HYDROGEOLOGY AND GROUND-WATER-QUALITY CONDITIONS AT THE EMPORIA-LYON COUNTY LANDFILL, EASTERN KANSAS, 1988

By Nathan C. Myers and Philip R. Bigsby

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CONVERSION FACTORS

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

Multiply inch-pound unit	*By*	*To obtain metric unit*
inch	2.540	centimeter
foot	0.3048	meter
mile	1.609	kilometer
acre	4,047	square meter
gallon	3.785	liter
gallon per minute	0.06309	liter per second
degree Fahrenheit (°F)	(1)	degree Celsius (°C)

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[1] °C = (°F-32)/1.8.

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

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HYDROGEOLOGY AND GROUND-WATER-QUALITY CONDITIONS AT THE EMPORIA-LYON COUNTY LANDFILL, EASTERN KANSAS, 1988

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ABSTRACT

An investigation of hydrogeology and water-quality conditions at the Emporia-Lyon County Landfill, eastern Kansas, was conducted from April 1988 through April 1989. After an initial information survey, 14 temporary wells were installed. Potentiometric-surface maps constructed from water levels in these wells indicated ground-water movement from the northeast and northwest towards the landfill and then south through the landfill towards the Cottonwood River. The maps indicate that during periods of low ground-water levels ground water flows northward in the northwest part of the landfill. Water withdrawal from wells north of the landfill or water ponded in waste lagoons south and west of the landfill could have induced this northerly ground-water flow. On the basis of analysis of the initial water-level data, 13 monitoring wells were installed for sampling upgradient and downgradient of the landfill.

Calcium bicarbonate type water was found in all monitoring wells. Ranges of major ion concentrations were: calcium, 110 to 180 mg/L (milligrams per liter); magnesium, 14 to 41 mg/L; sodium, 40 to 110 mg/L; bicarbonate, 460 to 980 mg/L; sulfate, 16 to 91 mg/L; and chloride, 11 to 160 mg/L. Iron concentrations ranged from 10 to 7,100 µg/L (micrograms per liter); and manganese, from 50 to 4,500 µg/L. Laboratory analyses detected organic compounds in the following ranges of concentrations: bis (2 ethylhexyl) phthalate, <10.0 to 42.6 µg/L; chloroform, <0.50 to 2.3 µg/L; prometone, <0.10 to 0.10 µg/L; and toluene, <0.40 to 0.6 µg/L.

No inorganic or organic chemical concentrations exceeded Kansas or Federal primary drinking-water standards for those constituents or compounds for which limits have been established. Kansas secondary drinking-water standards were equaled or exceeded in water from some or all wells for total hardness, dissolved solids, iron, and manganese. Water from upgradient well MW-2 contained larger concentrations of dissolved oxygen and nitrate, and smaller concentrations of bicarbonate, alkalinity, ammonia, arsenic, iron, and manganese as compared to all other monitoring wells.

The results of this investigation indicate that ground-water quality downgradient of well MW-2 has been affected by increased concentrations of some inorganic and organic compounds. Due to the industrial nature of the area and the changing directions of ground-water flow, however, it is not clear what the probable sources of the increased concentrations may be. Long-term monitoring, additional wells, and access to nearby waste lagoons and waste-lagoon monitoring wells would help identify the sources of the increased concentrations of inorganic and organic compounds.

INTRODUCTION

Shallow aquifers 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 concerning water resources. To gain information about the effects of landfills on water quality, the Kansas Department of Health and Environment currently (1990) requires that all public landfills in Kansas install ground-water-monitoring systems.

In April 1988, the U.S. Geological Survey, in cooperation with the city of Emporia and Lyon County, began a study of the hydrogeology and ground-water quality in the vicinity of the Emporia-Lyon County Landfill.

Purpose and Scope

The purpose of the study was to describe the geology, hydrology, and ground-water quality in the vicinity of the Emporia-Lyon County Landfill. The study is one of several in Kansas that focus on the effects of landfills on the quality of water in shallow aquifers. This report presents information on current hydrogeologic and ground-water-quality conditions in the vicinity of the Emporia-Lyon County Landfill, including a description of regional geology and hydrology, a description of alluvial sediments penetrated during drilling of wells in and near the landfill, a description of hydrologic conditions in the alluvial sediments in and near the landfill, and a description of inorganic and organic ground-water chemistry for water samples from 13 monitoring wells in and near the landfill.

General Description of Study Area

The Emporia-Lyon County Landfill is located on the southwest edge of the city of Emporia in east-central Kansas (figs. 1 and 2) in a physiographic region known as the Osage Cuestas.

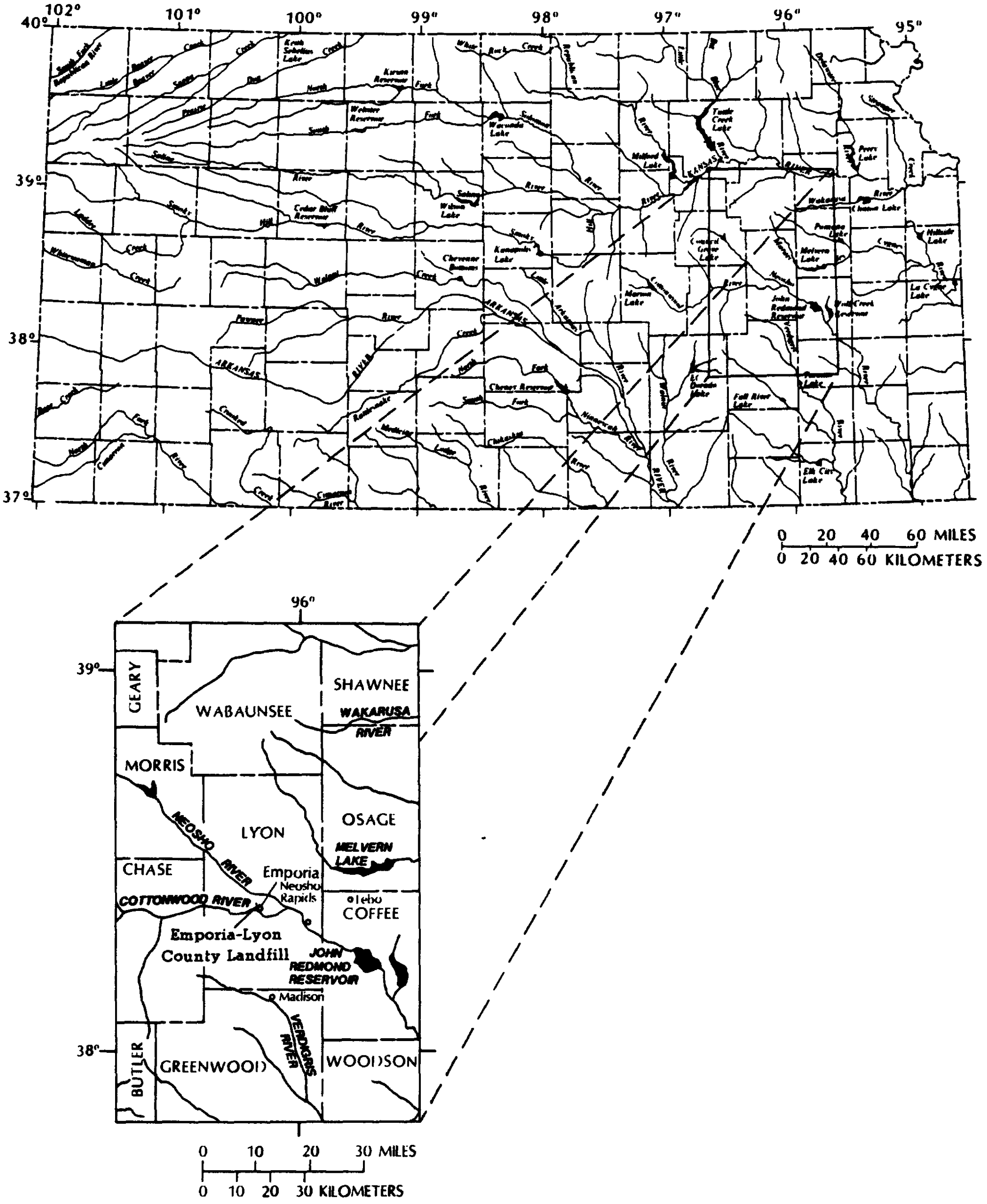

Figure 1. Location of Emporia-Lyon County Landfill near Emporia, Kansas.

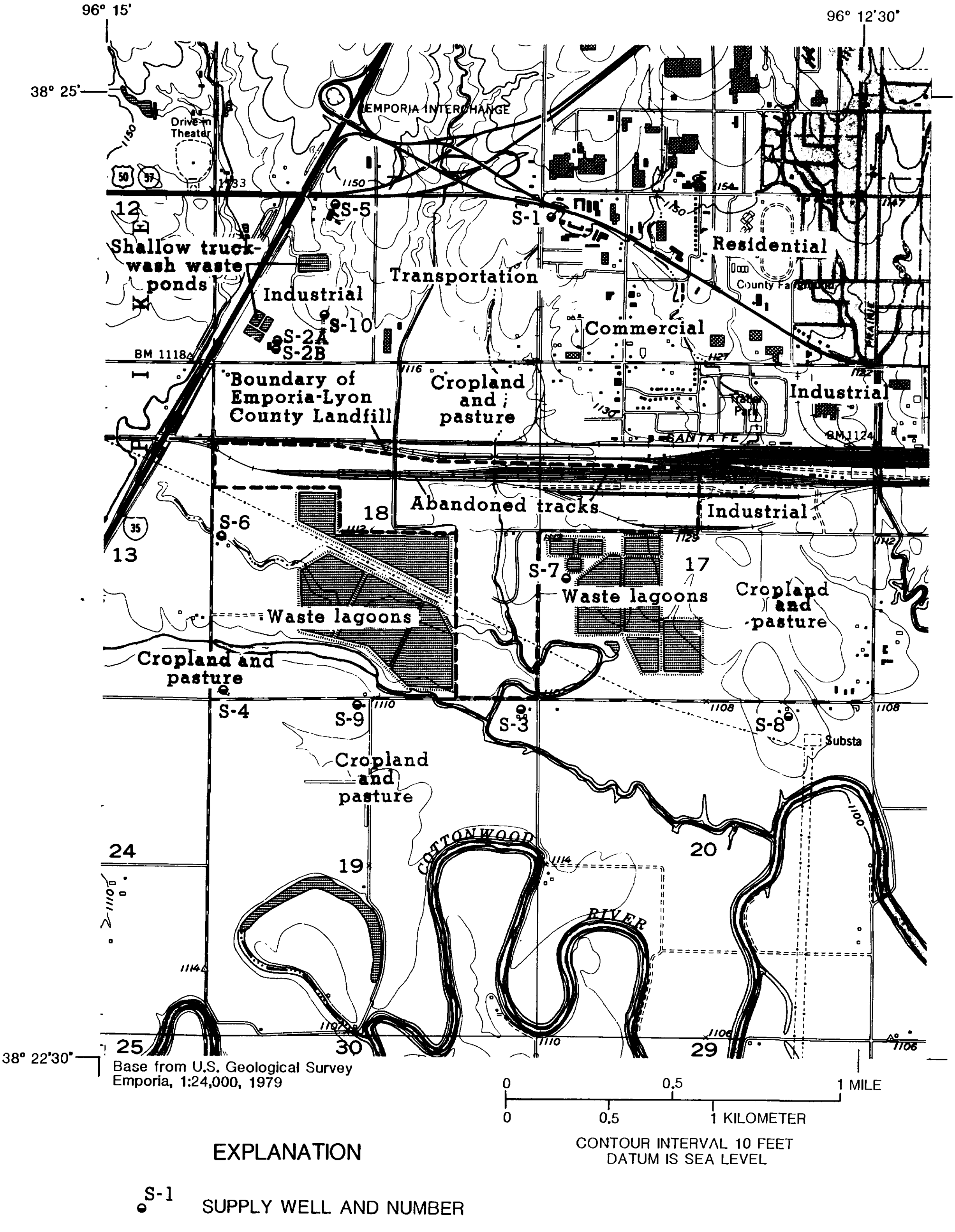

Figure 2. Topographic relief and land use in vicinity of Emporia-Lyon County Landfill, and location of supply wells outside Emporia city limits and in vicinity of landfill.

