HYDROGEOLOGY AND GROUND-WATER-QUALITY CONDITIONS AT THE LINN COUNTY LANDFILL, EASTERN KANSAS, 1988-89

By Ronald Falwell, Philip R. Bigsby, and Nathan C. Myers

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 90-4117

Prepared in cooperation with
LINN COUNTY, KANSAS

U.S. DEPARTMENT OF THE INTERIOR
March 3, 1849

Lawrence, Kansas

1990

U.S. DEPARTMENT OF THE INTERIOR
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CONVERSION FACTORS

For those readers who may prefer metric units (International System), the inch-pound units in this report may be converted using the following conversion factors:

Multiply inch-pound unit	*By*	*To obtain metric unit*
inch	2.54	centimeter
foot	0.3048	meter
mile	1.609	kilometer
square mile	2.590	square kilometer
acre	4,047	square meter
foot per mile	0.1894	meter per kilometer
gallon	3.785	liter
gallon per minute	0.06309	liter per second
degree Fahrenheit (°F)	(1)	degree Celsius (°C)

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[1] °C = 5/9 (°F-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."

DEFINITION OF TERMS

Equipotential line - A line in a two-dimensional ground-water flow field such that the total hydraulic head is the same for all points along the line.

Hydraulic conductivity - The amount of water at the existing kinematic viscosity that will move through a porous medium 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:

$$\frac{(\text{length}^3/\text{time})}{(\text{length}^2)\,(\text{length/length})} \quad \left(\frac{(\text{feet}^3/\text{day})}{(\text{feet}^2)\,(\text{feet/feet})}\text{, for example} \right)$$

but, as in this report, are commonly reported as length/time (feet/day, for example).

Hydraulic gradient - Rate of change in total hydraulic head per unit of distance of flow in a given direction.

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.

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ABSTRACT

A cooperative investigation of the geology, hydrology, and water-quality conditions in the vicinity of the Linn County Landfill was conducted from July 1988 through June 1989. The landfill is located in an area that was strip mined for coal in the 1950's and 1960's. An analysis of water levels from nine temporary wells and in strip-mine ponds indicated that the direction of ground-water flow in the shallow aquifers is southwest in the southwestern part of the landfill and northeast in the northeastern part of the landfill. A county road acts as a barrier to shallow ground water flowing southwest from the landfill. Seasonal variations may occur in the direction of ground-water flow.

Analyses of water samples from monitoring wells, a strip-mine pond, and potable water used during drilling were conducted for inorganic and organic compounds. Calcium sulfate type water was found in strip-mine spoil; magnesium calcium sulfate type water was found in underlying limestone; and calcium magnesium sulfate type water, present in some areas, may be a mix of the previous two water types. Sodium potassium sulfate type water may be the result of landfill contamination of ground water or cation-exchange processes in local shale. The volatile organic compounds benzene, carbon tetrachloride, 1,1-dichloroethane, and 1,1,1-trichloroethane were detected in monitoring wells, and chlorodibromomethane, chloroform, and dichlorobromomethane were detected in potable water supplies used for drilling. None of the inorganic or organic compounds detected exceeded Kansas primary drinking-water standards. Concentrations of total hardness, sulfate, dissolved solids, iron, and manganese exceeded Kansas secondary drinking-water standards in water from some or all monitoring wells and in water from pond A.

Larger concentrations of iron, manganese, and dissolved organic carbon in water from wells in or downgradient of landfill wastes indicate that landfill leachate is affecting ground-water quality. Leachate has the potential to migrate southwest, west, or northwest from the southwestern corner of the landfill. Leachate also would have the potential to migrate northeast from the northeastern part of the proposed landfill-expansion area if this area was used for trash disposal. Chemical concentrations and water levels in some nested wells indicate that there is hydraulic connection between the strip-mine spoil and underlying limestone. Leachate could migrate away from the landfill along fractures in the limestone.

INTRODUCTION

Shallow aquifers in eastern 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 nature of ground and surface water is an important contribution to informed public decision making where water resources are concerned. To gain information about the effects of landfills on water quality, the Kansas Department of Health and Environment 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 report presents the results of an investigation conducted by the U.S. Geological Survey in cooperation with Linn County, Kansas, from July 1988 through June 1989. This investigation is one of several being conducted in Kansas by the U.S. Geological Survey that focus on the effects of landfills on the quality of water in shallow aquifers.

Purpose and Scope

The purpose of the investigation was to determine the geology, hydrology, and ground-water-quality conditions in the vicinity of the Linn County Landfill and to describe the effects of the landfill on water quality.

This report describes the physical setting of the landfill, the fate of solid wastes in landfills in general, and methods used during this study. The results of drilling, coreing, 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 Linn County Landfill is located about 1 mile northeast of Prescott, Kansas, in the southeast corner of Linn County (fig. 1). A 250-acre tract on and adjoining the landfill to the north and west formerly was strip mined for coal (fig. 2). Total county-owned area is about 52 acres, on which active landfill operations occupy about 12 acres. The 12-acre area is in the northwest quarter of the northwest quarter of section 4, T. 23 S., R. 25 E., about 3 miles west of the Kansas-Missouri border (fig. 2).

The landfill is located in the Osage Cuestas physiographic province (fig. 3). The cuestas are low, sharply asymmetric ridges that trend northeast-southwest. Short, steep scarps edge the southeast side of each cuesta, whereas broad, gently undulating plains form the northwest side. The cuestas result from erosion of thin, uniformly dipping strata of different

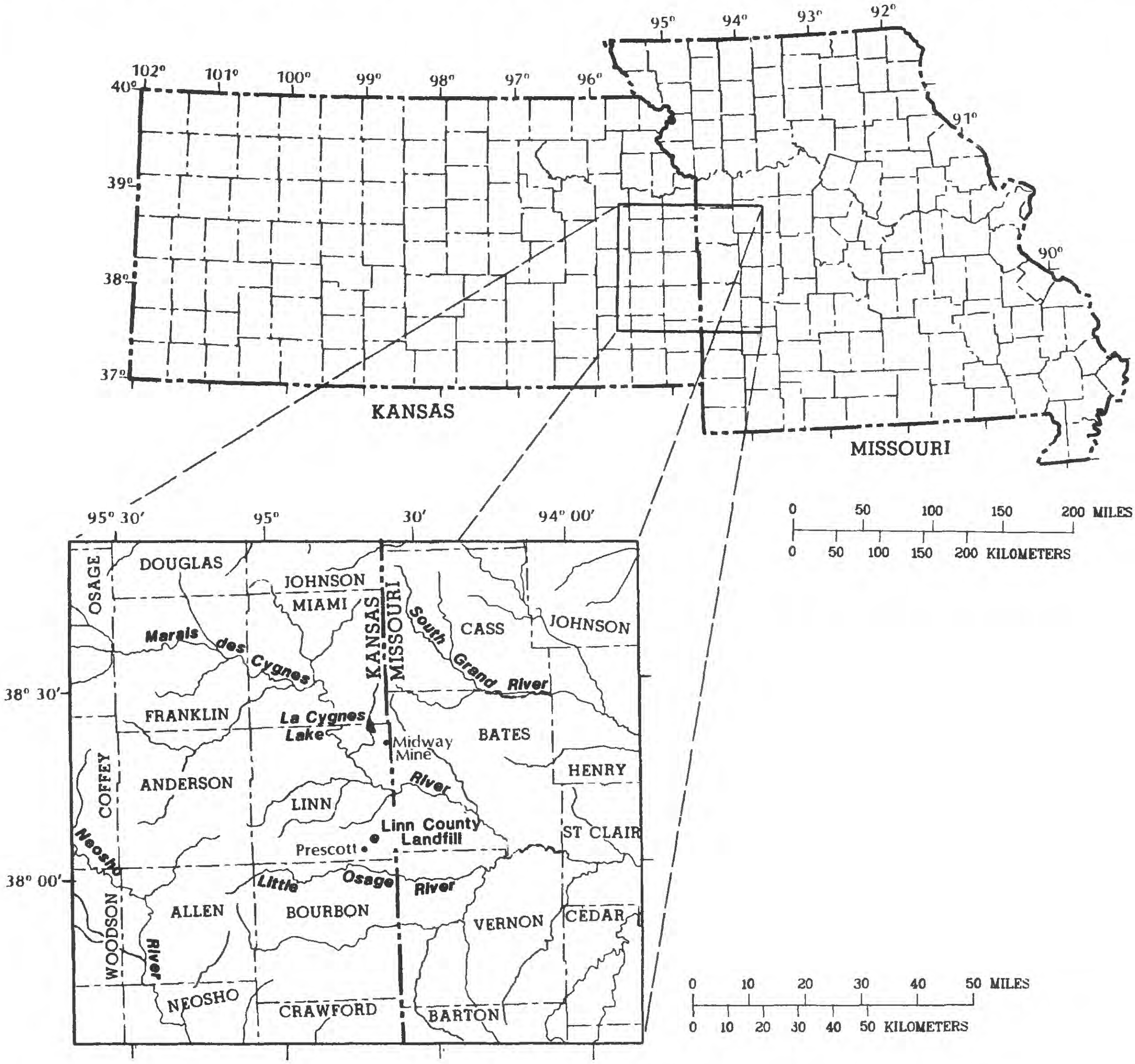
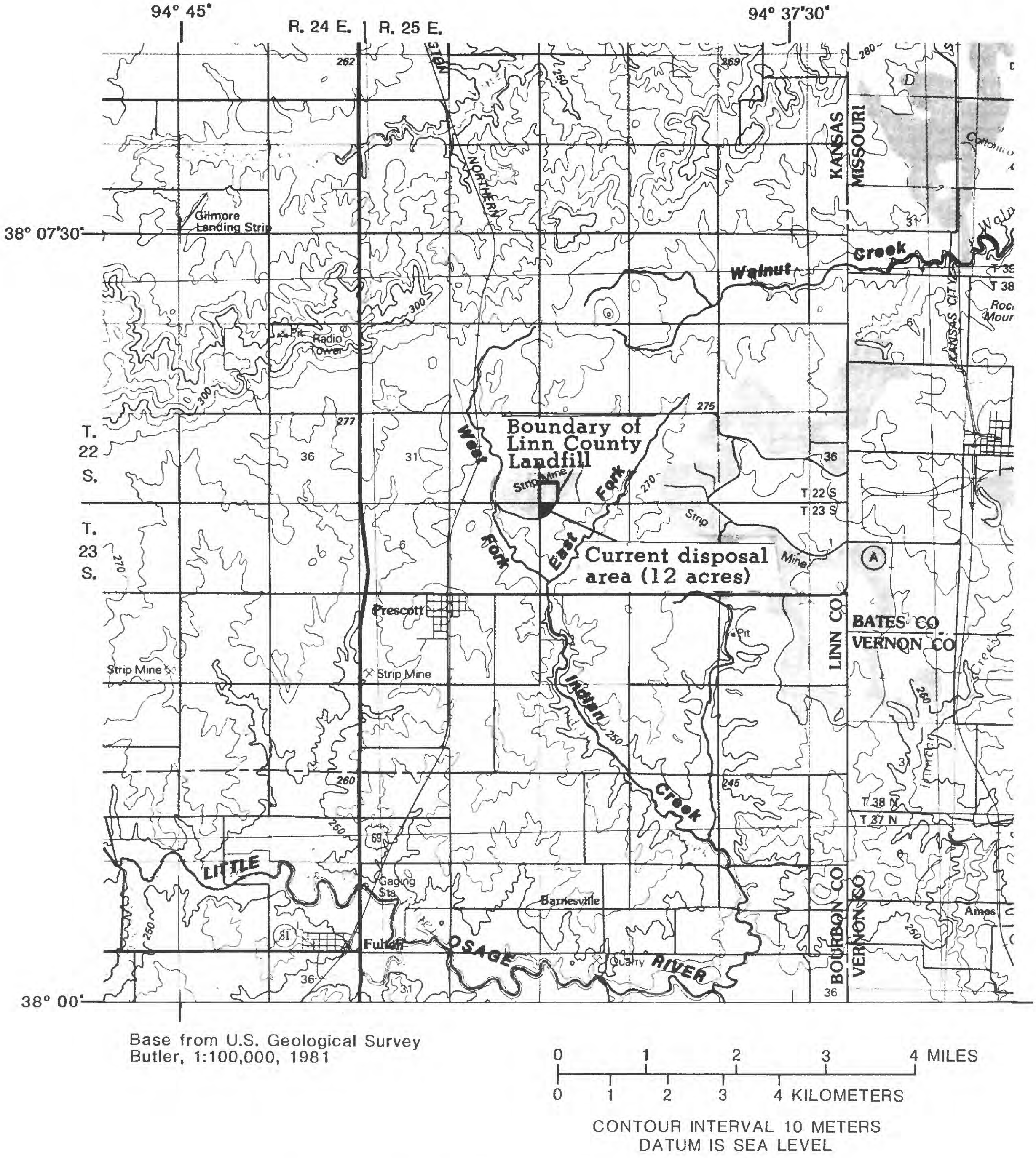


Figure 1. Location of Linn County Landfill.



Base from U.S. Geological Survey
Butler, 1:100,000, 1981

Figure 2. Topography in vicinity of Linn County Landfill.

erosional resistance. The scarps are the exposed edges of resistant rock, usually limestone. The gentle plains are formed on dip slopes, parallel to bedding. Hollows and valleys in soft shale are common where the dip slope of one cuesta begins to approach the steep scarp of another. "Mounds" in these areas are probably outliers of scarp limestone or remnants of locally developed resistant beds (Seevers, 1969). Valleys throughout the area have meandering stream channels on relatively wide flood plains, possibly due to a diminished stream gradient (Gentile, 1976), and are filled with sediment.

Mean annual precipitation is about 38 inches according to 1951-80 data from three climatological stations within 20 miles of the landfill (National Oceanic and Atmospheric

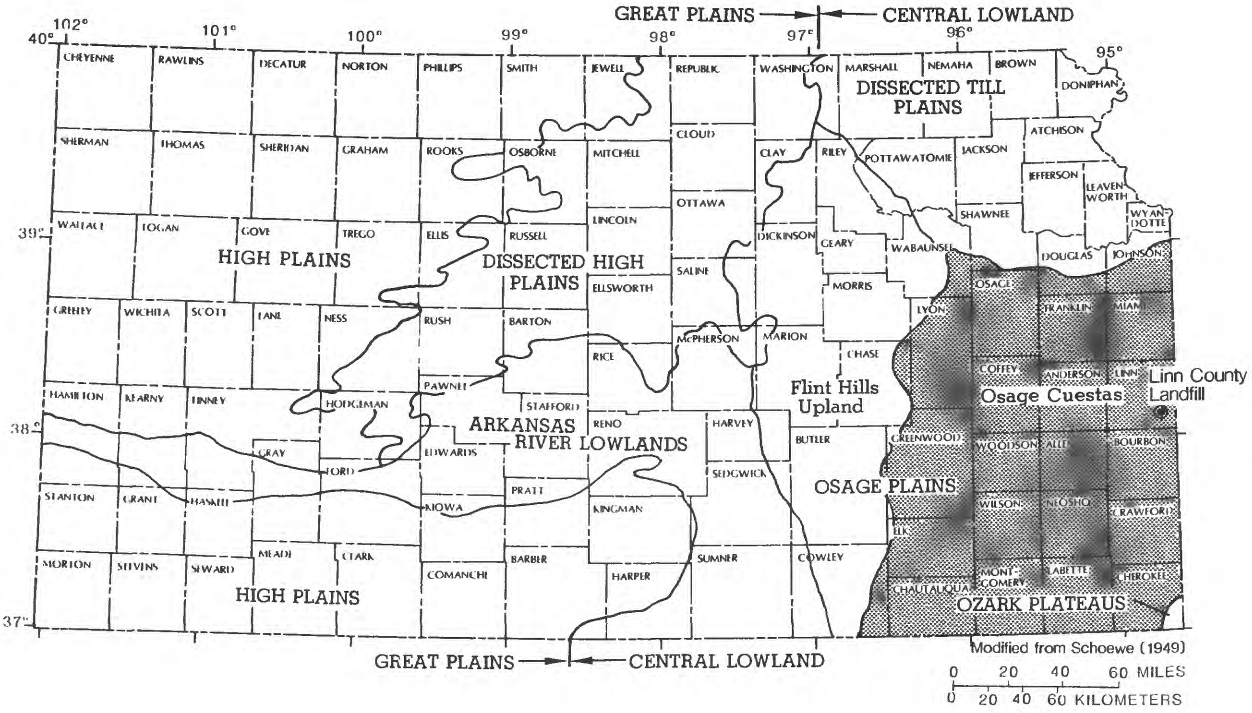


Figure 3. Physiographic areas of Kansas.

Administration, 1987). Characteristically, three-fourths of the rain falls from April through October during short intense thunderstorms, but dry periods may occur anytime. Temperatures range from greater than 100 to less than 0 °F. The coldest month is January, and the hottest is July, for which mean daily temperatures average 31 and 81 °F, respectively.

Surface drainage from the landfill is southward by Indian Creek to the Little Osage River, then into the Marais des Cygnes River in Missouri (figs. 1 and 2). The Marais des Cygnes River drains all of east-central Kansas and west-central Missouri.

Nearly all of the water used in Linn County is derived from surface-water bodies and is used mostly for cooling at the coal-fired electric-generating plant on La Cygnes Lake. Most of the remaining surface water is used for public-water supplies. The small amount of ground water used in the county is for stock water, industrial, and rural-domestic purposes. More than one-half of the wells in Linn County are dug wells (Seevers, 1969). Industrial use includes the repressurizing of hydrocarbon reservoirs at several oil fields with mineralized water from Ordovician limestone (Seevers, 1969).

Land use and land cover in Linn County is about 40-percent cultivated crops, 20-percent forest, 10-percent native grasses in pasture and rangeland, and 30-percent either urban, industrial, barren, wetlands, or water (Bevans and others, 1984). In the immediate vicinity of the landfill nearly 75 percent of the land area is unreclaimed strip-mine spoil, including areas of standing water in abandoned strip-mine cuts (U.S. Geological Survey, 1973) (fig. 4).

The most important industrial activity in the county currently (1989) is oil and gas production. Oil and gas fields underlie nearly one-third of Linn County. Principal production is from the Marmaton Group and "shoestring sands" of the Cherokee Group (Ebanks and others, 1979, p. 21). Coal mining also has been important during the last 100 years. Coal was mined from the Mulberry bed at more than 100 underground, contour, and strip operations (Schoewe, 1955). Mulberry coal is high-rank bituminous coal and contains about 4-percent sulfur. Currently (1989), only strip mining is economical, and the single operating mine in Linn County is the Midway Mine, 15 miles north of the landfill (fig. 1), which supplies coal to the La Cygnes powerplant. Mining in the landfill area was done in the 1950's and 1960's by Hume-Sinclair Mining Company, now merged with

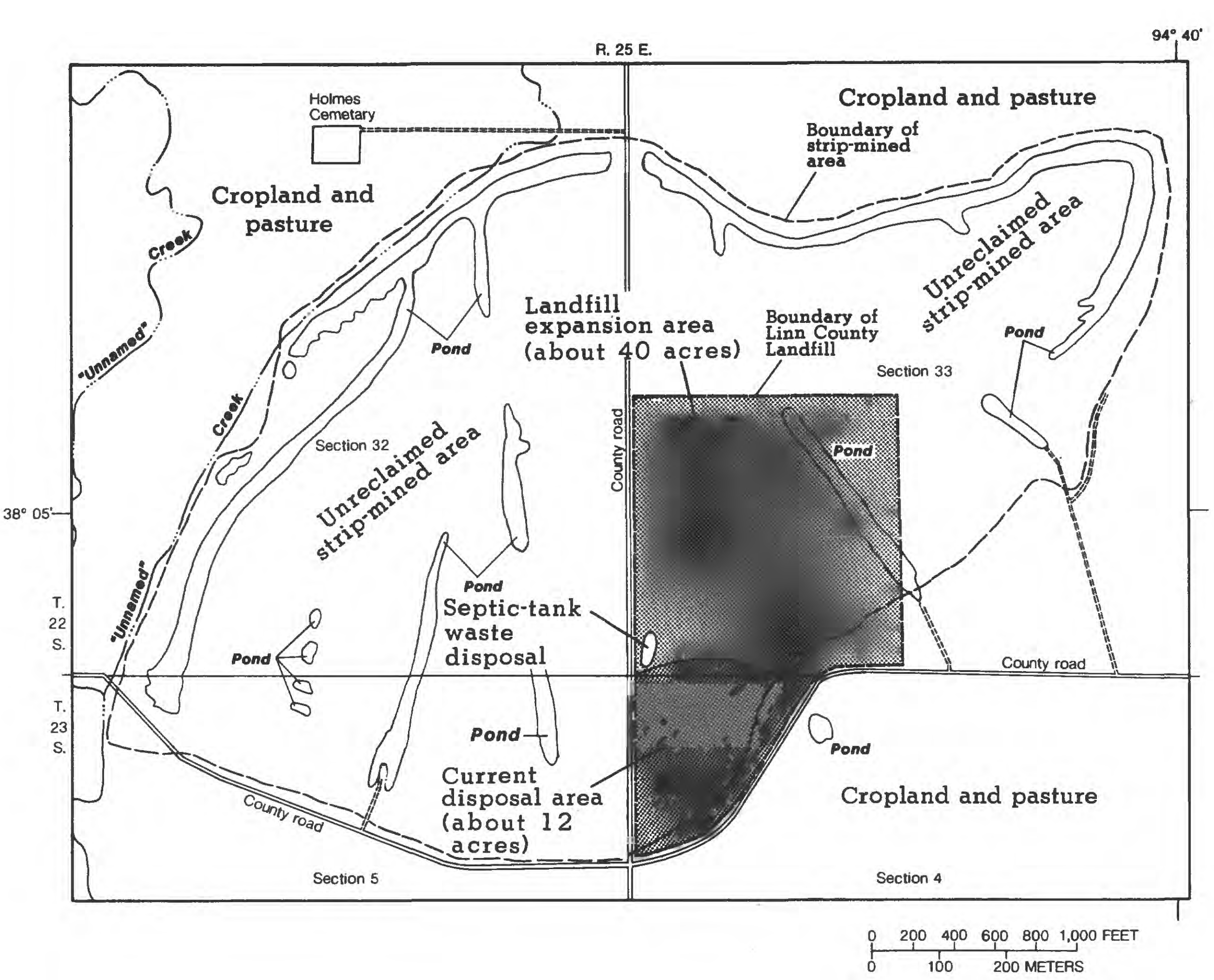


Figure 4. Current (1989) disposal and expansion areas in Linn County Landfill and surrounding land use.

