HYDROGEOLOGY AND GROUND-WATER-QUALITY CONDITIONS AT THE HARVEY COUNTY LANDFILL, SOUTH-CENTRAL KANSAS, 1990

By J.O. Helgesen, B.A. Heck, and D.A. Hargadine

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	*By*	*To obtain*
inch	2.54	centimeter
foot	0.3048	meter
mile	1.609	kilometer
acre	0.4047	hectare
gallon per minute	0.06309	liter per second
degree Fahrenheit (°F)	(1)	degree Celsius (°C)

---

[1] °C = (°F-32)/1.8.

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 the United States and Canada, formerly called Sea Level Datum of 1929.

DEFINITION OF TERMS

Aerobic	Living, active, or occurring only in the presence of free oxygen.
Anaerobic	Living, active, or occurring in the absence of free oxygen.
Confined aquifer	An aquifer that contains water under pressure significantly greater than atmospheric. Its upper limit is the bottom of a bed of distinctly smaller hydraulic conductivity than that of the aquifer material itself.
Equipotential line	A line in a two-dimensional ground-water flow field such that the value of the total hydraulic head is the same for all points along the line.
Hydraulic conductivity	The volume of water at the existing kinematic viscosity that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow. Units of hydraulic conductivity are: $\frac{(\text{length}^3/\text{time})}{(\text{length}^2)\ (\text{length/length})} \left(\text{for example, } \frac{(\text{feet}^3/\text{day})}{(\text{feet}^2)\ (\text{feet/feet})}\right)$ but, as in this report, are commonly reported in length/time (for example, feet/day).
Hydraulic gradient	Rate of change in total hydraulic head per unit of distance of flow in a given direction.
Hydraulic head	Height above a standard datum of the surface of a column of water that can be supported by the static pressure at a given point.
Porosity	Ratio of the volume of void spaces in a rock or sediment to the total volume of the rock or sediment.
Potentiometric surface	A surface that represents the levels to which water will rise in tightly cased wells. If the hydraulic head varies considerably with depth in an aquifer, then there may be more than one potentiometric surface for that aquifer.
Transmissivity	The rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient.
Unconfined aquifer	An aquifer that has a water table.
Water table	The surface in a ground-water body at which the water pressure is atmospheric.

HYDROGEOLOGY AND GROUND-WATER QUALITY CONDITIONS AT THE HARVEY COUNTY LANDFILL, SOUTH-CENTRAL KANSAS, 1990

by J.O. Helgesen, B.A. Heck, and D.A. Hargadine

ABSTRACT

An investigation of the hydrogeology and ground-water quality at the Harvey County Landfill was conducted from November 1989 through December 1990 because of concern about possible contamination. The area of the landfill contains shallow ground water in unconsolidated deposits consisting of clay and sand and underlain by shale bedrock. The landfill is developed in and above the clay-rich upper part of the unconsolidated deposits. The water table generally is about 5 feet below the bottom of the landfill. Ground water is unconfined to semiconfined, and the direction of flow is predominantly lateral from northeast to southwest beneath the site.

Analyses of ground-water samples indicated that water beneath the landfill was mainly a calcium bicarbonate type, and dissolved-solids concentrations ranged from 448 to 2,140 milligrams per liter. The landfill has a discernable effect on ground-water quality immediately downgradient of the site. Effects were apparent in the form of slightly decreased pH, increased chemical oxygen demand, hardness, and alkalinity, and increased concentrations of dissolved solids, manganese, and zinc. These differences reflect the introduction of leachate to the ground water and the action of landfill degradation processes. The chemistry of deeper downgradient ground water generally was similar to that of upgradient ground water, indicating that the effects of the landfill were greatest in the shallow part of the saturated zone, at least near the landfill. Effects of the landfill also were apparent as indicated by increased concentrations of dissolved organic carbon and specific organic compounds commonly associated with industrial or commercial uses. However, the presence of organic compounds in water upgradient from the landfill suggests other possible sources of contamination in addition to the landfill.

Although some effects of the landfill on water quality are concluded by this evaluation, a thorough understanding is complicated by spatial and temporal variations in hydrologic-system dynamics, waste-degradation processes, and other nearby activities. Some effects on ground-water quality probably extend away from the landfill to the southwest, but the extent of downgradient leachate migration is unknown.

INTRODUCTION

Shallow aquifers in much of Kansas provide water for public and private drinking-water supplies, for irrigation and livestock watering, and for industrial uses. Information describing the geologic characteristics of the aquifers, the sources and directions of ground-water flow, and the chemical quality of ground and surface water is necessary for sound management of water resources. To gain information about the effects of landfills on water quality, the Kansas Department of Health and Environment (KDHE) is requiring all public landfills in Kansas to install ground-water monitoring systems (Charles Linn, Kansas Department of Health and Environment, oral commun., 1988). This investigation, conducted by the U.S. Geological Survey (USGS) in cooperation with Harvey County, Kansas, from November 1989 through December 1990, is one of several that focus on the effects of landfills on the quality of water in shallow aquifers. The purpose of the investigation was to determine the hydrogeology and ground-water-quality conditions in the vicinity of the Harvey County Landfill and to determine the effects of the landfill on water quality.

Purpose and Scope

This report describes the physical setting of the landfill, the fate of solid wastes in landfills in general, and investigative methods used during this study. The results of drilling, geophysical logging, and water sampling are used to interpret the geology, hydrology, and water quality in the vicinity of the landfill.

General Description of Study Area

The Harvey County Landfill is located about 2 miles southwest of Newton, in south-central

Kansas (fig. 1). The study area is on the eastern margin of the Arkansas River Lowlands physiographic area; the Flint Hills Upland physiographic area is just to the east (Schoewe, 1949) (fig. 2). The Arkansas River Lowlands typically has low topographic relief and is underlain by stream-laid or wind-laid unconsolidated deposits of silt, clay, sand, and gravel. The topography of the landfill area is gently rolling with surface drainage generally to the south (fig. 3). Mud Creek, an intermittent stream flowing south along the west side of the

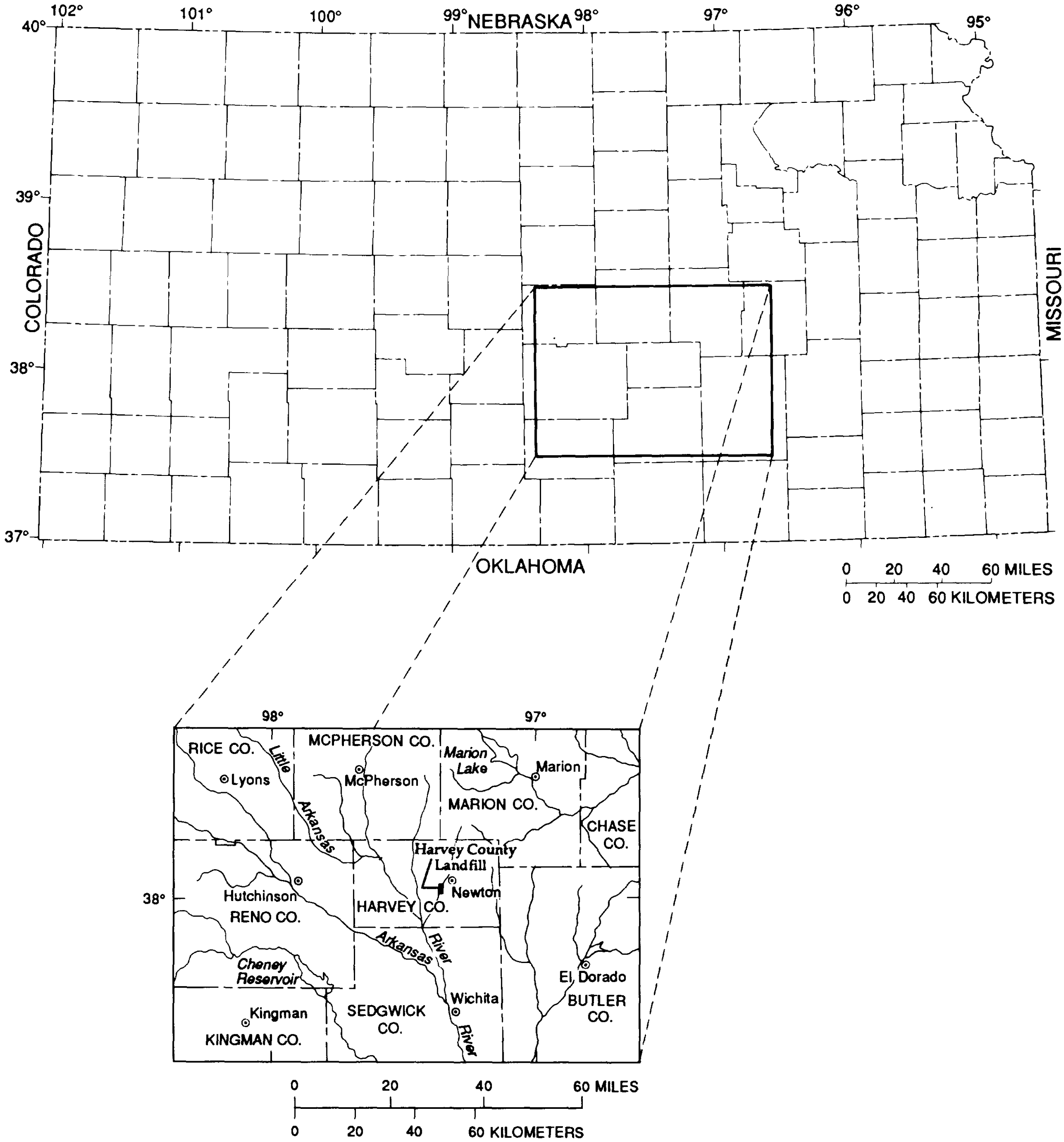


Figure 1. Location of Harvey County Landfill, south-central Kansas.

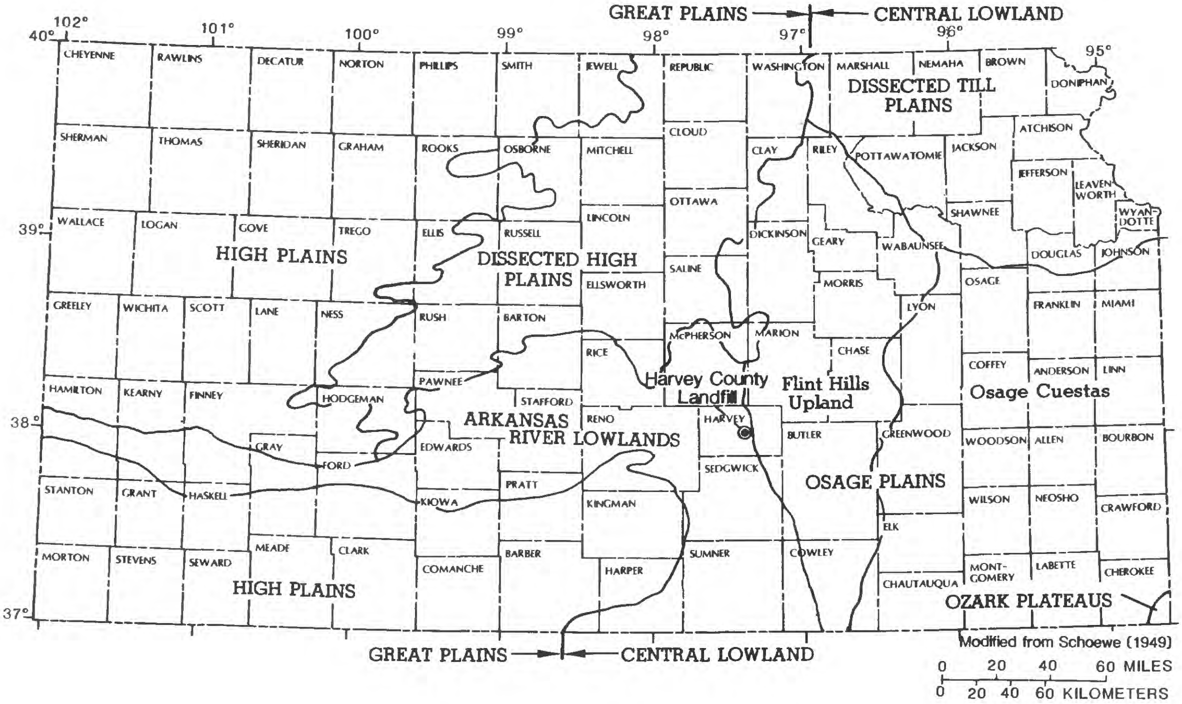


Figure 2. Physiographic areas of Kansas.

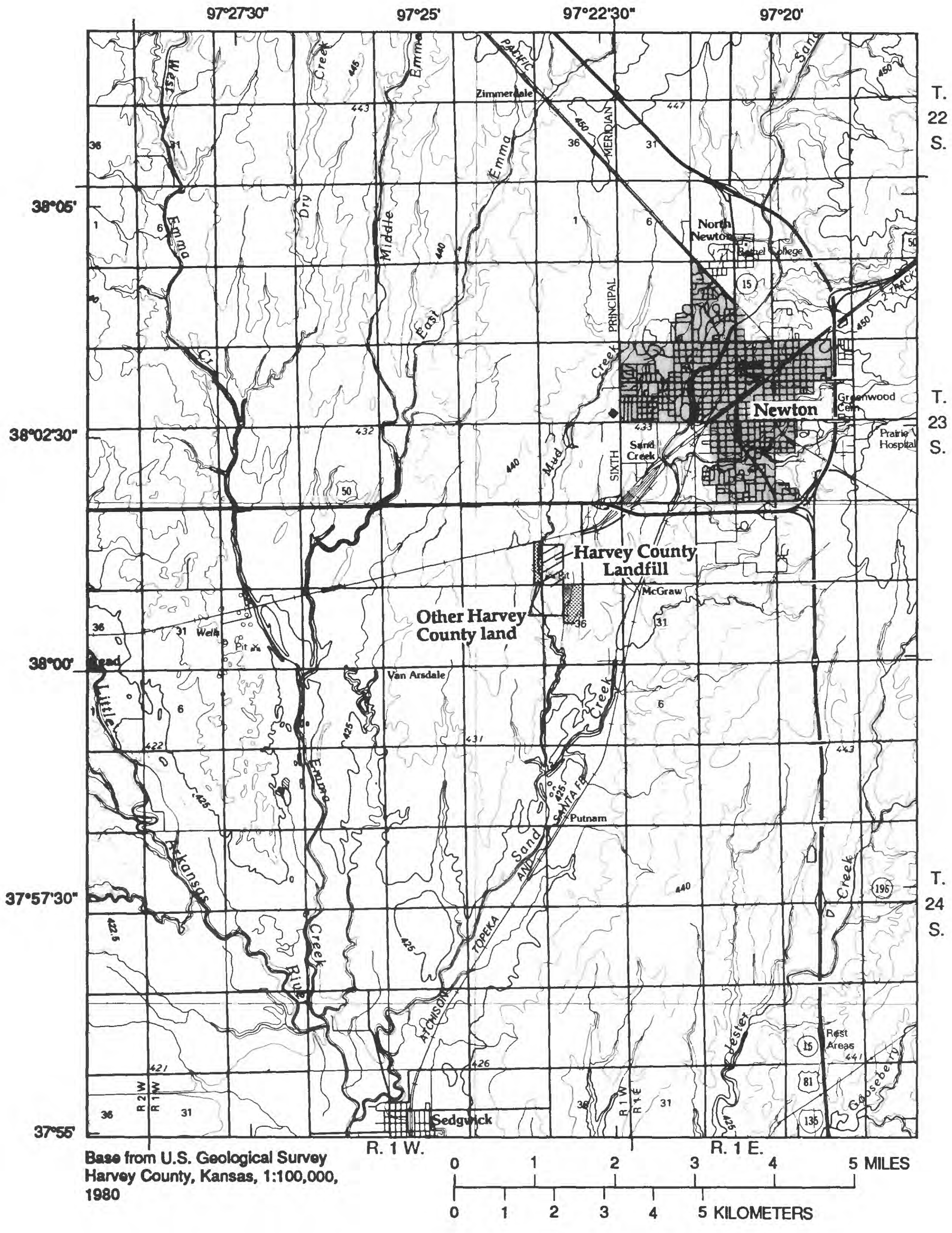
landfill, flows into Sand Creek, which flows into the Little Arkansas River near the southern border of Harvey County (fig. 3).

Mean annual precipitation during 1951-80 was about 31 inches (National Oceanic and Atmospheric Administration, 1987), as measured at a climatological station about 2 miles northeast of the landfill (fig. 3). Mean annual temperature at that station is about 56 °F.

Most water used in Harvey County is obtained from ground-water sources (Kenny, 1991). The western two-thirds of the county is underlain by the *Equus* beds aquifer, a productive source of ground water (Williams and Lohman, 1949; Stramel, 1956). The landfill is at the eastern edge of this aquifer. Farther east, on the Flint Hills Upland, sedimentary rocks of Permian age (mainly shale and limestone) are at or near land surface and yield only small ground-water supplies (Williams and Lohman, 1949).

