AN ABSTRACT OF THE THESIS OF

Ronald D. Falwell for the Master of Science Degree in Physical Science presented on November 30, 1989.

Title: Hydrogeology and ground-water quality at the Linn County Landfill, eastern Kansas, 1989.

Abstract Approved: James S Aber

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An investigation into the geology, hydrology, and ground-water quality 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 1950s and 1960s and is operated as a sanitary landfill. An analysis of water levels from nine temporary wells, nine monitoring wells, and strip-mine ponds indicates that ground-water flow in the shallow aquifers studied is to the southwest in the southwestern part of the landfill and to the northeast in the northeastern part of the landfill. A county road acts as a barrier to shallow ground water flowing southwest from the landfill and seasonal variations may also occur in the pattern of ground-water flow.

Analysis of water samples from the nine monitoring wells, an up-gradient pond, and two public-water supplies indicates that, based on major ion ratios, four water types

exist in this area. They are: calcium sulfate, calcium magnesium sulfate, magnesium calcium sulfate, and sodium potassium sulfate. Volatile organic compounds were detected in four of the monitoring wells and the two public-water supplies. 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 standards in some or all of the monitoring wells and in the up-gradient pond water.

Landfill leachate is affecting ground-water quality, as indicated by larger concentrations of organic compounds, iron, and manganese in water wells in or down gradient from landfill wastes. Leachate could migrate west or northwest from the current landfill area and will have the potential to migrate north from the landfill extension. Water levels and chemical concentrations indicate that a hydraulic connection exists between the coal-mine spoil material and the underlying limestone and also between the spoil material and the horizontally adjacent bedrock.

HYDROGEOLOGY AND GROUND-WATER-QUALITY AT THE LINN COUNTY LANDFILL, EASTERN KANSAS, 1989

A Thesis

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PREFACE

In 1988 a study was undertaken by the United States Geological Survey and Linn County, Kansas to determine the geology, geohydrology, and water quality at the Linn County landfill. As a participant in the Volunteer for Science program at the U.S.G.S. it became my task to co-author, as principal author, a U.S.G.S. publication which reports and interprets data obtained in this investigation. Participation in monitoring well installation, sampling, surveys, and most other phases of field work was also a part of my role in this investigation. Data, results, and interpretations from this investigation are also being reported to fulfill my thesis requirements.

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CHAPTER 1: INTRODUCTION

Purpose and Scope:

Shallow aquifers in eastern Kansas provide water for public and private drinking-water supplies, for irrigation and livestock, and for industrial uses. Information concerning the geologic nature 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. The fundamental objective of landfill monitoring is to serve as a check on potential leachate contamination.

This report presents the results of an investigation conducted by the U.S. Geological Survey and Linn County from July, 1988 through June, 1989. The purpose of the investigation was to describe the geology, hydrology, and the ground-water quality conditions in the vicinity of the Linn County Landfill.

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.

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) reported on the geology and water resources of adjacent Bates County in Missouri. Bevans et al. (1984) summarized available hydrologic information in an area of the Western Interior Coal Province nearly coincident with the Marais des Cygnes drainage basin. Kleeschulte et al. (1985) described and appraised the resource value of ground water of 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 (23,300 km^2) area over 7 southeastern Kansas counties and adjacent counties in Missouri and Oklahoma. Mesko (1987) investigated ground-water movement, quality, and recharge in a 275-acre (110 ha) reclaimed strip mine in Missouri, 7 miles (11 km) northeast of the Linn County Landfill.

General Description of Study Area:

The Linn County Landfill is located about one mile (1.6 km) northeast of Prescott, Kansas, in the southeastern corner of Linn County (Fig. 1). A 250-acre (100 ha) tract of land adjoining the landfill to the north and west was formerly strip mined for coal (Fig. 2). Total county-owned area is about 52 acres (21 ha), on which active landfilling operations occupy about 12 acres (4.9 ha). The 12-acre area is in the northwest quarter of the northwest quarter of section 4, T. 23 S., R. 25 E., 3 miles (4.8 km) east of the Kansas-Missouri border (Fig. 2).

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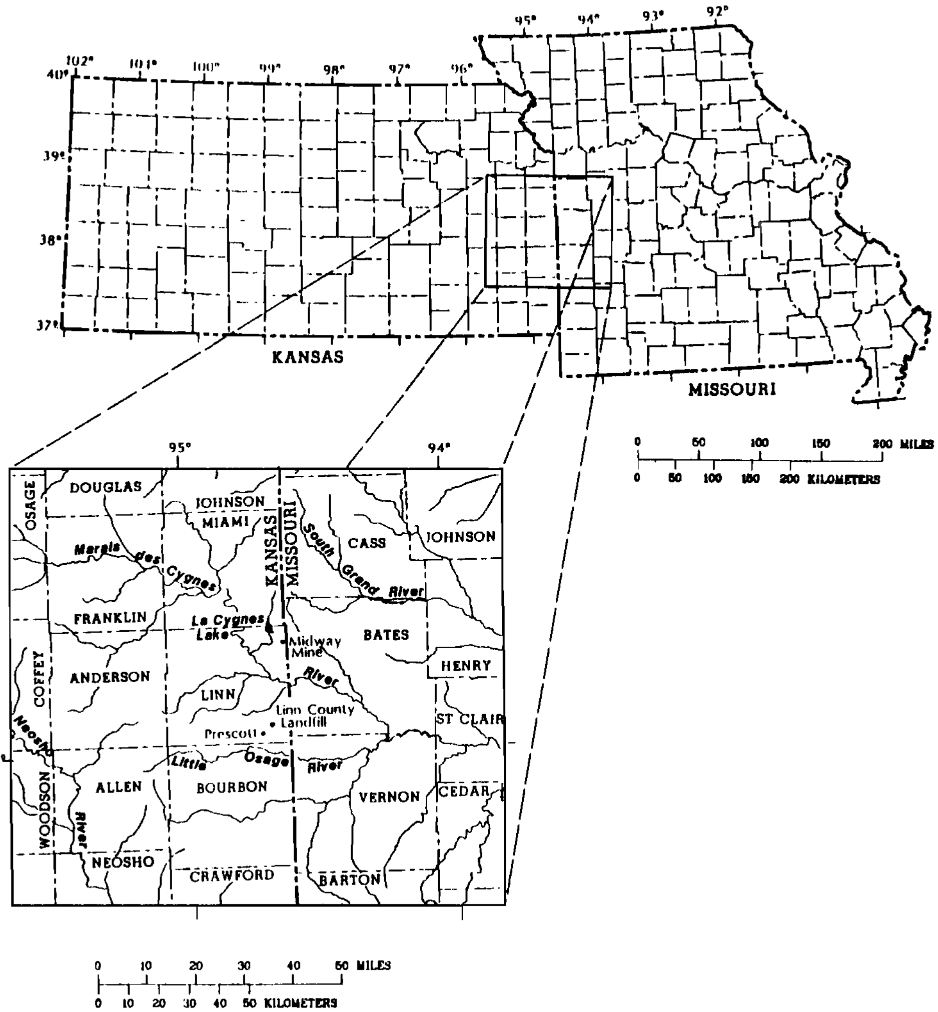
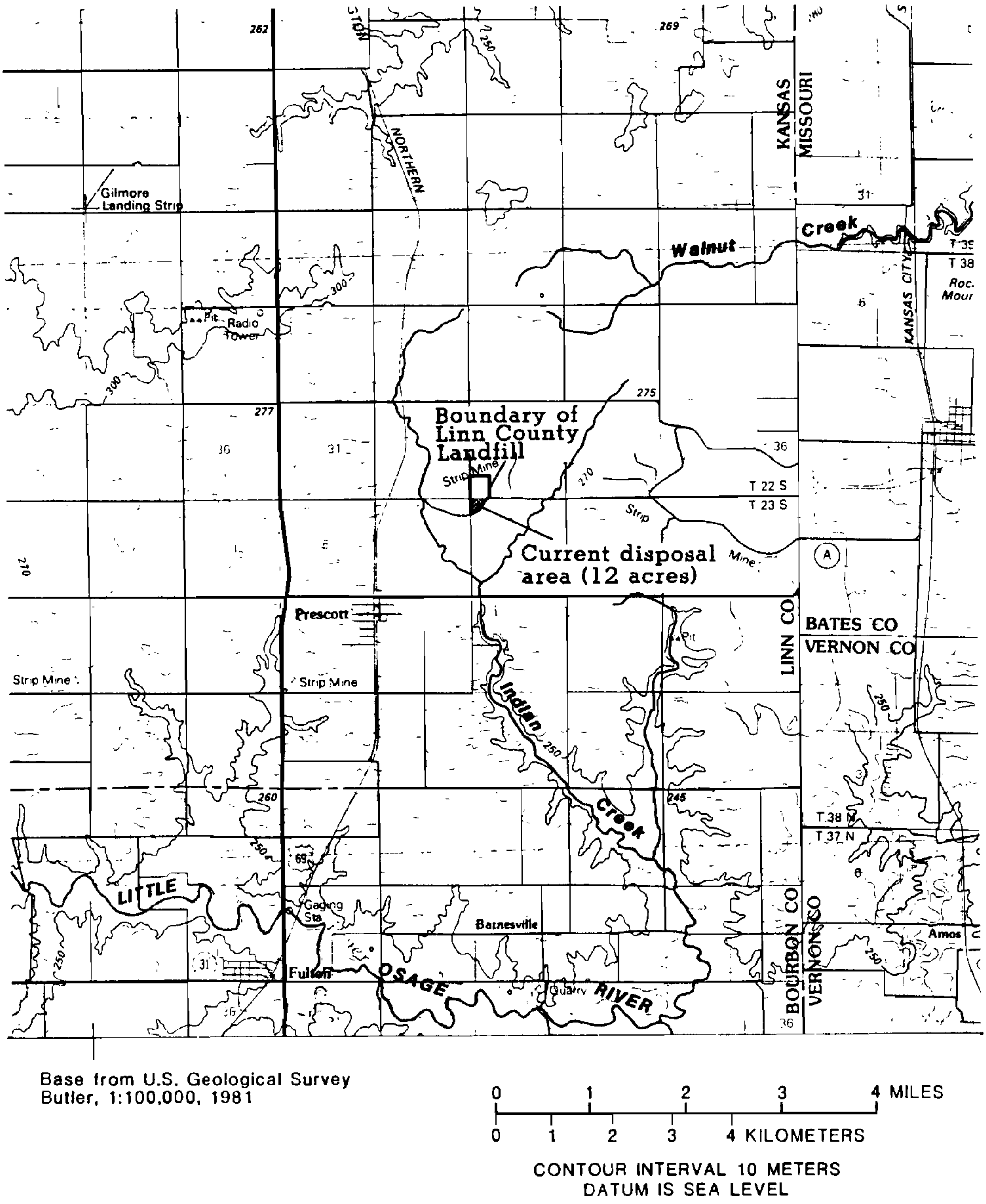


Figure 1. Location of Linn County Landfill.



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

CONTOUR INTERVAL 10 METERS
DATUM IS SEA LEVEL

Figure 2. Topography in vicinity of Linn County Landfill.

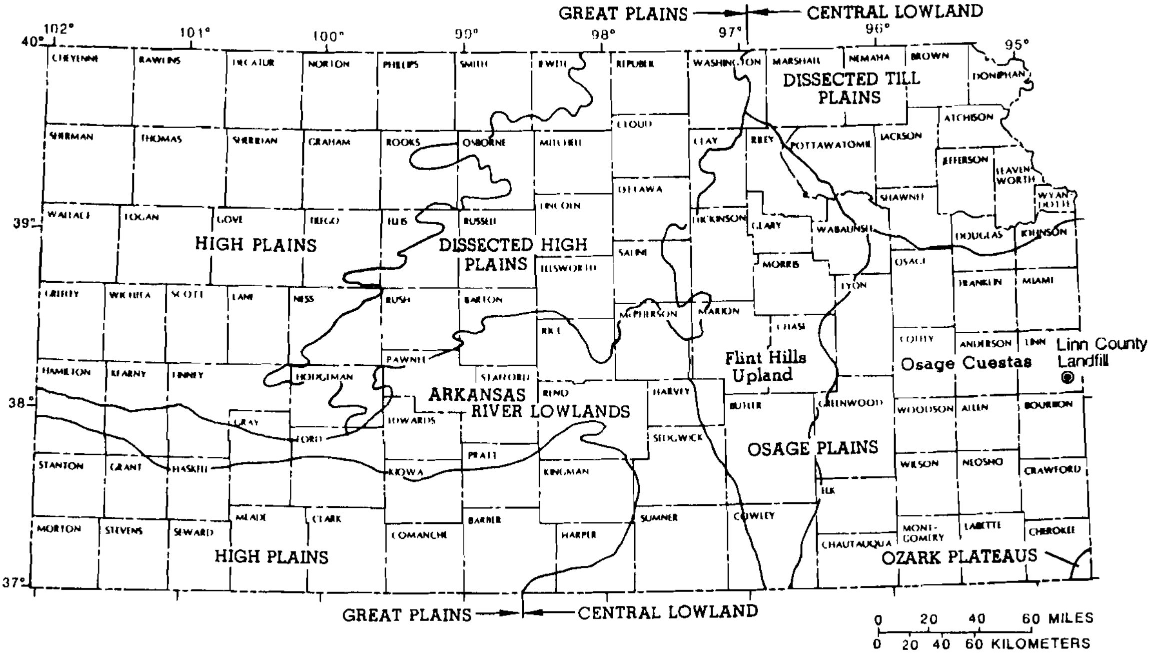


Figure 3. Physiographic areas of Kansas (modified from Schoewe 1949).

The landfill is located in the physiographic province known as the Osage Cuestas (Fig. 3). The cuestas are low, asymmetric ridges that trend northeast-southwest. The cuestas result from erosion of thin, uniformly dipping, sedimentary strata of different erosional resistance. The gentle dip slopes face west and north while the sedimentary strata outcrop to the east and south forming abrupt ridges. Troughs and valleys in soft shale are common where the dip slope of one cuesta begins to approach the steep scarp of another cuesta. Topographic mounds in this area are probably outliers of limestone or remnants of locally developed resistant beds (Seevers 1969). Valleys throughout the area contain meandering channels on relatively wide and well-developed floodplains and are filled with alluvial sediment.

Mean annual yearly precipitation is about 38 inches (97 cm) according to 1951 through 1980 data from three climatological stations within 20 miles (32 km) of the landfill. Three fourths of the rain normally falls from April through October in short, intense thunderstorms, but dry periods may occur any time. Temperatures range from greater than 38°C to less than 18°C with January being the coldest month and July being the hottest month.

Surface drainage from the landfill is southward into Indian Creek, continuing to the Little Osage River, then into the Marais des Cygnes River in Missouri (Figs.1 and 2).

The majority of the water used in Linn County is obtained from surface-water bodies, most of which is used for cooling at the coal-fired electric generating plant on La

Cygnes Lake. The remaining surface water use is mainly for public water supplies. The small amount of ground water used is for stock water, industrial, and rural domestic purposes. More than one half of the wells in Linn County are dug wells. Industrial use includes repressurizing hydrocarbon reservoirs at several oil fields. (Seevers 1969).

Land use and land cover in Linn County is about 40 percent cultivated for crops, 20 percent forest, 10 percent native grasses in pasture and rangeland, and 30 percent either urban, industrial, barren, wetlands, or water (Bevans et al. 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. Department of Interior, Geological Survey 1973) (Fig. 4).

The most important industrial activity in Linn County is currently oil and gas production. Oil and gas fields underlie nearly one third of Linn County. Coal mining has also 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 a mean value of about 4 percent sulfur regionally. Currently, only strip mining is economical, and the single Linn County operation is the Midway Mine, 15 miles (24 km) north of the landfill (Fig. 1), which supplies coal to the La Cygnes power plant.

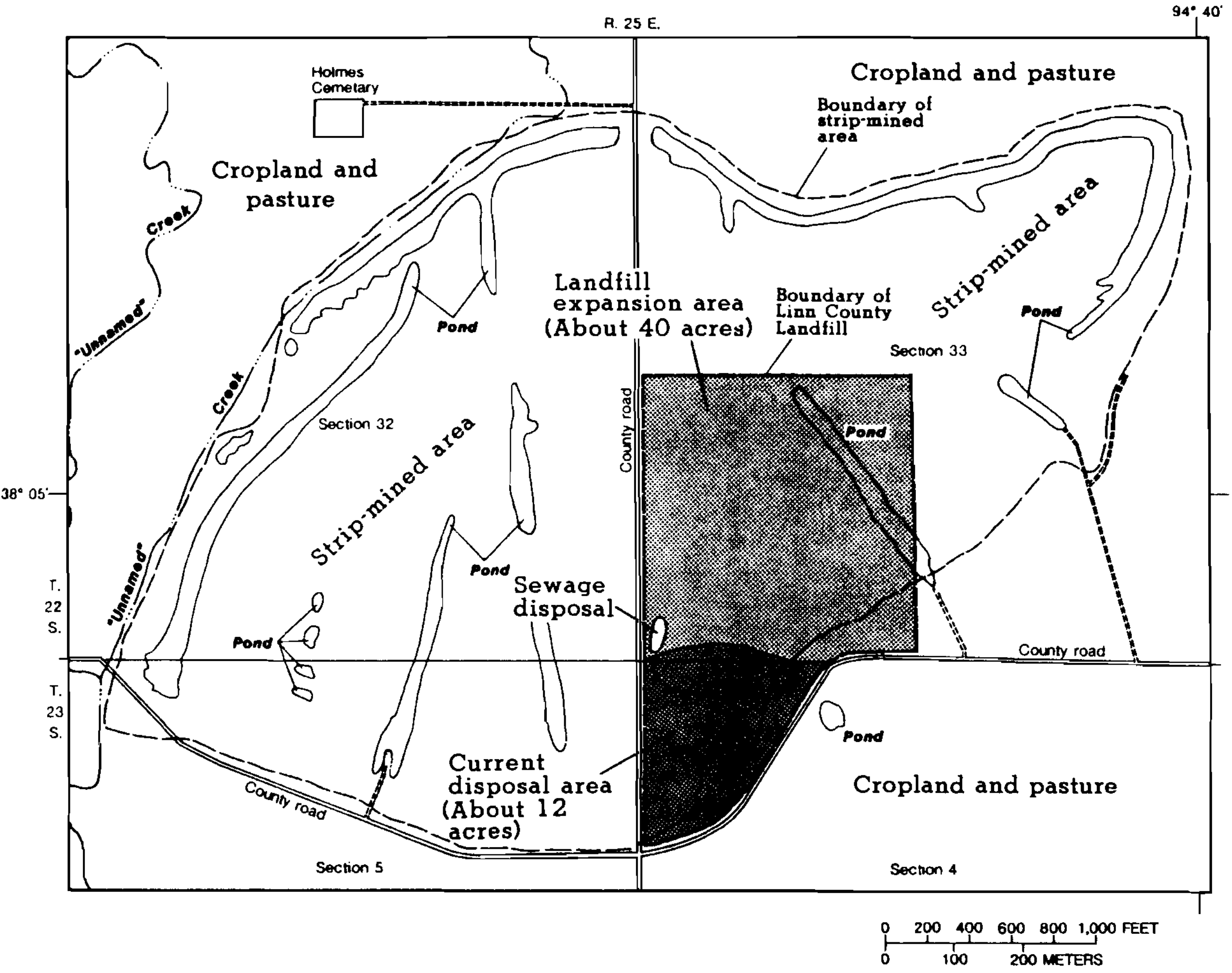


Figure 4. Current (1989) disposal and expansion areas of Linn County Landfill and surrounding land use.