The topography in the Osage Cuestas region is characterized by northeast-southwest irregularly trending, east-facing escarpments, with gently rolling or flat plains in between (Schoewe, 1949). The major drainage systems in Lyon County are the Cottonwood and Neosho Rivers. The landfill is located in the flood plain of the Cottonwood River.

Climate records from a station at Emporia indicate that, for this area, the mean annual precipitation from 1951-80 was about 37 inches (National Oceanic and Atmospheric Administration, 1988). More than 50 percent of the precipitation occurs during the months of May through July. Temperatures range from below zero to more than 100 °F. On the average, the coldest temperatures are recorded in January, the hottest in July.

Land use in the vicinity of the landfill is varied (fig. 2). Emporia is primarily residential, with some commercial and industrial development. Land adjacent to the landfill is used for beef-packing-plant waste lagoons, railroad yards, and agriculture.

Surface- and ground-water resources supply water for municipal, domestic, and industrial uses. The city of Emporia derives most of its water from the Neosho River to the north. Most domestic and industrial water users within Emporia use the city water supply, although wells may supply water for lawns and gardens or light industrial use. Outside the city limits, near the landfill, ground water is the primary source of water for domestic and industrial purposes. In some places, water for domestic use is hauled in by truck. Figure 2 shows the location of known dug or drilled supply wells outside the Emporia city limits and in the vicinity of the landfill.

Previous Studies

There are no published reports concerning the effect of the Emporia-Lyon County Landfill on ground- or surface-water quality. However, analyses of water from domestic and supply wells in the area are available. Regional studies of ground and surface water are published and include data for the Emporia area. Parker (1911) and Haworth (1913) summarized known data on ground-water supplies in Kansas. O'Connor (1953a) reported on the ground-water resources of Lyon County, including chemical analyses of water from wells in the Emporia area. The geology of Lyon County has been described by Smith (1903) and O'Connor (1953b). Jewett (1951) reported on structural features of the rocks of Kansas.

PUBLIC-LANDFILL SOLID WASTES AND EFFECTS ON WATER QUALITY

The following is a general discussion of solid-waste composition, solid-waste degradation, and leachate production in landfills. Although exact solid-waste composition and chemical processes in the Emporia-Lyon County Landfill are not known, they may be inferred to be similar to the general composition and chemical processes discussed in the following paragraphs.

Solid-Waste Composition

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

Composition of the Emporia-Lyon County Landfill wastes is not known explicitly, but typical nationwide composition, by weight, is 45-percent paper, 15-percent garbage, 11-percent yard and garden trimmings, 9-percent metal, 8-percent glass, 4-percent dirt, ashes, and concrete, 3-percent textiles, 3-percent plastics, and 2-percent wood (Tchobanoglous and others, 1977). About 80 percent is combustible, of which aggregate amounts of fixed carbon, moisture, and volatile organic matter represent 7, 20, and 53 percent of the waste, respectively. Waste composition varies due to climate, season, recycling, demography, packaging, and marketing (Tchobanoglous and others, 1977).

Solid-Waste Degradation

About 20 percent of typical solid waste

essentially is inert or degrades slowly, 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 and others, 1977). Initially, while wastes are exposed to the air, the landfill environment is oxidizing. After depletion of trapped or incoming oxygen by aerobic bacteria, the environment becomes reducing. Degradation processes in the landfill include biologic decomposition, solution, precipitation, sorption, ion exchange, and diffusion of gases (Baedecker and Back, 1979). Sufficient moisture, 40 to 60 percent, is essential, however, for significant degradation rates.

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

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

At any one time, different parts of the same landfill may be in different stages of decomposition. Stage and rate also will vary from one landfill to another, depending primarily on moisture and degradability. Decomposition stage and rate also depend on temperature and on landfill shredding, mixing, and compacting procedures. Many landfills complete the aerobic stage in a few weeks and go through anaerobiosis quickly enough to allow significant methane production to peak within 2 years and then decline for 25 years or longer (Tchobanoglous and others, 1977). The progress of anaerobic decomposition may be estimated by the attendant conditions. In step one of anaerobic decomposition, the leachate pH is 4 to 5; chemical oxygen demand is relatively large; and specific conductance, due to acidic solution of metals, is also large (O'Leary and Tansel, 1986). In step two of anaerobic decomposition, 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. 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, and miscible or immiscible components. Metabolic carbon dioxide, produced by bacterial action, dissolves easily, decreasing pH. The resulting dissolution of calcium carbonate increases hardness and dissolved solids. The solvent capability of the leachate is increased also by the bacterially generated organic acids, allowing some metals in the landfill to be dissolved, notably iron and manganese.

Chemical processes in leachate production are oxidation, reduction, dissolution, precipitation, ion exchange, and sorbtion; these processes probably are affected 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 variable.Some typical concentrations and composition ranges of the most abundant constituents are listed in table 1.

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

Constituent	Concentrations, in milligrams per liter, except as noted		
	Salvato and others, 1971	Tchobanoglous and others, 1977	Cameron, 1978
pH (standard units)	5.6-8.3	6.0	7.5
Chemical oxygen demand	7,130	18,000	800
Biochemical oxygen demand	7,050-32,400	10,000	120
Hardness, total as $CaCO_3$	537-8,120	3,500	--
Sodium	350-1,805	500	800
Potassium	655-1,860	300	490
Alkalinity, total as $CaCO_3$	1,290-8,100	3,000	3,400
Sulfate	99-1,220	300	5.3
Chloride	220-2,240	500	2,300
Dissolved solids	2,000-11,254	--	4,270
Nitrate, as N	1.1-4.1	5.6	--
Ammonia, as N	109-656	155	331
Nitrogen, organic, as N	152-550	200	--
Iron	219-336	60	24

Where ranges are given, the larger values are expected only in newer landfills because newly established landfills have a more-rapid rate early-stage biodegradation, which involves acid production.

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

Metals such as cadmium, chromium, cobalt, copper, lead, mercury, nickel, strontium, and zinc also may be detected in landfill leachate but are present in small and variable concentrations because, with the exception of lead, they are either in elemental form in insoluble metals and alloys, or are in special, unusual industrial wastes. Other environmentally significant metals found in landfill leachate include arsenic, boron, and selenium. Arsenic originates mainly in toxic compounds, such as insecticides. Boron is found in soap, glazes, and rubber, and selenium in ink and rubber.

METHODS OF INVESTIGATION

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

Information Survey

Prior to any field work, a survey of published literature, files of the Kansas Department of Health and Environment (Topeka), and files of the City of Emporia and Lyon County was completed. Geologic and hydrologic information allowed estimation of the directions of 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

Fourteen temporary wells (TW-1 to TW-14) were installed using 3 1/4-inch inside diameter (6 5/8-inch outside diameter) hollow-stem augers with a center plate over the bottom of the augers to prevent sediment from clogging the inside of the auger bit. In wet sediments it was necessary to "load" the augers with potable water to prevent formation sand and water from surging into the augers when the bottom plate was knocked out to set the well. Temporary wells consisted of 1 1/2-inch polyvinyl-chloride pipe with glued joints, capped at the bottom, and slotted with a hacksaw. Temporary wells were set to different depths at the same site (nested) to evaluate vertical ground-water movement. The location of temporary wells is shown in figure 3.

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

Monitoring-Well Installation

Thirteen monitoring wells (MW-1 to MW-10) were installed using 6 1/4-inch inside

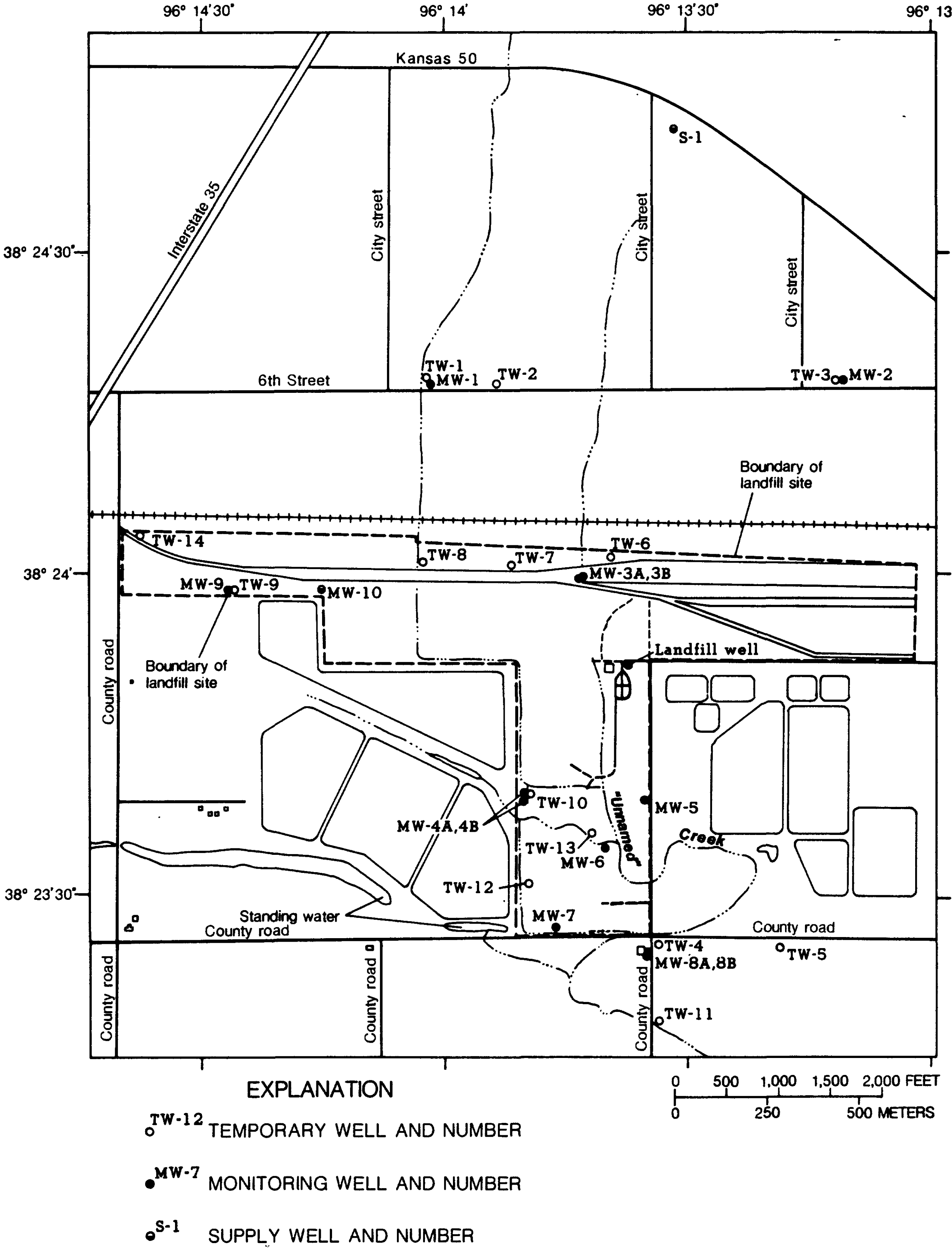

Figure 3. Location of temporary, monitoring, and supply wells.