Peabody Coal Company (Schoewe, 1955).

Previous Studies

No reports have been published that consider the effects of the Linn County Landfill on water quality; however, analyses of water from rural, domestic, and public-supply wells in the area have been made. Several regional studies of ground and surface water include data for the Prescott area.

The earliest systematic work in eastern Kansas was differentiation of the Carboniferous and Permian Systems by Swallow (1855). Further work by Swallow resulted in the correlation of rocks in extreme southeast Kansas with the Mississippian lead- and zinc-bearing strata of southwest Missouri and the identification of 22 different coal seams in Pennsylvanian rocks (Swallow and Hawn, 1865). Parker (1911) and Haworth (1913) summarized known data on Kansas ground water. Siebenthal (1915) discussed the origin of the Tri-State lead-zinc deposits of Kansas, Missouri, and Oklahoma.

Abernathy (1941) evaluated the ground-water resources of Mississippian, Ordovician, and Cambrian aquifers in Bourbon, Cherokee, Crawford, and Labette Counties, Kansas. He summarized expected well yields due to artesian conditions and salinity increases downdip (northwest) from Ozark-uplift recharge areas. Schoewe (1955) described Mulberry coal stratigraphy, quality, mining, and reserves in Bourbon and Linn Counties. Seevers (1969) described the ground-water resources and geology of Linn County, and Gentile (1976) described the geology and water resources of adjacent Bates County in Missouri. Bevans and others (1984) summarized available hydrologic information in an area of the Western Interior Coal Province nearly coincident with the Marais des Cygnes drainage basin. Kleeschulte and others (1985) described and appraised the resource value of ground water in Barton, Bates, and Vernon Counties, Missouri. Macfarlane and Hathaway (1987) presented recent data on regional hydrogeology and chemical variations in ground water in a 9,000-square-mile area in seven southeast Kansas counties and adjacent counties in Missouri and Oklahoma. Mesko (1987) investigated ground-water movement, quality, and recharge in a 275-acre reclaimed strip mine in Missouri, 7 miles northeast of the Linn County Landfill.

SOLID WASTES IN PUBLIC LANDFILLS

Although the exact solid-waste composition and chemical processes in the Linn County Landfill are not known, they may be inferred to be similar to the general compositions and chemical processes discussed in the following paragraphs.

Solid-Waste Composition

Solid wastes are discarded, unwanted materials. In the past, landfill sites often were merely convenient depressions, and solid wastes were considered as serviceable fill to level low-lying areas. Few if any sites were planned as engineering projects. Solid wastes commonly were left uncovered in open dumps. As an alternative, the sanitary landfill method was developed, incorporating engineering principles for maximum confinement and containment. Basic design features of a sanitary landfill are an impermeable bottom and sides, exclusion of drainage, compaction and daily covering of the solid waste, and final impermeable capping (Salvato and others, 1971; Degner, 1974).

The composition of Linn County Landfill solid wastes is not known explicitly, but typical nationwide composition, by weight, is 45-percent paper, 15-percent garbage, 11-percent yard and garden trimmings, 9-percent metal, 8-percent glass, 4-percent dirt, ashes, 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, of which aggregate amounts of fixed carbon, moisture, and volatile organic matter represent 7, 20, and 53 percent of the solid waste, respectively. Solid-waste composition varies due to climate, season, recycling, demography, packaging, and marketing (Tchobanoglous and others, 1977).

Solid-Waste Degradation

About 80 percent of typical solid waste, including paper, garbage, yard and garden trimmings, and ferrous metal, is totally or partly degradable. The other 20 percent, mostly glass, wood, rubber, plastics, and synthetic textiles, degrades more slowly (Tchobanoglous and others, 1977). Initially, while solid wastes are exposed to the air, the landfill environment is oxidizing. After depletion of trapped or incoming oxygen by aerobic bacteria, the chemical environment becomes reducing. Degradation processes in the landfill include biologic decomposition, solution, precipitation, sorption, ion exchange, and diffusion of gases (Baedecker and Back, 1979). Sufficient moisture, 40 to 60 percent, is essential, however, for significant degradation rates.

While oxygen is available, biologic decomposition is conducted by aerobic bacteria and then, in the absence of oxygen, by anaerobic bacteria. Aerobic decomposition proceeds rapidly and probably begins in easily degradable waste soon after deposition. Decomposition by hydrolysis allows bacteria to convert complex organic molecules to smaller, soluble ones that the bacteria can use for growth. Net products are primarily carbon dioxide and water, plus sulfate and ammonia (Baedecker and Back, 1979).

When oxygen is depleted, only anaerobic decomposition of the solid waste occurs. Anaerobic decomposition is slower and more complex than aerobic decomposition, and apparently requires symbiotic relations among different types of bacteria (Gaudy and Gaudy, 1980). It is thought of as occurring in two steps. Step one is fermentation, by faculative bacteria, to soluble smaller molecules and then to fatty acids and alcohols. Step two is methane formation by obligate methanogenic bacteria. The actual symbiosis probably involves hydrogen transfer between the two bacteria types and removal in methane. The hydrogen removal prevents buildup that would be toxic to methanogens and would suppress fatty-acid production (Gaudy and Gaudy, 1980). End products of fully completed anaerobic decomposition are methane, water, and carbon dioxide (Baedecker and Back, 1979). These end products probably first appear on the periphery of landfills (Metzler, 1975), where higher pH is more favorable to methanogenic bacteria.

At any specific time individual parts of the same landfill may be in different stages of decomposition. Stage and rate also 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. Many landfills complete the aerobic stage in a few weeks and go through anaerobiosis quickly enough to allow significant methane production to peak within 2 years and then decline for 25 years or longer (Tchobanoglous and others, 1977). The progress of anaerobic decomposition at any given time may be estimated from the attendant conditions. In step one, the leachate pH is 4.0 to 5.0; chemical oxygen demand is relatively large; and specific conductance, due to acidic solution of metals, is also large (O'Leary and Tansel, 1986). In step two, methane-gas concentrations in the landfill are large; leachate pH is 7.0 to 8.0; and specific conductance and chemical oxygen demand are relatively small (O'Leary and Tansel, 1986).

Leachate Production

Leachate is generated by the percolation of water through the waste and the extraction of dissolved and suspended materials, both biological and chemical (Tchobanoglous and others, 1977). Paper, which comprises about 45 percent of all waste absorbs most of the water originally available in the trash. Therefore, the production and discharge of leachate from a landfill above the water table require the infiltration of precipitation downward from the land surface. Solids, gases, and liquids from the waste are incorporated as dissolved, suspended, or sorbed, and miscible or immiscible components. 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 is increased also by the bacterially generated organic acids, which allow some metals in the landfill to be dissolved.

Chemical processes in leachate production are oxidation, reduction, solution, precipitation, ion exchange, and sorption. In the landfill, these processes are controlled to a large extent by the types of organic compounds present (Baedecker and Back, 1979). Physical processes are settlement, movement of evolved and ejected water by differential hydraulic heads, 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 1. Where ranges are given, the larger values are expected only in newer landfills because these are undergoing more rapid early-stage biodegradation, which involves acid production.

Sodium and potassium tend to stay in solution, unadsorbed by clay when calcium is present. Alkalinity normally is significant in leachate because bicarbonate is produced in anaerobic reactions, directly, 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, but sulfate is otherwise conservative. Chloride is nonreactive, and its variation in leachate is due mostly to dilution. Nitrogen is present mostly as ammonia because of pH and redox conditions stemming from anaerobic decomposition and the presence of dissolved iron (Apgar and Langmuir, 1971). Iron also is commonly present in large concentrations derived both from the waste and, with manganese, from oxide coatings and cements in soil and rock.

Trace metals, such as cadmium, chromium, cobalt, copper, lead, mercury, nickel, strontium, and zinc, also may be detected in landfill leachate but are present in small and variable concentrations because, with the exception of lead, they are either in elemental

Table 1. *Typical concentrations of constituents in and properties of landfill leachate*

[Concentrations in milligrams per liter (mg/L) except for pH]

Constituent or property	Concentrations		
	Salvato and others, 1971	Tchobanoglous and others, 1977	Cameron, 1978
pH (standard units)	5.6-8.3	6.0	7.5
Chemical oxygen demand	7,130	18,000	800
Biochemical oxygen demand	7,050-32,400	10,000	120
Hardness, total	537-8,120	3,500	--
Sodium	350-1,805	500	800
Potassium	655-1,860	300	490
Alkalinity, total as $CaCO_3$	1,290-8,100	3,000	3,400
Sulfate	99-1,220	300	5.3
Chloride	220-2,240	500	2,300
Dissolved solids	2,000-11,254	--	4,270
Nitrate, as N	1.1-4.1	5.6	--
Ammonia, as N	109-656	155	331
Nitrogen, organic, as N	152-550	200	--
Iron	219	60	24

form in insoluble metals and alloys or are in special, unusual industrial wastes. Other environmentally significant trace metals found in landfill leachate include arsenic, boron, and selenium. Arsenic originates mainly in toxic compounds, such as insecticides. Boron is found in soap, glazes, and rubber, and selenium in ink and rubber.

METHODS OF INVESTIGATION

There were four phases of investigation in the study of the Linn County Landfill. Data pertaining to the landfill's history, geology, hydrology, and land ownership were compiled during an initial information-gathering phase. On the basis of this information, temporary-well sites and potential monitoring-well sites were selected. Phase two, well installation, included the augering and drilling of test holes and the installation of temporary wells to determine the hydrology and geology of the area. Monitoring wells were installed on the basis of geologic and hydrologic information from the temporary wells. In the third phase, water samples were collected from all monitoring wells and from selected surface-water bodies and were analyzed by the Kansas Department of Health and Environment (Topeka) and U.S. Geological Survey (Arvada, Colo.) laboratories. This report concludes the fourth phase of data interpretation and reporting. The following sections relate details of investigation methods.

Information Survey

Prior to any field work, a survey of published literature, files of the Kansas Department of Health and Environment (Topeka), and Linn County files was completed. Geologic and hydrologic information enabled estimation of the directions of shallow ground-water flow, depth to bedrock, and geology in the vicinity of the landfill. This information was used for planning well locations, field activities, and material requirements.

Temporary-Well Installation

Nine temporary wells were installed using a combination of augering and rotary-drilling techniques (fig. 5). Augers were either 3 1/4-inch inside diameter (ID) [6 5/8-inch outside diameter (OD)] or 6 1/4-inch ID (9 7/8-inch OD) hollow-stem augers with a plate in the bottom of the augers to prevent earth material from entering the hollow stem. Below the water table it was necessary to load the augers with potable water to prevent formation sand and water from surging into the augers when the bottom plate was knocked out. Augering was generally the best method for penetrating mine spoil except that buried sandstone blocks were difficult to penetrate with the large (9 7/8-inch OD) augers. In such cases, a pilot hole was augered with the small augers, which made the use of the large augers easier. Rotary drilling with 4-inch and 6 3/8-inch bits was used in mine spoil and bedrock. Air proved to be the most satisfactory circulation medium for rotary drilling.

Lost circulation of water or bentonite-mud drilling fluids was a problem when drilling through mine spoil, especially where large blocks of rubble had created open cavities. A combination of augering and rotary drilling proved to be the most satisfactory method. In this combination, the large augers were advanced through the mine spoil to bedrock. The augers were left in place to act as a temporary casing for rotary drilling through bedrock. The borehole was advanced to the final depth by water or mud rotary drilling using a 4-inch tricone bit. Wells TW-1, TW-3, TW-5, and TW-8 were drilled using the combination technique. Other temporary wells were drilled with augers only.

Temporary wells were constructed of 1 1/2-inch polyvinyl-chloride pipe with glued joints and capped at the bottom or 2-inch polyvinyl-chloride pipe with threaded flush-coupled joints and capped at the bottom. Each had slotted screens cut with a hacksaw. Well screens were set to different depths at the same location (nested) to evaluate vertical ground-water movement.

After all temporary wells had been installed, the top-of-casing altitude for each well was determined by a level survey (table 2). Water levels in the temporary wells were measured to the nearest 0.01 foot with a steel tape. Water-level altitudes were used to construct potentiometric-surface maps to show directions of ground-water flow.

Geologic information was collected while augering and drilling. Auger cuttings were sampled and described. Cores taken with a split spoon or with a continuous coring-bit assembly were sampled and described. Bedrock cores were taken while rotary drilling to determine bedrock composition.

Monitoring-Well Installation

Nine monitoring wells were installed using the augering or rotary-drilling techniques

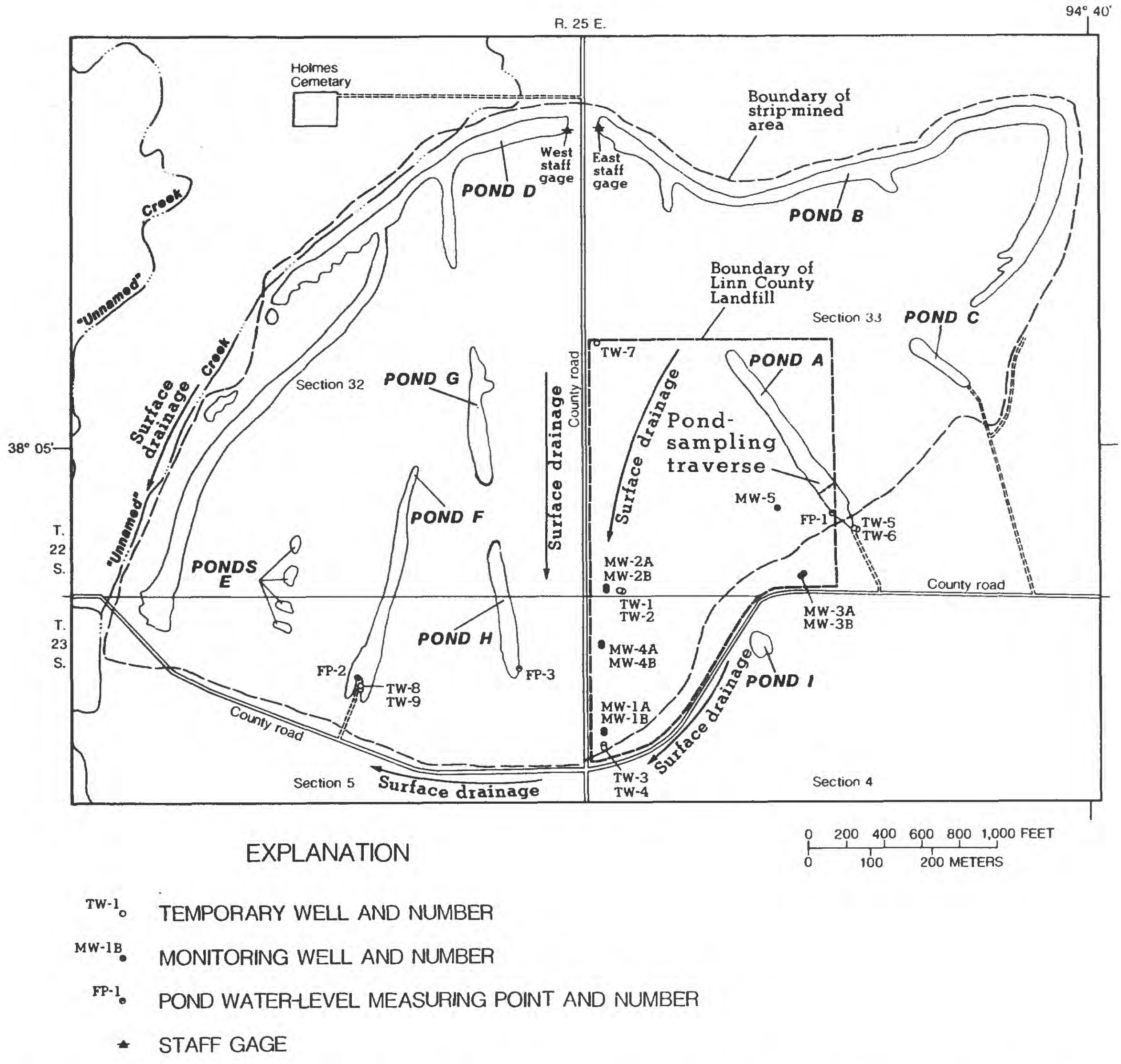


Figure 5. Location of temporary wells (TW), monitoring wells (MW), pond-sampling traverse (pond sample), pond water-level measuring points (FP), and staff gages.

previously described, or a combination of the two techniques. Wells MW-1A and MW-1B were drilled using a combination of augering and mud rotary drilling. Wells MW-2A, MW-3A, MW-3B, and MW-4A were drilled using a combination of augering and air rotary drilling. Wells MW-2B and MW-4B were drilled with augers, and well MW-5 was driven into the ground with a sledgehammer. After reaching the final depth, the well casing was lowered into the hollow augers or rotary borehole. Filter sand pack and bentonite chips were poured into place around each well as the augers were being withdrawn from the well.

Each monitoring well is comprised of a 5-foot stainless-steel screen, a 10-foot stainless-steel riser, and schedule-40 polyvinyl-chloride pipe to the surface (fig. 6). Well casings are threaded, flush-coupled, 2- or 4-inch diameter pipe. Teflon[1] tape was used to seal each joint; no glue or cement was used. Filter sand packs are 6 to 10 feet thick and extend from the bottom of the well screen to 1 to 5 feet above the top of the screen. The sand was followed by 2 or more feet of 3/8-inch bentonite chips to seal off the screened zone. Natural formation sediments were

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[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. *Top-of-casing altitudes and total depths for temporary wells (TW), monitoring wells (MW), staff gages, and pond water-level measuring points (FP)*

[Datum is sea level]

Measuring point (fig. 5)	Top-of-casing altitude (feet)	Total depth below land surface (feet)
TW-1	881.37	37.5
TW-2	879.57	30.0
TW-3	871.39	33.0
TW-4	870.11	14.0
TW-5	867.54	28.0
TW-6	867.18	7.0
TW-7	882.00	24.0
TW-8	857.83	28.0
TW-9	857.81	18.0
MW-1A	868.28	38.4
MW-1B	867.66	28.7
MW-2A	878.39	42.2
MW-2B	879.04	30.4
MW-3A	872.58	49.5
MW-3B	872.64	40.6
MW-4A	879.47	40.4
MW-4B	879.03	32.7
MW-5	868.62	8.7
East staff gage	[1]859.81	--
West staff gage	[1]849.81	--
FP-1	[2]866.53	--
FP-2	[2]855.10	--
FP-3	[2]856.04	--

[1] Altitude of 0.0-foot marker on staff gage.
[2] Altitude of top of steel post.

allowed to collapse or were added to the hole up to a depth of about 10 feet below land surface, then 3/8-inch bentonite chips were added to within 18 inches of the land surface. Finally, a cement pad and protective casing with a locking cap were set around the well casing.