Mining in the landfill area was done in the 1950's and 1960's by Hume-Sinclair Mining Company, now merged with Peabody Coal Company (Schoewe 1955).

Landfill Setting and Management:

The Linn County Landfill is constructed in an unreclaimed coal strip mine and occupies a triangular area of about 12 acres (4.9 ha) (Fig. 4). Adjacent to the north, an additional tract of about 40 acres (16 ha) has been acquired for expansion. Landfilling is currently conducted on the 12-acre tract, plus adjoining portions of the expansion area.

The Linn County Landfill is managed 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 the routine solid waste. Septic tank wastes are emptied near the southwestern corner of the 40-acre tract and covered with soil (Fig. 4).

Trench fill methods are employed in disposal of solid wastes at the Linn County Landfill since these methods are best suited to the ridge and valley topography left by strip mining. The valleys are used as disposal trenches and cover materials are taken from the spoil ridges. The 12-acre tract is currently nearing capacity. When finished, the area will have a 24-inch (61 cm) earth cover with drainage to the west and southwest. Drainage from the 12-acre tract will be directed beneath the county road near the southern end of the 12-acre tract.

CHAPTER 2: SOLID WASTE CHARACTERISTICS

The following is a general discussion of solid waste composition, solid waste degradation, and leachate production in landfills (adapted from Falwell et al. 1989). 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 process discussed in the following paragraphs.

Solid Waste Composition:

Solid wastes refer to discarded, unwanted, solid materials that do not have current economic value. Landfill sites often were merely convenient depressions, and solid wastes were considered as serviceable fill to level out low-lying areas. Until recently, few if any sites were engineered for proper containment of leachate. Solid wastes commonly were left uncovered in open dumps. Currently, the sanitary landfill method is incorporating engineering principles for maximum confinement and containment of waste and leachate. Basic design features of a sanitary landfill are an impermeable bottom and sides, exclusion of drainage, compaction and daily cover of the solid waste, and final impermeable capping (Degner 1974; Salvato et al. 1971).

The exact composition of Linn County Landfill solid wastes is not known. 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 et al. 1977). It shall be inferred that the Linn County composition is close to these values which are in close compliance with reports from other sources. About 80 percent of the solid waste is combustible (Tchobanoglous et al. 1977).

Solid Waste Degradation:

About 20 percent of typical solid waste is essentially inert, including glass, wood, rubber, plastics and synthetic textiles. The other 80 percent, mostly paper, garbage, yard and garden trimmings, and ferrous metal is totally or partly degradable (Tchobanoglous et al. 1977).

The landfill environment is oxidizing prior to consumption of the oxygen available from the waste materials and the voids within the trash pile. 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.

Biologic decomposition is conducted by aerobic bacteria in the presence of oxygen. Upon consumption of the available oxygen, anaerobic bacteria become the dominant factor controlling biologic decomposition. Aerobic decomposition proceeds rapidly and probably begins in easily degradable garbage soon after deposition of the waste. Net products are primarily carbon dioxide and water, and nitrate (Baedecker and Back 1979).

Anaerobic decomposition is slower and more complex than aerobic decomposition, and apparently requires symbiotic relationships (Gaudy and Gaudy 1980). It is thought of as occurring in two steps. In step one the acid forming bacteria act upon complex organics and change their form to simple, soluble organic materials known as organic or volatile acids and alcohols. Step two involves fermentation and gas formation by obligate methanogenic bacteria. These gas-forming bacteria use the organic acids produced in step one as substrate to produce the end-product gasses. The symbiosis probably involves transfer of hydrogen between the two groups of bacteria. The hydrogen then becomes incorporated in the methane gas. The hydrogen transfer prevents build up that would lower pH, resulting in an environment toxic to methanogenic bacteria. (Gaudy and Gaudy 1980). End products of fully completed anaerobic decomposition are methane, water, carbon dioxide, and traces of hydrogen sulfide (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 one time individual parts of the same landfill may be in different stages of decomposition. Stage and rate 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 solid waste. Many landfills complete the aerobic stage in a few weeks and go through anaerobisis quickly enough to allow significant methane production to peak within 2 years and then decline for 25 years or longer (Tchobanoglous et al. 1977). The progress of anaerobic decomposition at any given time may be estimated by the attendant conditions. In step one, leachate pH is 4 to 5; chemical oxygen demand is relatively large; and specific conductance, due to acid 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 to 8; 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 et al. 1977). Because paper probably absorbs both original and metabolically generated water, leachate production above the water table requires infiltration of surface water. Solids, gases, and liquids from the waste are incorporated as dissolved, suspended, or sorbed components. They can be either miscible or immiscible. Metabolic carbon dioxide, produced by bacterial action, dissolves easily, decreasing leachate pH. The resulting solution of calcium carbonate increases hardness and dissolved solids. Solvent ability of the leachate is increased also by the bacterially generated organic acids, allowing some metals in the landfill to be dissolved.

Chemical processes in leachate production are oxidation, reduction, solution, precipitation, ion exchange, and sorbtion. In the landfill, these processes are probably controlled by the organic environment (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 highly variable. Some typical concentrations of the most abundant constituents are listed in Table 1. Where ranges are given, the larger values are expected only in newer landfills because they are undergoing more rapid early stage biodegradation, which involves acid production.

Potassium and sodium tend to stay in solution, unadsorbed by clay when calcium is present. Alkalinity is normally very large in leachate because bicarbonate is produced in anaerobic reactions, directly and indirectly, when carbon dioxide dissolves. Bicarbonate is dissolved also from landfill ash, soil and rock. Sulfate, derived from ash and treatment wastes, may be reduced within the

Table 1. Reported concentrations of constituents in and properties of landfill leachate.

[Concentrations in milligrams per liter except for pH]

Constituent or Property	Concentrations		
	Salvato and et al.(1971)	Cameron (1978)	Tchobanoglous et al.(1977)
pH (std. units)	5.6-8.3	7.5	6.0
Chemical Oxygen Demand	7,130	800	18,000
Biochemical Oxygen Demand	7,050-32,400	120	10,000
Total Hardness	537-8,120	--	3,500
Sodium	350-1,805	800	500
Potassium	655-1,860	490	300
Alkalinity, total as $CaCO_3$	1,290-8,100	3,400	3,000
Sulfate	99-1,220	5.3	300
Chloride	300-2,240	2,300	500
Dissolved Solids	2000-9,190	4,270	--
Nitrate, as NO_3	5-18	--	25
Nitrogen, ammonia, as NH_4	141-845	427	200
Nitrogen, organic, as N	152-550	--	200
Iron	219	24	60

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. Iron is also 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. They are present in small and variable concentrations because, with the exception of lead, they are either in elemental form or in insoluble metals and alloys. They can also be found in selected industrial wastes. Other environmentally significant species 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. Selenium may be found in ink and rubber. (National Research Council 1977).

CHAPTER 3: METHODS OF INVESTIGATION AND PROCEDURE

The Linn County Landfill investigation consisted of four phases (adapted from Falwell et al.1989). 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. Samples were analyzed by the Kansas Department of Health and Environment (Topeka) and U.S. Geological Survey (Denver) laboratories. A final report concludes the fourth phase of data interpretation and reporting. The following sections describe details of the investigation methods.

Information Survey:

Prior to any field work, a survey of published literature 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 useful 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 used were either 3 1/4-inch (8.3 cm) inside diameter (ID) with a 6 5/8-inch (16.8 cm) outside diameter (OD) or 6 1/4-inch (15.9 cm) ID with a 9 7/8-inch (25.1 cm) OD. These augers were hollow stemmed with a plate in the bottom to prevent sediments from entering the hollow stem. Below the water table it was necessary to fill 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 when buried sandstone blocks were encountered using the larger auger. In such cases a pilot hole was augered with the small augers, making the use of large augers easier. Rotary drilling, with 4-inch (10.2 cm) and 6 3/8-inch (16.2 cm) bits, was used to drill mine spoil and bedrock. Rotary drilling with air circulation proved to be the most satisfactory method.

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 method the large augers were advanced through the mine spoil to bedrock and were left in place to act as a temporary casing for rotary drilling through the bedrock using air circulation and a 4-inch (10.2 cm) tricone bit. Tempo-

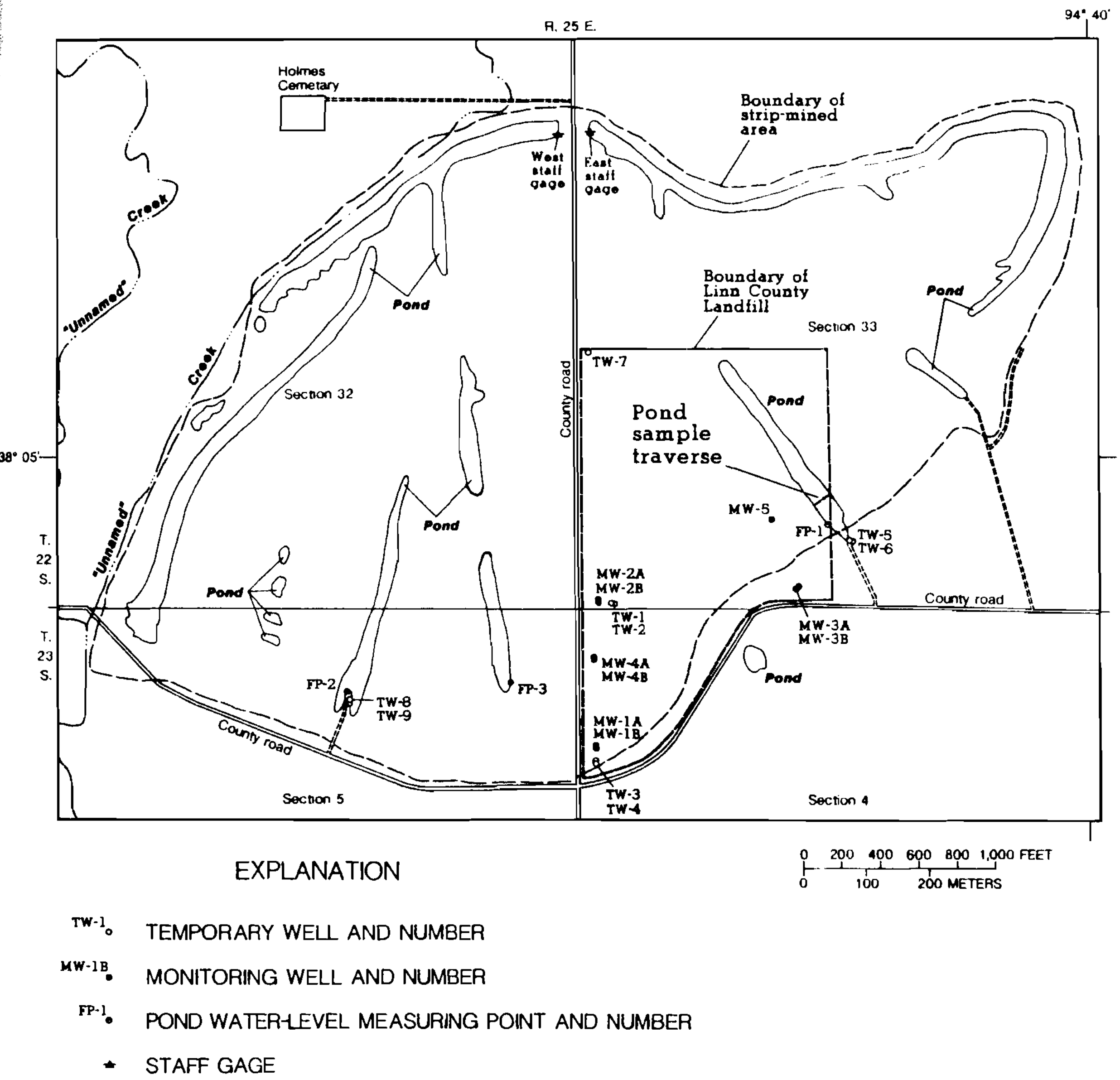


Figure 5. Location of temporary wells (TW), monitoring wells (MW), pond-sampling traverse (pond sample), pond water level measuring points (FP), and staff gages.

rary wells were constructed of 1 1/2-inch (3.8 cm) polyvinyl chloride pipe with glued joints and capped at the bottom, or 2-inch (5.1 cm) polyvinyl chloride pipe with threaded flush coupled joints and capped at the bottom. Each had slotted screens in the bottom 5 feet (1.5 m) which were cut with a hacksaw. Wells 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 (0.3 cm) with a steel tape, although these measurements are only reproducible to the nearest 0.05 foot (1.5 cm). Water-level altitudes were used to construct a preliminary potentiometric surface map to show the direction of shallow ground-water movement.

Monitoring Well Installation:

Nine monitoring wells were installed using the augering or rotary drilling techniques or a combination of the two. Geologic formation boundaries were noted while augering and drilling for purposes of correlating gamma ray logs. After reaching the final depth, the well casing was lowered into the hollow augers or rotary bore hole. Filter sand pack and bentonite chips were either poured into place around each well as the augers were being withdrawn from the well or poured into the anulus between the casing and the bore hole.

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	879.03	32.7
MW-4B	879.47	40.4
MW-5	868.62	8.7
EAST STAFF	(a) 859.81	---
WEST STAFF	(a) 849.81	---
FP-1	(b) 866.53	---
FP-2	(b) 855.10	---
FP-3	(b) 856.04	---

(a)= Altitude of 0.0 foot marker on staff gage.
(b)= Altitude of top of steel post.

Each monitoring well is constructed of a 5-foot (1.5 m) stainless steel screen at the bottom, a 10-foot (3.1 m) stainless-steel riser, and schedule-40 polyvinyl-chloride pipe to the surface (Fig. 6). Well casings are threaded, flush-coupled, 2- or 4-inch (5.1 or 10.2 cm) diameter pipe. Teflon tape was used to seal each joint; no glue or cement was used. Filter sand-packs are 6 to 10 feet (1.8 to 3.1 m) thick, extending from the bottom of the well screen to 1 to 5 feet (.31 to 1.5 m) above the top of the screen. The sand was followed by 2 or more feet (.62 m) of 3/8-inch (1 cm) bentonite chips to seal off the screened zone. Natural formation sediments were allowed to collapse or were added to the hole up to a depth of about 10 feet (3.1 m) below land surface, then bentonite chips were added to within 18 inches (46 cm) of the land surface. Finally, a cement pad and protective casing with a locking cap was 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-1A 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.

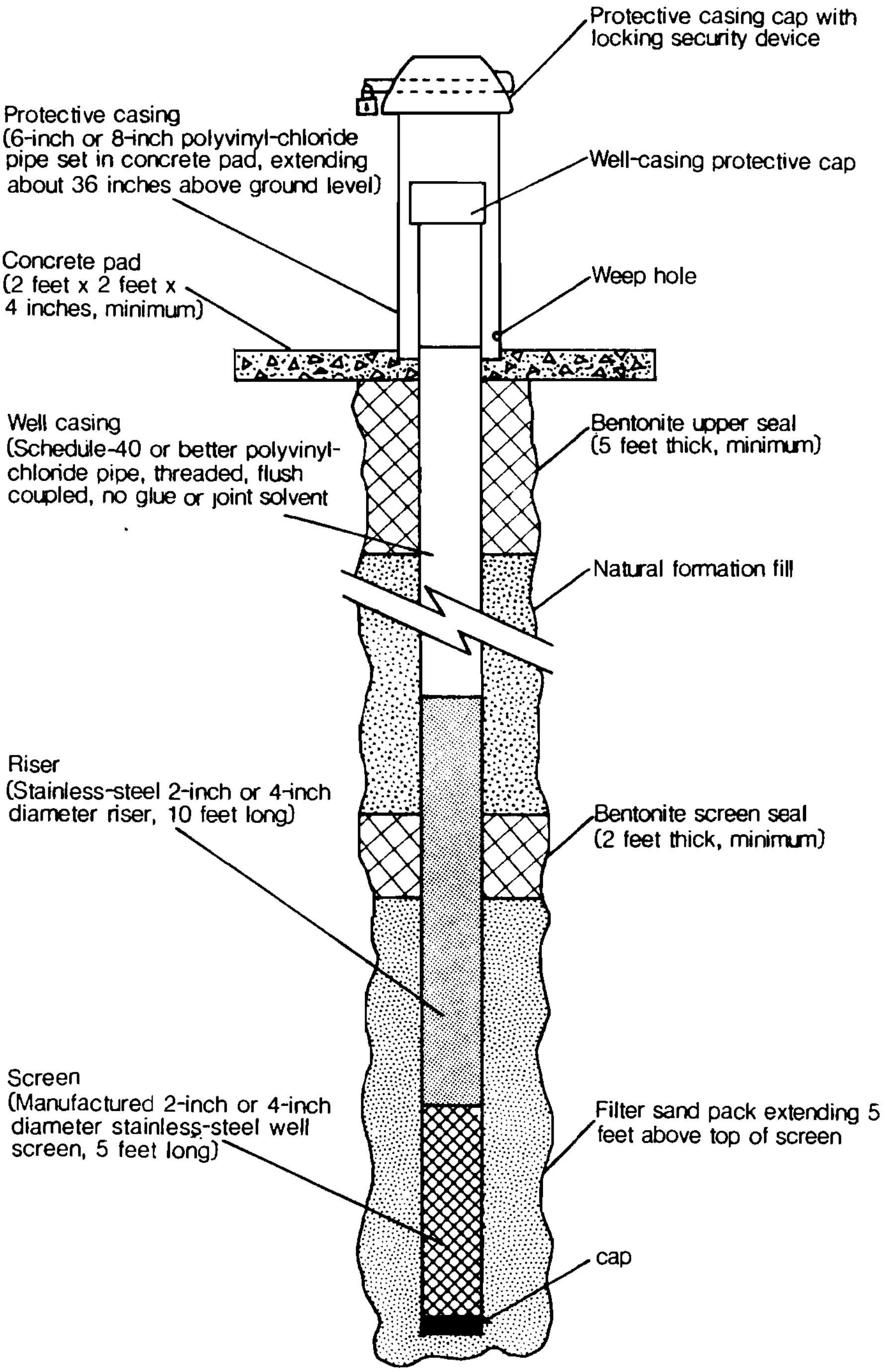


Figure 6. Schematic plan for monitoring well design to EPA standards; not to scale.