Table 2. *Top-of-casing altitudes and total depths for temporary wells (TW), monitoring wells (MW), landfill well, and unnamed creek*

[Datum is sea level]

Well or creek (fig. 3)	Top-of-casing altitude (feet)	Total depth below land surface (feet)
TW-1	1,118.02	18.0
TW-2	1,117.46	18.0
TW-3	1,137.81	23.0
TW-4	1,109.50	18.0
TW-5	1,108.82	18.5
TW-6	1,115.57	18.0
TW-7	1,112.04	18.5
TW-8	1,113.27	14.0
TW-9	1,116.52	18.5
TW-10	1,109.28	24.0
TW-11	1,101.42	14.0
TW-12	1,110.18	18.5
TW-13	1,104.58	18.5
TW-14	1,118.27	18.0
MW-1	1,119.57	40.78
MW-2	1,138.56	48.85
MW-3A	1,122.22	40.92
MW-3B	1,122.42	31.06
MW-4A	1,111.25	32.48
MW-4B	1,110.51	25.48
MW-5	1,107.18	32.60
MW-6	1,106.32	31.15
MW-7	1,109.71	32.43
MW-8A	1,110.74	30.03
MW-8B	1,110.81	26.55
MW-9	1,118.36	39.68
MW-10	1,115.53	38.13
Landfill well	1,114.02	15.30
Unnamed creek	1,104.95	(altitude is for chiseled square on west headwall of bridge)

diameter (9 7/8-inch outside diameter) hollow-stem augers with a bottom center plate. The augers were "loaded" with water during drilling to keep sediment and water from entering and clogging the augers. After reaching a desired depth, the well casing was lowered into the hollow augers and used to punch out the bottom plate. Sand pack and bentonite chips were poured into place around each well as the augers were being withdrawn from the well.

To avoid potential cross contamination between wells or from other sources, all equipment was cleaned prior to installation of each monitoring well. Loose sediment was 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 obtained from the City of Emporia and hauled to the site in a stainless-steel tank.

Monitoring-well design (fig. 4) is as follows. Each well is comprised of a 5-foot stainless-steel screen, a 10-foot stainless-steel riser, and schedule-40 polyvinyl-chloride pipe to the surface. Well casings were threaded, flush-coupled 2- or 4-inch-diameter pipe. Teflon[1] tape was used to seal each joint; no glue or cement was used. Sand-pack thicknesses were about 10 feet, extending from the bottom of the well screen to 5 feet above the top of the screen. The sand was followed by 2 or more feet of 3/8-inch bentonite chip. Natural formation material was allowed to collapse or was added to the hole up to a depth of about 10 feet, then 3/8-inch bentonite chips were added to within 18 inches below the land surface. Finally, a cement pad and protective locking casing were set around the well casing. Monitoring wells were developed using a positive-displacement hand pump or centrifugal pump until water ran clear from the well.

Water-Sampling Methods

Monitoring wells at the Emporia-Lyon County Landfill were sampled on September 13-16, 1988. Fourteen water samples were collected from the monitoring wells. No samples were collected from nearby creeks because they were

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

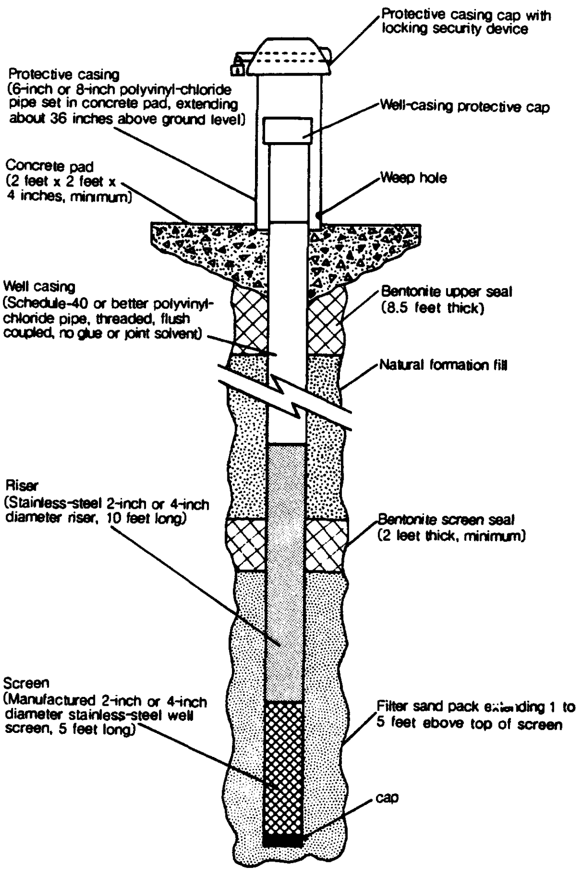


Figure 4. Monitoring-well design.

dry. The sampling procedure was as follows. Water levels and total depths in all monitoring wells were measured to the nearest 0.01 foot with a steel tape. The tape was cleaned with distilled water before each use. The well-sampling process began with the upgradient wells (MW-1, MW-2) and ended with the farthest downgradient wells (MW-8A, MW-8B). Each well was first purged of about five water-column volumes of water to bring fresh formation water into the well. The amount of water to purge from each well was determined from total-depth and water-level measurements (tables 2 and 3). Wells were purged with a positive-displacement hand pump, which was washed with an alconox solution, rinsed with potable water, and then rinsed with deionized water before each use.

Water samples were retrieved with a Teflon-bottom check-valve bailer suspended from a nylon cord. The bailer was decontaminated in the same fashion as the hand pump before each use, and the nylon cord was replaced before each use. Water samples were collected in the order of volatile organic compounds, semivolatile organic compounds, pesticides, total organic carbon, common ions, and trace metals, using standard U.S. Geological Survey and U.S. Environmental Protection Agency methods (Fishman and Friedman, 1989; Ford and others, 1983). 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. A complete set of duplicate samples was collected from well MW-7 (MW-7-D in tables 7 and 10) as a check of sample-analysis accuracy. Samples were immediately placed on ice. Trace-metal samples were filtered through a 0.45-micron filter. Each filter was flushed with about 250 milliliters of sample water before collecting a sample. Specific conductance, pH, water temperature, dissolved oxygen, and alkalinity measurements were made at the time of sample collection.

Water samples were delivered within 3 days of collection to the Kansas Department of Health and Environment laboratory (Topeka). Samples for triazine pesticide analyses were shipped within 4 days by mail to the U.S. Geological Survey laboratory in Arvada, Colorado. Inorganic constituents were analyzed according to Kansas Department of Health and Environment laboratory methods (Kansas Department of Health and Environment, 1988). Volatile organic constituents, semivolatile constituents, and pesticides were analyzed using U.S. Environmental Protection Agency methods 624, 625, and 608, repsectively (U.S. Environmental Protection Agency, 1982).

Hydraulic-Conductivity Determination

Hydraulic conductivity was determined by slug tests on monitor wells. For each slug test, a pressure transducer was lowered through a specially designed sealing well cap to a point 10 feet or less below the static water surface. The well then was pressurized with nitrogen 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 about a 2-minute duration starting

Table 3. *Water-column volumes purged from monitoring wells before sampling in September 1988*

Well (fig. 3)	Nominal diameter of well[1] (inches)	Height of water column in well casing (feet)	Volume in well (gallons)	Volume purged (gallons)
MW-1	2	24.81	4.32	20.7
MW-2	2	24.27	4.22	20.3
MW-3A	2	23.32	4.06	19.5
MW-3B	4	13.98	9.22	45.6
MW-4A	4	21.05	13.89	68.6
MW-4B	2	14.81	2.57	12.4
MW-5	2	23.17	4.03	19.3
MW-6	2	22.92	3.99	19.1
MW-7	2	18.91	3.29	15.8
MW-8A	4	13.81	9.11	45.0
MW-8B	2	9.93	1.73	8.3
MW-9	2	26.99	4.70	22.5
MW-10	2	28.23	4.91	23.6

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

when pressure was released from the well. Slug-test data were analyzed using methods developed by Nguyen and Pinder (1984).

REGIONAL HYDROGEOLOGY

Rocks exposed near the surface in Lyon County are primarily limestone and shale of Permian and Pennsylvanian age (O'Connor, 1953b). Unconsolidated alluvial, loess, and terrace deposits of Holocene and Pleistocene age occur in places along river valleys and on uplands (O'Connor, 1953b). Pennsylvanian and younger rocks are structurally part of the Prairie Plains monocline, dipping generally west at 30 feet per mile (Jewett, 1951). Mississippian and older, deeper rocks have a more northerly dip as part of the Bourbon arch, which separates the Forest City basin to the north from the Cherokee basin to the south (Jewett, 1951).

In Lyon County, water for public supply is obtained from unconsolidated alluvial deposits and from bedrock. Alluvial deposits in the Cottonwood and Neosho River valleys are an important source of water for municipal, domestic, stock, and industrial use (O'Connor, 1953a). Precipitation is the primary source of recharge to the alluvial aquifers, although some water flows into the alluvium from adjacent rock formations, and some water is recharged to the alluvium from the rivers (O'Connor, 1953a). Wells drilled in the Cottonwood River alluvium can yield from 75 to 150 gallons per minute (O'Connor, 1953a), depending on such factors as permeability of aquifer materials, well depth, casing diameter, and depth to water.

In areas remote from major stream valleys, stratified Permian and Pennsylvanian limestone and sandstone can be significant sources of water, especially in the northwestern part of Lyon County where well yields of as much as 40 gallons per minute may be obtained (O'Connor, 1953a). Ground water in Pennsylvanian and younger bedrock would be expected to flow westward in the direction of regional dip.

SITE DESCRIPTION AND LANDFILL HYDROGEOLOGY

Landfill Setting

The Emporia-Lyon County landfill is located in the flood plain of the Cottonwood River about 0.5 mile north of the river (fig. 2). The landfill is bordered by beef-packing-plant waste-processing lagoons to the east and west, by cropland, pasture, railroad tracks, and various light industries to the north, and by cropland and pasture to the south (fig. 2). Surface drainage in the landfill vicinity is from north to south by way of drainage ditches and creeks toward the Cottonwood River.

Landfill Siting, Design, and Management

The Emporia-Lyon County Landfill began operation in 1974 and expanded to its present (1990) size through a series of land acquisitions. Currently, the Emporia-Lyon County Landfill covers about 250 acres. Of the 250 acres, about 100 acres have been filled, about 20 acres are being readied for filling, about 20 acres are being used for sewage-solids disposal, and about 110 acres are being held for future development (fig. 5).

The Emporia-Lyon County Landfill is managed as a sanitary landfill using area-type fill and ramp-type fill methods. Ordinary waste is deposited in cells and covered with soil each day. Disposal areas with bases below the water table are raised with construction and demolition debris prior to burial of degradable wastes. Sewage solids are deposited on the ground surface in the southernmost 20 acres of the landfill (fig. 5). The landfill also receives small quantities of hazardous wastes, including asbestos, dynamite, paint residues, caustic mercury, various laboratory chemicals, paint thinner, mud from car-wash pits, paint filters, and hide manure. Asbestos is buried near the south end of the landfill, whereas other hazardous wastes are buried in specified areas of the landfill (fig. 5) or are buried in working fill areas. Drainage ditches have been constructed and maintained throughout the landfill area to facilitate runoff and to lower the water table in the area.

Geology

The landfill is located in the alluvium of the present-day and ancestral Cottonwood River. The alluvium consists of a basal 3- to 10-foot thick layer of sandy gravel overlain by 25 to 35 feet of sandy or silty clay and clay layers. Borehole logs indicate that the basal sandy gravel layer is continuous in the landfill area, but that sandy and silty clay layers, which overlie the basal layer, are discontinuous and grade laterally into more clay-rich sediments. The thickest basal gravel layers were found in wells MW-2 and MW-5 (fig. 6). Usually gravel was present in the clay layers overlying the basal gravel layer. The observed vertical and lateral changes in grain size and sediment type are the result of past deposition by the Cottonwood River as it meandered back and forth across its valley.

In the vicinity of the landfill, the alluvium is underlain by shale and limestone of the Upper Pennsylvanian Wabaunsee Group. Red shale was recovered from the auger bit in well MW-2. On the basis of borehole logs presented in O'Connor (1953b), the red shale in MW-2 may be the Dry Shale Member of the Stotler Limestone. The Stotler Limestone is composed of two limestone members, the Grandhaven Member, and the Dover Member, separated by the Dry Shale Member. The Grandhaven Member consists of 3.5 to 12 feet of interbedded shale and limestone; the Dover Member averages 2 feet in thickness; and the middle Dry Shale Member is 8 to 10 feet thick (O'Connor, 1953b; Zeller, 1968). The limestone beds in the Stotler Limestone are not considered to be a significant source of water (O'Connor, 1953a). In other boreholes drilled at the landfill, hard rock was encountered at total depth, but no samples of this material were recovered.