To avoid potential cross contamination between wells or from other sources, all equipment was cleaned prior to installation of each monitoring well (MW-1 to MW-5) (fig. 5). Loose cuttings were removed from augers and other tools with a high-pressure jet of potable water. Augers and tools were scrubbed with a water and Alconox mixture, rinsed with potable water, and finally rinsed with acetone. Potable water was purchased from the city of Prescott and hauled to the site in a stainless-steel tank or was obtained from the rural water district tap at the landfill.

Monitoring wells were developed using

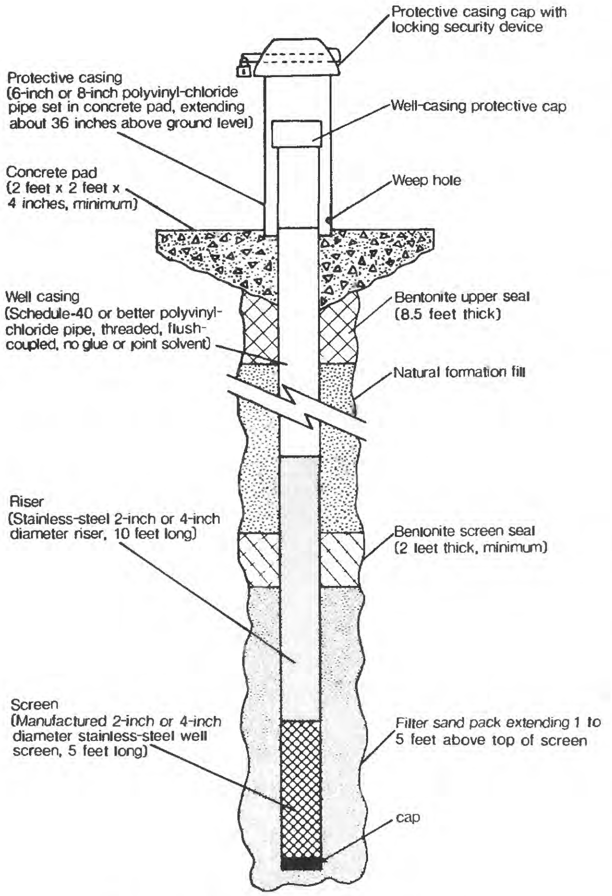


Figure 6. Monitoring-well design.

air-lift techniques or a positive-displacement hand pump until water ran clear from the well. In cases where there was very little water in the well, a positive-displacement hand pump or bailer was used to develop the wells.

For monitoring wells installed in nested pairs, the letter designation "A" indicates the deeper well, and the letter "B" indicates the shallower well. All "A" well screens are set in Pawnee Limestone. All "B" well screens, except MW-3B, are set in strip-mine spoil. The MW-3B well screen is set in Mulberry coal. Well MW-5, which does not have an "A" or "B" designation, is set in strip-mine spoil.

Water-Sampling Methods

The nine monitoring wells at the Linn County Landfill were sampled on March 2-3, 1989. The well-sampling process began with the upgradient wells (MW-3A, MW-3B, and MW-5) and ended with the downgradient wells (MW-1A, MW-1B, MW-2A, MW-2B, MW-4A, and MW-4B).

The sampling procedure was as follows. Water levels and total depths in all monitoring wells were measured to the nearest 0.01 foot with a steel tape. The tape was cleaned with distilled water before each use. Then each well was purged of five water-column volumes to assure that the water samples collected were representative of aquifer conditions. The volume of water to be purged from each well was determined from water-level and total-depth measurements (table 3). Wells were purged with a positive-displacement hand pump that was washed with an Alconox solution, rinsed with potable water, then rinsed with deionized water before each use. Water samples were retrieved with a Teflon-bottom check-valve bailer suspended from a nylon cord. The bailer was decontaminated in the same fashion as the hand pump before each use, and the nylon cord was replaced before each use.

Water samples were collected in the following order: (1) volatile organic compounds, (2) semivolatile organic compounds and pesticides, (3) dissolved organic carbon and common ions, and (4) trace metals. Care was taken not to aerate the water when lowering the bailer to collect a sample. Plastic sheeting was laid on the ground around the well to prevent the bailer cord from touching the ground. Samples were placed immediately on ice. Trace-metal samples were field filtered through a 0.45-micron filter. Dissolved-organic-carbon samples were field filtered through a 0.2-micron silver filter. Both types of filters were flushed with about 500 milliliters of sample water before filtration of the sample to be analyzed. Specific conductance, pH, water-temperature, dissolved-oxygen, and alkalinity determinations were made at the time of sample collection. Dissolved-oxygen concentrations were determined by lowering a probe into the well to the approximate depth of sampling.

In addition to the monitoring-well samples, a water sample was collected from strip-mine pond A just east of well MW-5 (fig. 5), and water samples were collected from the rural water-supply tap at the landfill and from a Prescott water-supply hydrant. Pond water was collected by dipping samples from a traverse across pond A and compositing the samples in a large container from which the individual samples were taken. Samples were collected and processed in the same order and in the same way

Table 3. *Water-column volumes purged from monitoring wells before sampling in March 1989*

Well (fig. 5)	Nominal diameter of well[1] (inches)	Height of water column (feet above bottom of well)	Volume in well (gallons)	Volume purged (gallons)
MW-1A	2	24.54	4.09	20.5
MW-1B	4	14.75	9.73	48.6
MW-2A	2	19.63	3.27	5.0 (bailed dry)
MW-2B	2	5.92	.99	4.9
MW-3A	2	20.30	3.39	5.0 (bailed dry)
MW-3B	2	31.25	5.22	6.0 (pumped dry)
MW-4A	2	15.48	2.58	12.9
MW-4B	2	8.19	1.36	6.8
MW-5	2	4.71	.30	1.5

[1] Actual inside diameter of 2-inch well casing is 2.067 inches.
Actual inside diameter of 4-inch well casing is 4.022 inches.

as for the monitoring wells, except that samples for volatile organic compounds were not collected. Samples of the rural and city water supplies were collected directly from the tap after first letting water flow from the tap for about 2 minutes.

Water samples were delivered within 3 days of collection to the Kansas Department of Health and Environment laboratory (Topeka). Samples for dissolved-organic-carbon analyses were shipped within 4 days by mail to the U.S. Geological Survey laboratory in Arvada, Colorado.

Hydraulic-Conductivity Determination

Hydraulic conductivity of spoil material and underlying limestone was determined from slug-test data using analysis methods from Nguyen and Pinder (1984). For each slug test, 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 within the well to a point above the pressure transducer. After the pressure in the well stabilized, the pressure was released suddenly. Pressure-transducer readings were recorded for a 2- to 10-minute duration starting when pressure was released from the well.

LANDFILL SETTING AND OPERATION

The Linn County Landfill is constructed in an unreclaimed coal strip mine. The active part of the landfill ocupies a triangular area of about 12 acres (fig. 4). Adjacent to the north, an additional tract of about 40 acres has been acquired for expansion.

The Linn County Landfill is operated as a sanitary landfill. Wastes are covered daily with soil, resulting in individual cells of waste. Small quantities of hazardous waste are deposited along with routine wastes. Septic-tank wastes are emptied near the southwest corner of the 40-acre tract and covered immediately with soil (fig. 4).

Trench and area fill methods are used in disposal of wastes at the Linn County Landfill; these methods are best suited to the ridge and valley terrain left by strip mining. The valleys are used for disposal trenches; cover materials are taken from the existing spoil ridges. The 12-acre tract is currently nearing capacity. When finished, the area will have a 24-inch earth cover with drainage to the west and southwest. Drainage from the 12-acre tract will be directed beneath the county road near the south end of the 12-acre tract.

REGIONAL HYDROGEOLOGY

Geology

Regional structural elements are, from oldest to youngest, the Bourbon arch, which trends east-west south of Linn County; the Nemaha ridge, which trends north-northeast across the central part of the eastern one-half of Kansas and extends into Nebraska and Oklahoma; and the Prairie Plains homocline, which dips gently northwest across all of eastern Kansas (fig. 7). The Bourbon arch is low and indistinct but separates Mississippian and Pennsylvanian sedimentation areas into the Forest City basin to the north and the Cherokee basin to the south. The Nemaha ridge is a major anticline, faulted in places on the east. Anticlinal uplift began in the Early Mississippian and continued until Late Pennsylvanian time. In places, the Nemaha ridge was eroded to the Precambrian basement, removing or developing karst in Mississippian carbonates, and causing Pennsylvanian sediment onlap (Ebanks and others, 1979). Continued movement of the Nemaha ridge through Mississippian and Pennsylvanian time is indicated also by northwest-trending folds and normal faults, some in Pennsylvanian rocks and some only in Mississippian rocks (Kleeschulte and others, 1985). The Prairie Plains homocline dips at about 20 feet per mile to the northwest. This regional dip is modified locally by other structural elements, such as the Nemaha ridge (Jewett, 1951). Formation of the Prairie Plains homocline occurred during post-Permian and pre-Cretaceous time (Jewett, 1951). All regional structures apparently began in Precambrian time and were rejuvenated periodically.

Structural features in Linn County at the surface include domes, faults, and anomalous dips, perhaps due to deformation of sediments by compaction or collapse on karst features developed in Upper Mississippian carbonates (Seevers, 1969; Yarger and Jarjur, 1972; Stewart, 1975). Subsurface mounds in Lower Ordovician rocks also may be due to paleotopography in the karst or on Precambrian highs (Cole, 1976; Macfarlane and Hathaway, 1987). Karstic limestone beds commonly are jointed northwest-southeast and northeast-southwest. Local variations in strike and dip of beds occur due to small-scale domes, folds, and

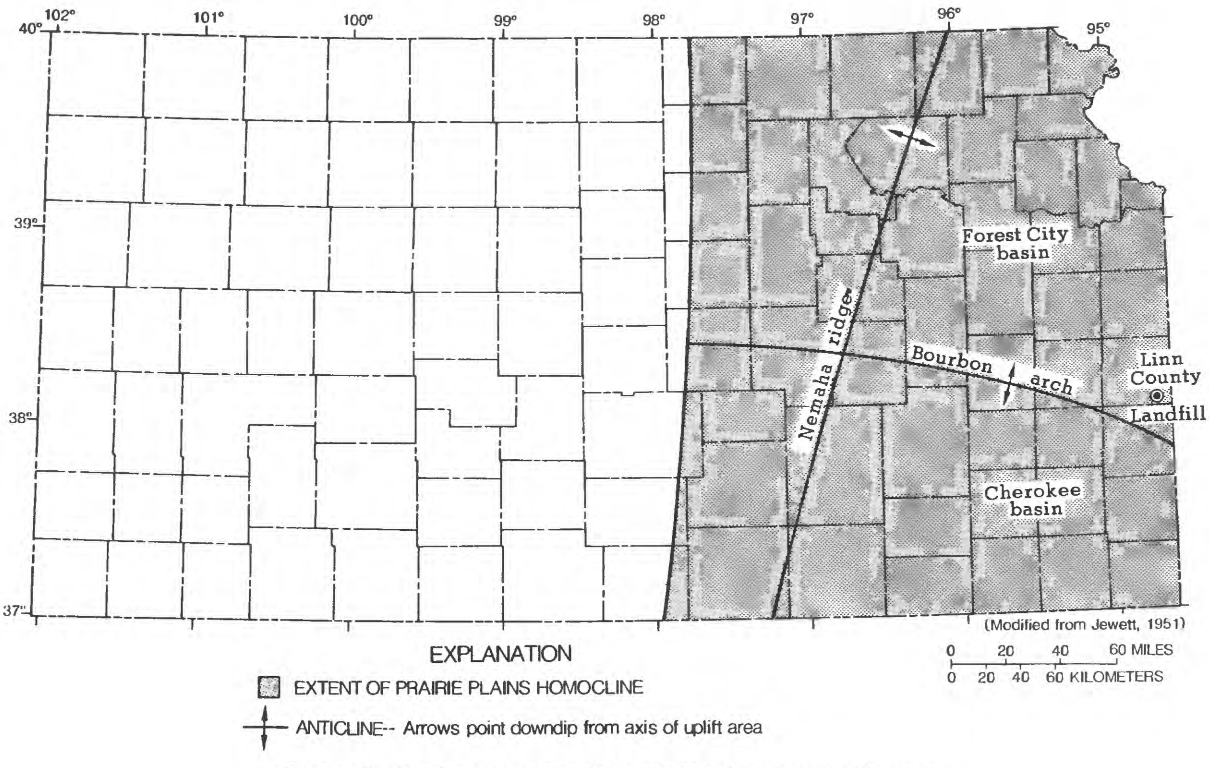


Figure 7. Regional geologic structure in eastern Kansas.

faults imposed on the regional structure (Moore, 1949). An episode of recent faulting is indicated in Bates County, Missouri (Gentile, 1976). West of Prescott, Hargadine (1966) described a threefold increase in dip (60 feet per mile) for the uppermost unit of the Pawnee Limestone, which is immediately beneath the Bandera Shale.

In Linn County, bedrock outcrops (of Pennsylvanian age) generally strike N. 30° E. and dip 20 feet per mile to the northwest in conformance with the Prairie Plains homocline (Moore, 1949). Mississippian and older rocks in the subsurface along the Bourbon arch usually dip more toward the north. The name and lithology of the bedrock formations that crop out in the area (Seevers, 1969), from the southeast corner of Linn County to a Swope Limestone escarpment 7 miles northwest of the landfill, are shown in figure 8.

Unconsolidated surficial material in Linn County consists of alluvial deposits along the streams. Alluvium in the flood plains is Wisconsin and Holocene in age and that in terraces is Illinoian (Seevers, 1969). The alluvium consists mainly of silt and clay, with gravel at the base. The subrounded, medium-to-coarse gravel is composed of limestone and chert and is 2 to 10 feet thick beneath the flood plains and as much as 5 feet thick in the terraces. Thickness of the Wisconsin and Holocene alluvium ranges from several feet in upstream parts of tributary valleys to 50 feet in principal valleys. These changes in alluvial thickness may result from aggrading due to late Pleistocene uplift farther downstream (Branson, 1944; Gentile, 1976). Total thickness of the terrace deposits is 20 to 35 feet.

Soils

Away from the streams, only thin soil overlies the bedrock. Soil on strip-mine spoil is generally deep, well-drained, on 4- to 50-percent slopes, with silty clay loam at the surface and moderately permeable, extremely shaly, silty clay loam in the subsurface (Penner, 1981; U.S. Department of Agriculture, Soil Conservation Service, 1986). Outside the strip-mine areas, lower hill slopes south of the landfill are covered by Kenoma silt loam (Penner, 1981). The Kenoma silt loam is deep and moderately well-drained, with very small permeability. Higher hill slopes south of the landfill and west of the West Fork Indian Creek are covered by Bates loam (Penner, 1981), which is moderately deep, well-drained, with moderate permeability. Silt loam of alluvial-derived soil along the forks of Indian Creek is moderately permeable. Infiltration rates determined from U.S. Soil Conservation Service tests were 0.1 inch per hour on bedrock-derived soil and 0.5 inch per hour on alluvial-derived soil (Seevers, 1969).

Ground Water

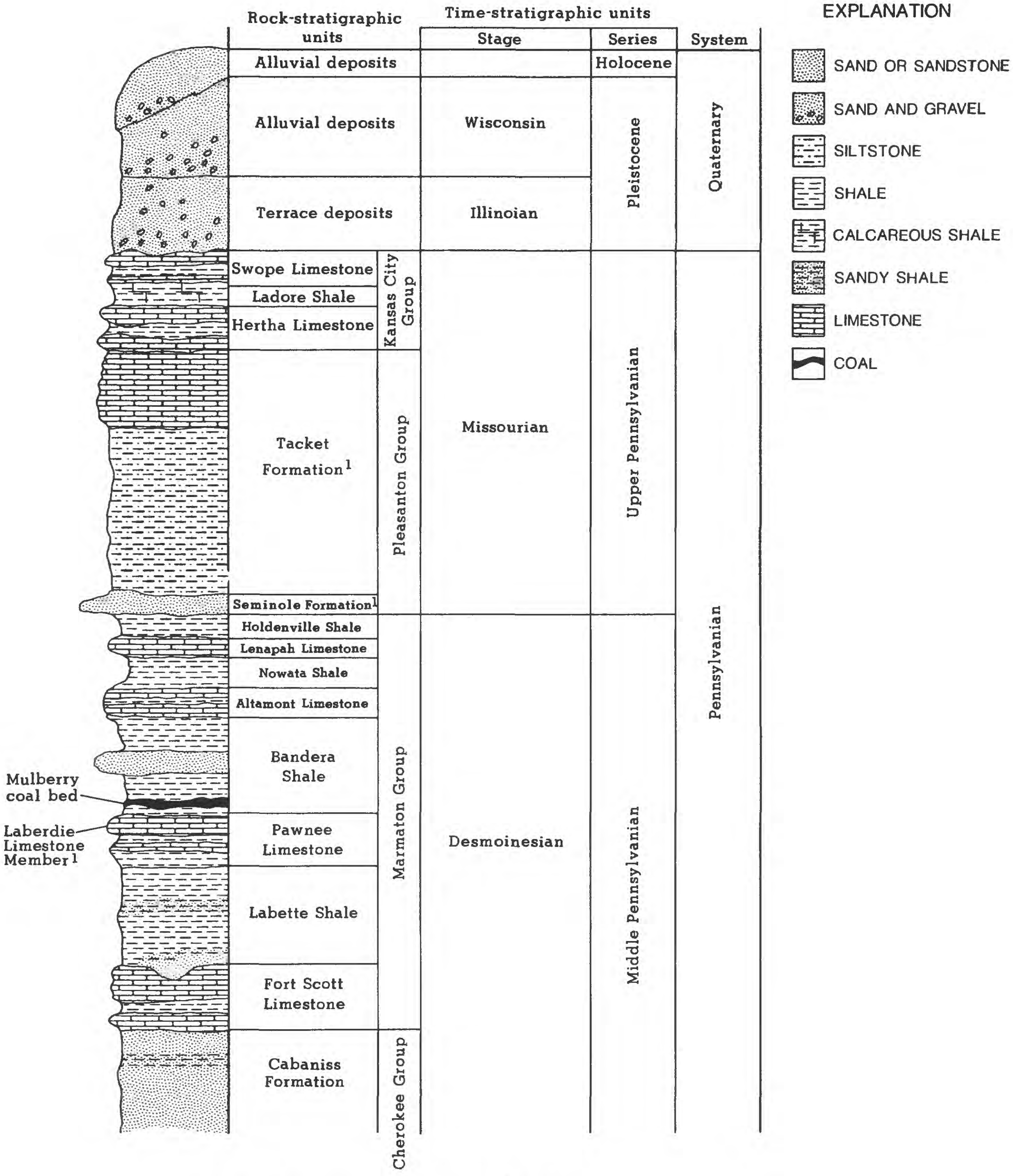
Water usage from bedrock formations in Linn County is limited by large chloride and sodium concentrations at depths greater than 100 feet in rocks other than the Cherokee Group. Above 100 feet, water yield is limited by the absence of thick, transmissive layers. The most productive formations are the Swope, Altamont, and Pawnee Limestones. The favorable water-yielding characteristics of these units include joints, thin bedding, and, when forming cuesta dip slopes, the near-surface position for recharge from precipitation. Estimated yields to wells from these formations range from 10 to 50 gallons per minute (Seevers, 1969).

Ground-water yields are most reliable from stream-valley alluvium. The alluvium is more permeable than bedrock and usually of adequate thickness to be an aquifer. Wisconsin and Holocene flood-plain materials are a more reliable aquifer than terrace materials because they are thicker in the principal valleys, more continuous, and in a topographically lower position to intercept runoff. Flood-plain wells in gravel may yield 100 gallons per minute, and terrace gravels may yield 5 gallons per minute to wells (Seevers, 1969).

LANDFILL HYDROGEOLOGY

Geology

The bedrock units that crop out in the landfill area occur in the Marmaton Group of the Pennsylvanian System. The Bandera Shale locally consists of about 30 to 35 feet of well-bedded, blocky, gray, clayey shale interbedded with brown-to-gray sandstone and siltstone, with some thin limestone in the middle part. The Mulberry coal, which has been mined in this area, is located in the bottom part of the Bandera



[1] Unit follows usage of Kansas Geological Survey.

Figure 8. Rock- and time-stratigraphic nomenclature showing relations among rocks and unconsolidated deposits. Rock units between and including the Labette Shale and the Swope Limestone crop out in southeastern Linn County (modified from Zeller, 1968).

