

**PRELIMINARY EVALUATION OF THE EFFECTS OF AN
ABANDONED OIL REFINERY ON CHEMICAL QUALITY OF
WATER IN THE ARKANSAS RIVER VALLEY, ARKANSAS
CITY, KANSAS, 1985-86**

By T.B. Spruill

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 89-4190

**Prepared in cooperation with the
KANSAS DEPARTMENT OF HEALTH
AND ENVIRONMENT**



**Lawrence, Kansas
1990**

DEPARTMENT OF THE INTERIOR

MANUEL LUJAN JR., Secretary

U.S. GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information write to:

District Chief
U.S. Geological Survey
Water Resources Division
4821 Quail Crest Place
Lawrence, Kansas 66049

**Copies of this report
can be purchased from:**

U.S. Geological Survey
Books and Open-File Reports
Denver Federal Center, Bldg. 810
Box 25425
Denver, Colorado 80225

CONTENTS

	Page
Abstract	1
Introduction	2
Hydrogeologic characteristics	3
Soil	3
Surface water	7
Geology	7
Aquifer characteristics	8
Methods of investigation	12
Identification of principal sources of contamination	12
Soil samples	12
Well installation and ground-water sampling	16
Monitoring wells	16
Supply wells	16
Surface-water sampling	18
Waste sampling	19
Sources of contaminants	20
Oil-refinery wastes and characteristics	20
Contaminated soil	27
Other wastes and characteristics	30
Chemical quality of leachate and contamination potential	30
Oil-refinery wastes	30
Contaminated soil	32
Effects of petroleum-refinery wastes and contaminated soil on water quality	32
Ground-water quality	32
Surface-water quality	48
Conclusions	51
References cited	52

ILLUSTRATIONS

Plate	Page
1. Map showing chemical-quality characteristics of water from sampling sites in the Arkansas River valley, Arkansas City, Kansas	(in pocket)

CONTENTS--Continued

Figure	Page
1. Map showing location of Arkansas City, Kansas, and Arkansas River	2
2. Map showing location of Arkansas City Dump Site	4
3. Map showing location of former oil tanks, waste areas, unvegetated areas, and selected features of Arkansas City Dump Site	5
4. Map showing soil types in area of Arkansas City Dump Site	6
5. Section showing geologic characteristics of Arkansas City Dump Site	8
6. Graph showing results of slug test conducted in well screened near KDHE MW1, July 1, 1986	9
7. Map showing distribution of average hydraulic-conductivity values on Arkansas City Dump Site	11
8. Maps showing potentiometric surface of alluvial aquifer for December 1985, March 1986, and June 1986	13
9. Map showing location of soil-sampling areas	15
10. Schematic diagrams showing designs for (A) deep and (B) shallow monitoring wells ..	18
11. Photograph showing use of mobile auger to place boreholes in acid sludge in northern waste area	19
12. Schematic diagram showing generation of acid sludge by oil industry at beginning of 20th century	20
13. Cross sections showing thickness of acid sludge in northern waste area	27
14. Schematic diagram showing cross section of depression in northern waste area	31
15. Graph showing comparison of selected chemical-constituent concentrations in water samples collected from monitoring wells, July 1982 and December 1985	37
16. Map showing areas with terrain conductivity of 20 microsiemens per meter or greater	39
17. Map showing distribution of total organic carbon in water from alluvial aquifer in vicinity of Arkansas City Dump Site, December 1985 through July 1986	45
18. Gas chromatograms of water samples collected from selected monitoring wells on Arkansas City Dump Site	46

CONTENTS--Continued

Table	Page
1. Estimates of hydraulic conductivity and transmissivity derived from lithologic logs of selected wells on the Arkansas City Dump Site	10
2. Summary of sampling-site information and analyses for monitoring wells	17
3. Selected physical and chemical characteristics of acid sludge	21
4. Organic compounds tentatively identified in waste and waste seepage	22
5. Concentrations of selected trace elements detected in waste and seepage samples ...	26
6. Organic compounds tentatively identified in soil from five areas in the vicinity of the Arkansas City Dump Site	28
7. Comparison of concentrations of selected trace elements in uncontaminated soil with median concentrations found in soil or sediment samples collected from sampling sites on the Arkansas City Dump Site	30
8. Statistical summary of chemical constituents and physical properties in water from monitoring wells in the vicinity of the Arkansas City Dump Site	33
9. Statistical summary of chemical constituents and physical properties in water from supply wells in the vicinity of the Arkansas City Dump Site	35
10. Organic compounds tentatively identified in water from monitoring wells on the Arkansas City Dump Site	40
11. Results of Spearman-rho correlation analysis between total organic-carbon concentrations, number of organic compounds, and total concentration of organic compounds	47
12. Statistical summary of chemical constituents and physical properties in surface water and sediment in the vicinity of the Arkansas City Dump Site	48
13. Organic compounds tentatively identified in samples from surface water and sediment in the vicinity of the Arkansas City Dump Site	50

CONVERSION FACTORS

For those interested readers, factors for converting the inch-pound units used in this report to metric units (International System) are given below:

<i>Multiply inch- pound unit</i>	<i>By</i>	<i>To obtain metric unit</i>
inch	2.54	centimeter
foot	0.3048	meter
mile	1.609	kilometer
square foot	0.09290	square meter
acre	4,047	square meter
gallon	3.785	liter
cubic foot	0.02832	cubic meter
cubic foot per second	0.02832	cubic meter per second
foot per day	0.3048	meter per day
foot per mile	0.1894	meter per kilometer
gallon per minute	0.06309	liter per second
foot squared per day	0.09290	meter squared per day
degree Fahrenheit (°F)	(1)	degree Celsius (°C)

¹ °C = 5/9 (°F-32).
°F = 9/5 (°C) + 32.

Sea level: In this report, sea level refers to the National Geodetic Vertical Datum of 1929--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Sea Level Datum of 1929."

PRELIMINARY EVALUATION OF THE EFFECTS OF AN ABANDONED OIL REFINERY ON CHEMICAL QUALITY OF WATER IN THE ARKANSAS RIVER VALLEY, ARKANSAS CITY, KANSAS, 1985-86

By T. B. Spruill

ABSTRACT

Samples of ground water, wastes, waste leachate, and soil collected between December 1985 and August 1986 indicate that wastes from an abandoned oil refinery at Arkansas City, Kansas, have caused local contamination of ground water in the alluvium of the Arkansas River valley. The Arkansas City Dump Site, as it is referred to, is currently (1986) on the National Priorities List of Hazardous-Waste Sites. Sources of ground-water contaminants are an acid-sludge pit located in the northern part of the site and petroleum-soaked aquifer material at various locations on the site.

Petroleum-refinery wastes have not affected major ionic composition of ground water under the site, except locally. Local occurrences of low pH (4.4) and increased sulfate concentrations in ground water under and immediately downgradient from an acid-sludge pit probably are caused by movement of some contaminated water from the acid-sludge pit to the water table. However, ionic composition of water from wells downgradient of the acid-sludge pit approximate quality characteristics of water from wells offsite, indicating that contaminants associated with petroleum-refinery wastes either have moved offsite into the Arkansas River or are not generated in sufficient quantity to appreciably affect ionic composition of water in the alluvium over a large area. Local occurrences of large concentrations of ammonia-nitrogen, arsenic, barium, iron, and manganese are thought to be due to reducing conditions created by anaerobic decomposition of organic matter present on the site.

Organic compounds are the principal contaminants derived from the petroleum-refinery wastes that affect water quality in the alluvium. Various alkanes, ketones, aldehydes,

sulfonic acids, and polynuclear aromatic (PNA) compounds were detected in ground water under the site. Oil-contaminated sediments are the principal source of hydrocarbons in ground water beneath the site. PNA compounds appear to pose the greatest environmental and public-health hazards. Limited detection of volatile organic compounds in water in wells onsite and the general absence of organic compounds in wells offsite suggest that either contaminants have been flushed from the aquifer, volatilized, reacted to form other compounds, or have biodegraded.

Few organic compounds were detected in surface water on and adjacent to the site. No dissolved forms of any organic compound were detected in water from three sites on the Arkansas River, and no concentrations of any refinery-related compound were detected in water from a small pond on the site or from a large sandpit lake. Heavy molecular-weight alkanes were detected in water from sediment samples in the Arkansas River, the sandpit lake, and the pond. Additionally, small concentrations (10 to 19 micrograms per kilogram) of PNA compounds were detected in sediment samples from the pond. Organic compounds in the sediment probably reflect sorption of hydrophobic compounds onto organic carbon of the sediment and accumulation of heavy molecular-weight aliphatic and cyclic hydrocarbons that are resistant to biodegradation.

A positive correlation (significant at the 1-percent level) between total organic-carbon concentrations and numbers and total concentrations of specific organic compounds identified by gas chromatography and mass spectrometry indicates that total organic carbon is a good indicator of organic-compound contamination from the oil refinery. Total

organic-carbon concentrations in water under the site ranged from 6.3 to 73 milligrams per liter, indicating contamination with organic compounds. Baseline concentrations for total organic carbon in the alluvial aquifer ranged from 2 to 6 milligrams per liter. Total organic-carbon concentrations in water from wells sampled downgradient were less than 6 milligrams per liter, and results from gas chromatography and mass spectrometry, high-performance liquid chromatography, and a gas chromatograph equipped with a flame-ionization detector indicate that PNA and other organic compounds were not present in quantities greater than 3 micrograms per liter in water-supply wells offsite.

INTRODUCTION

The Arkansas City Dump Site, located in Arkansas City, Kansas (fig. 1), currently (1986) is on the U.S. Environmental Protection Agency's National Priorities List of Hazardous-Waste Sites. The National Priorities List includes 400 sites that have "known or threatened release" of toxic or hazardous substances (U.S. Environmental Protection Agency, 1984). The Arkansas City Dump Site was used as an oil refinery between 1916 and the mid-1920's (Kansas Department of Health and

Environment, 1982) and as an unregulated municipal landfill after closure of the refinery. An explosion and fire occurred at the refinery in the mid-1920's, according to older residents in the area. Most of the site (160 acres) was used at various times as a waste-disposal area. A previous investigation of the site, conducted during 1981-82 (Kansas Department of Health and Environment, 1982), concluded that ground water beneath the site was contaminated by certain trace elements and organic substances, but these contaminants did not appear to be moving offsite.

To protect public health and the environment and to confirm and supplement information obtained in that initial investigation, a remedial investigation of the site was conducted during 1985-86 by the U.S. Geological Survey in cooperation with the Kansas Department of Health and Environment. The principal purpose of the investigation was to collect and sufficiently evaluate chemical, physical, human-health, and environmental data to allow implementation of an effective remedial solution to the major problems posed by the Arkansas City Dump Site.

Specific objectives of the investigation were to:

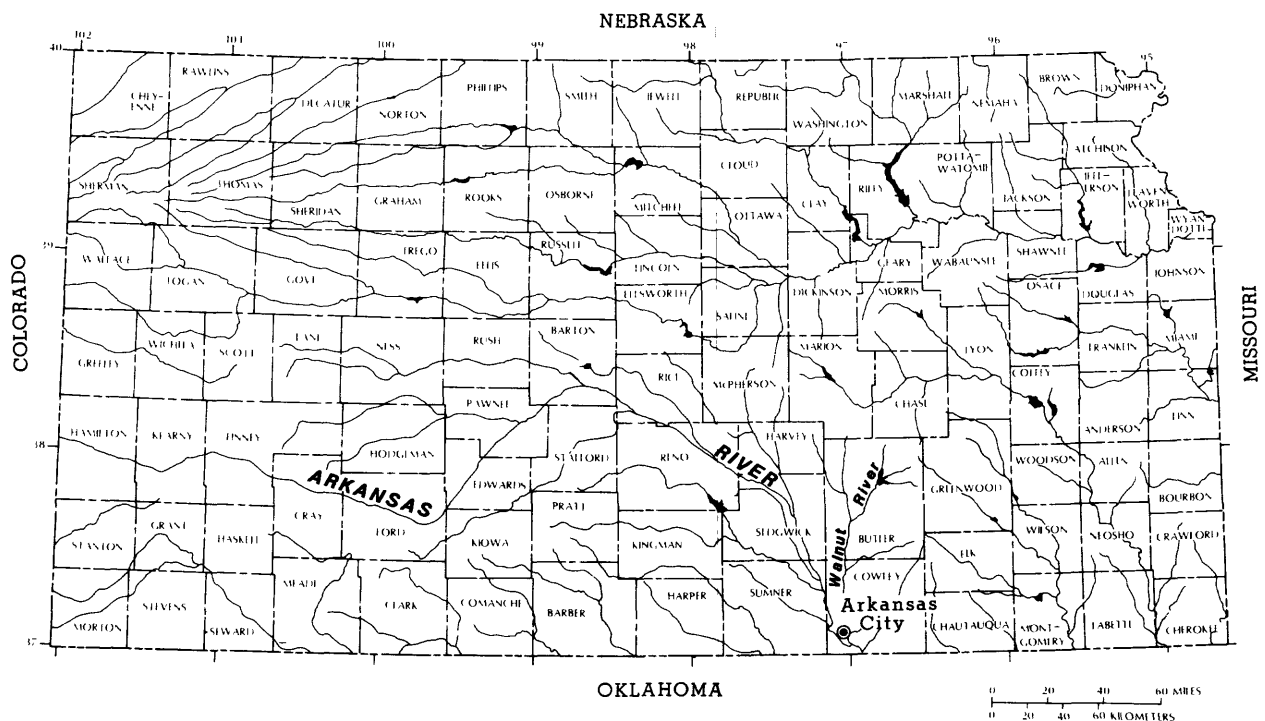


Figure 1. Location of Arkansas City, Kansas, and Arkansas River.

- (1) Identify principal contamination sources on the Arkansas City Dump Site;
- (2) describe hydrogeologic characteristics of the alluvial aquifer in the Arkansas River valley;
- (3) describe water-quality characteristics of surface and ground water in the vicinity of the Arkansas City Dump Site; and
- (4) evaluate major effects of contaminants from the abandoned oil refinery on water quality of the Arkansas City Dump Site.

This report presents the preliminary findings of the investigation pertaining to geohydrologic conditions and describes the principal effects of contaminants from the abandoned oil refinery on ground and surface water.

The Arkansas City Dump Site is located in the southwest part of Arkansas City, Cowley County, Kansas (fig. 1), about 3.5 miles north of the Kansas-Oklahoma state line. The site is bounded on the west and south by a levee that follows the Arkansas River (figs. 2 and 3). The eastern boundary of the site extends along and south of 8th Street to where the levee intersects the projected line of 8th Street. Madison Avenue currently (1986) is the northern boundary of the site. An extension of the site boundary has been proposed because of evidence that the refinery site existed north of Madison Avenue (fig. 2).

HYDROGEOLOGIC CHARACTERISTICS

Soil

The soil in and around the Arkansas City Dump Site (fig. 4) generally varies from a loamy fine sand to a silt loam (U.S. Soil Conservation Service, 1980). In general, the soil is very erodible if vegetation is not present.

Characteristics of principal soil types located within and adjacent to the Arkansas City Dump Site are described in the following paragraphs. Although data on soil vertical hydraulic conductivity (referred to as "permeability" in U.S. Soil Conservation Service reports) were obtained from soil cores collected about 1 to 2 feet below the land surface using a constant-head permeameter, most of the following information

and descriptions of soil types were obtained from the U.S. Soil Conservation Service (1980).

Attica (Aa) - This deep soil consists of loamy fine sand, is moderately sloping, and well drained. It usually occurs on uplands. Attica soil occurs in a small area located in the northeastern and extreme eastern parts of the dump site (fig. 4). Typically, the soil's surface layer is a brown, loamy fine sand about 9 inches thick. The subsoil is a brown, very friable, fine sandy loam about 27 inches thick. The substratum, to a depth of about 60 inches, is a brown, fine sandy loam. Hydraulic conductivity is moderately rapid in this soil, and runoff is slow. The available water capacity is small; the natural fertility is medium; and the organic-matter content is moderate. Attica soil is susceptible to wind erosion, but this potential problem can be controlled with adequate vegetation.

Attica-Tivoli (Ab) - This deep, rolling upland soil consists of loamy fine sand. The soil type is made up of 70 percent well-drained Attica soil and 25 percent excessively drained Tivoli soil. The soils are mixed, and it is impossible to separate them from mapping purposes. Typically, the Attica soil has a surface layer of brown loamy fine sand about 9 inches thick. The subsoil is a brown, very friable, fine sandy loam about 27 inches thick. The Tivoli soil has a surface layer of brown, loamy fine sand about 7 inches thick. The substratum is a very pale brown, fine sand, which extends to more than 60 inches in depth. Hydraulic conductivity is moderately rapid in the Attica soil and rapid in the Tivoli. Results of permeameter tests conducted on three soil cores collected during placement of monitoring wells USGS 1, 2, and 4 from 1 to 2 feet below the land surface indicated hydraulic-conductivity values that ranged from 3.5×10^{-6} to 1.6×10^{-2} centimeters per second (0.04 to 2 inches per hour). These values are less than or at the lower end of the range of hydraulic-conductivity values (2 to 6 inches per hour) published by the U.S. Soil Conservation Service (1980) for Attica-Tivoli soils. In both soils, fertility is medium, and organic content is moderate. Because of relatively large hydraulic-conductivity values, there is little or no runoff from these soils.

Canadian (Ca) - This fine sandy loam is

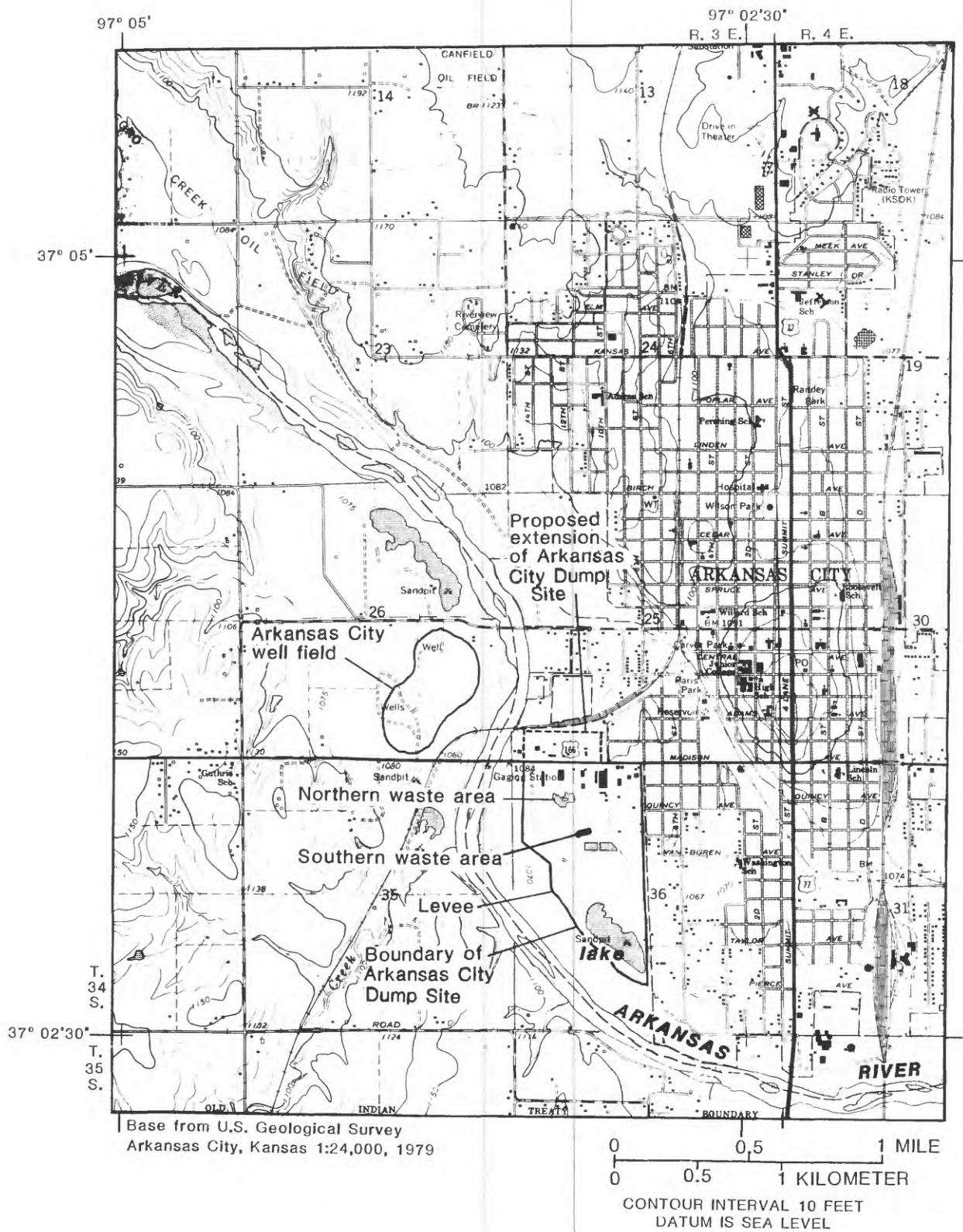


Figure 2. Location of Arkansas City Dump Site.