Monitoring wells were developed using air lift techniques or a positive displacement hand pump until water coming from the well was clear. In cases where little water was in the well, a positive displacement hand pump or bailer was used to develop the wells.

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 up-gradient wells (MW-3A, MW-3B and MW-5) and ended with the down-gradient wells (MW-2A, MW-2B, MW-1A, MW-1B, 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 (0.05 reproducibility) with a steel tape. The tape was cleaned with distilled water before each use. Each well was first purged of five water column volumes to assure that the water samples collected were representative of aquifer conditions. The volume of water to purge 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.

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

Well (Fig. 5)	Diameter of Well (inches)	Height of Water Column (feet)	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 (DRIED UP)
MW-2B	2	5.92	.99	4.9
MW-3A	2	20.30	3.39	5.0 (DRIED UP)
MW-3B	2	31.25	5.22	6.0 (DRIED UP)
MW-4A	2	8.19	1.36	6.8
MW-4B	2	15.48	2.58	12.9
MW-5	2	4.71	.30	1.5

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 take a sample. Plastic sheeting was laid on the ground around the well to prevent the bailer cord from accidentally touching the ground. Samples were immediately placed on ice. Trace metal samples were filtered through a 0.45-micron filter prior to collection. Dissolved organic carbon samples were filtered through a 0.2-micron silver filter prior to collection. Both types of filters were flushed with about 500 milliliters of sample water prior to use. Specific conductance, pH, water temperature, dissolved oxygen, and alkalinity measurements 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 the strip mine pond just east of 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 transect across the pond and combining 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 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 Denver, 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 (3.1 m) 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.

CHAPTER 4: GEOLOGY

Regional Geology:

Three regional structural elements are found in eastern Kansas. The Bourbon Arch trends east-west across southern Linn County. The Nemaha Ridge trends north-northeast to south-southwest across east-central Kansas and extends into Nebraska and Oklahoma. The Prairie Plains Homocline dips gently northwest across all of eastern Kansas (Fig. 7). The Bourbon Arch is 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 eastern flank. The Prairie Plains homocline dips at about 20 feet per mile (3.8 m/km) to the northwest. This regional dip is modified locally by other structural elements, such as the Nemaha Ridge (Jewett 1951).

Structural features in Linn County at the surface include domes, faults, and anomalous dips (Seevers 1969). The limestone beds are commonly vertically jointed, northwest-southeast and northeast-southwest. In Linn County, Pennsylvanian bedrock outcrops generally strike 30° and dip 20 feet per mile (3.8 m/km) in conformance with the Prairie Plains homocline (Seevers 1969).

Unconsolidated surficial material in Linn County consists of alluvium along the streams (Seevers 1969). The alluvium consists mainly of silt and clay with gravel at the base. The subrounded, medium to coarse gravel is composed

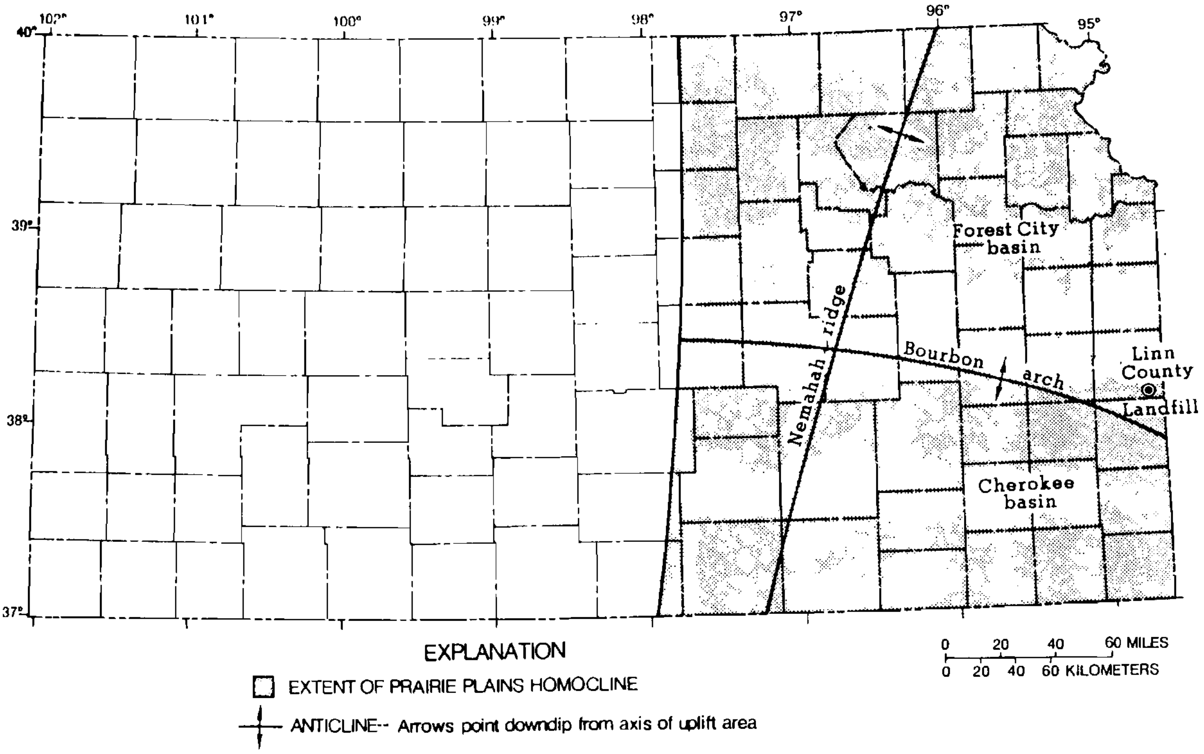


Figure 7. Regional geologic structure in eastern Kansas (modified from Jewett 1951).

of limestone and chert, up to 5 feet (1.3 m) thick in the terraces and 2 to 10 feet (.6 to 3.1 m) thick beneath the floodplains. Thickness of the alluvium ranges from several feet (.31 m) in upstream parts of tributary valleys to 50 feet (15.3 m) in principal valleys. These changes in alluvial thickness may result from agrading due to late Pleistocene uplift farther downstream (Gentile 1976). Total thickness of terrace alluvium is 20 to 35 feet (6.1 to 10.7 m).

Landfill Geology:

The bedrock units that crop out at the surface in the landfill area belong to the Marmaton Group of the Pennsylvanian System (Table 4). The Bandera Shale may be found in outcrops in Linn County. This unit locally consists of about 30 to 35 feet (9.1 to 10.7 m) of well-bedded, blocky, gray, clayey shale interbedded with brown to gray sandstone and siltstone, with some thin limestones partings in the middle section. The Mulberry Coal, which has been strip mined in this area, is located in the bottom part of the Bandera Shale, about 3 feet (.9 m) above the base. The coal locally is about 2 feet (.61 m) thick (Schoewe 1955). Separating the coal from the Laberdie Limestone Member of the Pawnee Limestone below is about 3 feet (.9 m) of clayey Bandera Shale. The stratigraphic relation between the Bandera Shale and the Laberdie Limestone Member is shown in Figures 8 and 9. The location of cross sections A-A' and B-B' of Figures 8 and 9 are shown in Figure 10. Average thickness of the Laberdie

Table 4. Geologic units of the Marmaton Group: youngest to oldest (Seevers 1969).

Unit	Thickness	Description
Holdenville Shale	1 to 30 feet (.3 to 9.1 m)	gray clay shale
Lenapah Limestone	4 to 17 feet (1.2 to 5.2 m)	limestone with shale parting, highly variable lithology
Nowata Shale	3 to 24 feet (.6 to 7.3 m)	light-gray shale with some sandstone near top and bottom
Altamont Limestone	10 feet (3 m)	massive, scarp forming, limestone with shale parting
Bandera Shale	45 feet (13.7 m)	light-gray sandy siltstone and fine sandstone with 2 ft. (.6 m) Mulberry Coal found 3 ft. (.9 m) above base
Pawnee Limestone	25 feet (7.6 m)	limestone and shale comprised of four members
Laberdie Limestone Member	6 feet (1.8 m)	light-gray, thin-bedded, wavy limestone, massive near base
Mine Creek Shale Member	6 feet (1.8 m)	gray, carbonaceous shale with limestone near top
Myrick Station Limestone Member	4 feet (1.2 m)	gray to blue gray, massive limestone, pseudoconchoidal fracturing
Anna Shale Member	2 feet (.6 m)	black fissile shale with phosphatic concretions
Fort Scott Limestone	20 feet (6.1 m)	massive limestone with shale parting in lower section

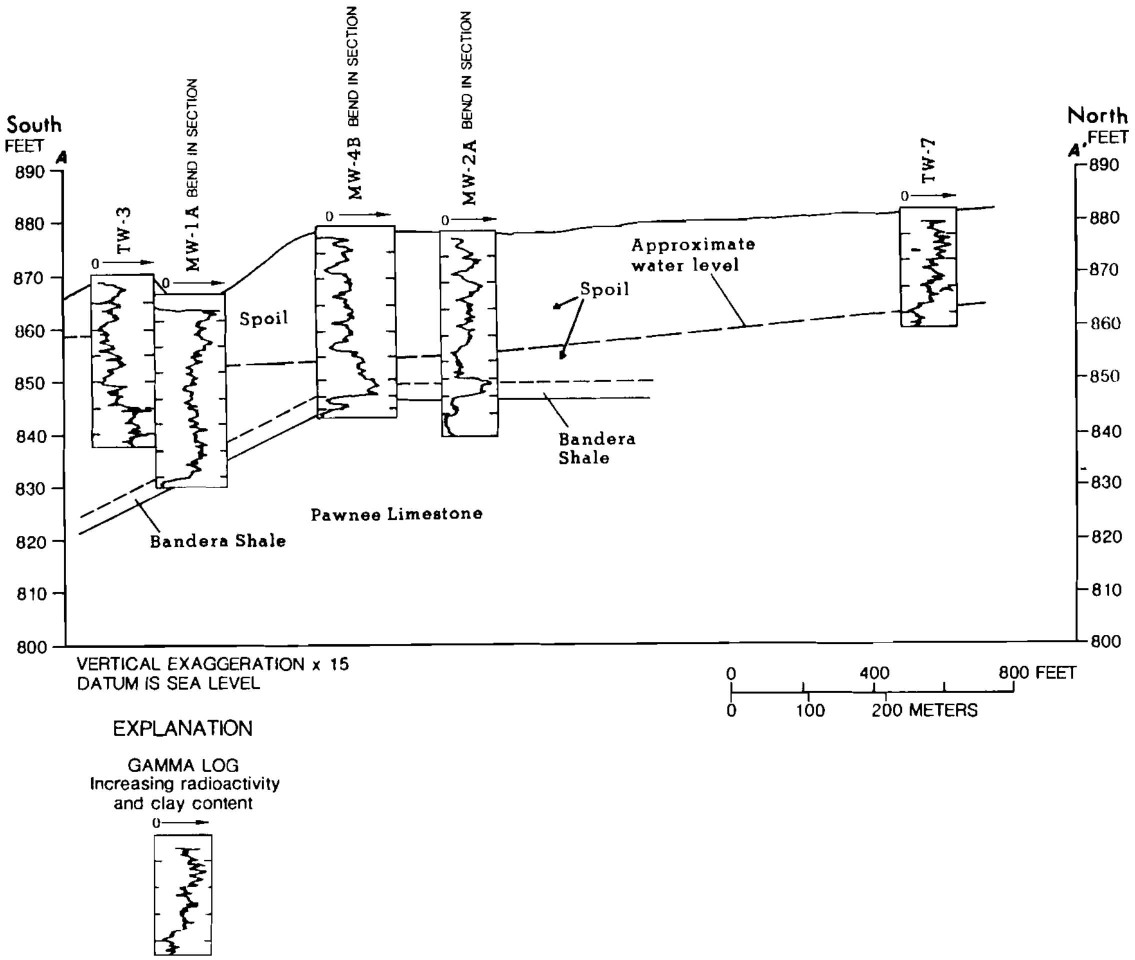


Figure 8. Geologic cross section based on gamma-ray logs and sample descriptions, north-south direction (A-A', see Fig. 10).

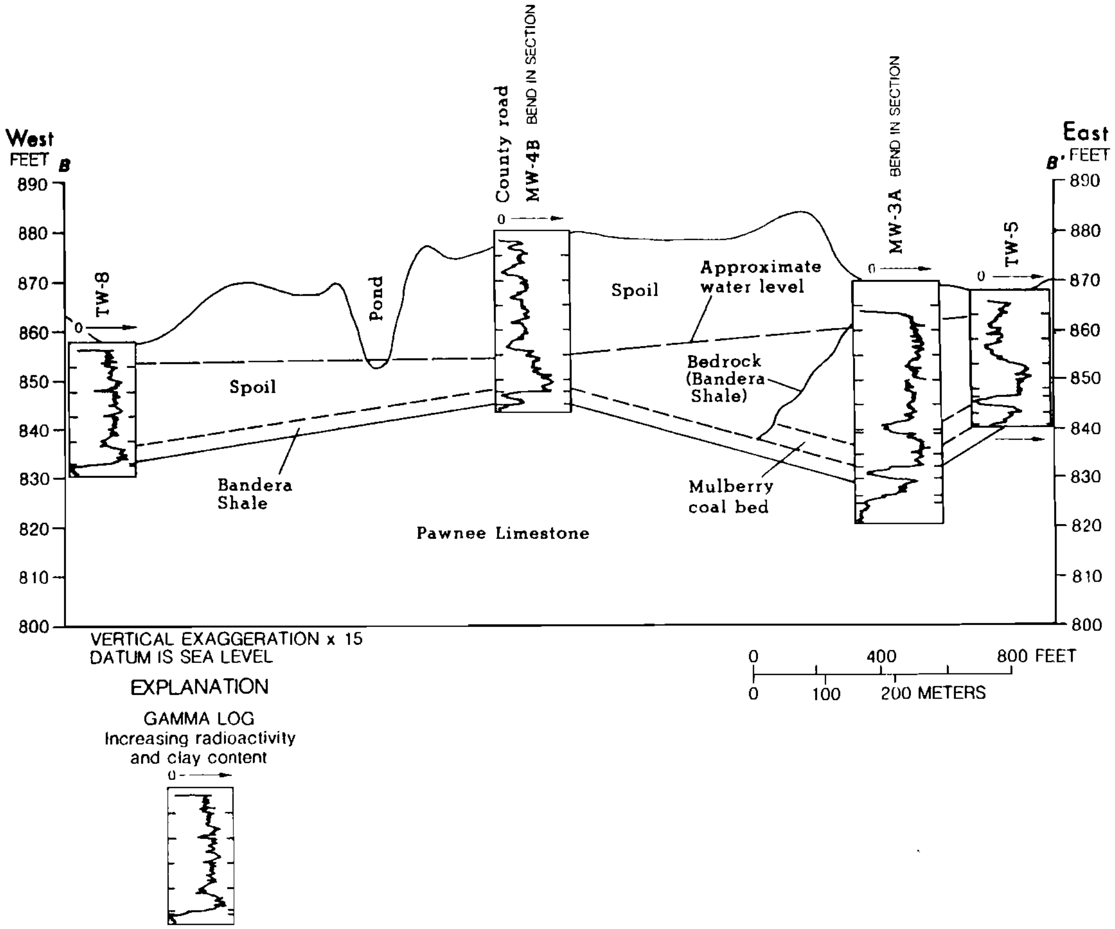


Figure 9. Geologic cross section based on gamma-ray logs and sample descriptions, east-west direction (B-B', see Fig. 10.

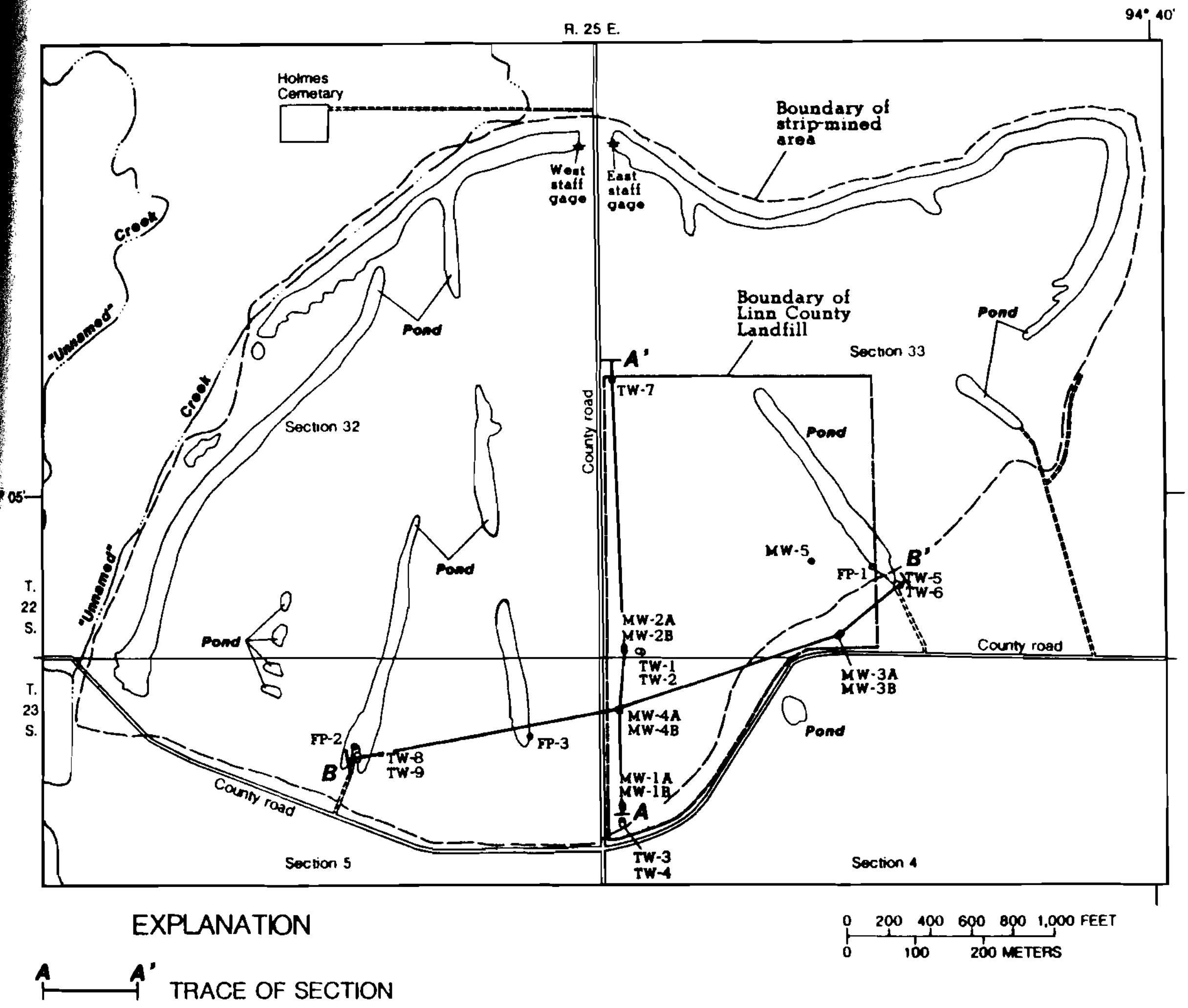


Figure 10. Location of geologic cross sections A-A' (Fig. 8) and B-B' (Fig. 9).