Shale, about 3 feet above the base. The coal is about 2 feet thick locally (Schoewe, 1955). Separating the coal from the Laberdie Limestone Member of the Pawnee Limestone below is about 3 feet of clayey Bandera Shale. The stratigraphic relations between the Bandera Shale and the Laberdie Limestone Member are shown in figures 8, 9, and 10. The location of hydrogeologic sections A-A' and B-B' is shown in figure 11. The Laberdie Limestone Member is light gray, crystalline, and thin bedded but more massive in the lower part (Jewett, 1941).

The top part of the Bandera Shale in the landfill area was stripped off as overburden in order to mine the underlying Mulberry coal. This stripped overburden was piled along previously stripped passes resulting in a series of parallel spoil ridges. The spoil is a loose, heterogeneous mixture of broken and crushed Bandera sandstone, shale, siltstone, limestone, and coal. Undisturbed bedrock generally

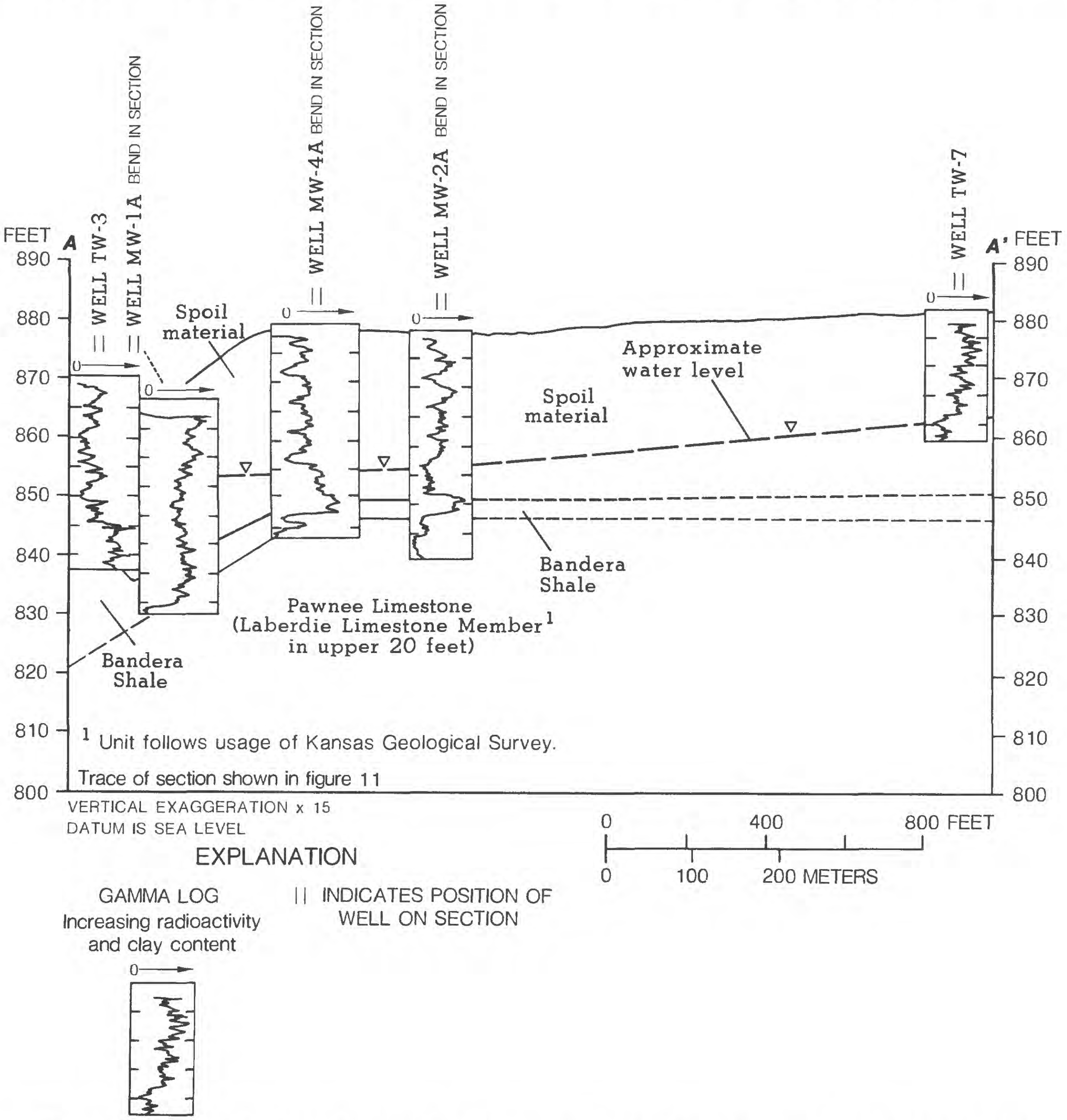


Figure 9. Hydrogeologic section based on gamma-ray logs and auger-, rotary-, and core-sample descriptions, north-south direction (A-A').

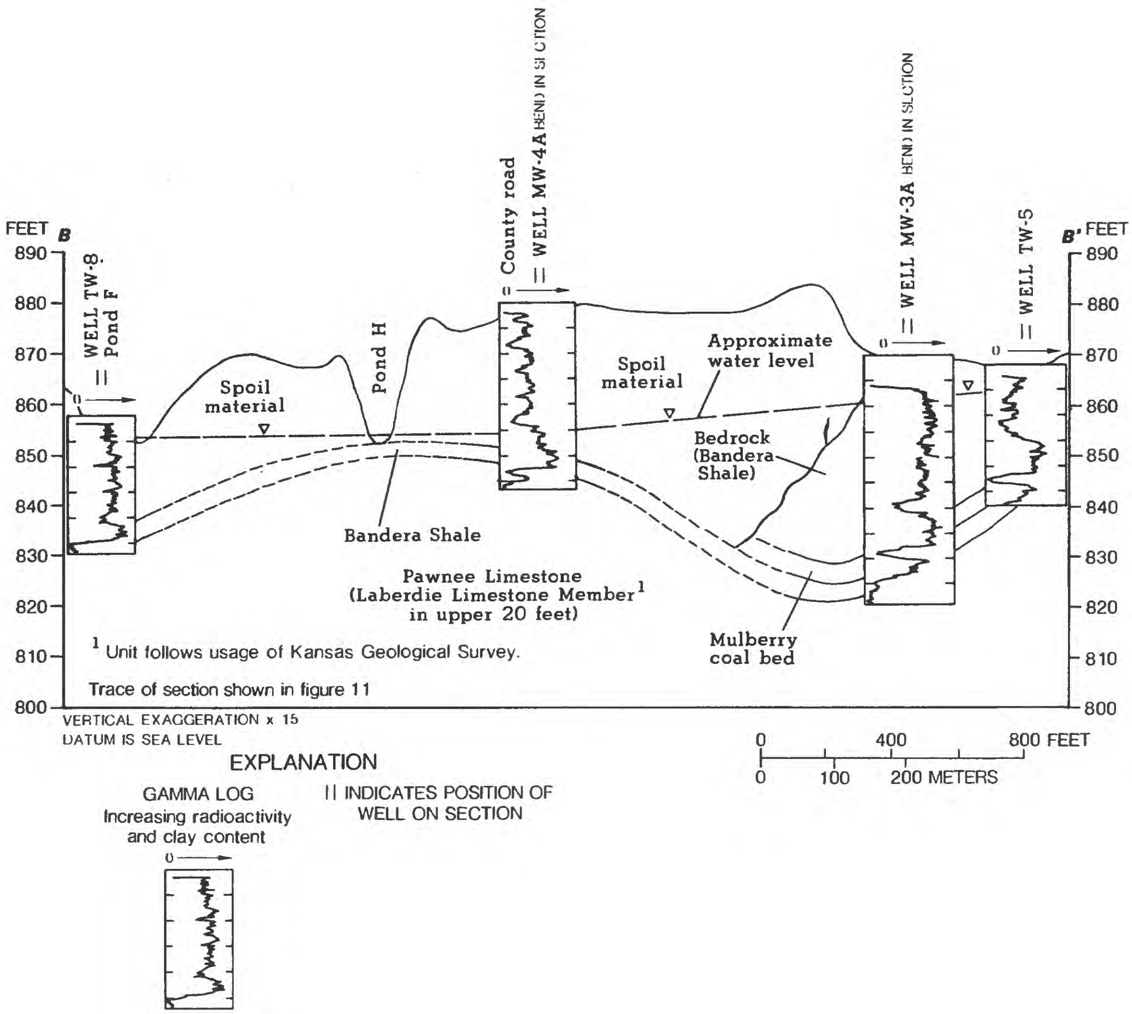


Figure 10. Hydrogeologic section based on gamma-ray logs and auger-, rotary-, and core-sample descriptions, east-west direction (B-B').

underlies the spoil, consisting of the basal few feet of Bandera Shale, below which is the Laberdie Limestone Member of the Pawnee Limestone. In places, however, the Laberdie Limestone Member reportedly was quarried for use as mine-haul road material. Where the Laberdie Limestone Member was quarried, the Bandera Shale was removed. Strip mining in this area has created a flat-bottomed basin filled with unconsolidated and unstratified strip-mine spoil. This basin fill is bounded by undisturbed bedrock; on the sides by interbedded siltstone, sandstone, shale, and coal of the Bandera Shale; and on the bottom by basal Bandera Shale or, where quarried, by the Laberdie Limestone Member.

Hydrology

The normal surface-water drainage patterns in the vicinity of the landfill have been disrupted by strip-mining activities. Prior to strip-mining operations, the general slope and drainage in the landfill area was southwesterly. Presently, drainage from the active landfill area is southwesterly to a low area at the southwestern corner of the landfill. Ditches along roadways provide the only continuous drainage through the stripped areas (fig. 5); however, there are no known culverts beneath the roadways bounding the landfill. The nearest natural drainage is the "unnamed" creek (fig. 5) that flows southward along the western edge of the stripped area. Within the unreclaimed strip-mine areas (fig. 4) the terrain is very hummocky, so there is no coherent drainage pattern. Low terrain may channel flow between ponds during times of intense rainfall or snowmelt, but generally, there is no surface flow between ponds.

The ground-water hydrology in the landfill area is complicated by the heterogeneous nature of the spoil, by underlying bedrock, which was quarried in places, by surface-water ponds

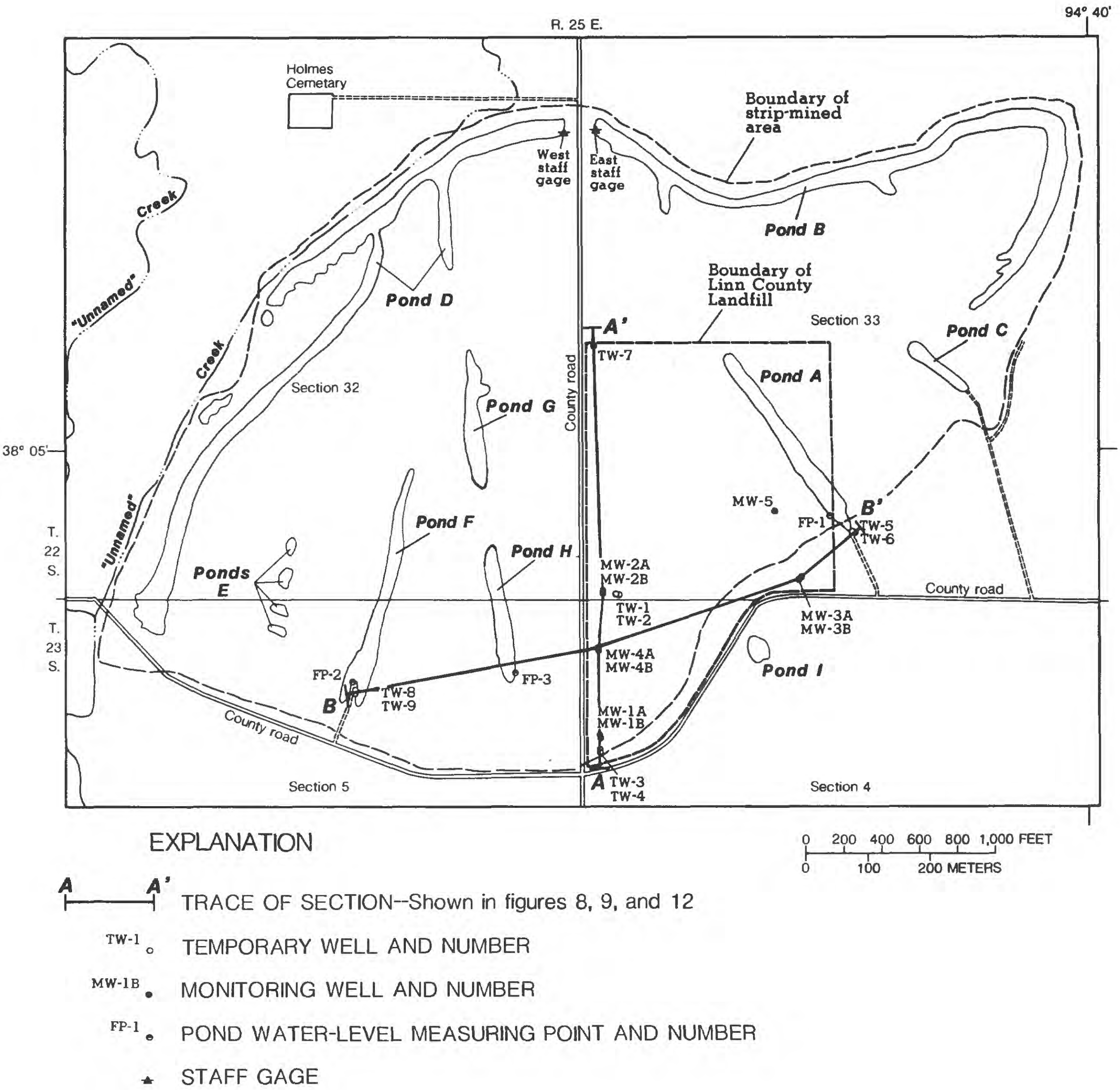
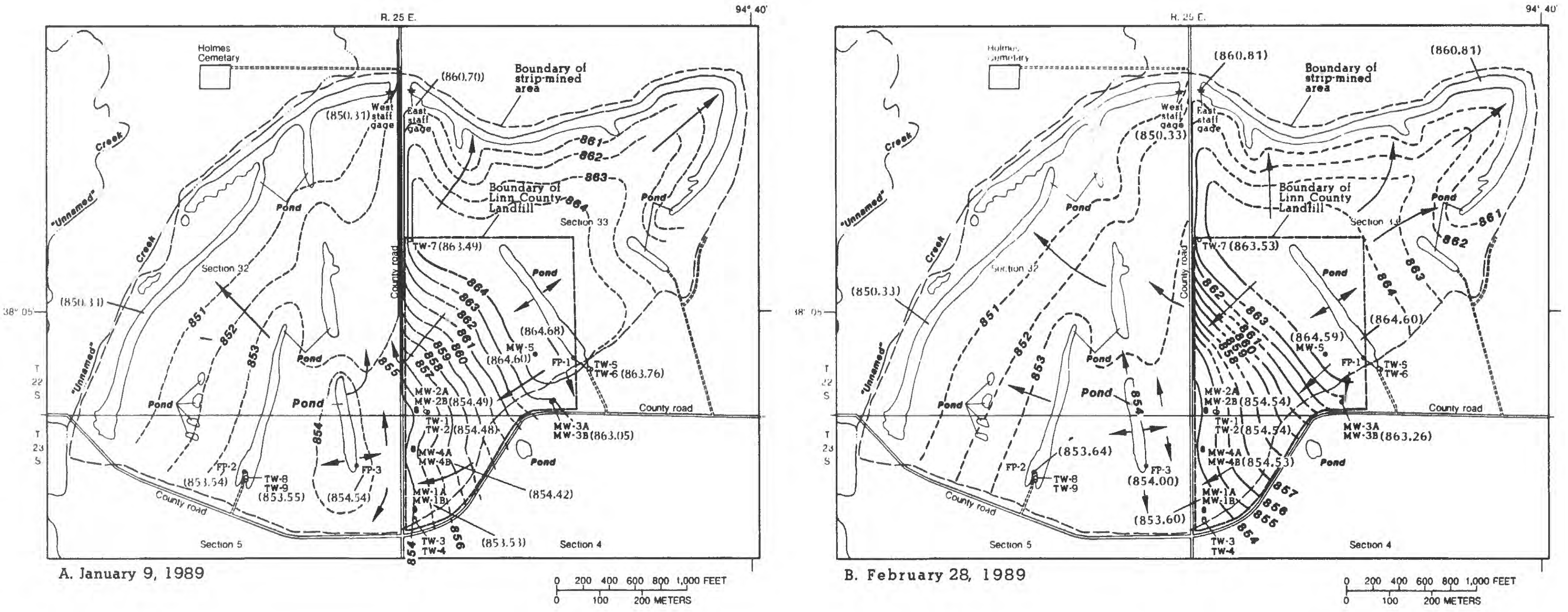


Figure 11. Location of hydrogeologic sections A-A' and B-B'.

along the unreclaimed strip-mine haul roads, and by damming of ground water against the county road fill as evidenced by potentiometric-surface maps (fig. 12). Horizontal and vertical ground-water movement, whether from the Bandera Shale into the spoil or from the spoil into the Bandera Shale, depends on the hydraulic gradient at a given location. In the vicinity of wells TW-3 and TW-4 and MW-1A and MW-1B, it is evident that water is moving laterally into the spoil pile from the bedrock because a potentiometric gradient exists from bedrock laterally into the spoil (table 4, figs. 12 A, B, C, D and 13 A, B). In the vicinity of wells MW-3A and MW-3B, the potentiometric surface of water in bedrock is slightly lower than that of water in adjacent spoil, and water is moving laterally from the spoil into bedrock (fig. 12 A, B, C, D). In areas where the Laberdie Limestone Member has been quarried and the Bandera Shale removed, vertical ground-water movement may occur more readily than in areas where the Bandera Shale is intact. Water levels in wells MW-1A, MW-1B, MW-2A, and MW-2B indicate that a hydraulic gradient exists upward from bedrock into the spoil (table 4, fig. 13), and thus, there is "potential" for the movement of water from the Laberdie Limestone Member into the spoil. Upward movement of water, in fact, may be occurring near wells MW-4A and MW-4B



A. January 9, 1989

B. February 28, 1989

Figure 12. Potentiometric surface of water in spoil material, (A) January 9, (B) February 28, (C) March 2, and (D) July 18, 1989.

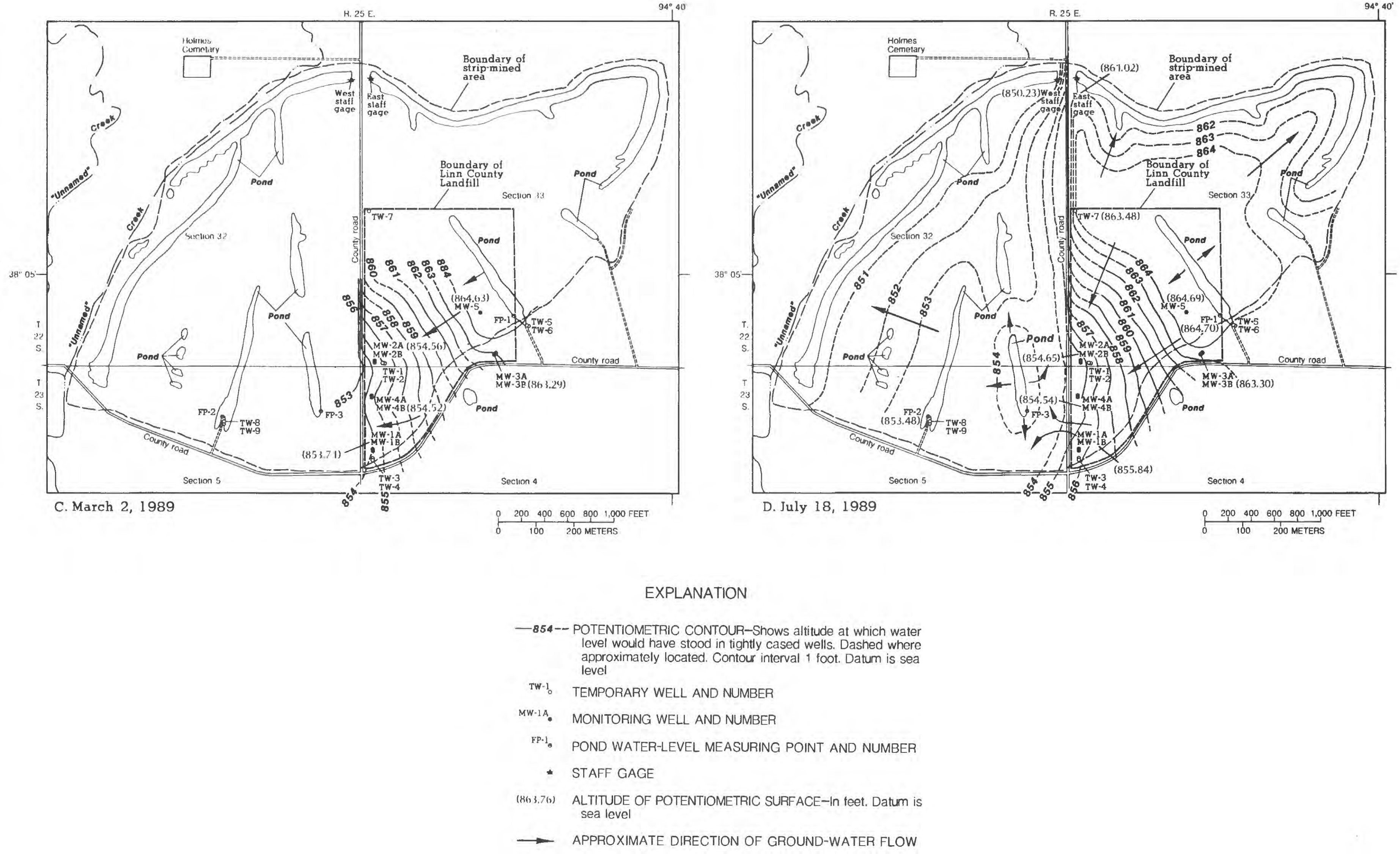


Figure 12. Potentiometric surface of water in spoil material, (A) January 9, (B) February 28, (C) March 2, and (D) July 18, 1989--Continued.