Land use in Harvey County, based on information compiled by the U.S. Department of Agriculture, Soil Conservation Service, is approximately 85-percent agricultural. About 80 percent of the agricultural land is cropland, and the remainder is rangeland and pasture (U.S. Department of Agriculture, Soil Conservation Service, written commun., 1986).

Landfill operations are active within an 80-acre tract (figs. 3 and 4), which is the western one-half of the southwest quarter of section 25, T. 23 S., R. 1 W. Harvey County also owns a 27.6-acre strip of land adjacent to the west, in section 26, and 80 acres diagonally to the southeast, which is in the eastern one-half of the northwest quarter of section 36 (fig. 3). Most land adjacent to the landfill is privately owned cropland or pasture (fig. 4). A pump station for a natural-gas pipeline is just south of the landfill (fig. 4). The urbanized area of the city of Newton (northeast of the landfill) extends to within 1 mile of the landfill (fig. 3). This area includes light industries, a railroad yard, residential areas, and sewage-disposal ponds. The main industries manufacture and distribute glass or wood products for mobile homes, farm machinery, recreational vehicles, and furniture.



Base from U.S. Geological Survey Harvey County, Kansas, 1:100,000, 1980

CONTOUR INTERVAL 5 METERS
DATUM IS SEA LEVEL

EXPLANATION

◆ METEOROLOGICAL DATA-COLLECTION SITE

Figure 3. Topography in vicinity of Harvey County Landfill.

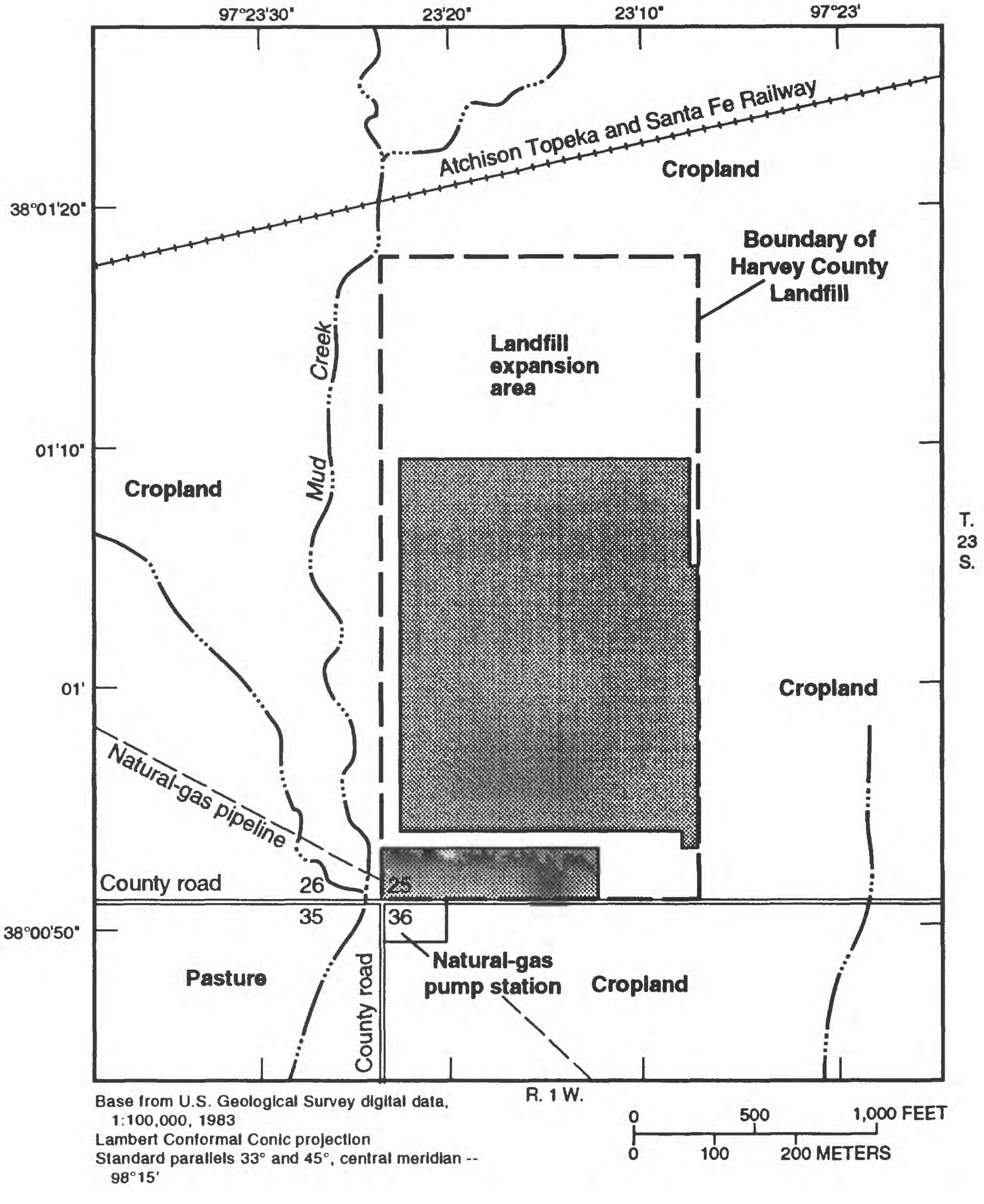


Figure 4. Disposal and expansion areas in Harvey County Landfill and surrounding land use as of 1990.

Previous Studies

No previous reports have been published that consider the effects of the Harvey County Landfill on water quality. However, the area of the landfill is included in several studies covering larger areas, and some unpublished information on the landfill is available. Parker (1911) and Haworth (1913) summarize early known data on Kansas ground water. Statewide descriptions relating to geology are presented by Frye and Leonard (1952), Merriam (1963), and Zeller (1968). Hoffman and Dowd (1974) describe the soils of Harvey County, but no county-wide reports on geology or ground water are published.

Substantial information exists on the *Equus* beds aquifer immediately west of the study area. The *Equus* beds is the easternmost part of the extensive High Plains aquifer (Gutentag and others, 1984; Stullken and others, 1985). The landfill site is located on the thin eastern edge of the *Equus* beds aquifer, in an area that received little attention in previous studies. Previous work focuses primarily on the thick, productive parts of the aquifer in western Harvey, northern Sedgwick, and northeastern Reno Counties, which are areas of relatively intensive ground-water development for irrigation, municipal, and industrial supply. Williams and Lohman (1949) describe the geology and ground water of the *Equus* beds aquifer in detail. Those authors and Stramel (1956; 1967) give particular emphasis to the effects of ground-water withdrawals in the Wichita well-field area. Water-quality aspects of the *Equus* beds area are reported by Williams and Lohman (1949), Leonard and Kleinschmidt (1976), Gogel (1981), Hathaway and others (1981), and Spruill (1983). Computer simulation efforts include solute-transport analysis presented by Sophocleous (1983) and Spinazola and others (1985).

Some data pertaining to the geology and ground-water quality at the Harvey County Landfill were collected prior to this study. During 1974, the county drilled test holes and installed three monitoring wells. During 1987, the county conducted additional test drilling west of the site and installed six additional monitoring wells at the site. Results of chemical analyses of several water samples collected from these monitoring wells since 1984 are available from the Kansas Department of Health and Environment (Topeka). The landfill site and operation were assessed in 1989 (G.J. Farquhar, consultant, written commun., April 4, 1989).

SOLID WASTES IN PUBLIC LANDFILLS

Solid wastes are materials that are no longer of value to the individual or community and are, therefore, discarded. The following is a general discussion of solid-waste composition, solid-waste degradation, and leachate production and composition in landfills. Much of the discussion is from Myers and Bigsby (1989). Although the exact composition of the solid-waste and chemical processes in the Harvey County Landfill are not known, they may be inferred to be similar to the general compositions and chemical processes reported in the literature.

Solid-Waste Composition

Typical nationwide composition of landfill solid wastes, by weight, is 45-percent paper, 15-percent food and kitchen wastes, 11-percent yard and garden trimmings, 9-percent metal, 8-percent glass, 4-percent dirt, ash, and concrete, 3-percent textiles, 3-percent plastics, and 2-percent wood (Tchobanoglous and others, 1977). About 80 percent of the solid waste is combustible. Total amounts of fixed carbon, moisture, and volatile organic matter represent 7, 20, and 53 percent of the solid waste. Solid-waste composition varies because of the climate, season, recycling, demography, packaging, and marketing (Tchobanoglous and others, 1977).

Solid-Waste Degradation

About 80 percent of typical solid waste, which includes paper, food and kitchen waste, yard and garden trimmings, and ferrous metal, can be degraded. The other 20 percent, mostly glass, wood, rubber, plastics, and synthetic textiles, degrades very slowly (Tchobanoglous and others, 1977). Degradation processes in the landfill include biologic decomposition, solution, precipitation, sorption, ion exchange, and diffusion of gases (Baedecker and Back, 1979). Sufficient moisture content, 20 to 60 percent, is essential for significant degradation rates. The moisture content depends on the composition of waste, the climate, the age and thickness of the landfill material, and other factors (Tchobanoglous and others, 1977). Typical moisture content for newly disposed solid waste is listed in table 1.

Degradation phases and components of an idealized, homogeneous landfill cell are represented in figure 5 (Christensen and others, 1989). Phase 1 represents the aerobic phase (oxidizing environment). Aerobic degradation proceeds rapidly and probably begins in easily degradable waste soon after deposition of the waste. Net products primarily are carbon dioxide and water, plus sulfate and ammonia (Baedecker and Back, 1979). The water produced by aerobic degradation increases the amount of moisture available for subsequent anaerobic degradation processes.

When oxygen is depleted by aerobic degradation, methane-generating anaerobic degradation of the organic wastes begins. Anaerobic degradation dominates in the reducing environment of phases 2 through 4, which are differentiated by the relative compositions of gas and leachate as shown in figure 5. Phase 5 is characterized by decreased methane production, increased nitrogen concentrations in the landfill gas, and aerobic zones in the upper layers of the landfill (Christensen and others, 1989). During phase 5, methane formation becomes minimal, and nitrogen diffuses from the atmosphere into the soil. End products of fully completed anaerobic degradation are methane, water, and carbon dioxide (Baedecker and Back, 1979).

At any specific time, individual parts of the same landfill may be in different stages of degradation. Stage and rate of degradation will vary from one landfill to another, depending primarily on moisture content but also on temperature and on local procedures for shredding, mixing, and compacting the wastes. The aerobic stage of a waste cell may be completed in a few days or weeks, and anaerobic degradation occurs rapidly enough to allow significant methane production to peak within

Table 1. *Typical moisture content of newly disposed municipal solid-waste components*

[Modified from Tchobanoglous and others, 1977]

Component	Moisture, in percent	
	Range	Typical
Food waste	50-80	70
Paper	4-10	6
Cardboard	4-8	5
Plastics	1-4	2
Textiles	6-15	10
Rubber	1-4	2
Leather	8-12	10
Garden trimmings	30-80	60
Wood	15-40	20
Glass	1-4	2
Tin cans	2-4	3
Nonferrous metals	2-4	2
Ferrous metals	2-6	3
Dirt, ash, brick, and other	6-12	8
Municipal solid wastes (composite of above components)	15-40	20

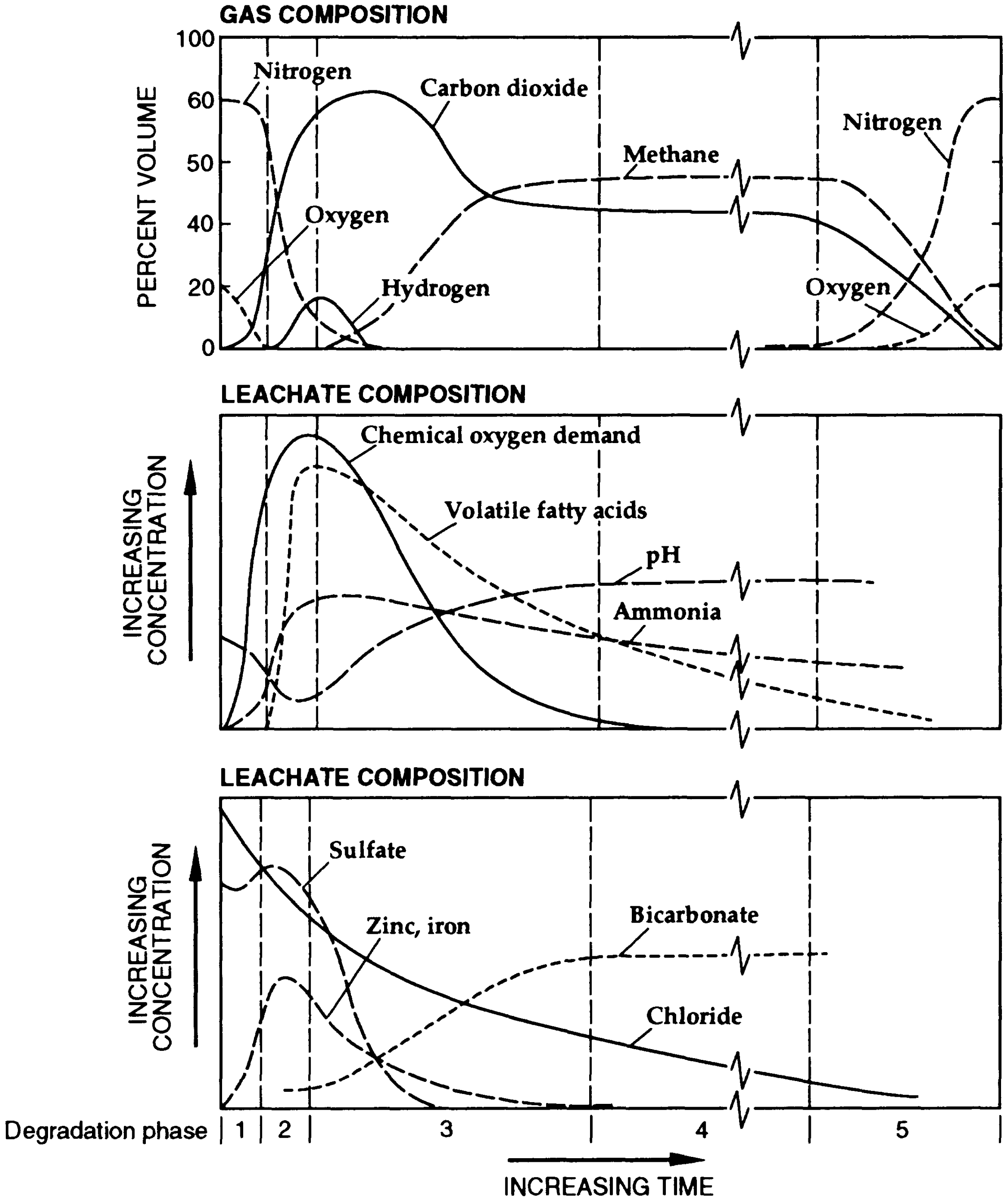


Figure 5. Degradation phases and components of idealized, homogeneous landfill cell (modified from Christensen and others, 1989).

2 years and then decline for 25 years or more (Tchobanoglous and others, 1977).

Leachate Production and Composition

Leachate is generated by the waste itself, the percolation of water through the waste, and the biological and chemical extraction of dissolved and suspended materials (Tchobanoglous and others, 1977). Paper, which comprises about 45 percent of all landfill waste, absorbs most of the water originally available in the waste. Therefore, the production and discharge of leachate from a landfill above the water table require the infiltration of water downward from the land surface. Initially, the waste is unsaturated, and most percolated water is retained by the waste, particularly paper products. Once the waste becomes nearly saturated, lateral and downward movement of leachate occurs. Solids, gases, and liquids from the waste are incorporated into the leachate as dissolved, suspended, or sorbed components that may be miscible or immiscible. Metabolic carbon dioxide, produced by bacterial action, dissolves easily, decreasing leachate pH. The resulting dissolution of calcium carbonate, if present, increases hardness and dissolved solids. Solvent capability of the leachate also is increased by the bacterially generated organic acids, which cause some metals in the landfill to dissolve.

Chemical processes in leachate production are oxidation, reduction, solution, precipitation, ion exchange, and sorption. In the landfill, these processes are affected to a large extent by the types of organic compounds present (Baedecker and Back, 1979). Physical processes contributing to leachate production are settlement, movement of evolved and ejected water, entrainment of colloidal and particulate material in flushing water, filtration, change of solute concentration by osmosis and concentration gradients, density separation of immiscible phases, and vertical and horizontal migration of gases.

Leachate composition is variable. Some typical concentrations and composition ranges of the most abundant constituents are listed in table 2. Where ranges are given, the larger values are expected in newer landfills because these are undergoing more rapid early-stage biodegradation, involving acid production. Sodium and potassium tend to remain in solution, unadsorbed by clay when calcium is present. Bicarbonate is produced directly in anaerobic reactions and indirectly when carbon dioxide dissolves. Bicarbonate also is dissolved from landfill ash, soil, and rock. Sulfate, derived from ash and treatment wastes, may be reduced within the landfill anaerobic environment and precipitated as ferrous sulfide or evolved as hydrogen sulfide gas, but is otherwise nonreactive. Chloride is nonreactive, and concentrations vary in leachate primarily because of dilution. Nitrogen is present mostly as ammonia because of conditions stemming from anaerobic degradation and the presence of dissolved iron (Apgar and Langmuir, 1971). Iron and manganese commonly are present in leachate in large concentrations. These constituents can be derived from wastes and also from oxide coatings and cements in soil and rock.