Limestone Member in Linn County is about six feet (1.8 m). It is light gray, crystalline, thin-bedded but more massive in the lower part (Jewett 1941). The general regional strike of these units is 30° and the dip is about 20 feet per mile (3.8 m/km) to the northwest (Moore 1949). Local variations in strike and dip occur due to small-scale domes, folds, and faults imposed on the regional structure.

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 melange of loose, heterogeneous, broken and crushed Bandera sandstone, shale, siltstone, limestone, and coal. Undisturbed bedrock generally underlies the spoil, consisting of the basal few feet (.3 m) of Bandera Shale, below which is the Laberdie Limestone Member of the Pawnee Limestone. In places, however, the Laberdie Limestone Member was quarried for use as mine haul road material. Where the Laberdie Limestone Member was quarried the basal Bandera Shale was also 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 Laberdie Limestone except in places where quarrying occurred.

CHAPTER 5: HYDROLOGY

Regional Hydrology:

Water usage from bedrock formations in Linn County is limited by excessive chloride and sodium contents to less than 100 feet (30 m) deep in rocks other than the Cherokee Group. Above 100 feet, water yield is limited by the absence of thick, permeable layers. The most productive formations are the Swope, Altamont, and Pawnee Limestones. Their characteristics favorable for water yield include joints, thin bedding, and cuesta forming dip slopes in near surface position for precipitation recharge. Estimated yields from wells screened in these formations range from 10 to 50 gallons (38 to 190 l) per minute (Seevers 1969).

Ground-water yield is 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 floodplain material is more reliable than terrace material as an aquifer since it is thicker in the principal valleys, more continuous, and in a topographically lower position which facilitates the interception of runoff and consequent recharge. Floodplain wells in gravel may yield 100 gallons (85 l) of water per minute, and terrace gravels may yield 5 gallons (19 l) of water per minute from wells (Seevers 1969).

The regional hydraulic gradient or direction of ground-water movement in shallow bedrock aquifers in Linn County is to the northwest except in small areas of localized anomalous structures (Seevers 1969).

Landfill Hydrology:

The hydrology in the landfill area is complicated by the heterogeneous makeup of the spoil material, by underlying bedrock materials which have been breached due to quarrying in places and by surface ponds in the unreclaimed strip mine haul roads. Ground water is dammed against the county road fill, as evidenced by the potentiometric surface (Fig. 11).

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, TW-4, 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 5, Figs. 11A, B, C and 12A, 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 the bedrock (Fig. 11 A,B,C). In areas where the Laberdie Limestone Member has been quarried and the basal Bandera Shale removed beneath the spoil pile, vertical ground-water movement between the spoil pile and underlying limestone aquifers may occur more readily than in areas where basal Bandera Shale is intact. Water levels in wells MW-1A, MW-1B, MW-2A, and

Table 5. Water level altitudes in temporary wells (TW), in monitoring wells (MW), at staff gages, and at pond measuring points (FP).

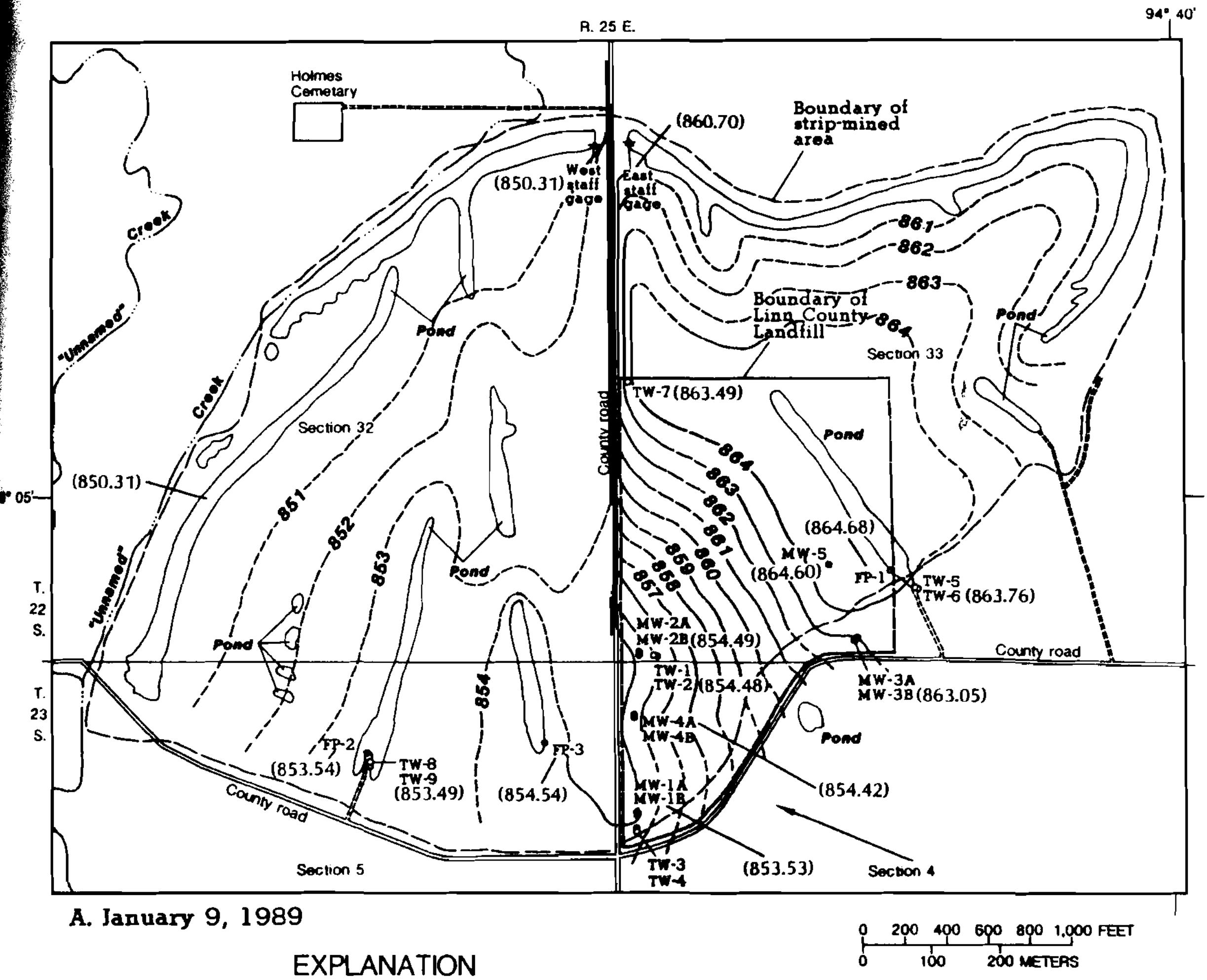
[Datum is sea level. NI = not installed, NM = not measured,

PULLED = well removed at prior date]

Measuring Point (Fig. 5)	Water Level Altitudes (feet) on Given Date			
	11/18/88	12/1/88	12/6/88	12/20/88
TW-1	854.37	854.73	854.72	854.56
TW-2	854.48	854.68	854.64	854.51
TW-3	NM	838.19	838.90	840.88
TW-4	855.33	859.11	858.61	857.93
TW-5	864.74	864.75	864.92	864.69
TW-6	863.99	864.15	864.12	863.76
TW-7	NI	863.60	863.64	863.50
TW-8	NI	854.30	853.60	853.51
TW-9	NI	850.96	852.65	853.13
MW-1A	NI	NI	NI	854.25
MW-1B	NI	NI	NI	853.47
MW-2A	NI	NI	NI	855.91
MW-2B	NI	NI	NI	854.51
MW-3A	NI	NI	NI	NI
MW-3B	NI	NI	NI	NI
MW-4A	NI	NI	NI	NI
MW-4B	NI	NI	NI	NI
MW-5	NI	NI	NI	NI
EAST STAFF	NI	860.79	860.68	860.59
WEST STAFF	NI	850.37	850.31	850.30
FP-1	NI	NI	NI	NI
FP-2	NI	852.53	NM	NM
FP-3	NI	NI	NI	NI

Table 5. (continued)

Measuring Point (Fig. 5)	Water Level Altitudes (feet) on Given Date				
	1/9/89	2/28/89	3/2/89	4/17/89	7/18/89
TW-1	854.52	854.57	PULLED		
TW-2	854.48	854.54	PULLED		
TW-3	856.48	857.57	PULLED		
TW-4	858.10	858.70	PULLED		
TW-5	864.57	PULLED			
TW-6	863.76	PULLED			
TW-7	863.49	863.53	PULLED		
TW-8	853.58	PULLED			
TW-9	853.55	PULLED			
MW-1A	854.30	854.36	854.42	854.63	856.60
MW-1B	853.53	853.60	853.71	853.89	855.84
MW-2A	855.92	855.87	855.82	855.96	855.65
MW-2B	854.49	854.54	854.56	855.01	854.65
MW-3A	861.38	861.77	843.38	863.95	861.44
MW-3B	863.05	863.26	863.29	862.06	863.30
MW-4A	854.42	854.46	854.52	854.94	854.54
MW-4B	854.47	854.53	854.53	854.98	854.62
MW-5	864.60	864.59	864.63	865.28	864.69
EAST STAFF	860.70	860.81	NM	NM	861.02
WEST STAFF	850.31	850.33	NM	NM	850.23
FP-1	864.68	864.60	NM	NM	864.70
FP-2	853.54	853.64	NM	NM	853.48
FP-3	854.54	854.00	NM	NM	NM



A. January 9, 1989

EXPLANATION

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

TW-1 ○ TEMPORARY WELL AND NUMBER

MW-1A ● MONITORING WELL AND NUMBER

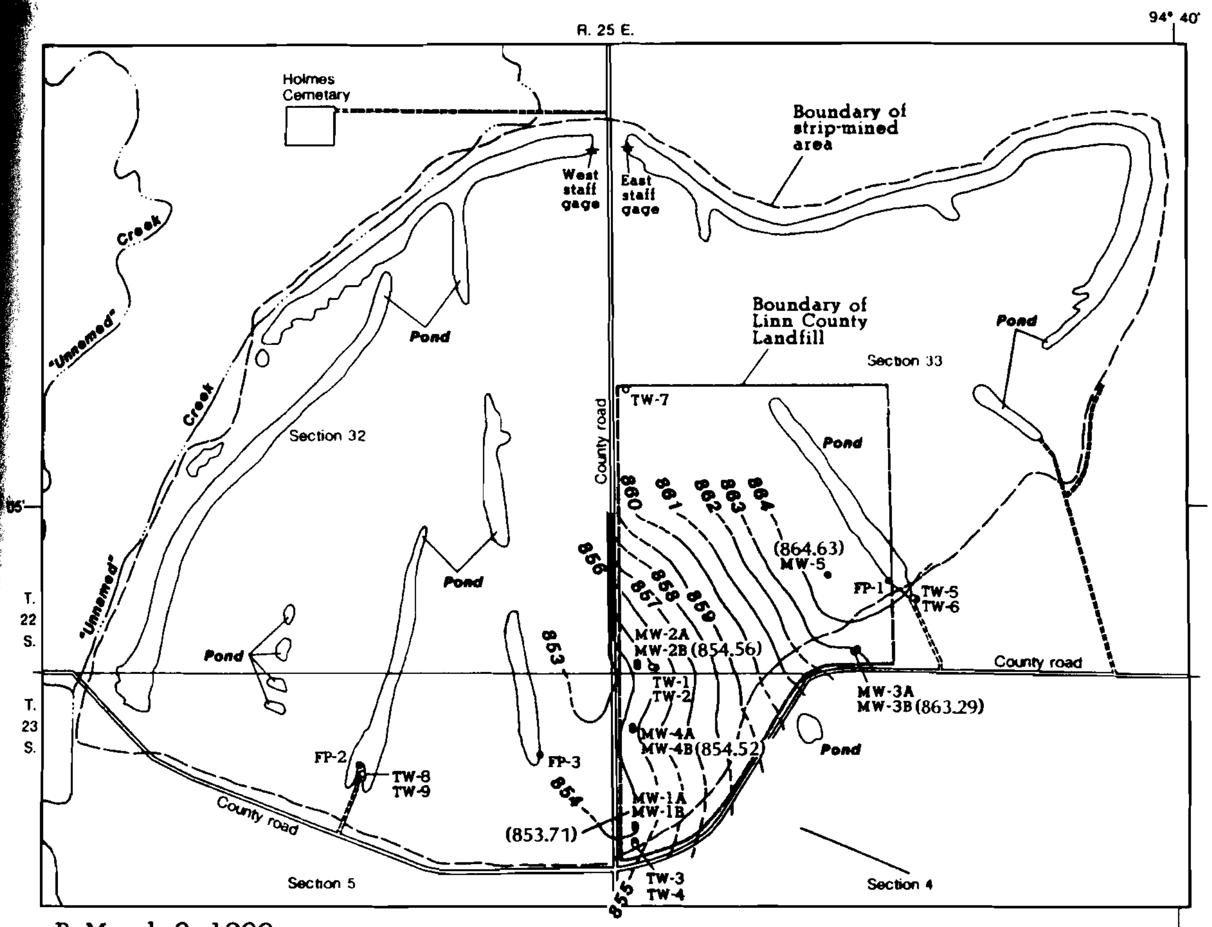
FP-1 ● POND WATER-LEVEL MEASURING POINT AND NUMBER

✦ STAFF GAGE

(863.76) ALTITUDE OF POTENTIOMETRIC SURFACE–In feet. Datum is sea level

—→ APPROXIMATE DIRECTION OF GROUND-WATER FLOW

Figure 11A. Potentiometric surface in spoil material, January 9, 1989.



B. March 2, 1989

Figure 11B. Potentiometric surface in spoil material, March 2, 1989.

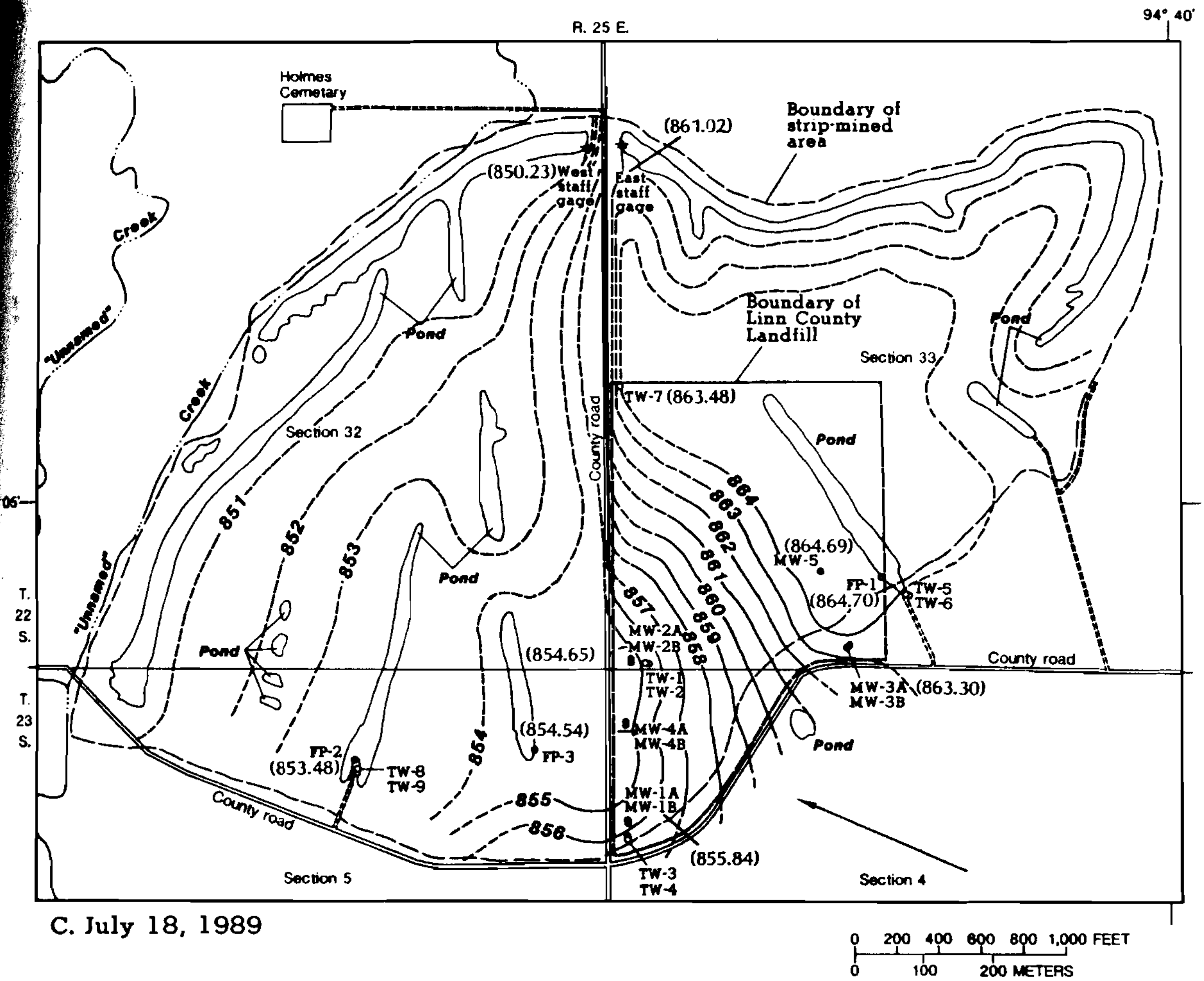
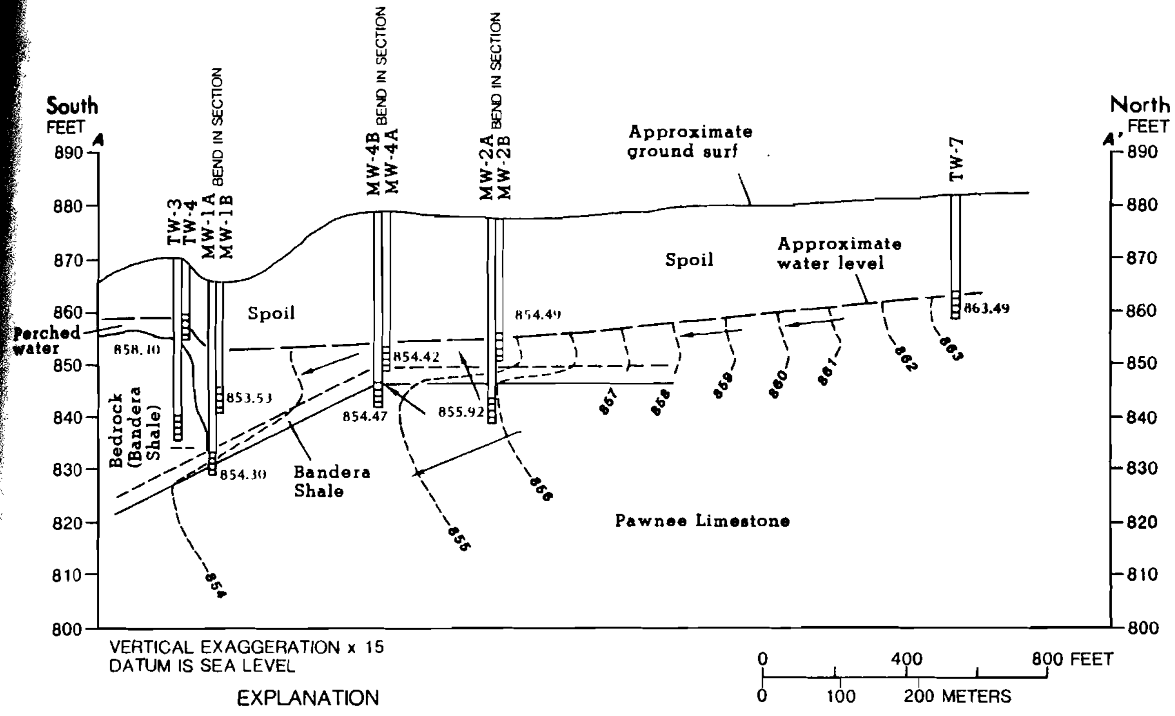


Figure 11C. Potentiometric surface in spoil material, July 18, 1989.