Table 4. *Water-level altitudes in temporary wells (TW) and monitoring wells (MW), and at staff gages and pond water-level measuring points*

[Datum is sea level. NA, not available; NM, not measured; PULLED, well removed from site prior to date of measurement]

Measuring point (fig. 5)	Water-level altitudes (feet)								
	Date (month/day/year)								
	11/18/88	12/1/88	12/6/88	12/20/88	1/9/89	2/28/89	3/2/89	4/17/89	7/18/89
TW-1	854.37	854.73	854.72	854.56	854.52	854.57	PULLED	NA	NA
TW-2	854.48	854.68	854.64	854.51	854.48	854.54	PULLED	NA	NA
[1]TW-3	NM	838.19	838.90	840.88	856.48	857.57	PULLED	NA	NA
TW-4	855.33	859.11	858.61	857.93	858.10	858.70	PULLED	NA	NA
TW-5	864.74	864.75	864.92	864.69	864.57	PULLED	NA	NA	NA
TW-6	863.99	864.15	864.12	863.76	863.76	PULLED	NA	NA	NA
TW-7	NA	863.60	863.64	863.50	863.49	863.53	NM	NM	NA
TW-8	NA	854.30	853.60	853.51	853.58	PULLED	NA	NA	NA
TW-9	NA	850.96	852.65	853.13	853.55	PULLED	NA	NA	NA
MW-1A	NA	NA	NA	854.25	854.30	854.36	854.42	854.63	856.60
MW-1B	NA	NA	NA	853.47	853.53	853.60	853.71	853.89	855.84
MW-2A	NA	NA	NA	855.91	855.92	855.87	855.82	855.96	855.65
MW-2B	NA	NA	NA	854.51	854.49	854.54	854.56	855.01	854.65
MW-3A	NA	NA	NA	NA	861.38	861.77	843.38	863.95	861.44
MW-3B	NA	NA	NA	NA	863.05	863.26	863.29	862.06	863.30
MW-4A	NA	NA	NA	NA	854.47	854.53	854.53	854.98	854.62
MW-4B	NA	NA	NA	NA	854.42	854.46	854.52	854.94	854.54
MW-5	NA	NA	NA	NA	864.60	864.59	864.63	865.28	864.69
East staff gage	NA	860.79	860.68	860.59	860.70	860.81	NM	NM	861.02
West staff gage	NA	850.37	850.31	850.30	850.31	850.33	NM	NM	850.23
FP-1	NA	NA	NA	NA	864.68	864.60	NM	NM	864.70
FP-2	NA	852.53	NA	NA	853.54	853.64	NM	NM	853.48
FP-3	NA	NA	NA	NA	854.54	854.00	NM	NM	NM

[1] Water levels measured in well TW-3 are not considered to be reliable indicators of the actual water level in the formation. The well screen was set in low-permeability shale, and the water level did not stabilize throughout the term of the study. Therefore, the data have been excluded from potentiometric-surface maps and hydrogeologic sections showing lines of equal potential.

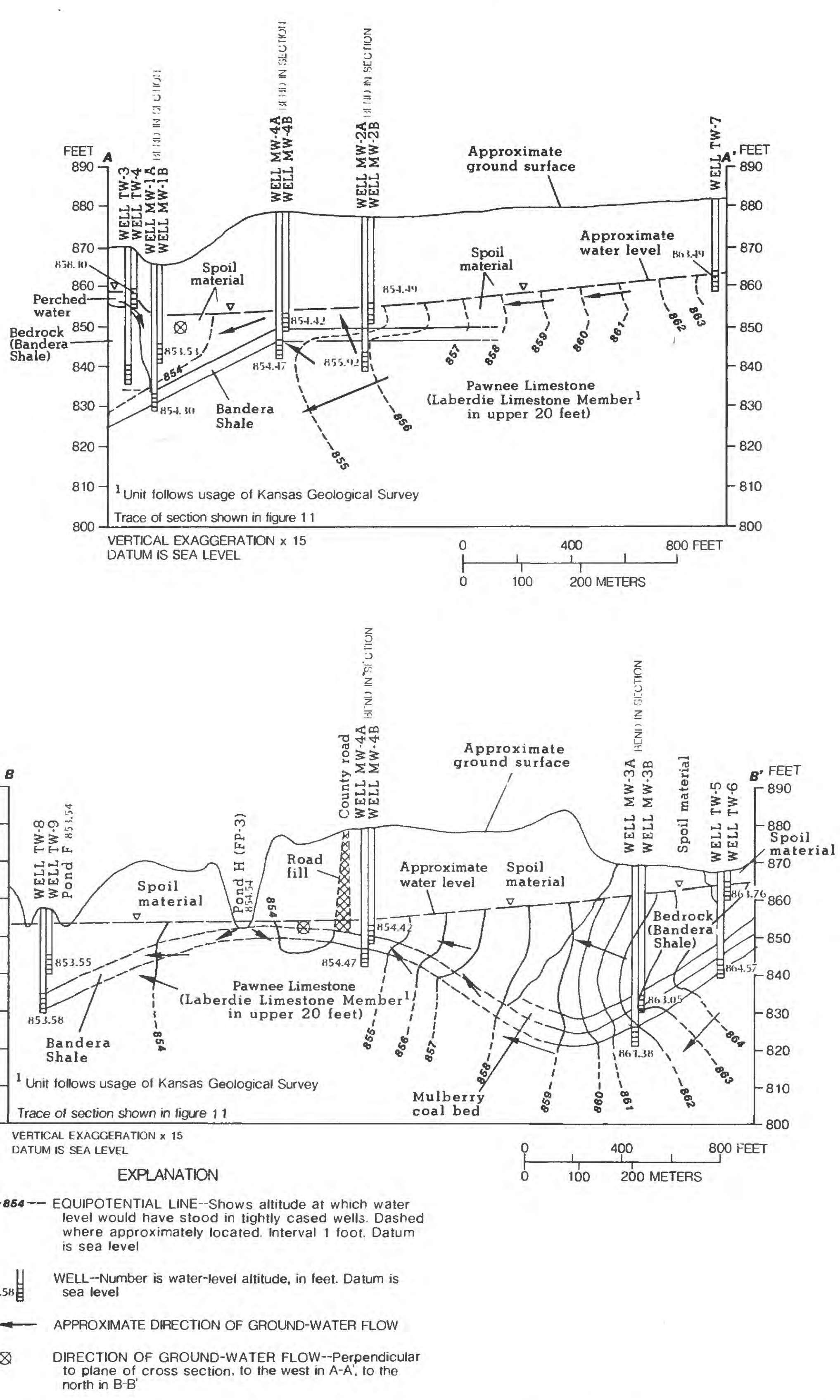


Figure 13. Hydrogeologic sections showing equipotential lines, January 9, 1989, (A) A-A' and (B) B-B'.

where a slight mounding of ground water is evident from the deflection of potentiometric contours near wells MW-4A and MW-4B in figures 12 A, B, C, and D.

Surface ponding of water in the abandoned mine-haul roads also affects ground-water flow. Data indicate that the ponds recharge the aquifers within the limits of the strip-mined area. The recharge from these ponds apparently is dominant in determining local flow within the strip-mined area, at least at the times when water levels were measured during this investigation. Data collected during an 8-month period support this finding. It is possible that due to the lack of significant precipitation immediately prior to water-level measurements, seasonal or temporary variations in this aspect of water movement were not observed. During periods of intense rainfall, aquifer recharge from these ponds may not play as significant a role and may even have an opposite effect on base flow in that water actually may flow from the spoil material into the ponds and from the spoil material horizontally or vertically into bedrock in places where water movement is currently in the opposite direction. If this situation of changing flow patterns does occur, it will change the pattern of ground-water movement and leachate transport in the landfill area.

The county road trending north-south on the west side of the landfill represents the greatest disturbance of shallow ground-water flow in the spoil (fig. 12 A, B, C, D). On either side of the road, along the northern edge of the strip-mined area, water levels in ponds about 100 feet apart differ by about 10 feet, the east-side water surface being 10 feet higher than the west-side water surface. The hydraulic gradient between them is steep, sloping to the west. Apparently, the road material is very compacted and retards ground-water flow.

The overall direction of ground-water movement in the spoil material through the landfill site is from the northeast to the southwest, except in the northeast part of the landfill expansion area where flow is to the northeast (fig. 12 A, B, C, D). The direction of movement in the current disposal area is from east to west, with a slight southerly component. On the basis of pond water-level altitudes, the direction of ground-water movement in the strip-mined area west of the county road ranges from north to southwest. Ground-water flowing west and northwest through the spoil material eventually would be intercepted by the ponds along the west and northwest edges of the strip-mined area.

In the northeast part of the expansion area, a ground-water divide is apparent, trending northwest-southeast (fig. 12 A, B, C, D). Southwest of the divide, ground-water flows to the southwest, but northeast of the divide, ground-water flows northeasterly. Flow north of the divide also would be intercepted by pond B.

Ground-water flow in the Pawnee Limestone appears to be generally southwest, as shown by a potentiometric-surface map (fig. 14) for January 9, 1989, water levels in wells screened in the Laberdie Limestone Member of the Pawnee Limestone. West of the landfill, the flow in bedrock also appears to be southwestward. The flow directions in places are oblique to the local structure of the top of the Pawnee Limestone (fig. 15). The structure contours in figure 15 show minor departures from the regional northwest dip, and the flow directions may represent local perturbations from regional northwest flow.

Between spoil-material ground water and Pawnee Limestone ground water, the relatively impermeable 3 or 4 feet of basal Bandera Shale, where left in place during strip mining, provides a barrier to ground-water flow. Even though these two ground-water systems are separate for the most part, they are interconnected where the basal shale and the limestone were excavated during mining and possibly also at local fractures and faults. These interconnections provide pathways for water from the spoil material and water from the limestone to migrate between aquifers and transport chemical constituents between them. The direction of water movement between aquifers would depend on relative hydraulic pressures within each aquifer and could vary on a seasonal basis and among geographic locations. At the times water levels were measured, an upward hydraulic gradient existed between the Laberdie Limestone Member and the spoil (table 4, figs. 12A, B, C, D; 13; and 14).

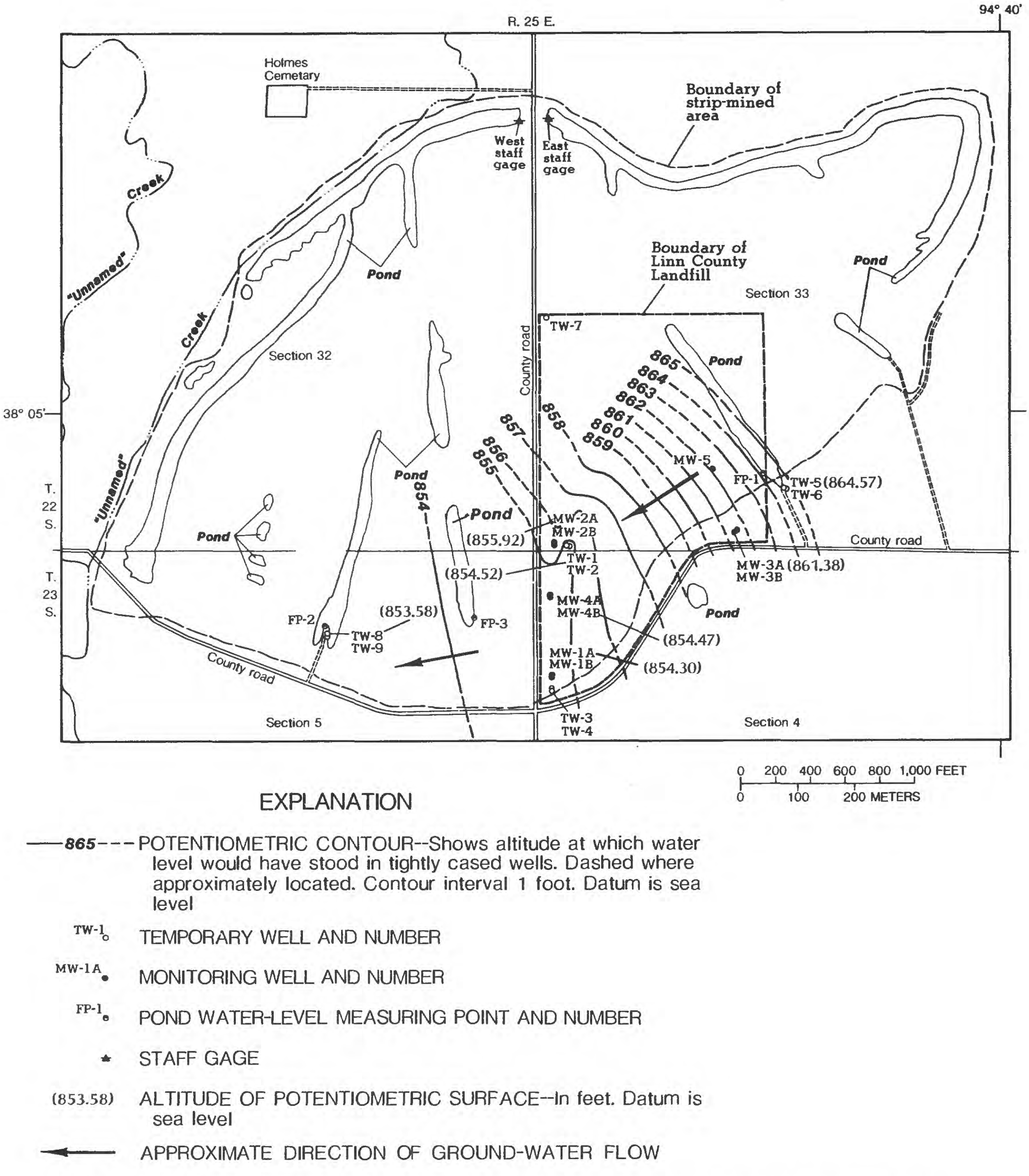
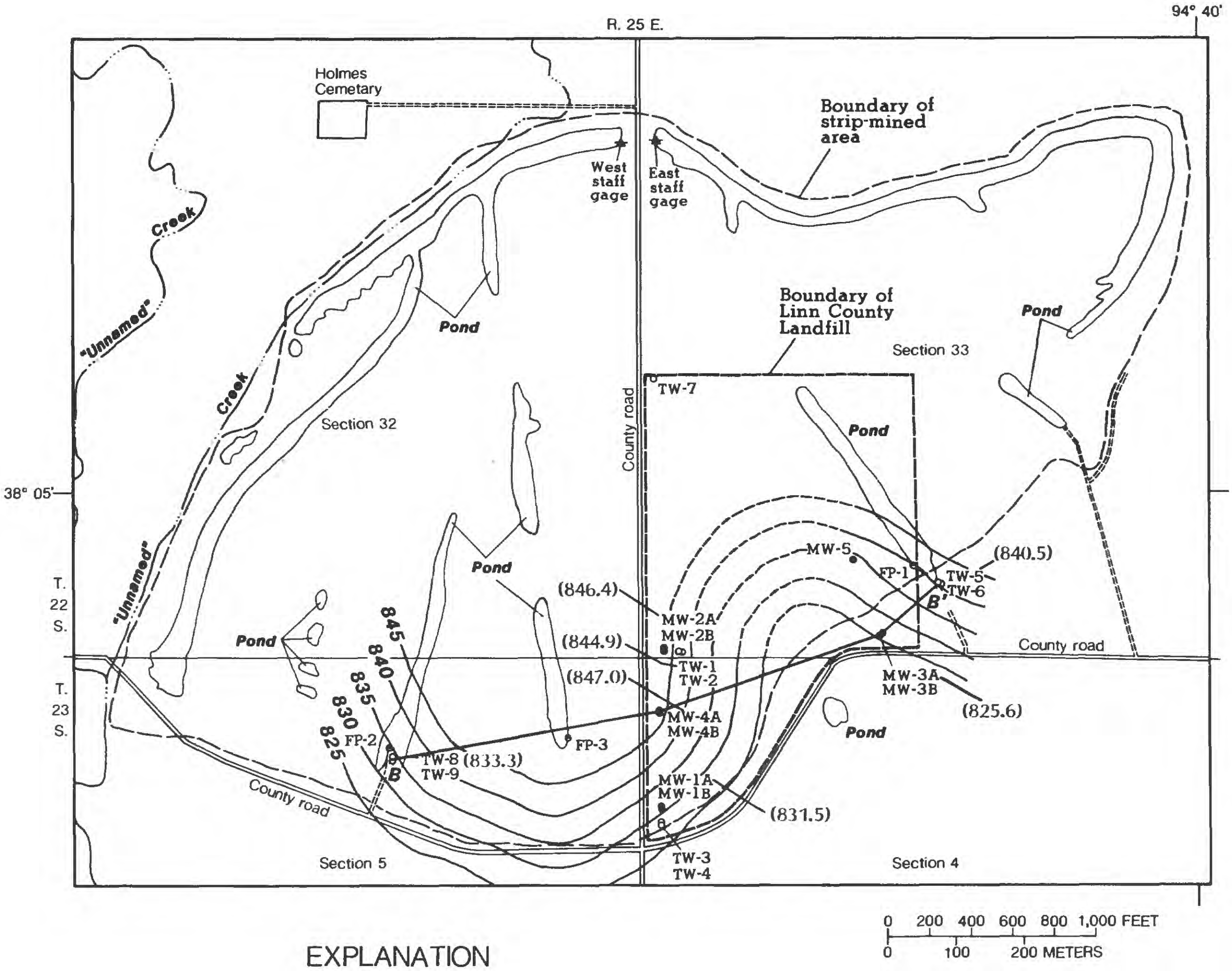


Figure 14. Potentiometric surface of water in Pawnee Limestone in part of landfill area, January 9, 1989.

Hydraulic conductivity was determined for spoil material and for the Pawnee Limestone from slug-test data using analysis methods from Nguyen and Pinder (1984). With one exception, tests in the spoil material indicated much greater hydraulic conductivity than tests in the limestone (table 5). Test data from a Pawnee Limestone well (MW-1A) indicated a hydraulic conductivity much larger than the other tests in limestone and nearly as large as tests in the spoil material. Due to this relatively large hydraulic conductivity, it is thought that well MW-1A penetrated the limestone at or very near a fracture zone. Fractures within a limestone aquifer normally provide a pathway through which water can move much more readily than it is possible for water to move through the



EXPLANATION

—825--- STRUCTURE CONTOUR--Shows altitude of top of Pawnee Limestone. Dashed where approximately located. Contour interval 5 feet. Datum is sea level

TW-1○ TEMPORARY WELL AND NUMBER

MW-1A● MONITORING WELL AND NUMBER

FP-1◉ POND WATER-LEVEL MEASURING POINT AND NUMBER

★ STAFF GAGE

(833.3) ALTITUDE OF TOP OF PAWNEE LIMESTONE--In feet. Datum is sea level

Figure 15. Structure contours showing altitude of top of Pawnee Limestone in part of landfill area.

unfractured limestone. The average hydraulic conductivity of the underlying Pawnee Limestone, based on slug-test results, is 14.0 feet per day. The average hydraulic conductivity of the spoil material was 59.7 feet per day. The only well screened in Mulberry coal (well MW-3B) had a hydraulic conductivity of 3.0 feet per day.