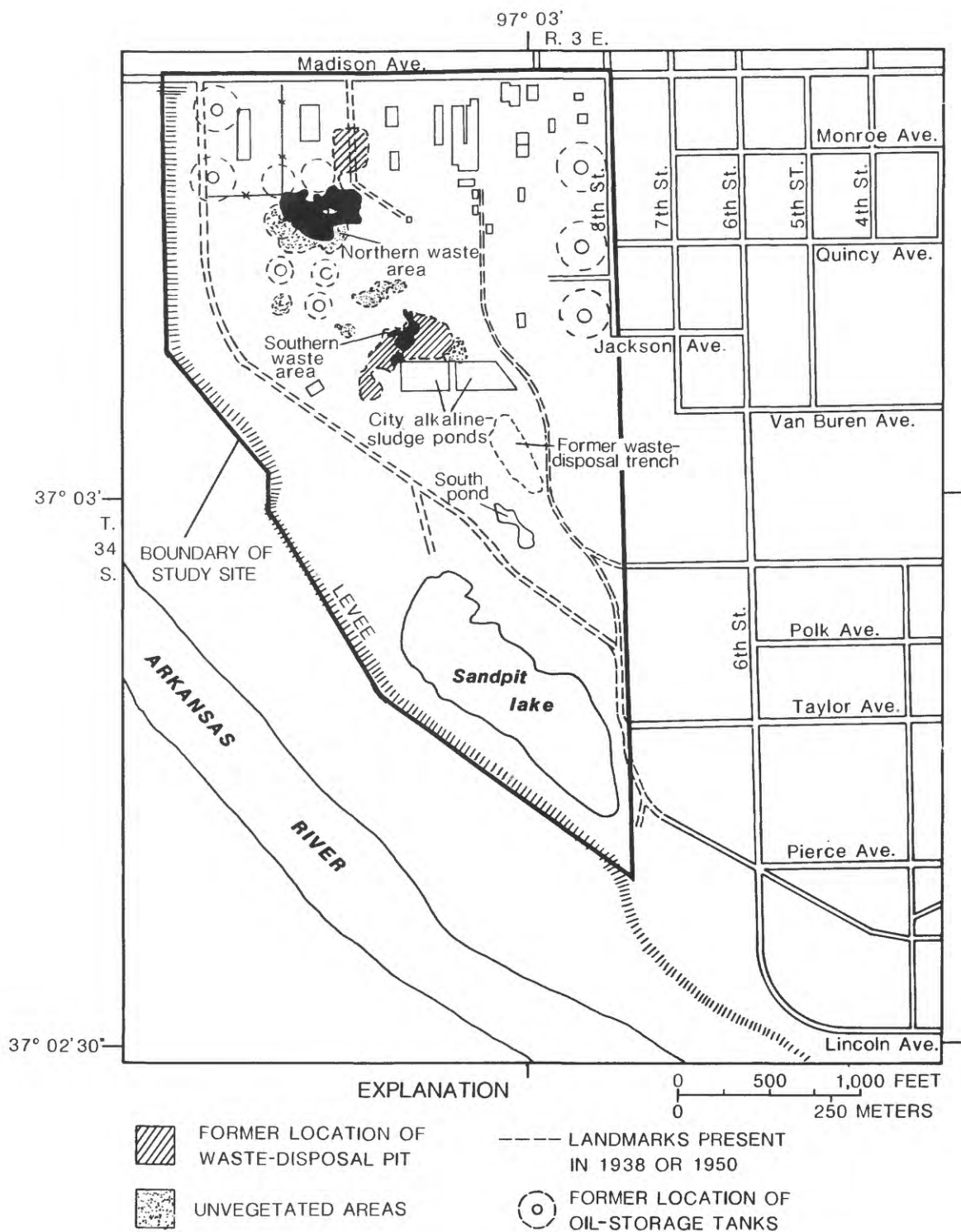


Figure 3. Location of former oil tanks, waste areas, unvegetated areas, and selected features of Arkansas City Dump Site.

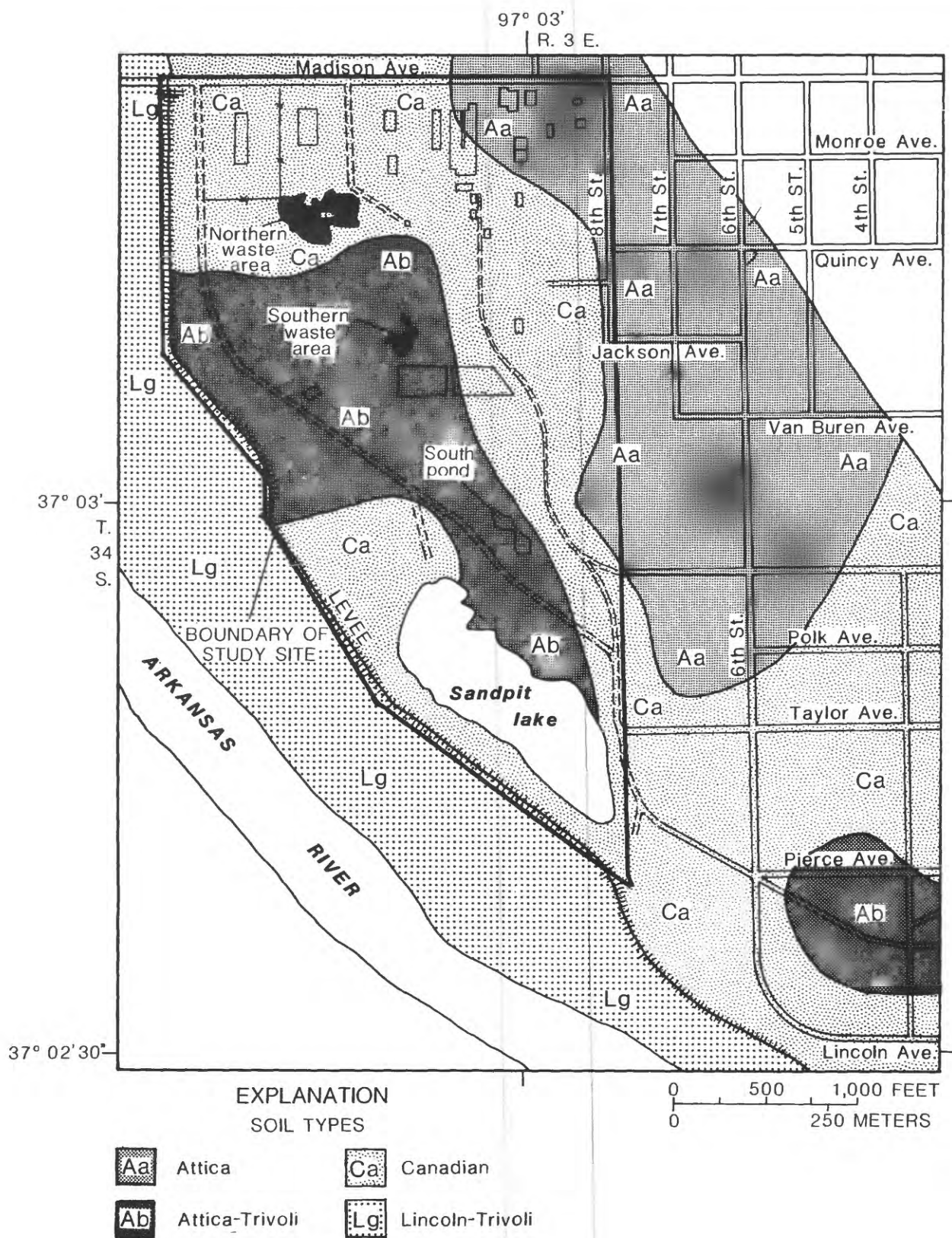


Figure 4. Soil types in area of Arkansas City Dump Site.

nearly level and well drained. It occurs in long narrow areas on stream terraces along the Arkansas River. Canadian fine sandy loam occupies the perimeter of the Arkansas City Dump Site. Typically, the surface layer is a grayish-brown, fine sandy loam about 16 inches thick. The subsoil is a brown, very friable, sandy loam about 12 inches thick. The substratum is a yellowish-brown, fine sandy loam, which extends to a depth of 60 inches. Some areas are calcareous at depths less than 20 inches, whereas other areas have a sandy surface layer. Hydraulic conductivity for the Canadian soil is moderately large; available water capacity is moderate; and runoff is slow. Permeameter tests conducted on soil cores collected during placement of monitoring wells USGS 3 and 5 collected at 1 foot below the land surface had vertical hydraulic-conductivity values of 3×10^{-2} and 4×10^{-2} centimeters per second (4 to 6 inches per hour). The organic-matter content is moderate, and fertility is medium.

Lincoln-Tivoli complex (Lg) - This soil occurs on nearly flat to rolling areas along the Arkansas River. It is excessively drained and occasionally floods. Soil of this type lies adjacent to the Arkansas City Dump Site and in the western and southern parts of the site. This soil complex is made up of 55-percent Lincoln soil and 30-percent Tivoli soil. The two soils are so mixed that it is not practical to separate them for mapping. Lincoln soil typically has a grayish-brown, fine sandy loam surface layer about 9 inches thick. The substratum extends to a thickness of more than 60 inches. The soil is a very pale brown, fine loam in the upper layers, and a reddish-yellow, loamy, very fine sand in the lower layers. Typically, the Tivoli soil has a brown, loamy fine sand surface layer about 7 inches thick. The substratum is a very pale brown, fine loam extending to a depth of 60 inches. Hydraulic-conductivity values are large in the Lincoln-Tivoli complex. Available water capacity is small in both soils. Surface runoff is small in the Lincoln and very slow in the Tivoli. Natural fertility and organic-matter content is slight in both soils.

Based on the hydraulic-conductivity values of soil in the area, water and contaminated leachate could move quite rapidly through soil on the Arkansas City Dump Site. However, some of the soil on the site is calcareous (U.S. Soil Conservation Service, 1980) and, thus, has some neutralization capacity for acidic leachate and could immobilize many trace elements. In

addition, the carbon content of the shallow soil is approximately 1 percent (based on a total organic-carbon analysis of soil collected near monitoring well KDHE MW1, map no. 12, plate 1), which makes the soil capable of sorbing organic contaminants and thus retarding or preventing movement of contaminants from the surface to the water table. Recent studies by Karickhoff and others (1979) and Schwartzbach and Westall (1981) have shown that mobility of many organic contaminants can be reduced significantly in soil having greater than 0.1-percent organic carbon.

Surface Water

The Arkansas River, which borders the Arkansas City Dump Site to the south and west, a sandpit lake (the lake formed as a result of sand-and-gravel mining operations), and a series of small contiguous ponds (termed the south pond) comprise the major surface-water bodies on or near the study site (plate 1). Generally, there is no surface drainage on the sandy alluvial soil on the site, and precipitation that falls on the site moves directly downward and recharges the alluvial aquifer. The sandpit lake, which is located on the site, is the result of sand excavation from a quarry established between 1950 and 1956. By 1963, water had filled the sand quarry and formed a lake. The maximum measured depth was about 25 feet in 1986. The south pond, which is a series of irregular, but continuous, surface depressions, was visible in a 1938 aerial photograph of the area and presumably was created from a bulldozer being used for waste-disposal activities at that time.

Geology

Geologic characteristics of the Arkansas City Dump Site are shown in figure 5. The bedrock underlying the site is of Permian age and has a gentle westward regional dip averaging about 25 feet per mile, or a 0.45-percent grade. Along and adjacent to the Arkansas River, Pleistocene (Wisconsin glaciation) terrace deposits and Holocene alluvium overlie the bedrock (Bayne, 1962). Previous geologic mapping and lithologic and gamma logs from drilling records for the monitoring wells constructed in the vicinity of the Arkansas City Dump Site show that Holocene alluvium and Wisconsin terrace deposits, up to 50 feet in thickness, overlie Permian limestone and shale of the Chase Group.

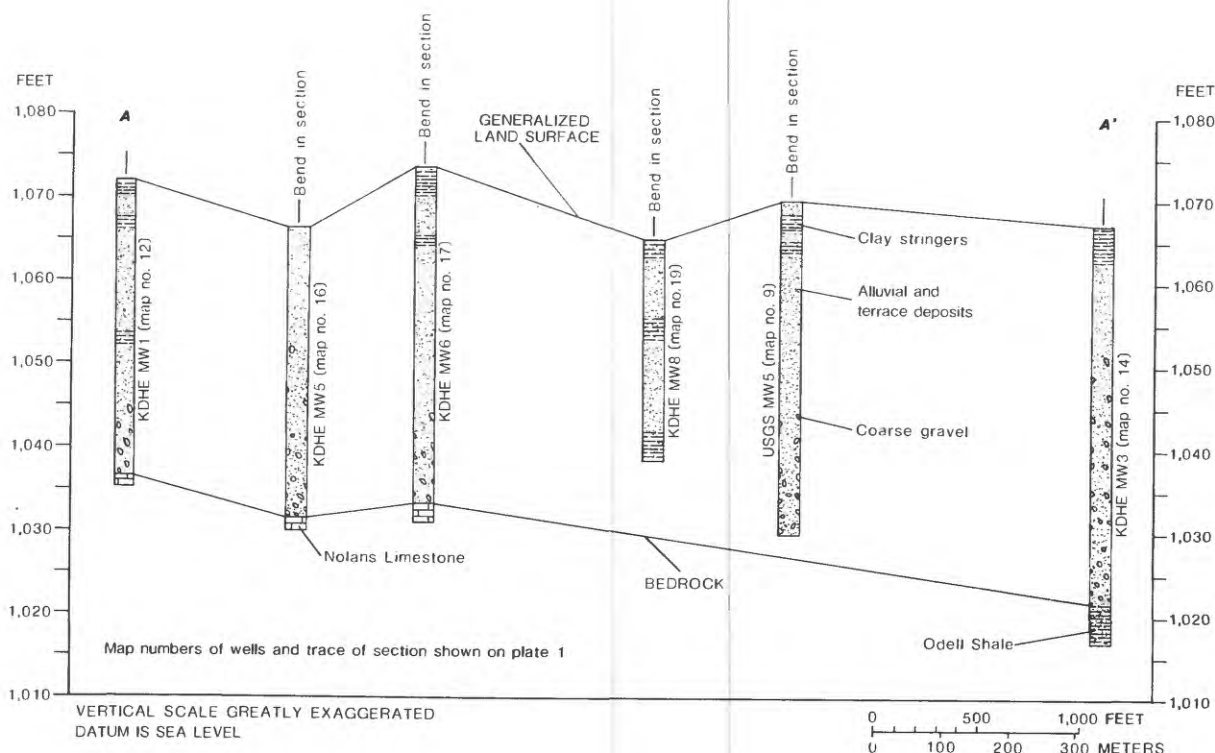


Figure 5. Geologic characteristics of Arkansas City Dump Site.

The Arkansas River borders the Arkansas City Dump Site to the west and south. Alluvium and terrace deposits extend over the entire Arkansas City Dump Site. The alluvium and terrace deposits are lithologically similar, and therefore, it is difficult to differentiate between the two. Both types of deposits are composed of unconsolidated silt, clay, and arkosic sand and gravel that are increasingly coarse with depth and quite gravelly near the bedrock contact. The gravel near the bedrock is less than 15 feet thick beneath most of the site. The thickness of this gravel may be as much as 25 feet near the river, as indicated by the lithologic log from well KDHE MW3 (fig. 5).

Erosional characteristics of the bedrock are such that the upper two formations of the Permian Chase Group underlie and are in contact with the alluvium and terrace deposits that cover the Arkansas City Dump Site. The Nolans Limestone is the uppermost formation of the Chase Group and is composed of interbedded white to gray limestone and gray to blue-gray shale. Underlying the Nolans Limestone is a

sequence of interbedded gray, green, and red shale comprising the Odell Shale.

Aquifer Characteristics

The Holocene alluvium and Wisconsin terrace deposits along the Arkansas and Walnut Rivers (fig. 1) are the most important sources of ground water in Cowley County, and well yields as great as 1,000 gallons per minute are common (Bayne, 1962, p. 72). It appears that discontinuous clay stringers occur throughout these deposits (fig. 5). Therefore, on the basis of gamma and lithologic logs, the alluvial aquifer may be considered as relatively homogeneous. Underlying the unconsolidated alluvium and terrace deposits, the Nolans Limestone of Permian age yields water principally from the Herington Limestone Member. Use of the Nolans Limestone as a water supply occurs primarily in the northwestern part of the county. The shale units within the Nolans Limestone do not yield large quantities of water. The underlying Odell Shale is not known to yield water to wells (Bayne, 1962, p. 28). Because of poor transmissive characteristics of underlying

bedrock, there appears to be little potential for downward movement of water from the alluvium into the Nolans Limestone. No supply wells that yield water from the Nolans Limestone and are within a 3-mile radius of the Arkansas City Dump Site were found in well-log files of the Kansas Department of Health and Environment (Topeka, Kansas).

To estimate ground-water velocity and to provide a basis for modeling contaminant movement, an estimate of hydraulic conductivity of the aquifer is necessary. Estimates of hydraulic conductivity can be derived from slug tests and lithologic estimates (Lohman, 1979). In addition, a flow net was constructed at the beginning of the study to conceptualize flow patterns in the alluvial aquifer and to yield estimates of hydraulic conductivity with minimal information. These techniques are described in the following paragraphs.

A slug test was conducted during July 1986 in a well screened near monitoring well KDHE MW1 (plate 1, map number 12) by pouring water into the casing and measuring the rate of decline in head (fig. 6). Results of analyzing the data using the graphical method described in Cooper and others (1967) yielded an estimate of hydraulic conductivity of about 75 feet per day.

Estimates of hydraulic conductivity of the alluvial aquifer were calculated at the outset of the investigation using water-level measurements made by the Kansas Department of Health and Environment during July 1982 from monitoring wells on the Arkansas City Dump Site and data from Bayne (1962). A flow net for the Arkansas City Dump Site was constructed according to techniques outlined in Freeze and Cherry (1979). The flow net depicted the potentiometric surface for the alluvial aquifer with idealized flow lines indicating the direction of ground-water flow, which is primarily to the south and southwest toward the Arkansas River.

Hydraulic-conductivity values for each of 17 cells in the flow net were calculated using Darcy's law:

$$Q = KIA, \quad (1)$$

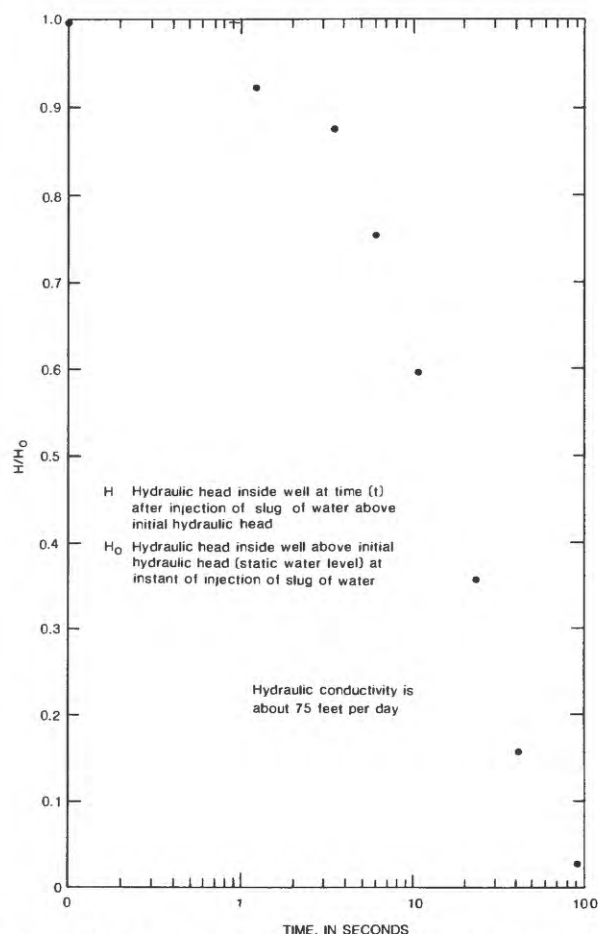


Figure 6. Results of slug test conducted in well screened near KDHE MW1, July 1, 1986. Hydraulic-conductivity value was derived from graphical analysis presented in Cooper and others (1967).

where Q = quantity of water leaving the downgradient area of a cell, in cubic feet per day;
 K = the hydraulic conductivity, in feet per day;
 I = hydraulic gradient as decline in hydraulic head, in feet, divided by distance, in feet; and
 A = the area through which water is flowing to the next downgradient cell, in square feet (thickness of saturated part of the aquifer times the width of the downgradient boundary of the cell).

The hydraulic conductivity used for cells in the northern part of the site was 100 feet per day and was based on results from the slug test conducted

in well KDHE MW1 (previously described) and lithologic estimates of hydraulic conductivity based on values for a medium-to-coarse sand aquifer given in Lohman (1979). Recharge for each downgradient cell was added to the amount of recharge entering from the upgradient cells. A recharge value of 20 percent of the annual precipitation was assumed and was based on estimates made for Arkansas River valley deposits in south-central Kansas (Williams and Lohman, 1949). Using this technique, hydraulic

conductivity for the 17 cells ranged from 25 to 246 feet per day, with smallest values in the northern part of the site.