Leachate can contain trace elements such as cadmium, chromium, cobalt, copper, lead, mercury, nickel, strontium, and zinc in detectable concentrations. Other environmentally significant elements detected in landfill leachate include arsenic, boron, and selenium. These elements can occur naturally in the environment or can be derived from the landfill wastes. Elements present at concentrations above natural background are likely derived from municipal and industrial wastes or dissolution of natural compounds by leachate.

METHODS OF INVESTIGATION

There were four phases of investigation of the Harvey County Landfill. The first was an initial information-gathering phase for the general area and the landfill. The information gathered included the landfill's history, the geology and hydrology of the area, and data for existing monitoring and other wells in the vicinity of the landfill. The second phase consisted of installation of monitoring wells to supplement the existing monitoring-well network. Locations for these wells were selected on the basis of the geologic and hydrologic information from the existing monitoring wells. In the third phase, water samples were collected and analyzed from monitoring wells and Mud Creek. This report, which concludes the fourth phase, presents and interprets data obtained during this study.

Information Search

Prior to any work onsite, a search of published literature and files of the Kansas Department of Health and Environment (Topeka), the Kansas Geological Survey (Lawrence), and Harvey County (Newton) was completed. Preliminary estimates of lithology

Table 2. *Typical physical-property values and typical chemical-constituent concentrations in landfill leachate*

[Concentrations in milligrams per liter (mg/L) except as noted; ----, not determined]

Property or constituent	Concentrations Steiner and others, 1971	U.S. Environmental Protection Agency, 1973	U.S. Environmental Protection Agency, 1975	Tchobanoglous and others, 1977
Specific conductance[1]	----	----	6,000-9,000	----
pH[2]	4.0-8.5	3.7-8.5	5.2-6.4	6.0
Chemical oxygen demand	100-51,000	0-89,520	16,000-22,000	18,000
Hardness, total	200-5,250	0-22,800	3,500-5,000	3,500
Calcium (Ca)	----	5-4,080	900-1,700	----
Magnesium (Mg)	----	16.5-15,600	160-250	----
Sodium (Na)	100-3,800	0-7,700	450-500	500
Potassium (K)	----	2.8-3,770	295-310	300
Alkalinity, total as $CaCO_3$	----	0-20,850	800-4,000	3,000
Sulfate (SO_4)	25-500	1-1,826	400-650	300
Chloride (Cl)	100-2,400	34-2,800	600-800	500
Dissolved solids, total	----	0-42,276	10,000-14,000	----
Nitrate, total	20-500	0-1,416	----	5.6
Phosphate (P)	5-130	0-154	----	----
Iron (Fe)	200-1,700	0.2-5,500	210-325	60
Lead (Pb)	----	0-5.0	1.6	----
Manganese (Mn)	----	0.06-1,400	75-125	----
Zinc (Zn)	1-135	0-1,000	10-30	----

[1] Values in microsiemens per centimeter at 25 degrees Celsius.

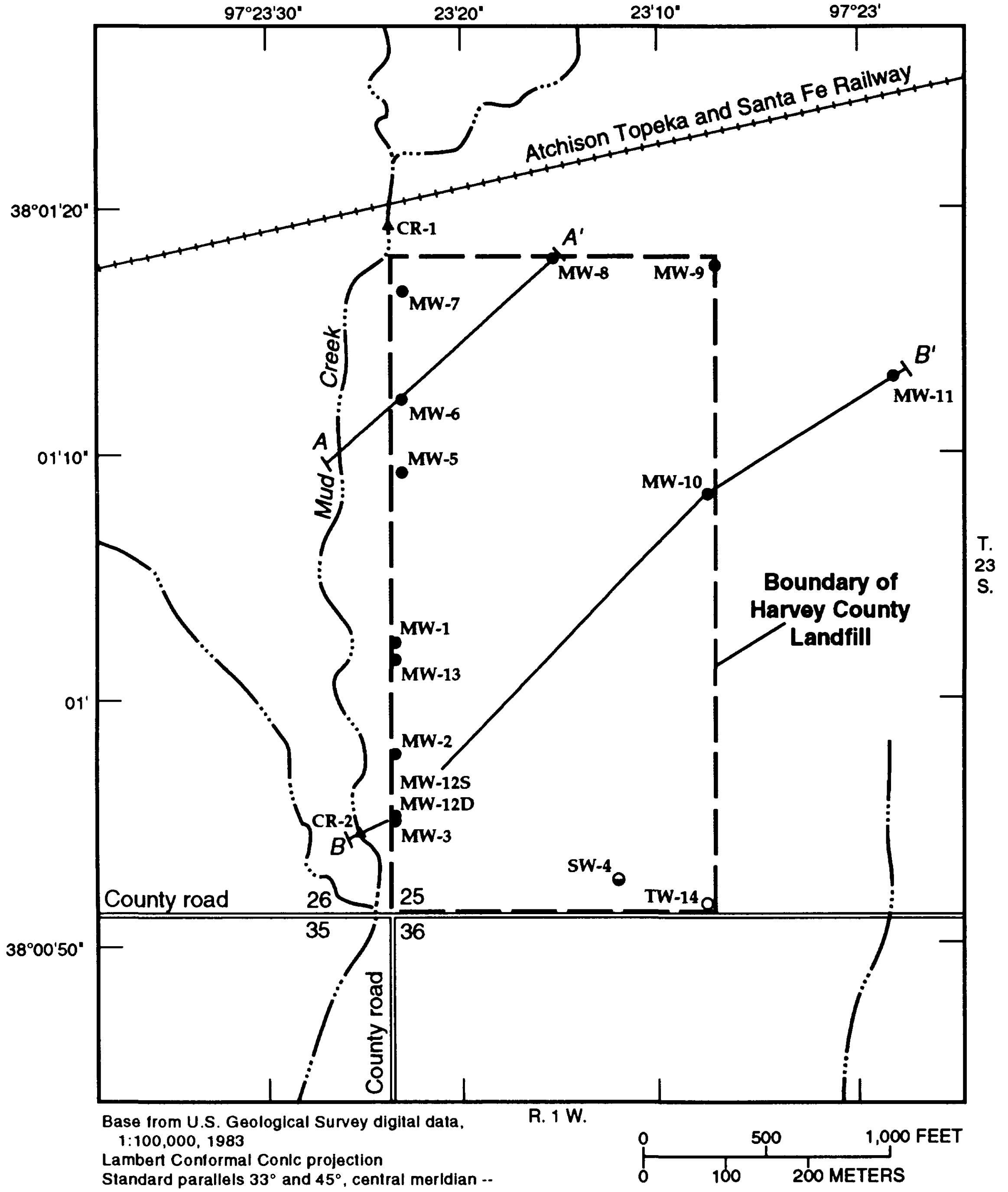
[2] Values in standard units.

and ground-water flow directions at the landfill site were made on the basis of previous geologic and hydrologic information. This information was useful for planning well locations, data-collection activities, and material requirements.

Monitoring-Well Installation

The following description refers to four monitoring wells (wells MW-11, MW-12S, MW-12D, and MW-13) installed by the U.S. Geological Survey in June 1990 (fig. 6). Wells MW-12S and MW-12D comprise a nested pair of wells; "S" indicates the shallower well, and "D" indicates the deeper well. Well TW-14 was a temporary well installed to obtain lithologic and water-level altitude data in the extreme southeast corner of the landfill.

Bore holes for the monitoring wells were drilled using 3 1/4-inch inside-diameter hollow-stem augers. To avoid potential cross contamination between wells or from other sources, all equipment and materials were



Base from U.S. Geological Survey digital data, 1:100,000, 1983
Lambert Conformal Conic projection
Standard parallels 33° and 45°, central meridian -- 98°15'

EXPLANATION

B —— B' TRACE OF SECTION--Shown in figures 10 and 14

——··· — INTERMITTENT STREAM

MW-12S ● MONITORING WELL AND NUMBER-- S indicates shallow well; D indicates deep well

SW-4 ◒ SUPPLY WELL AND NUMBER

TW-14 ○ TEMPORARY WELL AND NUMBER

CR-1 ▲ CREEK SAMPLING SITE AND NUMBER

Figure 6. Location of monitoring wells, supply well, temporary well, sampling sites on Mud Creek, and hydrogeologic sections A-A' and B-B'.

rinsed with a high-pressure jet of potable water, scrubbed with a low-phosphate detergent solution, and rinsed with potable water prior to installation of each well.

A steel plate was placed in the auger bit to prevent sediment from clogging the auger bit and flights while drilling. When the specified depth was reached, the auger stem was removed, and pipe for the monitoring well was lowered inside the open hole. Monitoring wells were 2-inch inside-diameter polyvinyl-chloride (PVC) pipe that had flush-threaded joints (no glue was used), a 5-foot screen with 0.01-inch slots, and a capped bottom. A centralizer was used to keep the well casing centered in the hole. Silica sand was added around the screen; a 10-foot long sand pack was installed, except in the shallowest wells, where a 6-foot long sand pack was installed. Bentonite chips were added to fill the annular space around the well casing to within 18 inches of the land surface. Depth measurements in the annular space ensured that sand packs and bentonite were placed properly. The wells were developed immediately, with a positive-displacement hand pump, to ensure that most fine-grained material was removed from around the well screen. The wells were purged dry numerous times until turbidity cleared. Finally, a concrete pad with a protective casing and locking well cap were installed around the well casing. Monitoring-well features are illustrated in figure 7. The location of all wells at the landfill site, determined by measuring distances from fence lines, is shown in figure 6.

Geologic information was noted while augering. Gamma-ray logs were obtained from all monitoring wells (including the previously installed monitoring wells) to aid in lithologic definition. The top-of-casing altitudes were determined by a level survey. Top-of-casing altitudes and depths for all wells are listed in table 3. Water levels were measured with a steel tape to the nearest 0.01 foot. Water-level altitudes were used to construct potentiometric-surface maps to show approximate directions of ground-water flow.

Water-Sampling Methods

On July 10-11, 1990, water samples were collected from the four newly installed monitoring wells (wells MW-11, MW-12S, MW-12D, and MW-13) and three of the previously existing monitoring wells (wells MW-2, MW-5, and MW-9). In addition, samples were collected from ponded water at two locations in the Mud Creek channel (sampling sites CR-1 and CR-2).

Water levels and total depths in all monitoring wells were measured with a steel tape. The tape was cleaned with distilled water before use. Each monitoring well was purged of at least five water-column volumes to ensure that the water samples collected were representative of the aquifer. All monitoring wells were purged with dedicated, pre-cleaned, positive-displacement hand pumps. Water samples were collected from the spigots of the dedicated hand pumps. Grab samples were collected from ponded water in Mud Creek.

Water samples were collected in the following order: (1) volatile organic compounds,

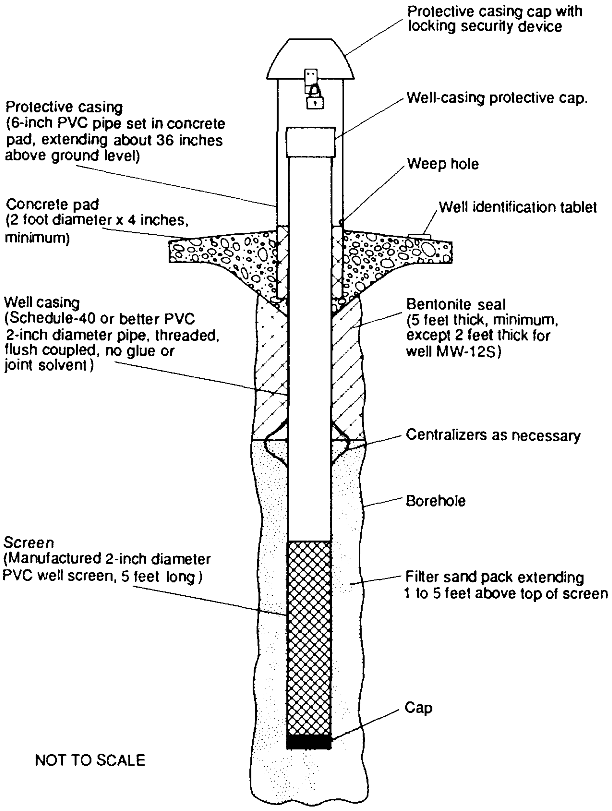


Figure 7. Monitoring-well features.

Table 3. *Top-of-casing altitudes and total depths for monitoring wells (MW), supply well (SW), and temporary well (TW) at Harvey County Landfill*

[Top of casing is from 1 to 4 feet above the land surface]

Well (fig. 6)	Top-of-casing altitude (feet above sea level)	Total depth below top of casing (feet)
MW-1	1,412.92	12.8
MW-2	1,412.07	17.8
MW-3	1,412.15	15.3
MW-5	1,413.86	30.3
MW-6	1,414.19	25.3
MW-7	1,415.33	25.3
MW-8	1,423.60	35.3
MW-9	1,435.14	48.7
MW-10	1,433.60	48.9
MW-11	1,426.11	33.0
MW-12S	1,411.59	10.9
MW-12D	1,412.19	27.7
MW-13	1,411.75	17.7
SW-4	1,430.24	(1)
TW-14	1,427.57	36.1

[1] Not measured. According to files of the Kansas Geological Survey, the well is 60 feet deep, with screened interval 20 to 40 feet just above the bedrock.

(2) semivolatile organic compounds, (3) dissolved organic carbon and common ions, (4) trace metals, and (5) nutrients. Care was taken not to aerate the water when collecting samples. The samples for chemical oxygen demand, nutrients, and trace metals were preserved with chemicals. All samples, except anion and trace metal samples, were chilled and maintained at 4 °C. Anion, nutrient, and trace metal samples were filtered onsite through a 0.45-micrometer filter, and dissolved organic carbon samples were filtered onsite through a 0.2-micrometer silver filter. Both types of filters were pre-flushed onsite with about 500 milliliters of sample water before collecting the sample to be analyzed. Specific conductance, pH, water temperature, and alkalinity measurements were determined at the time of sample collection. Two grab samples from Mud Creek (sampling sites CR-1 and CR-2) were processed in the same order as just described. Samples for volatile organics compounds were not collected from Mud Creek.

Water samples were shipped to the U.S. Geological Survey Water-Quality Laboratory in Arvada, Colo. Constituents were analyzed according to U.S. Geological Survey methods for determining inorganic substances (Fishman and Friedman, 1989) and organic substances (Wershaw and others, 1987) in water.

Hydraulic-Conductivity Determination

An estimate of hydraulic conductivity of the aquifer material was determined from a slug test at monitoring well MW-12D. A pressure transducer was lowered through a specially designed sealing well cap to a point 10 feet or less below the static water surface. The well then was pressurized with nitrogen gas to depress the water level in the well to a point above the pressure transducer. The pressure and water level in the well were stabilized for about 5 minutes before the pressure was released suddenly. Pressure-transducer readings were recorded for a 20-minute duration starting when the pressure was released from the well. Hydraulic conductivity was calculated using the analysis method of Cooper and others (1967).

LANDFILL DESCRIPTION AND OPERATION

The Harvey County Landfill began operation in 1974. As of December 1990, approximately 50 acres had been filled (fig. 4), with plans to complete the filling of the 80-acre tract.

The disposal operation is managed as a sanitary landfill using a moving-trench method. The initial trench was cut in an east-west direction across the center of the 80-acre tract. Trenches, approximately 100 feet wide, were cut and filled progressively southward from the center, then progressively northward from the center. A typical west-east profile across the site, as shown by initial design specifications (fig. 8), illustrates various design features, including a westward-sloping trench bottom and a final grade that is higher than the original land surface across most of the site. The direction of final surface drainage approximates the original surface drainage (mostly to the west).

Waste is deposited in cells and covered each day with 6 inches of clay retained from the trench excavation. Upon completion of the operation at the site, the landfill then will be covered with topsoil. The landfill has received small quantities of industrial-type special wastes, such as asbestos, paint residues, mud from car- and truck-wash operations, school-laboratory chemicals, and gasoline-contaminated soil. The landfill does not receive sewage waste.

