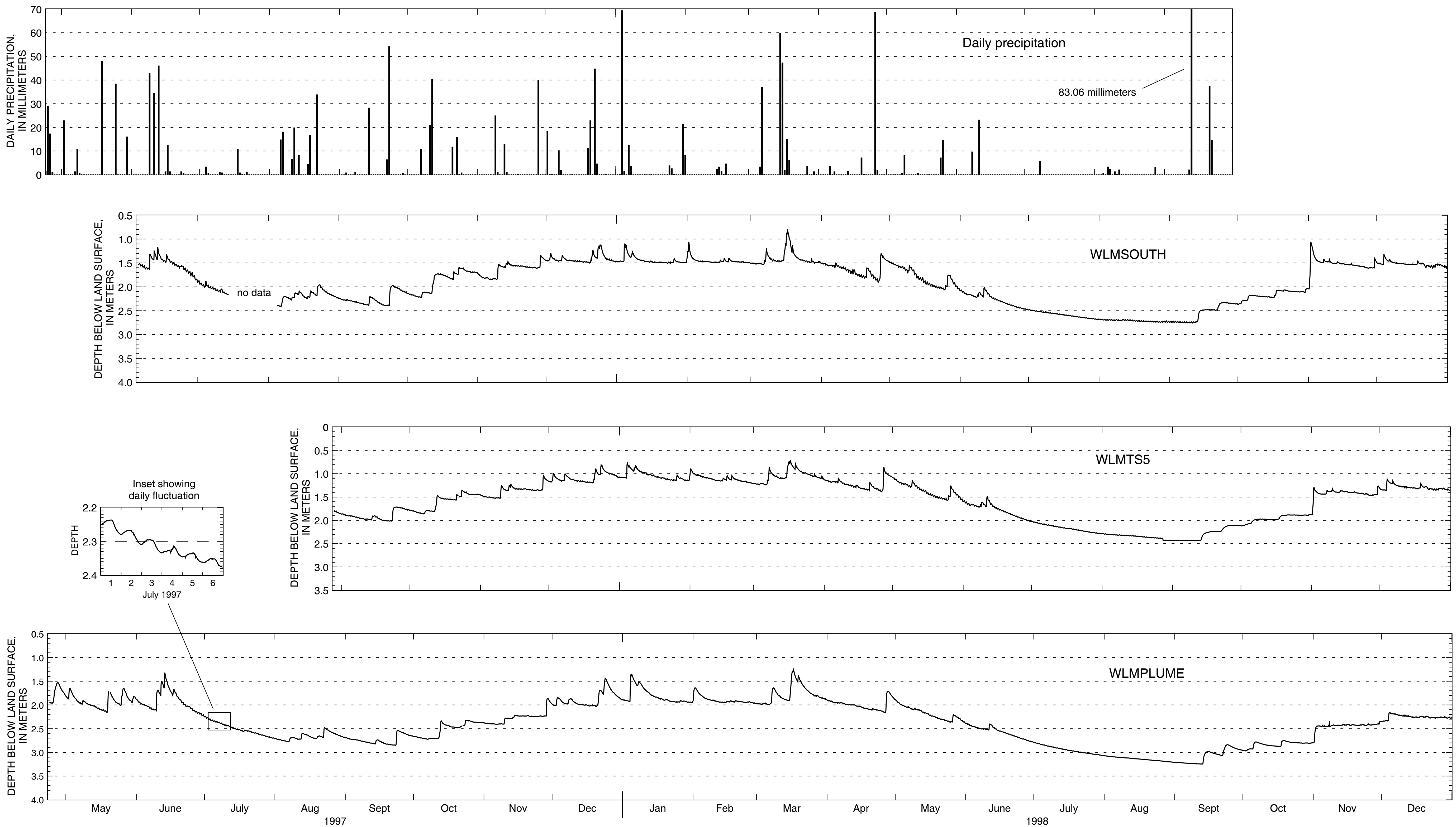


Figure 6. Changes in precipitation and ground-water levels at wells WLMSOUTH, WLMTS5, and WLMPLUME near a closed municipal landfill, Norman, Oklahoma.

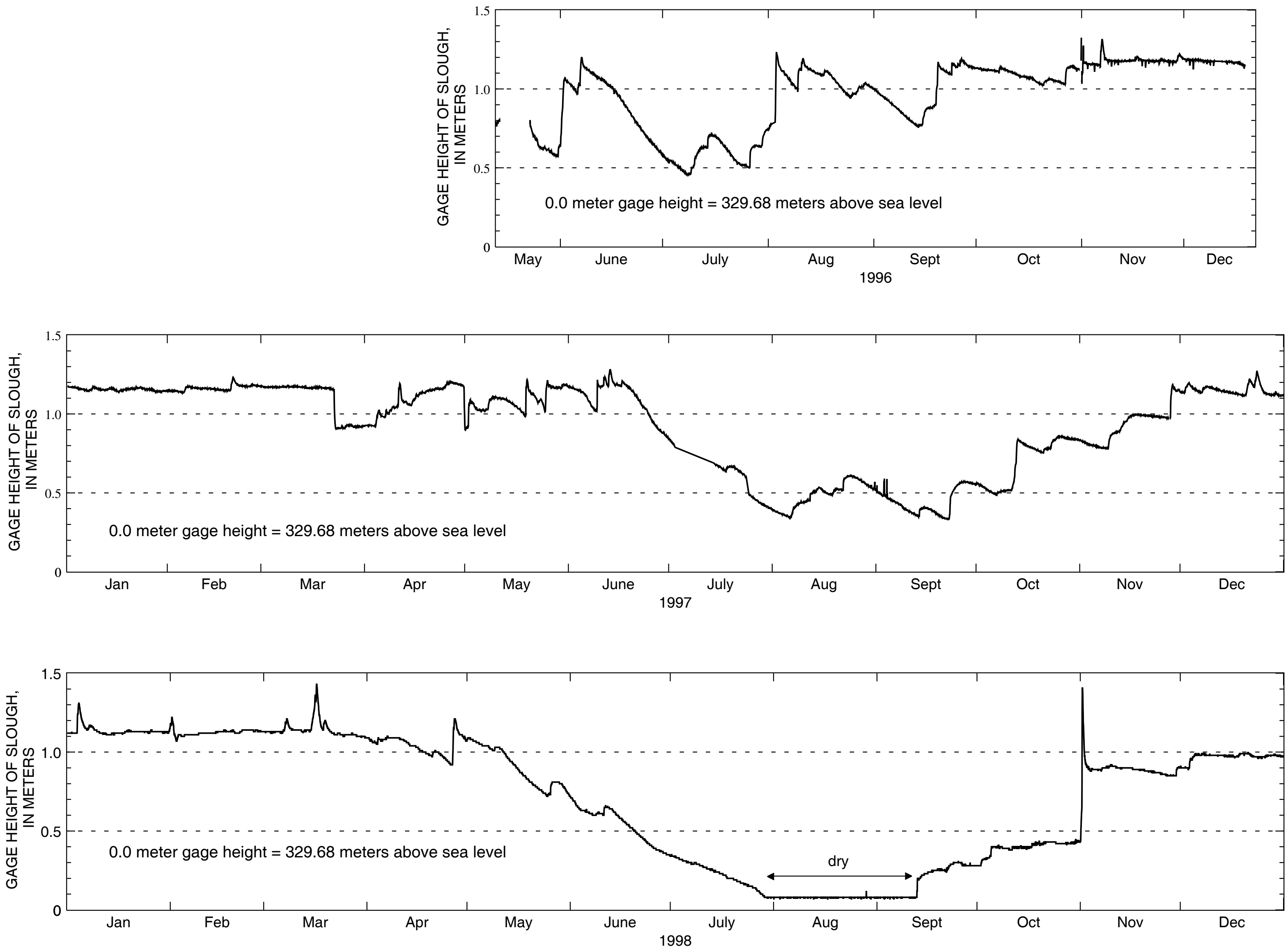


Figure 7. Gage height of slough at a closed municipal landfill, Norman, Oklahoma, May 1996 through August 1998.