On the basis of information in Lohman (1979, p. 53) and lithologic information from selected wells and test holes on the site (table 1), hydraulic conductivity (K) of the alluvial aquifer would be expected to range from about 15 feet per day for fine sand found in the upper 10 feet of the aquifer to about 800 feet per day for coarse sand

Table 1. *Estimates of hydraulic conductivity (K) and transmissivity (T) derived from lithologic logs of selected wells on the Arkansas City Dump Site*

[Values for K from Lohman (1979). FS = fine sand; M = medium sand; C = coarse sand; V = very coarse sand; G = gravel. Dash between codes indicates intermediate lithologies]

Well (map no. shown on plate 1)	Interval (feet)	Interval lithology code	Interval thickness (feet)	Estimated hydraulic conductivity for interval (feet per day)	Estimated transmissivity for interval (feet squared per day)	Average hydraulic conductivity (feet per day)
2	14-24	M-C	10	100	1,000	233
	24-29	C-G	5	500	2,500	
9	12-14	F-M	2	30	60	373
	14-24	M-C	10	100	1,000	
	24-34	C-V	10	500	5,000	
	34-39	C-G	5	800	4,000	
10	5-10	M-C	5	100	500	217
	10-28	C-V	18	250	4,500	
12	11-13	F	3	15	45	76
	13-18	M-F	5	30	150	
	18-35	M-C	17	100	1,700	
13	11-17	FS	6	15	90	25
	17-30	F-M	13	30	390	
14	6-16	F	10	15	150	228
	16-35	M-C	19	100	190	
	35-46	C-V	11	800	8,800	
16	4-7	F	3	15	45	82
	7-13	M	6	50	300	
	13-34.5	M-C	21.5	100	2,150	
17	9-12	F	3	15	45	210
	12-30	F-M	18	50	900	
	30-42	C-V	12	500	6,000	

and gravel found in the lower 5 to 10 feet in the lower part of the alluvial aquifer.

Estimates of average hydraulic conductivity were made from lithologic information from logs of wells and test holes where sufficient notes describing grain size were made during augering (table 1). Hydraulic conductivity for each homogeneous stratum was estimated from

information in Lohman (1979) and multiplied by the thickness to yield a transmissivity for the stratum. Average hydraulic conductivity for each point then was computed by dividing the sum of the individual transmissivity values by the total saturated thickness of the aquifer. Average hydraulic-conductivity values from eight wells and the areal distribution of hydraulic conductivity are shown in figure 7.

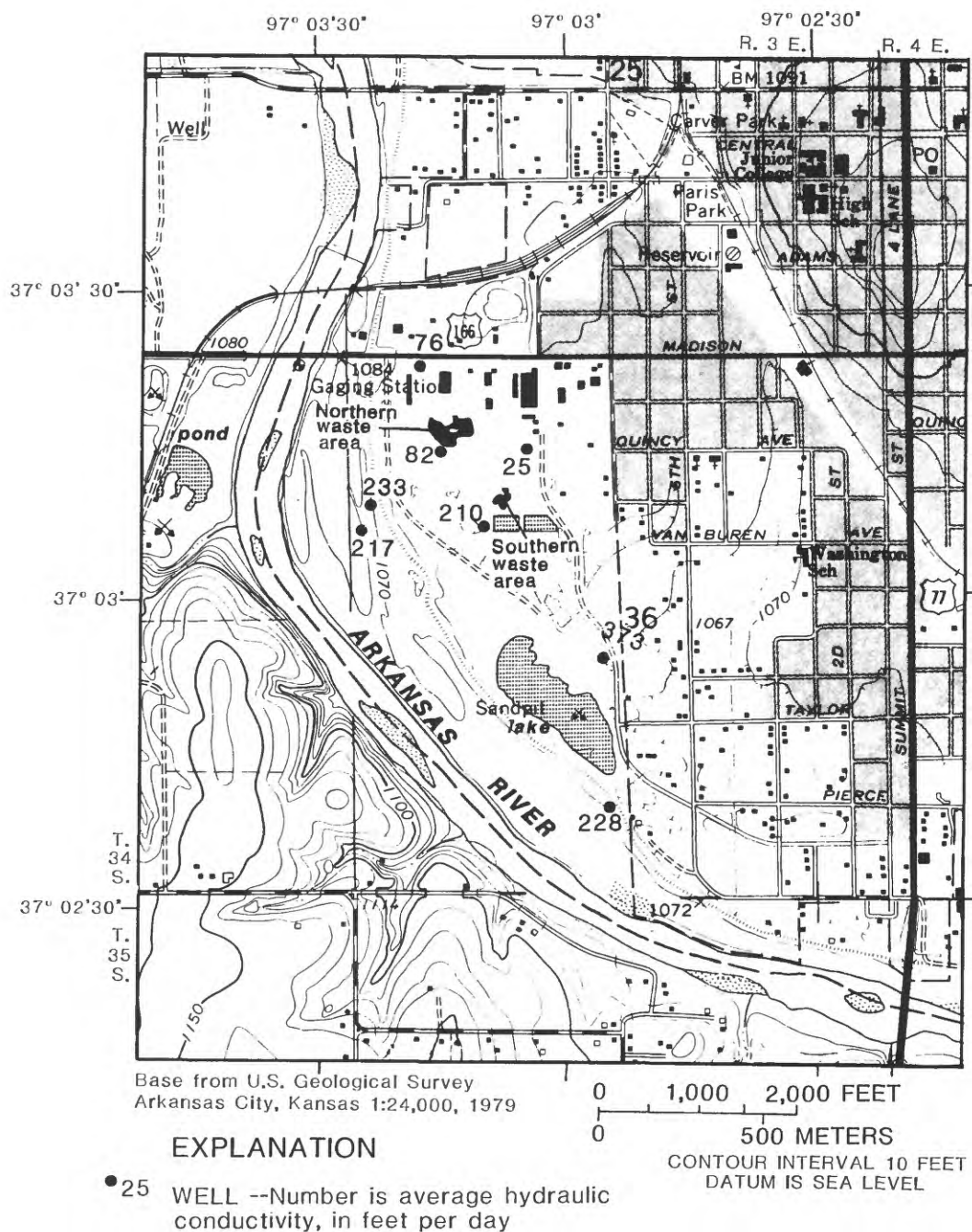


Figure 7. Distribution of average hydraulic-conductivity values on Arkansas City Dump Site.

On the basis of the information presented in figure 7, average hydraulic conductivity ranges about 25 to 373 feet per day. This map shows that hydraulic conductivity is generally smaller in the northern part of the site than in the southern part. This is due to thin sections or lack of coarse sand in the lower part of the saturated zone in the northern part of the site. Hydraulic conductivity of the aquifer south of the northern waste area generally appears to be greater than 200 feet per day, whereas hydraulic conductivity of the aquifer north of the northern waste area appears to be less than 200 feet per day. The distribution of hydraulic conductivity derived from these lithologic estimates agree closely with estimates derived from the flow-net analysis previously described.

An estimate of average ground-water velocity can be made from the following equation (from Lohman, 1979, p. 10-11):

$$V = \frac{K(dh/dl)}{S} \quad (2)$$

where V is ground-water velocity; K is hydraulic conductivity; dh/dl is the hydraulic gradient; and S is storage coefficient. On the basis of water-level measurements shown in figures 8A and B, the hydraulic gradient in the vicinity of the site ranges from approximately 5 to 10 feet per mile. If a storage coefficient of 0.2 is assumed [0.2 is generally thought to be a good estimate of the storage coefficient for an unconfined aquifer (Lohman, 1979, p. 8)], and an average hydraulic conductivity of 250 feet per day is assumed to exist south of the northern waste area, average ground-water velocity on the site ranges from 1 foot per day to more than 2 feet per day. It should be noted that this is an average value and that velocity in fine-grained deposits in the upper part of the aquifer could be as small as 0.07 foot per day and as large as 3.5 feet per day in coarse sand and gravel in the lower part of the aquifer.

In the vicinity of the Arkansas City Dump Site, the water table ranged from 8 to 12 feet below land surface when monitoring wells were completed in November 1985. The potentiometric surface of the alluvial aquifer is shown for three different time periods in figure 8. The potentiometric surface in December 1985 (fig. 8A) resembles that for June 1986 (fig. 8C), although the surface was about 1 foot lower in December. The average hydraulic gradient in the alluvial deposits is approximately 5 feet per mile. Although the aquifer discharged water to the river during December and June, the

Arkansas River apparently recharges the aquifer during relatively wet periods, such as occurred during March 1986 (fig. 8B). Information from the potentiometric-surface maps indicates that a ground-water divide occurs approximately through the middle of the Arkansas City Dump Site and that ground water flows southwesterly in the western one-half of the site and southeasterly in the eastern one-half. Therefore, these water-level data indicate that contaminated water could move from the site toward the river and toward residential areas on the eastern edge of the site.

Water-level data collected from wells installed at the site also indicate that a downward vertical gradient occurs, signifying a recharge area. Water levels from wells screened approximately 10 to 15 feet below the water table were generally lower by a few tenths of a foot than wells screened at the water table. Therefore, there is potential for contaminated water to move deep into the aquifer system as water moves toward the river where it discharges. A few additional wells with screens placed above the bedrock surface would need to be installed to evaluate this potential before a final remedial-action is adopted.

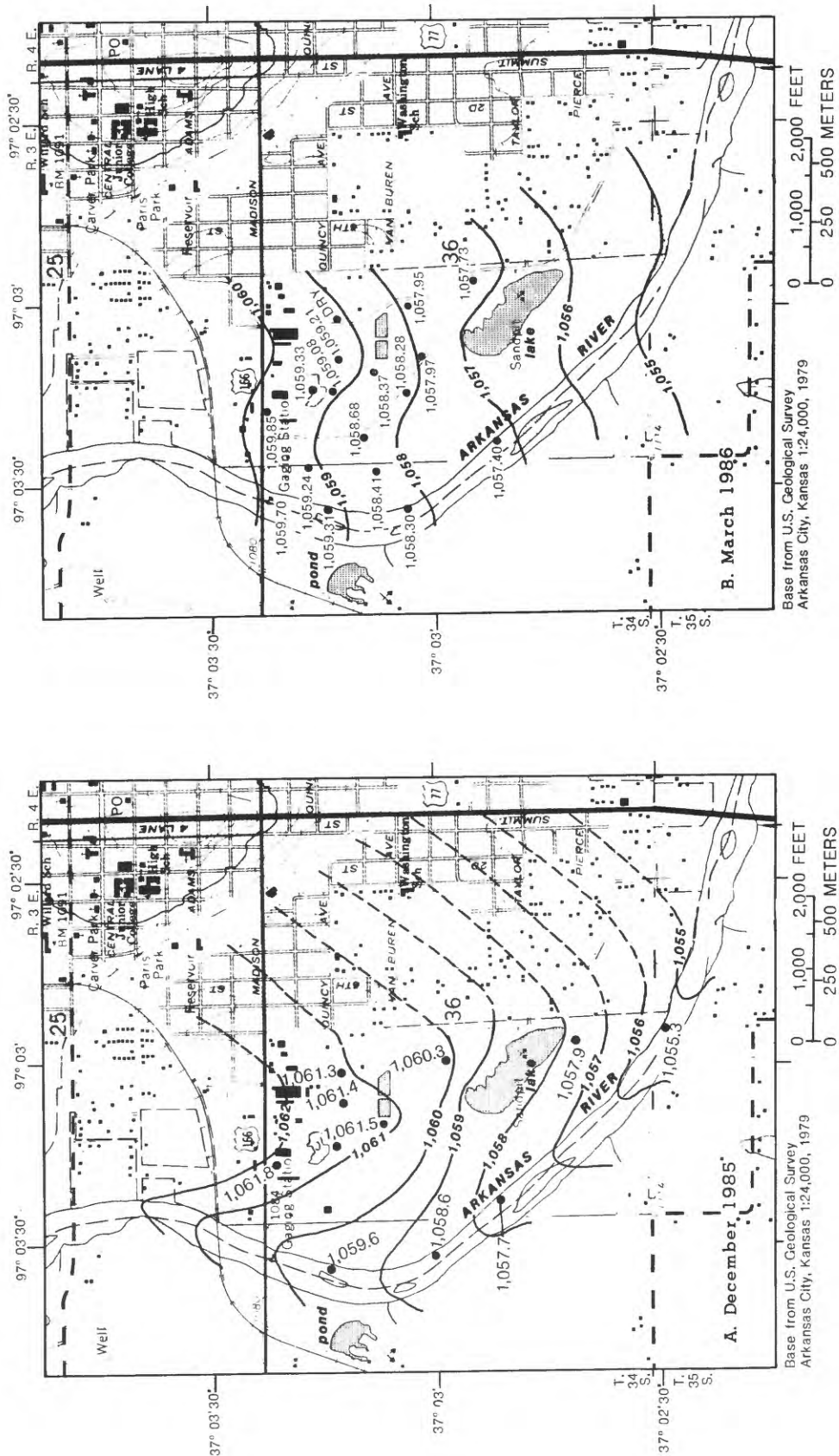
METHODS OF INVESTIGATION

Identification of Principal Sources of Contamination

Onsite measurements and analyses of samples of soil, air, and water were made to determine the presence of contaminants. Where potential sources of contaminants could release contaminants in the future, such as unruptured drums containing liquid wastes, measurements were made to determine areas of anomalous terrain conductivity. Large values of terrain-conductivity could indicate the presence of buried metal drums, metallic material, or very conductive fluids. Aerial photographs taken from 1938 through 1981 were used to determine land-use activities on the site and to identify past possible contaminant sources.

Soil Samples

Five areas were selected for soil sampling (fig. 9). Areas 1 to 3 are located within the boundary where most of the refinery operations were located. Area 1 is the unvegetated area around the northern waste area. Area 2 is the generally vegetated area between the northern



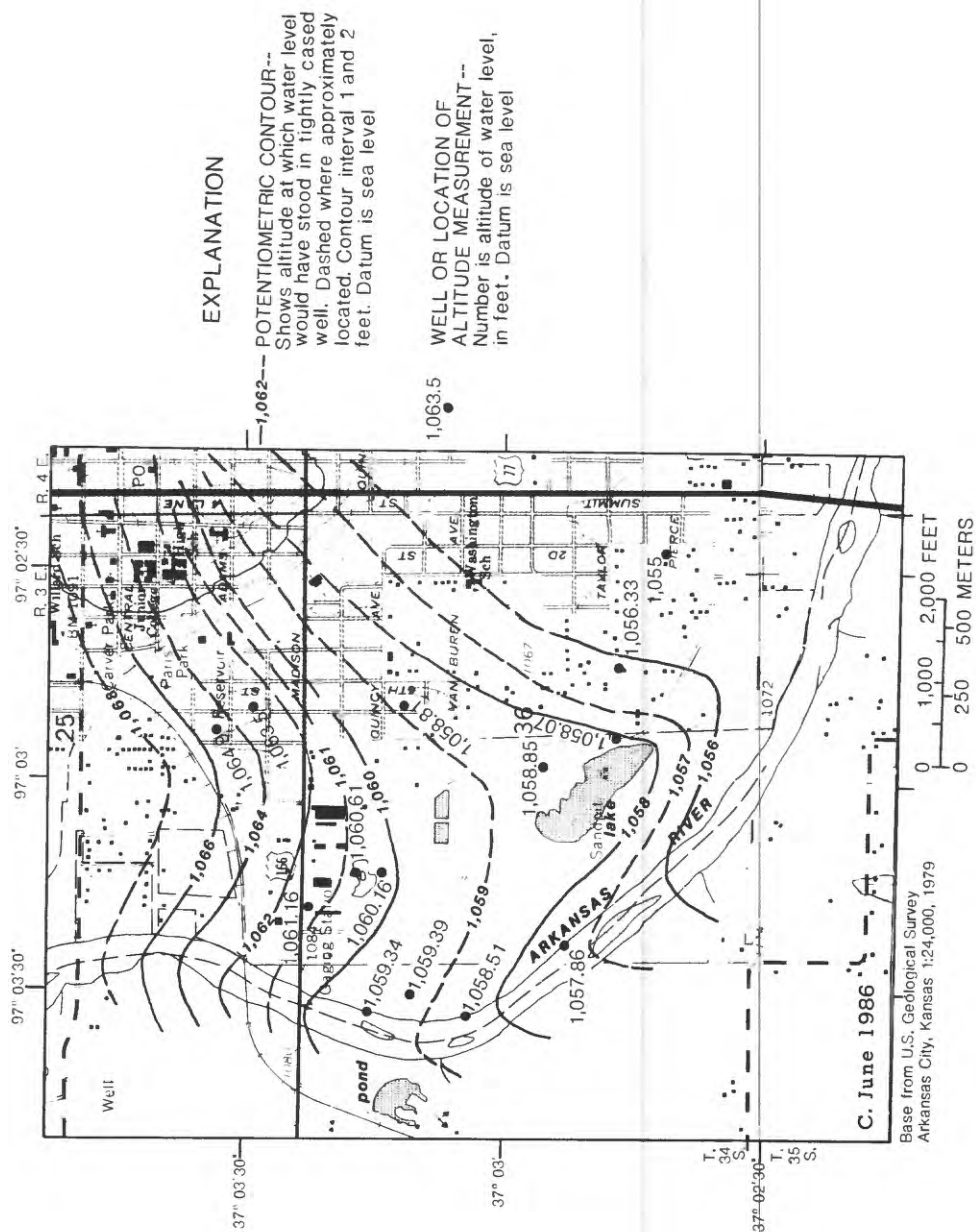


Figure 8. Potentiometric surface of alluvial aquifer for (A) December 1985 (B) March 1986, and (C) June 1986--Continued.

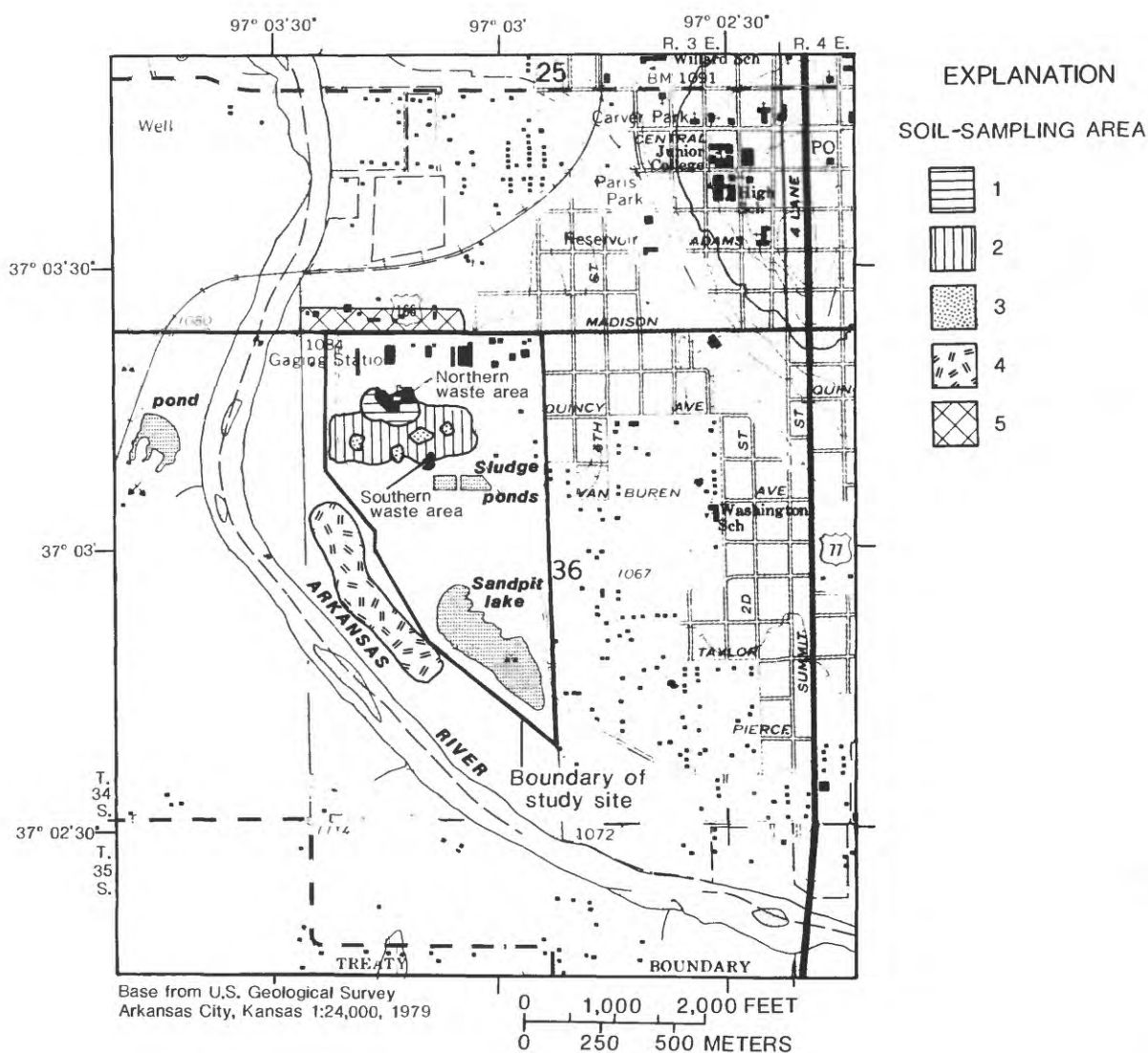


Figure 9. Location of soil-sampling areas.

and southern waste areas. Area 3 is composed of several unvegetated areas located within area 2. Area 4 is located south and southwest of the Arkansas City Dump Site. Area 4 is upwind (based on a predominant wind direction from the southwest) of the refinery site and is the control area. Area 5 is located north and downwind of the Arkansas City Dump Site.

The sampling grid was constructed and overlain on a 7.5-minute U.S. Geological Survey topographic quadrangle, and 10 points within the grid in each area were selected for sampling, except for area 3 where one sample was collected

from each of the four unvegetated areas shown in figure 4. Ten soil samples were collected randomly, using an epoxy-coated sampling trowel, in each of the five areas shown in figure 4. All samples from each area then were composited. Two sets of soil subsamples then were collected from the composited sample for each area; the subsamples to be analyzed for trace elements were placed in a cardboard or plastic freezer carton, and the remaining material to be analyzed for organic compounds was placed in a 1-liter glass jar and chilled in ice-filled coolers.