REGIONAL HYDROGEOLOGY

The bedrock that underlies essentially all of Harvey County is the Wellington Formation of Permian age. These strata consist mostly of shale interbedded with smaller quantities of dolomite, anhydrite, and gypsum. The strata have a slight westerly dip. The Wellington Formation is at or near land surface in approximately the eastern one-third of the county. The bedrock surface slopes generally westward and is covered by progressively

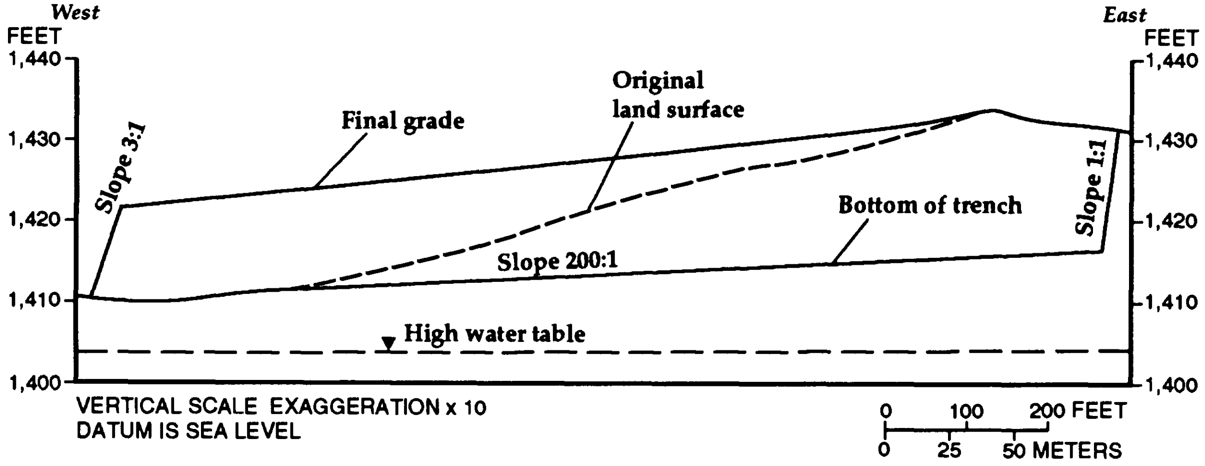


Figure 8. Typical cross section of Harvey County Landfill showing design specifications (modified from unpublished preliminary drawing by Delamater, Freund, and Scherer, Consulting Engineers, Wichita, Kans. written commun., 1974).

thicker unconsolidated deposits of Pleistocene age, which consist principally of stream-laid sand, gravel, silt, and clay (*Equus* beds). Generally, soil types reflect the parent material, as relatively sandy soils have developed from the unconsolidated deposits of the *Equus* beds, whereas clayey soils have developed on shale-outcrop areas farther east.

Small quantities of ground water (well yields typically less than 10 gallons per minute) are available in this area from the Wellington Formation, which generally has very slight hydraulic conductivity (Williams and Lohman, 1949; Leonard and Kleinschmidt, 1976). Well yields from bedrock may be adequate for domestic or stock-watering supplies at a given location. Ground-water availability is substantially greater in the *Equus* beds aquifer, especially as the aquifer thickens to the west. Well yields of several hundred to thousands of gallons per minute are possible in the areas of thickest and coarsest (sand and gravel) materials (Williams and Lohman, 1949).

Most recharge to ground water is derived from direct infiltration of precipitation. Regional ground-water flow is toward major streams; in much of Harvey County, ground-water flow is southwesterly toward the Little Arkansas River. Depth to the water table generally is less than 50 feet below land surface (Williams and Lohman, 1949; Gutentag and others, 1984).

LANDFILL HYDROGEOLOGY

Geology

The shallowest bedrock beneath the landfill site consists of dark-gray to greenish-gray shale of the Wellington Formation. Rocks of the Wellington Formation crop out at land surface about 2 miles northeast and east of the landfill. Total topographic relief on the top of the bedrock surface across the site is about 10 feet.

Interbedded clay, silt, and sand deposits overlie the bedrock at the landfill site and range from about 17 to 45 feet in thickness. These unconsolidated deposits are thickest along the eastern side of the site, which also is topographically highest. The texture of these materials varies; the clay commonly is silty or sandy, and the sand ranges from fine to coarse grained. The descriptive log and gamma-ray log for well MW-10 are typical (fig. 9). Increased radioactivity, as shown by the gamma log, is indicative of increased clay content. Although the lithology varies laterally (fig. 10), clay generally predominates in the upper part of the unconsolidated deposits, and a sand layer several feet thick commonly is present just above the bedrock. This sand layer is as thick as 14 feet (at well MW-10) and commonly contains weathered bedrock fragments. The clay, observed in trench cuts as well as described in driller's logs, is reddish brown to brown and may have a blocky structure. Excavations for the landfill have been entirely within the upper, clay-rich part of the unconsolidated deposits. The soil generally is a silt loam to a silty clay.

Hydrology

Surface drainage at the landfill site is mainly west toward Mud Creek. A south-north service road along the west side of the landfill (between the edge of the fill and the line of monitoring wells) intercepts the surface drainage. Three culverts provide for some drainage under the road, but the east ends of the culverts are buried now (1990). Surface drainage along the eastern edge of the landfill site is southeast toward a small intermittent stream. Mud Creek also is an intermittent stream in the area of the landfill, and generally begins perennial flow (that is, receives continuous ground-water discharge) some distance downstream from the landfill, depending on climatic conditions. During the period of this study, part of the channel of Mud Creek adjacent to the landfill contained ponded water, but upstream and downstream reaches were dry.

Ground water is present at shallow depths beneath the landfill site. The shale bedrock underlying the site transmits water very slowly in comparison to the unconsolidated deposits. However, some interchange of water between the bedrock and the unconsolidated deposits probably occurs throughout long time periods.

The lower part of the unconsolidated deposits is saturated throughout the landfill site. The depth to the top of the saturated zone ranges from a few feet near Mud Creek to 20 feet

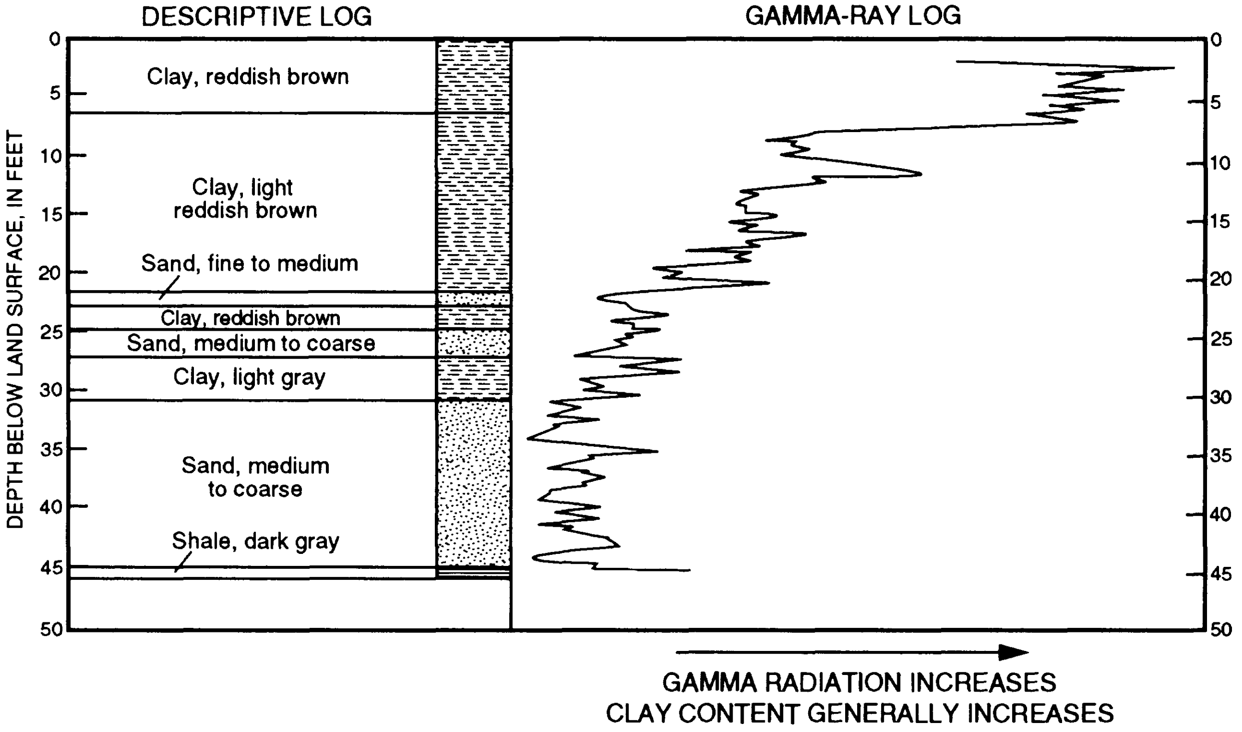


Figure 9. Descriptive and gamma-ray logs for monitoring well MW-10 at Harvey County Landfill.

or more along the eastern edge of the site. Although no water-level data pertain to directly beneath the landfill itself, the water table is inferred to be approximately 5 feet below the buried waste (fig. 10). It is possible that water from the waste could result in a local rise, or mounding, of the water table beneath the landfill.

The lower part of the saturated interval tends to be more transmissive than the upper part because of greater sand content. Monitoring wells MW-1, MW-2, MW-3, and MW-12S are completed in relatively localized shallow sand deposits, whereas the other monitoring wells are open to the lower sand deposits, which are thicker and more extensive. Water in the unconsolidated deposits is unconfined to semiconfined (a condition intermediate between unconfined and confined). No significant hydraulic-head variation (less than 0.10 foot) is apparent with depth, and lateral flow of ground water dominates (fig. 10).

Ground-water flow is approximately from northeast to southwest beneath the site, as indicated by the slope of the potentiometric surface (figs. 11 and 12). The potentiometric contours were not drawn to illustrate any mounding of the water table, the possibility of which was mentioned previously. The altitude of the potentiometric surface may vary by a few feet seasonally and probably by a greater amount in response to long-term climatic trends. The hydraulic gradient of the potentiometric surface also varies through time. The gradient across the main part of the landfill site was about 0.0038 feet per foot on July 11, 1990 (fig. 11), and about 0.0025 feet per foot on November 1, 1990 (fig. 12). The smaller hydraulic gradient in November was the consequence of a prolonged dry period.

Lateral variations in hydraulic gradient may reflect lateral variations in transmissivity. For example, the relatively steep gradient beneath the northern part of the site (figs. 11 and 12), as indicated by relatively closely spaced potentiometric contours, corresponds to an area of thinner sand deposits, according to descriptive and gamma logs for the monitoring wells. The lithologies and hydraulic gradients also are illustrated in hydrogeologic sections (fig. 10).

Horizontal hydraulic conductivity of the aquifer material was determined from analysis of slug-test data collected at well MW-12D.

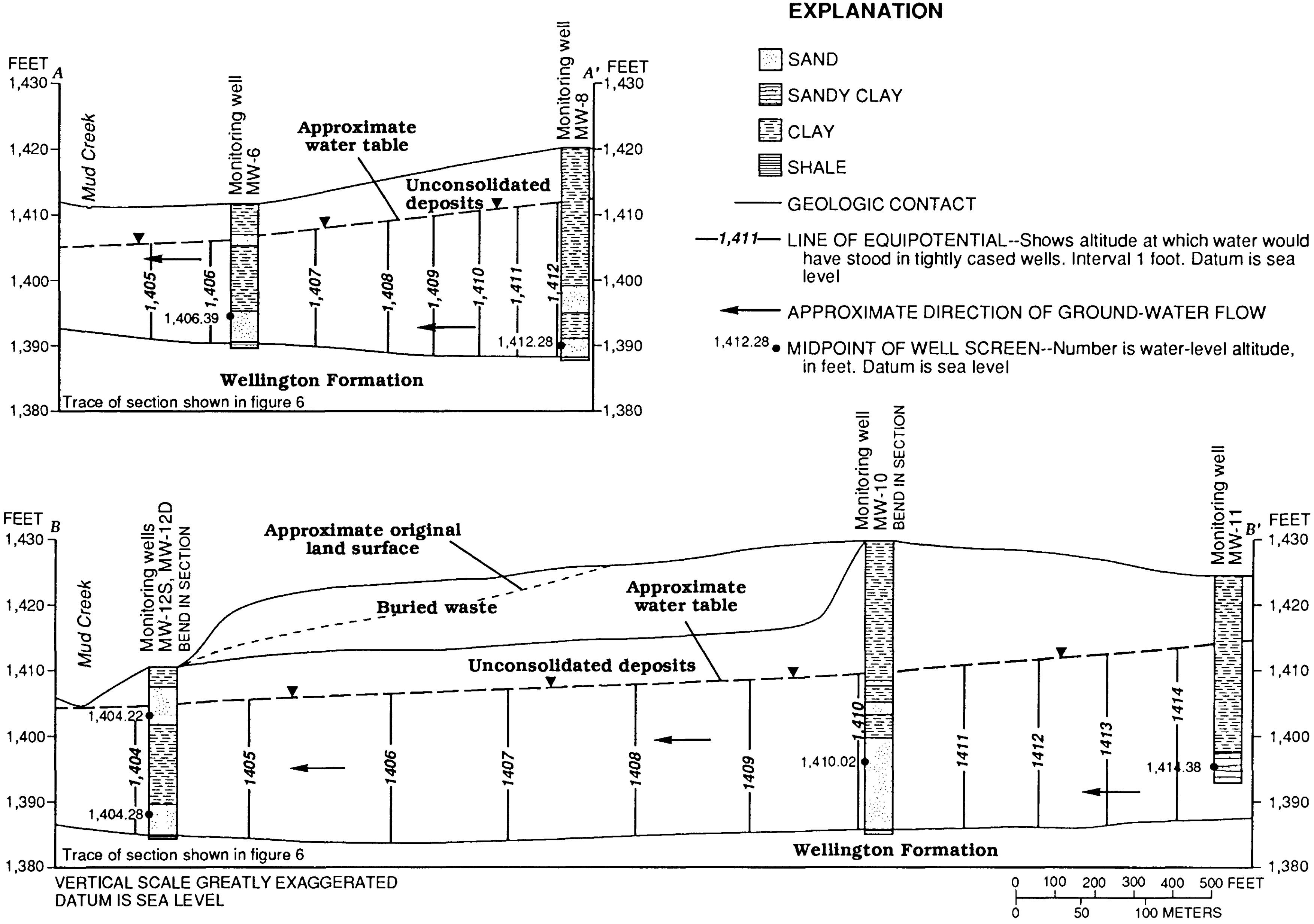
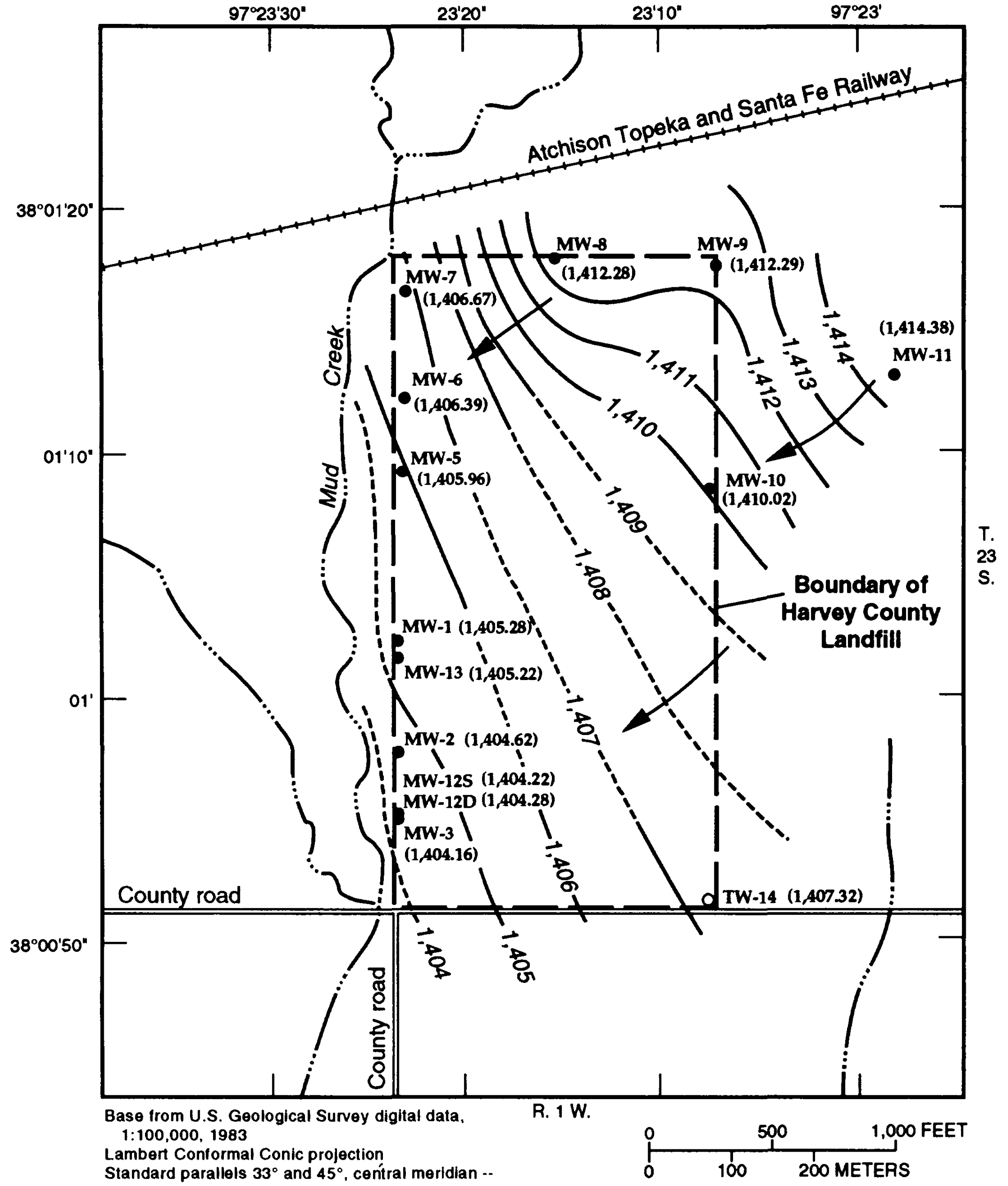


Figure 10. Hydrogeologic sections through Harvey County Landfill showing lithology, lines of equipotential, and approximate direction of ground-water flow, July 11, 1990.