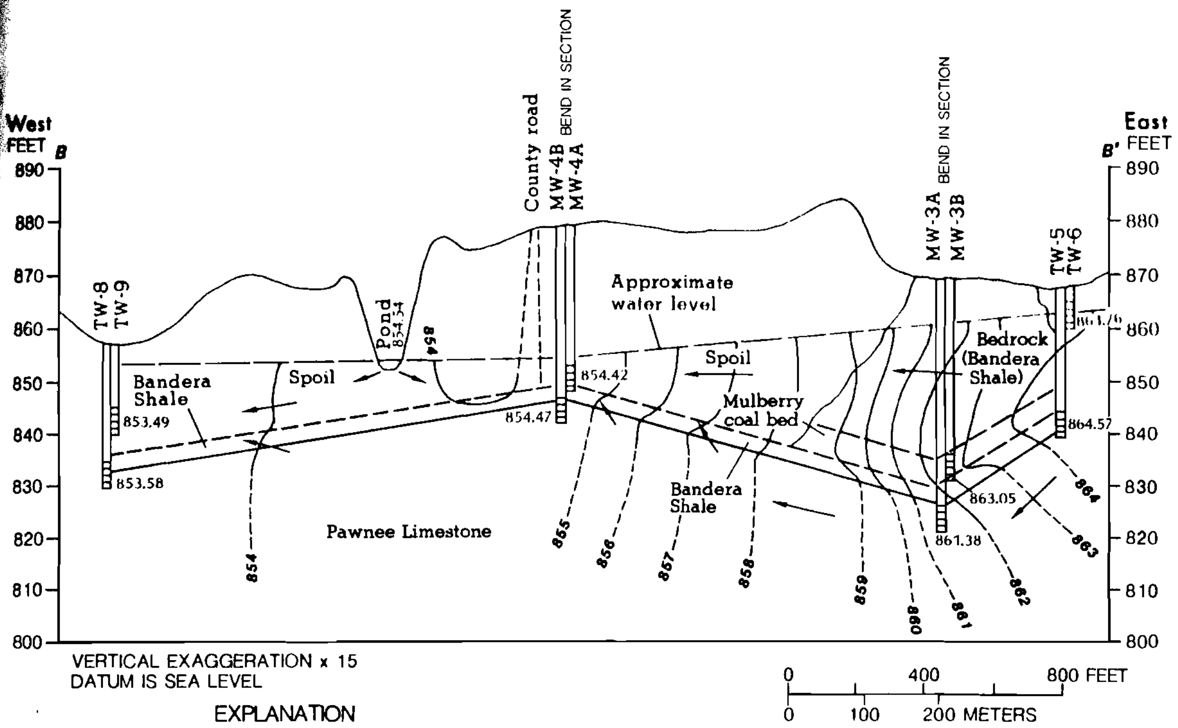
EXPLANATION

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

853.53 WELL--Number is water-level altitude, in feet. Datum is sea level

←—— APPROXIMATE DIRECTION OF GROUND-WATER FLOW

Figure 12A. Cross section (A-A', Fig. 10) showing potentiometric surface, January 9, 1989.



VERTICAL EXAGGERATION x 15
DATUM IS SEA LEVEL

EXPLANATION

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

853.58 WELL--Number is water-level altitude, in feet. Datum is sea level

←— APPROXIMATE DIRECTION OF GROUND-WATER FLOW

Figure 12B. Cross section (B-B', Fig. 10) showing potentiometric surface, January 9, 1989.

MW-2B indicate that a hydraulic gradient exists upward from bedrock into the spoil (Table 5, Fig. 12A, B), and thus, there is a potential for a movement of water from the Laberdie Limestone Member up into the spoil. Upward movement of water may be occurring near wells MW-4A and MW-4B where a slight mounding of ground water is evident from the deflection of the potentiometric contours near these wells as seen in figures 11A, B, and C.

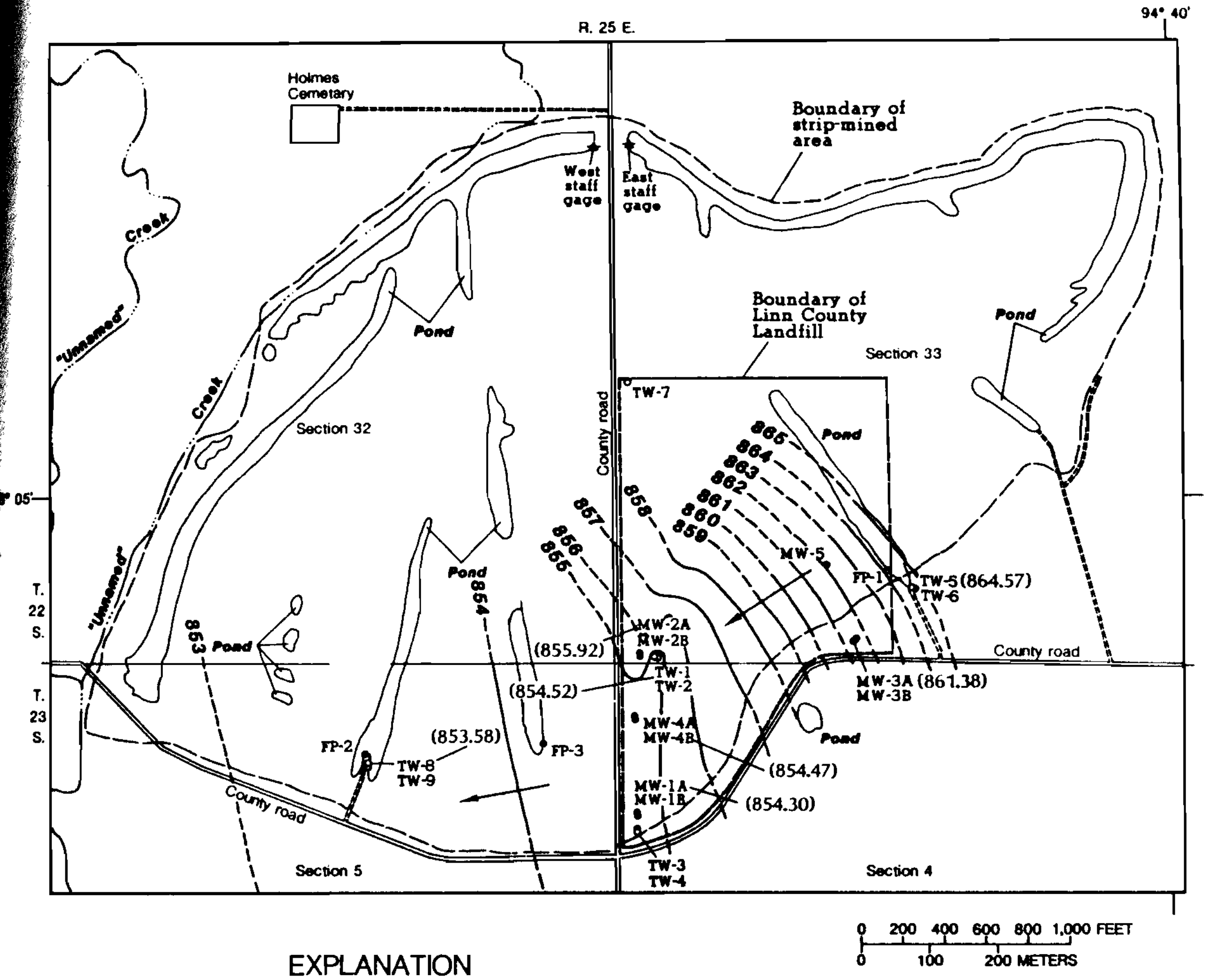
Surface ponding of water in the abandoned mine haul roads also affects ground-water flow. Data indicate that the ponds recharge the aquifers within the limits of the strip mined area. The recharge from these ponds is apparently dominant in determining local flow within the strip-mined area, at least during the times when water levels were measured. Data collected during a period of eight months support this finding. It is possible that due to the lack of significant precipitation immediately prior to water level measurements, seasonal or temporary deviations from 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 an opposite effect may even occur. Water may actually 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 pattern does occur, it will change the pattern of ground-water movement and leachate transport in the landfill area. Chemical data from up gradient wells MW-3A and MW-3B suggests that this phenomenon may occur. These wells display characteristics of landfill leachate waters.

The county road trending north-south on the west side of the landfill represents the greatest disturbance of ground-water flow in the spoil (Fig. 11A, B, C). Along the northern perimeter of the strip-mined area, water levels in the two ponds monitored by staff gages differ consistently by about 10 feet (3.1 m) throughout the survey period. These ponds are separated by the road and are about 100 feet (30.5 m) apart. The east side water surface is 10 feet (3.1 m) higher than the west side water surface. The hydraulic gradient between them is steep, decreasing to the west. Apparently the road and spoil material beneath the road are highly compacted and act as an aquitard. Apparent westward water movement in the spoil is deflected to the south along the road until it reaches a point immediately west of the current landfill site. Here it passes beneath the road possibly due to less compacted conditions in the spoil aquifer or an uncompacted, isolated portion of in-place bedrock aquifer underlying the road in lateral communication with spoil material at the shallower southern strip-mine perimeter.

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 proposed landfill expansion area where flow is from the southwest to the northeast (Fig. 11A, B, C). The direction movement in the current disposal area is from east to est with a slight southerly component. This direction of ovement turns northwestward after the water passes beneath he county road. Without additional data south and west of he landfill, it is difficult to determine which direction a leachate plume would migrate after passing beneath the county road. A leachate plume could continue southwest, or it could migrate northwest, depending on seasonal variations in precipitation and potentiometric gradients. When rainfall recharge is secondary to that from the ponds as indicated by current conditions, northwestward flow is probable. Ground water flowing in this direction through the spoil material would eventually be intercepted by water in the ponds along the northwest edge of the strip mined area.

In the northeastern part of the proposed expansion area, a ground-water divide is apparent, trending northwest-southeast (Fig. 11A, B, C). Southwest of the divide, ground water flows to the southeast but northeast of the divide, ground water flows north and east. Flow north of the divide would also be intercepted by a pond. Use of this area for trash disposal could result in the flow of leachate contaminated ground water to the north and east into the pond.

Ground-water flow in the Pawnee Limestone appears to be generally southwest, as shown by a potentiometric surface map (Fig. 13) for January 9, 1989, water levels in wells screened in the Pawnee Limestone. West of the landfill the flow in bedrock appears to be southwestward. Structure contours of the top of the Pawnee Limestone (Fig. 14) show



EXPLANATION

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

TW-1○ TEMPORARY WELL AND NUMBER

MW-1A● MONITORING WELL AND NUMBER

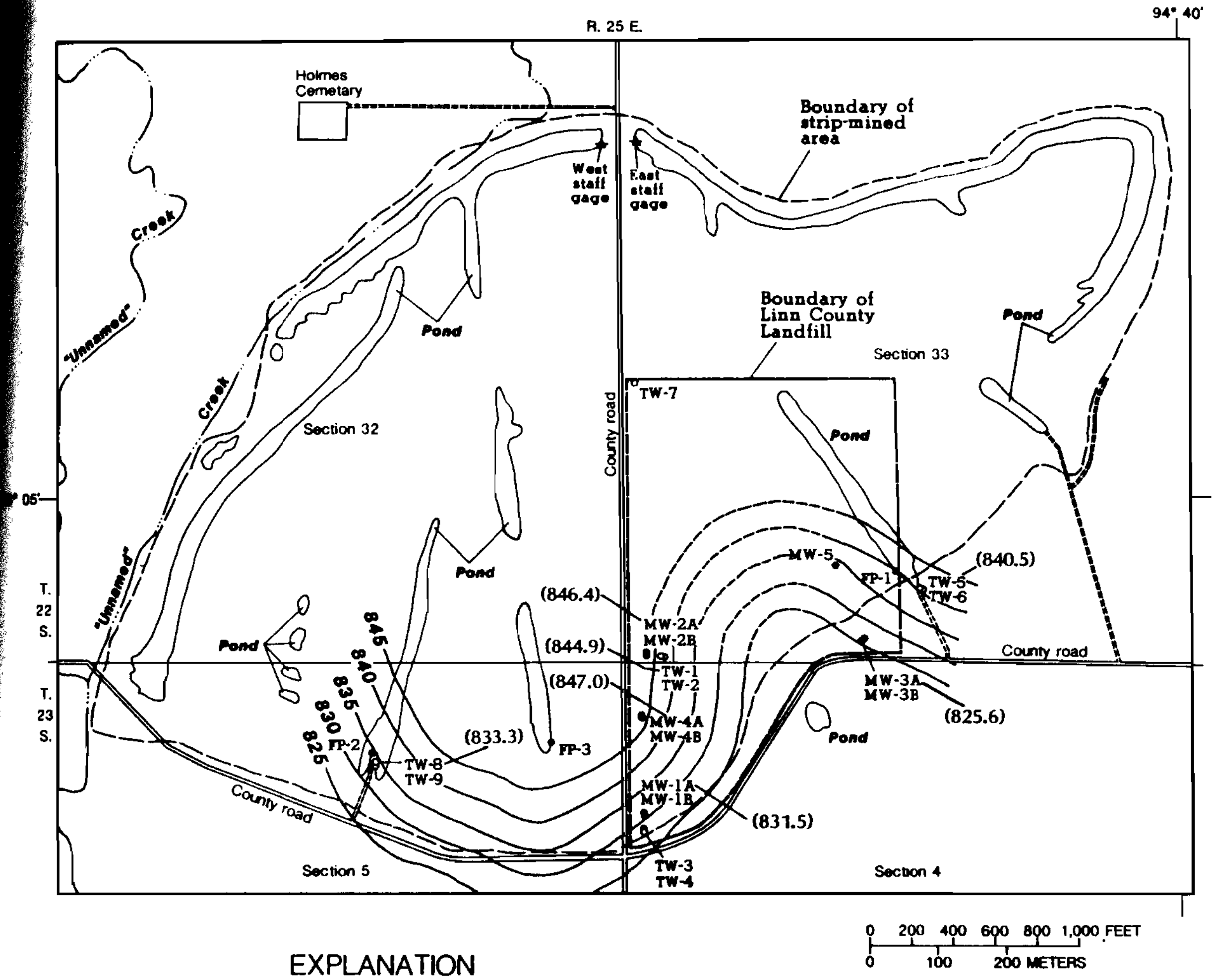
FP-1● POND WATER-LEVEL MEASURING POINT AND NUMBER

✦ STAFF GAGE

(853.58) ALTITUDE OF POTENTIOMETRIC SURFACE—In feet. Datum is sea level

←—— APPROXIMATE DIRECTION OF GROUND-WATER FLOW

Figure 13. Potentiometric surface in Pawnee Limestone in part of landfill area, January 9, 1989.



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 LIMSTONE—In feet. Datum is sea level

Figure 14. Structure contours showing top of Pawnee Limestone in part of landfill area.

a small fold or dome. The structure is probably a minor departure from regional northwest dip, and the flow directions represent local deviations from the regional northwest flow.

Between spoil ground water and Pawnee Limestone ground water, the relatively impermeable three or four feet (1 m) of basal Bandera Shale, where left in place during strip mining, provides a barrier to vertical ground-water flow between the two aquifers. Even though these two systems are for the most part separate, they will be interconnected where the basal shale and the limestone were excavated during mining, and possibly also at local fractures and faults. These interconnections will provide pathways for waters from the spoil material and waters from the limestone to migrate between aquifers and transport chemical constituents between aquifers. The direction of water movement between aquifers would depend on relative hydraulic pressures within each aquifer and could vary on a seasonal basis and between geographic locations. This indefinable movement of water and chemical constituents adds complication to the evaluation of the geohydrology and leachate migration in this area.

Hydraulic Conductivity:

Hydraulic conductivities were determined for spoil material and for Pawnee Limestone from slug test data using an analysis method from Nguyen and Pinder (1984). With one exception, the wells screened in the spoil material showed much greater hydraulic conductivity than wells screened in the limestone (Table 6). A Pawnee Limestone well, MW-1A, displayed a hydraulic conductivity much larger than the other limestone wells and nearly as large as the spoil material wells. 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 unfractured limestone. The average hydraulic conductivity of the underlying Pawnee Limestone, based on slug test data, was 10.5 feet (3.2 m) per day with one well (MW-3A) having a hydraulic conductivity which was too low to measure and one well (MW-1A) having an exceptionally high hydraulic conductivity. The average hydraulic conductivity of the spoil material was 59.7 feet (18.2 m) per day. The only well screened in the coal had a hydraulic conductivity of 3.0 feet (.9 m) per day.