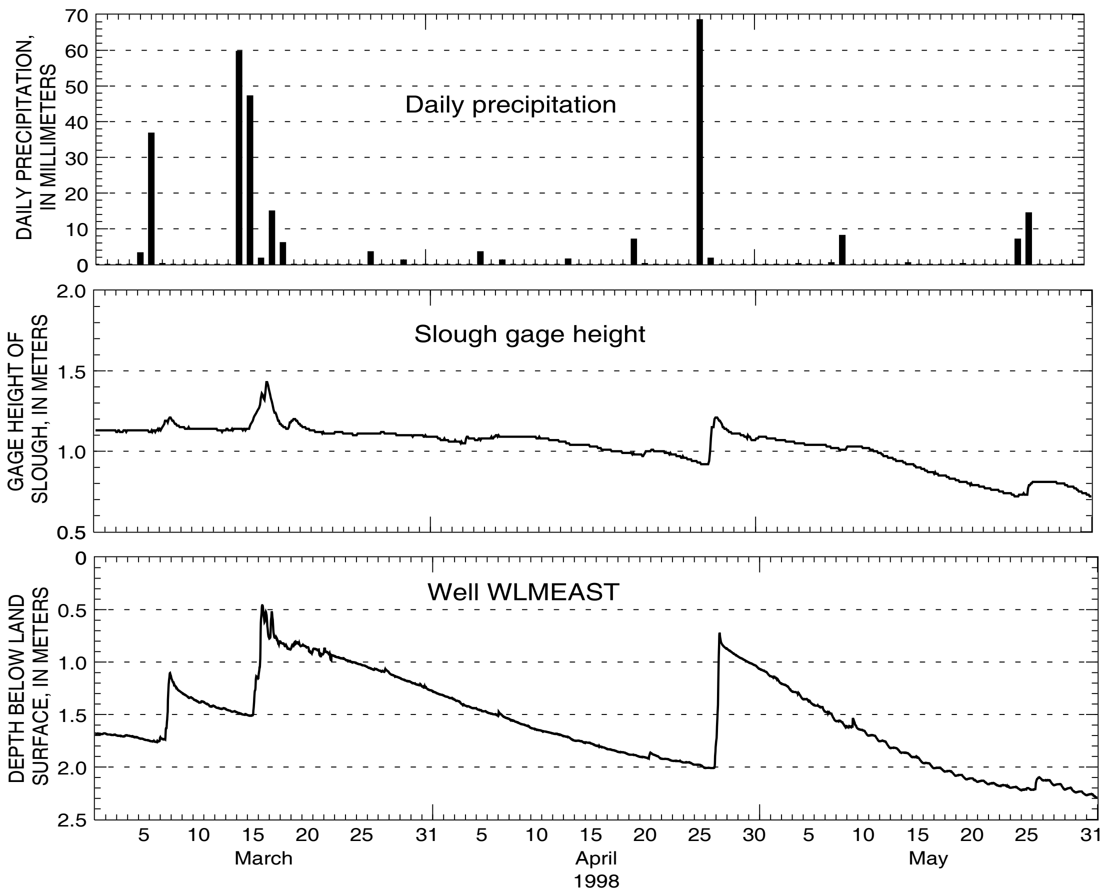


Figure 8. Daily precipitation, gage height of slough, and ground-water levels at well WLMEAST at a closed municipal landfill, March, April, and May 1998. Hydrographs show temporal water-level changes in ground water and the slough, indicating a hydrologic connection. Ground-water levels generally rise within 24 hours of precipitation event.

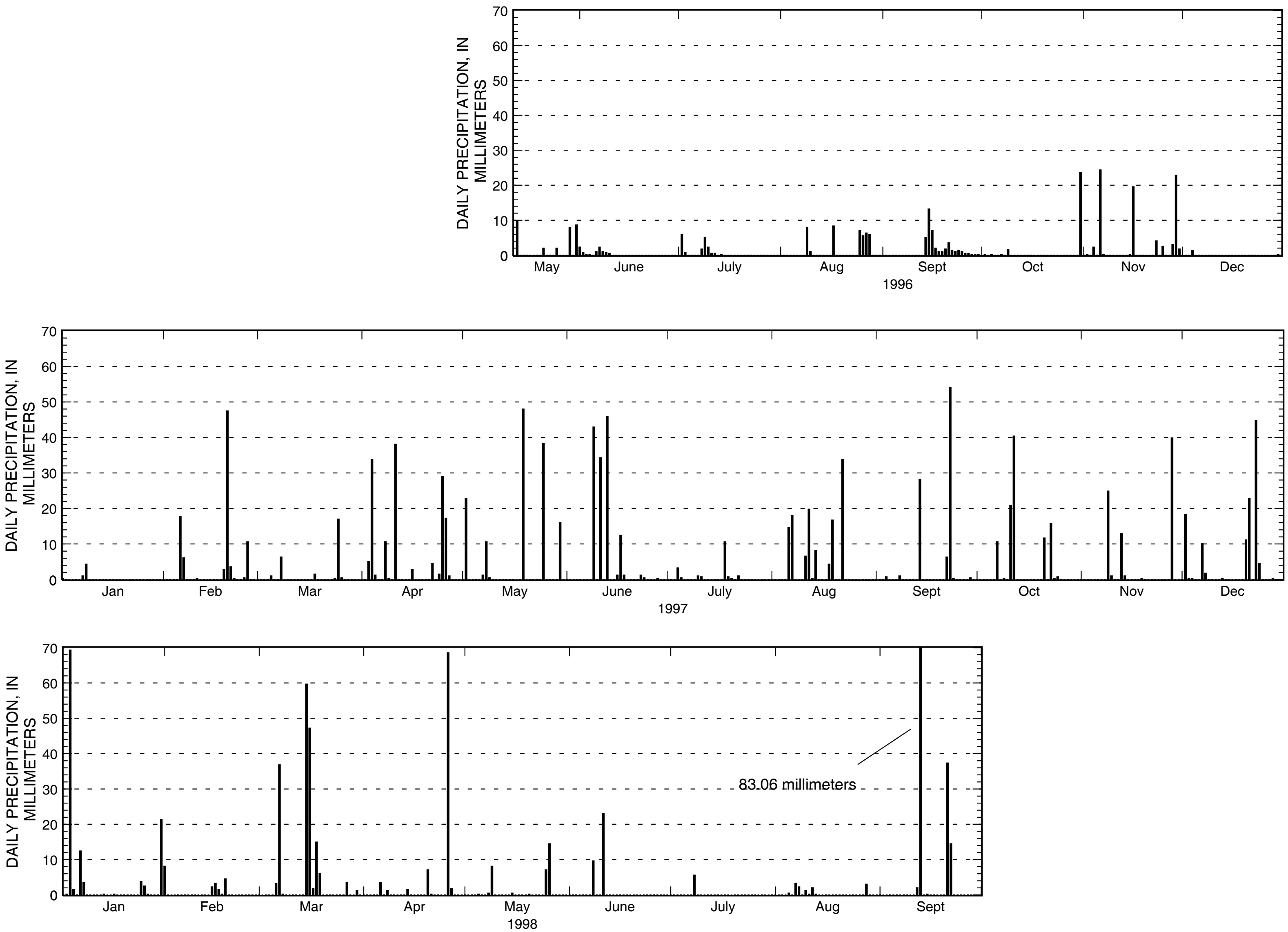


Figure 9. Daily precipitation at a closed municipal landfill, Norman, Oklahoma, May 1996 through September 1998.

of specific conductance were constructed to delineate the vertical and horizontal distribution of the leachate plume.

Data Collection Sites

Data were collected from wells installed using several construction methods. The ground-water level monitoring well network was used for continuous ground-water level measurements and the multi-level sampler network permitted sampling and measurements from seven discrete intervals at each well location. The 17 multi-level-sampler well sites, 15 south, 1 west, and 1 north of the west cell, were composed of seven nested well casings staggered in length each with a screen 0.11 or 0.12 meter in length. Slug tests were used to measure hydraulic conductivity at 10 sites in temporary drive-point wells (Scholl and Christenson, 1998) (Appendix 1). The specific conductance of the ground water and leachate were measured during slug tests and in other temporary drive-point wells.

Direction of Ground-Water Flow at Shallow and Deep Depths

Potentiometric head was measured in 15 multi-level sampler wells on January 29, 1998. Figures 10 and 11 show the potentiometric surface, from which the direction of ground-water flow can be inferred. The direction of ground-water flow in the alluvial aquifer surrounding the landfill was generally north-northeast to south-southwest toward the river (Scholl and Christenson, 1998, fig. 2). However, between the west cell and the slough along the 40–SOUTH transect, head measurements indicate a directional change to the east and southeast toward the sewage outfall (figs. 10 and 11). Near the 35–80 transect, at 0.5 meter below the water table and at the base of the aquifer, the direction of ground-water flow was south-southwest with a gradient of about 30 centimeters per 100 meters (figs. 10 and 11).

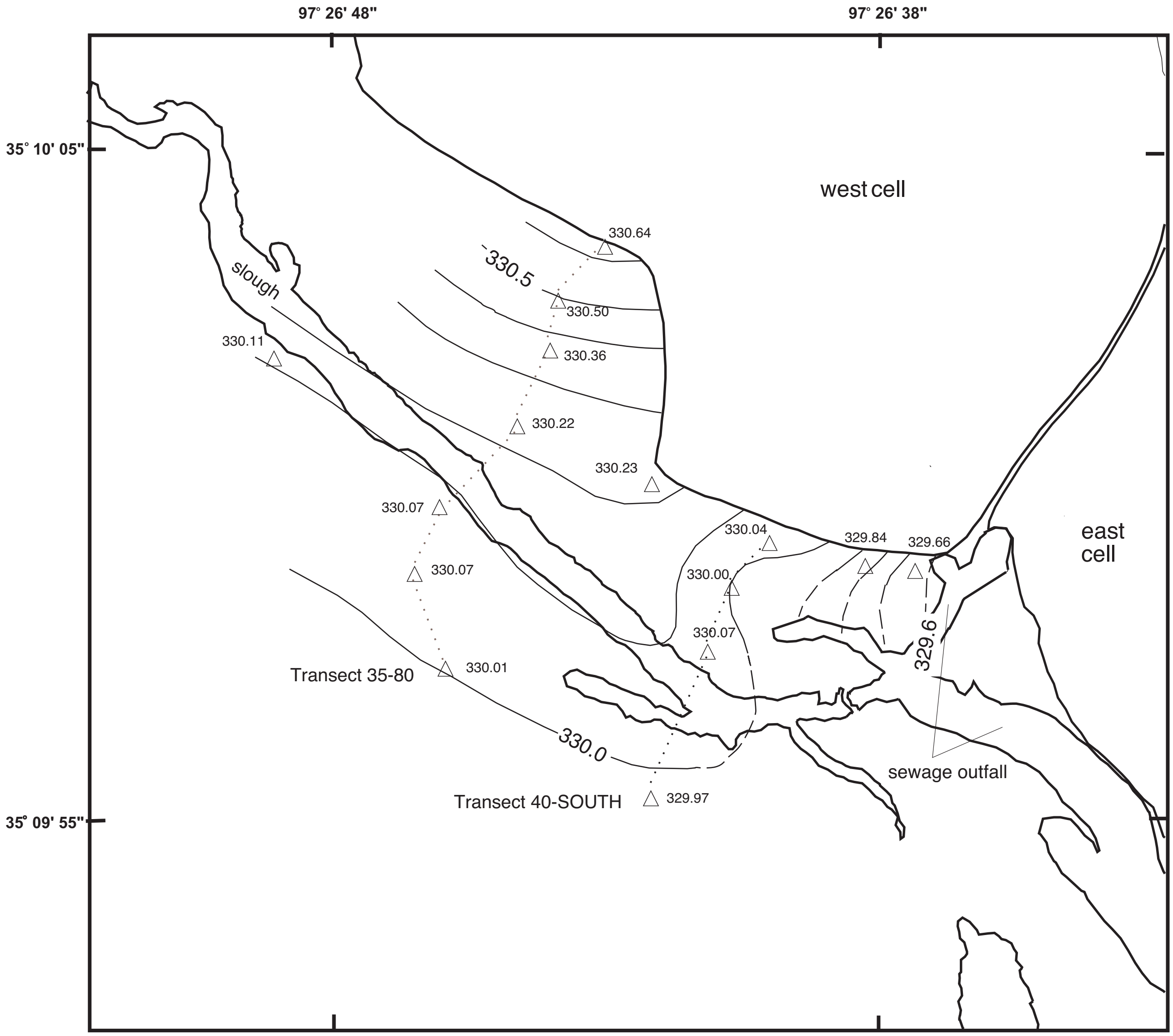
Vertical and Horizontal Plume Distribution Based on Specific Conductance