Hydrology

The direction and rate of ground-water movement in the alluvium in the vicinity of the landfill was determined by water-level measurements and slug tests (tables 4 and 5). The potentiometric surface, based on water-level data from wells and nearby creeks, indicates that ground water generally flows from the northeast and northwest towards the landfill area, then south through the landfill to the Cottonwood River (figs. 7 and 8).

This general flow pattern may change

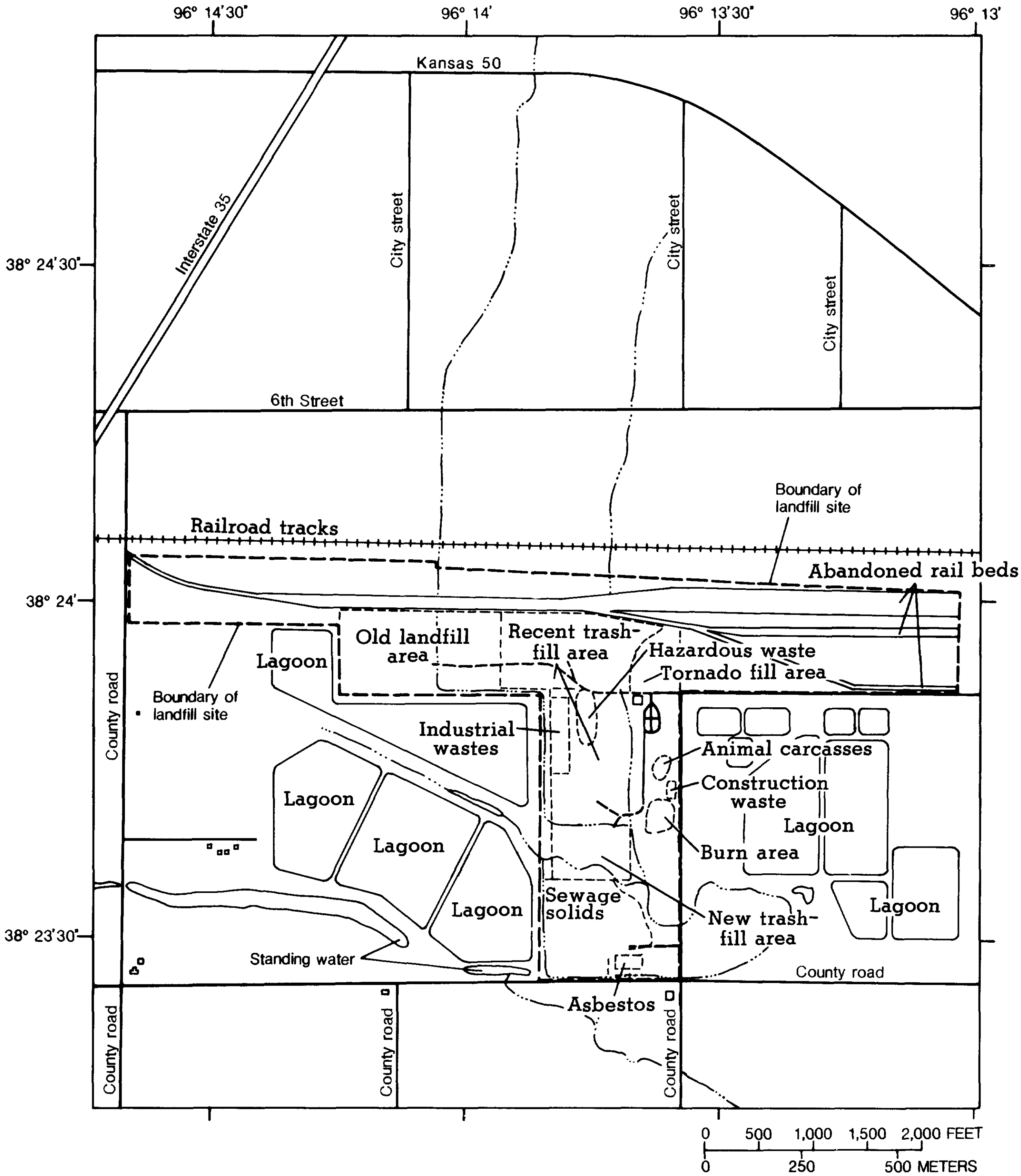


Figure 5. Site features and land use. Lagoons are for beef-packing-plant waste processing.

during dry periods when there is little recharge to the alluvial aquifer. Precipitation records from the Emporia climatological station indicate that monthly precipitation amounts for 1988 were substantially less than normal (fig. 9). In the 38 days preceding the September 13, 1988, water-level measurement, rainfall totaled 0.29 inch, and there was no rain in the 15 days before water-level measurement. Water levels measured just prior to sampling (September 13, 1988) indicate that a ground-water mound under the northwest-most waste lagoon is affecting water-flow directions in the northwest and north-central part of the landfill (fig. 7D) causing the ground water to move northward instead of southward. During periods when water levels in

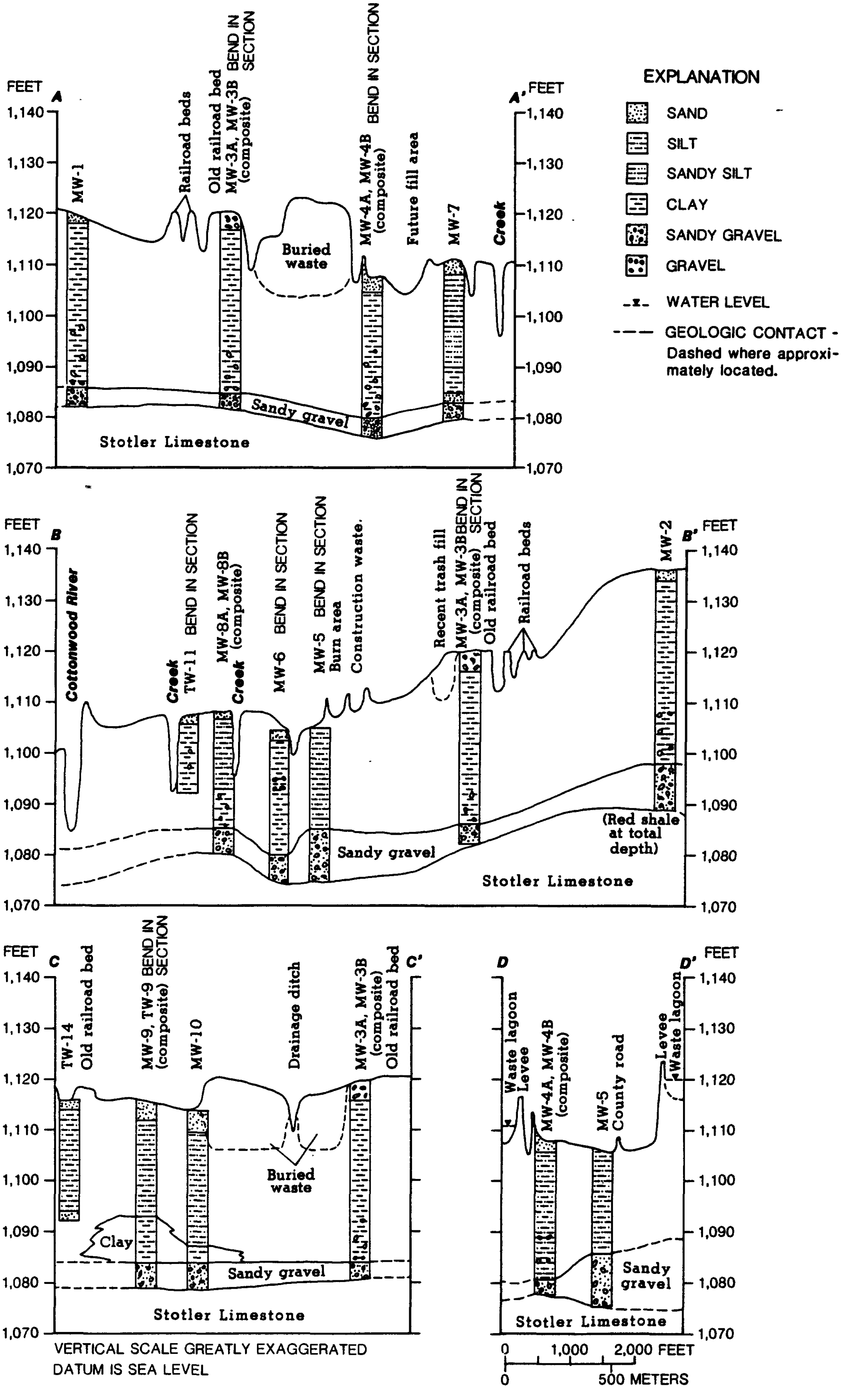


Figure 6. Geologic sections of Emporia-Lyon County Landfill from north to south and west to east.

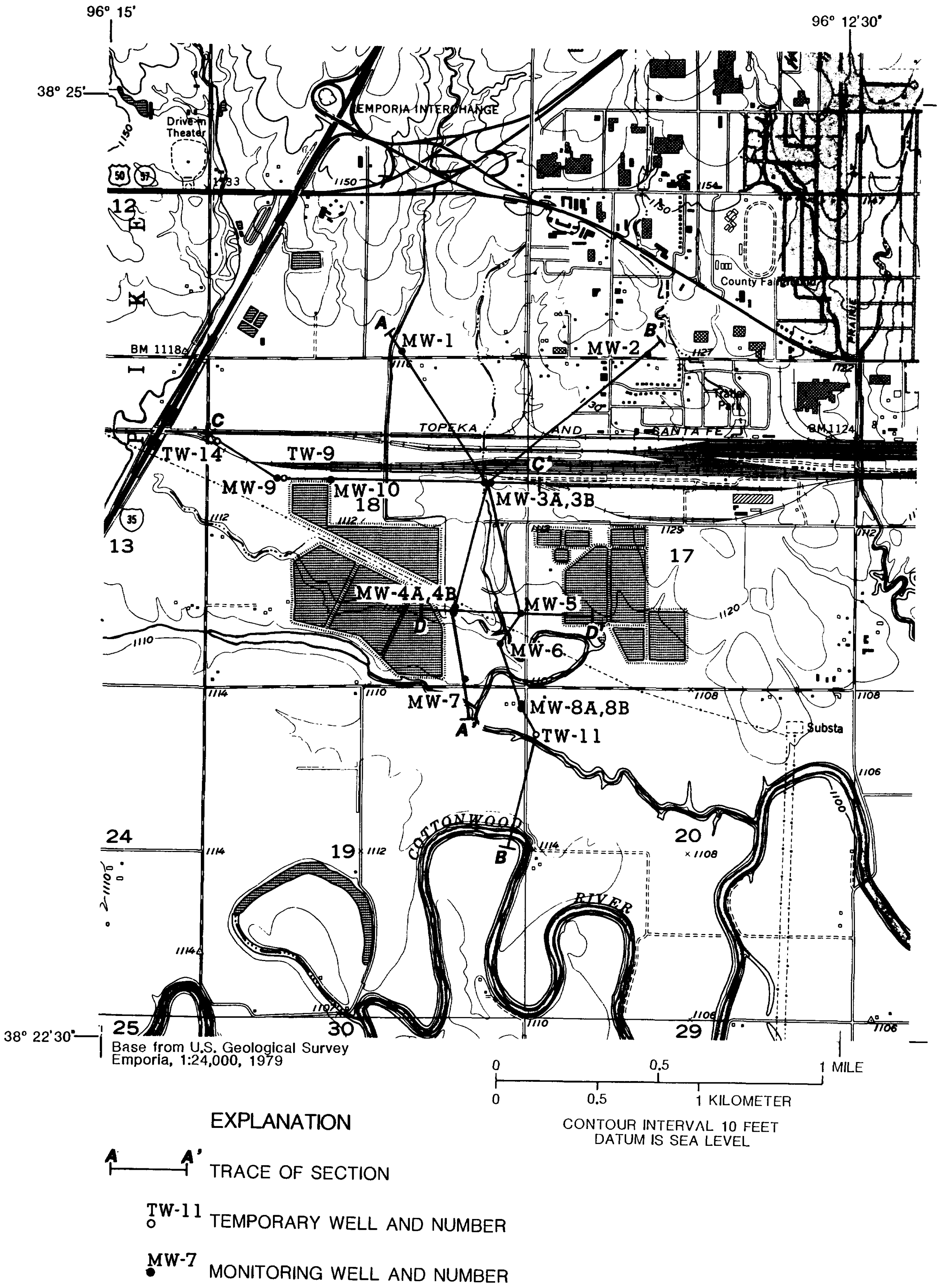


Figure 6. Geologic sections of Emporia-Lyon County Landfill from north to south and west to east--Continued.