The actual velocity of water movement through an aquifer depends on the hydraulic conductivity (K), the hydraulic gradient (dh/dl), and the porosity (n) of the aquifer material. This relationship is expressed by the equation in Table 6 (Freeze and Cherry 1979) . Typical hydraulic gradients on January 9, 1989, in the active landfill area were 0.0075 for the spoil material and 0.0050 for the Pawnee Limestone. Calculated velocity of ground water movement using the average observed hydraulic conductivities

Table 6. Hydraulic conductivity calculated from slug test data using the methods of Nguyen and Pinder (1984) and equation for water velocity determination.

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	46	Mine Spoil
MW-4B	3	Pawnee Limestone
MW-5	--	Mine Spoil

EQUATION FOR GROUND WATER VELOCITY:

$$V = \frac{K(dh/dl)}{n}$$

where:

V = ground water velocity, in feet per day
K = hydraulic conductivity, in feet per day
dh = difference in hydraulic heads between wells, in feet
dl = distance between wells, in feet
n = aquifer porosity, in percent

for spoil material and Pawnee Limestone are 1.49 feet (.45 m) per day in the spoil material and 0.53 feet (.16 m) per day in the Pawnee Limestone. These calculations are based on estimated porosity values of 30 percent for the spoil material and 10 percent for the Pawnee Limestone. Rates could exceed these values in the heterogeneous spoil and in limestone fractures.

CHAPTER 6: WATER QUALITY

Regional Water Quality:

In Linn County, analyses of ground-water samples collected by Seevers (1969), indicated that total dissolved solids concentrations are generally larger in wells yielding water from bedrock than in wells yielding water from alluvium. Ground water from all sources had relatively large calcium carbonate hardness (18 to 1,070 mg/l). Chloride concentrations ranged from 5.0 to 2,800 mg/l; water from >100 feet (30 m) deep normally exceeds the 250 mg/l Kansas secondary drinking water standard. Objectionable iron concentrations are possible, as water sample concentrations ranged from 0.01 to 5.2 mg/l. Relatively large fluoride concentrations in water samples ranged from 0.4 to 363 mg/l and were apparently associated with phosphate in black shales. 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. Sulfate, bicarbonate, calcium, and magnesium ions are found in larger concentrations in ground water from strip mine areas due to oxidation of the sulfide minerals and accompanying acid formation. This acid environment results in solution of limestones.

Landfill Area Water Quality:

Twelve sources of water samples were used for analysis of water quality. Four of these were from wells screened in the Pawnee Limestone (MW-1A, MW-2A, MW-3A, and MW-4B), one was from an up-gradient well screened in the spoil material (MW-5), one was from a down-gradient well screened in the spoil material (MW-1B), one was from a well screened in the trash (MW-4A), one was from a well screened in the spoil material adjacent to and down-gradient from a sewage disposal area (MW-2B), one was from a well screened in the Mulberry coal (MW-3B), two were from taps connected to treated public water supplies (city of Prescott and Rural Water District landfill tap), and one was from an up-gradient pond (Fig. 5). Results of the analysis of these samples are presented in Tables 7 and 8. Samples from the city of Prescott and the rural water supply were analyzed to provide background chemical data potable for the water used during augering and drilling operations.

Water Properties:

Specific conductance is a measure of total ion concentration in solution based upon the ability of the solution to transmit an electrical current. Specific conductance was smallest in the tap samples indicating a small ion concentration as would be expected of treated water from a surface source. Specific conductance of the remaining samples ranged from 1620 uS/cm in the up-gradient pond to 4260 uS/cm in MW-2B. These larger conductivity values indicate larger concentrations of ions in the untreated waters which come into contact with the sediments and trash in this vicinity.

Values for pH range from a low of 6.4 in water from MW-1A to a high of 8.4 in the up-gradient pond. The pH of water from all nine monitoring wells was between 6.4 and 6.9 while the pH of waters from municipal supplies and the up-gradient pond were between 7.6 and 8.3. 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. MW-5, being the shallowest well, had a temperature of 8.0° C while the remainder of the wells had temperatures between 14.0° and 16.5° C. The temperature of the surface pond water was seasonal at 11.0° C. The landfill tap was coldest at 4.5° C which is a function of pipeline depth and time of year.

Dissolved oxygen concentrations for water analyzed in seven wells ranged from a low of 0.6 mg/l in MW-2A and MW-4A to a high of 2.5 mg/l in MW-3B. Dissolved oxygen values were not obtained for MW-2B and MW-3A due to water levels being too low in these wells for the instrument to function properly. Dissolved oxygen values were also not obtained for the tap and surface water samples.

The chemical oxygen demand was determined for all samples, except for the tap water, with the smallest being 18.0 mg/l in water from MW-3B and the largest being 91.0 mg/l in water from MW-3A. In the wells where both dissolved oxygen concentrations and chemical oxygen demand were determined, as one value increased the other would decrease as is evidenced in MW-3B which has the largest DO and the smallest COD. The chemical oxygen demand was largest in the two wells (MW-2B and MW-3A) which had water levels too low to obtain dissolved oxygen values.

Total hardness expressed as mg/l of $CaCO_3$ was determined for each sample. The two tap water samples were the lowest as would be expected with values of 97 and 210 mg/l $CaCO_3$. The remaining samples ranged from 1000 mg/l $CaCO_3$ in the up-gradient pond to 2800 mg/l as $CaCO_3$ in MW-2B.

Alkalinity, as determined in the field and expressed as mg/l of $CaCO_3$, ranged in the wells from a low of 340 mg/l in MW-5 to a high of 680 mg/l in MW-2B. The alkalinity of the up-gradient pond was 110 mg/l. The alkalinity of the tap water was not determined in the field. Alkalinity data indicate that, as water enters the ground from the pond, the alkalinity increases as it comes into contact with and travels through the aquifer materials. The alkalinity of water from MW-5, located near the pond, is intermediate in value at 340 mg/l and the alkalinity of 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 the pond as MW-5, the alkalinity is larger in water from these two wells due to water flowing to these wells from bedrock in close proximity and mixing with water from the pond.

Dissolved solids concentrations, as calculated from the sum of the constituents, were smallest in the tap water with concentrations of 107 and 169 mg/l as would be expected of treated water. The surface pond was intermediate at 1390 mg/l and the wells ranged from 1970 mg/l in MW-1B to 3670 mg/l in MW-2A.

Major Cations:

Major cations included in the analysis were calcium, magnesium, sodium, and potassium (Table 7, Appendix). Data for each cation is reported in mg/l of that specific cation.

Calcium concentrations were smallest in the treated municipal water at 32 and 75 mg/l. Of the remaining samples, the smallest concentration of 190 mg/l was detected in water from MW-3A, and the largest concentration of 600 mg/l was detected in water from MW-2B.

Magnesium concentrations were again considerably smaller in the treated municipal water supplies with concentrations of 4.1 and 5.7 mg/l. Of the remaining samples the smallest concentration of 120 mg/l was detected in the up-gradient pond and the largest concentration of 410 mg/l was detected in MW-2A.

Sodium concentrations are smallest in the treated municipal water samples with the landfill tap being the smallest at 7.9 mg/l. The tap at Prescott is considerably larger at 21 mg/l. The remaining samples range from a low of 46 mg/l in the up-gradient pond to a high of 580 mg/l in MW-3A.

Potassium concentrations are again among the smallest, at 2 and 3 mg/l, in the treated municipal water although MW-2B and MW-5 had a concentration of 3 mg/l. Potassium concentrations in the remaining samples range from 3.1 mg/l in MW-5 to 10.0 mg/l in MW-2A.

Major Anions:

Major anions included in the analysis were bicarbonate (calculated from alkalinity), sulfate, chloride, fluoride.

Bicarbonate concentrations reported here are calculated from field data and do not include concentrations for the tap samples. The concentration in the up-gradient pond was the smallest at 130 mg/l. Of the remaining wells, the smallest concentration of 420 mg/l was in water from MW-5 and the largest concentration of 830 mg/l was in water from MW-2B. The smallest bicarbonate concentration is in the up-gradient pond water; an intermediate bicarbonate concentration is present in the nearby and slightly down-gradient MW-5; and the remainder of the bicarbonate concentrations in the monitoring wells are significantly larger. This pattern indicates that the bicarbonate concentration increases with prolonged exposure to aquifer materials and landfill wastes. At the pH levels present in these water samples, carbonate ions and hydroxide ions would not be stable or expected to occur.

Sulfate concentrations were smallest in the treated municipal water samples with concentrations of 35 and 60 mg/l. Of the remaining samples the smallest concentration of 1000 mg/l was found in the up-gradient pond and the largest concentration of 2600 mg/l was found in MW-2A. The sulfate concentrations are very large in this area and are probably due to the presence of sulfur and sulfide minerals in the Mulberry Coal which was mined here. Concentrations of sulfate detected in water from the landfill area are shown in Figures 15 and 16.

Chloride concentrations are not smallest in the treated municipal water probably due to chlorination during treatment. The smallest chloride concentration of 3.0 mg/l was detected in water from MW-5 with the largest value of 30 mg/l being detected in MW-3A.

Fluoride concentration is small in water from the up-gradient pond, MW-1A, MW-1B, MW-5, and the Prescott tap at 0.2 mg/l and largest in the landfill tap sample at 0.9 mg/l. The larger concentration at the landfill tap is possibly due to fluoridation during treatment.

Dissolved silica concentration was smallest at 0.2 mg/l in the up-gradient pond, at an intermediate concentration of 9.3 mg/l in MW-5, and largest at 24 mg/l in MW-3B. This indicates an increase in concentration down gradient with prolonged exposure to aquifer materials.

Water Types:

Four basic water types can be defined on the basis of major ion concentrations. They are plotted on Figure 17 in the form of Stiff diagrams. Stiff diagrams present a graphi-

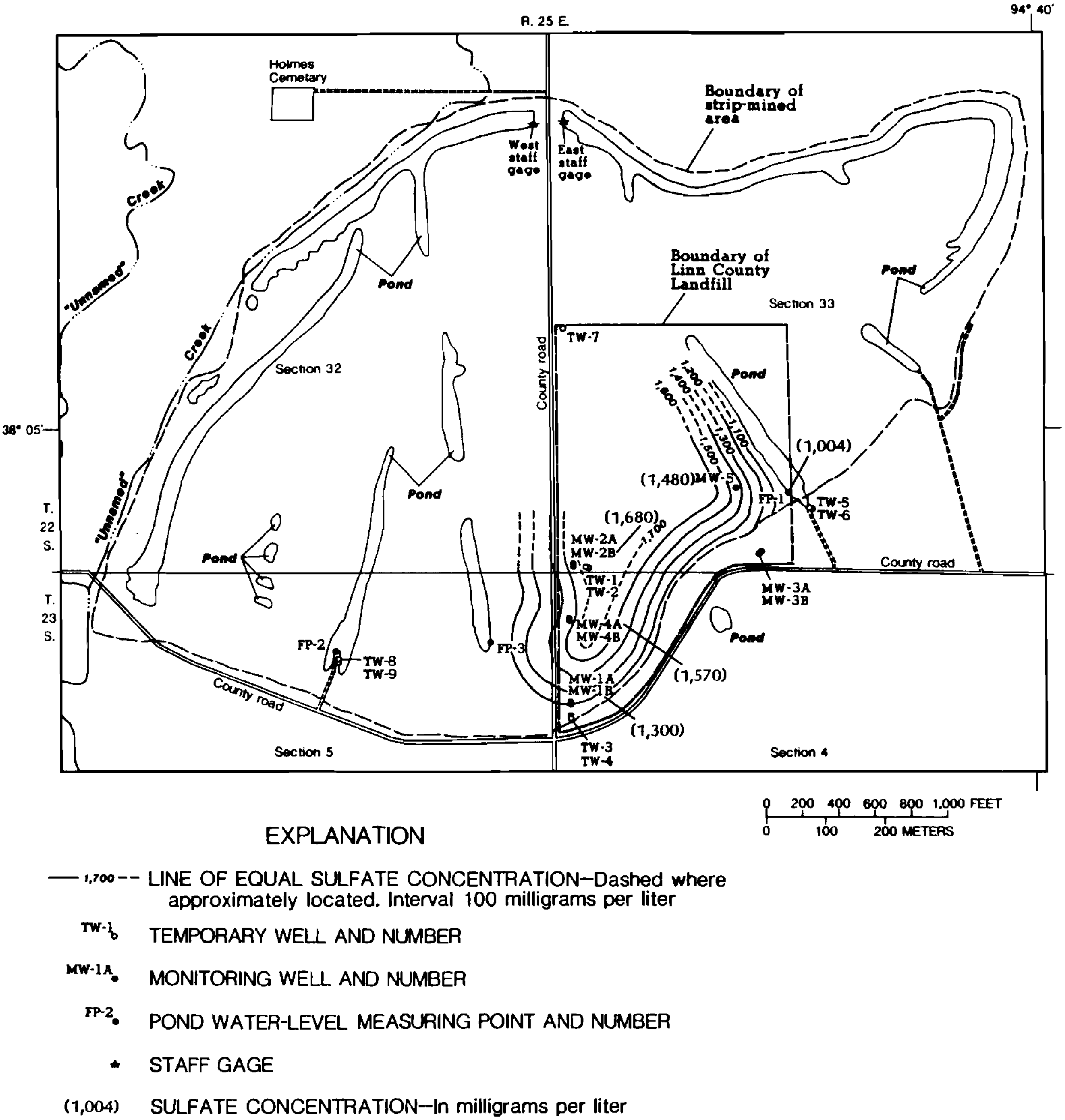


Figure 15. Distribution of sulfate concentrations in water samples from spoil material.

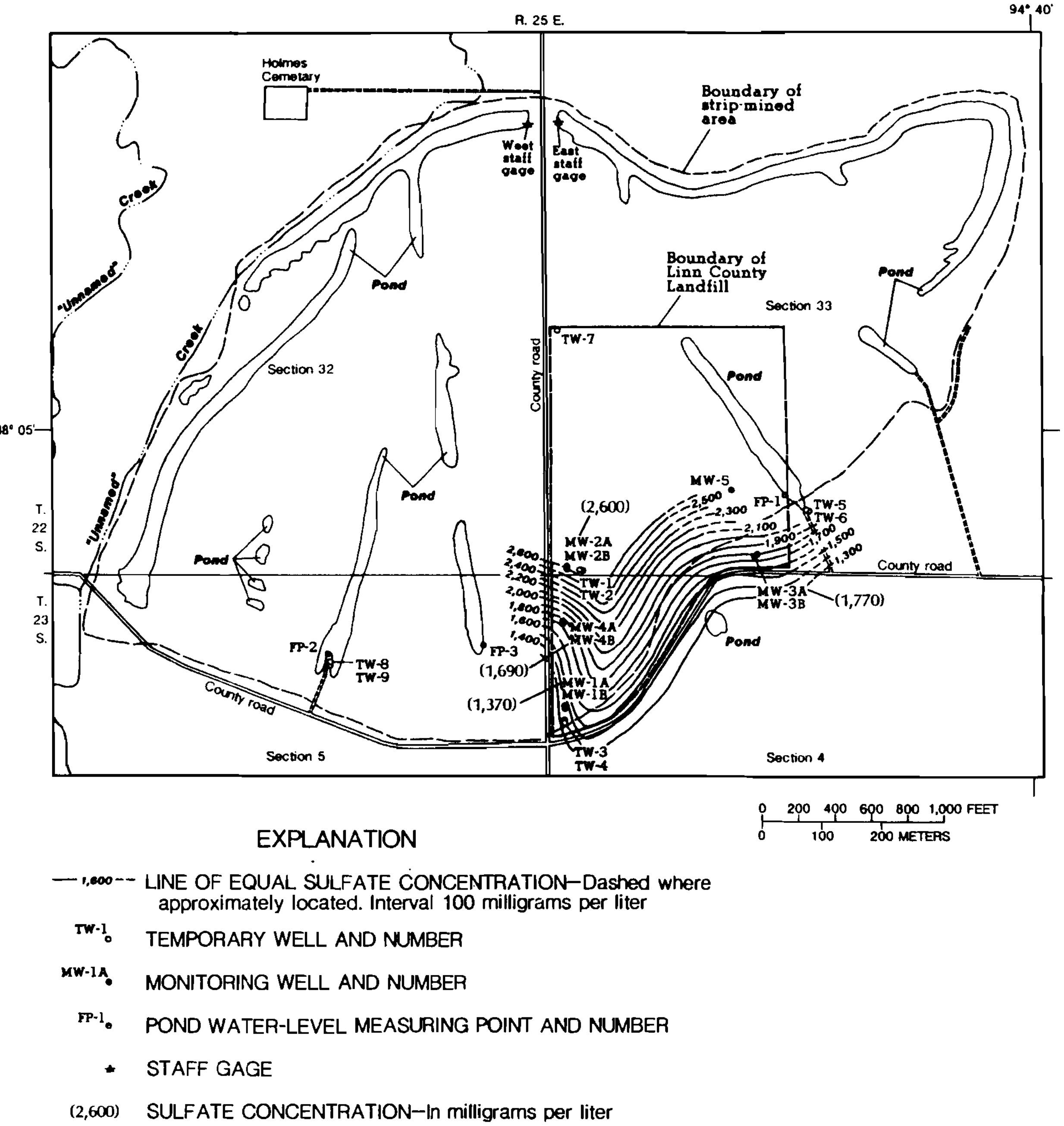


Figure 16. Distribution of sulfate concentrations in water samples from Pawnee Limestone.