The actual velocity of movement of water 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, 1987):

$$\bar{v} = \frac{-Kdh}{ndl} , \qquad (1)$$

where

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

K = hydraulic conductivity, in feet per day;

Table 5. *Hydraulic conductivity calculated from monitoring-well slug-test data using the methods of Nguyen and Pinder (1984)*

Well (fig. 5)	Hydraulic conductivity (feet per day)	Aquifer material
MW-1A	37	Pawnee Limestone
MW-1B	83	Mine spoil
MW-2A	2	Pawnee Limestone
MW-2B	50	Mine spoil
MW-3A	--	Pawnee Limestone
MW-3B	3	Mulberry coal
MW-4A	3	Pawnee Limestone
MW-4B	46	Mine spoil
MW-5	--	Mine spoil

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

and

n = porosity, in percent (Heath, 1987).

Typical hydraulic gradients on January 9, 1989, in the active landfill area were 0.00625 for the spoil material and 0.0125 for the Pawnee Limestone. From equation 1, the average linear velocity of ground-water movement is about 1.7 feet per day in the spoil material and about 4.6 feet per day in the Pawnee Limestone (directions vary as shown in figures 12 and 14) as calculated using the maximum observed hydraulic conductivity for spoil material (83 feet per day) and the Pawnee Limestone (37 feet per day) and porosity values of 30 percent for spoil material and 10 percent for limestone. These rates of ground-water movement could be exceeded in the heterogenous spoil material and in limestone fractures.

REGIONAL WATER QUALITY

In Linn County, analyses of ground-water samples collected by Seevers (1969) indicated that dissolved-solids concentrations are generally larger in water from wells screened in bedrock than in water from wells screened in alluvium. Ground water from all sources had relatively large calcium carbonate hardness (18 to 1,070 mg/L, milligrams per liter). Chloride concentrations ranged from 5.0 to 2,800 mg/L; chloride concentrations in water from more than 100 feet deep may be expected to exceed the 250-mg/L Kansas secondary drinking-water standard (Kansas Department of Health and Environment, 1986). Large iron concentrations are possible, as water-sample concentrations ranged from 0.01 to 5.2 mg/L (Seevers, 1969). Relatively large fluoride concentrations, among sample results ranging from 0.4 to 363 mg/L, apparently were associated with phosphate in black shale (Seevers, 1969). Sulfate concentrations ranged from 4.1 to 608 mg/L, with larger concentrations in water from bedrock wells in contact with black shale and coal containing pyrite and other sulfide minerals (Seevers, 1969).

In coal strip-mine areas of Linn County, ground-water chemistry is affected by the presence of sulfide minerals, such as pyrite or marcasite, in the coal. Calcium, magnesium, bicarbonate, sulfate ions are found in increased concentrations in ground water from strip-mine areas due to oxidation of the sulfide minerals and accompanying acid formation, followed by dissolution of limestone and the removal, as carbonate precipitate, of the iron, lead, and zinc originally in the sulfide (Kenny and others, 1982).

Sampling of water from monitoring wells in spoil material and in coal refuse was conducted by Mesko (1987) at the Tiger Worland mine, Missouri, 7 miles northeast of the Linn County Landfill. Like some of the mining in the vicinity of the landfill, that at the Tiger Worland mine had been done in the early 1930's by conventional furrow methods. Thereafter, until 1957, the site was used as a dumping ground for coal refuse from a nearby processing plant. In a 1984-85 reclamation project, the spoil-pile and coal-refuse areas were leveled, and coal exposures remaining were covered with clay. In the Mesko study (1987), 15 monitoring wells were installed, 2 upgradient and 13 inside the mined area. Of the 13, 8 were along the upgradient edge. The other 5, in the central part, have water samples that probably best reflect chemical characteristics developing in place. Characteristics of 3 of these wells are attributable to water in contact with coal refuse, and characteristics of the other 2 wells are attributable to water in contact with spoil material.

The three wells sampling coal-refuse water at the Tiger Worland mine were in an elongated area where coal refuse was thickest (Mesko, 1987). Mean pH was about 3.5, and mean concentrations of significant constituents in water from these wells were 440 mg/L, calcium plus magnesium; 60 mg/L, sodium plus potassium; 1.0 mg/L, chloride; 4,430 mg/L, sulfate; and 1,000 mg/L, iron. The two wells representing spoil material were on either side of the elongated area. Mean pH of water from these wells was about 6.5, and mean concentrations of significant constituents were 560 mg/L, calcium plus magnesium; 170 mg/L, sodium plus potassium; 6.0 mg/L, chloride; 2,300 mg/L, sulfate; and 40 mg/L, iron (Mesko, 1987).

LANDFILL-AREA WATER QUALITY

Twelve sources of water were sampled and used for an analysis of water quality in the landfill area. Four water samples were from wells screened in the Pawnee Limestone (MW-1A, MW-2A, MW-3A, and MW-4A), one was from an upgradient well screened in the spoil material (MW-5), one was from a downgradient well screened in the spoil material (MW-1B), one was from a well screened in the trash (MW-4B), one was from a well screened in the spoil material adjacent to and downgradient from a septic-tank waste-disposal area (MW-2B), one was from a well screened in the Mulberry coal (MW-3B), and one was from pond A. Results of the analysis of these samples are presented in tables 6 and 7.

None of the values of water properties or concentrations of inorganic compounds measured exceeded Kansas or Federal primary drinking-water standards (table 6). However, the concentrations of total hardness, sulfate, dissolved solids, iron, and manganese exceeded Kansas secondary drinking-water standards for some or all of the monitoring-well and pond A water samples.

Water Properties

Specific conductance of samples from monitoring wells and pond A ranged from 1,600 µS/cm (microsiemens per centimeter at 25 °C) in water from pond A to 3,900 µS/cm in water from well MW-2B. These values indicate a large ion concentration in ground and surface water.

Values for pH ranged from 6.4 in water from well MW-1A to 8.4 in water from pond A. The pH of water in all nine monitoring-well samples was between 6.4 and 6.9. Water temperatures varied between samples primarily as a function of the date of sampling and the depth of the well. These temperature differences would cause some variation in the pH values observed. Water from the shallowest well, MW-5 (8.7 feet deep), had a temperature of 8.0 °C, whereas water from the remainder of the wells had temperatures between 14.0 and 16.5 °C. The temperature of pond-A water was 11.0 °C at the time of sampling but would vary seasonally.

Dissolved-oxygen concentrations for water analyzed in seven wells ranged from 0.6 mg/L in water from wells MW-2A and MW-4B to 2.5 mg/L in water from well MW-3B.

Chemical oxygen demand was determined for all samples. The smallest chemical oxygen demand was 18.0 mg/L in water from well MW-3B and the largest, 91.0 mg/L, in water from well MW-3A. In wells where both dissolved-oxygen concentrations and chemical oxygen demand were determined, a large value for dissolved oxygen would correspond to a small value for

Table 6. *Physical properties and inorganic constituents detected in water samples*

[Units of measurement: µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; except as noted. <1.0, constituent not detected at a detection limit of 1.0 µg/L; --, not analysed]

Sampling site (fig. 5)	Date (month-day-year)	Aquifer source material	Specific conductance (µS/cm)	pH (standard units)	pH, labotatory (standard units)	Water temperature (degree Celsius)	Turbidity (Jackson turbidity units)	Oxygen, dissolved (mg/L)	Chemical oxygen demand, total (mg/L)	Hardness, total (mg/L as $CaCO_3$)
MW-1A	03-02-89	Pawnee Limestone	2,620	6.4	6.7	14.0	30	1.9	28.0	1,700
MW-1B	03-02-89	Mine spoil	2,600	6.5	6.9	14.0	35	.9	31.0	1,700
MW-2A	03-03-89	Pawnee Limestone	3,000	6.5	7.0	16.5	460	.6	81.0	2,800
MW-2B	03-03-89	Mine spoil	3,900	6.9	6.8	16.0	1,100	--	89.0	2,200
MW-3A	03-02-89	Pawnee Limestone	3,450	6.9	7.2	14.5	40	--	91.0	1,200
MW-3B	03-02-89	Mulberry coal	3,650	6.6	6.9	14.0	800	2.5	18.0	2,300
MW-4A	03-03-89	Pawnee Limestone	3,000	6.6	6.8	16.0	290	.9	61.0	2,100
MW-4B	03-03-89	Mine spoil	2,900	6.7	6.7	16.0	1,400	.6	73.0	2,000
MW-4B[1]	03-03-89	Mine spoil	2,900	6.6	6.7	16.0	900	.6	56.0	2,000
MW-5	03-02-89	Mine spoil	2,500	6.6	6.9	8.0	950	1.0	73.0	1,700
Pond A	03-15-89	--	1,600	8.4	8.0	11.0	3	--	21.0	1,000
Rural water	03-03-89	--	420	7.6	7.5	4.5	.4	--	--	210
Prescott	03-15-89	--	280	7.8	7.5	7.0	.6	--	--	97
Kansas drinking-water standards[2]										
Primary			--	--	--	--	41.0	--	--	--
Secondary			--	6.5-8.5	6.5-8.5	--	--	--	--	400
Federal primary drinking-water standards[3]			--	--	--	--	--	--	--	--

Table 6. *Physical properties and inorganic constituents detected in water samples*--Continued

Sampling site (fig. 5)	Date (month-day-year)	Calcium, dis-solved (mg/L as Ca)	Magne-sium, dis-solved (mg/L as Mg)	Sodium, dis-solved (mg/L as Na)	Potas-sium, dis-solved (mg/L as K)	Bicar-bonate, cal-cu-lated (mg/L as HCO_3)	Alka-linity, total field (mg/L as $CaCO_3$)	Alka-linity, total labor-atory (mg/L as $CaCO_3$)	Sulfate, dis-solved (mg/L as SO_4)	Chlo-ride, dis-solved (mg/L as Cl)
MW-1A	03-02-89	360	190	100	5	700	580	510	1,400	11
MW-1B	03-02-89	360	180	100	4	660	540	500	1,300	10
MW-2A	03-03-89	420	410	180	10	730	600	610	2,600	26
MW-2B	03-03-89	600	160	49	3	830	680	580	1,700	21
MW-3A	03-02-89	190	170	580	9	770	630	630	1,800	30
MW-3B	03-02-89	410	310	170	9	780	640	540	2,200	12
MW-4A	03-03-89	550	170	63	5	780	640	620	1,700	19
MW-4B	03-03-89	540	170	61	4	770	630	500	1,600	17
MW-4B[1]	03-03-89	530	160	61	4	760	620	470	1,500	19
MW-5	03-02-89	420	160	66	3	420	340	380	1,500	3.0
Pond A	03-15-89	210	120	46	5	130	110	150	1,000	4.9
Rural water	03-03-89	75	5.7	7.9	2	--	--	140	60	9.5
Prescott	03-15-89	32	4.1	21	3	--	--	80	35	9.9
Kansas drinking-water standards[2]										
Primary		--	--	--	--	--	--	--	--	--
Secondary		--	--	--	--	--	--	--	250	250
Federal primary drinking-water standards[3]		--	--	--	--	--	--	--	--	--

Table 6. *Physical properties and inorganic constituents detected in water samples*--Continued

Sampling site (fig. 5)	Date (month-day-year)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Solids, sum of constituents, dissolved (mg/L)	Nitrogen, nitrate, dissolved (mg/L as N)	Nitrogen, ammonia, dissolved (mg/L as N)	Phosphorous, dissolved (mg/L as P)	Arsenic dissolved (µg/L as As)	Barium, dissolved (µg/L as Ba)	Cadmium dissolved (µg/L as Cd)
MW-1A	03-02-89	0.2	12	2,360	<0.01	0.14	0.03	3	40	1
MW-1B	03-02-89	.2	12	2,260	<.01	.12	.07	3	<10	<1
MW-2A	03-03-89	.7	16	4,030	<.01	.66	.05	<1	40	<1
MW-2B	03-03-89	.4	15	2,880	<.01	.16	.33	2	70	1
MW-3A	03-02-89	.8	13	3,140	<.01	1.7	.06	<1	10	<1
MW-3B	03-02-89	.3	24	3,430	<.01	1.1	.12	<1	80	<1
MW-4A	03-03-89	.3	15	2,890	<.01	.94	.29	1	30	<1
MW-4B	03-03-89	.4	14	2,680	<.01	.68	.77	3	<10	<1
MW-4B[1]	03-03-89	.4	13	2,620	<.01	.69	.27	3	120	<1
MW-5	03-02-89	.2	9.3	2,370	<.01	.19	1.0	2	<10	1
Pond A	03-15-89	.2	.2	1,480	.04	.06	.07	6	<10	<1
Rural water	03-03-89	.9	5.6	253	.36	--	.01	--	--	--
Prescott	03-15-89	.2	1.6	157	.14	.05	.06	--	--	--
Kansas drinking-water standards[2]										
Primary		1.8	--	--	10.0	--	--	50	1,000	10
Secondary		--	--	500	--	--	--	--	--	--
Federal primary drinking-water standards[3]		1.4	--	--	10.0	--	--	50	1,000	10

Table 6. *Physical properties and inorganic constituents detected in water samples*--Continued

Sampling site (fig. 5)	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 Ag)	Zinc, dissolve (µg/L as Zn
MW-1A	03-02-89	<10	20	1,100	<1	3,500	0.5	<1	2	30
MW-1B	03-02-89	<10	20	110	<1	3,300	<.5	<1	3	30
MW-2A	03-03-89	<10	30	900	<1	610	<.5	<1	3	20
MW-2B	03-03-89	<10	30	1,500	<1	5,100	<.5	<1	2	30
MW-3A	03-02-89	<10	20	310	<1	120	.5	2	1	<10
MW-3B	03-02-89	<10	20	140	<1	220	<.5	<1	2	10
MW-4A	03-03-89	<10	20	25,000	<1	5,100	<.5	<1	2	20
MW-4B	03-03-89	<10	20	18,000	<1	6,300	<.5	<1	2	30
MW-4B[1]	03-03-89	<10	20	20,000	<1	6,200	<.5	<1	1	20
MW-5	03-02-89	<10	10	40	<1	4,100	<.5	<1	2	3,600
Pond A	03-15-89	<10	20	10	3	320	<.5	<1	3	<10
Rural water	03-03-89	--	--	80	--	40	--	--	--	--
Prescott	03-15-89	--	--	300	--	20	--	--	--	--
Kansas drinking-water standards[2]										
Primary		50	--	--	50.	--	2.0	10.0	50	--
Secondary		--	1,000	300	--	50	--	--	--	5,000
Federal primary drinking-water standards[3]		50	--	--	50.	--	2.0	10.0	50	--

---

[1] Duplicate sample.

[3] Kansas Department of Health and Environment (1986).

[2] U.S. Environmental Protection Agency (1986; 1987)

[4] Treated drinking water.

Table 7. *Organic compounds detected in water samples*

[Concentrations in milligrams per liter (mg/L) or micrograms per liter (µg/L)]

Compound	Monitoring well (fig. 5)										Pond A	Rural water supply	Prescott water supply	Drinking-water standard		
	MW-1A	MW-1B	MW-2A	MW-2B	MW-3A	MW-3B	MW-4A	MW-4B	MW-4B[1]	MW-5				KNL[2]	KAL[3]	KPDWS[4]
Dissolved organic carbon (mg/L)	1.4	1.4	3.0	4.3	2.8	1.3	4.9	5.1	5.0	1.7	6.5	--	--	--	--	--
Methylene blue active substances (mg/L)	.45	.36	.33	.46	.63	<.20	1.3	1.0	1.0	.24	.40	--	--	--	--	--
Benzene (µg/L)	<.50	<.50	<.50	<.50	.90	<.50	<.50	<.50	<.50	<.50	--	<0.50	<0.50	0.67	6.7	5.0
Carbon tetrachloride (µg/L)	<.70	1.8	<.70	<.70	<.70	<.70	<.70	<.70	<.70	<.70	--	<.70	<.70	.27	2.7	5.0
Chlorodibromomethane (µg/L)	<.70	<.70	<.70	<.70	<.70	<.70	<.70	<.70	<.70	<.70	--	<.70	2.3	[5]100	(5)	--
Chloroform (µg/L)	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	--	40	72	[5]100	(5)	--
Dichlorobromomethane (µg/L)	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	--	8.4	17	[5]100	(5)	--
1,1-dichloroethane (µg/L)	<.50	<.50	<.50	3.0	<.50	<.50	<.50	1.4	1.5	<.50	--	<.50	<.50	(6)	(7)	--
1,1,1-trichloroethane (µg/L)	<.70	<.70	<.70	.70	<.70	<.70	<.70	<.70	<.70	<.70	--	<.70	<.70	16.8	168	200
Total trihalomethanes (µg/L)	<.70	<.70	<.70	<.70	<.70	<.70	<.70	<.70	<.70	<.70	--	48.4	91.3	[5]100	(5)	--

[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] KPDWS, Kansas primary drinking-water standard (Kansas Department of Health and Environment, 1986).
[5] Total of all trihalomethane compounds not to exceed 100 micrograms per liter.
[6] Any positive detection.
[7] Insufficient data to establish standard.

chemical oxygen demand, or a small dissolved-oxygen concentration would correspond to a large chemical oxygen demand as is evidenced in water from well MW-3B, which has the largest dissolved-oxygen concentration and the smallest chemical oxygen demand. Chemical oxygen demand was largest in water from two wells (MW-2B and MW-3A) that had water levels too low to determine dissolved-oxygen values.

Total hardness, expressed in milligrams per liter of $CaCO_3$, was determined for each sample. Total hardness values of the samples ranged from 1,000 mg/L in water from pond A to 2,800 mg/L in water from well MW-2A.

Alkalinity for well-water samples, as determined onsite and expressed in milligrams per liter of $CaCO_3$, ranged from 340 mg/L in water from well MW-5 to 680 mg/L in water from well MW-2B. The alkalinity of water in pond A was 110 mg/L. Alkalinity data indicate that, as the water enters the ground from pond A, the alkalinity increases as it comes into contact with and travels through aquifer materials. The alkalinity of water in well MW-5, located near pond A, is intermediate in value at 340 mg/L, and the alkalinity of water in the remainder of the wells is larger, indicating a longer period of contact with the aquifer materials. Although wells MW-3A and MW-3B are located nearly as close to pond A as well MW-5, the alkalinity is larger in water from these two wells due to water flowing to these wells from bedrock.

Dissolved Solids and Major Ions

Dissolved-solid concentrations in water from pond A were intermediate at 1,480 mg/L and ranged from 2,260 mg/L in water from well MW-1B to 4,030 mg/L in water from well MW-2A.

Major cations included in the water analyses were calcium, magnesium, sodium, and potassium (table 6). Data for each cation is reported in milligrams per liter of that specific cation. The smallest calcium concentration of 190 mg/L was detected in water from well MW-3A, and the largest concentration of 600 mg/L was detected in water from well MW-2B. The smallest magnesium concentration of 120 mg/L was detected in water from pond A, and the largest concentration of 410 mg/L was detected in water from well MW-2A. Sodium concentrations ranged from 46 mg/L in the water from pond A to 580 mg/L in water from well MW-3A. Potassium concentrations ranged from 3 mg/L in water from wells MW-2B and MW-5 to 10 mg/L in water from well MW-2A.

Major anions included in the analysis were bicarbonate, sulfate, and chloride. Bicarbonate concentrations reported here were calculated from onsite alkalinity data. The bicarbonate concentration in water from pond A was the smallest at 130 mg/L. The smallest bicarbonate concentration from a well was 420 mg/L in water from well MW-5, and the largest concentration of 830 mg/L was in water from well MW-2B. The larger bicarbonate concentrations in water from downgradient wells, as compared to the smaller concentrations in water from pond A and in water from well MW-5, indicate that bicarbonate concentrations increase with prolonged exposure to aquifer materials and landfill wastes. At the pH levels present in water samples from monitoring wells and pond A, carbonate ions and hydroxide ions would not be stable.

The smallest concentration of 1,000 mg/L sulfate was detected in water from pond A, and the largest concentration of 2,600 mg/L was detected in water from well MW-2A. These large sulfate concentrations probably are due to the presence of sulfur and sulfur minerals in the Mulberry coal, which was mined here. Concentrations of sulfate detected in water from the landfill area are shown in figures 16 and 17.

Chloride concentrations in the treated public water were larger than in pond-A water, and in a water sample from the relatively shallow well MW-5, probably due to chlorination during treatment. The smallest chloride concentration of 3.0 mg/L was detected in water from well MW-5, with the largest concentration of 30 mg/L being detected in water from well MW-3A.