Table 4. *Water-level altitudes in temporary wells (TW), monitoring wells (MW), landfill well, and unnamed creek*

[Datum is sea level; Pulled, well removed prior to measurement date; --indicates no data available]

Well or creek (fig. 3)	Water-level altitudes (feet)						
	Date (month/day/year)						
	6/24/88	6/28/88	7/8/88	7/20/88	8/3/88	9/13/88	2/24/89
TW-1	1,109.89	1,109.72	Pulled				
TW-2	1,111.02	1,110.76	1,111.68	--	1,110.18	Pulled	
TW-3	1,115.52	1,115.42	Pulled				
TW-4	1,096.52	1,096.33	1,096.54	Pulled			
TW-5	1,098.45	1,098.32	1,098.82	Pulled			
TW-6	1,104.48	--	--	--	--	Pulled	
TW-7	1,105.69	1,105.50	1,105.99	--	1,104.96	Pulled	
TW-8	1,106.37	1,106.22	1,106.41	--	1,105.47	Pulled	
TW-9	1,109.22	1,109.05	1,108.96	1,108.46	1,107.73	Pulled	
TW-10	1,101.29	1,101.17	Pulled				
TW-11	1,094.18	1,093.91	1,094.09	Pulled			
TW-12	1,099.55	1,099.39	1,099.45	--	1,098.87	Pulled	
TW-13	1,100.47	1,100.30	1,100.78	--	1,099.75	Pulled	
TW-14	--	1,110.85	1,111.47	--	1,109.68	Pulled	
MW-1	--	--	1,107.62	1,107.62	1,106.17	1,103.60	1,104.30
MW-2	--	--	1,115.58	1,115.59	1,115.21	1,113.98	1,112.60
MW-3A	--	--	1,107.47	1,107.65	1,106.40	1,104.62	1,106.87
MW-3B	--	--	1,108.40	1,108.39	1,107.06	1,105.34	1,107.20
MW-4A	--	--	1,101.78	1,101.67	1,100.99	1,099.82	1,100.75
MW-4B	--	--	1,101.78	1,101.67	1,101.25	1,099.84	1,100.75
MW-5	--	--	--	1,100.21	1,099.46	1,097.75	1,098.96
MW-6	--	--	--	1,100.92	1,099.40	1,098.09	1,099.22
MW-7	--	--	--	1,098.41	1,097.81	1,094.23	1,097.49
MW-8A	--	--	--	1,096.82	1,095.97	1,094.52	1,095.00
MW-8B	--	--	--	1,096.45	1,095.80	1,094.19	1,094.86
MW-9	--	--	--	1,108.09	1,107.39	1,105.67	1,104.61
MW-10	--	--	--	1,107.13	1,106.70	1,105.63	1,104.97
Landfill well	--	1,108.42	--	--	--	--	--
Unnamed creek	--	--	--	1,097.86	1,096.89	Dry	Dry

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

Well (fig. 3)	Hydraulic conductivity (feet per day)
MW-1	16
MW-2	8
MW-3A	14
MW-3B	--
MW-4A	--
MW-4B	22
MW-5	32
MW-6	47
MW-7	42
MW-8A	7
MW-8B	1
MW-9	8
MW-10	108

the alluvial aquifer are higher, the effects of ground-water mounds under waste lagoons are present, although not as apparent (fig. 7A, B, C, and E). Additional water-level measuring points near the waste lagoons would be necessary to fully determine the hydrologic effect of the lagoons.

A mound of ground water was observed in the vicinity of the abandoned railroad beds near wells MW-3A and MW-3B (fig. 7B and 7C). This mound may be caused by water stored in the gravel-ballast fill upon which the tracks were laid. During wet periods, it was evident that each gravel-ballast fill was separated from its neighbor by clay fill. The ballast may form "pockets" and be as much as 12 feet thick in places where the railroad bed has subsided and new ballast has been added (Robert Manlove, Santa Fe Railway Co., oral commun., 1989). However, a series of test holes drilled near MW-3A and MW-3B showed the gravel ballast to be about 2 feet thick. Ballast surrounded by clay fill could temporarily store ground water, which would eventually recharge the alluvial aquifer. Additional evidence that water is stored in the ballast was observed in June 1988 when a spring seep formed where a bulldozer cut a ramp down through the side of the railroad beds.

Slug tests (table 5) indicate that hydraulic conductivity in the alluvial aquifer ranges from 1 to 108 feet per day. The largest hydraulic-conductivity value was found in well MW-10, whereas the smallest value was found in well MW-8B. No pump-test or specific-capacity data are available for comparison; however, hydraulic conductivity of 1 to 108 feet per day is compatible with hydraulic conductivity measured for silty sand and sandy gravel (Freeze and Cherry, 1979, table 2.2). The range of hydraulic conductivity indicates lateral and vertical variability in the grain size and composition of sediments but, in some places, may reflect inadequate development of wells (MW-8A, MW-8B). The actual velocity of water flow in the vicinity of the landfill, determined from an average hydraulic gradient (about 0.0025 for September 13), an average hydraulic conductivity (about 31 feet per day for the sandy gravel), and an assumed porosity of 30 percent for the sandy gravel, is about 0.26 foot per day in the vicinity of well MW-6. Near well MW-10, a maximum actual velocity of about 0.58 foot per day would occur for a gradient of 0.0016. Flow rates near the landfill will change as the hydraulic gradient changes. Changes in the hydraulic gradient may be caused by periods of dryness, periods of rainfall, well pumping, and changes in stage of the Cottonwood River.

The direction of ground-water flow may reverse during high river stages. All water-level measurements during this investigation were made during low river stages and do not indicate what effect high river stages might have on ground-water flow direction. Fader (1974) has shown that during high river stages along the Kansas River the direction of ground-water flow may be predominantly away from the river and that this reversal of flow direction may extend to more than 3,000 feet away from the river. A similar reversal of flow direction could be expected when the Cottonwood River is at high stage, but it is unknown if the flow reversal would extend as far as the landfill.

The direction of ground-water flow also may be affected by large withdrawals of water from nearby wells. Wells S-2A and S-2B (fig. 2) are used to supply water to a cattle-truck-washing operation. These two wells probably represent the largest volume of ground-water use in the vicinity of the landfill. Other wells near the landfill are used for domestic, stock-watering,

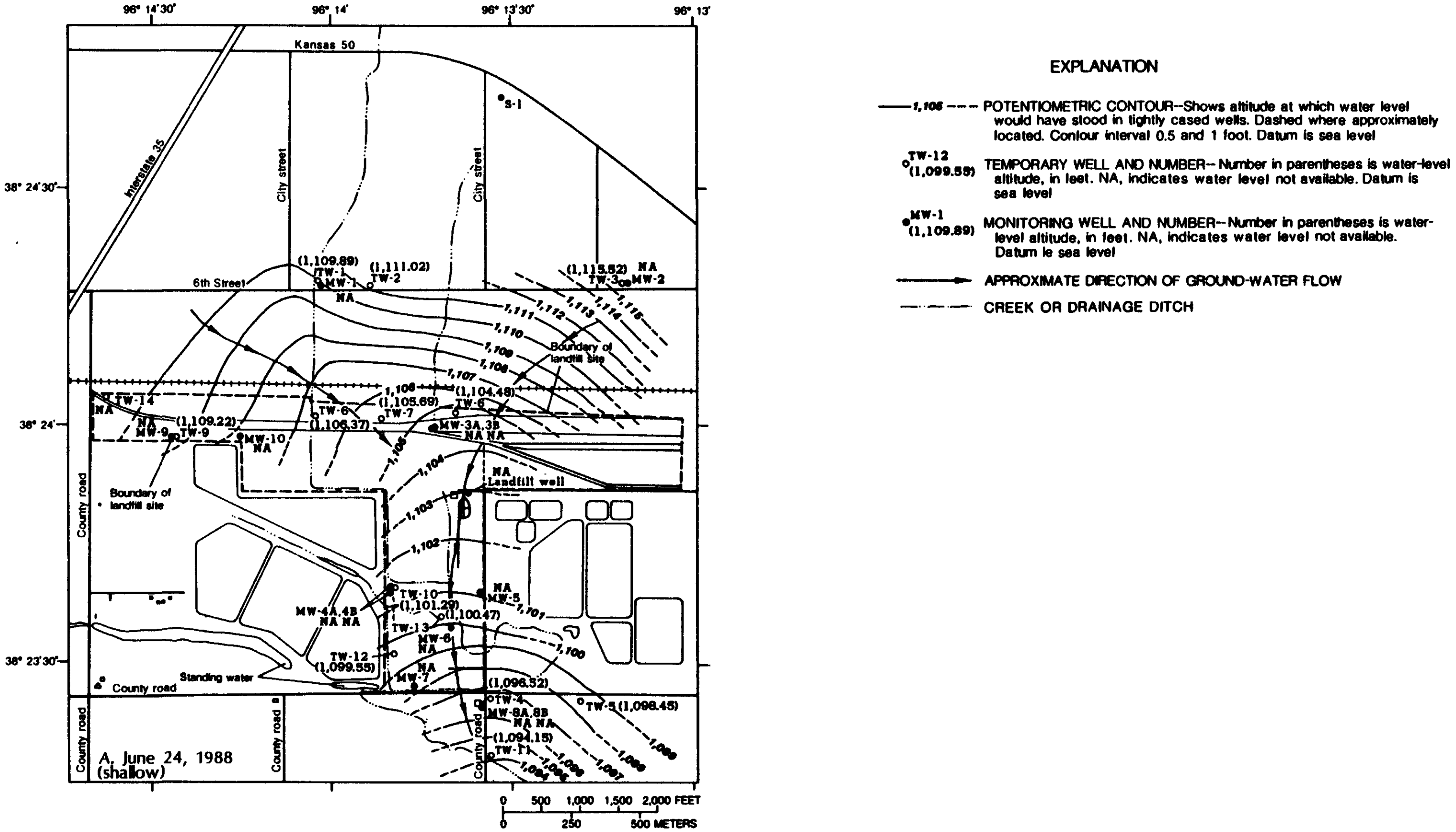


Figure 7. Potentiometric surface in vicinity of Emporia-Lyon County Landfill (A) June 24 (shallow), (B) August 3 (shallow), (C) August 3 (deep), (D) September 13, 1988 (deep), and (E) February 24, 1989 (deep).