Well Installation and Ground-Water Sampling

Monitoring Wells

Monitoring wells were positioned along ground-water flow paths to intercept possible contaminants from the northern and southern waste areas. Ground-water flow paths were determined initially from a potentiometric-surface map presented in Kansas Department of Health and Environment (1982). Well screens were positioned in selected wells so that possible contaminants could be detected either at or near the water table for floating organic- or dissolved-phase hydrocarbons and about 10 to 15 feet below the water table for dissolved-phases hydrocarbons. Both polyvinyl-chloride (PVC) and stainless-steel materials were used to construct wells. Stainless steel was used to minimize possible sorption or desorption of contaminants from the casing where ground water would be in continuous contact with the screen. PVC casing was used to minimize cost where ground water would not be in continuous contact with the screen.

Eleven monitoring wells were installed by the U.S. Geological Survey for the investigation (plate 1). Information on these wells is presented in table 2. Four deep monitoring wells (USGS MW1B, 2B, 3B, and 4B) were installed using 2-inch stainless-steel screens and risers up to 1 foot above the static water level. PVC risers were used from the top of the stainless-steel riser above the water table to the land surface for wells screened 10 to 15 feet below the water table (fig. 10A). Five shallow wells (USGS MW1A, 2A, 3A, 4A, and 5) were installed with 5-foot stainless-steel screens near the water table, with 1 foot of screen projecting above the static water level. PVC risers were used to the land surface (fig. 10B). Well USGS MW6 was continuously screened from 1 foot above the static water level to approximately 20 feet below the water table. Well USGS MW7 was installed with 1.25-inch PVC risers and 2-foot PVC screen set approximately 10 feet below the water table. Wells were developed by bailing or pumping 8 to 10 well volumes.

Water-level data were collected from wells in the vicinity of the Arkansas City Dump Site during December 1985 and March and June 1986

to determine the direction of ground-water flow. Permeater and slug tests were conducted to obtain information on hydraulic properties of the soil and aquifer materials.

Ground-water samples were collected from two wells (KDHE MW1 and 5), installed by the Kansas Department of Health and Environment during 1982, and the 11 wells installed by the U.S. Geological Survey during 1985-86 (plate 1). Water samples were collected in Teflon¹ bailers after purging 3 to 5 well volumes. Inorganic chemical constituents in samples from these wells were analyzed by the U.S. Geological Survey's laboratory in Denver, Colo., using methods presented in Fishman and Friedman (1985). For samples from all monitoring wells, volatile organic compounds included on the U.S. Environmental Protection Agency's Priority Pollutant List were analyzed according to the U.S. Environmental Protection Agency's Method 624 (U.S. Environmental Protection Agency, 1982). Priority pollutant acid base-neutral compounds were analyzed using gas chromatography and mass spectrometry, according to the U.S. Environmental Protection Agency's Method 625 (U.S. Environmental Protection Agency, 1982). In addition, all samples were screened for additional compounds included in the National Bureau of Standards (NBS) library. Identification of compounds by the NBS mass-spectral library are tentative and were not confirmed using known standards. Specific conductance, dissolved oxygen, pH, and water temperature were determined onsite according to techniques described in Wood (1976).

Supply Wells

Fourteen supply wells and two abandoned wells located in the vicinity of the Arkansas City Dump Site were sampled during the investigation (plate 1). All of these wells were sampled and analyzed for total organic carbon. Three of these wells (map numbers 101, 102, and 104, plate 1) had both inorganic and organic analyses performed on samples collected.

¹ The use of brand names in this report is for identification purposes only and does not imply endorsement by the U.S. Geological Survey.

Table 2. Summary of sampling-site information and analyses for monitoring wells

[--, no sample collected]

Map number (plate 1)	Sampling site	Well location (township, range, section)	Site-identification number (latitude and longitude and 2-digit suffix)	Well depth (feet below land surface)	Screen interval (feet below land surface)	Altitude of top of casing (feet above sea level)	Sample date (month-day- year)	Use	Type of sample collected ¹
1	U'SGS MW1A	3403E36BCB	370307097032401	15.32	10.32 - 15.32	1,074.45	12-04-85 07-03-86	Observation well	ABCDEF
2	U'SGS MW1B	3403E36BCB	370307097032402	27.67	22.67 - 27.67	1,074.69	12-04-85	do.	ABCDEF
3	U'SGS MW2A	3403E36BDC	370300097030801	16.05	16.05 - 16.05	1,071.25	12-05-85	do.	ABCDEF
4	U'SGS MW2B	3403E36BDC	370300097030802	21.26	16.26 - 21.26	1,071.44	12-05-85	do.	ABCDEF
5	U'SGS MW3A	3403E36BDD	370300097030001	13.84	8.84 - 13.84	1,073.41	12-05-85	do.	ABCDEF
6	U'SGS MW3B	3403E36BDD	370300097030002	27.32	22.32 - 27.32	1,073.47	12-05-85	do.	ABCDEF
7	U'SGS MW4A	3403E36BCA	370307097031601	17.83	12.83 - 17.83	1,076.97	12-04-85	do.	ABCDEF
8	U'SGS MW4B	3403E36BCA	370307097031602	25.34	20.34 - 25.34	1,077.24	12-05-85	do.	ABCDEF
9	U'SGS MW5	3403E36CAA	370245097030001	16.78	11.78 - 16.78	1,070.33	12-05-85	do.	ABCDEF
10	U'SGS MW6	3403E36BCC	370300097032401	27.0	7.0 - 27.0	1,066.23	03-12-86	do.	ABCDEF
11	U'SGS MW7	3403E36BBA	370313097031601	24.5	22.5-24.5	1,072.74	03-27-86	do.	ABCDEF
12	KDHE MW1	3403E36BBA	370320097031601	30.9	10.9 - 30.9	1,072.2	12-03-85	do.	ABCDEF
13	KDHE MW2	3403E36BAD	370313097030012	23.8	3.8-23.8	1,074.8	--	do.	--
14	KDHE MW3	3403E36DDC	370234097023512	29.9	9.9-29.9	1,067.1	--	do.	--
15	KDHE MW4	3403E36AAA	370320097022712	32.2	2.2-32.2	1,069.8	--	do.	--
16	KDHE MW5	3403E36BBC	370313097031601	21.5	1.5 - 21.5	1,066.4	03-11-86	do.	ABCDEF
17	KDHE MW6	3403E36ACB	370307097025212	36.5	6.5-36.5	1,073.7	--	do.	--
18	KDHE MW7	3403E36BAC	370254097030812	23.5	3.5-23.5	1,075.1	--	do.	--
19	KDHE MW8	3403E36AAC	370313097023612	20.5	0.5-20.5	1,065.0	--	do.	--

¹ Sample designations are as follows:

A = Inorganic compounds
B = Volatile organic compounds and acid base-neutral extractable compounds
C = Total organic carbon.

D = Pesticides

E = Onsite determinations--pH, specific conductance, and water temperature.

F = Acid base-neutral extractable compounds, unfiltered sample.

G = Acid base-neutral extractable compounds, filtered sample.

Because concentrations of polynuclear aromatic (PNA) compounds in water supplies from onsite wells, which were less than the 5- $\mu\text{g/L}$ (micrograms per liter) detection limit, could pose a possible health hazard [the U.S. Environmental Protection Agency ambient water-quality criterion is 2.8 ng/L (nanograms per liter)], both gas chromatography/mass spectrometry (GC/MS) and high-performance, liquid chromatography techniques (HPLC) (U.S. Environmental Protection Agency Method 610) were used by two different laboratories (Wilson Laboratories, Salina, Kans., and Midwest Research Institute, Kansas City, Mo.) in an effort to detect these compounds at the smallest concentration practicable. The detection limit for the GC/MS technique was about 0.05 $\mu\text{g/L}$, and the detection limit for the HPLC technique ranged from 0.01 to 0.8 $\mu\text{g/L}$ for particular PNA compounds. In addition, an organic-compound scan was conducted by the U.S. Geological

Survey's laboratory in Denver, Colo., using a gas chromatograph equipped with a flame-ionization detector (GC/FID) on samples collected from six wells located offsite to detect the possible presence of any other compounds that might pose a health or environmental problem.

Surface-Water Sampling

Surface-water samples were collected during December 1985 from sites shown on plate 1. Discharge at all three sites was about 1,500 cubic feet per second. Grab samples were collected from the river sites along the left bank. Three sites on the Arkansas River were sampled. The sandpit lake, with a maximum measured depth of about 25 feet, was sampled at five points in zones just below the water surface and at about 15 to 20 feet below the water surface. The five shallow sandpit samples were composited into one sample, as were the five deep sandpit

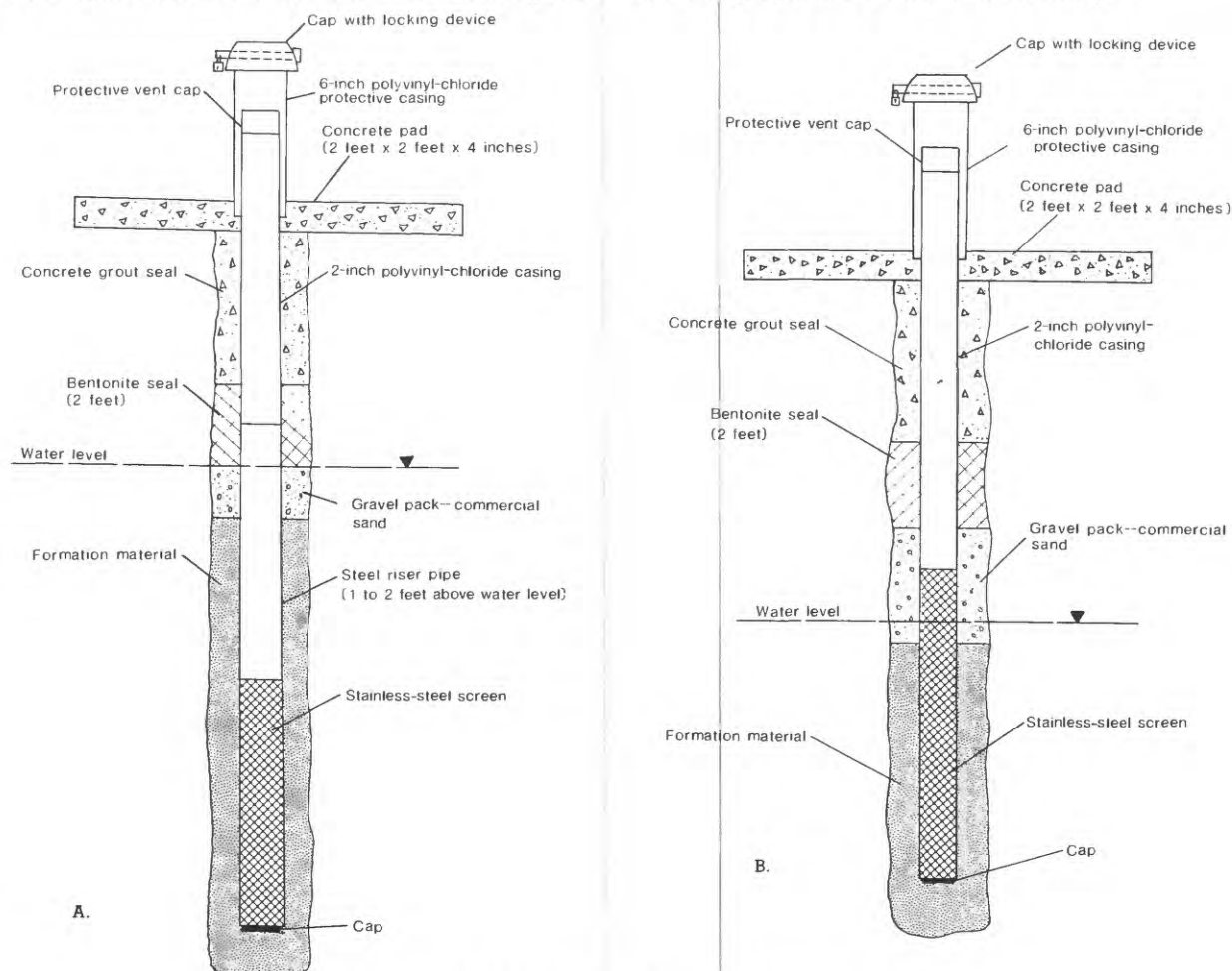


Figure 10. Designs for (A) deep and (B) shallow monitoring wells.

samples. A composite sample also was made from samples collected from six selected areas in a small pond (labeled "South pond," plate 1), located about 1/8-mile north of the sandpit lake. Samples were collected about 2 feet below the water surface. Surface-water samples were analyzed for the same constituents analyzed in ground-water samples.

Bottom sediment samples also were collected from all surface-water sites using a dredge sampler. Bottom sediment samples were analyzed for acid base-neutral extractable compounds and trace elements.

Waste Sampling

Acid-sludge and waste-seepage sampling sites are shown on plate 1. Ten boreholes were placed in the northern waste area using a trailer-mounted mobile auger (fig. 11), and notes regarding consistency and thickness of the sludge were recorded. Ionizable vapors were measured using a photoionization detector, and gas-detector tubes were used to detect the presence of hydrogen sulfide, methane, cyanide, and sulfur dioxide in selected boreholes. A waste

sample was collected from the northern waste area at below land surface from auger flights using a metal trowel (for samples to be analyzed for organic compounds) and with an epoxy-coated trowel (for samples to be analyzed for trace elements). Because waste located at more than 1.5 feet below the sludge surface was apparently homogeneous (resembling fresh asphalt), based on visual comparison with sludge from other samples in the northern waste area, one sample was considered sufficient to describe the organic composition of the sludge from this area. Several boreholes placed on the southern waste area (not shown on plate 1) indicated that the sludge was dry, hard, and less than 2-feet thick.

Water contained in a depression in the center of the northern waste area and water standing at the surface in the southern waste area also were sampled to determine compounds present in these waters and the possible source of contaminants to ground water flowing beneath the areas and to the surrounding soil. Semisolid waste from the northern waste area was analyzed for the same organic compounds and trace elements analyzed in soil samples.



Figure 11. Use of mobile auger to place boreholes in acid sludge in northern waste area.

SOURCES OF CONTAMINANTS

Oil-Refinery Wastes and Characteristics

The Milliken Oil Refinery was the primary producer of potential hazardous-waste materials at the site. Acid sludge and spilled crude- and refined-oil products are the principal sources of contaminants found in soil and water in the vicinity of the Arkansas City Dump Site. On the basis of information from the literature (Abraham, 1918; Kalichevsky and Stagner, 1933), sludge asphalt, or acid sludge, was produced from purification of petroleum distillates by treatment with sulfuric acid. The distillate products, such as gasoline, kerosene, and lubricating oils, probably were treated with acid in a lead-lined agitator with a conical bottom, and the sludge then was removed from the tank through the lower valve (Abraham, 1918).

Acid sludge was produced at almost every step in the distillation process (fig. 12). The amount of sludge produced varied depending upon the product being refined. Generally, the nonviscous distillates, such as light naphthas, would lose from 0.5 to 8 percent by volume to the acid to form sludge (Kalichevsky and Stagner, 1933). The more viscous distillation components, such as kerosene, paraffin distillates (from which lubrication oils were produced), and asphalt, lost from 30 to 40 percent of the product to acid sludge (Kalichevsky and Stagner, 1933).

Acid sludge generally is characterized by a large percentage of sulfur (up to 10 percent) and a relatively small percentage of saturated hydrocarbons (Abraham, 1918). The sludge consists primarily of acid and organic material. The organic substances in the sludge are complex in nature and are the result of reactions of sulfuric acid with various components of the oil. Reactions among alcohols and unsaturated hydrocarbons in the oil form mono- and dialkyl-sulfuric esters; alcohols form from olefins; sulfonic acids result from reactions with PNA compounds; and PNA compounds result from condensation reactions (Kalichevsky and Stagner, 1933).

Acid content of the sludge depends on the type of product purified. Acid sludge from distillation of lubrication oil, for example, could contain from 60- to 80-percent sulfuric acid and 20- to 40-percent hydrocarbons. Gasoline, however, is treated with small quantities of acid to desulfurize the oil, and consequently the sludge contains a smaller percentage of acid. Acid content of the various sludges ranges from 20 to 90 percent (Bigda, 1982). On the basis of an acidity determination of sludge collected from the northern waste area, acid content of the sludge from the northern waste area on the Arkansas City Dump Site is estimated to be approximately 20 percent by weight. Samples of sludge collected from the southern waste area did not affect the pH of deionized water, indicating that sludge from this area no longer contains significant quantities of sulfuric acid.

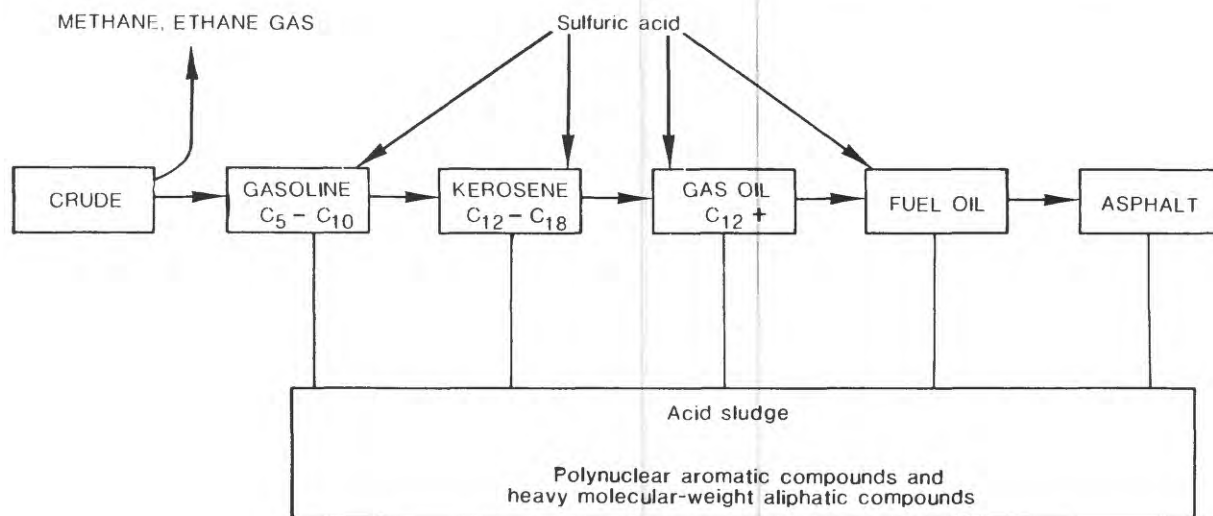


Figure 12. Generation of acid sludge by oil industry at beginning of 20th century.

General physical and chemical characteristics of acid sludge are listed in table 3. Organic compounds tentatively identified in sludge waste from the northern and southern waste areas are listed in table 4. Concentrations of selected trace elements detected in waste samples are presented in table 5.