On the basis of major ion concentrations, four basic water types can be defined in the Linn County Landfill area and are depicted in figure 18 in the form of stiff diagrams. These four water types are calcium sulfate (wells MW-2B, MW-4A, MW-4B, and MW-5), calcium magnesium sulfate (wells MW-1A, MW-1B, and pond A), magnesium calcium sulfate (wells MW-2A

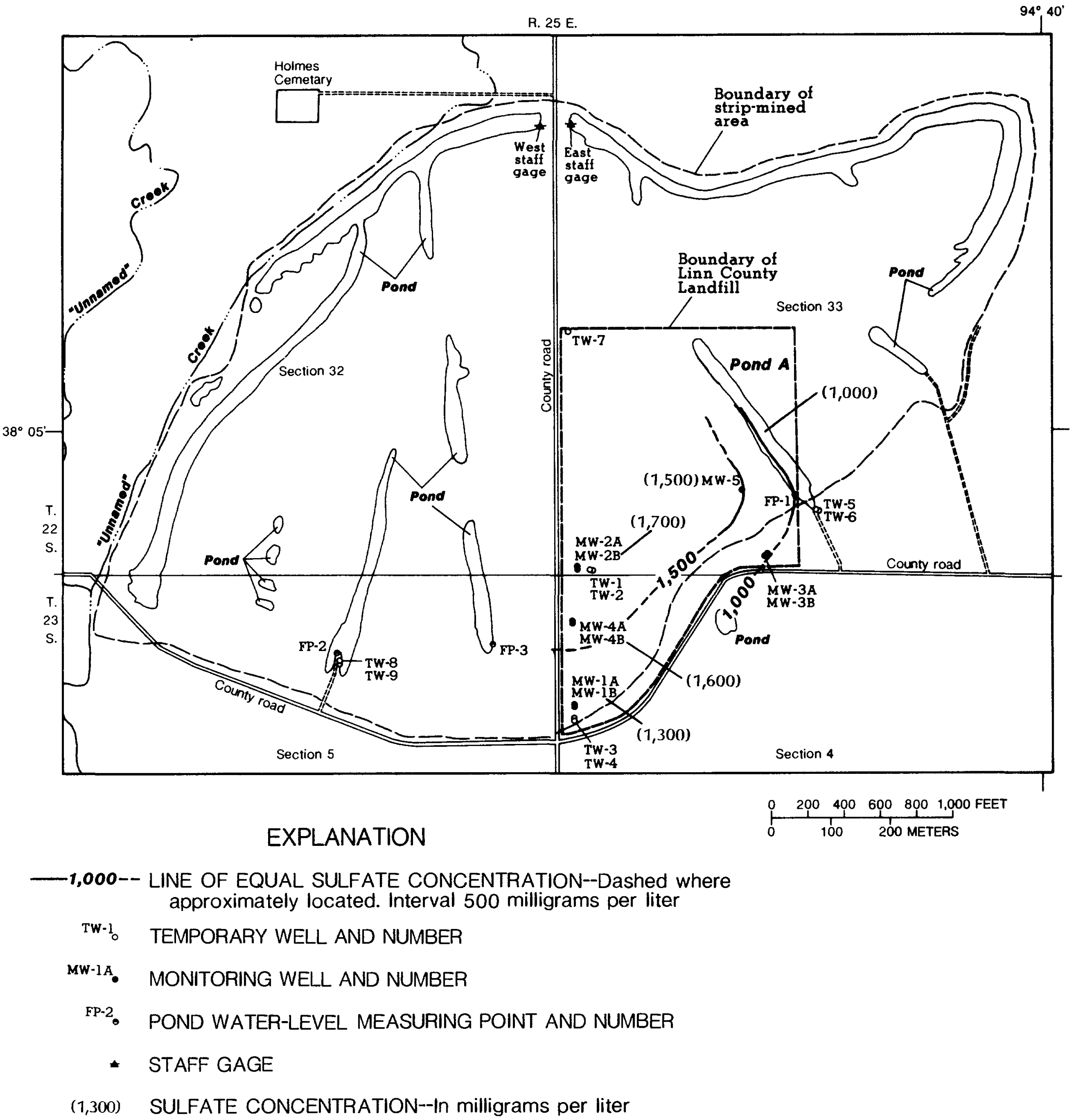


Figure 16. Distribution of sulfate concentrations in water samples from spoil material and pond A.

MW-3B), and sodium potassium sulfate (well MW-3A).

Nutrients

Nitrate is expressed as nitrogen in milligrams per liter in this report. All nine of the monitoring wells had nitrate concentrations smaller than the detection limit of 0.01 mg/L. Water in pond A had 0.04 mg/L nitrate. All these concentrations are less than the State and Federal primary drinking-water standard of 10 mg/L for nitrate (see table 6).

Ammonia is expressed also as nitrogen in milligrams per liter in this report. Ammonia concentrations ranged from 0.06 mg/L in water from pond A to 1.7 mg/L in water from well MW-3A. These concentrations of ammonia, lack of nitrate, and small dissolved-oxygen concentrations indicate that a mildly reducing environment currently is present in this area.

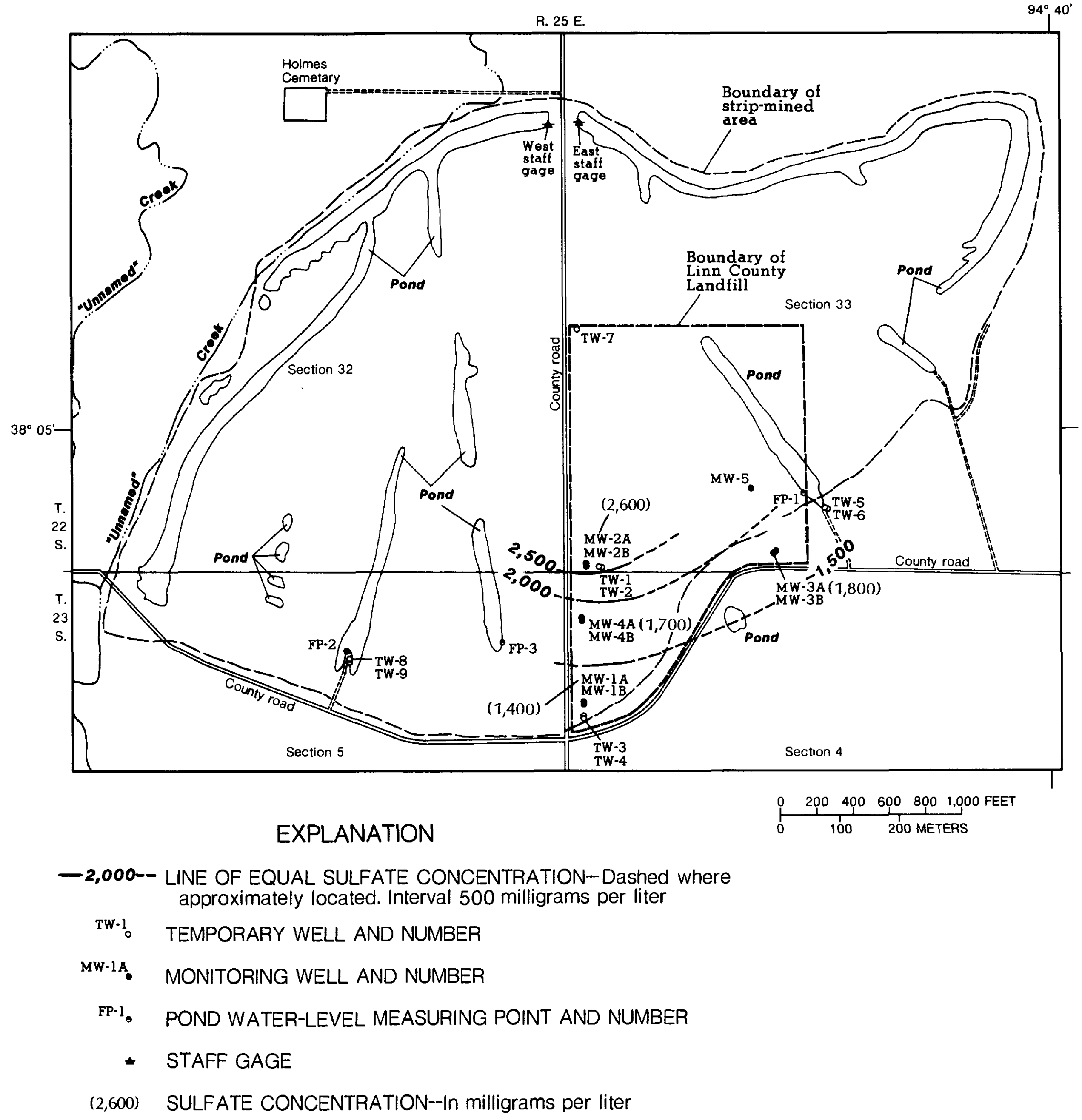


Figure 17. Distribution of sulfate concentrations in water samples from Pawnee Limestone.

Phosphorus, reported in milligrams per liter, ranged from 0.03 mg/L in water from well MW-1A to 1.0 mg/L in water from well MW-5.

Trace Elements

In addition to major ions, analyses were conducted for several inorganic trace elements in water samples from monitoring wells and pond A. These trace elements were arsenic, barium, cadmium, chromium, copper, iron, lead, manganese, mercury, selenium, silver, and zinc. Of these 12 trace elements, iron, manganese, and zinc had large concentrations.

Iron concentrations ranged from 10 µg/L in water from pond A to 25,000 µg/L in water from well MW-4A (fig. 19). The largest iron concentrations were detected in water from wells MW-4A and MW-4B, which are located in the trash pile, indicating that iron is being derived from landfill waste or from the chemical action of landfill leachate on iron-bearing sediments. Concentrations of manganese ranged from 120 µg/L in water from well MW-3A to 6,300 µg/L in water from well MW-4B (fig. 19). Zinc concentrations were large in water from well MW-5 (3,600 µg/L) and small (<10 to 30 µg/L) in the rest of the samples.

Other Inorganic Constituents

Fluoride concentrations were small in water from pond A and wells MW-1A, MW-1B, and MW-5 at 0.2 mg/L. Dissolved silica was smallest at 0.2 mg/L in water from pond A, at an intermediate concentration of 9.3 mg/L in water from well MW-5, and at 24 mg/L in water from well MW-3B, indicating an increase in concentration with prolonged exposure to aquifer materials.

Organic Compounds

Analyses were conducted for five groups of organic compounds. These were volatile organic

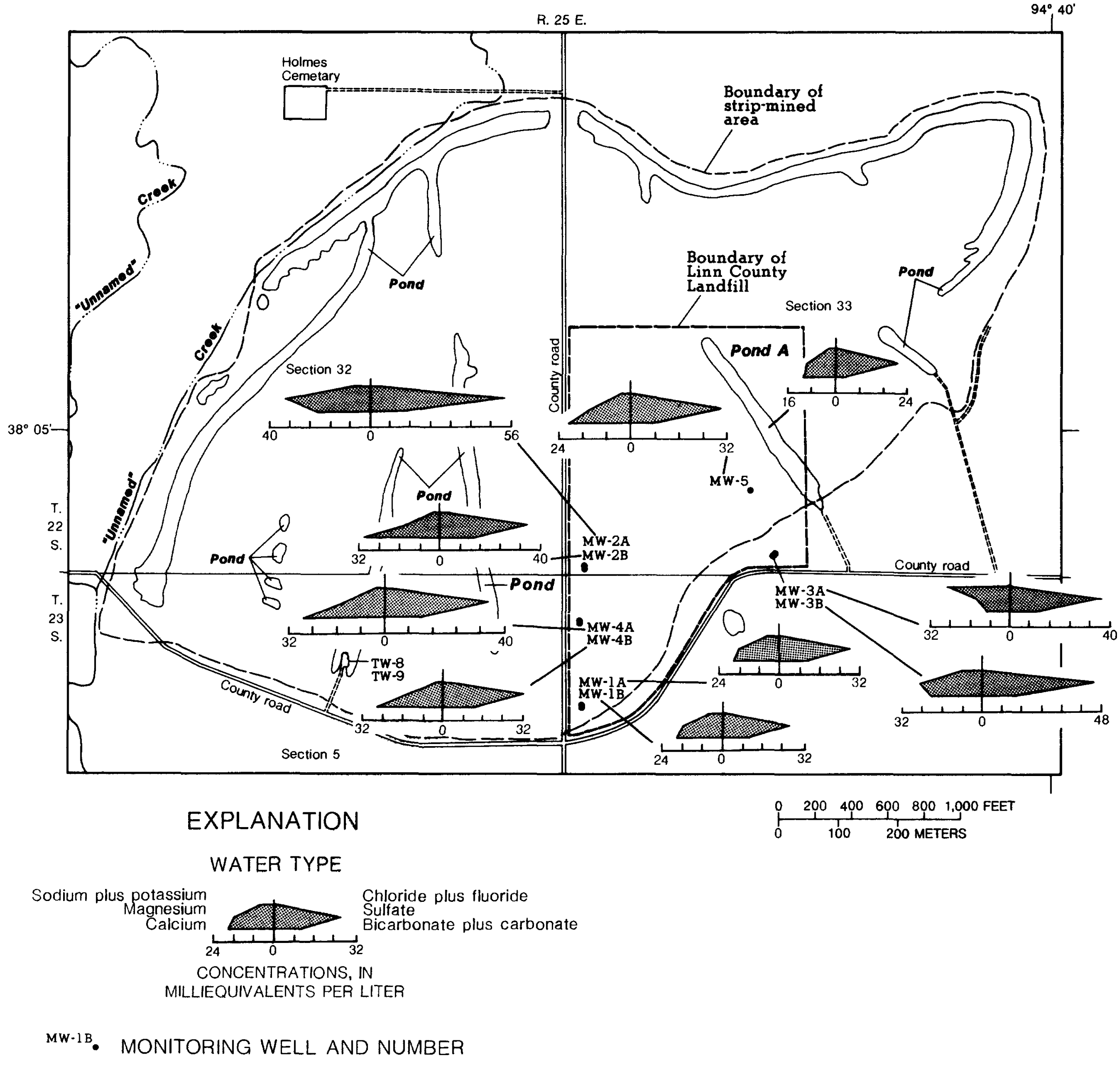


Figure 18. Stiff plots of major ion concentrations in water samples from monitoring wells and pond A.

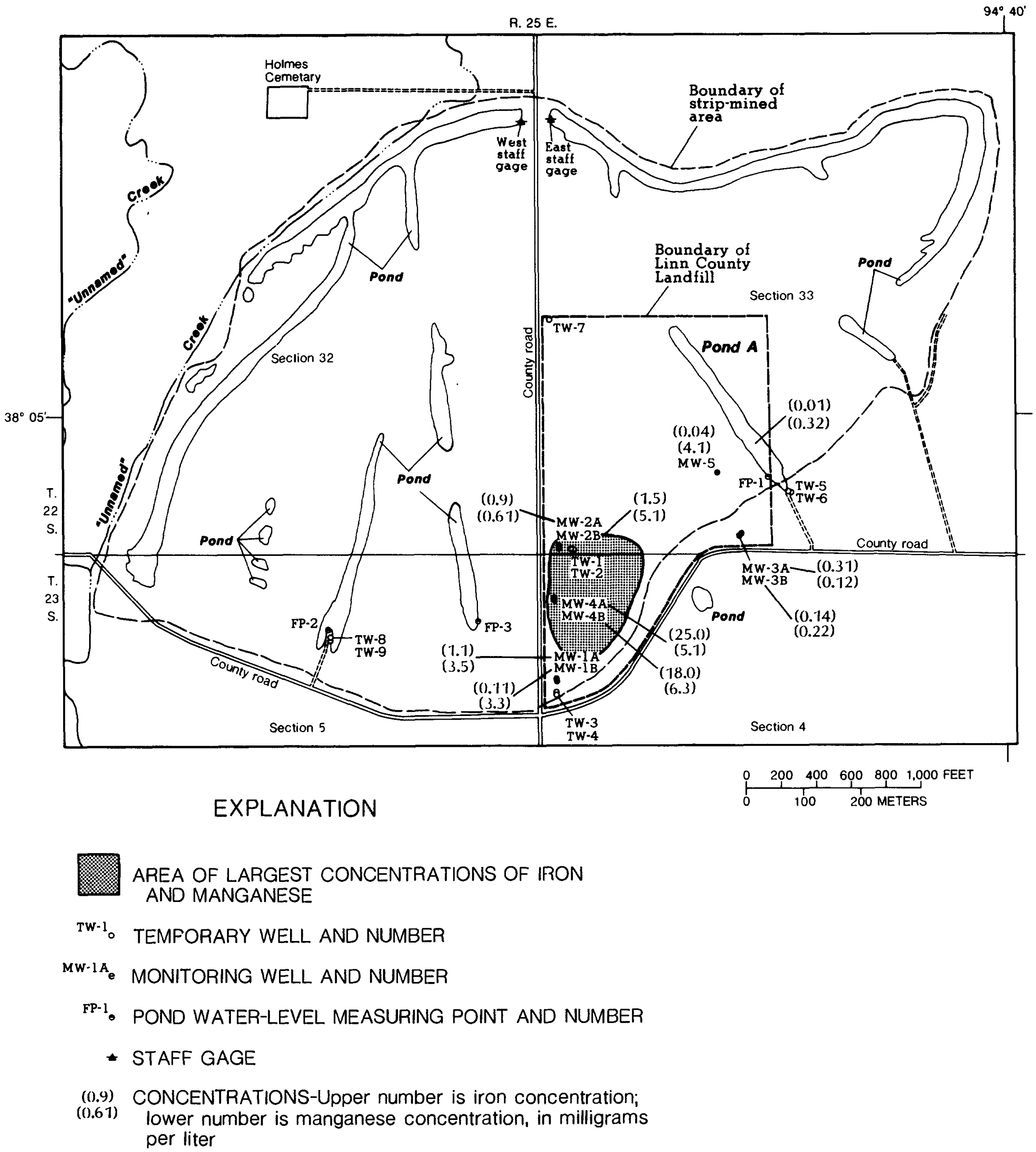


Figure 19. Distribution of iron and manganese concentrations in water samples from monitoring wells and pond A.

compounds, semivolatile acid-extractable organic compounds, semivolatile base-neutral extractable organic compounds, pesticides, and polychlorinated biphenyls. A complete listing of compounds in each of these categories is provided in table 8. Volatile organic compounds were detected in four of the monitoring-well samples. No acid-extractable organic compounds, base-neutral extractable organic compounds, pesticides, or polychlorinated biphenyls were detected at or above the detection limits. Methylene blue active substances (primarily detergents and surfactants) were detected in the pond-A water sample and in all well samples, except in water from well MW-3B. Table 7 contains a listing of all organic compounds detected and their concentrations in pond-A and well samples.

Dissolved-organic-carbon (DOC) concentrations were determined for water samples from the nine monitoring wells and for water from

Table 8. *List of organic compounds for which analyses were done*

Volatile Organic Compounds

benzene
carbon tetrachloride
chlorodibromomethane
chloroform
1,3-dichlorobenzene
dichlorobromomethane
1,2-dichloroethane
1,2-dichloropropane
trans-1,3-dichloropropene
methyl bromide
methylene chloride
tetrachloroethylene
1,2-trans-dichloroethene
1,1,2-trichloroethane
vinyl chloride
p-xylene
bromoform
chlorobenzene
chloroethane
1,2-dichlorobenzene
1,4-dichlorobenzene
1,1-dichloroethane
1,1-dichloroethylene
cis-1,3-dichloropropene
ethylbenzene
methyl chloride
1,1,2,2-tetrachloroethane
toluene
1,1,1-trichloroethane
trichloroethylene
m-xylene

Semivolatile, Acid Extractable

2,4-dichlorophenol
4,6-dinitro-o-cresol
o-chlorophenol
p-nitrophenol
pentachlorophenol
2,4,6-trichlorophenol
2,4-dimethylphenol
2,4-dinitrophenol
o-nitrophenol
parachlorometa cresol
phenol

Semivolatile, Base-Neutral Extractable

acenaphthene
anthracene
1,2,4- trichlorobenzene
benzo (b) fluoranthene
benzo (g,h,i) perylene
bis (2-chloroethoxy) methane
bis (2-ethylhexyl) phthalate
2-chloronaphthalene
chrysene
diethyl phthalate
di-n-butyl phthalate
2,4-dinitrotoluene
fluorene
hexachlorobenzene
hexachloroethane
naphthalene
phenanthrene
acenaphthylene
benzo (a) anthracene
benzo (a) pyrene
benzo (k) fluoranthene
bis (2-chloroethyl) ether
bis (2-chloroisopropyl) ether
4-bromophenylphenylether
4-chlorophenylphenylether
1,2:5,6-dibenzanthracene
dimethyl phthalate
di-n-octyl phthalate
2,6-dinitrotoluene
fluoranthene
hexachlorobutadiene
indeno (1,2,3-c,d) pyrene
butylbenzyl phthalate
pyrene, total

Table 8. *List of organic compounds for which analyses were done*--Continued

Pesticides

alachlor
alpha BHC (benzene hexachloride)
atrazine
chlordane
delta BHC
endosulfan I
endrin
gamma BHC
heptachlor epoxide
metribuzin
p,p' DDE
prometon
propazine
simetryn
trifluralin

aldrin
ametryn
beta BHC
cyanazine
dieldrin
endosulfan II
endosulfan sulfate
heptachlor
metolachlor
p,p' DDD
p,p' DDT
prometryn
simazine
toxaphene

Polychlorinated biphenyls (PCBs)

aroclor 1016
aroclor 1232
aroclor 1248
aroclor 1260

aroclor 1221
aroclor 1242
aroclor 1254

pond A. DOC concentrations are reported in milligrams per liter as carbon (table 7) and are shown plotted in figure 20. Concentrations ranged from 1.3 mg/L in water from well MW-3B to 6.5 mg/L in water from pond A. The expected range for DOC concentrations in ground water is 0.2 to 15 mg/L, with the median concentration of 0.7 mg/L being the most common (Thurman, 1985). Most ground water does not exceed 2 mg/L (Thurman, 1985). Water in eutrophic lakes, such as pond A, can range from 3 to 34 mg/L DOC, with the mean concentration being 10 mg/L (Thurman, 1985).