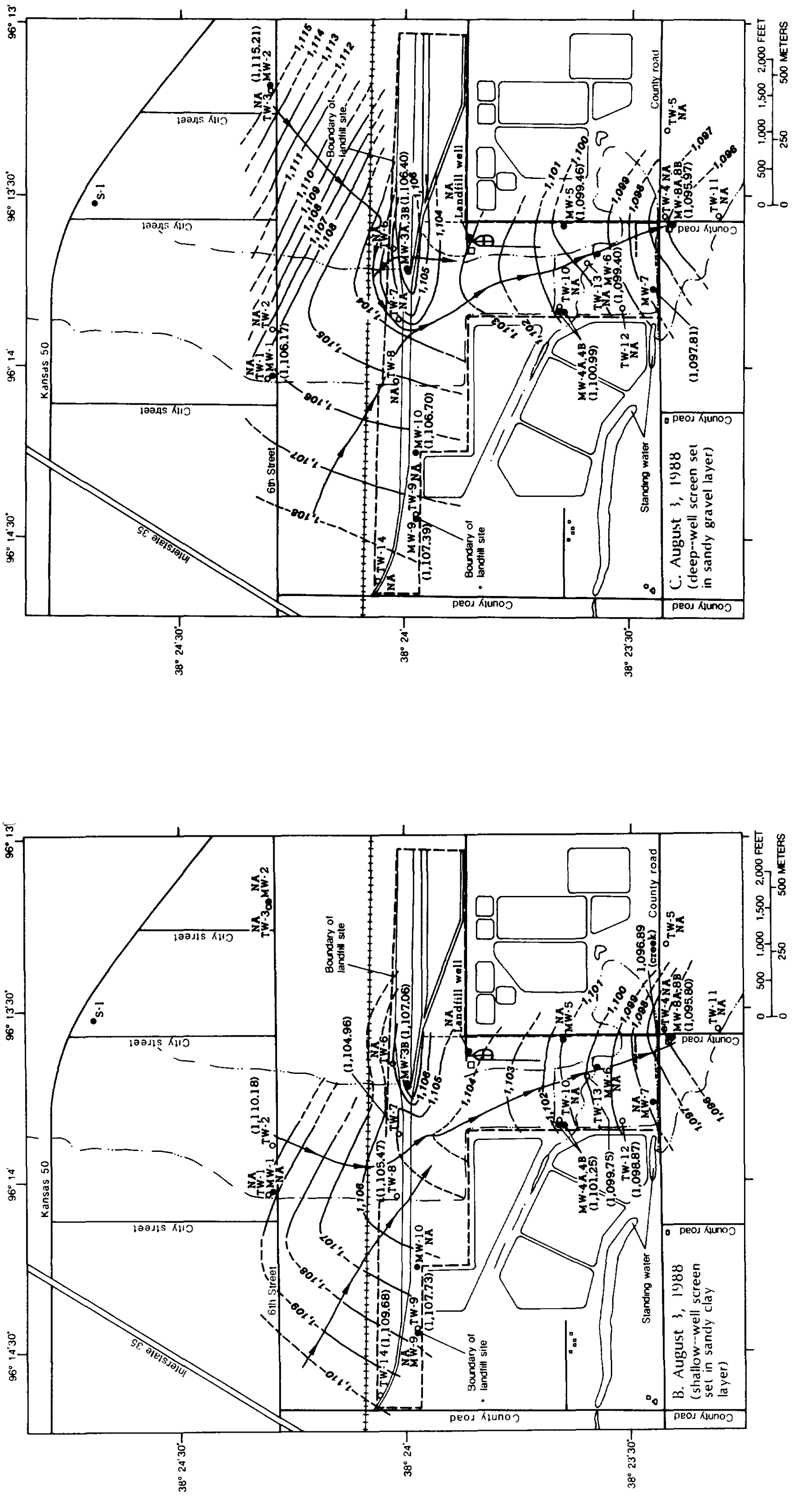


Figure 7. Potentiometric surface in vicinity of Emporia-Lyon County Landfill (A) June 24 (shallow), (B) August 3 (shallow), (C) August 3 (deep), (D) September 13, 1988 (deep), and (E) February 24, 1989 (deep)--Continued.

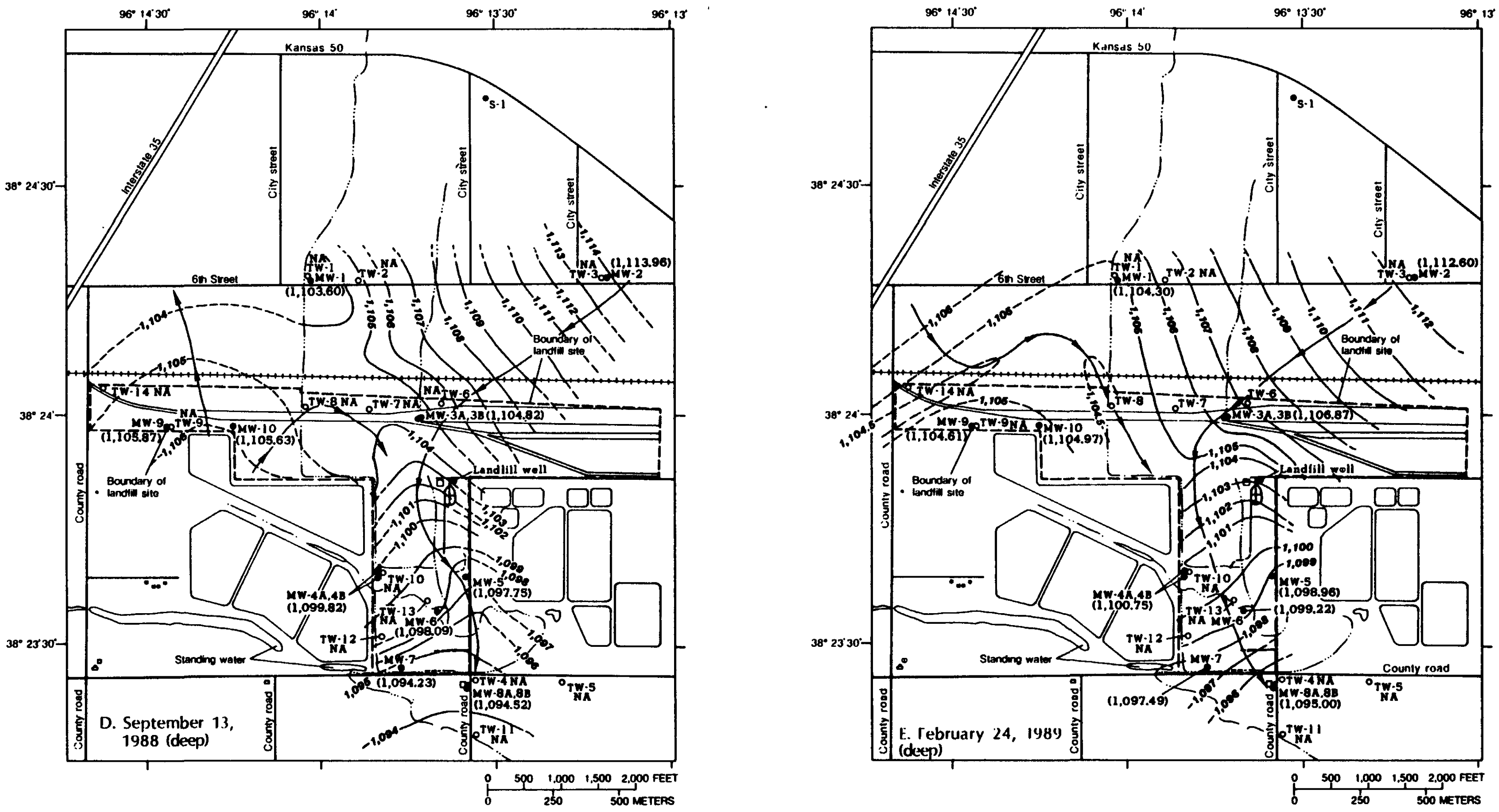
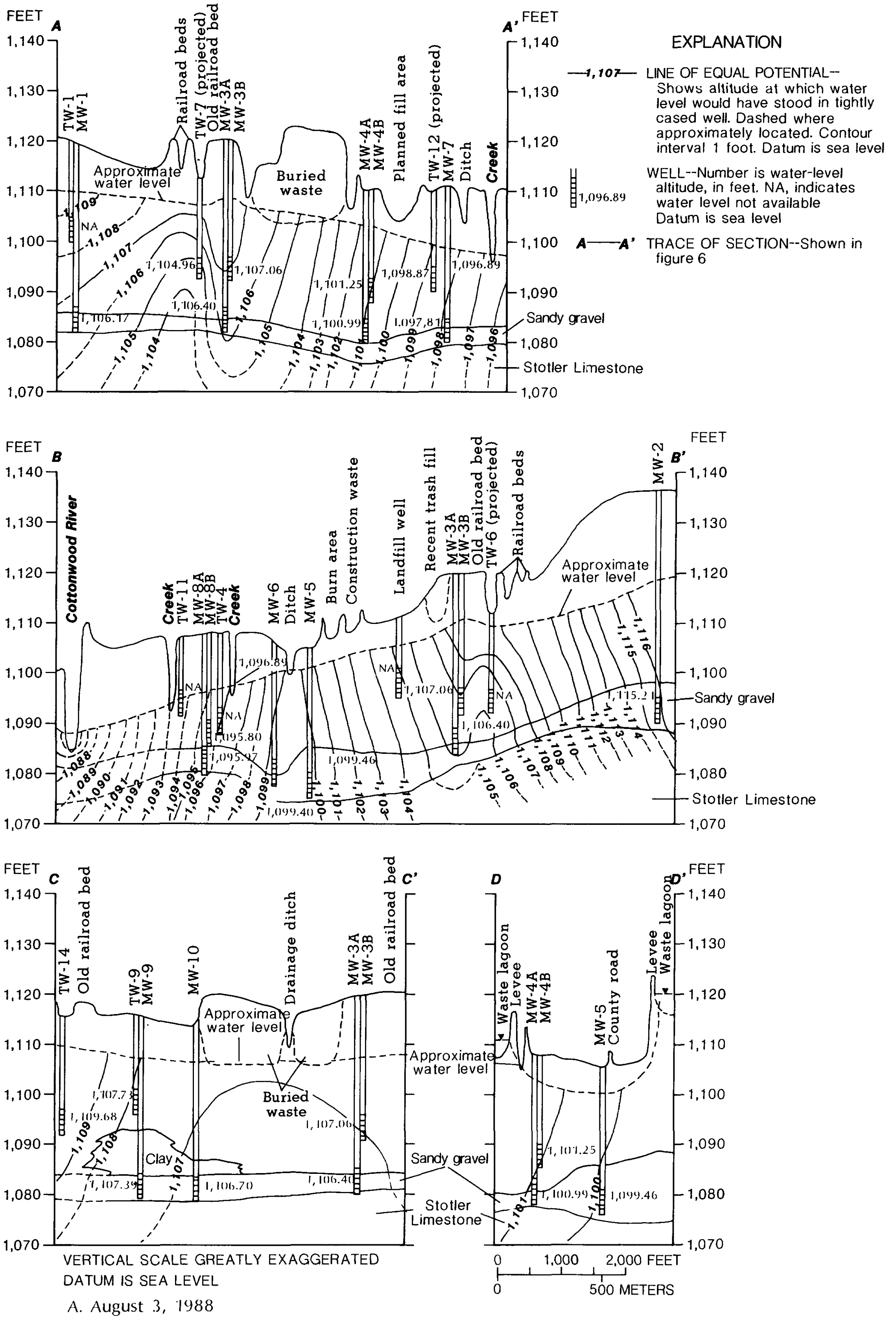
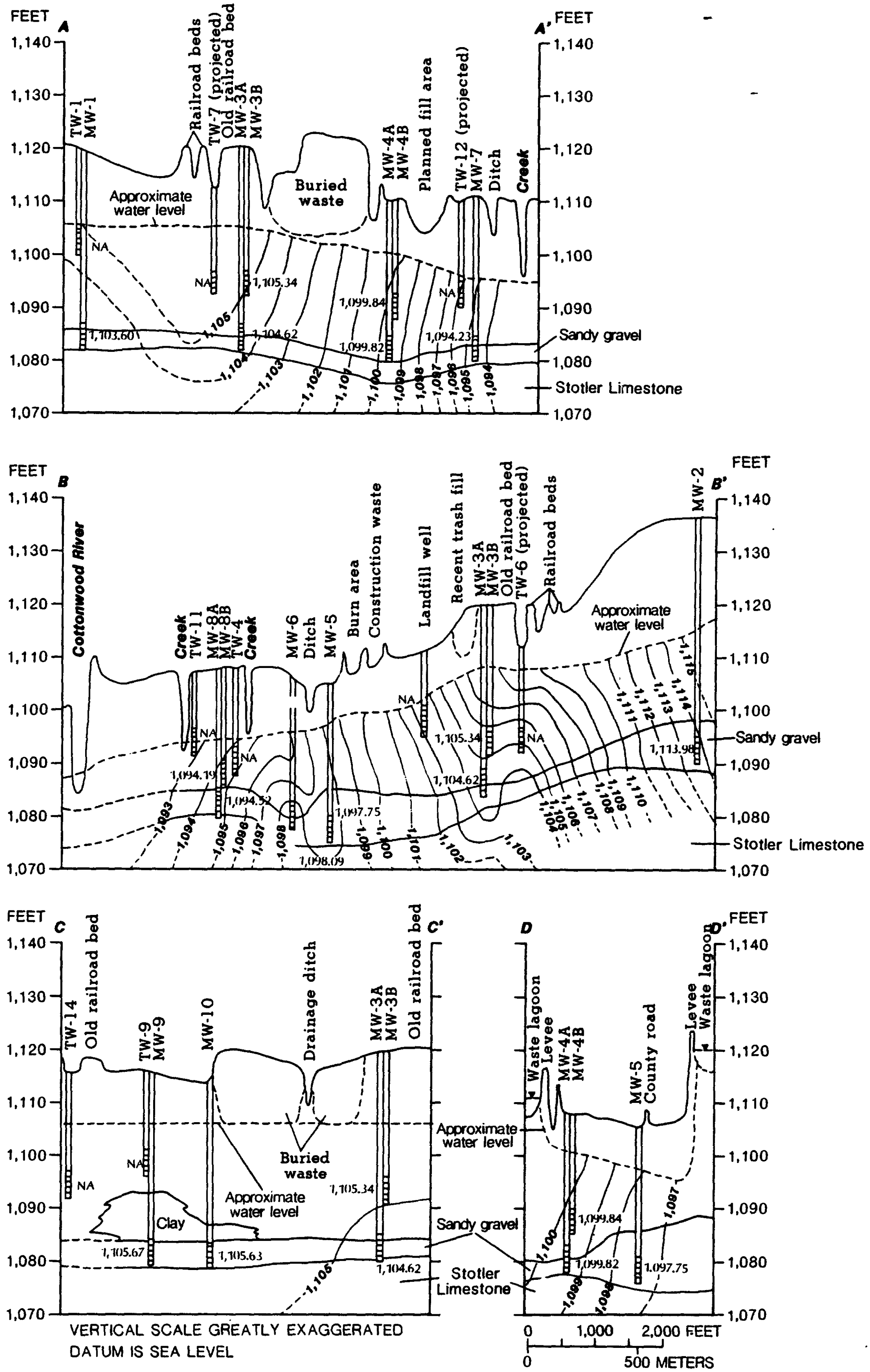