Base from U.S. Geological Survey digital data,
1:100,000, 1983
Lambert Conformal Conic projection
Standard parallels 33° and 45°, central meridian --
98°15'

EXPLANATION

—*1,407*-- POTENTIOMETRIC CONTOUR--Shows altitude at which water level would have stood in tightly cased wells. Dashed where approximately located. Contour interval 1 foot. Datum is sea level

◄— APPROXIMATE DIRECTION OF GROUND-WATER FLOW

—···— INTERMITTENT STREAM

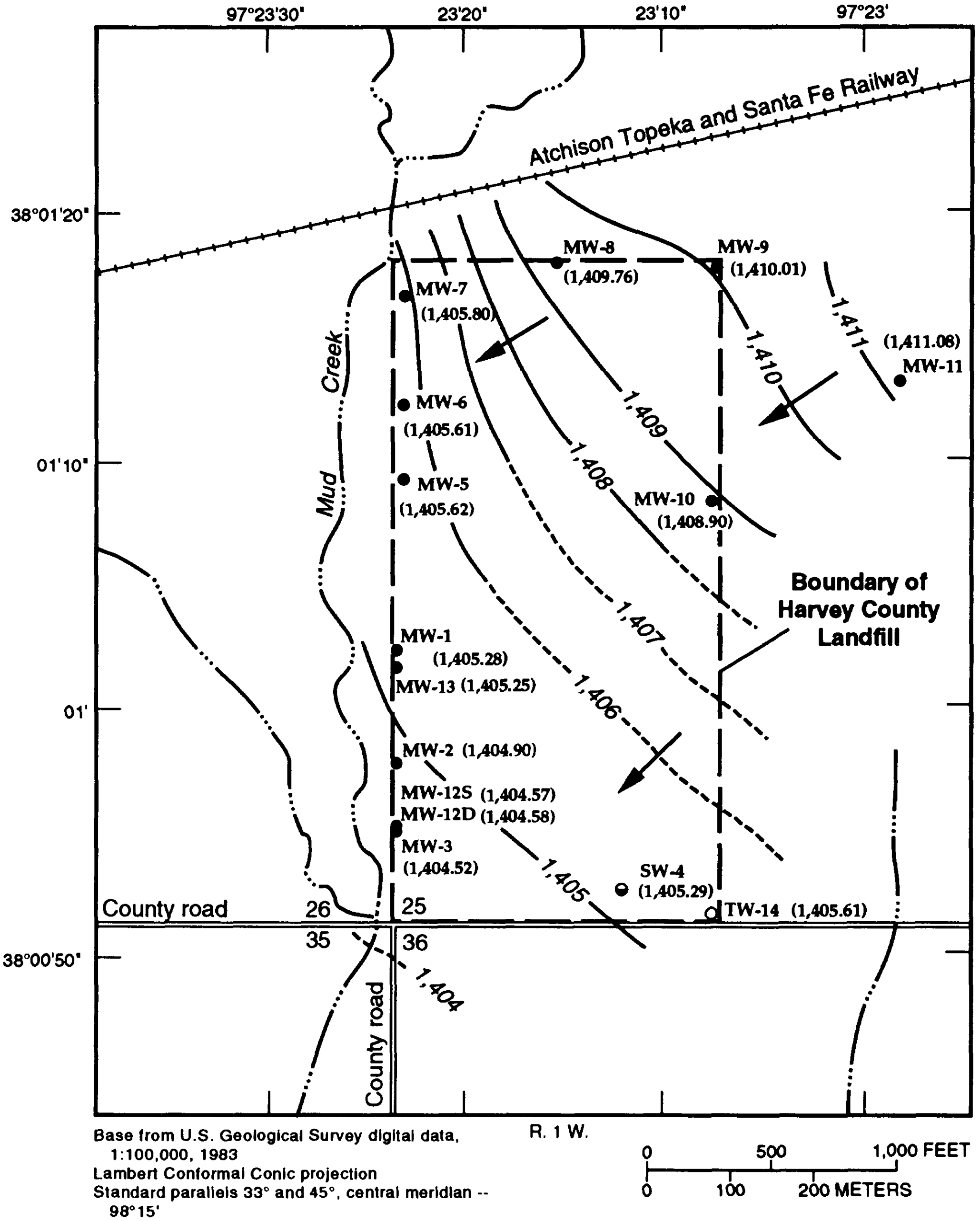
MW-12S ● MONITORING WELL AND NUMBER--S indicated shallow well; D indicates deep well

SW-4 ◉ SUPPLY WELL AND NUMBER

TW-14 ○ TEMPORARY WELL AND NUMBER

(1,405.28) ALTITUDE OF POTENTIOMETRIC SURFACE--In feet. Datum is sea level

Figure 11. Potentiometric surface of water in unconsolidated deposits, July 11, 1990.



Base from U.S. Geological Survey digital data, 1:100,000, 1983
Lambert Conformal Conic projection
Standard parallels 33° and 45°, central meridian -- 98°15'

EXPLANATION

—1,407--	POTENTIOMETRIC CONTOUR--Shows altitude at which water level would have stood in tightly cased wells. Dashed where approximately located. Contour interval 1 foot. Datum is sea level	MW-12S ●	MONITORING WELL AND NUMBER--S indicated shallow well; D indicates deep well
		SW-4 ●	SUPPLY WELL AND NUMBER
◄—	APPROXIMATE DIRECTION OF GROUND-WATER FLOW	TW-14 ○	TEMPORARY WELL AND NUMBER
—···—	INTERMITTENT STREAM	(1,405.28)	ALTITUDE OF POTENTIOMETRIC SURFACE--In feet. Datum is sea level

Figure 12. Potentiometric surface of water in unconsolidated deposits, November 1, 1990.

Analyses, according to the method of Cooper and others (1967), yielded a hydraulic- conductivity value of approximately 1 foot per day. Other data on hydraulic conductivity are very limited, although Spinazola and others (1985) assigned model-input values of hydraulic conductivity in the range of 5 to 25 feet per day to this area of the *Equus* beds aquifer.

The velocity of water movement through an aquifer depends on the hydraulic conductivity, the hydraulic gradient, and the porosity of the aquifer material, and is expressed by the equation (Heath, 1983):

$$\bar{v} = \frac{-K\ dh}{n\ dl}, \qquad (1)$$

where $\bar{v}$ = average linear velocity of ground-water movement, in feet per day;

K = hydraulic conductivity, in feet per day;

$\frac{dh}{dl}$ = hydraulic gradient, in feet per foot; and

n = porosity, as a decimal fraction.

If it is assumed that hydraulic conductivity is within the order of magnitude of 1 to 10 feet per day, that the hydraulic gradient is 0.003 feet per foot, and that porosity is 0.25 [a reasonable value for sand (Heath, 1983)], then the average linear velocity of ground-water movement is in the range of 0.01 to 0.1 foot per day.

Ground water in the unconsolidated deposits beneath the landfill is derived partly from direct infiltration of precipitation on the site and partly from subsurface flow from the northeast. Quantitative determinations of direct infiltration and subsurface inflow were not made, but it is estimated that both sources are major components of the local ground-water budget. When water is present in the channel of Mud Creek, it could provide some local recharge to shallow ground water beneath the stream channel.

Small, localized seepage areas are reportedly observed at times near the bottom of the west-side slope of the landfill. Leachate that accumulates on the bottom of the sloping trench (fig. 8) may move preferentially downslope some distance before resuming vertical percolation to the underlying water table. The observed seepage areas probably result from the movement of some leachate westward to the edge of the landfill.

Most ground-water discharge from beneath the site is to the southwest. Some ground-water discharge to Mud Creek, or as evapotranspiration along the creek, may occur at times adjacent to the southern part of the landfill site (section B-B', fig. 10). Farther north (section A-A', fig. 10), the water table appears to be several feet below the creek, suggesting that surface drainage is the main source for ponded water in the stream channel. Downstream from the landfill, where Mud Creek was observed to be dry, ground water probably flows in a south-to-southwest direction before discharging to Mud Creek or other streams.

The only ground-water development on the landfill is supply well SW-4. This well, reportedly screened from 20-40 feet below land surface (table 3), supplies water for nonpotable use at the landfill office and shop. Several wells within a mile or so of the landfill withdraw ground water for domestic, lawn- and garden-watering, or stock-watering purposes.

REGIONAL GROUND-WATER QUALITY

Chemical characteristics of ground water in Harvey County vary considerably depending on the source and direction of water movement. Water in the unconsolidated deposits of central Harvey County (just west of the study area) is derived principally from local precipitation and is generally suitable for most uses. In general, this ground water is a calcium bicarbonate type with dissolved-solids concentrations less than 500 mg/L (milligrams per liter), sodium concentrations less than 150 mg/L, chloride concentrations less than 75 mg/L, and sulfate concentrations less than 50 mg/L (Hathaway and others, 1981). The water commonly is very hard (greater than 180 mg/L as calcium carbonate).

Saline water is typical of the Permian bedrock of the area (Parker, 1911; Williams and Lohman, 1949; Gogel, 1981). This saline water has the potential to migrate upward into freshwater systems in some areas (Williams and

Lohman, 1949; Gogel, 1981). In addition to this natural process of contamination, disposal of brine associated with oil production has affected shallow water in parts of the *Equus* beds aquifer (Williams and Lohman, 1949; Leonard and Kleinschmidt, 1976; Sophocleous, 1983; Spinazola and others, 1985). These contamination processes are not known to have affected the Harvey County Landfill area but have been of concern farther west.

LANDFILL-AREA WATER QUALITY

Analyses of water samples collected at the landfill site July 10-11, 1990, provide the primary basis for characterizing and evaluating the local water-quality conditions. The following discussion commonly refers to specific groupings of samples in relation to the hydrogeology--in particular, samples collected upgradient from the landfill and samples collected downgradient from the landfill. Samples from monitoring wells MW-9 and MW-11 (figs. 11 and 12) represent conditions upgradient from the landfill. Samples from wells MW-2, MW-12S, MW-12D, and MW-13 represent downgradient conditions. Samples from well MW-5 and from Mud Creek are less definitive of water quality as related to the flow system in the vicinity of the landfill. In the downgradient area, it also is useful to distinguish between relatively deep and shallow water samples. Water from wells MW-2 and MW-12S is from shallow sand deposits, whereas water from wells MW-12D and MW-13 is from deeper sand deposits.

Water Properties

Results of analyses for various properties of water (specific conductance, pH, temperature, chemical oxygen demand, hardness, and alkalinity) are included in table 4. Kansas and Federal drinking-water regulations were not exceeded for any of these properties except hardness, for which the Kansas secondary drinking-water regulation of 400 mg/L was exceeded in several water samples.

Specific conductance, a property indicative of the dissolved-solids concentration in water, was 850 and 880 μS/cm (microsiemens per centimeter at 25 °C) in samples collected upgradient from the landfill (fig. 13). Specific conductance ranged from 940 to 2,710 μS/cm in samples collected downgradient from the landfill; however, the value for the sample from well MW-12D (940 μS/cm) was considerably smaller than for samples from the other downgradient wells, suggesting more of a similarity with water laterally upgradient than with the water vertically above. This relation is illustrated in figure 14.

pH, a measure of hydrogen ion activity, ranged from 6.8 to 7.5 in ground-water samples and 8.1 to 8.5 in the ponded water samples from Mud Creek, as determined onsite. Chemical oxygen demand (COD), which is a measure of the oxidizable material in water and generally indicates the minimum amount of organic and reducing material present, ranged from 19 to 120 mg/L. Hardness is generally a measure of the calcium and magnesium content of water and ranged from 160 to 1,500 mg/L (considered hard to very hard water). Alkalinity, the capacity of solutes in water to neutralize acidity, ranged from 160 to 700 mg/L, as determined onsite. Spatial patterns similar to that previously described for specific conductance also are discernible for these properties; distributions of pH, COD, and hardness, for example, are illustrated in figure 14. Differences are apparent between the shallow downgradient sample (from well MW-12S) and the upgradient sample (well MW-11). However, properties of water collected from the deeper downgradient well (well MW-12D) are similar to upgradient water properties.

Properties of samples collected from ponded water in Mud Creek appear considerably different from the ground-water samples. For example, specific conductance was 638 and 555 μS/cm, much smaller than that of the adjacent ground water. These differences probably reflect limited connection between the creek and ground water. The ponded water in the channel of Mud Creek probably is derived mostly from surface (rather than subsurface) sources, at least during the period of this study.

Dissolved Solids and Major Ions

Dissolved-solids concentrations in ground water at or near the landfill ranged from 448 to 2,140 mg/L in samples collected July 10-11, 1990 (table 4). Ground water upgradient from the landfill (samples from wells MW-9 and

Table 4. *Physical properties of and inorganic constituent concentrations in water samples from Harvey County Landfill, July 10-11, 1990*

[Units of measurement: µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter. <, less than indicated reporting level; --, not determined; __, no regulation established]

Well or sampling site (fig. 6)	Date (month-day-year)	Specific conductance, field (µS/cm)	pH, field (standard units)	Water temperature (degrees Celsius)	Chemical oxygen demand, total (mg/L)	Hardness, total (mg/L as $CaCO_3$)	Alkalinity, total, field (mg/L as $CaCO_3$)	Dissolved solids, residue at 105 degrees Celsius (mg/L)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)
MW-2	07-10-90	2,090	6.8	16.0	56	830	520	1,130	270	37
MW-5	07-11-90	2,700	7.2	15.0	25	1,500	160	2,140	440	98
MW-9	07-11-90	850	7.3	15.0	19	300	320	448	97	15
MW-11	07-10-90	880	7.5	15.0	31	280	390	553	100	7.6
MW-11[1]	07-10-90	880	7.4	15.0	37	280	380	550	100	7.6
MW-12S	07-10-90	2,710	7.1	20.0	75	1,000	700	1,630	330	45
MW-12D	07-10-90	940	7.5	17.0	40	400	350	586	120	25
MW-13	07-10-90	1,650	7.2	16.0	100	710	490	926	230	33
CR-1	07-10-90	638	8.1	24.0	120	320	380	441	100	16
CR-2	07-10-90	555	8.5	24.5	73	160	170	305	47	11
Federal and Kansas Maximum Contaminant Level[2]		__	__	__	__	__	__	__	__	__
Federal and Kansas Secondary Maximum Contaminant Level[3]		__	6.5-8.5	__	__	400[4]	__	500	__	__

Table 4. *Physical properties of and inorganic constituent concentrations in water samples from Harvey County Landfill, July 10-11, 1990*--Continued

Well or sampling site (fig. 6)	Date (month-day-year)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Bicarbonate, field[5] (mg/L as HCO_3)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)
MW-2	07-10-90	72	2.7	640	26	370	<0.1	37
MW-5	07-11-90	39	2.0	200	1,400	36	.9	23
MW-9	07-11-90	56	1.4	390	45	12	<.1	29
MW-11	07-10-90	100	1.8	480	32	47	.3	27
MW-11[1]	07-10-90	100	2.0	460	35	49	.3	28
MW-12S	07-10-90	170	11	850	320	310	.5	22
MW-12D	07-10-90	38	2.0	430	120	25	.2	44
MW-13	07-10-90	60	1.5	600	67	200	.3	37
CR-1	07-10-90	40	9.8	460	4.7	33	.3	10
CR-2	07-10-90	27	8.3	210	13	34	.4	7.0
Federal and Kansas Maximum Contaminant Level[2]		—	—	—	—	—	1.8[6]	—
Federal and Kansas Secondary Maximum Contaminant Level[3]		—	—	—	250	250	2.0	—

Table 4. *Physical properties of and inorganic constituent concentrations in water samples from Harvey County Landfill, July 10-11, 1990*--Continued