Maps were constructed from specific conductance data collected in the field from October 1995 to November 1997. The greatest specific conductance was used in the report when multiple measurements were available for a well or sampling point. The 2,000-microsiemens-per-centimeter contour was considered to be the estimated edge of the leachate plume, based on the range of specific conductance measurements in background wells and monitoring wells downgradient of the west cell. The vertical distribution of the leachate plume along the 35–80 and 40–SOUTH transects is shown on figures 12 and 13. The horizontal distribution of the leachate plume is shown at 328 to 329 meters above sea level, near land surface, and at 319 to 320 meters above sea level at the base of the alluvial aquifer (figs. 14 and 15). The selection of intervals for showing the horizontal distribution of leachate was based on the distribution and availability of data.

Along the 35–80 transect, the leachate appears to have flowed into and around a low permeability layer of silt and clay at a depth of about 4 meters (fig. 12). The top of the leachate plume varied from 1.5 to 4.0 meters below land surface and extended under the slough to site 80. Below the clay layer, the plume extended downward to the base of the aquifer and downgradient of site 80. The leading edge of the plume extended more than 250 meters downgradient of the west cell. The plume at the base of the aquifer may be moving in the high permeability gravel layer at the base of the alluvial aquifer (Schlottmann, 2001).

The leading edge of the leachate plume along the 40–SOUTH transect had moved about 60 meters from the west cell in a south-southwesterly direction and had not moved past the slough as of 1997 (fig. 13). Specific conductance measurements exceeding 7,000 microsiemens per centimeter at site 40 indicate the most concentrated part of the plume remained in the upper half of the alluvial aquifer adjacent to the west cell. This may be due to discharge of the plume to the adjacent slough (Schlottmann, 2001). A low permeability layer also appears along this transect at about 5.5 meters below land surface at sites 41 and 42.

At shallow depths, 328 to 329 meters above sea level, the southern edge of the leachate plume was located about 60 meters from the south end of the west cell along transect 40–SOUTH and does not appear to have moved past the slough (fig. 14). However, from the west and southwest sides of the west cell, the leading edge of the plume had moved about 200 meters downgradient from the west cell. The western edge of the plume at shallow depths was located



Global Positioning System digital data, U.S. Geological Survey, 1995
Universal Transverse Mercator projection, zone 14, North American Datum of 1983

0 50 100 METERS

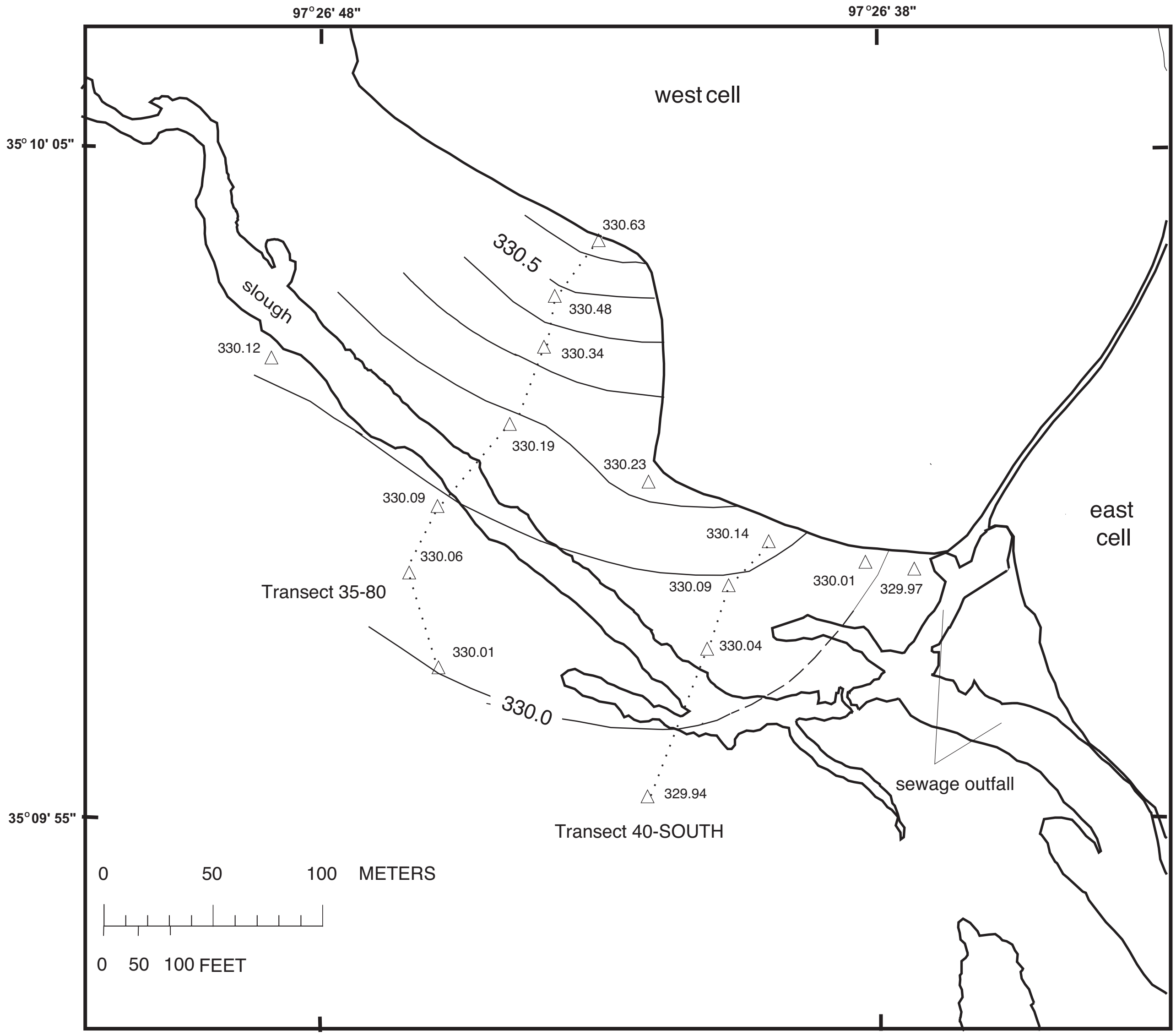
0 50 100 FEET

EXPLANATION
Site and identifier

△ 330.22 **Multi-level sample well--**Number is altitude of potentiometric surface measured 0.5 meter below the water table in meters above sea level

—— 330.0 —— **Potentiometric contour--**Shows altitude above sea level of potentiometric surface of the Canadian River alluvial aquifer, measured 0.5 meter below the water table on January 29, 1998. Contour interval is 0.1 meter. Dashed where estimated

Figure 10. Potentiometric surface of the Canadian River alluvial aquifer near a closed municipal landfill, Norman, Oklahoma, measured in multi-level sample wells 0.5 meter below the water table on January 29, 1998.



Global Positioning System digital data, U.S. Geological Survey, 1995
Universal Transverse Mercator projection, zone 14, North American Datum of 1983

EXPLANATION
Site and identifier

△ 331.14 **Multi-level sample well--**Number is altitude of potentiometric surface measured at the base of the alluvial aquifer in meters above sea level

—— 330.0 — — **Potentiometric contour--**Shows altitude above sea level of potentiometric surface of the Canadian River alluvial aquifer, measured at base of the alluvial aquifer on January 29, 1998. Contour interval is 0.1 meter. Dashed where estimated

Figure 11. Potentiometric surface of the Canadian River alluvial aquifer near a closed municipal landfill, Norman, Oklahoma, measured in multi-level sample wells at base of the alluvial aquifer on January 29, 1998.