Figure 7. Potentiometric surface in vicinity of Emporia-Lyon County Landfill (A) June 24 (shallow), (B) August 3 (shallow), (C) August 3 (deep), (D) September 13, 1988 (deep), and (E) February 24, 1989 (deep)--Continued.



A. August 3, 1988

Figure 8. Potentiometric profiles in vicinity of Emporia-Lyon County Landfill, (A) August 3 and (B) September 13, 1988.



B. September 13, 1988

Figure 8. Potentiometric profiles in vicinity of Emporia-Lyon County Landfill, (A) August 3 and (B) September 13, 1988--Continued.

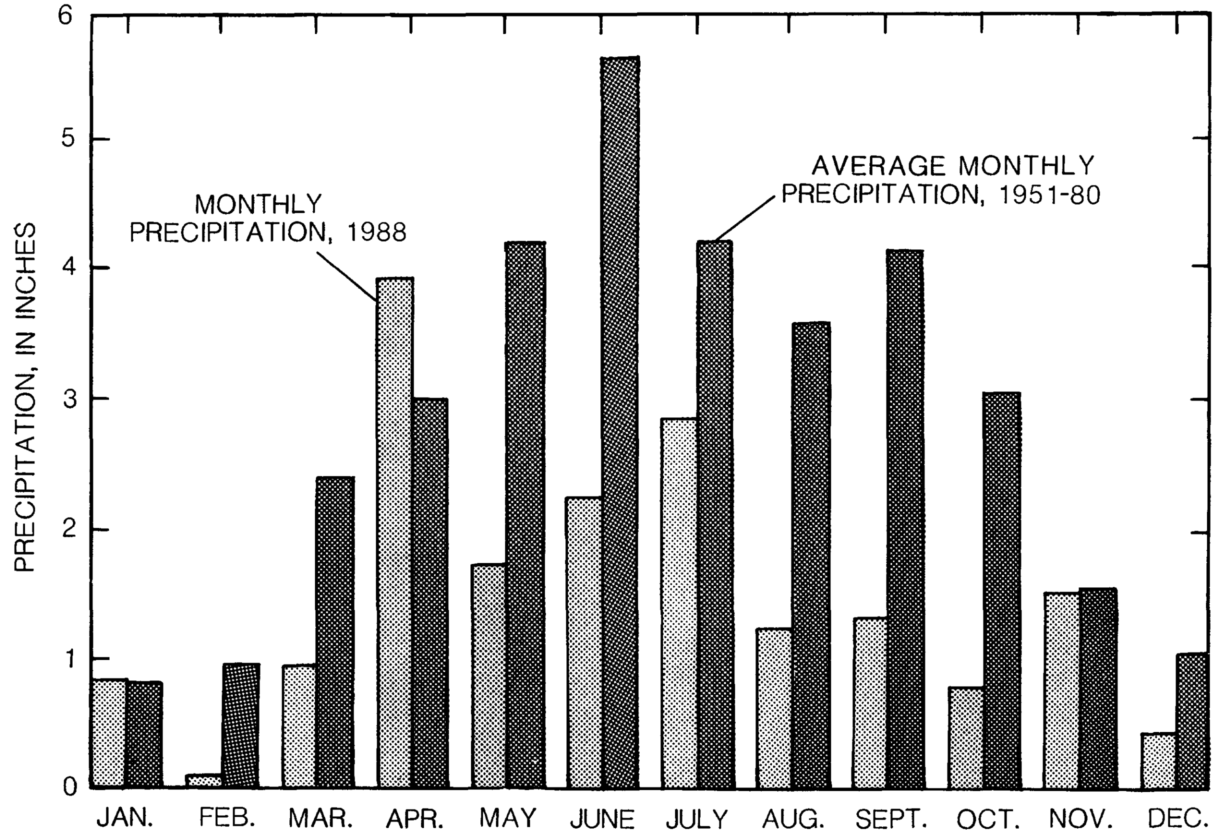


Figure 9. Monthly precipitation at Emporia for 1988 (data from National Oceanic and Atmospheric Administration, 1988).

and small-shop purposes and probably do not affect significantly ground-water flow. It is possible that the northerly flow of ground water, in the northwest part of the landfill, seen in figures 7D and 7E, could be attributed partially to withdrawals from wells S-2A and S-2B (fig. 2). However, these wells are used regularly throughout the year and so could not be the sole cause of northerly ground-water flow (figs. 7D and 7E) since this flow direction was not observed on previous dates (figs. 7A, 7B, and 7C). It is likely that water ponded in nearby waste lagoons is a significant contributor to the northerly flow of ground water indicated in figures 7D and 7E.

WATER QUALITY

State and Federal primary drinking-water standards have been established for chemical constituents that can produce adverse health effects (Kansas Department of Health and Environment, 1986; U.S. Environmental Protection Agency, 1986). Secondary drinking-water standards have been established for constituents that affect the aesthetic properties and desirability of drinking water but which are not believed to have adverse health effects (Kansas Department of Health and Environment, 1986). Kansas action levels are established for concentrations that could produce adverse health effects after long-term consumption of water (Kansas Department of Health and Environment, 1986). Kansas notification levels are established for concentrations that have no adverse health effects for lifetime consumption, or, for carcinogens, which increase the risk of cancer by no more than one in 1,000,000 (Kansas Department of Health and Environment, 1986).

Regional

The quality of ground water in Lyon County depends upon the type of aquifer in which the water occurs. Ground water in Lyon County occurs in alluvial deposits along river valleys and in consolidated rocks, primarily limestone, elsewhere. Table 6 shows the ranges

Table 6. *Ranges and median chemical-constituent concentrations in water from wells in alluvial and limestone aquifers in Lyon County, and from wells upgradient of the Emporia-Lyon County Landfill*

Chemical constituent or property	Concentration, in milligrams per liter, except as noted						
	Alluvial aquifer[1] (11 wells)		Limestone aquifer[1] (22 wells)		Upgradient wells S-1[1], MW-1[2], MW-2[2]	Kansas drinking-water standards[3]	
	Range	Median	Range	Median	Range	Primary	Secondary
Hardness, as $CaCO_3$	266-958	472	270-1,166	473	330-600	--	400
Calcium	74-292	148	77-337	118	110-176	--	--
Magnesium	13-56	25	19-163	42	14-39	--	--
Sodium plus potassium	10-148	86	8.7-337	63	41-63	--	--
Bicarbonate, as HCO_3	278-514	364	200-710	385	364-650	--	--
Sulfate	24-519	111	64-914	162	30-338	--	250
Chloride	6-464	52	9-200	40	22-75	--	250
Fluoride	0.1-0.4	.2	0.1-0.7	.35	0.2-0.4	1.8	--
Silica	2.6-23	5.6	2.2-15	6.8	4.4-24	--	--
Dissolved solids	337-1,430	803	323-2,251	742	497-864	--	500
Nitrate, as N	7.1-407	25	0.8-358	64	<0.01-2.0	10	--
Iron (micrograms per liter)	60-550	110	50-9,900	240	50-7,100	--	300

[1] Data from O'Connor (1953a).
[2] Data collected by U.S. Geological Survey, September 1988.
[3] Kansas Department of Health and Environment, 1986.

and median values for chemical constituents in water from alluvial and limestone aquifers. Water from the alluvial aquifer usually is preferred because of its generally better chemical quality, larger yields, and greater reliability of wells during periods of drought (O'Connor, 1953a). On the basis of data reported by O'Connor (1953a), hardness, dissolved-solids, and nitrate concentrations exceed Kansas primary or secondary drinking-water standards in water from some wells (table 6).

Landfill

Water from well S-1 near the landfill (fig. 2) and from wells MW-1 and MW-2, which are upgradient of the landfill, is representative of ambient ground-water quality in the vicinity of the Emporia-Lyon County Landfill (table 6). Compared to other wells completed in the alluvial aquifer in Lyon County, wells S-1, MW-1, and MW-2 have similar chemical-concentration ranges, except that these wells have a much larger range of iron concentrations and smaller ranges of hardness, chloride, dissolved solids, and nitrate (table 6).

EFFECT OF LANDFILL ON WATER QUALITY

Inorganic Compounds

Chemical analyses of monitoring-well water samples collected in September 1988 indicate that calcium bicarbonate type water is the dominant ground-water type in the vicinity of the landfill (figs. 10 and 11). For the major ions, calcium concentrations ranged from 110 to 180 mg/L (milligrams per liter); magnesium, from 14 to 41 mg/L; sodium, from 40 to 110 mg/L; bicarbonate, as HCO_3, from 460 to 980 mg/L, sulfate, from 16 to 91 mg/L; and chloride, from 11 to 160 mg/L. Total hardness, as $CaCO_3$ ranged from 330 to 610 mg/L; dissolved solids, from 497 to 860 mg/L; iron, from 10 to 7,100 µg/L (micrograms per liter); and manganese, from 50 to 4,500 µg/L (table 7). None of the concentrations of inorganic constituents detected in water from landfill monitoring wells exceeded Kansas or Federal primary drinking-water standards. However, Kansas secondary drinking-water standards were equaled or exceeded for total hardness in water from wells MW-2, MW-3A, MW-3B, MW-4A, MW-5, MW-6, and MW-8B; for dissolved solids in water from all monitoring wells except MW-1 and MW-4B; for iron in water from all monitoring wells except MW-2 and MW-8B; and for manganese in water from all monitoring wells (table 7).