Well or sampling site (fig. 6)	Date (month-day-year)	Nitrogen, nitrate, dissolved (mg/L as N)	Nitrogen, nitrate, dissolved (mg/L as N)	Nitrogen, nitrite plus nitrate, dissolved (mg/L as N)	Nitrogen, ammonia, dissolved (mg/L as N)	Phos-phorus, ortho, dissolved (mg/L as P)	Arsenic, dissolved (µg/L as As)	Barium, dissolved (µg/L as Ba)	Cadmium, dissolved (µg/L as Cd)
MW-2	07-10-90	< .10	<0.01	< 0.10	<0.01	0.19	4	270	<1
MW-5	07-11-90	0.30	< .01	.30	.09	< .01	1	<100	<1
MW-9	07-11-90	10	< .01	10	.03	.10	2	320	<1
MW-11	07-10-90	2.8	< .01	2.8	.03	.01	3	170	<1
MW-11[1]	07-10-90	2.8	< .01	2.8	.02	.01	3	170	<1
MW-12S	07-10-90	< .10	< .01	< .10	.07	< .01	<1	<100	1
MW-12D	07-10-90	< .10	< .01	< .10	.28	.08	7	140	<1
MW-13	07-10-90	17	.02	17	< .01	.28	3	260	<1
CR-1	07-10-90	< .10	.02	< .10	.21	.29	12	240	<1
CR-2	07-10-90	< .10	.01	< .10	< .01	.03	6	130	<1
Federal and Kansas Maximum Contaminant Level[2]		10	—	10[7]	—	—	50	1,000	10
Federal and Kansas Secondary Maximum Contaminant Level[3]		—	—	—	—	—	—	—	—

Table 4. *Physical properties of and inorganic constituent concentrations in water samples from Harvey County Landfill, July 10-11, 1990*--Continued

Well or sampling site (fig. 6)	Date (month-day-year)	Chromium, dissolved (µg/L as Cr)	Copper, dissolved (µg/L as Cu)	Iron, dissolved (µg/L as Fe)	Lead, dissolved (µg/L as Pb)	Manganese, dissolved (µg/L as Mn)	Mercury, dissolved (µg/L as Hg)	Selenium, dissolved (µg/L as Se)	Silver, dissolved (µg/L as as Ag)	Zinc, dissolved (µg/L as Zn)
MW-2	07-10-90	<1	8	20	<1	53	0.3	<1	<1	15
MW-5	07-11-90	4	2	100	<1	80	<.1	<1	<1	<10
MW-9	07-11-90	10	6	10	<1	4	--	1	<1	4
MW-11	07-10-90	5	7	10	<1	5	.2	2	2	5
MW-11[1]	07-10-90	5	7	20	1	3	<.1	2	<1	7
MW-12S	07-10-90	3	19	30	<1	400	<.1	<1	1	40
MW-12D	07-10-90	3	44	160	2	850	<.1	<1	<1	46
MW-13	07-10-90	2	7	9	<1	440	.1	3	<1	17
CR-1	07-10-90	1	22	130	1	2,000	<.1	<1	<1	10
CR-2	07-10-90	<1	9	20	<1	69	<.1	<1	<1	10
Federal and Kansas Maximum Contaminant Level[2]		50	—	—	50	—	2.0	10	50	—
Federal and Kansas Secondary Maximum Contaminant Level[3]		—	1,000	300	—	50	—	—	—	5,000

[1] Duplicate sample.

[2] Maximum Contaminant Level for drinking water (Kansas Department of Health and Environment, 1986; U.S. Environmental Protection Agency, 1989a).

[3] Secondary Maximum Contaminant Level for drinking water (Kansas Department of Health and Environment, 1986; U.S. Environmental Protection Agency, 1989b).

Table 4. *Physical properties of and inorganic constituent concentrations in water samples from Harvey County Landfill, July 10-11, 1990*--Continued

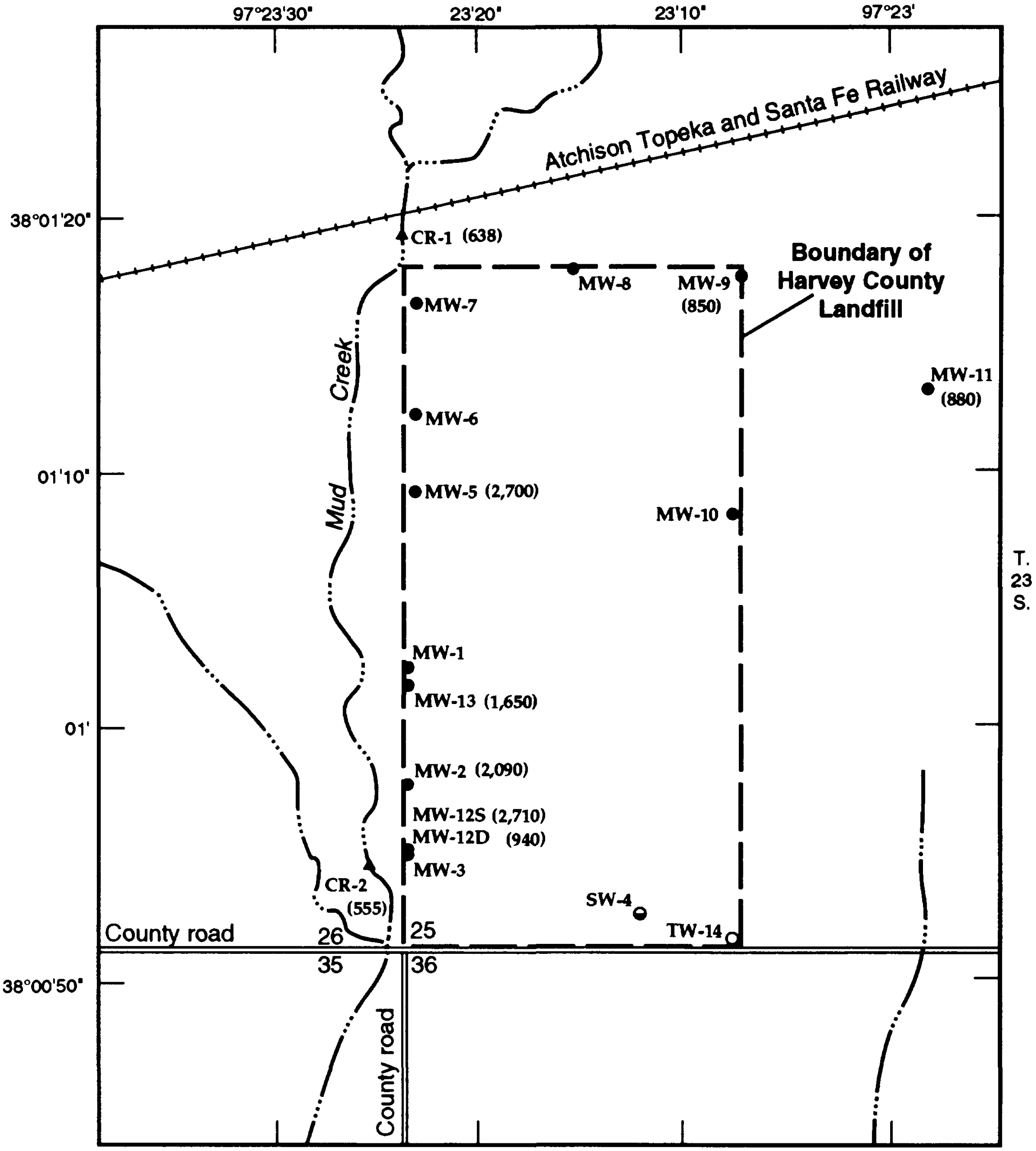
[4] Kansas Secondary Maximum Contaminant Level (Kansas Department of Health and Environment, 1986).

[5] Bicarbonate concentration is calculated by dividing field alkalinity concentration by 0.8202 (Hem, 1985) and rounding to the nearest tens place.

[6] Kansas Maximum Contaminant Level for fluoride is 1.8 mg/L, the Federal Maximum Contaminant Level for fluoride is 4.0 mg/L, and the Federal Secondary Maximum Contaminant Level for fluoride is 2.0 mg/L (Kansas Department of Health and Environment, 1986; U.S. Environmental Protection Agency, 1989b).

[7] The Kansas and Federal primary drinking-water regulation is 10 mg/L for nitrate only.

[8] The detection level for a method of analysis may vary depending on factors such as specific conductance and dissolved-solids concentration.



Base from U.S. Geological Survey digital data, 1:100,000, 1983
Lambert Conformal Conic projection
Standard parallels 33° and 45°, central meridian -- 98°15'

EXPLANATION

—··· — INTERMITTENT STREAM

MW-12S ● MONITORING WELL AND NUMBER-- S indicated shallow well; D indicates deep well

SW-4 ⊖ SUPPLY WELL AND NUMBER

TEMPORARY WELL AND NUMBER

TW-14 ○ TEMPORARY WELL AND NUMBER

CR-1 ▲ CREEK SAMPLING SITE AND NUMBER

(880) SPECIFIC CONDUCTANCE--In microsiemens per centimeter at 25 degrees Celsius

Figure 13. Specific conductance of water, July 1990.

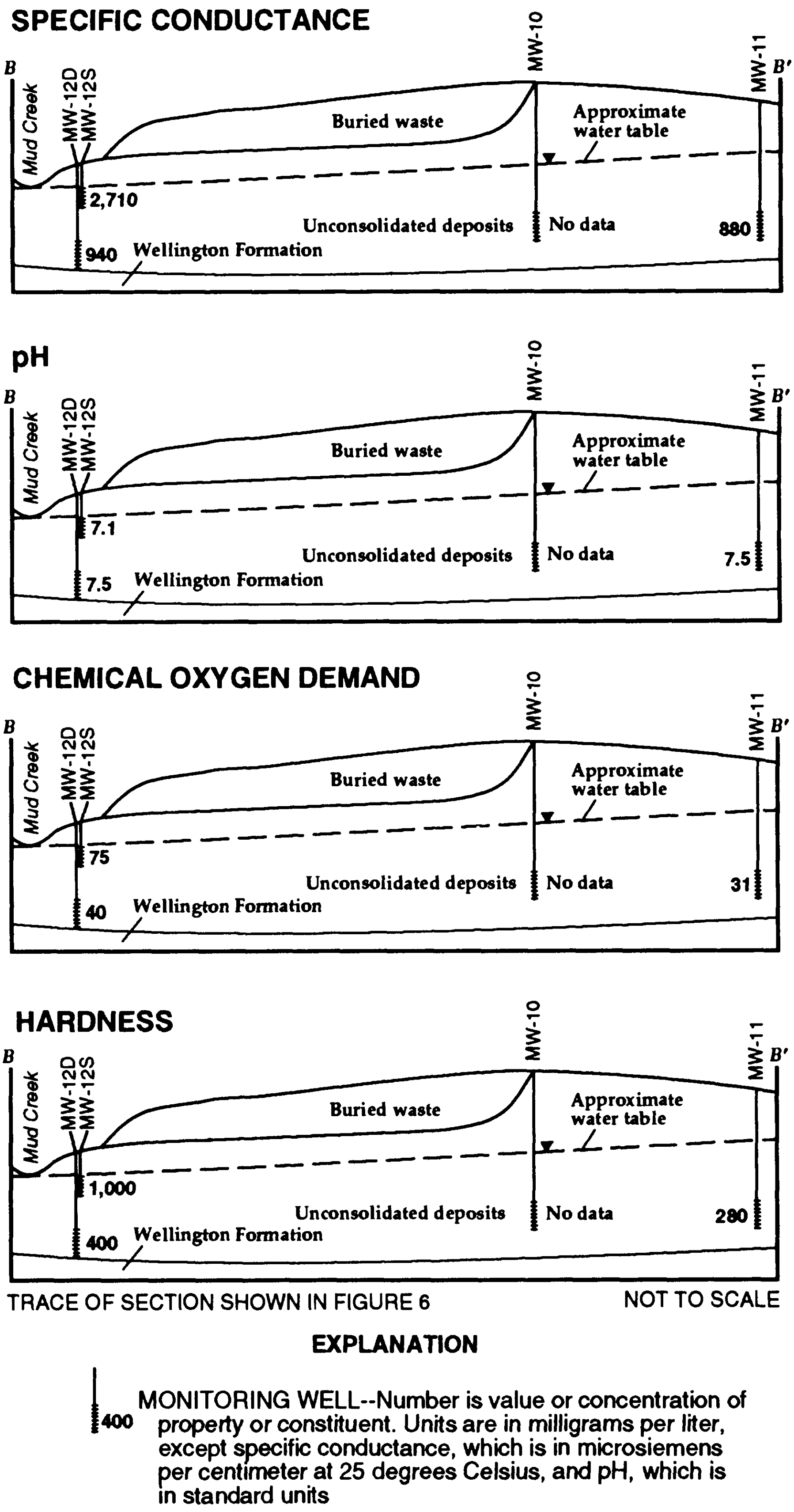


Figure 14. Values or concentrations of selected physical properties and inorganic constituents along section B-B' at Harvey County Landfill, July 1990.

MW-11) had concentrations approximating the Kansas and Federal secondary drinking-water regulation of 500 mg/L. Shallow downgradient ground water (wells MW-2 and MW-12S) had dissolved-solids concentrations two to three times that of upgradient water, thus exceeding the secondary drinking-water regulation. Deeper downgradient ground water (well MW-12D) contained only slightly larger dissolved-solids concentrations than upgradient water. This relation was demonstrated in the previous section in terms of specific-conductance values (fig. 14). Dissolved-solids concentrations in the ponded water of Mud Creek were small (305 and 441 mg/L) relative to concentrations in ground water.

Water sampled was a calcium bicarbonate type with some exceptions (fig. 15). Water from well MW-11 was a calcium sodium bicarbonate type, water from well MW-2 was a calcium bicarbonate chloride type, and water from well MW-5 was a calcium sulfate type. Calcium bicarbonate water generally characterizes the *Equus* beds aquifer in this area (Hathaway and others, 1981). Dominance of other major ions locally could indicate (1) ion exchange as water moves through clay-rich parts of the unconsolidated deposits, (2) interchange of water with the sedimentary bedrock that directly underlies the unconsolidated deposits at shallow depths, or (3) effects of human activities. Kansas and Federal secondary drinking-water regulations of 250 mg/L were exceeded for sulfate in samples from two wells (wells MW-5 and MW-12S) and for chloride in samples from two wells (wells MW-2 and MW-12S).

Nutrients

Nitrite plus nitrate concentrations as nitrogen ranged from less than 0.10 to 17 mg/L in water samples at and near the landfill (table 4; fig. 16). Concentrations were less than the 0.01-mg/L level in several water samples, but exceeded the Kansas and Federal primary drinking-water regulation of 10 mg/L in one downgradient sample (well MW-13) and equalled the regulation in one upgradient sample (well MW-9).

Ammonia as nitrogen was detected in some samples (fig. 16), including those from upgradient wells (wells MW-9 and MW-11). Orthophosphorus concentrations were slightly larger in samples from downgradient wells than in samples from upgradient wells (fig. 16).

Trace Elements

Results of analyses for 12 trace elements in water samples are included in table 4. No drinking-water regulations were exceeded, except manganese, for which the Kansas and Federal secondary drinking-water regulation of 50 µg/L (micrograms per liter) was exceeded in all downgradient samples and in the samples from Mud Creek. Obvious patterns of spatial distributions were not apparent for concentrations of most trace elements. However, manganese and zinc concentrations were relatively large in samples from downgradient wells and Mud Creek compared to concentrations of other trace elements (fig. 17).

Other Inorganic Constituents

Other inorganic constituents analyzed were fluoride and silica. Fluoride and silica concentrations were fairly uniform throughout the landfill area. Fluoride concentrations were 0.9 mg/L or less in all samples, none exceeding Kansas or Federal primary or secondary drinking-water regulations (table 4). Silica concentrations were smallest in samples from the ponded water in Mud Creek, supporting the concept that ground water is not a major source of the ponded water.