The presence of coal in sediments can cause a larger-than-normal dissolved-organic-carbon concentration (Thurman, 1985). DOC concentrations in water from wells MW-1A, MW-1B, MW-3B, and MW-5 ranged from 1.3 to 1.7 mg/L and are probably normal for ground water in coal-mine spoil.

DOC concentrations in water from wells MW-2A, MW-2B, MW-4A, and MW-4B ranged from 3.0 to 5.1 mg/L. These wells are positioned in the trash pile or near the sewage-disposal location. The larger DOC concentrations in water from these wells indicate that organic chemicals are present in larger concentrations in the ground water and probably are being derived from landfill wastes. Well MW-3A is an upgradient well that is screened in the Pawnee Limestone and had water with a DOC concentration of 2.8 mg/L. This larger-than-expected DOC concentration is probably a reflection of the 0.90 µg/L concentration of benzene detected in this well as DOC is an indication of dissolved organic compounds in water. It also could be caused by water from the nearby pond A, which had a DOC concentration of 6.5 mg/L.

Benzene, which is produced by petroleum

refining, coal-tar distillation, coal processing, and coal coking, was detected in water from well MW-3A at 0.90 µg/L, with a detection limit of 0.50 µg/L. Carbon tetrachloride, which is used in the manufacture of chlorofluoromethanes and in grain fumigants, fire extinguishers, solvents, and cleaning agents, was detected in water from well MW-1B at 1.8 µg/L, with a detection limit of 0.70 µg/L. 1,1 dichloroethane was detected in water from well MW-2B at 3.0 µg/L and in water from well MW-4B at 1.4 µg/L. The detection limit for this compound is 0.50 µg/L. 1,1 dichloroethane is a constituent in paint, varnish, finish removers, soap, scouring compounds,

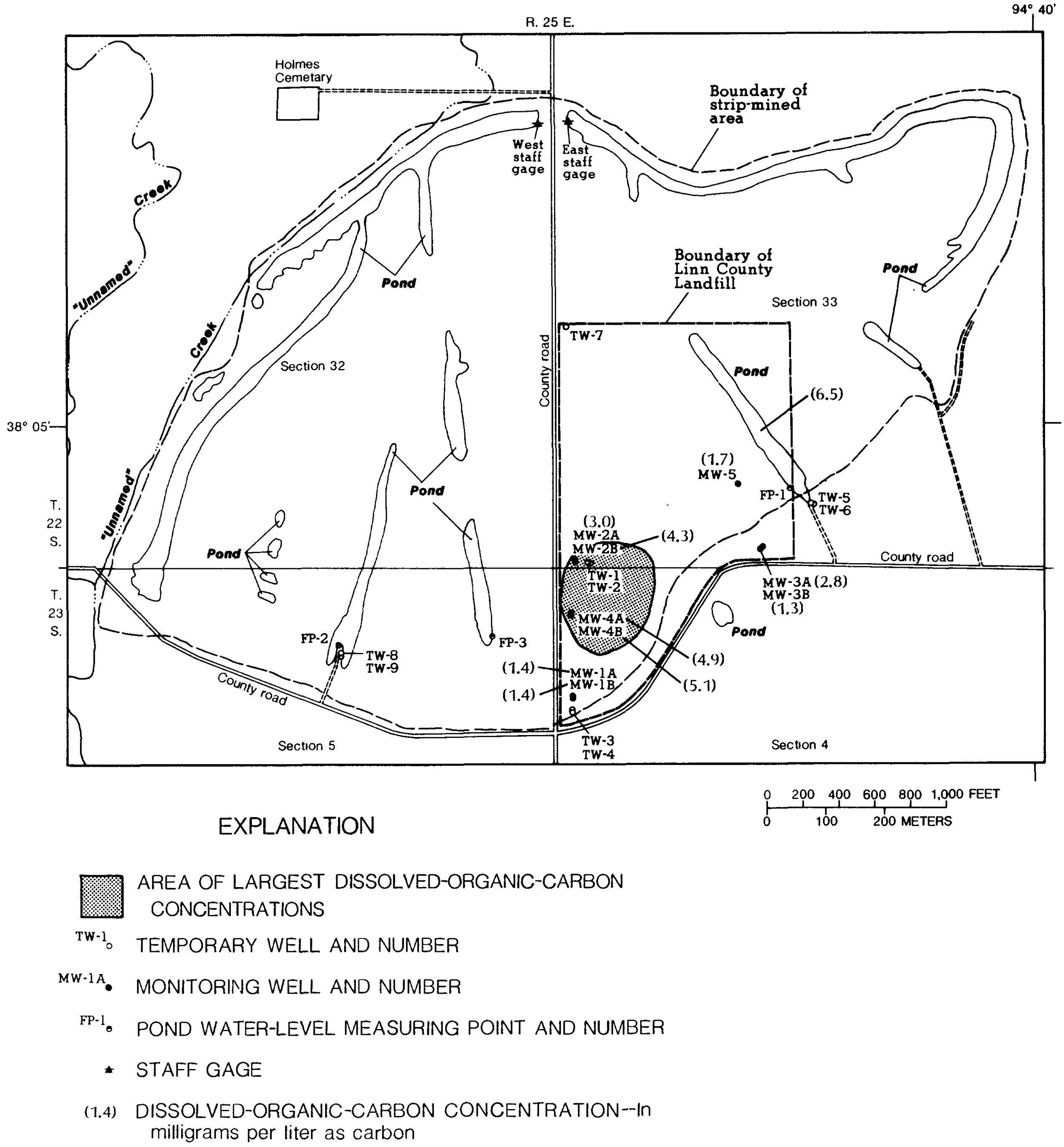


Figure 20. Dissolved-organic-carbon concentrations in water smples from monitoring wells and pond A.

wetting agents, and penetrating agents. It is used also as a metal degreaser. 1,1,1 trichloroethane, which is used as a solvent for fats, oils, waxes, and resins, was detected in water from well MW-2B at the detection limit of 0.70 µg/L. These compounds all indicate the presence of contamination in water from wells in which they were detected. None of the concentrations of organic chemicals detected exceeded Kansas primary drinking-water standards or the Kansas action levels (table 7). However, the concentrations of benzene, carbon tetrachloride, and 1,1-dichloroethane exceeded Kansas notification levels (table 7).

ANALYSIS OF SAMPLES FROM PUBLIC-WATER SUPPLIES

Samples from the rural water supply at the landfill and the city of Prescott water supply were analyzed to provide background chemical data for the potable water used during augering and drilling operations. This was necessary to ensure that monitoring-well water samples were representative of ground-water conditions in the shallow aquifers and had not been altered chemically by the presence of the potable water. Water properties and the concentrations of major ions, nutrients, trace metals, and organic compounds were analyzed for the public-water supply samples. The results of analyses are given in tables 6 and 7.

Water properties determined for public-water supply samples were specific conductance, pH, temperature, turbidity, hardness, alkalinity, and dissolved-solids concentrations. Specific conductance was 420 µS/cm in the rural water supply and 280 µS/cm in Prescott city water. Specific conductance is a measure of the total ion concentration in solution based on the ability of the solution to transmit an electrical current. The pH of the rural water supply and Prescott water was 7.6 and 7.8, respectively. Water temperature was 4.5 °C for the rural water supply and 7.0 °C for the Prescott water. These cool temperatures reflect wintertime pipeline temperatures at shallow ground depths. The small turbidity values of 0.4 and 0.6 JTU (Jackson turbidity units) for the rural water supply and Prescott water, respectively, are a reflection of the clarity of the water. Hardness values for the rural water supply and Prescott water were 210 and 97 mg/L, respectively. Laboratory alkalinity values were 140 mg/L for the rural water supply and 80 mg/L for Prescott water. Dissolved-solids concentrations were 253 mg/L for the rural water supply and 157 mg/L for Prescott water.

Major ion concentrations for the rural water supply and Prescott water, respectively, were 75 and 32 mg/L for calcium, 5.7 and 4.1 mg/L for magnesium, 7.9 and 21 mg/L for sodium, 2 and 3 mg/L for potassium, 60 and 35 mg/L for sulfate, 9.5 and 9.9 mg/L for chloride, 0.9 and 0.2 mg/L for fluoride, and 5.6 and 1.6 mg/L for silica.

Nutrient concentrations were determined for nitrate, expressed as nitrogen, for both public-water supply samples, for ammonia, expressed as nitrogen, for the Prescott water sample, and for phosphorous for both public-water supply samples. Nitrate concentrations were 0.36 mg/L for the rural water supply and 0.14 mg/L for the Prescott water. The ammonia concentration in the Prescott water was 0.05 mg/L. Phosphorous concentrations were 0.01 and 0.06 mg/L for the rural water supply and Prescott water, respectively.

Trace-metal concentrations were determined for iron and manganese in public-water supply samples. Iron concentrations were 80 and 300 µg/L for the rural water supply and Prescott water, respectively. Manganese concentrations were 40 and 20 µg/L for the rural water supply and Prescott water, respectively.

None of the values of water properties or concentrations of inorganic constituents measured exceeded Kansas primary or secondary drinking-water standards. However, the concentration of iron in the Prescott water (300 µg/L) equals the Kansas secondary drinking-water standard for iron. Primary drinking-water standards are established for compounds that can have detrimental health effects. Kansas secondary drinking-water standards are established for compounds that can affect the esthetic qualities of drinking water, such as color or taste.

The public-water supply samples were analyzed for the volatile organic compounds listed in table 8. Of the compounds listed, chlorodibromomethane was detected at a concentration of 2.3 µg/L in the Prescott water; chloroform as detected at concentrations of 40 and 72 µg/L in the rural water supply and Prescott water, respectively; and dichlorobromomethane was detected at concentrations of 8.4 and 17 µg/L in the rural water supply and Prescott water, respectively. These three compounds, known as trihalomethane compounds, are common constituents of water that has been treated with chlorine (National Research Council, 1977). Total trihalomethane concentrations for the rural water supply and Prescott water are 48.4 and 91.3 µg/L, respectively. These concentrations are less than the 100 µg/L Kansas notification and action levels for total trihalomethane compounds in drinking water.

A comparison of the public-water supply, monitoring-well, and surface-water analyses shows that, in general, water from public-water supplies may be distinguished from monitoring-well and surface water by its smaller ion content (table 6) and the lack of any detectable trihalomethane compounds in monitoring-well water and surface water (table 7). This comparison also shows that water from public-water supplies is most similar to water from well MW-5 and pond A. But because no potable water was used in the construction of well MW-5 or in the processing of pond-A samples, this similarity is coincidental and reflects the fact that the source of the rural water and Prescott supplies is lake water (Art Terry, Prescott City Public Works Department, oral commun., November 1988). It is evident that the potable water supplies used during drilling operations did not significantly affect the chemistry of ground-water or surface-water samples.

EFFECTS OF LANDFILL ON WATER QUALITY

Four water types have been defined in the Linn County Landfill area--calcium sulfate, calcium magnesium sulfate, magnesium calcium sulfate, and sodium potassium sulfate (fig. 18). The chemical constituents of the water types all are contributed predominantly by the local lithology, with the possible exception of the sodium and potassium. These two exceptions, which were detected in abundance in water from well MW-3A (table 6, fig. 18), may indicate the presence of water contaminated by landfill wastes. The distribution of the four water types within the study area appears to be the result of a mixing effect of the water from the spoil material and the bedrock. It may be generalized that the calcium sulfate type water originates in the spoil material, and the magnesium calcium sulfate type water originates in the bedrock. The calcium magnesium sulfate type water may be a mix of the two previously mentioned water types. The sodium potassium sulfate type water may be the result of contamination by landfill wastes or ion-exchange processes occurring in the Bandera Shale.

The Bandera Shale reportedly is not continuous across the base of the Linn County Landfill, as discussed previously in the "Landfill Hydrogeology" section, allowing movement of ground water between the Pawnee Limestone and the spoil material. The distributions of sulfate within the spoil material and the underlying limestone show similar patterns, as depicted in figures 16 and 17. This similarity of distributions may reflect the interaction of the water between these two units. The sulfate could originate from sulfate minerals in the limestone or in the spoil.

The largest concentrations of iron and manganese both within the spoil material and within the Pawnee Limestone occur in the same area (fig. 19), which suggests interaction of water between these two units. The larger concentrations of iron and manganese probably result from chemical reactions between landfill leachate and iron and manganese oxides in rocks and sediments. Iron and manganese also may be derived from landfill wastes. The distribution of organic compounds (table 7) and dissolved organic carbon (table 7, fig. 20) indicates that organic compounds are being derived from landfill wastes. The largest concentrations of dissolved organic carbon within the spoil material and the Pawnee Limestone occur in the same area, which further supports the concept of interaction of water between the spoil material and the Pawnee Limestone.

On the basis of the similarity in distribution patterns for sulfate, iron, manganese, and dissolved organic carbon in the spoil material and the Pawnee Limestone and the probable leachate-related source of iron, manganese, and organic compounds, it is evident that leachate contaminated ground water is present in the Pawnee Limestone. This is contrary to the general upward flow of ground water indicated by water-level measurements (figs. 13 A, B). The most reasonable explanation is that, during periods of intense rainfall, the net movement of ground water is downward from the spoil material into the Pawnee Limestone, and this could account for the presence of leachate-contaminated ground water in the Pawnee Limestone.

Water traveling through limestone fracture systems may not benefit from the natural removal of some leachate constituents as would water passing through an aquifer containing unconsolidated materials. Leachate-contaminated ground water also may flow from the spoil material into surrounding bedrock aquifers at the perimeters of the spoil pile where spoil contacts truncated bedrock aquifers. The dominant flow direction (from the spoil into the bedrock or from the bedrock into the spoil) could change seasonally with precipitation. At times of water-level measurement, the direction of ground-water flow in spoil material and the Pawnee Limestone indicated that leachate-contaminated ground water has the potential to move offsite west of the active landfill area. Use of the northeastern part of the landfill-expansion area for trash disposal could result in the migration of leachate northeasterly toward the ponds that bound the northern and northeastern edges of the strip-mined area.

The presence of methylene blue active substances (MBAS), which generally are derived from detergents, is indicated for the pond-A water sample and all monitoring-well samples except well MW-3B (table 7). However, it should be noted that the presence of MBAS at concentrations less than 0.5 mg/L also may be the result of chemical interferences during analysis; therefore, the indicated presence of MBAS in water from pond A and wells MW-1A, MW-1B, MW-2A, MW-2B, and MW-5 may not be significant. However, the concentration of MBAS in water from wells MW4A and MW-4B, located in the trash pile, is significantly larger than the rest of the samples.

Of the major ions and inorganic trace elements detected, it appears that these are derived mainly from the local bedrock and spoil material although the landfill trash is likely contributing to the concentrations at a nearly indistinguishable level. Major ion and trace-element concentrations are affected by local water pH, lithology, trash, bacteria, available oxygen, and various other factors. Lithology appears to be the dominate factor in this situation. Iron, manganese, and dissolved organic carbon seem to originate from the trash pile and might prove useful as tracers for determining leachate movement.

SUMMARY AND CONCLUSIONS

A cooperative investigation of the hydrogeology and ground-water quality in the vicinity of the Linn County Landfill near Prescott, Kansas, was undertaken from July 1988 through June 1989. The Linn County Landfill is located in an area that has been strip mined for coal. The effect of the mining activities was to create a flat-bottomed basin filled with strip-mine spoil, bounded at the edges by undisturbed bedrock. Near-surface bedrock adjacent to the strip-mined area consists of Pawnee Limestone overlain by Bandera Shale. Within the strip-mined area, mine spoil is underlain by about 3 feet of Bandera Shale and then by the Pawnee Limestone. Quarrying of the Pawnee Limestone for road material at places within the strip-mined area would have placed strip-mine spoil in superposition to the Pawnee Limestone.

Nine temporary wells were installed, and water-level measuring points were established on nearby surface-water bodies to determine the direction of ground-water flow. Nine monitoring wells then were installed in positions upgradient, in, and downgradient of the landfill.

The hydrogeology of the landfill area is complicated by lateral and vertical variability in sediment and rock type. Factors affecting the flow of water in the spoil material include the north-south county road, which retards shallow, lateral ground-water flow; the surface ponds; and, possibly, seasonal variations in precipitation. In the spoil material, ground water flows southwest except in the northeastern part of the landfill-expansion area where it flows northeast. In the underlying Pawnee Limestone, ground water flows southwest in the vicinity of the landfill. At the times of water-level measurement, an upward hydraulic gradient prevailed between the Pawnee Limestone and the spoil material. However, during periods of intensive rainfall, the hydraulic gradient may be reversed.

Chemical analyses of water samples were conducted for inorganic and organic compounds. Major ion concentrations indicate the presence of four water types in the landfill area. These types are: (1) calcium sulfate, (2) calcium magnesium sulfate, (3) magnesium calcium sulfate, and (4) sodium potassium sulfate. The distribution of these water types indicates that calcium sulfate type water is found in the spoil material, and magnesium calcium sulfate type water is found in the bedrock. Calcium magnesium sulfate type water may be a mix of water from spoil material and bedrock, and the sodium potassium sulfate type water may be the result of contamination by landfill wastes or cation-exchange processes in local shale.

Of the trace elements, iron and manganese seem to be good indicators of the presence of leachate-contaminated ground water. The largest iron concentrations were detected in water from well MW-4A, and the largest manganese concentrations were detected in water from well MW-4B. These were the wells that penetrated landfill wastes.

Dissolved organic carbon was detected in all water samples at normal background and larger concentrations. The largest concentrations were detected in water from wells MW-2A, MW-2B, MW-4A, and MW-4B, reflecting the proximity of these wells to the liquid septic-tank disposal location and to solid wastes. Volatile organic compounds were detected in water from several wells. Benzene was detected in water from well MW-3A, and carbon tetrachloride was detected in water from well MW-1B. 1,1 dichloroethane was detected in water from wells MW-2B and MW-4B, and 1,1,1 trichloroethane was detected in water from well MW-2B.

The similarity in the distribution of concentrations of sulfate, iron, manganese, and dissolved organic carbon in the spoil material and the Pawnee Limestone may result from downward ground-water flow from the spoil material to the Pawnee Limestone during periods of intense rainfall. Leachate-contaminated ground water could flow southwest, west, or northwest from the southwest corner of the landfill. The extent of offsite leachate migration could be determined by installation of offsite wells. Use of the northeast part of the landfill extension for waste disposal could result in the contamination of surface pond B because of the northeastward flow of ground water in this area. Determinations of hydrologic conditions in the landfill-expansion area could be refined by installing drive-point wells in this area.

Continued yearly analyses of selected inorganic and organic constituents would provide long-term information on the effects of the landfill on water quality. Frequent or continuous water-level measurements would provide an increased understanding of seasonal fluctuations in ground-water levels and the direction of ground-water movement. To determine the extent and route of leachate migration from the current landfill area, additional wells could be installed west and southwest of the landfill.

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☆U.S. GOVERNMENT PRINTING OFFICE: 1991 - 555-480/20094