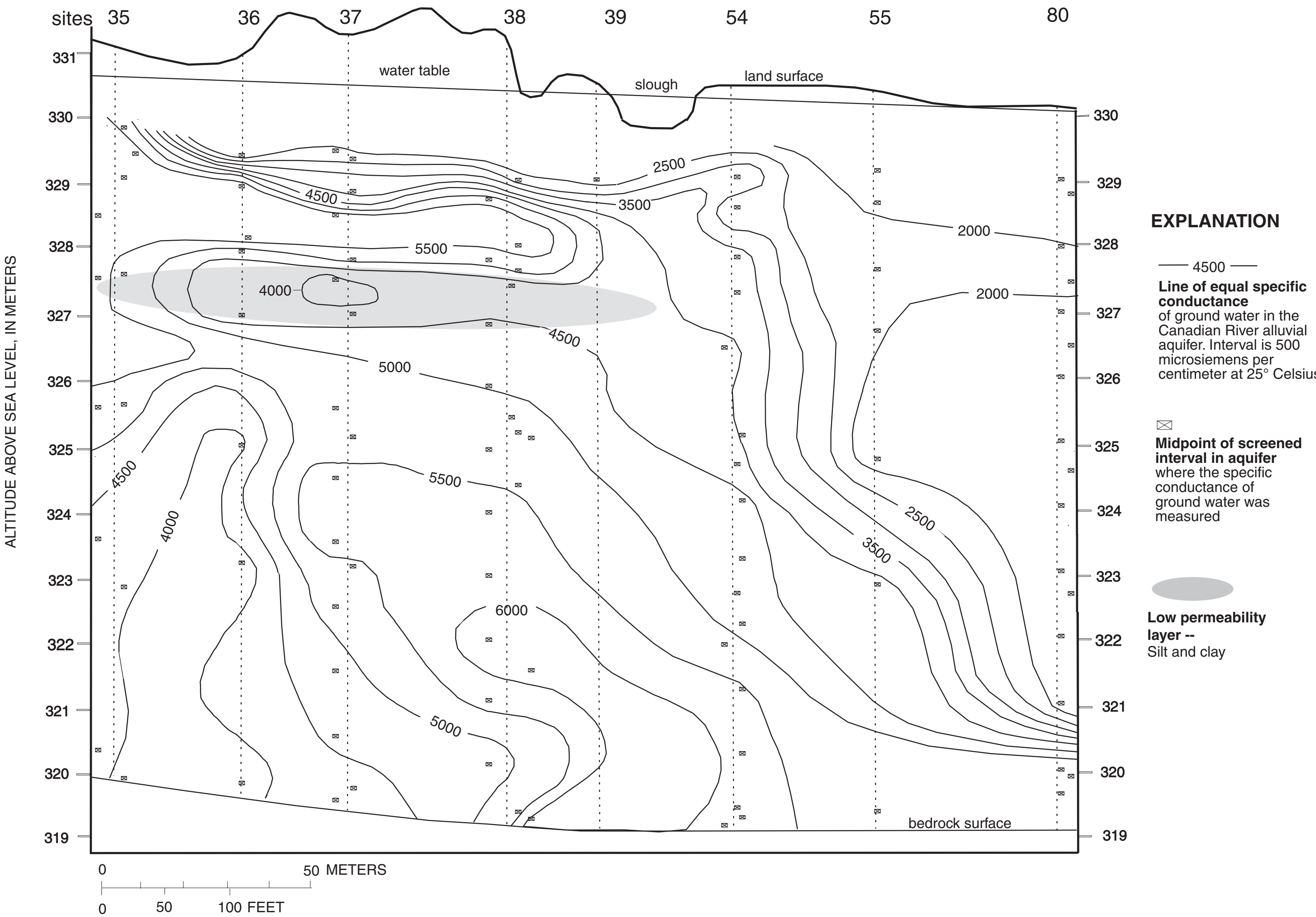


Figure 12. Vertical distribution of leachate plume along 35–80 transect mapped using specific conductance downgradient from a closed municipal landfill, Norman, Oklahoma. Map was constructed using specific conductance measurements collected from October 1995 to November 1997. Altitude of water table was measured January 29, 1998.

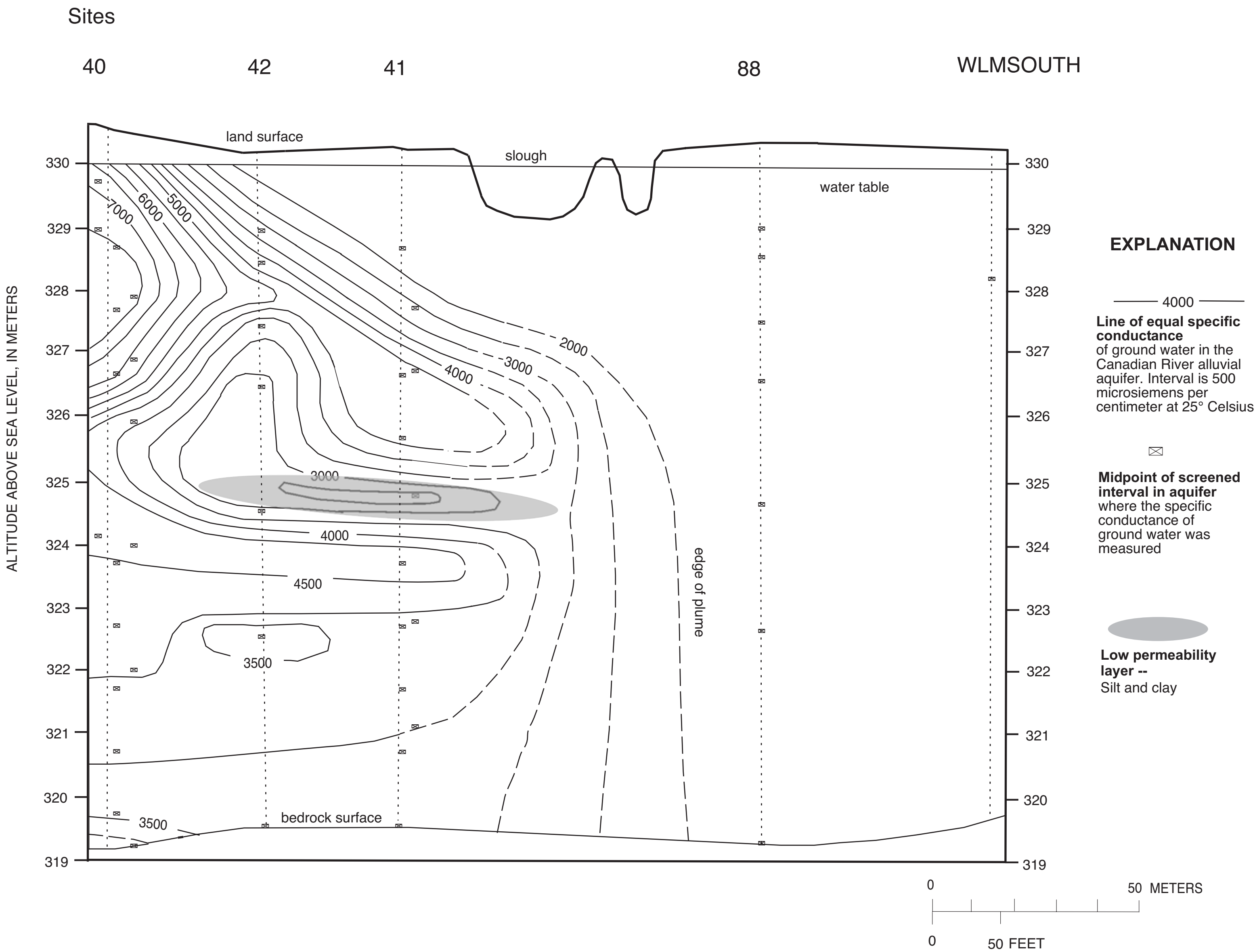
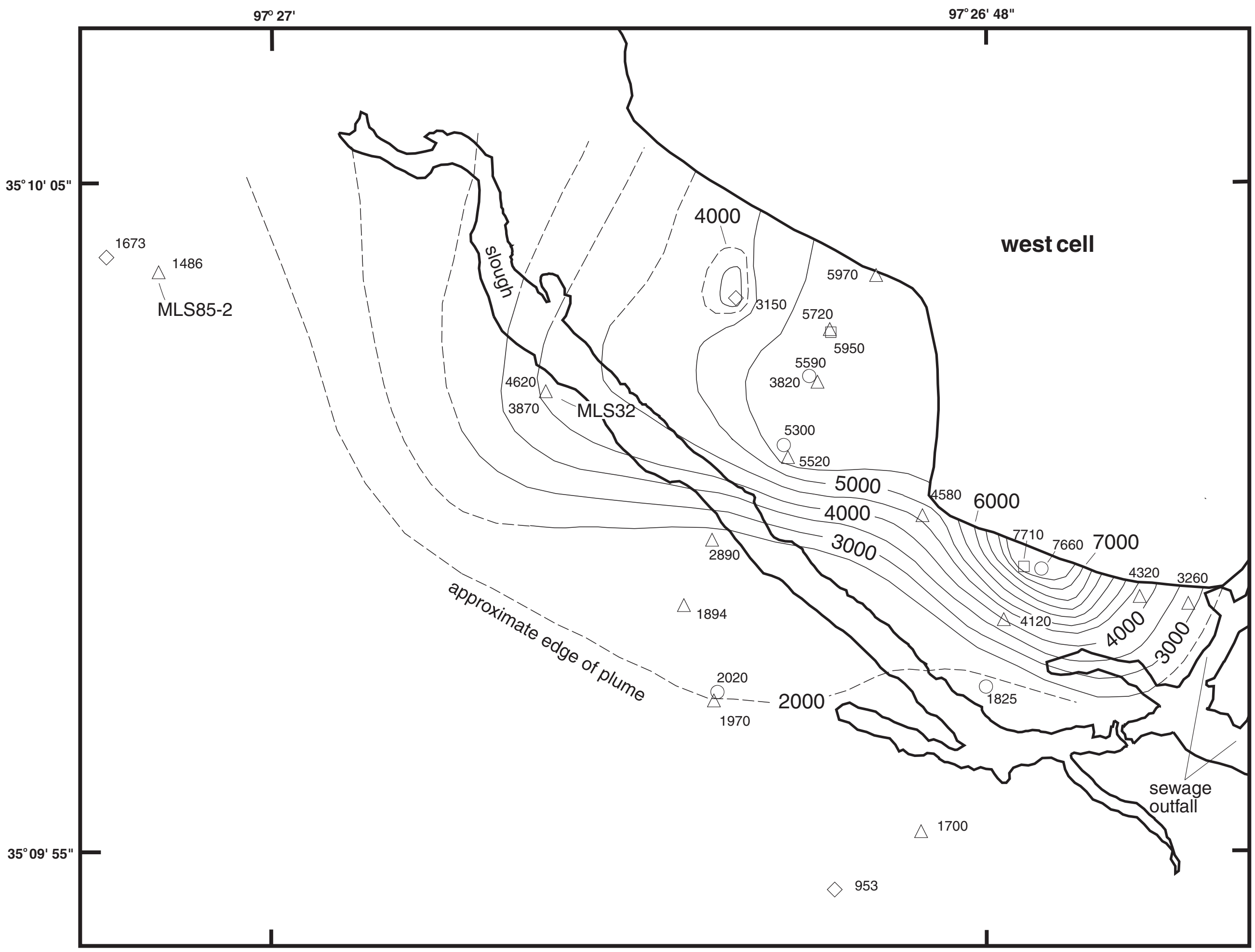