Acid sludge in the northern and southern waste areas comprises the bulk of visible wastes

at the Arkansas City Dump Site (fig. 3). To estimate the total amount of sludge wastes present on the site, 13 boreholes were augered at selected areas in the northern (plate 1) and the southern waste areas. The approximate thickness of acid sludge in the northern waste area was 9 feet. Cross sections showing the thickness of the sludge are shown in figure 13. Although a hardened crust, about 1 to 2 feet thick, exists on the surface, the sludge is

Table 3. *Selected physical and chemical characteristics of acid sludge*
[Data from Abraham, 1918]

Color in mass	Black
Homogeneity to the eye at room temperature	Uniform
Homogeneity under microscope	Variable
Appearance surface aged indoors 1 week	Bright
Fracture	Conchoidal
Luster	Bright
Specific gravity at 77 °F	1.05-1.20
Odor on heating	Oily; similar to residual asphalt
Behavior on melting	Passes rapidly from the solid to the liquid state
Volatile matter 500 °F in 4 hours	2- 20 percent
Flash point	300- 500 °F
Fixed carbon	5- 30 percent
Solubility in carbon disulphide	95-100 percent
Non-mineral matter insoluble	0- 5 percent
Mineral matter	0- 1 percent
Solubility at 88° naphtha	60- 95 percent
Sulfur	5- 10 percent
Oxygen	3- 7 percent
Saturated hydrocarbons	Less than 10 percent

Table 4. Organic compounds tentatively identified in waste and waste seepage

[Concentrations in water are in micrograms per liter (µg/L). Concentrations in sediments are in micrograms per kilogram (µg/kg). T indicates compound detected as trace (concentration less than 5 µg/L). ND indicates not detected at less than 5 µg/L. Asterisk indicates positive identification with National Bureau of Standards library]

Organic compound	Northern waste area acid sludge (µg/kg)	Northern waste area seepage (µg/L)	Southern waste area seepage (µg/L)
	Map number 301	shown on plate 1 301	302
1-Pentatriacontanol	30,532	ND	ND
5-Eicosene, (E)-	ND	ND	ND
Alkane	ND	389	T
Do.	ND	668	6
Do.	ND	618	T
Do.	ND	224	11
Do.	ND	1,215	15
Do.	ND	251	7
Do.	ND	302	26
Do.	ND	1,640	T
Do.	ND	224	32
Do.	ND	908	T
Do.	ND	643	T
Do.	ND	1,259	T
Do.	ND	1,709	33
Do.	ND	284	T
Do.	ND	350	35
Do.	ND	338	T
Do.	ND	229	31
Do.	ND	331	T
Do.	ND	370	23
Do.	ND	1,253	10
Do.	ND	269	22
Do.	ND	2,306	T
Do.	ND	487	20
Do.	ND	1,049	T
Do.	ND	1,627	T
Do.	ND	1,151	19

Table 4. Organic compounds tentatively identified in waste and waste seepage--Continued

Organic compound	Northern waste area acid sludge (µg/kg)	Northern waste area seepage (µg/L)	Southern waste area seepage (µg/L)
	Map number shown on plate 1		
	301	301	302
Alkane			
Do.	ND	432	T
Do.	ND	42	11
Do.	ND	60	T
Do.	ND	65	T
Do.	ND	52	14
Do.	ND	36	T
Do.	ND	23	11
Do.	ND	15	T
Do.	ND	9	T
Do.	ND	10	ND
Do.	ND	T	ND
Do.	ND	T	ND
Do.	ND	T	ND
Do.	ND	T	ND
Do.	ND	T	ND
Do.	ND	T	ND
Do.	ND	T	ND
Do.	ND	T	ND
Do.	ND	T	ND
Do.	ND	T	ND
Do.	ND	T	ND
Do.	ND	T	ND
Do.	ND	236	ND
Alkene	ND	T	ND
Do.	ND	ND	ND
*Anthracene	20,016	ND	ND
Anthracene, 1-methyl-	ND	945	ND

Table 4. Organic compounds tentatively identified in waste and waste seepage--Continued

Organic compounds	Northern waste area acid sludge (µg/kg)	Northern waste area seepage (µg/L)	Southern waste area seepage (µg/L)
	Map number shown on plate 1		
	301	301	302
Anthracene, 2-methyl-	ND	7	ND
*Benz(a)anthracene	41,283	ND	T
*Benz(b)fluoranthene	15,250	ND	ND
Benzene, 1,3,5-trimethyl-	ND	ND	ND
Benzene, 1,2,4,5-tetramethyl-	ND	ND	T
*Benzo(a)pyrene	46,465	ND	T
*Butylbenzyl-phthalate	6,255	ND	ND
*Chrysene	165,191	5,520	T
Chrysene, 5-methyl-	122,145	ND	ND
Cyclohexane, 1-bromo-2-chlor-, cis	ND	3	ND
*Dibenz(a,h)anthracene	1,251	ND	ND
Docosane	158,079	ND	ND
Dodecane, 2,6,11-trimethyl-	28,541	ND	ND
Dotriacontane	27,665	ND	ND
Eicosane	29,338	ND	ND
*Fluoranthene	1,668	ND	T
Heptacosane	ND	312	ND
Heptadecane	287,863	ND	ND
Hexadecane, 2,6,10,14-tetramethyl-	32,097	ND	ND
Hexatriacontane	141,314	ND	ND
*Indeno (1,2,3-cd)pyrene	834	ND	ND
1,3 Isobenzofuran-dione	ND	ND	5
Isophorone	ND	ND	T

Table 4. Organic compounds tentatively identified in waste and waste seepage--
Continued

Organic compound	Northern waste area acid sludge (µg/kg)	Northern waste area seepage (µg/L)	Southern waste area seepage (µg/L)
	Map number shown on plate 1		
	301	301	302
*Naphthalene	ND	ND	ND
Naphthalene, 2-methyl-	ND	ND	ND
Naphthalene, 1-methyl-	ND	ND	ND
Naphthalene, 1,7-dimethyl-	ND	ND	ND
Naphthalene, 1,8-dimethyl-	ND	ND	ND
Naphthalene, 1,6-dimethyl-	ND	ND	ND
Naphthalene, 2,3-dimethyl-	ND	ND	ND
Naphthalene, 1,4-dimethyl-	ND	ND	T
N-nitrosodi-methylamine	ND	ND	ND
N-nitrosodi-phenylamine	ND	ND	ND
Nonadecane	91,659	ND	ND
Octacosane	136,765	ND	ND
*Phenanthrene	17,156	320	ND
Phenol,4-chloro-3-methyl-	ND	ND	ND
Phenol,2,4-dimethyl-	ND	ND	ND
Phenol,4-nitro	ND	ND	T
Phenanthrene, 4-methyl-	ND	952	T
Phenanthrene, 2,5-dimethyl-	109,736	244	ND
Phenanthrene, 2,3-dimethyl-	32,300	265	ND
Phenanthrene, 2,7-dimethyl	ND	31	ND
Phenanthrene	17,156	ND	T
Phenanthrene, 4-methyl-	41,498	ND	ND
Pyrene	5,361	ND	9

Table 4. Organic compounds tentatively identified in waste and waste seepage--
Continued

Organic compound	Northern waste area acid sludge (µg/kg)	Northern waste area seepage (µg/L)	Southern waste area seepage (µg/L)
	Map number shown on plate 1		
	301	301	302
Quinoline, 2,6-dimethyl-	ND	ND	ND
Tricosane	133,396	ND	ND
Tritetracontane	266,750	ND	ND

Table 5. Concentrations of selected trace elements detected in waste and seepage samples

[NA indicates not analyzed; µg/g = micrograms per gram; µg/L = micrograms per liter]

Inorganic constituent	Northern waste area acid sludge (µg/g)	Northern waste area seepage (µg/L)	Southern waste area seepage (µg/L)
	Map number shown on plate 1		
	301	301	302
Aluminum	60	51,000	160
Arsenic	NA	12	1
Barium	10	60	84
Beryllium	1	2	0.5
Cadmium	2	25	1
Chromium	30	2	1
Copper	1	60	35
Iron	3,000	110,000	2,800
Lead	50	320	20
Manganese	10	1,100	660
Zinc	10	560	43

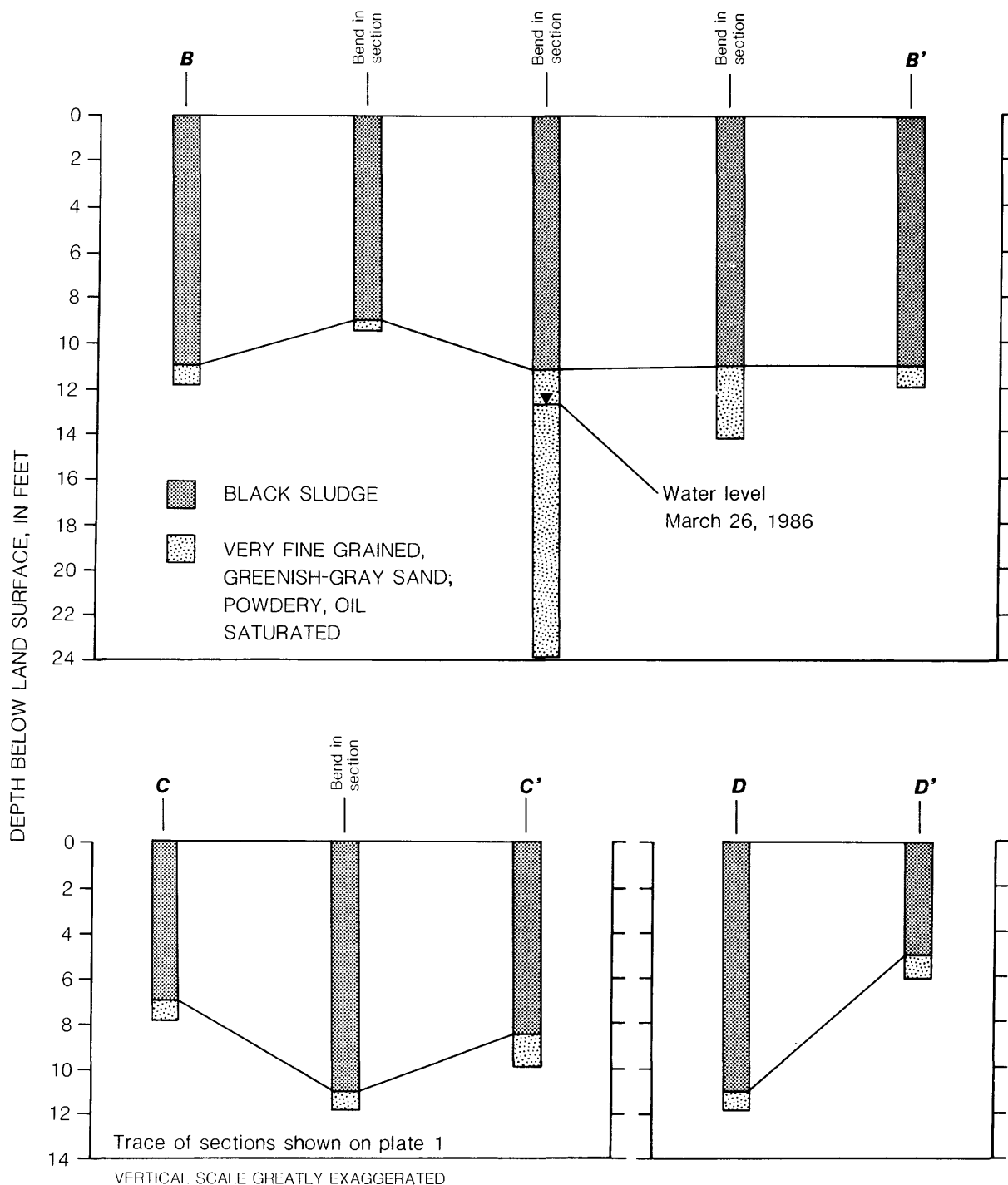


Figure 13. Cross sections showing thickness of acid sludge in northern waste area. Lateral dimensions are not to scale.

semisolid and has an oily odor in the inner part of the mass. The thickness of sludge in the southern waste area is only 1 to 2 feet, and sludge from this area is hardened and resembles coke in appearance. On the basis of information from the boreholes, it is estimated that approximately 800,000 to 1,200,000 cubic feet of acid sludge are present on the site, with the bulk of this material (92 to 95 percent) located in the

northern waste area.

Contaminated Soil

Soil samples indicate that the area north of Madison Street and the area located between the northern and southern waste areas are contaminated with petroleum-derived hydrocarbons (table 6). Only heavy molecular-

Table 6. Organic compounds tentatively identified in soil from five areas in the vicinity of the Arkansas City Dump Site

[Areas correspond to those shown in figure 9. Concentrations in micrograms per kilogram ($\mu\text{g/kg}$) and are equivalent to parts per billion (ppb). ND indicates not detected. Asterisk indicates positive identification with standard]

Organic compound	Area 1 soil ($\mu\text{g/kg}$)	Area 2 soil ($\mu\text{g/kg}$)	Area 3 soil ($\mu\text{g/kg}$)	Area 4 soil ($\mu\text{g/kg}$)	Area 5 soil ($\mu\text{g/kg}$)
1,3-Isobenzofurandione	ND	ND	ND	ND	ND
1-Octadecanol	ND	ND	1,852	ND	ND
11H-Benzol[b]fluorene	ND	ND	ND	ND	514
14-Octadecenal	ND	ND	ND	208	ND
4h-Pyr-4-one,3-hydrox-2-met-	ND	ND	ND	ND	ND
9-Tricosane	ND	ND	ND	120	ND
*Anthracene	ND	536	1,256	ND	255
Anthracene, 1-methyl-	ND	1,985	ND	ND	954
Anthracene, 2-methyl-	ND	ND	1,187	ND	487
*Benz(a)anthracene	ND	2,159	2,200	ND	1,334
*Benzo(a)pyrene	ND	1,369	1,900	ND	1,938
*Benz(ghi)pyrene	ND	2,948	ND	ND	1,235
*Benz(b)fluoranthene	1,426	698	ND	ND	1,116
Benz[a]anthracene, 1-methyl-	ND	4,033	ND	ND	ND
Benz[a]anthracene,7-methyl-	ND	ND	1,515	ND	1,609
*Chrysene	11,168	4,083	4,236	ND	2,696
Cyclodocosane, ethyl-	ND	ND	ND	239	ND
Chrysene, 5-methyl-	ND	1,261	1,860	ND	504
Dibenzothiophene, 4-methyl-	ND	1,018	ND	ND	ND
Dibenzothiophene	ND	670	1,417	ND	ND
Dibenzothiophene, 3-methyl-	ND	ND	1,574	ND	ND
Eicosane	ND	ND	2,352	ND	ND
Eicosane	ND	2,680	ND	ND	ND
*Fluoranthene	ND	389	840	ND	717
Heneicosane	ND	12,684	ND	ND	ND
Heptadecane, 2,6,10,15-tetramethyl-	ND	943	1,923	ND	ND
Hexadecane	ND	805	1,194	ND	1,712
Hexatriacontane	ND	ND	ND	620	ND
Indeno (1,2,3-cd)pyrene	ND	ND	ND	ND	420
Methyl-ethyl-naphthalene	ND	559	ND	ND	ND
Methyl-phenanthrene or methyl-anthracene	ND	3,637	1,812	ND	762
*Naphthalene	ND	258	884	ND	ND

Table 6. *Organic compounds tentatively identified in soil from five areas in the vicinity of the Arkansas City Dump Site--Continued*

Organic compound	Area 1 soil (µg/kg)	Area 2 soil (µg/kg)	Area 3 soil (µg/kg)	Area 4 soil (µg/kg)	Area 5 soil (µg/kg)
Naphthalene, 2-methyl-	ND	987	ND	ND	ND
Naphthalene, 1,5-dimethyl-	ND	1,148	ND	ND	ND
Naphthalene, 1,6-dimethyl-	ND	1,118	ND	ND	ND
Naphthalene, 2,7-dimethyl-	ND	640	ND	ND	ND
Naphthalene, 1,4,6-trimethyl-	ND	587	ND	ND	ND
Naphthalene, 1-methyl-	ND	ND	6,028	ND	ND
Naphthalene, 1,7-dimethyl-	ND	ND	2,103	ND	ND
Naphthalene, 2,3-dimethyl-	ND	ND	1,555	ND	ND
Nonacosane	ND	ND	ND	1,005	ND
Nonadecane	14,708	1,392	ND	ND	ND
Nonane, 2-methyl-	ND	837	ND	ND	ND
Nonane, 3,7-dimethyl-	ND	630	ND	ND	ND
Octacosane	20,584	ND	ND	ND	ND
Octadeconoic acid, 2-oxo-, methyl ester	22,203	ND	ND	ND	ND
Octadecane	ND	1,733	ND	ND	ND
Octane, 2,4,6-trimethyl-	ND	ND	1,542	ND	ND
Phenanthrene	ND	4,310	9,216	ND	1,458
Pyrene	ND	5,258	3,656	ND	2,657
Pentacosane	ND	ND	ND	204	ND
Pentadecane	10,862	1,363	ND	ND	ND
Pentadecane, 3-methyl-	ND	ND	ND	ND	829
Phenanthrene, 2,5-dimethyl-	12,515	2,743	ND	ND	2,234
Phenanthrene, 2,3-dimethyl-	ND	1,143	ND	ND	ND
Phenanthrene, 3-methyl-	ND	ND	4,325	ND	ND
Phenanthrene, 9-methyl-	ND	ND	3,139	ND	ND
Phenanthrene, 4,5-dimethyl-	ND	ND	1,214	ND	ND
Phenanthrene, 2,5-dimethyl-	ND	ND	2,988	ND	ND
Phenanthrene, 4-methyl-	ND	ND	ND	ND	1,722
Pyrene, 1-methyl-	ND	5,880	1,373	ND	1,720
Tricosane	17,212	ND	ND	ND	643
Tridecane	ND	785	ND	ND	ND
Triosane, 2-methyl-	ND	ND	3,286	ND	ND
Triphenylene	ND	ND	1,892	ND	ND
Tritetracontane	92,988	ND	ND	187	796
Undecane	ND	ND	2,062	ND	ND

weight aliphatic compounds, some of which may occur naturally in plants (Oro and others, 1965), were detected in the control area (area 4, fig. 9), whereas combinations of many alkanes, cycloalkanes, and PNA compounds were detected at concentrations of a few hundred to several thousand parts per billion in other areas shown in figure 9. Currently (1986), there is insufficient information to estimate the volume of oil-soaked soil on the site. However, on the basis of shallow soil samples collected on- and offsite and aerial photographs of the site, it is estimated that at least one-half of the land area within the site boundaries is contaminated with several PNA hydrocarbons at concentrations greater than 600 µg/kg. Concentrations of trace elements from shallow soil samples in general approximated concentrations expected for natural soil (table 7).

Other Wastes and Characteristics

Various types of municipal and rural solid wastes have been disposed at the Arkansas City Dump Site since the late 1920's, and limited

waste disposal still occurs on the site. At the beginning of this investigation in 1985, several 55-gallon drums containing liquid wastes (apparently waste oil) were found in the northeastern part of the site. Solid wastes, such as discarded refrigerators, paper, tires, and brush, were still being disposed of in the northeastern part of the site during this study. Currently (1986), the city of Arkansas City disposes brush and asphalt materials on the site and disposes of alkaline sludge, generated from their water-treatment plant, in ponds excavated in the central part of the site (fig. 3). Although it is possible that some disposal of drummed industrial liquid wastes could have occurred on the site, it appears that most of the waste disposed of at the site after 1938 was solid waste.

CHEMICAL QUALITY OF LEACHATE AND CONTAMINATION POTENTIAL

Oil-Refinery Wastes

Most of the material in the northern waste

Table 7. Comparison of concentrations of selected trace elements in uncontaminated soil with median concentrations found in soil¹ or sediment samples collected from sampling sites on the Arkansas City Dump Site

[Data for uncontaminated soils from Lindsay, 1979]

Trace element	Common range in uncontaminated soil (parts per million)	Range and median concentrations (in parentheses) onsite (parts per million)	
		Soil	Sediment
Arsenic	1 - 50	2-3 (3)	1-90 (1)
Barium	100 - 3,000	40-80 (50)	40-320 (60)
Beryllium	0.1 - 40	ND ² (<1) (<1 ³)	ND (<1) (<1 ³)
Cadmium	0.01 - 0.7	<1-2 (<1 ³)	ND (<1) (<1 ³)
Chromium	1 - 1,000	20-109 (40)	20-1,110 (20)
Copper	2 - 100	5-30 (10)	20-70 (30)
Lead	2 - 200	20-80 (40)	10-50 (10)
Zinc	10 - 300	10-219 (30)	20-60 (40)

¹ Shallow soil samples collected from five areas shown in figure 9.

² Not detected.

³ Detection limit.

area is a black, semisolid sludge that resembles fresh asphalt. Material in a depression in the northern waste area appears to be a black weathered sludge composed of fine-particulate carbonaceous matter. There is standing water in the depression in the northern waste area during wet periods (water was observed standing in the depression during June 1986) when water rises above the bottom of the depression (note B in fig. 14). The weathered sludge in the northern waste area may act, however, as a perched "aquifer," and during dry periods, as in early March 1986, the water surface moves below the bottom of the depression (note A in fig. 14). Water was encountered in March 1986 after digging approximately 2 feet through the weathered material.

Water contained in the depression in the northern waste area (termed northern waste area seepage) is a calcium magnesium sulfate type (plate 1, map no. 301) characterized by low pH values (2.1) and large concentrations of aluminum (51,000 µg/L), cadmium (25 µg/L), iron (110,000 µg/L), lead (320 µg/L), and manganese (1,100 µg/L) (table 5). Unfiltered water from the depression in the northern waste area also contained large concentrations of organic carbon (400 mg/L) and large

concentrations of several PNA and alkane compounds (table 4). As long as the sludge remains exposed to precipitation, acidic water containing large concentrations of various trace elements and hydrocarbon compounds can recharge the underlying alluvial aquifer.

Water in the southern waste area is ponded on the surface of the sludge. Sludge in this area is hard, dry, and resembles coke. The thickness of this material is generally less than 2 feet, and the sludge in the southern waste area is more completely weathered, with most of the acid having been removed.

Ponded seepage from acid sludge in the southern waste area is a calcium magnesium bicarbonate sulfate type (plate 1, map no. 302), has a pH of 6.5, and contains small concentrations of most trace elements (table 5). Concentrations of trace elements in water from the southern waste area are much smaller than concentrations in water from northern waste area. The smaller concentrations probably are the result of the lack of an acid source and a high enough pH to limit solubility of most trace elements. Water samples collected from the southern waste area, however, contain large concentrations of total organic carbon (340

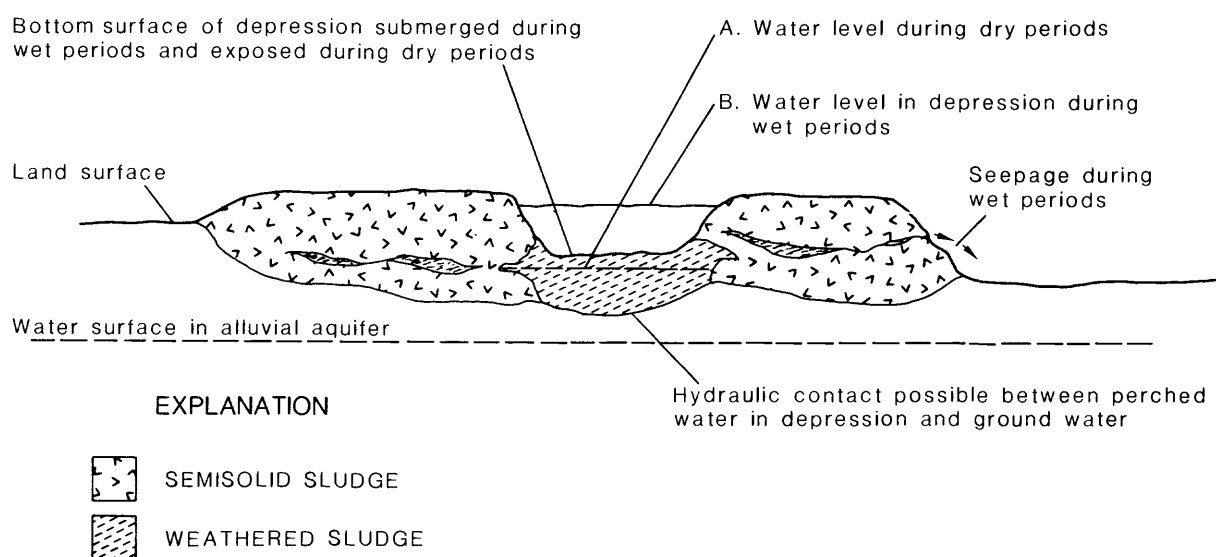


Figure 14. Schematic diagram showing cross section of depression in northern waste area.

mg/L). Several alkanes were detected at concentrations ranging from 6 µg/L to more than 35 µg/L (table 4). Pyrene was the only PNA compound detected at a concentration larger than 5 µg/L.