Organic Compounds

Water samples collected July 10-11, 1990, also were analyzed for dissolved organic carbon, methylene-blue active substances, and an extensive list of volatile and semivolatile organic compounds and other non-target organic compounds (tables 5, 6, and 7). A non-target compound is a compound that was not specifically analyzed for using the gas chromatograph/mass spectrometer. The computerized library search uses the spectra of a non-target compound, at the gas-chromatography peak maxima, and compares the spectra to National Bureau of Standards library-reference spectra. The best library match is inspected manually to provide the best-possible identification, but the non-target

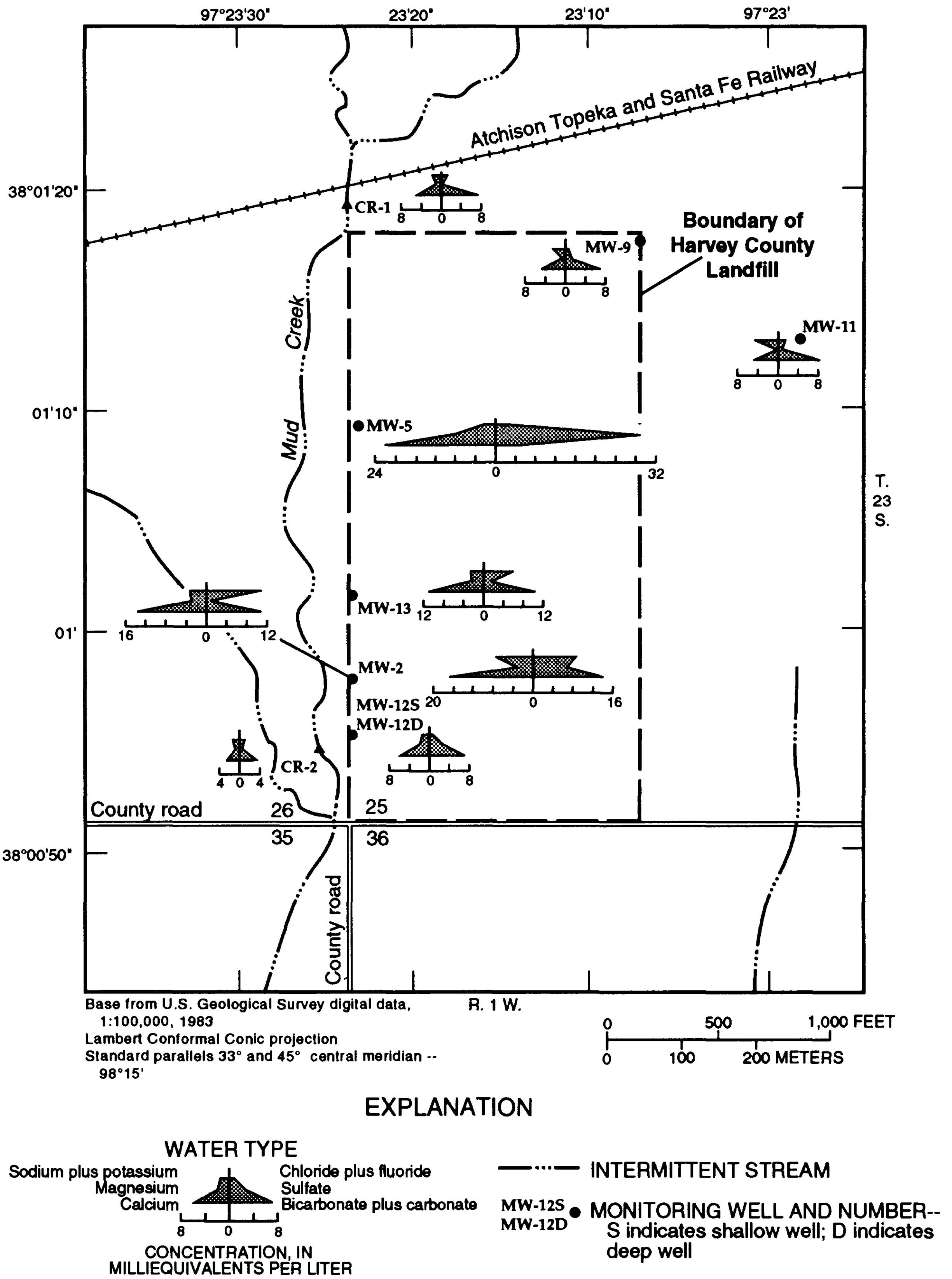
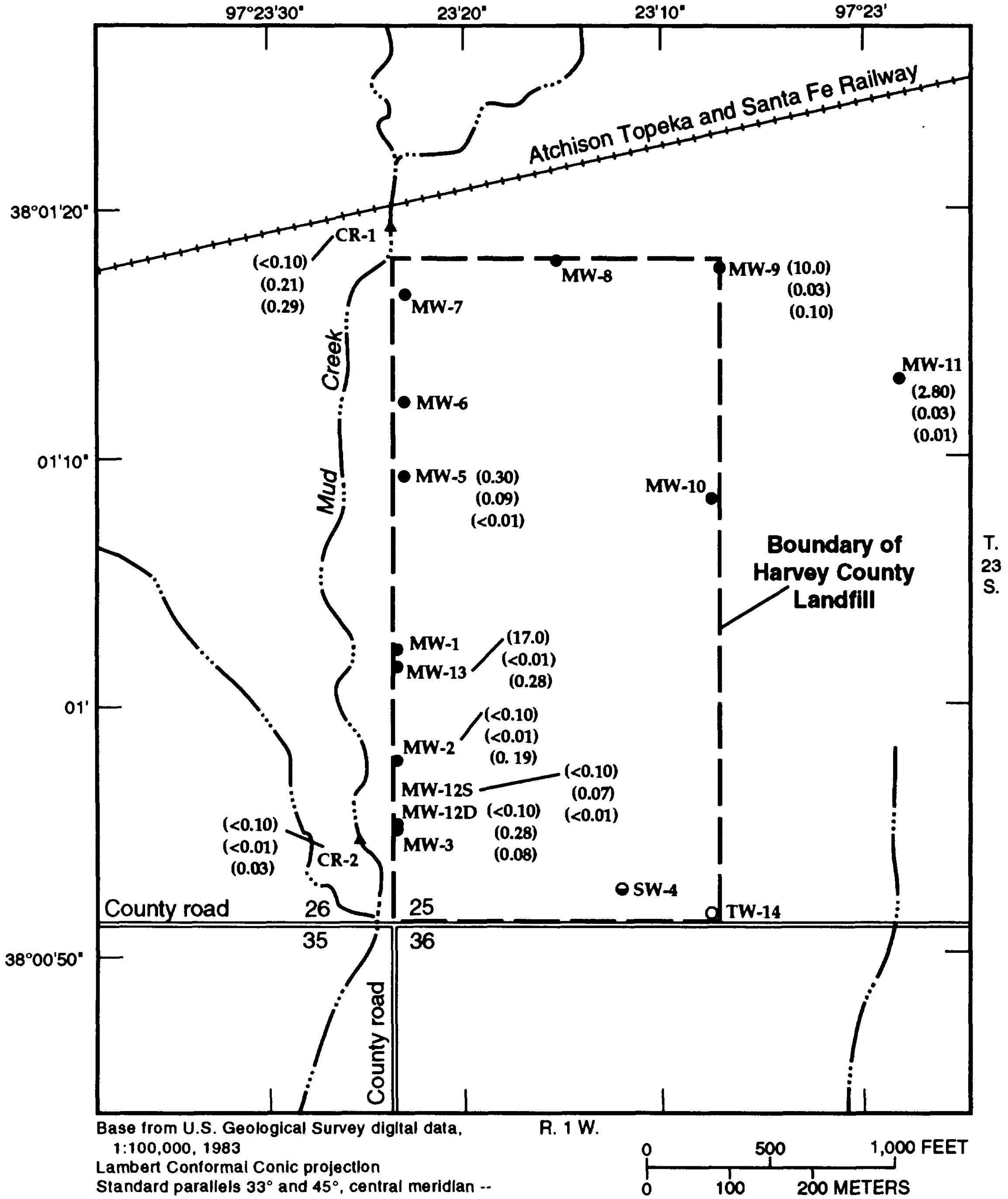


Figure 15. Concentrations of major ions in water, July 1990 (plotting method modified from Stiff, 1951).



Base from U.S. Geological Survey digital data, 1:100,000, 1983
Lambert Conformal Conic projection
Standard parallels 33° and 45°, central meridian -- 98°15'

EXPLANATION

—···— INTERMITTENT STREAM

MW-12S ● MONITORING WELL AND NUMBER-- S indicates shallow well; D indicates deep well

SW-4 ⊖ SUPPLY WELL AND NUMBER

TW-14 ○ TEMPORARY WELL AND NUMBER

CR-2 ▲ CREEK SAMPLING SITE AND NUMBER

(0.30)
(0.09)
(<0.01) CONCENTRATIONS AS NITROGEN-- Upper number is nitrite plus nitrate concentration; middle number is ammonia concentration; lower number is orthophosphorus concentration, in milligrams per liter; <, less than indicated reporting level

Figure 16. Concentrations of nitrite plus nitrate, ammonia, and orthophosphorus in water, July 1990.

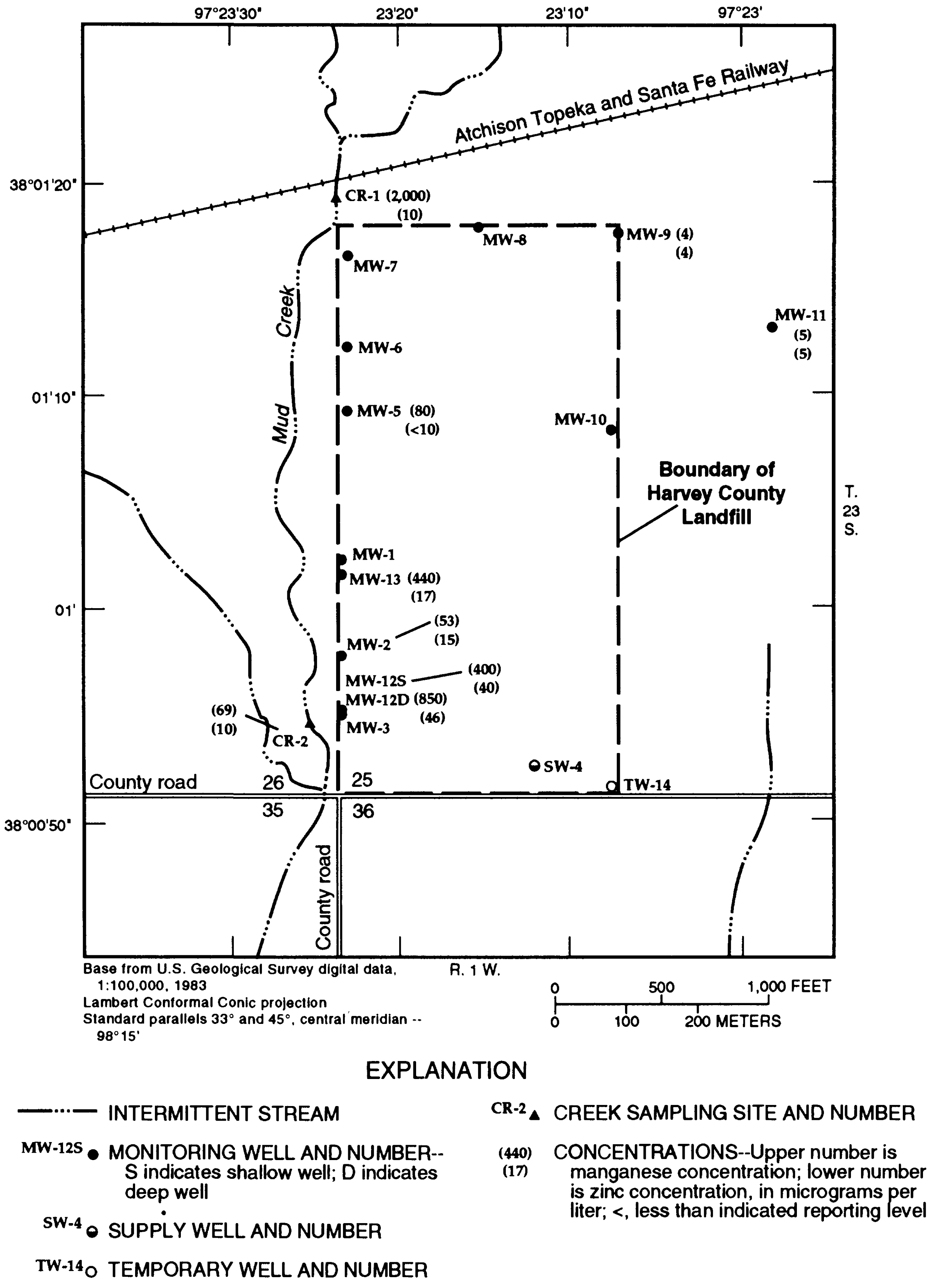


Figure 17. Concentrations of manganese and zinc in water, July 1990.

Table 5. *Organic compounds analyzed in water samples from Harvey County Landfill*

Compound	Reporting level, in micrograms per liter
Volatile Organic Compounds	
benzene	0.20
bromoform	.20
carbon tetrachloride	.20
chlorobenzene	.20
chloroethane	.20
2-chloroethyl vinyl ether	.20
chloroform	.20
chloromethane	.20
dibromochloromethane	.20
1,2-dibromoethane	.20
dichlorobromomethane	.20
1,2-dichlorobenzene	.20
1,3-dichlorobenzene	.20
1,4-dichlorobenzene	.20
dichlorodifluoromethane	.20
1,1-dichloroethane	.20
1,2-dichloroethane	.20
1,1-dichloroethylene	.20
1,2-trans-dichloroethylene	.20
1,2-dichloropropane	.20
cis-1,3-dichloropropene	.20
trans-1,3-dichloropropene	.20
1,3-dichloropropene	.20
ethylbenzene	.20
methyl bromide	.20
methylene chloride	.20
styrene	.20
1,1,2,2-tetrachloroethane	.20
tetrachloroethylene	.20
toluene	.20
1,1,1-trichloroethane	.20
1,1,2-trichloroethane	.20
trichloroethylene	.20
trichlorofluoromethane	.20
vinyl chloride	.20

Table 5. *Organic compounds analyzed in water samples from Harvey County Landfill*--Continued

Compound	Reporting level, in micrograms per liter
Volatile Organic Compounds--Continued	
xylenes, mixed	0.20
Semivolatile, Acid Extractable, Compounds	
2-chlorophenol	5.0
2,4-dichlorophenol	5.0
2,4-dimethylphenol	5.0
4,6-dinitro-2-methylphenol	30
2,4-dinitrophenol	20
2-nitrophenol	5.0
4-nitrophenol	30
pentachlorophenol	30
phenol	5.0
2,4,6-trichlorophenol	20
4-chloro-m-cresol	30
Semivolatile, Base-Neutral Extractable, Compounds	
acenaphthene	5.0
acenaphthylene	5.0
anthracene	5.0
benzo (a) anthracene	10
benzo (a) pyrene	10
benzo (b) fluoranthene	10
benzo (k) fluoranthene	10
benzo (g,h,i) perylene	10
4-bromophenyl phenyl ether	5.0
butyl benzyl phthalate	5.0
bis (2-chloroethoxy) methane	5.0
bis (2-chloroethyl) ether	5.0
bis (2-chloroisopropyl) ether	5.0
bis (2-ethylhexyl) phthalate	5.0
2-chloronaphthalene	5.0
4-chlorophenyl phenyl ether	5.0
chrysene	10
dibenzo (a,h) anthracene	10
1,2-dichlorobenzene	5.0

Table 5. *Organic compounds analyzed in water samples from Harvey County Landfill*--Continued

Compound	Reporting level, in micrograms per liter
Semivolatile, Base-Neutral Extractable, Compounds--Continued	
1,3-dichlorobenzene	5.0
1,4-dichlorobenzene	5.0
diethyl phthalate	5.0
dimethyl phthalate	5.0
di-n-butyl phthalate	5.0
2,4-dinitrotoluene	5.0
2,6-dinitrotoluene	5.0
di-n-octylphthalate	10
fluoranthene	5.0
fluorene	5.0
hexachlorobenzene	5.0
hexachlorobutadiene	5.0
hexachlorocyclopentadiene	5.0
hexachloroethane	5.0
ideno (1,2,3-c,d) pyrene	10
isophorone	5.0
naphthalene	5.0
nitrobenzene	5.0
n-nitrosodimethylamine	5.0
n-nitrosodi-n-propylamine	5.0
n-nitrosodiphenylamine	5.0
phenathrene	5.0
pyrene	5.0
1,2,4-trichlorobenzene	5.0

compound identification is still considered to be tentative (Brooke Connor, U.S. Geological Survey, written commun., 1990).

Reporting level is the smallest measured constituent concentration that may be reliably reported using a given analytical method. Detection level is the minimum constituent concentration that can be identified, measured, and reported with confidence that the concentration is larger than zero. The reporting level is set somewhat larger than the detection level because of sample-composition (matrix) effects.

Analysis of dissolved organic carbon (DOC) represents a single determination of the total amount of organic material dissolved in water. In general, DOC concentrations in ground water range from 0.2 to 15 mg/L but usually do not exceed 2.0 mg/L (Thurman, 1985). At or near the landfill, DOC concentrations ranged from 1.2 to 9.6 mg/L in ground-water samples, and 13 and 16 mg/L in samples of ponded water in Mud Creek (table 6). DOC concentrations in samples from three of the downgradient wells (wells MW-12S, MW-12D, and MW-13) were notably larger than concentrations in other ground-water samples (fig. 18).

Methylene-blue active substances (MBAS) consist of surfactants, including alkyl benzene sulfonate and linear alkyl sulfonate (Wershaw and others, 1987), which are common components of detergents. Organic and inorganic compounds may interfere with the MBAS analysis, giving readings that are erroneously large. For small concentrations of MBAS (less than 0.5 mg/L), interferences render the results unreliable (American Public Health Association, 1976). Concentrations in all samples from the landfill site were less than 0.5 mg/L (table 6); thus, results may reflect interferences rather than true MBAS concentrations.

Semivolatile and volatile organic compounds that were detected in at least one sample from the landfill site are listed in table 6, along with results of the analyses. Brief discussions on individual compounds follow, including some uses of the compounds based on information from Sax and Lewis (1987).

Chloroethane (ethyl chloride) was detected in the sample from well MW-12S. This compound is used as a refrigerant, solvent, alkylating agent, analytical reagent, insecticide, and in the manufacture of tetraethyl lead.