Figure 13. Vertical distribution of leachate plume along 40–SOUTH transect mapped using specific conductance downgradient from a closed municipal landfill, Norman, Oklahoma. Map was constructed using specific conductance measurements collected from October 1995 to November 1997. Altitude of water table was measured January 29, 1998.



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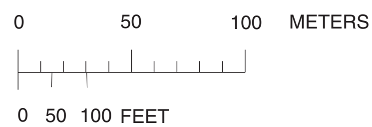
Universal Transverse Mercator projection, zone 14, North American Datum of 1983



EXPLANATION
Site and identifier

5950 △ 5970 **Multi-level sample well --** Number is specific conductance of ground water in microsiemens per centimeter at 25°Celsius. Two numbers indicate two measurements from interval

○ 5300 **Slug test site --** Number is specific conductance of ground water in microsiemens per centimeter at 25°Celsius

□ 7710 **Temporary well --** Number is specific conductance of ground water in microsiemens per centimeter at 25°Celsius

◇ 3150 **Water-level monitoring well --** Number is specific conductance of ground water in microsiemens per centimeter at 25°Celsius

—— 4000 - - - - **Line of equal** specific conductance of ground water in the Canadian River alluvial aquifer measured near land surface (328 to 329 meters above sea level). Dashed where estimated. Contour Interval is 500 microsiemens per centimeter at 25°Celsius

Figure 14. Horizontal distribution of leachate plume near land surface (328 to 329 meters above sea level) mapped using specific conductance downgradient from a closed municipal landfill, Norman, Oklahoma. Map was constructed using specific conductance measurements collected from October 1995 to November 1997.

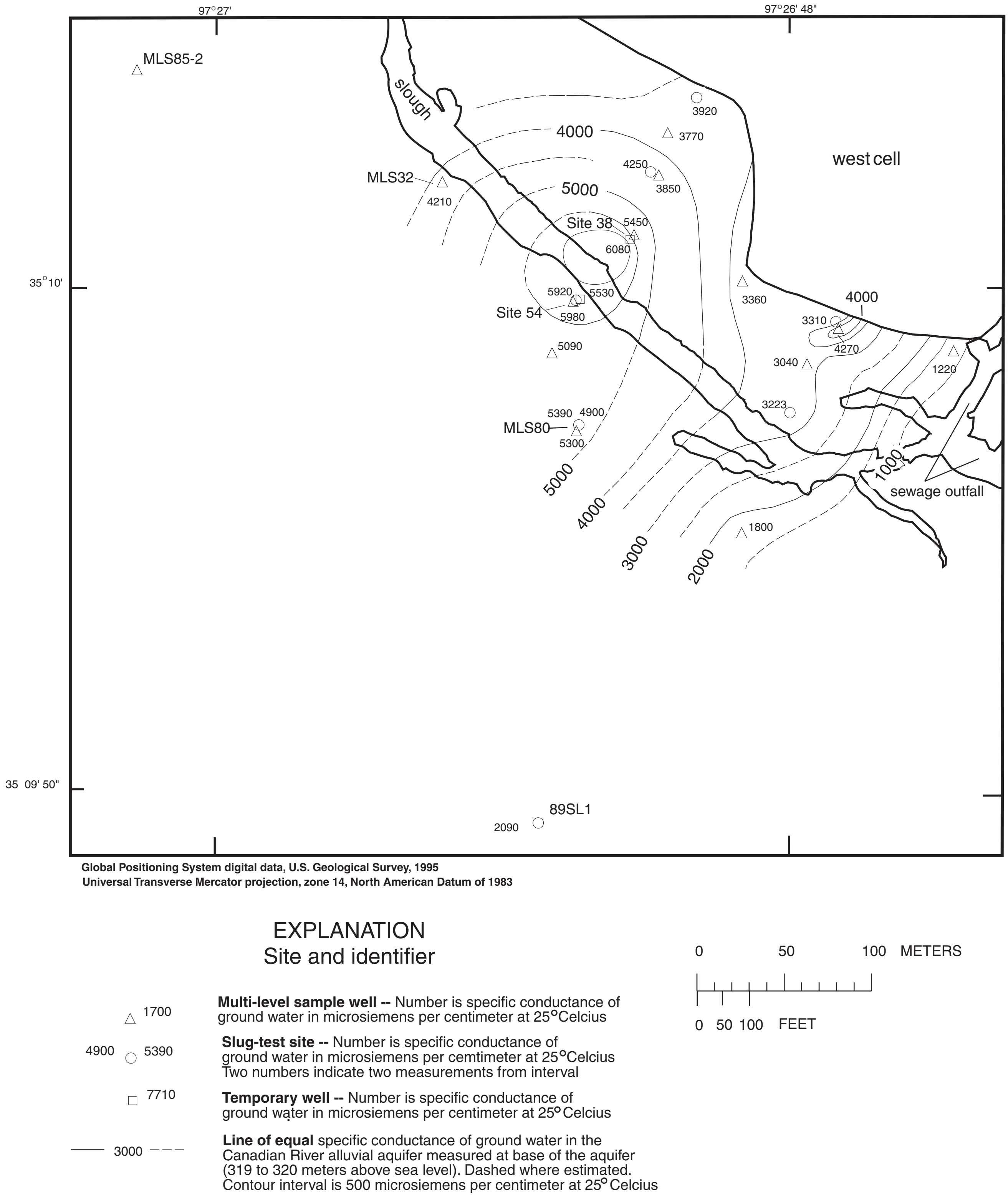


Figure 15. Horizontal distribution of leachate plume at base of aquifer (319 to 320 meters above sea level) mapped using specific conductance downgradient from a closed municipal landfill, Norman, Oklahoma. Map was constructed using specific conductance measurements collected from October 1995 to November 1997.

between wells MLS32 and MLS85-2 (fig. 14). The eastern and southeastern limits of the leachate plume could not be determined because of insufficient data.

The most concentrated part of the plume near the base of the aquifer (319-320 meters above sea level), was measured at site 38, not near the base of the west cell (fig. 15). The leading southern edge of the plume was probably moving downgradient in the high permeability layer at the base of the aquifer and may have been near well 89SL1 (figs. 2 and 15). Insufficient data west of well MLS32 and southwest of the 35-80 transect precluded delineation of the west and southwest edges of the plume. There were no data available for this interval at well MLS85-2.

SUMMARY

The City of Norman operated a solid-waste municipal landfill at two sites on the Canadian River alluvium in Cleveland County, Oklahoma from 1970 to 1985. The sites, referred to as the west and east cells of the landfill, were originally excavations in the unconsolidated alluvial deposits and were not lined. Operations stopped in 1985, and the west and east cells were closed and covered with a clay cap. Analysis of ground-water samples indicate that leachate from the west cell is discharging into an adjacent abandoned river channel, referred to as the slough, and is migrating downgradient in ground water toward the Canadian River.

The alluvial aquifer generally consists of unconsolidated lenticular beds of clay, silt, sand, and gravel overlain by dune sand and is highly permeable. Generally, ground-water levels in the alluvial aquifer were higher during the winter months and lower during summer months, due to a normal decrease in precipitation and increased evapotranspiration in the summer. Water levels in the slough were similar to ground-water levels; water in the slough generally was 0.5 to more than 1.0 meter higher during winter months and decreased during summer months. Hydrographs show temporal water-level changes in ground water and the slough, indicating a hydrologic connection between the alluvial aquifer and the slough.