Runoff from the surface of the sludge in the southern waste area can act as a source of organic contaminants to water in the alluvial aquifer. However, movement of trace elements from sludge in this area appears unlikely due to the absence of acid, as indicated by the seepage pH (6.5) and the small concentrations of trace elements (table 5).

Contaminated Soil

Shallow soil on the Arkansas City Dump Site is contaminated with concentrations of a variety of heavy molecular-weight alkanes, alkenes, and several PNA compounds. Concentrations of PNA compounds in the control area (area 4, table 6) were less than 200 µg/kg, whereas concentrations of several PNA compounds (for example, pyrene, phenanthrene, and derivatives) on the Arkansas City Dump Site were typically several thousand micrograms per kilogram. Although it is possible that contaminants in the shallow soil could move to the water table, the background concentration of about 1 percent total carbon in the shallow soil and additional carbon associated with relatively insoluble heavy molecular-weight alkanes would prevent or greatly retard movement of more soluble hydrocarbons. Therefore, it does not appear that hydrocarbons in the shallow soil would be a major source of organic ground-water contaminants. Concentrations of trace elements in shallow soil (table 7) should not be a significant source of inorganic ground-water contaminants.

Although shallow soil samples collected onsite generally did not indicate trace-element contamination, a sample of soil located just below the bottom of the sludge in the northern waste area had much larger concentrations of aluminum (8,200 µg/g), chromium (680 µg/g), iron (21,000 µg/g), and lead (12,000 µg/g) than the sludge from the northern waste area (data not shown). These data indicate that soil located immediately under the acid sludge is contaminated with these trace elements. These increased concentrations suggest that significant

precipitation and sorption of trace elements occurred when large volumes of leachate moved from the sludge to the water table when the refinery was operating. Large concentrations of trace elements in this soil could be a source of locally elevated concentrations of trace elements in ground water during times when acidic leachate moves from the sludge in the northern waste area.

EFFECTS OF PETROLEUM-REFINERY WASTES AND CONTAMINATED SOIL ON WATER QUALITY

Ground-Water Quality

Concentrations of chemical constituents in and values of physical properties of water are summarized for monitoring wells in table 8 and for supply wells in table 9. Water quality in the alluvial aquifer in the vicinity of the Arkansas City Dump Site is characterized by relatively large concentrations of dissolved solids (generally greater than 400 mg/L). The smallest dissolved-solids concentrations were found in samples collected from shallow monitoring wells (map nos. 2,4,5, and 7, plate 1) on the Arkansas City Dump Site during December 1985 and probably reflect shallow water in the upper part of the aquifer diluted by precipitation received during September, October, and November. The largest dissolved-solids concentration occurred in water from a supply well located east of the Arkansas City Dump Site (map no. 101, plate 1).

Stiff water-quality diagrams, shown on plate 1, indicate that water in the alluvial aquifer is a mixed-ion type. Water quality, as depicted on plate 1, suggests that calcium bicarbonate type water exists in the upper part of the aquifer as a result of rain percolating through the soil zone and dissolving calcium and bicarbonate ions from soil on the site; water collected from wells screened at the water table (plate 1, map nos. 1, 3, 5, and 7) generally had proportionately larger concentrations of calcium and, particularly, bicarbonate and smaller concentrations of dissolved solids than other wells sampled. Generally, water samples collected from other wells (screened approximately 10 feet below the water table or deeper) had proportionately larger concentration of sodium and chloride.

Table 8. Statistical summary of chemical constituents and physical properties in water from monitoring wells in the vicinity of the Arkansas City Dump Site

[If constituent was not detected, the detection limit is reported and indicated by an asterisk, *]

Constituent or property	Units of measurement	Number of analysis	Value or concentration				
			Minimum	First quartile	Median	Third quartile	Maximum
Specific conductance	microsiemens per centimeter at 25 °C	14	518	781	1,210	1,435	1,540
pH	standard units	14	4.40	6.67	6.90	7.10	7.30
Dissolved oxygen	milligrams per liter	13	.20	.20	.40	.70	2.60
Calcium, dissolved as Ca	do.	15	80	100	130	170	180
Magnesium, dissolved as Mg	do.	15	8.0	18	20	24	32
Sodium, dissolved as Na	do.	15	4.30	29	65	78	150
Potassium, dissolved as K	do.	15	.80	3.8	6.7	14	120
Alkalinity, total as CaCO ₃	do.	14	198	284	337	490	618
Sulfate, dissolved as SO ₄	do.	15	6.7	15	48	130	300
Chloride, dissolved as Cl	do.	15	1.10	24	57	190	280
Silica, dissolved as SiO ₂	do.	15	15	18	21	30	48
Dissolved solids, residue at 180 °C	do.	14	319	461	687	821	1,020
Nitrite plus nitrate, dissolved as N	do.	14	.10	.10	.28	1.37	6.8
Nitrogen, ammonia, dissolved solids as N	do.	14	.04	.13	1.04	8.42	76
Aluminum, total as Al	micrograms per liter	15	10	10	10	30	9,300
Arsenic, dissolved as As	do.	15	1	1	2	7	84
Barium, dissolved as Ba	do.	15	34	210	370	620	2,000
Beryllium, dissolved as Be	do.	15	.5	.5	.5	.5	2.0
Cadmium, dissolved as Cd	do.	15	1	1	1	1	3

Table 8. Statistical summary of chemical constituents and physical properties in water from monitoring wells in the vicinity of the Arkansas City Dump Site--Continued

Constituent or property	Units of measurement	Number of analysis	Value or concentration				
			Minimum	First quartile	Median	Third quartile	Maximum
Chromium, dissolved as Cr	micrograms per liter	15	1	1	1	1	4
Copper, dissolved as Cu	do.	15	1	1	1	8	18
Iron, dissolved as Fe	do.	15	27	260	2,700	8,400	24,000
Lead, dissolved as Pb	do.	15	1	1	1	1	1
Manganese, dissolved as Mn	do.	15	20	460	790	1,100	1,600
Mercury, dissolved as Hg	do.	15	.10	.10	.10	.10	.30
Nickel, dissolved as Ni	do.	15	1	1	6	8	71
Selenium, dissolved as Se	do.	15	1	1	1	1	2
Vanadium, dissolved as V	do.	15	6	6	6	6	41
Zinc, dissolved as Zn	do.	15	3.0	8.0	14	29	540
Carbon, organic total as C	milligrams per liter	14	6.30	8.97	21	35	73
Cyanide, dissolved as Cn	micrograms per liter	15	*.01	*.01	*.01	*.01	*.01

A source of sodium and chloride in the alluvial aquifer may be river water recharging the aquifer during certain times of the year when the river stage is higher than the water table. The potentiometric surface of the aquifer during March 1986 (fig. 8B) illustrates that the river periodically recharges the alluvial aquifer. Consequently, water quality in the alluvial aquifer apparently can change relatively rapidly

due to seasonal climatic changes. Monitoring wells sampled during July 1982 had larger median concentrations of sodium, chloride, and sulfate than water collected from the same wells during December 1985 (a comparatively wet year) (fig. 15). This phenomenon provides evidence that water in the alluvial aquifer has much smaller concentrations of these constituents during wet periods when the aquifer

Table 9. Statistical summary of chemical constituents and physical properties in water from supply wells in the vicinity of the Arkansas City Dump Site

[If constituent was not detected, the detection limit is reported and indicated by an asterisk, *. --, not determined]

Constituent or property	Units of measurement	Number of analysis	Value or concentration				
			Minimum	First quartile	Median	Third quartile	Maximum
Specific conductance	microsiemens per centimeter at 25 °C	15	400	890	1,160	1,490	2,500
pH	standard units	15	6.20	6.90	7.20	7.60	8
Dissolved	milligrams per liter	0	--	--	--	--	--
Calcium, dissolved as Ca	do.	3	55	55	120	190	190
Magnesium, dissolved as Mg	do.	3	16	16	17	33	33
Sodium, dissolved as Na	do.	3	34	34	150	200	200
Potassium, dissolved as K	do.	3	5.30	5.30	7.00	7.40	7.40
Alkalinity, total as CaCO ₃	do.	3	312	--	--	--	468
Sulfate, dissolved as SO ₄	do.	3	93	93	100	220	220
Chloride, dissolved as Cl	do.	3	48	48	240	280	280
Silica, dissolved as SiO ₂	do.	3	11	11	15	19	19
Dissolved solids, residue at 180 °C	do.	3	544	544	651	1,200	1,200
Nitrogen, ammonia, dissolved as N	do.	3	.05	.05	.08	.23	.23
Nitrate plus nitrate, dissolved as N	do.	3	.58	.58	3.40	3.50	3.50
Aluminum, total as Al	micrograms per liter	3	10	10	10	50	50
Arsenic, dissolved as As	do.	3	1	1	1	1	1
Barium, dissolved as B	do.	3	51	51	66	120	120
Beryllium, dissolved as Be		3	0.5	0.5	0.5	2.0	2.0
Cadmium, dissolved as Cd	do.	3	1	1	1	3	3
Chromium, dissolved as Cr	do.	3	*1	*1	*1	*1	*1
Copper, dissolved as Cu	do.	3	3	3	5	5	5
Iron, dissolved as Fe	do.	3	16	16	29	660	660
Lead, dissolved as Pb	do.	3	*1	*1	*1	*1	*1

Table 9. Statistical summary of chemical constituents and physical properties in water from supply wells in the vicinity of the Arkansas City Dump Site--Continued

Constituent or property	Units of measurement	Number of analysis	Value or concentration				
			Min-imum	First quartile	Median	Third quartile	Maxi-mum
Manganese, dissolved as Mn	micrograms per liter	3	24	24	340	600	600
Mercury, dissolved as Hg	do.	3	.10	.10	.10	1.00	1.00
Nickel, dissolved as Ni	do.	3	2	2	4	4	4
Selenium, dissolved as Se	do.	3	1	1	1	5	5
Vanadium, dissolved as V	do.	3	6	6	6	18	18
Zinc, dissolved as Zn	do.	3	100	100	200	340	340
Carbon, organic total as C	milligrams per liter	14	1.00	2.22	3.65	5.12	12.00
Cyanide, dissolved as Cn	micrograms per liter	3	*.01	*.01	*.01	*.01	*.01

is diluted by recharge from precipitation and when the water table is relatively high, minimizing natural infiltration from the river.

Stiff water-quality diagrams presented on plate 1 also illustrate the local effects of refinery wastes in the northern waste area on native ground water. Analyses of seepage collected from the depression in the northern waste area indicated very acidic water (pH=2.16), with anions dominated by sulfate (plate, 1, map no. 301). Analyses of water from well KDHE MW5 (plate 1, map no. 16) indicate contamination by leachate from the northern waste area. This contamination is illustrated by the proportionately large sulfate concentration found in water from well KDHE MW5. The small pH of 4.4 in water from well USGS MW7 (plate 1, map no. 11) indicates a definite, but apparently, local effect. The stiff diagram from this well shows that sulfate is the principal anion present in the sample, which indicates acid leachate from the sludge is entering the ground water.

There is some evidence that a slug of contaminated water from the oil refinery moved offsite toward the river many years ago. On the basis of analyses performed by the Kansas State Board of Health in 1931 on water samples collected from former Arkansas City municipal water-supply wells 3 and 4 (these wells are located about 1,200 feet south of map no. 108 on plate 1), sulfate concentrations in both wells were 479 and 486 milligrams per liter (data in files of the U.S. Geological Survey, Lawrence, Kansas). These relatively large sulfate concentrations in 1931, which were not observed in water from wells on- or offsite either during this investigation (1986) or in a previous investigation (Kansas Department of Health and Environment, 1982), suggest that a slug of contaminants from the oil refinery passed through the well field at that time. The old well field was shut down in 1933 (Bayne, 1962), and the well field was moved west of Arkansas City.

Currently (1986), mixing of any leachate generated from the landfill and refinery wastes

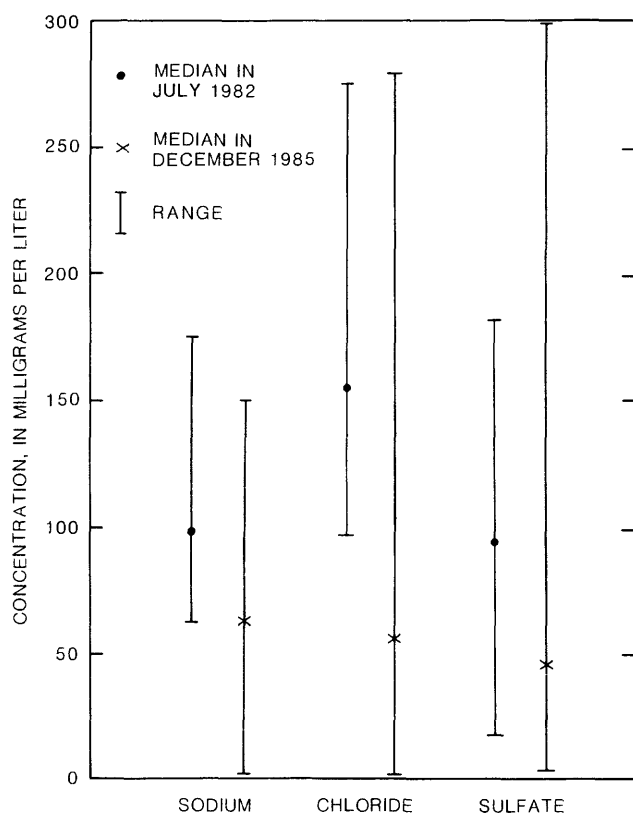


Figure 15. Comparison of selected chemical-constituent concentrations in water samples collected from monitoring wells, July 1982 and December 1985.

with move oxygenated ground water and dilution of the leachate with water from the alluvial aquifer away from the Arkansas City Dump Site should prevent mobilization of trace elements and movement from the Arkansas City Dump Site. Any areally extensive effect of acid leachate on concentrations of inorganic constituents is not apparent. The pH of water from most wells onsite, with the exception of well USGS MW7, is between 6 and 7, and ionic composition of ground water onsite closely resembles the ionic composition of water from wells located offsite (plate 1), implying minimal effects of leachate (currently derived from the refinery wastes) on major-ion concentrations in the ground water directly under or downgradient from the Arkansas City Dump Site. From the available ground-water-quality data, it appears that most inorganic contaminants from refinery wastes either have flushed from the system, have been neutralized, precipitated, or chemically converted (for example, sulfate reduced to hydrogen sulfide in anaerobic zones).

Generally, with respect to inorganic constituents, water in the alluvial aquifer is of usable quality for certain limited industrial applications but periodically may contain quantities of sodium, chloride, and sulfate that exceed Federal and State suggested maximum contaminant levels of 100, 250, and 250 mg/L, respectively. The large concentrations of sodium and chloride in the alluvial aquifer in the vicinity of Arkansas City is due, as has been suggested, to seasonal movement of water from the Arkansas River and to the lack of diluted recharge from precipitation. Analyses of samples of water collected from monitoring wells on the site indicate that, whereas some wells have large concentrations of certain inorganic chemical constituents (iron and manganese, particularly), most monitoring wells yield water that contained dissolved-solids, chloride, nitrate-as-nitrogen, sulfate, and selenium concentrations similar to concentrations of these chemical constituents reported by Spruill (1983) to be typical of water from Kansas supply wells in this part of the State.

In general, it does not appear that leachate from either the oil-refinery or buried wastes on the dump site presently appreciably affects the major-ion composition of the ground water, with the possible exception of iron and manganese. Mobile inorganic components of oil-refinery wastes either were relatively insignificant or, more likely, were flushed from the aquifer system many years ago. On the basis of an estimated average velocity of about 1.5 feet per day, it would take only 3 to 5 years for conservative constituents to discharge to the Arkansas River west of the site and approximately 10 to 15 years to discharge to the river east of the site. The pH of water in well USGS MW7 (plate 1, map no. 11) and elevated sulfate and trace-element concentrations do indicate, however, that some leachate currently is moving from the acid sludge to the water table.

Concentrations of both iron and manganese in water from monitoring wells onsite are substantially larger than the regional median of 20 µg/L for iron and 10 µg/L for manganese reported by Spruill (1983). Large concentrations of both iron and manganese in a landfill in Delaware were hypothesized to be caused by mobilization of iron- and manganese-oxide coatings on the aquifer sand and clay created by reducing conditions in the aquifer

(Baedecker and Back, 1979). Similar mobilization created by these reducing conditions could be caused by oxidation of organic matter either from the landfill or from the oil at the Arkansas City Dump Site. The small median concentration of dissolved oxygen (0.2 to 0.4 mg/L) and the relatively large median concentration of ammonia-nitrogen (1.04 mg/L) in water collected from the monitoring wells on the site also suggest oxygen consumption and creation of reducing conditions by degradation of organic material.

In addition to iron and manganese, locally large concentrations of arsenic, barium, ammonia-nitrogen, and total organic carbon and small concentrations of dissolved oxygen (less than 0.4 mg/L) detected in water from shallow wells (map nos. 1 and 7, plate 1) suggest localized degradation of waste material deposited in the western part of the site (rubber tires and debris were encountered during the installation of wells USGS MW1A and 4A) or from the presence of large concentrations of carbon derived from municipal refuse or oily wastes. Wells USGS MW1A and 4A are located in an area where terrain conductivity was found to be greater than 20 microsiemens per meter (fig. 16), suggesting the presence of buried metallic material. Such material could have organic debris buried along with it.

Many organic compounds were tentatively identified in water samples collected from the monitoring wells installed on the Arkansas City Dump Site (table 10), indicating that wastes present on the site do contribute significant quantities of organic compounds to the ground water. Because concentrations of PNA compounds greater than 5 µg/L (and thus several orders of magnitude greater than the U.S. Environmental Protection Agency drinking-water criteria) were detected in water from many wells onsite during this and a previous investigation (Kansas Department of Health and Environment, 1982) and because PNA compounds are known carcinogens and mutagens (Safe Drinking Water Committee, 1982) and can be quite mobile in certain hydrogeologic environments (Schwartzbach and others, 1983; Pereira and Rostad, 1986), PNA compounds probably pose the greatest health and environmental hazard.

Concentrations of total organic carbon in water from wells on the site ranged from 6.3 to 73 mg/L. These concentrations are greater than background concentrations of total organic carbon (2 to 5 mg/L) from wells located upgradient from the dump site (fig. 17). Gas-chromatographic analyses with a flame-ionization detector of unfiltered water samples collected during December 1985 from several wells (KDHE MW1 and USGS MW1A, 2A, and 7, fig. 18) in the shallow aquifer do indicate significant contamination with heavy molecular-weight hydrocarbon compounds. The "clean" chromatogram (fig. 18A) from the control well (KDHE MW1) indicates only the presence of the surrogate compounds added by the laboratory for quality-control purposes. Chromatograms from the other three monitoring wells indicated the presence of many organic compounds, as demonstrated by the "hydrocarbon envelopes" or humps on the chromatogram. The chromatogram from well USGS MW7 contained the largest concentrations of organic compounds, as indicated by the large "hydrocarbon envelope" shown in figure 18D.