1,1-dichloroethane (ethylidene chloride) also was detected in the sample from well MW-12S. This compound is used as an extraction solvent and fumigant.

Diethyl phthalate was detected in several samples, at concentrations of as much as 2.4 µg/L. This compound is used as a solvent, plasticizer, wetting agent, and insecticidal spray.

Bis (2-ethylhexyl) phthalate was detected in several samples at concentrations as large as 7.7 µg/L. This compound is used as a plasticizer and is ubiquitous; its detection at small concentrations such as this could result from sample processing as well as from actual presence in the ground water.

Methylene chloride (dichloromethane) was detected at 0.2 µg/L in the sample from well MW-2. Uses for this compound include paint removal, solvent degreasing, plastics processing, as a blowing agent in foams, solvent extraction, and as an aerosol propellant.

Naphthalene was detected in water sample CR-1 from Mud Creek. This compound is used in the manufacture of dye and as a fungicide, lubricant, and preservative.

Several organic compounds detected in water samples were tentatively identified (table 7) on the basis of a match of the spectrum of the compound of interest to that in a library of identified compounds. These compounds, like the organic compounds discussed previously, commonly have industrial or commercial uses. It also is possible that some compounds may be derived from other compounds as a result of degradation or chemical reactions. Unknown organic compounds also were detected in all samples.

Most detections of organic compounds (tables 6 and 7) were in samples from wells downgradient of the landfill (wells MW-2, MW-12S, MW-12D, MW-13) or from Mud Creek (sampling sites CR-1 and CR-2). The only identified specific organic compounds from upgradient wells (wells MW-9 and MW-11) were

Table 6. *Organic compounds detected in water samples from Harvey County Landfill, July 10-11, 1990*

[Concentrations in milligrams per liter (mg/L) or micrograms per liter (µg/L); <, less than indicated reporting level; --, not determined; __, no regulation established]

Compound	Well or sampling site (fig. 6)										Drinking-water regulation		
	MW-2	MW-5	MW-9	MW-11	MW-11[1]	MW-12S	MW-12D	MW-13	CR-1	CR-2	KNL[2]	KAL[3]	KDWR[4]
Dissolved organic carbon (mg/L)	2.4	1.2	--	2.2	2.8	9.6	5.5	8.0	13	16	__	__	__
Methylene-blue active substances (mg/L)	<.01	.11	--	.21	.24	.34	.42	<.01	.10	.08	__	__	__
Bis(2-ethylhexyl) phthalate (µg/L)	<5.0	<5.0	2.6[5]	7.7	5.4	<5.0	3.3[5]	<5.0	<5.0	<5.0	__	__	__
Chloroethane (µg/L)	<.2	<.2	<.2	<.2	<.2	.3	<.2	<.2	--	--	(5)	(6)	__
1,1-Dichloroethane (µg/L)	<.2	<.2	<.2	<.2	<.2	.3	<.2	<.2	--	--	(5)	(6)	__
Diethyl phthalate (µg/L)	1.7[5]	1.7[5]	<5.0	1.8[5]	<5.0	2.2[5]	2.4[5]	<5.0	1.8[5]	1.8[5]	__	__	__
Di-n-butylphthalate (µg/L)	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	3.1[5]	3.1[5]	__	__	__
Methylene chloride (µg/L)	.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	--	--	(5)	150	__
Napthalene (µg/L)	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	.21	<5.0	__	__	__

[1] Duplicate sample.

[2] KNL, Kansas Notification Level (Kansas Department of Health and Environment, 1986).

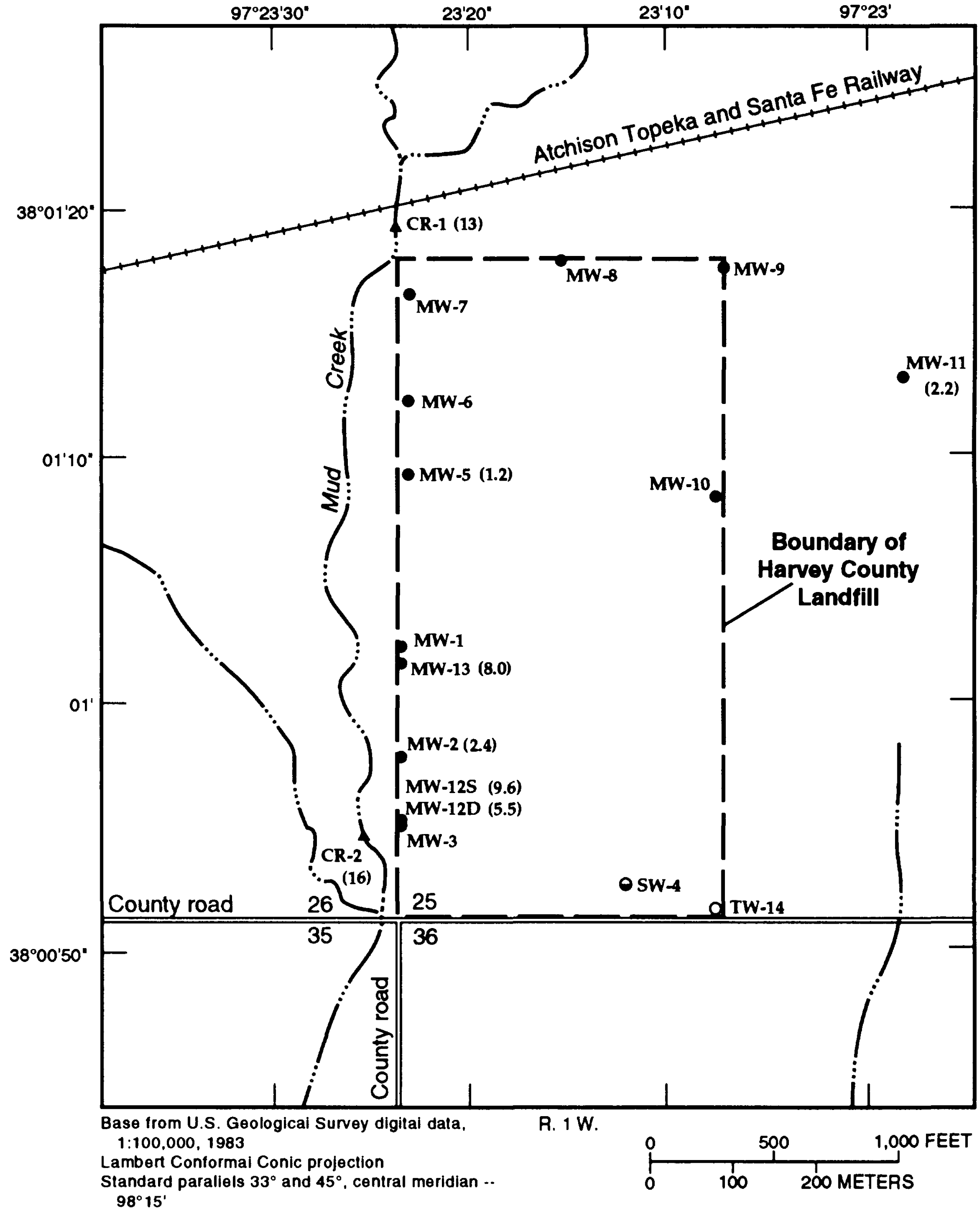
[3] KAL, Kansas Action Level (Kansas Department of Health and Environment, 1986).

[4] KPDWR, Kansas primary drinking-water regulation (Kansas Department of Health and Environment, 1986).

[5] Sample composition (matrix) allowed this constituent to be quantified at concentrations less than the reporting level.

[6] Any positive detection.

[7] Insufficient data to establish regulation.



Base from U.S. Geological Survey digital data, 1:100,000, 1983
Lambert Conformal Conic projection
Standard parallels 33° and 45°, central meridian -- 98°15'

EXPLANATION

———···——— INTERMITTENT STREAM

MW-12S ● MONITORING WELL AND NUMBER--S indicates shallow well; D indicates deep well

SW-4 ● SUPPLY WELL AND NUMBER

TW-14 ○ TEMPORARY WELL AND NUMBER

CR-1 ▲ CREEK SAMPLING SITE AND NUMBER

(2.4) DISSOLVED ORGANIC-CARBON CONCENTRATION--In milligrams per liter

Figure 18. Concentrations of dissolved organic carbon in water, July 1990.

Table 7. *Organic compounds detected in water samples from Harvey County Landfill, tentatively identified by computerized library search, July 1990*

[X, compound detected; --, compound not detected]

Compound	Well or sampling site (fig. 6)									
	MW-2	MW-5	MW-9	MW-11	MW-11[1]	MW-12S	MW-12D	MW-13	CR-1	CR-2
2,5-bis (1,1-dimethylpropyl) 2,5-cyclohexadiene-1,4-dione	--	--	--	--	--	X	--	--	--	--
2-butoxy-ethanol	--	--	--	--	--	X	--	--	--	--
Dichlorofluoromethane	X	--	--	--	--	--	--	--	--	--
Chloroiodo-methane	--	--	--	--	--	X	--	--	--	--
6-chloro-n-ethyl-n'-(1-methylethyl) 1,3,5-triazine-2,4-diamine	--	--	--	--	--	--	--	--	X	X
Citronellyl propionate	--	--	--	--	--	--	--	--	X	--
Cycloeicosane	--	--	--	--	--	--	--	--	X	--
Diethyl ether	--	--	--	--	--	X	--	--	--	--
2,5-diethyltetra-hydro-furan	--	--	--	--	--	--	--	X	--	--
2,4-dihydroxy-6-methyl-benzoic acid	--	--	--	--	--	--	--	--	X	--
2,5-dimethyl-1,4-dioxane	--	--	--	--	--	X	--	--	--	--
1,4-dioxane	--	--	--	--	--	X	--	--	--	--
3-ethyl-4-methyl-2,5-furandione	--	--	--	--	--	--	--	--	--	X
N-(1,1-dimethylethyl)-3-methyl benzamide	X	--	--	--	--	--	--	--	X	X
N-(1,1-dimethylethyl)-4-methyl benzamide	X	--	--	--	--	--	--	--	--	--
9-methyl phenathrene	--	--	--	--	--	--	--	--	X	--
Neophytadiene	--	--	--	--	--	--	--	--	X	--
Sulfur	--	--	--	--	--	--	--	X	--	--

[1] Duplicate sample.

bis(2-ethylhexyl) phthalate and diethyl phthalate.

Several samples from the previously installed monitoring wells and from the landfill supply well (well SW-4) were collected and analyzed, prior to this study, by the Kansas Department of Health and Environment. Although results of those analyses are not reported here because analytical methods were different from those used in this study, it should be noted that samples from well SW-4 (which was not sampled for the present study) were found to contain several organic compounds (unpublished data from the Kansas Department of Health and Environment, Topeka, 1988 and 1990). Some of the identified compounds detected in those water samples, such as methylene chloride and 1,1-dichloroethane, also were detected in samples collected from monitoring wells by the U.S. Geological Survey.

EFFECTS OF LANDFILL ON WATER QUALITY

Several characteristics of water quality in the area of the Harvey County Landfill are important in evaluating the effect of the landfill. These characteristics include certain water properties and the presence and concentrations of certain inorganic and organic constituents. The interpretation relies on comparisons of water quality upgradient (northeast) of the landfill with water quality immediately downgradient (southwest) of the landfill. Some differences in water quality are attributable to the presence of the landfill.

Relatively small pH values, measured in samples of shallow downgradient ground water (table 4; fig. 14), are a normal result of the biological decomposition processes in landfills. Relatively large COD values downgradient (table 4; fig. 14) are indicative of an increased contaminant load in ground water.

Distributions of major-ion concentrations are not definitive of a particular source because they relate to geology and chemical processes in the natural hydrologic system, in addition to the effects of human activities. However, downgradient increases in hardness, alkalinity, and concentrations of dissolved solids (table 4; fig. 14) reflect the introduction of soluble materials to the water consistent with the decrease in pH. Concentrations of manganese and zinc are largest downgradient from the landfill (fig. 17); zinc probably is dissolved from the landfill waste, whereas manganese may be derived from the unconsolidated deposits as well as from the landfill waste.

Concentrations of nitrate as nitrogen (which may be relatively large in an oxidizing environment) and ammonia (which would dominate in a reducing environment) do not vary systematically in relation to the landfill and the ground-water flow system (fig. 16). However, the conditions described in the previous paragraphs are characteristic of a reducing environment, at least in some areas, immediately downgradient of the landfill. Although different parts of the landfill may be undergoing different phases of degradation, the action of anaerobic degradation processes commonly is reflected in the observed water-quality characteristics.

The increase in concentrations of dissolved organic carbon in ground water downgradient of the landfill (fig. 18) probably is derived from the waste material. Also, several organic compounds not detected in upgradient samples were present in downgradient samples (tables 6 and 7). The presence of some organic compounds, commonly associated with industrial, commercial, or agricultural uses, in water from upgradient wells and (or) from Mud Creek (tables 6 and 7) suggests that water quality also may be affected somewhat by other activities northeast and north of the landfill. Data are too limited to determine sources of specific contaminants.

Ground-water-quality characteristics indicate that landfill leachate has moved into the saturated zone and then downgradient, or southwest (figs. 11 and 12), in the ground-water-flow system. Immediately downgradient from the landfill, water-quality effects are most apparent in the very shallow ground water, indicating that the distribution of leachate in the saturated zone is affected principally by lateral ground-water flow. Water quality at well SW-4, completed in the deeper sand deposits, appears to demonstrate an exception to this concept because, as noted in the previous section, several organic compounds have been detected at that location. However, it is possible that periodic pumping of that well has induced movement of contaminants from a shallower zone to the deeper, screened part of the well.

Lack of information farther downgradient (southwest) of the landfill prevents better definition of the extent of contamination or other water-quality effects at this time. If steeper downward hydraulic gradients and effective hydraulic continuity (predominance of sand) are present downgradient from the landfill, these conditions would allow expansion of water-quality effects deeper into the saturated zone. An estimate of the rate of lateral movement can be obtained using the ground-water velocity computations presented in an earlier section of this report. At an average velocity of 0.1 foot per day, it would require about 36 years to move 0.25 mile. This provides some perspective on the slow rate of ground-water movement. However, it should be recognized that this approximation is based on sparse data, that velocity may vary considerably depending on local hydraulic conductivity, and also that contaminants may be retarded, changed chemically, or diluted during migration.

SUMMARY AND CONCLUSIONS

An investigation of the hydrogeology and ground-water quality at the Harvey County Landfill was conducted from November 1989 through December 1990. The landfill is located on the eastern edge of the *Equus* beds aquifer. Surface drainage over most of the landfill site is westward toward Mud Creek. Unconsolidated stream- and wind-laid deposits, consisting mostly of clay and sand, are 17 to 45 feet thick and overlie shale bedrock. Clay predominates in most of the upper part of these deposits, into or above which the landfill has been developed using a moving-trench method.

The water table typically is several feet below the bottom of the landfill. Sand content generally increases with depth, so that the aquifer is unconfined to semiconfined. Ground-water flow beneath the landfill site is predominantly lateral from northeast to southwest. During the period of this study, the channel of Mud Creek contained ponded (nonflowing) water that probably was derived principally from surface runoff.

Chemical analyses of water samples collected July 10-11, 1990, indicated that water at or near the landfill was mainly a calcium bicarbonate type. Dissolved-solids concentrations in ground water ranged from 448 to 2,140 mg/L, and the water was generally very hard.

Values or concentrations of some water properties and constituents indicate effects of the landfill on shallow ground-water quality. Values or concentrations of specific conductance, pH, chemical oxygen demand, hardness, alkalinity, dissolved solids, manganese, and zinc generally varied according to upgradient or downgradient location. However, values or concentrations in deeper ground water downgradient of the landfill commonly were similar to those in upgradient ground water, indicating that effects were greatest in the shallow part of the saturated zone immediately downgradient of the landfill.

Effects of the landfill also were reflected by relatively large dissolved organic-carbon concentrations downgradient of the site. Several specific organic compounds, most associated with industrial or commercial uses, were detected downgradient from the landfill. However, some organic compounds were present upgradient and in Mud Creek, suggesting possible additional sources of contamination related to activities northeast and north of the site.

Ground-water-quality conditions downgradient from the landfill show some evidence of anaerobic decomposition processes active in the solid waste. However, nonsystematic patterns of values or concentrations also reflect many complexities, such as: the active degradation phases probably vary spatially within the landfill as the filling of the landfill progresses; the composition of the waste varies spatially; the natural dynamics of the hydrologic system (hydraulic, chemical, and biological) vary spatially and temporally; and other human activities near the landfill also affect water quality. Many such factors collectively contribute to observed conditions.

This investigation has described the hydrologic system and effects of the landfill on local ground-water quality. Additional information would be useful for improving the definition of contamination processes and the extent of offsite leachate migration. Periodic analyses of selected water properties would provide long-term information on the effects of the landfill on water quality. Ongoing water-level measurements could provide improved understanding of the hydraulics of the system. Additional wells installed southwest of the site could help evaluate overall contamination potential.

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