The potentiometric head, measured at about 0.5 meter below the water table and at the base of the aquifer, shows that ground-water flows toward the sewage outfall at shallow and deep depths.

Along the 35-80 transect, the plume appears to have flowed into and around a low permeability layer of silt and clay at a depth of about 4 meters. Below the clay layer, the plume extended downward to the base of the aquifer and downgradient of the west cell. The leading edge of the plume extended over 250 meters downgradient of the west cell.

The edge of the leachate plume along the 40-SOUTH transect had moved about 60 meters from the west cell in a south-southwesterly direction and had not moved past the slough as of 1997. Specific conductance measurements exceeding 7,000 microsiemens per centimeter at site 40 indicate the most concentrated part of the plume remained in the upper half of the alluvial aquifer adjacent to the west cell.

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APPENDIX

Appendix 1. Site and well information, bedrock altitude, and selected specific conductance and potentiometric-surface measurements of ground water near a closed municipal landfill, Norman, Oklahoma

[--, no data; datum is sea level; altitude in meters refers to distance above sea level; μS/cm, microsiemens per centimeter at 25° Celsius]

Well name[1]	Site number	Altitude of land surface (meter)	Altitude of midscreen (meter)	Length of screen (meter)	Altitude of bedrock (meter)	Date of specific conductance measurement (year-month-day)	Specific conductance (μS/cm)	Altitude of potentiometric surface[2] (meter)
Multi-level sample wells								
MLS32-1	351002097265303	330.55	328.86	0.12	--	1997-03-31	3,870	330.11
MLS32-2	351002097265304	330.55	328.35	0.12	--	1997-10-06	4,620	330.11
MLS32-3	351002097265305	330.55	327.36	0.12	--	1997-10-06	4,920	330.12
MLS32-4	351002097265306	330.55	326.34	0.12	--	1997-03-31	4,310	330.12
MLS32-5	351002097265307	330.55	325.14	0.12	--	1997-03-27	4,260	330.12
MLS32-6	351002097265308	330.55	322.34	0.12	--	1997-03-27	4,310	330.12
MLS32-7	351002097265309	330.55	319.72	0.12	319.7	1997-03-27	4,210	330.12
MLS35-1	351004097264701	331.29	330.10	0.12	--	--	--	330.64
MLS35-2	351004097264702	331.29	329.58	0.13	--	--	--	330.63
MLS35-3	351004097264703	331.29	328.67	0.11	--	1997-10-07	5,970	330.63
MLS35-4	351004097264704	331.29	327.71	0.12	--	1997-10-07	5,640	330.63
MLS35-5	351004097264705	331.29	325.71	0.12	--	1997-02-25	5,490	330.64
MLS35-6	351004097264706	331.29	323.67	0.12	--	1997-02-25	4,400	330.63
MLS35-7	351004097264707	331.29	320.40	0.12	320.3	1997-02-25	4,120	330.63
MLS36-1	351003097264801	330.93	329.47	0.11	--	1997-03-18	2,440	330.50
MLS36-2	351003097264802	330.93	328.99	0.11	--	1997-10-08	5,720	330.50
MLS36-3	351003097264803	330.93	327.99	0.12	--	1997-10-08	4,820	330.49
MLS36-4	351003097264804	330.93	327.00	0.12	--	1997-03-18	4,470	330.49
MLS36-5	351003097264805	330.93	324.98	0.11	--	1997-03-18	3,920	330.49
MLS36-6	351003097264806	330.93	323.16	0.11	--	1997-03-18	3,550	330.48
MLS36-7	351003097264807	330.93	319.75	0.11	319.7	1997-03-18	3,770	330.48
MLS37-1	351002097264802	331.18	329.42	0.12	--	1997-03-31	2,680	330.36
MLS37-2	351002097264803	331.18	328.92	0.12	--	1997-03-31	3,820	330.34

Appendix 1. Site and well information, bedrock altitude, and selected specific conductance and potentiometric-surface measurements of ground water near a closed municipal landfill, Norman, Oklahoma — Continued

Well name[1]	Site number	Altitude of land surface (meter)	Altitude of midscreen (meter)	Length of screen (meter)	Altitude of bedrock (meter)	Date of specific conductance measurement (year-month-day)	Specific conductance (μS/cm)	Altitude of potentiometric surface [2] (meter)
MLS37-3	351002097264804	331.18	327.86	0.12	--	1997-10-08	5,360	330.33
MLS37-4	351002097264805	331.18	327.02	0.12	--	1997-03-31	4,140	330.33
MLS37-5	351002097264806	331.18	325.07	0.12	--	1997-03-31	5,000	330.33
MLS37-6	351002097264807	331.18	323.11	0.12	--	1997-03-31	5,450	330.32
MLS37-7	351002097264808	331.18	319.73	0.12	319.6	1997-03-31	3,850	330.34
MLS38-1	351001097264906	331.38	329.60	0.12	--	--	--	330.22
MLS38-2	351001097264907	331.38	329.09	0.12	--	1997-05-01	2,750	330.22
MLS38-3	351001097264908	331.38	328.08	0.12	--	1997-10-08	5,520	330.22
MLS38-4	351001097264909	331.38	327.69	0.12	--	1997-05-02	5,080	330.22
MLS38-5	351001097264910	331.38	325.18	0.11	--	1997-05-02	5,200	330.20
MLS38-6	351001097264911	331.38	324.37	0.12	--	1997-05-02	5,460	330.19
MLS38-7	351001097264912	331.38	319.31	0.12	319.2	1997-05-02	5,450	330.19
MLS40-1	350959097264404	330.61	328.45	0.12	--	1997-05-06	6,840	330.04
MLS40-2	350959097264405	330.61	327.96	0.12	--	1997-10-15	7,590	330.04
MLS40-3	350959097264406	330.61	326.96	0.12	--	1997-02-25	6,330	330.04
MLS40-4	350959097264407	330.61	325.97	0.12	--	1997-02-25	4,060	330.08
MLS40-5	350959097264408	330.61	324.00	0.12	--	1997-02-25	4,860	330.13
MLS40-6	350959097264409	330.61	322.02	0.12	--	1997-02-25	4,190	330.13
MLS40-7	350959097264410	330.61	319.22	0.12	319.1	1997-02-25	4,270	330.14
MLS41-1	350958097264501	330.35	329.27	0.12	--	--	--	330.07
MLS41-2	350958097264502	330.35	328.76	0.12	--	--	--	330.08
MLS41-3	350958097264503	330.35	327.78	0.12	--	1997-10-16	3,100	330.04
MLS41-4	350958097264504	330.35	326.78	0.12	--	1997-10-16	4,990	330.04
MLS41-5	350958097264505	330.35	324.79	0.12	--	1997-03-24	2,450	330.04
MLS41-6	350958097264506	330.35	322.79	0.12	--	1997-03-24	3,850	330.04
MLS41-7	350958097264507	330.35	321.12	0.12	319.5	1997-03-24	3,690	330.04

Appendix 1. Site and well information, bedrock altitude, and selected specific conductance and potentiometric-surface measurements of ground water near a closed municipal landfill, Norman, Oklahoma — Continued

Well name[1]	Site number	Altitude of land surface (meter)	Altitude of midscreen (meter)	Length of screen (meter)	Altitude of bedrock (meter)	Date of specific conductance measurement (year-month-day)	Specific conductance (µS/cm)	Altitude of potentiometric surface [2] (meter)
MLS42-1	350959097264501	330.25	329.01	0.12	--	1997-03-26	3,410	330.00
MLS42-2	350959097264502	330.25	328.50	0.12	--	1997-10-15	4,120	330.01
MLS42-3	350959097264503	330.25	327.49	0.12	--	1997-10-15	3,660	330.00
MLS42-4	350959097264504	330.25	326.52	0.11	--	1997-03-26	2,850	330.00
MLS42-5	350959097264505	330.25	324.55	0.12	--	1997-03-26	3,030	330.09
MLS42-6	350959097264506	330.25	322.55	0.12	--	1997-03-26	3,230	330.08
MLS42-7	350959097264507	330.25	319.61	0.12	319.5	1997-03-26	3,040	330.09
MLS43-1	351000097264601	330.44	329.01	0.12	--	1997-03-26	4,300	330.23
MLS43-2	351000097264602	330.44	328.50	0.12	--	1997-03-26	4,580	330.23
MLS43-3	351000097264603	330.44	327.50	0.12	--	1997-10-16	5,280	330.23
MLS43-4	351000097264604	330.44	326.52	0.12	--	1997-03-26	4,240	330.23
MLS43-5	351000097264605	330.44	324.54	0.12	--	1997-03-26	3, 890	330.23
MLS43-6	351000097264606	330.44	322.67	0.12	--	1997-04-16	4,300	330.23
MLS43-7	351000097264607	330.44	319.58	0.12	319.5	1997-04-16	3,360	330.23
MLS51-1	350959097264101	330.31	328.89	0.12	--	--	--	329.66
MLS51-2	350959097264102	330.31	328.41	0.12	--	1997-03-20	3,260	329.65
MLS51-3	350959097264103	330.31	327.39	0.12	--	1997-10-19	4,270	329.65
MLS51-4	350959097264104	330.31	326.46	0.12	--	1997-10-09	3,760	329.67
MLS51-5	350959097264105	330.31	324.45	0.12	--	1997-03-20	2,600	329.96
MLS51-6	350959097264106	330.31	322.48	0.12	--	1997-03-20	1,660	329.96
MLS51-7	350959097264107	330.31	319.38	0.12	319.3	1997-03-20	1,220	329.97
MLS54-1	351000097265003	330.51	329.14	0.12	--	1997-05-05	3,340	330.07
MLS54-2	351000097265004	330.51	328.67	0.12	--	1997-05-05	2,890	330.07
MLS54-3	351000097265005	330.51	327.90	0.12	--	1997-10-06	3,680	330.08
MLS54-4	351000097265006	330.51	327.35	0.12	--	1997-05-05	3,720	330.08
MLS54-5	351000097265007	330.51	324.69	0.11	--	1997-05-06	4,400	330.09