Specific organic compounds tentatively identified in unfiltered water samples collected from monitoring wells installed on the Arkansas City Dump Site are shown in table 10 and represent total concentrations. These concentrations may be derived from organic-phase water emulsions and compounds sorbed on sediment that entered the well screen. The major compounds identified were alkanes, cycloalkanes, PNA compounds, and various sulfonation products. These compounds are associated with weathered petroleum and acid sludge, indicating that refinery wastes are the major source of ground-water contaminants. Caprolactam, a monomer of nylon 6, also was identified in water from several monitoring wells. This compound may be derived from cyclohexane present in petroleum compounds. Generally, concentrations of volatile organic compounds were not detected at concentrations greater than 3 µg/L. Because 93 percent of the water-soluble fraction of refined products such as gasoline, fuel oils, and kerosene is composed of volatile organic compounds such as benzene, toluene, and xylene (Coleman and others, 1984), the absence of volatile organic compounds

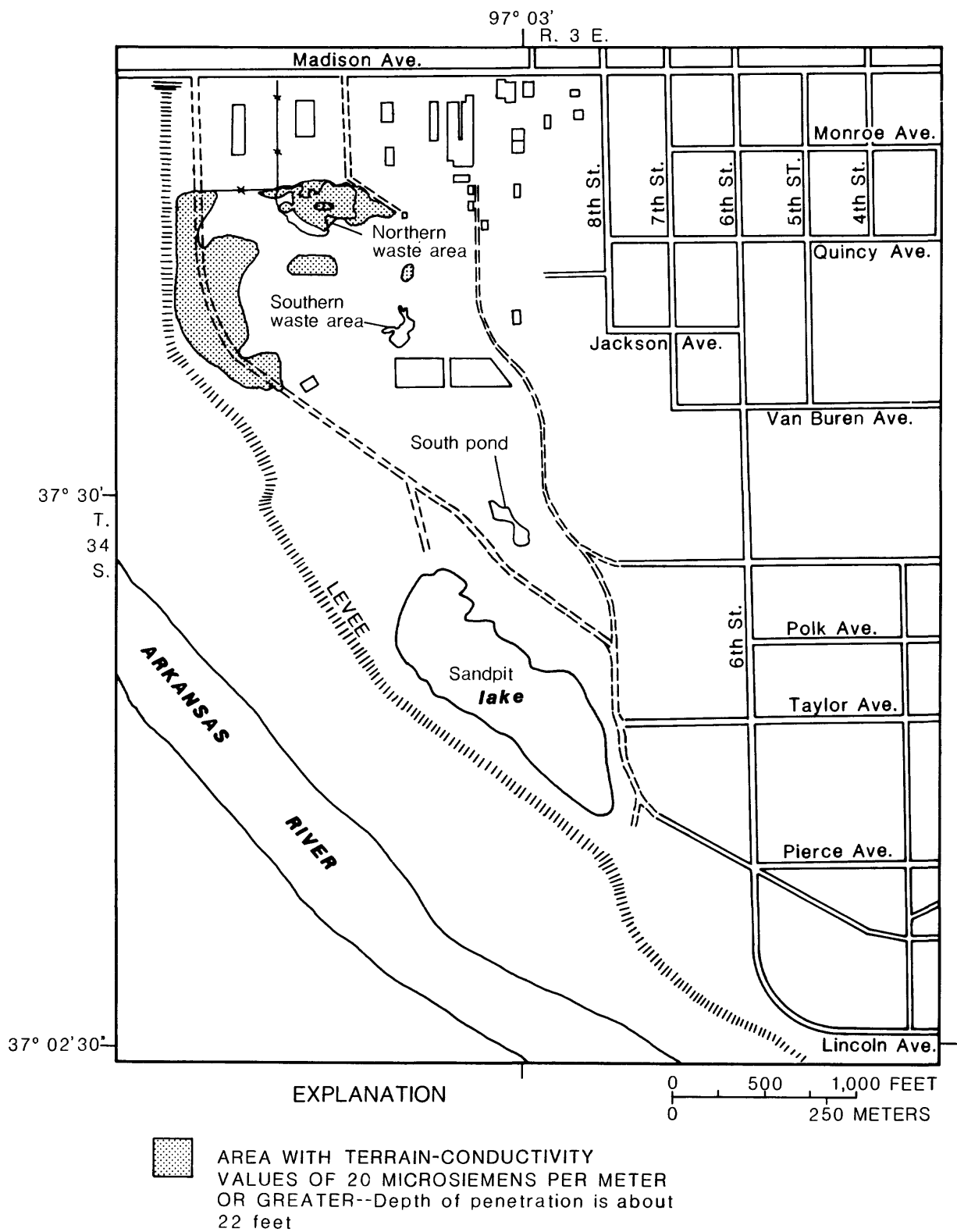


Figure 16. Areas with terrain conductivity of 20 microsiemens per meter or greater (depth of survey penetration is about 22 feet).

Table 10. Organic compounds tentatively identified in water from monitoring wells on the Arkansas City Dump Site

[Concentrations given in micrograms per liter (µg/L). T indicates compound detected as trace (concentrations less than 5 µg/L). ND indicates not detected as less than 5 µg/L. Asterisk indicates positive identification with standard]

Organic compound	Monitoring well							KDHE- MW5 (shallow)	KDHE- MW5 (deep)
	USGS- MW1A	USGS- MW1B	USGS- MW2A	USGS- MW2B	USGS- MW3A	USGS- MW3B			
	Map number shown on plate 1								
	1	2	3	4	5	6	16	16	
1H-Indene, 2,3-dihydro-	ND	ND	ND	ND	6	ND	ND	T	
2(3H)-benzothiazolone	12	ND	ND	ND	ND	ND	ND	ND	
2H-azepin-2-one, hexahydro-	5	ND	ND	ND	ND	ND	ND	ND	
2-toluenesulfonamide	12	ND	17	7	6	ND	ND	ND	
Acetophenone	T	ND	ND	ND	ND	ND	ND	ND	
Benzene	ND	ND	ND	T	ND	ND	ND	ND	
Benzene, propyl-	ND	ND	ND	T	ND	ND	ND	ND	
Benzothiazolone	T	ND	ND	ND	ND	ND	ND	ND	
Cyclohexane, 1-bromo-2-chloro,cis-	ND	T	ND	ND	ND	ND	ND	ND	
Ethanol, 2-butoxy-,phosphate (3:1)	T	ND	ND	ND	ND	ND	ND	ND	
Heptadecane	9	ND	ND	ND	ND	ND	ND	ND	
Heptacosane	15	ND	ND	ND	ND	ND	ND	ND	
Hexanoic acid, 6-amino-	ND	ND	ND	ND	ND	12	ND	ND	
N-methyl-n-(tolysulfonyl-(4)-nitrosamide	11	ND	ND	ND	ND	ND	ND	ND	
Octacosane	T	ND	ND	ND	ND	ND	ND	ND	
Octadecane	5	ND	ND	ND	ND	ND	ND	ND	
Phenol, 3-(1,1-dimethylethyl)-	12	ND	ND	ND	ND	ND	ND	ND	
Tosyl derived of ethylamine	8	ND	ND	ND	ND	ND	ND	MD	
Triacontane	5	ND	ND	ND	ND	ND	ND	MD	
Tritetracontane	4	ND	ND	ND	ND	ND	ND	MD	
1,3,5-triazine-2,4-diamine,-6-chloro-N-ethyl-(methylethyl)-	ND	ND	ND	ND	ND	ND	ND	MD	

**Table 10. Organic compounds tentatively identified in water from monitoring wells on the Arkansas City Dump Site--
Continued**

Organic compound	Monitoring well								
	USGS- MW4A	USGS- MW4B	USGS- MW5	USGS- MW6 (shal- low)	USGS- MW6 (deep)	KDHE- MW7	KDHE- MW1	KDHE- MW5 (shal- low)	KDHE- MW5 (deep)
	Map number shown on plate 1								
	7	8	9	10	10	11	12	16	16
1,3,5-Triazine-2,4-diamine, 6-methoxy-N,N'bis(1-methylethyl)	ND	ND	ND	ND	ND	ND	2	ND	ND
2H-Azepin-2-one, hexahydro-(caprolactam)	ND	ND	56	ND	ND	ND	ND	ND	ND
Alkane	ND	ND	ND	ND	ND	72	ND	T	T
Do.	ND	ND	ND	ND	ND	26	ND	T	T
Do.	ND	ND	ND	ND	ND	16	ND	ND	T
Do.	ND	ND	ND	ND	ND	74	ND	ND	T
Do.	ND	ND	ND	ND	ND	27	ND	ND	T
Do.	ND	ND	ND	ND	ND	15	ND	ND	T
Do.	ND	ND	ND	ND	ND	71	ND	ND	T
Do.	ND	ND	ND	ND	ND	61	ND	ND	T
Do.	ND	ND	ND	ND	ND	18	ND	ND	T
Do.	ND	ND	ND	ND	ND	42	ND	ND	ND
Do.	ND	ND	ND	ND	ND	23	12	ND	ND
Do.	ND	ND	ND	ND	ND	45	ND	ND	ND
Do.	ND	ND	ND	ND	ND	127	ND	ND	ND
Do.	ND	ND	ND	ND	ND	41	ND	ND	ND
Do.	ND	ND	ND	ND	ND	125	ND	ND	ND
Do.	ND	ND	ND	ND	ND	20	ND	ND	ND
Alkene	ND	ND	ND	ND	ND	ND	ND	ND	T
Do.	ND	ND	ND	ND	ND	ND	ND	ND	T
Do.	ND	ND	ND	ND	ND	ND	ND	ND	T
Alkene/cycloalkane	ND	ND	ND	ND	ND	18	ND	ND	ND

Table 10. Organic compounds tentatively identified in water from monitoring wells on the Arkansas City Dump Site--Continued

Organic compound	Monitoring well								
	USGS- MW4A	USGS- MW4B	USGS- MW5	USGS- MW6 (shal- low)	USGS- MW6 (deep)	USGS- MW7	KDHE- MW1	KDHE- MW5 (shal- low)	KDHE- MW5 (deep)
	Map number shown on plate 1								
	7	8	9	10	10	11	12	16	16
Alkene/cycloalkane	ND	ND	ND	ND	ND	16	ND	ND	ND
Do.	ND	ND	ND	ND	ND	20	ND	ND	ND
Do.	ND	ND	ND	ND	ND	29	ND	ND	ND
Do.	ND	ND	ND	ND	ND	30	ND	ND	ND
Do.	ND	ND	ND	ND	ND	32	ND	ND	ND
Do.	ND	ND	ND	ND	ND	16	ND	ND	ND
Do.	ND	ND	ND	ND	ND	39	ND	ND	ND
Do.	ND	ND	ND	ND	ND	70	ND	ND	ND
Do.	ND	ND	ND	ND	ND	17	ND	ND	ND
Do.	ND	ND	ND	ND	ND	19	ND	ND	ND
Do.	ND	ND	ND	ND	ND	34	ND	ND	ND
Do.	ND	ND	ND	ND	ND	25	ND	ND	ND
Do.	ND	ND	ND	ND	ND	14	ND	ND	ND
Do.	ND	ND	ND	ND	ND	18	ND	ND	ND
Do.	ND	ND	ND	ND	ND	27	ND	ND	ND
Do.	ND	ND	ND	ND	ND	16	ND	ND	ND
Do.	ND	ND	ND	ND	ND	49	ND	ND	ND
Do.	ND	ND	ND	ND	ND	18	ND	ND	ND
Do.	ND	ND	ND	ND	ND	18	ND	ND	ND
Do.	ND	ND	ND	ND	ND	42	ND	ND	ND
Do.	ND	ND	ND	ND	ND	73	ND	ND	ND
Do.	ND	ND	ND	ND	ND	15	ND	ND	ND

Table 10. Organic compounds tentatively identified in water from monitoring wells on the Arkansas City Dump Site--Continued

Organic compound	Monitoring well								
	USGS- MW4A	USGS- MW4B	USGS- MW5	USGS- MW6 (shal- low)	USGS- MW6 (deep)	USGS- MW7	USGS- MW1	KDHE- MW5 (shal- low)	KDHE- MW5 (deep)
	Map number shown on plate 1								
	7	8	9	10	10	11	12	16	16
Alkene/cycloalkane	ND	ND	ND	ND	ND	46	ND	ND	ND
Do.	ND	ND	ND	ND	ND	44	ND	ND	ND
Do.	ND	ND	ND	ND	ND	20	ND	ND	ND
Do.	ND	ND	ND	ND	ND	42	ND	ND	ND
Do.	ND	ND	ND	ND	ND	21	ND	ND	ND
Do.	ND	ND	ND	ND	ND	71	ND	ND	ND
Do.	ND	ND	ND	ND	ND	20	ND	ND	ND
Do.	ND	ND	ND	ND	ND	18	ND	ND	ND
Do.	ND	ND	ND	ND	ND	49	ND	ND	ND
Do.	ND	ND	ND	ND	ND	18	ND	ND	ND
Do.	ND	ND	ND	ND	ND	30	ND	ND	ND
Do.	ND	ND	ND	ND	ND	46	ND	ND	ND
Do.	ND	ND	ND	ND	ND	26	12	ND	ND
Do.	ND	ND	ND	ND	ND	52	ND	ND	ND
Do.	ND	ND	ND	ND	ND	33	ND	ND	ND
Do.	ND	ND	ND	ND	ND	67	ND	ND	ND
Anthracene	ND	ND	ND	ND	ND	T	ND	ND	ND
*Benz(a)anthracene	ND	ND	ND	ND	ND	80	ND	ND	ND
Benz(a)fluranthene	ND	ND	ND	ND	ND	T	ND	ND	ND
Benz(k)fluoranthene	ND	ND	ND	ND	ND	T	ND	ND	ND
Benz(a)pyrene	ND	ND	ND	ND	ND	T	ND	ND	ND
Benzene, 1,4-dichloro-	T	ND	ND	ND	ND	ND	ND	ND	ND

**Table 10. Organic compounds tentatively identified in water from monitoring wells on the Arkansas City Dump Site--
Continued**

Organic compound	Monitoring well								
	USGS- MW4A	USGS- MW4B	USGS- MW5	USGS- MW6 (shal- low)	USGS- MW6 (deep)	USGS- MW7	KDHE- MW1	KDHE- MW5 (shal- low)	KDHE- MW5 (deep)
	Map number shown on plate 1								
	7	8	9	10	10	11	12	16	16
Benzene, pentamethyl-	ND	ND	ND	ND	ND	ND	T	T	ND
Benzene, 1,2,3,4-tetramethyl-	ND	ND	ND	ND	ND	ND	ND	ND	T
Benzene, 1,3-dimethyl-5(1-methylethe)	ND	ND	ND	ND	ND	ND	ND	ND	T
Chrysene	ND	ND	ND	ND	ND	T	ND	ND	ND
Cyclopentasiloxane, decamethyl-	ND	ND	ND	ND	ND	ND	T	ND	ND
Cyclohexane	ND	ND	ND	ND	ND	ND	ND	ND	ND
Cyclohexane, 1-bromo-2-chloro-,cis	ND	ND	ND	ND	ND	ND	7	ND	ND
*Dibenz(a,h)anthracene	ND	ND	ND	ND	ND	104	ND	ND	ND
Fluoroene	ND	ND	ND	ND	ND	T	ND	ND	T
Fluoranthene	ND	ND	ND	ND	ND	T	ND	ND	ND
*Fluoranthene	6	ND	ND	ND	ND	T	ND	ND	ND
Hexanoic acid, 6-amino-	23	ND	ND	ND	ND	ND	ND	ND	ND
Indeno(1,2,3-cd)pyrene	ND	ND	ND	ND	ND	T	ND	ND	ND
Isophorone	ND	ND	ND	ND	ND	T	ND	ND	T
N-nitrosidiphenylamine	ND	ND	ND	ND	ND	T	ND	ND	ND
Naphthalene	ND	ND	ND	ND	ND	T	ND	T	T
Napthalene decahydro.	ND	ND	ND	ND	ND	17	ND	ND	ND
Napthalene, 1-methyl-	ND	ND	ND	ND	ND	ND	ND	ND	T
Nonane	ND	ND	ND	ND	T	ND	ND	ND	ND
Phenol.	ND	ND	ND	T	ND	T	ND	ND	T
Phenol. 4-chloro-3-methyl	ND	ND	ND	ND	ND	T	ND	ND	ND
Phenol.4-nitro-	ND	ND	ND	ND	ND	ND	ND	ND	T
*Phenanthrene	14	ND	ND	ND	ND	T	ND	ND	ND
*Pyrene	6	ND	ND	ND	ND	ND	ND	ND	T
Toluene	ND	ND	ND	T	ND	ND	ND	ND	ND
Toluene,2,6-dinitro-	ND	ND	ND	ND	ND	ND	ND	ND	T

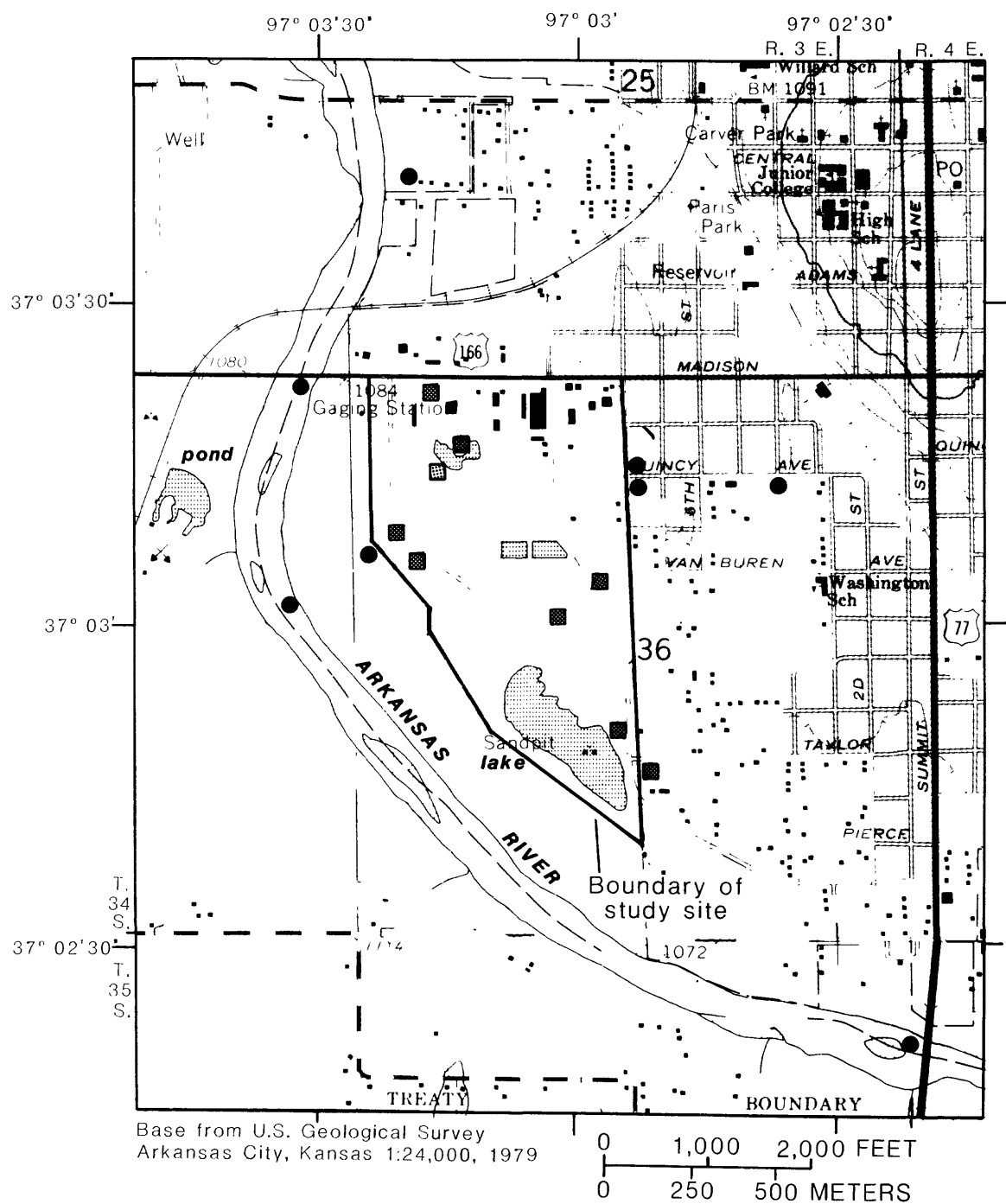


Figure 17. Distribution of total organic carbon in water from alluvial aquifer in vicinity of Arkansas City Dump Site, December 1985 through July 1986.

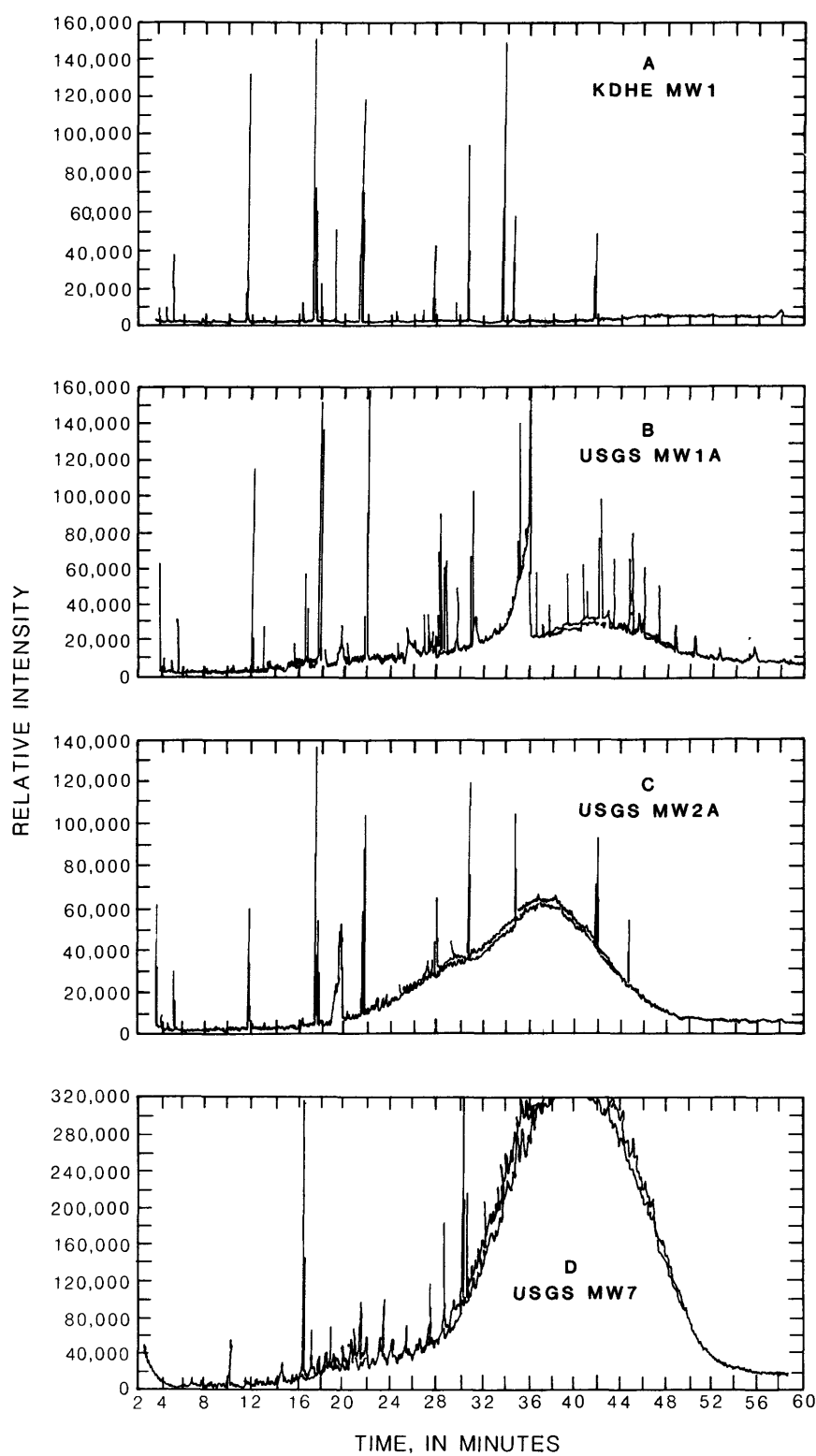


Figure 18. Gas chromatograms of water samples collected from selected monitoring wells on Arkansas City Dump Site.

suggests that these compounds have volatilized, flushed from the aquifer, or degraded. The triazine herbicides, atrazine, propazine, and simazine were detected in water from well KDHE MW1. The source of these compounds is not known.