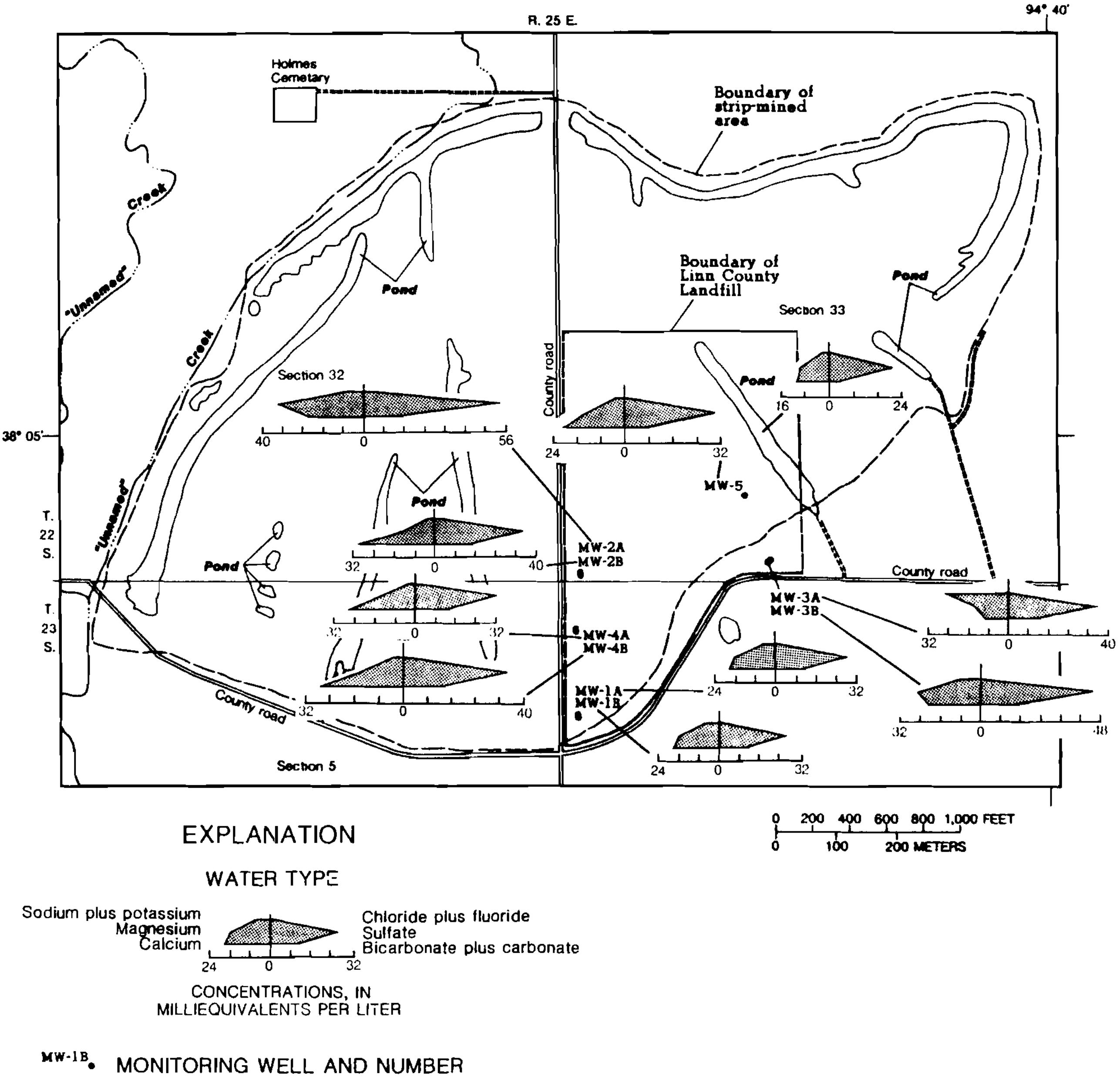


Figure 17. Stiff plots for major ion concentrations in water samples from monitoring wells; cations to the left; anions to the right; horizontal scale varies slightly between sites.

cal representation of the major cation and anion balance. Concentration of each ion is plotted on the horizontal axis adjacent to the label for that ion. The vertical axis has no set value other than an equidistant spacing between ions. The result of this plot is a two dimensional, geometric figure which represents the water type having a given ion balance. The four water types are calcium sulfate (MW-2B, MW-4A, MW-4B, and MW-5), calcium magnesium sulfate (MW-1A, MW-1B, and the up-gradient pond), magnesium calcium sulfate (MW-2A and MW-3B), and sodium potassium sulfate (MW-3A).

Nutrients:

Nitrate is expressed as nitrogen in mg/l within this report. All nine of the monitoring wells had nitrate concentrations smaller than the detection limit of 0.01 mg/l. The up-gradient pond water had 0.04 mg/l, the landfill tap had 0.36 mg/l, and the Prescott tap had 0.14 mg/l. All of these concentrations are less than the State and Federal primary drinking water standard of 10.0 mg/l for nitrate.

Ammonia is expressed as nitrogen in mg/l within this report. A concentration for ammonia in water from the landfill tap was not reported although it is likely that it would be comparable to the 0.06 mg/l found in the up-gradient pond and the 0.05 mg/l found in the Prescott tap as high ammonia concentrations are normally found only in reducing environments. Ammonia concentrations ranged from 0.12 mg/l in MW-1B to 1.6 mg/l in MW-3A. These concentrations of ammonia, lack of nitrite, and low dissolved oxygen indicate that a mildly reducing environment is currently present in this area.

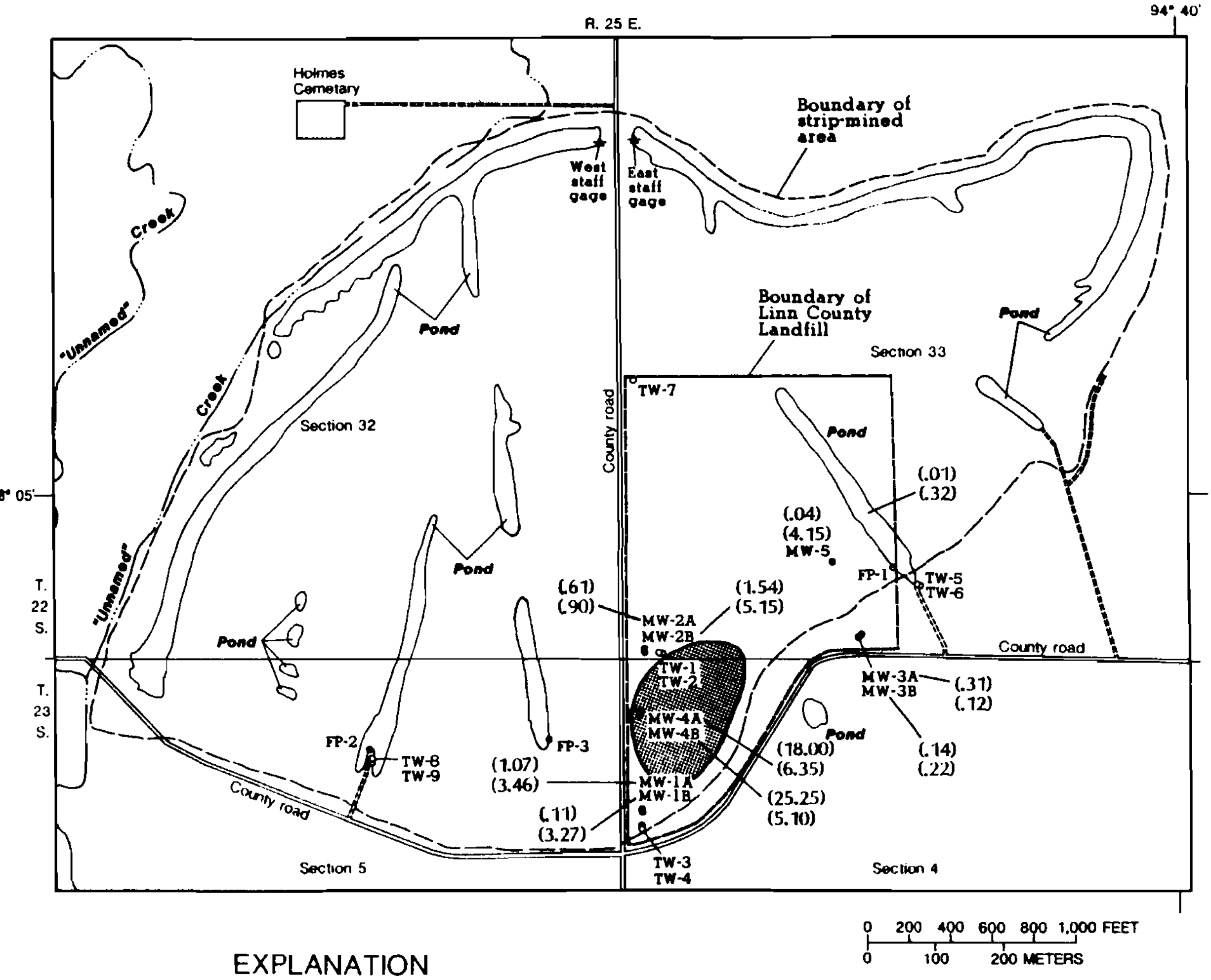
Phosphorus, reported in mg/l, ranged from a low of 0.01 mg/l in the landfill tap to a high of 1.0 mg/l in MW-5.

Trace Elements:

In addition to the major ions, several inorganic trace elements were evaluated in these water samples. These trace elements were arsenic, barium, cadmium, chromium, copper, iron, lead, manganese, mercury, selenium, silver, and zinc. Of these 11 trace elements, only iron and manganese concentrations exceeded secondary drinking water standards as established by the State of Kansas.

The secondary drinking water standard for iron is 300 ug/l (micrograms per liter). Eight of the twelve water samples analyzed equaled or exceeded this standard. Water from the Prescott tap equaled this limit of 300 ug/l and seven of the well samples exceeded this limit and ranged from 310 ug/l in MW-3A to 25,000 ug/l in MW-4B (Fig. 18). 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.

The secondary drinking water standard for manganese is 50 ug/l. Water samples from the up-gradient pond and the nine monitoring wells exceeded this standard (Fig. 18). The



EXPLANATION

▨ AREA OF LARGEST CONCENTRATIONS OF IRON AND MANGANESE

TW-1 ○ TEMPORARY WELL AND NUMBER

MW-1A ● MONITORING WELL AND NUMBER

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

✦ STAFF GAGE

(.61)
(.90) CONCENTRATIONS-Upper number is iron concentration; lower number is manganese concentration, in milligrams per liter

Figure 18. Distribution of iron and manganese concentrations in water samples from monitoring wells.

two tap samples from municipal water supplies had manganese concentrations that were smaller than this standard. Concentrations ranged from 120 ug/l in MW-3A to 6,300 ug/l in MW-4A.

Organic compounds:

The organic compounds that were analyzed in these samples can be divided into four groups. These were volatile organic compounds, acid extractable organic compounds, base neutral extractable organic compounds, and pesticides. A complete listing of compounds in each of these categories is provided in Table 8. The two tap samples and four of the monitoring well samples contained volatile organic compounds above the detection limit. No base neutral extractable organic compounds, acid extractable organic compounds, or pesticides were found to be present at or above the detection limits. Methylene blue active substances were detected in the pond sample and in all well samples except MW-3B. Table 9 (Appendix) contains a listing of all organic compounds and concentrations detected in the pond and monitoring well samples.

The Prescott tap sample contained three volatile organic trihalomethane compounds. These were chlorodibromomethane at 2.3 ug/l, chloroform at 72 ug/l, and dichlorobromomethane at 17 ug/l. The landfill tap sample contained chloroform at 40 ug/l and dichlorobromomethane at 8.4 ug/l. The presence of these chlorinated hydrocarbons, which are suspected carciogenic compounds, in the public water supply is likely

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

Volatile Organic Compounds

benzene
carbon tetrachloride
chloroethane
1,2-dichlorobenzene
1,4-dichlorobenzene
1,1-dichloroethane
cis-1,3-dichloropropene
ethlybenzene
methyl chloride
1,1,2,2-tetrachloroethane
toluene
1,1,1-trichloroethane
trichloroethylene
m-xylene

bromoform
chlorobenzene
chloroform
1,3-dichlorobenzene
dichlorobromomethane
1,2-dichloroethane
1,2-dichloropropane
trans-1,3-dichloropropene
methlybromide
methylenechloride
tetrachloroethylene
1,2-trans-dichloroethene
1,1,2-trichloroethane
p-xylene

Semivolatile, Acid Extractable

2,4-dichlorophenol
4,6-dinitroorthocresol
ortho-chlorophenol
4-nitrophenol
pentachlorophenol
2,4,6-trichlorophenol

2,4-dimethylphenol
2,4-dinitrophenol
2-nitrophenol
parachlorometa cresol
phenol

Semivolatile, Base-Neutral Extractables

acenaphthene
anthracene
1,2,4-trichlorobenzene
benzo (b) fluoranthene
benzo (g,h,i) perylene
bis (2-chloroethoxy) methane
bis (2-ethlyhexyl) 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
dimethly phalate
di-n-octly phthalate
2,6-dinitrotoluene
fluoranthene
hexachlorobutadadiene
indeno (1,2,3-c,d) pyrene
butylbenzyl phthalate
pyrene, total

Table 8. (continued)

Pesticides

alachlor
BHC
aroclor 1016 pcb
aroclor 1232 pcb
aroclor 1248 pcb
aroclor 1260 pcb
b-benzene hexachloride
chlordane
g-benzene hexachloride
endosulfan I
endrin
heptachlor
metolachlor (Dual)
p,p' ddd
p,p' ddt
prometryn
simazine
toxaphene

aldrin
ametryn
aroclor 1221 pcb
aroclor 1242 pcb
aroclor 1254 pcb
atrazine
d-benzene hexachloride
cyanazine
dieldrin
endosulfan II
endosulfane sulfate
heptachlor epoxide
metribuzin
p,p' dde
prometon
propazine
simetryn
trifluralin

due to chlorination of the water during treatment. These trihalomethane compounds in the public water supplies which were used for drilling the temporary wells and monitoring wells MW-1A and MW-1B were not detected in any of the water samples from the monitoring wells.

Carbontetrachloride, 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 ug/l, with a detection limit of 0.70 ug/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 ug/l, with a detection limit of 0.50 ug/l.

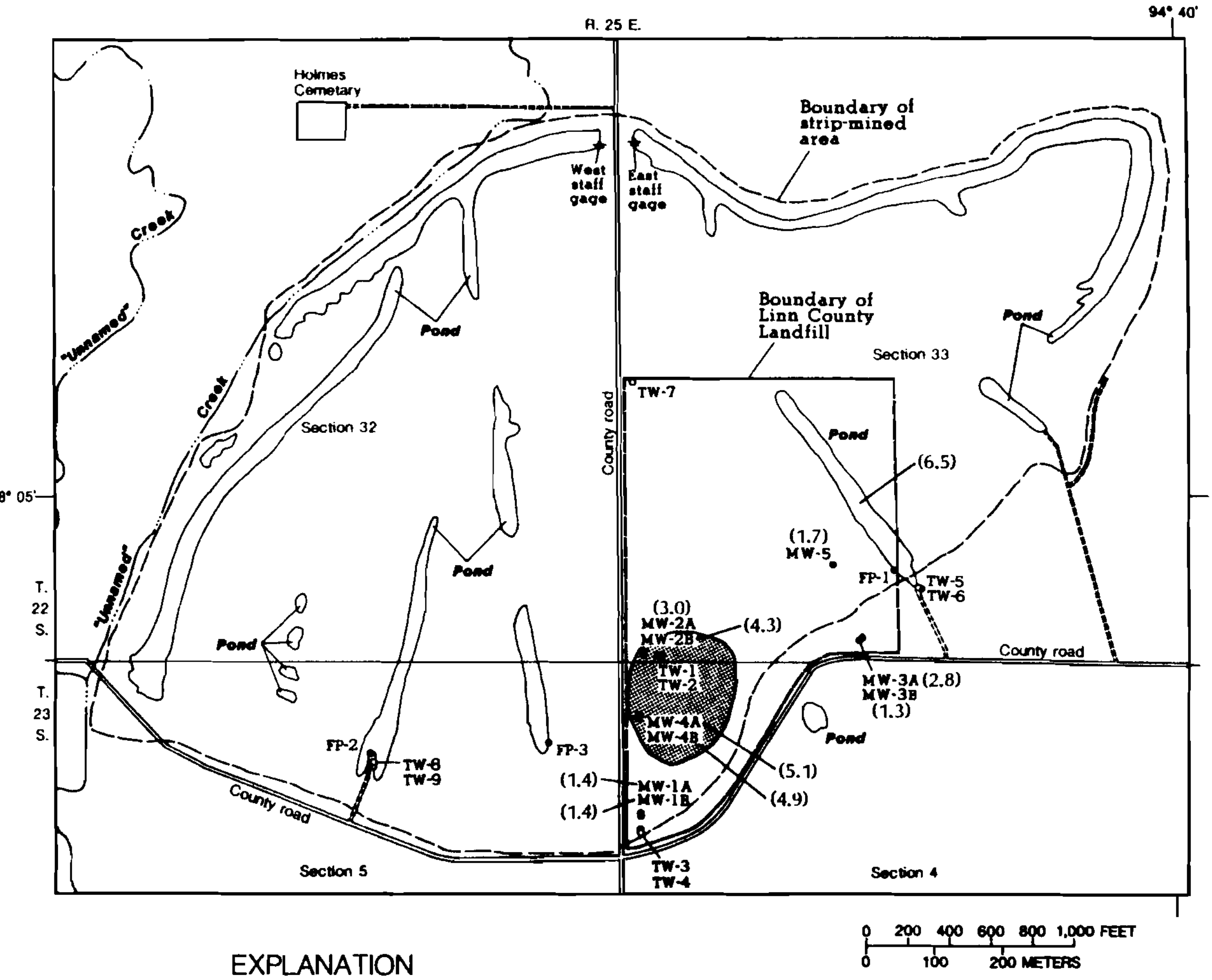
1,1 dichloroethane was detected in water from well MW-2B at 3.0 ug/l and in water from well MW-4A at 1.4 ug/l. The detection limit for this compound is 0.50 ug/l. It is a constituent in paint, varnish, finish removers, soap, scouring compounds, wetting agents, and penetrating agents. It is also used 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 ug/l.

These compounds would all indicate the presence of water contamination in their respective wells (National Research Council, 1977).

Dissolved organic carbon (DOC) concentrations were determined for the nine monitoring well water samples and for the up-gradient pond sample. Concentrations are reported in mg/l as carbon (Table 9, Appendix) and are shown plotted in Figure 19. Concentrations ranged from 1.3 mg/l in MW-3B to 6.5 mg/l in the up-gradient pond. Large dissolved organic carbon concentrations are found in MW-4A, MW-4B, MW-2A, and MW-2B which are located in the trash pile or near the sewage disposal dump indicating that dissolved organic carbon is being derived from the landfill waste. Well MW-3A is an up gradient well that is screened in the Pawnee Limestone and had a DOC concentration of 2.8 mg/l. This large concentration is possibly a reflection of the 0.90 ug/l concentration of benzene, which contributes to DOC, detected in this well. It may also be a result of water from the near by up-gradient pond, which had a DOC concentration of 6.5 mg/l, migrating into this well bore.

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. Water in eutrophic lakes, such as the up-gradient pond, can range from 3 to 34 mg/l DOC, with the mean concentration being 10 mg/l. The presence of coal in the sediments can cause a larger than normal DOC 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 water in coal mine spoil.