Appendix 1. Site and well information, bedrock altitude, and selected specific conductance and potentiometric-surface measurements of ground water near a closed municipal landfill, Norman, Oklahoma — Continued

Well name[1]	Site number	Altitude of land surface (meter)	Altitude of midscreen (meter)	Length of screen (meter)	Altitude of bedrock (meter)	Date of specific conductance measurement (year-month-day)	Specific conductance (µS/cm)	Altitude of potentiometric surface [2] (meter)
MLS54-6	351000097265008	330.51	322.69	0.11	--	1997-05-06	5,190	330.09
MLS54-7	351000097265009	330.51	319.37	0.11	319.3	1997-05-06	5,920	330.09
MLS55-1	350959097265002	330.53	329.24	0.12	--	1997-03-10	1,870	330.07
MLS55-2	350959097265003	330.53	328.74	0.12	--	1997-10-02	1,894	330.06
MLS55-3	350959097265004	330.53	327.71	0.12	--	1997-10-02	2,300	330.06
MLS55-4	350959097265005	330.53	326.76	0.12	--	1997-03-10	2,060	330.06
MLS55-5	350959097265006	330.53	324.77	0.11	--	1997-03-10	1,810	330.07
MLS55-6	350959097265007	330.53	322.83	0.12	--	1997-03-10	4,080	330.06
MLS55-7	350959097265008	330.53	319.32	0.12	319.2	1997-03-10	5,090	330.06
MLS80-1	350957097265002	330.21	328.88	0.12	--	1997-03-10	1,970	330.01
MLS80-2	350957097265003	330.21	328.45	0.12	--	--	--	330.01
MLS80-3	350957097265004	330.21	327.52	0.12	--	1997-10-02	2,110	330.02
MLS80-4	350957097265005	330.21	326.53	0.11	--	1997-10-02	2,100	330.01
MLS80-5	350957097265006	330.21	324.59	0.11	--	1997-03-10	1,601	330.02
MLS80-6	350957097265007	330.21	322.69	0.12	--	1997-03-10	1,805	330.01
MLS80-7	350957097265008	330.21	319.86	0.12	319.8	1997-03-10	5,300	330.01
MLS81-1	350959097264201	330.73	328.88	0.12	--	--	--	329.84
MLS81-2	350959097264202	330.73	328.34	0.12	--	1997-10-09	4,320	329.83
MLS81-3	350959097264203	330.73	327.40	0.12	--	1997-10-09	4,950	329.81
MLS81-4	350959097264204	330.73	326.29	0.12	--	1997-02-27	3,490	329.80
MLS81-5	350959097264205	330.73	324.69	0.11	--	1997-02-27	2,940	330.00
MLS81-6	350959097264206	330.73	322.76	0.11	--	1997-02-27	2,320	330.00
MLS81-7	350959097264207	330.73	320.19	0.12	320.1	1997-02-27	2,260	330.01
MLS85-2	351004097270016	330.48	328.28	0.11	--	1997-09-30	1,486	--
MLS88-1	350955097264601	330.40	329.04	0.11	--	1997-03-27	1,825	329.97
MLS88-2	350955097264602	330.40	328.59	0.12	--	1997-03-27	1,700	329.97

Appendix 1. Site and well information, bedrock altitude, and selected specific conductance and potentiometric-surface measurements of ground water near a closed municipal landfill, Norman, Oklahoma — Continued

Well name[1]	Site number	Altitude of land surface (meter)	Altitude of midscreen (meter)	Length of screen (meter)	Altitude of bedrock (meter)	Date of specific conductance measurement (year-month-day)	Specific conductance (μS/cm)	Altitude of potentiometric surface [2] (meter)
MLS88-3	350955097264603	330.40	327.55	0.12	--	1997-03-27	1,730	329.94
MLS88-4	350955097264604	330.40	326.61	0.11	--	1997-03-27	1,556	329.95
MLS88-5	350955097264605	330.40	324.65	0.11	--	1997-03-27	1,788	329.95
MLS88-6	350955097264606	330.40	322.64	0.12	--	1997-03-27	1,810	329.95
MLS88-7	350955097264607	330.40	319.26	0.12	319.2	1997-03-27	1,800	329.94
MLSNPD-1	351019097263601	332.66	330.19	0.12	--	1997-02-28	1,088	331.71
MLSNPD-2	351019097263602	332.66	329.70	0.12	--	1997-09-29	1,316	331.71
MLSNPD-3	351019097263603	332.66	328.66	0.12	--	1997-09-29	1,591	331.71
MLSNPD-4	351019097263604	332.66	327.69	0.12	--	1997-04-30	1,630	331.71
MLSNPD-5	351019097263605	332.66	326.53	0.12	--	1997-04-30	1,590	331.71
MLSNPD-6	351019097263606	332.66	323.70	0.12	--	1997-05-01	1,570	331.72
MLSNPD-7	351019097263607	332.66	319.67	0.12	319.6	1997-05-01	1,040	331.73
Temporary slug-test sites								
35SL1B	351003097264703	331.17	329.90	0.31	--	1996-06-13	5,250	--
35SL1D	351003097264706	331.17	329.13	0.30	--	1996-06-14	5,420	--
35SL1E	351003097264707	331.17	327.63	0.31	--	1996-06-14	5,240	--
35SL1F	351003097264708	331.17	325.62	0.30	--	1996-06-15	5,350	--
35SL1G	351003097264710	331.17	319.91	0.31	319.7	1996-06-18	3,920	--
35SL1X	351003097264709	331.17	322.79	0.30	--	1996-06-18	4,310	--
37SL1A	351002097264801	331.52	329.54	0.31	--	1996-11-04	2,740	--
37SL1B	351002097264810	331.52	328.55	0.30	--	1996-11-04	5,590	--
37SL1C	351002097264811	331.52	327.55	0.30	--	1996-11-05	3,890	--
37SL1E	351002097264812	331.52	325.56	0.30	--	1996-11-19	5,420	--
37SL1F	351002097264813	331.52	324.48	0.30	--	1996-11-19	5,780	--
37SL1G	351002097264814	331.52	323.49	0.30	--	1996-11-20	5,860	--
37SL1H	351002097264815	331.52	322.48	0.31	--	1996-11-20	5,130	--

Appendix 1. Site and well information, bedrock altitude, and selected specific conductance and potentiometric-surface measurements of ground water near a closed municipal landfill, Norman, Oklahoma — Continued

Well name[1]	Site number	Altitude of land surface (meter)	Altitude of midscreen (meter)	Length of screen (meter)	Altitude of bedrock (meter)	Date of specific conductance measurement (year-month-day)	Specific conductance (µS/cm)	Altitude of potentiometric surface [2] (meter)
37SL1I	351002097264816	331.52	321.49	0.30	--	1996-12-02	4,680	--
37SL1J	351002097264817	331.52	320.48	0.30	--	1996-12-02	4,510	--
37SL1K	351002097264818	331.52	319.49	0.30	319.3	1996-12-03	4,250	--
38SL2A	351001097264904	331.41	327.45	0.77	--	1996-06-12	4,150	--
38SL2C	351001097264924	331.41	325.42	0.76	--	1996-06-12	5,630	--
38SL4A	351001097264913	331.17	328.79	0.29	--	1997-10-29	5,300	--
38SL4B	351001097264914	331.17	327.85	0.29	--	1997-10-30	4,270	--
38SL4C	351001097264915	331.17	326.86	0.30	--	1997-10-30	4,550	--
38SL4D	351001097264916	331.17	325.90	0.29	--	1997-10-31	4,990	--
38SL4E	351001097264917	331.17	324.92	0.30	--	1997-10-31	5,110	--
38SL4F	351001097264918	331.17	323.94	0.29	--	1997-11-01	5,690	--
38SL4G	351001097264919	331.17	322.96	0.29	--	1997-11-03	5,700	--
38SL4H	351001097264920	331.17	321.97	0.29	--	1997-11-04	6,010	--
38SL4I	351001097264921	331.17	321.03	0.29	--	1997-11-04	5,740	--
38SL4J	351001097264922	331.17	320.04	0.29	319.8	1997-11-05	4,620	--
40SL1WT	350959097264403	330.70	329.79	0.31	--	1996-06-13	6,700	--
40SL1A	350959097264420	330.70	329.03	0.30	--	1996-06-17	7,400	--
40SL1C	350959097264421	330.70	327.66	0.30	--	1996-06-18	6,670	--
40SL1E	350959097264423	330.70	324.15	0.30	--	1996-06-19	4,860	--
40SL2A	350959097264411	330.69	328.74	0.29	--	1997-10-29	7,660	--
40SL2B	350959097264412	330.69	327.75	0.28	--	1997-10-30	7,660	--
40SL2C	350959097264413	330.69	326.73	0.29	--	1997-10-30	6,520	--
40SL2F	350959097264415	330.69	323.72	0.28	--	1997-10-31	4,480	--
40SL2G	350959097264416	330.69	322.72	0.29	--	1997-10-31	4,130	--
40SL2H	350959097264417	330.69	321.72	0.29	--	1997-11-01	3,890	--
40SL2I	350959097264418	330.69	320.72	0.29	--	1997-11-03	3,711	--