Organic compounds derived from the petroleum-refinery wastes generally were not detected offsite. Few organic compounds were tentatively identified in supply wells, which suggests that organic compounds derived from the Arkansas City Dump Site for the most part have been sorbed and are not moving offsite or, if they have moved, have degraded or have been flushed from the aquifer. Cyclohexane was detected in one supply well (plate 1, map no. 101) used for industrial purposes. A trace of naphthalene was found in a shallow supply well (plate 1, map no. 103) and in one monitoring well (plate 1, map no. 10) adjacent to the Arkansas City Dump Site, but the amount could not be quantified. Analyses from four wells (plate 1, map no. 104, 105, 112, and 114) downgradient of the site indicated no PNA concentration greater than 0.05 µg/L. An organic-compound scan using gas chromatography equipped with a flame-ionization detector also identified no organic contamination in these wells.

An interesting finding of this study is that total organic carbon (TOC) is a very effective

indicator of organic contamination from refinery wastes. A simple correlation analysis of TOC concentrations versus total number of ground-water compounds and total concentration of organic compounds identified indicates a positive correlation significant at the 1-percent level (table 11). Thus, TOC data are indicative of organic ground-water contamination from the abandoned oil refinery. The distribution of total organic carbon in the alluvial aquifer in the vicinity of the Arkansas City Dump Site (fig. 17) therefore reflects the extent of contamination. The smallest concentrations (generally less than 6.0 µg/L) of organic contaminants were present in water samples collected outside of the site boundaries.

There is evidence that indicates that nonaqueous-phase organic liquids associated with weathered petroleum and viscous sludge wastes are distributed heterogeneously throughout the site. For example, oil product was found in water from well KDHE MW6. Oil product in water from well KDHE MW6 was reported also during the 1981-82 investigation. It is possible that pockets of oil occur in other areas on the site and that these "oil stringers" serve as localized sources for water-soluble contaminants. An oil sheen was observed in water from most of the wells installed on the site, suggesting that oil and gasoline hydrocarbons

Table 11. *Results of Spearman-rho correlation analysis between total organic-carbon concentrations, number of organic compounds, and total concentration of organic compounds*

[26 sample pairs included in both of the cases shown]

Total organic carbon versus number of organic compounds	Total organic carbon versus total concentration of organic compounds
$p = 0.712$	$p = 0.835$
<u>Level of significance</u>	
$p = \text{less than } 0.01$	$p = \text{less than } 0.01$

occur in ground water beneath much of the site. Oil-soaked soil was noted during the drilling of all monitoring wells except USGS MW5.

On the basis of information collected as part of this investigation, residual oil products and wastes retained in aquifer sediments in the saturated zone are the principal source of concentrations of organic contaminants in water in the alluvial aquifer on the site.

Surface-Water Quality

Statistical summaries of constituents from surface-water and sediment samples are presented in tables 12 and 13. Water samples collected from three sites along the Arkansas River, the sandpit lake, and the south pond (plate 1) do not indicate large concentrations of trace elements (table 12) or organic compounds (table

13). Only concentrations less than 200 µg/kg of a few organic compounds were found in sediment samples from these sites.

Although the river and surface ponds on the site probably have received ground-water inflows contaminated with refinery-derived compounds in the past, the small concentrations or absence of these compounds in the water could be due to sorption on the bottom sediment or microbial, fungal, and algal degradation of these compounds in the surface-water environment. Information presented by Kobayashi and Rittmann (1982) indicates that members of almost every class of organic chemicals can be degraded by some microorganism. The relatively rich diversity of microorganisms and algae in surface water as compared to soil organisms could allow degradation by several biotic pathways. In addition, some PNA compounds

Table 12. *Statistical summary of chemical constituents and physical properties in surface water and sediment in the vicinity of the Arkansas City Dump Site*

[If constituent was not detected, the detection limit was reported and indicated by an asterisk, *]

Constituent or property	Units of measurement	Number of analyses	Value or concentration				
			Minimum	First quartile	Median	Third quartile	Maximum
Specific conductance	microsiemens per centimeter at 25 °C	4	1,120	1,195	1,510	1,697	1,730
pH	standard units	4	7.50	7.62	8.00	8.00	8.00
Dissolved oxygen, DO	milligrams per liter	3	12.9	12.9	13	13.7	13.7
Calcium, dissolved as Ca	do.	6	68	79	92	110	110
Magnesium, dissolved as Mg	do.	6	19	19	24	25	27
Sodium, dissolved as Na	do.	6	110	117	165	220	220
Potassium, dissolved as K	do.	6	4.8	4.8	5	5.8	6.0
Alkalinity, total as CaCO ₃	do.	5	147	147	234	234	234
Sulfate, dissolved as SO ₄	do.	6	55	83	111	132	140
Chloride, dissolved as Cl	do.	6	170	192	275	362	370
Silica, dissolved as SiO ₂	do.	6	6.0	12	15	15	16
Dissolved solids, residue at 180 °C	do.	5	616	648	683	1,010	1,010
Nitrite plus nitrate, dissolved as N	do.	6	.10	.24	1.26	1.90	1.90
Nitrogen, ammonia, dissolved as N	do.	6	.03	.70	.94	1.00	1.00

Table 12. Statistical summary of chemical constituents and physical properties in surface water and sediment in the vicinity of the Arkansas City Dump Site--Continued

Constituent or property	Unit of measurement	Number of analyses	Value or concentration				
			Minimum	First quartile	Median	Third quartile	Maximum
Aluminum, total as Al	micrograms per liter	6	*10	*10	*10	*10	*10
Arsenic, dissolved as As	do.	6	1.0	2.5	3.0	4.2	5.0
Arsenic, total in bottom material as As	micrograms per gram	5	1.0	1.0	1.0	17.0	190
Barium, dissolved as Ba	micrograms per liter	6	180	180	185	190	190
Barium, total in bottom material as Ba	micrograms per gram	5	40	50	60	225	320
Beryllium, dissolved as Be	micrograms per liter	6	*.50	*.50	*.50	*.50	*.50
Beryllium, total in bottom material as Be	micrograms per gram	5	*1.00	*1.00	*1.00	*1.00	*1.00
Cadmium, dissolved as Cd	micrograms per liter	6	*1.00	*1.00	*1.00	*1.00	*1.00
Cadmium, total in bottom material as Cd	micrograms per gram	5	1.00	1.00	1.00	2.00	3.00
Chromium, dissolved as Cr	micrograms per liter	5	1.00	1.00	1.00	1.00	2.00
Chromium, total in bottom material as Cr	micrograms per gram	5	20	20	20	90	1,100
Copper, dissolved as Cu	micrograms per liter	6	1.00	1.00	2.50	3.00	3.00
Copper, total in bottom material as Cu	micrograms per gram	5	20	25	30	60	70
Iron, total bottom material as Fe	do.	6	6.00	7.50	9.00	12.00	15.00
Lead, dissolved as Pb	micrograms per liter	6	*1.00	*1.00	*1.00	*1.00	*1.00
Lead, total bottom material as Pb	micrograms per gram	5	10	10	10	40	50
Manganese, total bottom material as Mn	do.	6	18	21	49	91	90
Mercury, dissolved as Hg	micrograms per liter	5	.10	.10	.10	.20	.30
Nickel, dissolved as Ni	do.	6	1.00	1.75	2.50	3.00	3.00
Selenium, dissolved as Se	do.	6	1.00	1.00	1.00	2.00	2.00
Vanadium, total bottom material as V	micrograms per gram	6	*6.00	*6.00	*6.00	*6.00	*6.00
Zinc, dissolved as Zn	micrograms per liter	6	3.00	3.00	3.00	7.00	10.00
Zinc, total bottom material as Zn	micrograms per gram	5	20	25	40	60	60
Carbon, organic total as C	milligrams per liter	6	4.00	4.60	7.30	10	13
Cyanide, dissolved as Cn	micrograms per liter	6	*.01	*.01	*.01	*.01	*.01

Table 13. Organic compounds tentatively identified in samples from surface water and sediment in the vicinity of the Arkansas City Dump Site

[Concentrations in water are in micrograms per liter (µg/L). Concentrations in sediment are in micrograms per kilogram (µg/kg). T indicates compound detected as trace (concentration less than 5 µg/L). ND indicates not detected at less than 5 µg/L. Asterisk indicates positive identification with standard]

Organic compound	Arkansas River at Highway 166 (water)	Arkansas River at Highway 166 (sediment)	Arkansas River at midpoint (water)	Arkansas River at midpoint (sediment)	Arkansas River at Highway 77 (water)	Arkansas River at Highway 77 (sediment)	South pond (water)	South pond (sediment)	Sandpit lake (shallow water)	Sandpit lake (deep water)
	201	201	202	202	203	203	204	204	205	205
Map number shown on plate 1										
1-Octadecanol	ND	270	ND	ND	ND	ND	ND	ND	ND	ND
3-Eicosene, (E)-	ND	2,348	ND	ND	ND	ND	ND	ND	ND	ND
Atrazine	ND	ND	ND	ND	ND	ND	11	ND	ND	ND
Cyclohexane, 1-bromo, 2-chloro-, cis-	ND	ND	ND	ND	ND	ND	ND	ND	ND	T
Heptacosane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Naphthalene	ND	ND	ND	ND	ND	ND	T	ND	ND	ND
*Phenanthrene	ND	ND	ND	ND	ND	ND	ND	19	ND	ND
*Pyrene	ND	ND	ND	ND	ND	ND	ND	17	ND	ND
1-pentatriacontanol	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Propazine	ND	ND	ND	ND	ND	ND	5	ND	ND	ND
1-methyl naphthalene	ND	ND	ND	ND	ND	ND	ND	11	ND	ND
Alkane	ND	ND	ND	ND	ND	ND	ND	8.9	ND	ND
Alkane	ND	ND	ND	ND	ND	ND	ND	36	ND	ND
Methylester tetra-deanoic acid	ND	ND	ND	ND	ND	ND	ND	12	ND	ND
Hexathiapane	ND	ND	ND	ND	ND	ND	ND	188	ND	ND
Methylester hexa-decanoic acid	ND	ND	ND	ND	ND	ND	ND	54.3	ND	ND
Hexadecanoic acid	ND	ND	ND	ND	ND	ND	ND	52	ND	ND

are known to be subject to photolysis (Zepp and Cline, 1977). However, it is reported that certain compounds, such as cycloalkanes and heavy molecular-weight aromatic compounds (Atlas, 1981), are particularly resistant to microbial degradation. Thus, cycloalkanes and heavy molecular-weight alkanes could persist for long periods of time, even in surface water; 1-bromo-2-chloro cyclohexane was detected in samples collected from the sandpit lake, and heavy molecular-weight aliphatic compounds, such as 3-eicosene and 1-octadecanol, were detected in samples collected from bottom sediments in the river. Any quantity of PNA compounds in the water probably would be sorbed by the fine organic sediments of the surface-water bodies. Relatively small concentrations of PNA compounds (10 to 19 $\mu\text{g/kg}$) were found in sediment samples from the south pond.

CONCLUSIONS

Leachate derived from a petroleum refinery has caused local contamination of water in the alluvial aquifer underlying the Arkansas City Dump Site. Sources of ground-water contaminants are an acid-sludge pit located in the northern part of the site and petroleum-contaminated aquifer material near the water table at various locations on the site.

Petroleum-refinery wastes have not affected the major chemical ionic composition of ground water under the site, except locally under the acid-sludge wastes located in the northern part of the site. Although water contained in a depression in the acid sludge in the northern waste area had a low pH (2.1) and large concentrations of sulfate (1,100 mg/L), cadmium (25 $\mu\text{g/L}$), iron (109,000 $\mu\text{g/L}$), lead (320 $\mu\text{g/L}$), and manganese (1,100 $\mu\text{g/L}$), ground water under the acid-sludge pit had a higher pH (4.4), and much smaller concentrations of sulfate (140 $\mu\text{g/L}$), cadmium (2 $\mu\text{g/L}$), iron (24,000 $\mu\text{g/L}$), and lead (1 $\mu\text{g/L}$).

Because ionic composition and pH of water in wells downgradient from the acid-sludge pit approximate water-quality characteristics of wells located offsite, inorganic contaminants associated with petroleum-refinery wastes, with the exception of iron and manganese, apparently either have moved offsite and into the Arkansas River or do not appreciably affect ionic

composition of water in the alluvium. Local occurrences of decreased pH and increased sulfate concentrations in ground water beneath and immediately downgradient from the acid-sludge wastes probably are due to movement of contaminated water from the depression in the northern waste area to the water table. The occurrence of locally large concentrations of ammonia-nitrogen, arsenic, barium, iron, and manganese in some wells suggests reducing conditions created by organic decomposition of refuse deposited in the landfill.

Various organic compounds are the principal contaminants derived from petroleum-refinery wastes that affect water quality in the alluvium. Petroleum "pockets" and oil-contaminated sediment are the principal source of hydrocarbons in ground water beneath the site. Various alkanes, ketones, aldehydes, and polynuclear aromatic (PNA) compounds associated with petroleum and petroleum-refinery wastes were detected in ground water under the site. PNA compounds derived from the oil-refinery wastes appear to pose the greatest environmental and public-health hazards.

A significant (at the 1-percent level) positive correlation between numbers and total concentrations of specific organic compounds and total organic-carbon (TOC) concentrations was found on the Arkansas City Dump Site, which indicates that TOC is a good indicator of organic contamination from the oil refinery. Whereas baseline concentrations of TOC for water in the alluvial aquifer range from 2 to 6 mg/L, TOC in ground water under the site ranged from 6.3 to 73 mg/L. The largest TOC concentrations on the site were detected in water from wells located under the sludge in the northern waste area, suggesting that these wastes are contributing significant quantities of organic compounds to water in the aquifer. Evidence that organic-compound contamination is greatest in the upper part of the saturated zone was derived from the detection of the largest TOC concentrations in water from the monitoring wells screened at the water table.

Evidence from this investigation suggests that organic contaminants probably are not moving offsite, although additional sampling would be needed to confirm this conclusion. TOC

concentrations in water from supply wells offsite generally were less than 6 mg/L, which indicates little or no contamination. In addition, results from GC/FID scans for any organic compounds and GC/MS and HPLC analyses for selected PNA compounds generally did not indicate the presence of organic contaminants at concentrations greater than 3 µg/L. However, traces of naphthalene and concentrations of cyclohexane were found in three wells offsite. The general absence of organic compounds at concentrations greater than 5 µg/L in offsite wells suggests that either contaminants have been flushed from the aquifer, have not moved offsite, or have biodegraded.

Few organic contaminants were detected in surface water on and adjacent to the Arkansas City Dump Site. A cycloalkane was detected in water from a sandpit lake in the southern part of the site. No dissolved forms of any organic compound were detected in water from three sites located on the Arkansas River, and no concentrations of any refinery-related organic compound were detected in water from a small pond in the southern part of the site. Heavy molecular-weight alkanes were detected in water from sediment samples in the Arkansas River, the sandpit lake, and the south pond. In addition, sediment samples from the south pond had small concentrations (10 to 19 µg/kg) of PNA compounds. The presence of organic compounds in the sediment probably reflect sorption of hydrophobic compounds onto organic carbon of the sediment and accumulation of insoluble heavy molecular-weight aliphatic and cyclic hydrocarbons that are resistant to biodegradation.

REFERENCES CITED

- Abraham, Herbert, 1918, *Asphalts and allied substances*: New York, D. Van Nostrand Co., 305 p.
- Atlas, R.M., 1981, Microbial degradation of petroleum hydrocarbons--An environmental perspective: *Microbiological Reviews*, March 1981, p. 180-209.
- Baedecker, M.J., and Back, William, 1979, Hydrogeological processes and chemical reactions at a landfill: *Ground Water*, v. 17, no. 5, p. 429-437.
- Bayne, C.K., 1962, *Geology and ground-water resources of Cowley County, Kansas*: Kansas Geological Survey Bulletin 158, 219 p.
- Bigda, R.J., 1982, Can black wastes turn into gold?: *Pollution Engineering*, August 1982, p. 25-27.
- Coleman, W.E., Munch, J.W., Streicher, R.P., Ringhand, H.P., and Kopfler, F.C., 1984, The identification and measurement of compounds in gasoline, kerosene, and no. 2 fuel oil that partition into the aqueous phase after mixing: *Archives of Environmental Contaminant Toxicology*, v. 13, p. 171-178.
- Cooper, H.H., Bredehoeft, J.D., and Papadopoulos, S.S., 1967, Response of a finite-diameter well to an instantaneous charge of water: *Water Resources Research*, v. 3, no. 3, p. 263-269.
- Fishman, M.J., and Friedman, L.C., eds., 1985, *Methods for determination of inorganic substances in water and fluvial sediments*: U.S. Geological Survey Open-File Report 85-495, 709 p.
- Freeze, R.A., and Cherry, J.A., 1979, *Ground-water*: Englewood Cliffs, New Jersey, Prentice-Hall Inc., 604 p.
- Kalichevsky, V.A., and Stagner, B.A., 1933, *Chemical refining of petroleum--The actions of various refining agents and chemicals on petroleum and its products*: New York, The Chemical Catalog Co., Inc., 451 p.
- Kansas Department of Health and Environment, 1982, *Report on the investigation of the Milliken Oil Refinery*: Topeka, Kansas Department of Health and Environment, unnumbered pages.
- Karickhoff, S.W., Brown, D.S., and Scott, T.A., 1979, Sorption of hydrophobic pollutants on natural sediments: *Water Research*, v. 13, p. 241-248.
- Kobayashi, Hester, and Rittmann, B.E., 1982, Microbial removal of hazardous organic compounds: *Environmental Science Technology*, v. 16, no. 3, p. 170A-182A.

- Lindsay, W.L., 1979, Chemical equilibria in soils: New York, John Wiley and Sons, 449 p.
- Lohman, S.W., 1979, Ground-water hydraulics: U.S. Geological Survey Professional Paper 708, 70 p.
- Oro, J., Nooner, D.W., and Wikstrom, S.A., 1965, Paraffinic hydrocarbons in pasture plants: Science, v. 147, p. 870-873.
- Pereira, W.E., and Rostad, C.E., 1986, Geochemical investigations of organic contaminants in the subsurface at a creosote works, Pensacola, Florida, in H.C. Matraw and B.J. Franks, Movement and fate of creosote waste in ground water, Pensacola, Florida: U.S. Geological Survey Water-Supply Paper 2285-E, p. 33-40.
- Safe Drinking Water Committee, 1982, Drinking water and health, volume 4: Washington, D.C., National Academic Press, 299 p.
- Schwartzbach, R.P., Giger, W., Hoehn, E., and Schneider, J.K., 1983, Behavior of organic compounds during infiltration of river water to ground water--Field studies: Environmental Science Technology, v. 17, p. 472-479.
- Schwartzbach, R.P., and Westhall, J., 1981, Transport of non-polar organic compounds from surface water to ground water--Laboratory sorption studies: Environmental Science Technology, v. 15, p. 1350-1367.
- Spruill, T.B., 1983, Statistical summaries of selected chemical constituents in Kansas ground-water supplies, 1976-81: U.S. Geological Survey Open-File Report 83-263, 29 p.
- U.S. Environmental Protection Agency, 1982, Methods for organic chemical analysis of municipal and industrial wastewater: U.S. Environmental Protection Agency EPA-600/4-82-57, unnumbered pages.
- _____, 1984, Amendment to National Oil and Hazardous Substances Contingency Plan--The National Priorities List, Proposed rule: Federal Register, Oct. 15, 1984, p. 40320-40352.
- _____, 1986, Quality criteria for water 1986: U.S. Environmental Protection Agency EPA-440/5-86-001, unnumbered pages.
- U.S. Soil Conservation Service, 1980, Soil survey of Cowley County, Kansas: U.S. Department of Agriculture, 123 p.
- Williams, C.C., and Lohman, S.W., 1949, Geology and ground-water resources of a part of south-central Kansas, with specific references to the Wichita municipal water supply: Kansas Geological Survey Bulletin 79, 455 p.
- Wood, W.W., 1976, Guidelines for collection and field analysis of ground-water samples for selected unstable constituents: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 1, Chapter D2, 24 p.
- Zepp, R.G., and Cline, D.M., 1977, Rates of direct photolysis in aquatic environments: Environmental Science Technology, v. 11, no. 9, p. 359-366.