EXPLANATION

▨ AREA OF INCREASED DISSOLVED-ORGANIC-CARBON CONCENTRATIONS

TW-1 ○ TEMPORARY WELL AND NUMBER

MW-1A ● MONITORING WELL AND NUMBER

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

✦ STAFF GAGE

(1.4) DISSOLVED-ORGANIC-CARBON CONCENTRATION—In milligrams per liter as carbon

Figure 19. Dissolved-organic-carbon concentrations in water samples from monitoring wells and up-gradient pond.

CHAPTER 7: INTERPRETATION

Four basic water types can be defined in this area and are displayed on Figure 17 in the form of Stiff plots. These four types are calcium sulfate, calcium magnesium sulfate, magnesium calcium sulfate, and sodium potassium sulfate. The chemical constituents of these water types are all dominantly contributed by the local lithology with the possible exception of the sodium and potassium. These two exceptions, which were detected in abundance in MW-3A may indicate the presence of water contaminated by landfill wastes. The distribution of the four water types within this study area appears to be a result of a mixing effect of the water from the spoil and the bedrock. In general, it appears that the calcium sulfate water type originates in the spoil and the magnesium calcium sulfate water type originates in the bedrock. The calcium magnesium sulfate water type may be a mix of the two previously mentioned water types. The sodium potassium sulfate water type may be a result of contamination by landfill wastes or ion-exchange processes occurring in the Bandera Shale.

Complications in the hydrology of this specific area include: the damming effect by the county road, the undefined breaches in the shale and limestone underlying the spoil piles, the possibility of seasonal reversals in direction of ground-water flow in the spoil materials, and the changes in interaction of waters from the surrounding and underlying bedrock with the landfill water. Because of these complications, the use of a simple, conceptual model for defining the geohydrology and ground-water quality in this area is not possible. Water-level data from periods of greater precipitation could show a different pattern of ground-water movement and resulting leachate transport.

It is evident that the Bandera Shale is not continuous across the base of the Linn County Landfill, which allows movement of ground water between the Pawnee Limestone and the spoil. The distribution of sulfates within the spoil material and the underlying limestone is very similar (Figs. 15 and 16). The similarity of distribution is probably due to interaction of the waters of these two aquifers. The sulfate could originate from sulfate minerals in the limestone but more likely originates in the spoil material.

The distribution of iron and manganese in the two aquifers studied also shows similiar patterns (Fig. 18), which again suggests interaction of the waters of these two aquifers. This large concentration of these two elements within the landfill area may be a result of direct derivation from landfill wastes or a result of leachate action on iron and manganese oxides in the aquifer material.

The distribution of organic compounds and dissolved organic carbon (Fig. 19) indicates that these organic compounds are being derived from landfill wastes. The distribution of dissolved organic carbon within the spoil material and the Pawnee Limestone is again similiar and indicates the interaction of water between these two aquifers.

On the basis of the similarity in distribution patterns for sulfate, iron, manganese, and organic compounds, it is evident that leachate-contaminated ground water is moving downward from the spoil material, in which the trash is buried, into the Pawnee Limestone. This is contrary to the general upward flow of ground water indicated by water level measurements (Figs. 12A, B). This supports the theory that ground-water-movement patterns change in this area possibly as a result of seasonal precipitation fluctuations.

Water traveling through limestone fracture systems may not undergo the natural removal of some leachate constituents, as would water passing through an aquifer containing clays or other unconsolidated fine materials. Leachate-contaminated water may also pass from the trash into the surrounding bedrock aquifers at the perimeters of the spoil pile where spoil contacts truncated bedrock aquifers. It is uncertain whether the dominate flow direction is from the spoil into the bedrock or from the bedrock into the spoil. This could change seasonally.

The presence of methylene blue active substances (MBAS), which are generally derived from detergents, in the pond sample and all monitoring well samples except MW-3B indicates that leachate from the landfill may be present to some degree in the pond and all monitoring wells. The absence of these compounds in MW-3B may be due to the filtering effect of the coal in which this well is screened. It should be noted that chemical interferences can produce false positives for MBAS as high as 0.5 mg/l; therefore, the indicated presence of MBAS at concentrations less than 0.5 mg/l in water from the pond and wells MW-1A, MW-1B, MW-2A, MW-2B, and MW-5 may not be of significance. However, the concentration of MBAS in wells MW-4A and MW-4B, which are located in the trash pile, is significantly larger than the rest of the samples and is twice that of possible interference causes, indicating that MBAS are present.

Of the inorganic trace elements and major ions detected in water samples from the landfill, it appears that they are derived mainly from the local bedrock and spoil material, although the landfill trash is a minor contributor to the concentrations. Major ion and trace element concentrations are affected by local water pH, lithology, trash, bacteria, available oxygen and various other controls. Lithology appears to be the dominate control in this situation. Iron, manganese, and dissolved organic carbon seem to be originating from the trash pile and might prove useful as tracers for determining leachate movement.

CHAPTER 8: SUMMARY AND CONCLUSIONS

Chemical analyses of water samples from monitoring wells and an up-gradient pond indicate that the landfill is affecting ground-water quality. This is evident from the elevated iron, manganese, dissolved organic carbon, and methylene blue active substance concentrations in wells MW-4A, MW-4B, MW-1A, and MW-1B. It is evident from the similarity in chemistry of water from MW-4A and MW-4B that an interconnection exists between strip-mine spoil and the underlying Pawnee Limestone. Hydrologic data indicate that at the landfill ground-water flow is toward the southwest in the spoil and in the Pawnee Limestone. Leachate from the landfill has the potential to migrate to the southwest, west, or northwest from the landfill in either spoil or the Pawnee Limestone. Seasonal variations in ground-water flow direction would affect the direction of leachate migration.

Ground water in the northeastern portion of the 40-acre (16 ha) landfill extension probably flows northeastward towards ponds bounding the strip mine area on the north and east. Use of the area in which ground water flows northeastward for landfill activities could lead to contamination of these boundary ponds with leachate.

Continued yearly analyses of selected inorganic and organic constituents would provide long-term information on the effect of the landfill on water quality. Quarterly water-level measurements and continuous short-term water-level measurements would give a better understanding of seasonal fluctuations in ground water-levels and the direction of ground-water movement.

Estimates of ground-water flow direction in the 40-acre landfill extension area could be refined by installing drive-point wells in this area. In order 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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APPENDIX

Table 7. Physical properties and inorganic constituents detected in water samples.

[Concentrations in mg/l (milligrams per liter), μg/l (micro grams per liter), uS/cm (microsiemens per centimeter @ 25 degrees Celsius), except as noted. <x.x = constituent less than detection limit of x.x; -- = not analysed NA= not applicable]

Sample Location (Fig. 5)	Date	Specific Conductance (uS/cm)	pH (std. units)	Water Temp. (°C)	Turbidity (Jackson units)
MW-1A	3/2/89	2,620	6.4	14.0	30
MW-1B	3/2/89	2,600	6.5	14.0	35
MW-2A	3/3/89	3,000	6.5	16.5	460
MW-2B	3/3/89	3,900	6.9	16.0	1,100
MW-3A	3/2/89	3,450	6.9	14.5	40
MW-3B	3/2/89	3,650	6.6	14.0	800
MW-4A	3/3/89	2,900	6.7	16.0	1,400
MW-4B	3/3/89	3,000	6.6	16.0	290
MW-5	3/2/89	2,500	6.6	8.0	950
Pond	3/15/89	1,600	8.4	11.0	3
Rural	3/3/89	420	7.6	4.5	.4
Prescott	3/15/89	280	7.8	7.0	.6
Kansas drinking-water standards					
Primary		NA	NA	NA	1.0
Secondary		NA	6.5-8.5	NA	NA
Federal drinking-water standards					
Primary		NA	NA	NA	NA

Table 7. (continued)

Sample Location (Fig. 5)	Oxygen, dissolved (mg/l)	Chemical Oxygen Demand (mg/l)	Hardness, total (mg/l as $CaCO_3$)
MW-1A	1.9	28.0	1,700
MW-1B	.9	31.0	1,700
MW-2A	.6	81.0	2,800
MW-2B	--	89.0	2,200
MW-3A	--	91.0	1,200
MW-3B	2.5	18.0	2,300
MW-4A	.6	73.0	2,000
MW-4B	.9	61.0	2,100
MW-5	1.0	73.0	1,700
Pond	--	21.0	1,000
Rural	--	--	210
Prescott	--	--	97
Kansas drinking-water standards			
Primary	NA	NA	NA
Secondary	NA	NA	400
Federal drinking-water standards			
Primary	NA	NA	NA

Table 7. (continued)

Sample Location (Fig. 5)	Calcium, dissolved (mg/l as Ca)	Magnesium, dissolved (mg/l) as Mg)	Sodium, dissolved (mg/l) as Na)
MW-1A	360	190	100
MW-1B	360	180	100
MW-2A	420	410	180
MW-2B	600	160	49
MW-3A	190	170	580
MW-3B	410	310	170
MW-4A	540	170	61
MW-4B	550	170	63
MW-5	420	160	66
Pond	210	120	46
Rural	75	5.7	7.9
Prescot	32	4.1	21
Kansas drinking-water standards			
Primary	NA	NA	NA
Secondary	NA	NA	NA
Federal drinking-water standards			
Primary	NA	NA	NA

Table 7. (continued)

Sample Location (Fig. 5)	Potassium, dissolved (mg/l as K)	Bicarbonate, calculated (mg/l as HCO_3)	Alkalinity, total (mg/l as $CaCO_3$)
MW-1A	5.0	700	580
MW-1B	4.0	660	540
MW-2A	10.0	730	600
MW-2B	3.0	830	680
MW-3A	9.0	770	630
MW-3B	9.0	780	640
MW-4A	4.0	770	630
MW-4B	5.0	780	640
MW-5	3.0	420	340
Pond	5.0	130	110
Rural	2.0	--	--
Prescot	3.0	--	--
Kansas drinking-water standards			
Primary	NA	NA	NA
Secondary	NA	NA	NA
Federal drinking-water standards			
Primary	NA	NA	NA

Table 7. (continued)

Sample Location (Fig. 5)	Sulfate, dissolved (mg/l as SO_4)	Chloride, dissolved (mg/l as Cl)	Fluoride, dissolved (mg/l as F)
MW-1A	1,400	11	.2
MW-1B	1,300	10	.2
MW-2A	2,600	26	.7
MW-2B	1,700	21	.4
MW-3A	1,800	30	.8
MW-3B	2,200	12	.3
MW-4A	1,600	17	.4
MW-4B	1,700	19	.3
MW-5	1,500	3.0	.2
Pond	1,000	4.9	.2
Rural	60	9.5	.9
Prescot	35	9.9	.2
Kansas drinking-water standards			
Primary	NA	NA	1.8
Secondary	250	250	NA
Federal drinking-water standards			
Primary	NA	NA	1.4

Table 7. (continued)

Sample Location (Fig. 5)	Silica, dissolved (mg/l as SiO_2)	Solids, dissolved (mg/l)	Nitrate, dissolved (mg/l as N)
MW-1A	12	2,360	<.01
MW-1B	12	2,260	<.01
MW-2A	16	4,030	<.01
MW-2B	15	2,880	<.01
MW-3A	13	3,140	<.01
MW-3B	24	3,430	<.01
MW-4A	14	2,680	<.01
MW-4B	15	2,890	<.01
MW-5	9.3	2,370	<.01
Pond	.2	1,480	.04
Rural	5.6	253	.36
Prescot	1.6	157	.14
Kansas drinking-water standards			
Primary	NA	NA	10.0
Secondary	NA	500	NA
Federal drinking-water standards			
Primary	NA	NA	10.0

Table 7. (continued)

Sample Location (Fig. 5)	Ammonia, dissolved (mg/l as N)	Phosphorous, dissolved (mg/l as P)	Arsenic, dissolved (ug/l as As)
MW-1A	.14	.03	3
MW-1B	.12	.07	3
MW-2A	.66	.05	<1
MW-2B	.16	.33	2
MW-3A	1.7	.06	<1
MW-3B	1.1	.12	<1
MW-4A	.68	.77	3
MW-4B	.94	.29	1
MW-5	.19	1.0	2
Pond	.06	.07	6
Rural	--	.01	--
Prescot	.05	.06	--
Kansas drinking-water standards			
Primary	NA	NA	10
Secondary	NA	NA	NA
Federal drinking-water standards			
Primary	NA	NA	10

Table 7. (continued)

Sample Location (Fig. 5)	Barium, dissolved (ug/l as Ba)	Cadmium, dissolved (ug/l as Cd)	Chromium, dissolved (ug/l as Cr)
MW-1A	40	1	<10
MW-1B	<10	<1	<10
MW-2A	40	<1	<10
MW-2B	70	1	<10
MW-3A	10	<1	<10
MW-3B	80	<1	<10
MW-4A	<10	<1	<10
MW-4B	30	<1	<10
MW-5	<10	1	<10
Pond	<10	<1	<10
Rural	--	--	--
Prescot	--	--	--
Kansas drinking-water standards			
Primary	1,000	10	NA
Secondary	NA	NA	5,000
Federal drinking-water standards			
Primary	1,000	10	NA

Table 7. (continued)

Sample Location (Fig. 5)	Copper, dissolved (ug/l as Cu)	Iron, dissolved (ug/l as Fe)	Lead, dissolved (ug/l as Pb)
MW-1A	20	1,100	<1
MW-1B	20	110	<1
MW-2A	30	900	<1
MW-2B	30	1,500	<1
MW-3A	20	310	<1
MW-3B	20	140	<1
MW-4A	20	18,000	<1
MW-4B	20	25,000	<1
MW-5	10	20,000	<1
Pond	20	10	3
Rural	--	80	--
Prescot	--	300	--
Kansas drinking-water standards			
Primary	NA	NA	50
Secondary	1,000	300	NA
Federal drinking-water standards			
Primary	NA	NA	50

Table 7. (continued)

Sample Location (Fig. 5)	Manganese, dissolved (ug/l as Mn)	Mercury, dissolved (ug/l as Hg)	Selenium, dissolved (ug/l as Se)
MW-1A	3,500	.5	<1
MW-1B	3,300	<.5	<1
MW-2A	610	<.5	<1
MW-2B	5,100	<.5	<1
MW-3A	120	.5	2
MW-3B	220	<.5	<1
MW-4A	6,300	<.5	<1
MW-4B	5,100	<.5	<1
MW-5	4,100	<.5	<1
Pond	320	<.5	<1
Rural	40	--	--
Prescot	20	--	--
Kansas drinking-water standards			
Primary	NA	2.0	10.0
Secondary	50	NA	NA
Federal drinking-water standards			
Primary	NA	2.0	10.0

Table 7. (continued)

Sample Location (Fig. 5)	Silver, dissolved (ug/l as Ag)	Zinc, dissolved (ug/l as Zn)
MW-1A	2	30
MW-1B	3	30
MW-2A	3	20
MW-2B	2	30
MW-3A	1	<10
MW-3B	2	10
MW-4A	2	30
MW-4B	2	20
MW-5	2	3,600
Pond	3	<10
Rural	--	--
Prescot	--	--
Kansas drinking-water standards		
Primary	NA	NA
Secondary	NA	5,000
Federal drinking-water standards		
Primary	NA	NA

Table 9. Organic compounds detected in water samples.

Sample Location (Fig. 5)	Dissolved Organic Carbon (mg/l)	Methyl Blue Active Substances (mg/l)	Benzene (ug/l)	Carbontetrachloride (ug/l)
MW-1A	1.4	.45	<.50	<.70
MW-1B	1.4	.36	<.50	1.8
MW-2A	3.0	.33	<.50	<.70
MW-2B	4.3	.46	<.50	<.70
MW-3A	2.8	.63	.90	<.70
MW-3B	1.3	<.20	<.50	<.70
MW-4A	5.1	1.0	<.50	<.70
MW-4B	4.9	1.3	<.50	<.70
MW-5	1.7	.24	<.50	<.70
Pond	6.5	.40	--	--
Rural	--	--	<.50	<.70
Prescot	--	--	<.50	<.70
KNL	--	--	.67	.27
KAL	--	--	.67	2.7
KPDWS	--	--	5.0	5.0

KNL = Kansas Notification Level (Kansas Department of Health and Environment 1986).

KAL = Kansas Action Level (Kansas Department of Health and Environment 1986.

KPDWS = Kansas Primary Drinking Water Standard (Kansas Department of Health and Environment 1986).

(a) = Total of Trihalomethane Compounds
(b) = Any Positive Detection
(c) = Insufficient Data to Establish Standard

Table 9. (continued)

Sample Location (Fig. 5)	Chlorodibromomethane (ug/l)	Chloroform (ug/l)	Dichlorobromomethane (ug/l)
MW-1A	<.70	<.50	<.50
MW-1B	<.70	<.50	<.50
MW-2A	<.70	<.50	<.50
MW-2B	<.70	<.50	<.50
MW-3A	<.70	<.50	<.50
MW-3B	<.70	<.50	<.50
MW-4A	<.70	<.50	<.50
MW-4B	<.70	<.50	<.50
MW-5	<.70	<.50	<.50
Pond	<.70	<.50	<.50
Rural	<.70	40	8.4
Prescot	2.3	72	17
KNL	100 (a)	100 (a)	100 (a)
KAL	(a)	(a)	(a)
KPDWS	--	--	--

KNL = Kansas Notification Level (Kansas Department of Health and Environment 1986).

KAL = Kansas Action Level (Kansas Department of Health and Environment 1986.

KPDWS = Kansas Primary Drinking Water Standard (Kansas Department of Health and Environment 1986).

(a) = Total of Trihalomethane Compounds
(b) = Any Positive Detection
(c) = Insufficient Data to Establish Standard

Table 9. (continued)

Sample Location (Fig. 5)	1,1-dichloroethane (ug/l)	1,1,1-tricholoroethane (ug/l)	Total Trihalomethanes (ug/l)
MW-1A	<.50	<.70	<.70
MW-1B	<.50	<.70	<.70
MW-2A	<.50	<.70	<.70
MW-2B	3.0	.70	<.70
MW-3A	<.50	<.70	<.70
MW-3B	<.50	<.70	<.70
MW-4A	1.4	<.70	<.70
MW-4B	<.50	<.70	<.70
MW-5	<.50	<.70	<.70
Pond	--	<.70	--
Rural	<.50	<.70	48.8
Prescot	<.50	<.70	91.3
KNL	(b)	16.8	100 (a)
KAL	(c)	168	(a)
KPDWS	--	200	--

KNL = Kansas Notification Level (Kansas Department of Health and Environment 1986).

KAL = Kansas Action Level (Kansas Department of Health and Environment 1986.

KPDWS = Kansas Primary Drinking Water Standard (Kansas Department of Health and Environment 1986).

(a) = Total of Trihalomethane Compounds
(b) = Any Positive Detection
(c) = Insufficient Data to Establish Standard