Appendix 1. Site and well information, bedrock altitude, and selected specific conductance and potentiometric-surface measurements of ground water near a closed municipal landfill, Norman, Oklahoma — Continued

Well name[1]	Site number	Altitude of land surface (meter)	Altitude of midscreen (meter)	Length of screen (meter)	Altitude of bedrock (meter)	Date of specific conductance measurement (year-month-day)	Specific conductance (µS/cm)	Altitude of potentiometric surface [2] (meter)
40SL2J	350959097264419	330.69	319.73	0.29	319.5	1997-11-03	3,310	--
41SL1A	350958097264508	330.27	328.73	0.30	--	1997-11-05	1,825	--
41SL1B	350958097264509	330.27	327.71	0.29	--	1997-11-05	2,148	--
41SL1C	350958097264510	330.27	326.71	0.30	--	1997-11-06	4,685	--
41SL1D	350958097264511	330.27	325.71	0.30	--	1997-11-06	4,910	--
41SL1F	350958097264513	330.27	323.71	0.29	--	1997-11-17	4,640	--
41SL1G	350958097264514	330.27	322.71	0.30	--	1997-11-18	3,650	--
41SL1H	350958097264515	330.27	321.71	0.30	--	1997-11-18	3,740	--
41SL1I	350958097264516	330.27	320.71	0.29	--	1997-11-18	3,240	--
41SL1J	350958097264517	330.27	319.73	0.30	319.5	1997-11-19	3,223	--
54SL1A	351000097265002	330.54	329.15	0.30	--	1996-10-29	1,336	--
54SL1B	351000097265024	330.54	328.15	0.30	--	1996-10-29	1,660	--
54SL1C	351000097265025	330.54	327.13	0.31	--	1996-10-30	3,040	--
54SL1E	351000097265026	330.54	325.14	0.31	--	1996-10-31	3,700	--
54SL1F	351000097265027	330.54	324.13	0.30	--	1996-11-01	4,520	--
54SL1G	351000097265028	330.54	323.23	0.30	--	1996-11-01	4,740	--
54SL1H	351000097265029	330.54	322.22	0.30	--	1996-11-03	4,790	--
54SL1I	351000097265030	330.54	321.21	0.30	--	1996-11-04	5,580	--
54SL1J	351000097265031	330.54	320.21	0.31	--	1996-11-04	5,960	--
54SL1K	351000097265032	330.54	319.22	0.31	319.0	1996-11-18	5,980	--
80SL1A	350957097265001	330.22	329.10	0.31	--	1996-10-28	1,599	--
80SL1B	350957097265010	330.22	328.06	0.31	--	1996-10-28	2,020	--
80SL1C	350957097265011	330.22	327.05	0.31	--	1996-10-29	1,369	--
80SL1D	350957097265012	330.22	326.04	0.31	--	1996-10-30	1,488	--
80SL1E	350957097265013	330.22	325.05	0.31	--	1996-10-30	1,177	--
80SL1F	350957097265014	330.22	324.05	0.30	--	1996-11-01	1,516	--

Appendix 1. Site and well information, bedrock altitude, and selected specific conductance and potentiometric-surface measurements of ground water near a closed municipal landfill, Norman, Oklahoma — Continued

Well name[1]	Site number	Altitude of land surface (meter)	Altitude of midscreen (meter)	Length of screen (meter)	Altitude of bedrock (meter)	Date of specific conductance measurement (year-month-day)	Specific conductance (µS/cm)	Altitude of potentiometric surface [2] (meter)
80SL1G	350957097265015	330.22	323.04	0.30	--	1996-11-01	1,630	--
80SL1H	350957097265016	330.22	322.03	0.30	--	1996-11-02	1,513	--
80SL1I	350957097265017	330.22	320.99	0.30	--	1996-11-02	1,905	--
80SL1J	350957097265018	330.22	319.96	0.31	--	1996-11-03	5,390	--
80SL1K	350957097265019	330.22	319.59	0.31	319.4	1996-11-03	4,900	--
89SL1A	350949097265101	330.12	328.40	0.30	--	1997-11-04	473	--
89SL1B	350949097265102	330.12	327.39	0.29	--	1997-11-04	554	--
89SL1C	350949097265103	330.12	326.40	0.29	--	1997-11-05	652	--
89SL1D	350949097265104	330.12	325.40	0.29	--	1997-11-05	670	--
89SL1E	350949097265105	330.12	324.40	0.30	--	1997-11-05	802	--
89SL1F	350949097265106	330.12	323.40	0.30	--	1997-11-06	890	--
89SL1G	350949097265107	330.12	322.39	0.29	--	1997-11-06	1,294	--
89SL1H	350949097265108	330.12	321.40	0.30	--	1997-11-06	1,544	--
89SL1I	350949097265109	330.12	320.41	0.30	--	1997-11-12	1,930	--
89SL1J	350949097265110	330.12	319.42	0.30	319.2	1997-11-17	2,090	--
Other temporary wells								
DPNPD-D	351019097263704	332.77	322.80	0.09	322.7	--	--	--
DP12-C	351018097272503	331.46	330.35	0.09	320.6	--	--	--
DP35-G	351003097264715	331.15	319.90	0.09	319.8	--	--	--
DP38-2B	351001097264927	331.41	320.20	0.08	320.2	--	--	--
DP40-F	350959097264428	330.69	319.98	0.08	319.9	--	--	--
NL940608-1	351019097270101	332.00	--	--	318.9	--	--	--
PS17	351001097270801	331.04	328.62	0.76	--	1995-11-01	980	--
PS18	350957097271401	330.22	328.65	0.76	--	1995-10-30	993	--
PS35	351004097264601	331.18	329.59	0.76	--	1995-11-06	5,620	--
PS36	351003097264604	331.03	328.26	0.76	--	1995-11-07	5,950	--

Appendix 1. Site and well information, bedrock altitude, and selected specific conductance and potentiometric-surface measurements of ground water near a closed municipal landfill, Norman, Oklahoma — Continued

Well name[1]	Site number	Altitude of land surface (meter)	Altitude of midscreen (meter)	Length of screen (meter)	Altitude of bedrock (meter)	Date of specific conductance measurement (year-month-day)	Specific conductance (μS/cm)	Altitude of potentiometric surface [2] (meter)
PS37	351003097264701	331.52	328.83	0.76	--	1995-11-08	3,170	--
PS38	351000097264901	331.33	328.57	0.76	--	1995-11-13	2,940	--
PS38-B	351000097264902	331.33	325.11	0.76	--	1995-11-30	5,350	--
PS38-C	351000097264903	331.33	321.49	0.76	--	1995-12-04	6,180	--
PS38-D	351000097264904	331.33	319.23	0.76	318.7	1995-12-04	6,080	--
PS39	350959097264902	330.75	329.14	0.76	--	1995-11-13	2,430	--
PS40	351001097264401	330.49	328.95	0.76	--	1995-11-22	7,710	--
PS54	351001097265101	330.60	329.08	0.76	--	1995-11-22	1,861	--
PS54-B	351001097265102	330.60	325.46	0.76	--	1995-11-29	4,150	--
PS54-C	351001097265103	330.60	321.97	0.76	--	1995-11-30	5,130	--
PS54-D	351001097265104	330.60	318.96	0.76	318.5	1995-12-05	5,530	--
SSEAST DEEP	350959097264303	331.00	319.87	0.61	319.6	-	-	--
SSWEST DEEP	351003097264603	331.00	319.72	0.61	319.4	-	-	--
Water-level monitoring wells								
WLMAPE	351017097270001	332.93	329.72	1.39	--	1997-10-20	1,340	--
WLMEAST	350955097263101	330.90	328.155	1.39	--	1997-10-01	668	--
WLMNPD	351018097263801	332.37	330.245	1.39	--	1997-07-10	1, 790	--
WLMPLUME	351003097264902	331.46	328.535	1.39	--	1997-07-10	3,150	--
WLMSOUTH	350954097264801	330.39	328.245	1.39	--	1997-09-30	953	--
WLMTS5	351004097270101	330.46	328.535	1.39	--	1997-09-30	1,673	--
Core sites								
[3]18-1		332.20			320.01			
[3]18-2		332.23			320.19			
[3]7-9		332.57			319.77			
VC-A	351001097264925	330.93			319.65			
VC-F	350953097265101	330.29			319.32			

Appendix 1. Site and well information, bedrock altitude, and selected specific conductance and potentiometric-surface measurements of ground water near a closed municipal landfill, Norman, Oklahoma — Continued

Well name[1]	Site number	Altitude of land surface (meter)	Altitude of midscreen (meter)	Length of screen (meter)	Altitude of bedrock (meter)	Date of specific conductance measurement (year-month-day)	Specific conductance (μS/cm)	Altitude of potentiometric surface [2] (meter)
VC-G	350944097265501	330.05			319.08			
Additional non-USGS sites								
COMPOST1		338.52			329.83			
COMPOST2		338.15			329.92			

1. The letters A, B, C, D, E, F, G, H, I, J, and K in the slug test and temporary well names indicate interval tested, with A being closest to land surface and K being farthest from land surface (for example, PS54-B, PS54-C, PS54-D). The numbers 1-7 in the multi-level sample well name indicate the interval the well is completed in, with 1 being closest to land surface and 7 being farthest from land surface (for example, MLS35-2, MLS35-3).

2. Date of measurement is January 29, 1998.

3. Stacy (1961)