Monitoring wells were installed upgradient and downgradient of the Emporia-Lyon County Landfill to compare upgradient water quality with downgradient water quality. Wells MW-1, MW-2, MW-3A, and MW-3B were upgradient of the landfill at the time of sampling, and wells MW-4A, MW-4B, MW-5, MW-6, MW-7, MW-8A, and MW-8B were downgradient of the landfill at the time of sampling (fig. 7). Wells MW-9 and MW-10 were intended to be upgradient wells until the landfill expands into their vicinity. However, at the time of sampling, water-level measurements indicate that MW-9 and MW-10 were downgradient of the adjacent waste lagoon but were neither upgradient nor downgradient of buried wastes. Therefore, these wells will be considered separately from the other wells. Permission was not granted to take water samples or water-level measurements from adjacent waste lagoons and waste-lagoon monitoring wells.

Table 8 shows the ranges and median concentrations of constituents and properties in water from the upgradient and downgradient wells and from wells MW-9 and MW-10. Water from wells MW-3A and MW-3B had large concentrations of calcium, magnesium, sodium, chloride, ammonia, manganese, zinc, and large specific-conductance values as compared to other wells. Water from well MW-1 had the largest iron concentration as compared to other wells. Water from well MW-5 had large concentrations of barium and iron, and water from well MW-9 had a large ammonia concentration as compared to other wells (table 7).

There are no appreciable differences between the median constituent concentrations in water from upgradient and downgradient groups of monitoring wells (figs. 12 and 13). However, differences are evident from a comparison of constituent concentrations in water from wells MW-2 and S-1 with all other monitoring wells. Water from well MW-2 had larger concentrations of dissolved oxygen and nitrate, and smaller concentrations of bicarbonate, alkalinity, ammonia, arsenic, and manganese than all

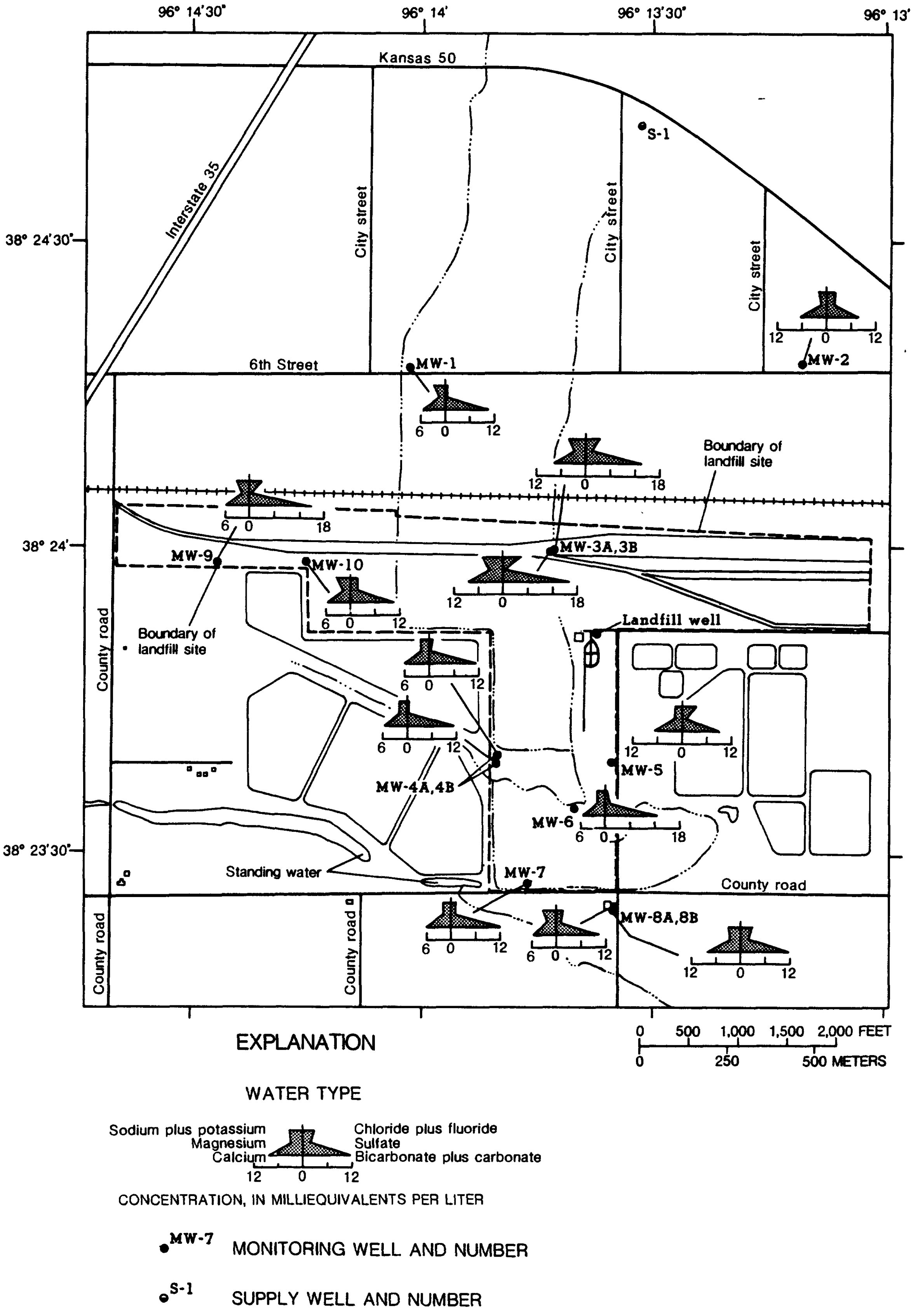


Figure 10. Areal distribution of water-quality constituents in samples collected from monitoring wells, September 1988.

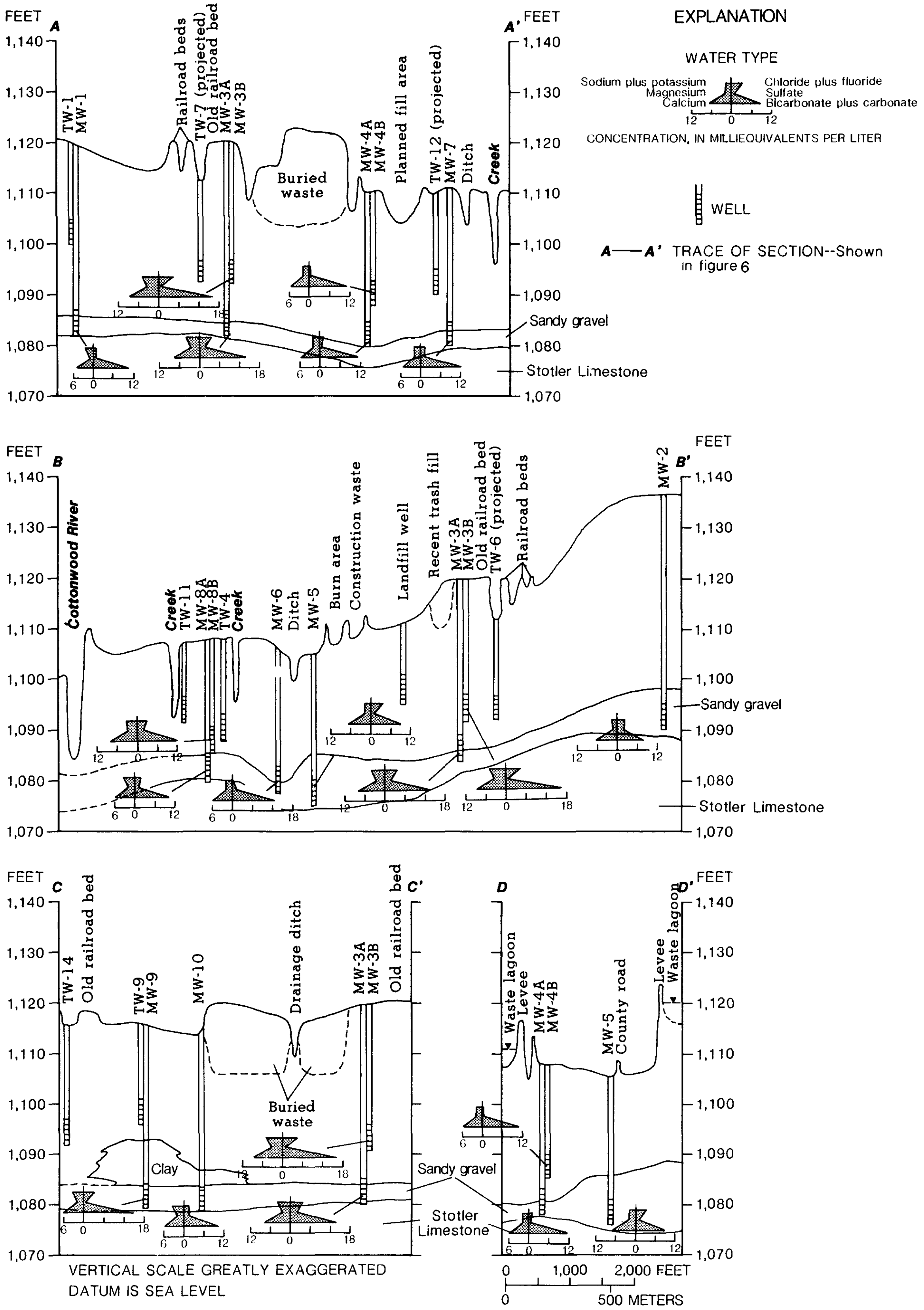


Figure 11. Vertical distribution of water-quality constituents in samples collected from monitoring wells, September 1988.

Table 7. *Inorganic constituents and properties detected in water samples from monitoring and supply wells*

[Units of measurement: mg/L, milligrams per liter; µS/cm; microsiemens per centimeter at 25 degrees Celsius; JTU, Jackson turbidity units; mm of Hg, millimeters of mercury; µg/L; micrograms per liter. <1.0, constituent not detected at detection limit of 1.0]

Well (fig. 3)	Date of collection (month-day-year)	Specific conductance (µS/cm)	pH (standard units)	pH, laboratory (standard units)	Water temperature (degree Celsius)	Turbidity (JTU)	Oxygen, dissolved (mg/L)	Barometric pressure (mm of Hg)	Hardness, total (mg/L as CaCO$_3$)
MW-1	09-13-88	1,080	6.7	7.1	16.5	2,500	1.2	737	330
MW-2	09-14-88	963	7.2	7.2	15.5	200	3.1	737	400
MW-3A	09-14-88	1,490	6.6	7.1	17.0	2,000	1.6	736	530
MW-3B	09-14-88	1,750	6.5	7.0	16.5	1,000	2.4	735	610
MW-4A	09-15-88	1,010	7.1	7.2	17.0	270	1.5	736	400
MW-4B	09-15-88	880	6.6	7.1	16.5	290	1.3	736	380
MW-5	09-15-88	1,160	7.2	7.1	16.0	700	1.6	736	440
MW-6	09-15-88	950	7.1	6.9	16.0	1,100	1.6	735	400
MW-7	09-16-88	955	7.2	7.0	15.0	850	1.5	737	390
MW-7-D^1	09-16-88	960	7.1	7.1	15.0	900	--	737	390
MW-8A	09-15-88	1,040	7.2	7.1	15.0	340	2.1	735	380
MW-8B	09-15-88	1,400	7.0	7.1	15.0	270	2.1	734	540
MW-9	09-13-88	1,150	7.0	7.0	16.5	2,300	2.3	738	380
MW-10	09-14-88	1,010	6.6	6.9	16.0	400	2.1	735	370
S-1^2	09-12-51	--	--	--	--	--	--	--	600
Kansas drinking-water standards^3									
Primary		--	--	--	--	^{3}1.0	--	--	--
Secondary		--	6.5-8.5	6.5-8.5	--	--	--	--	400.0
Federal primary drinking-water standards^4		--	--	--	--	^{3}1.0	--	--	--

Table 7. *Inorganic constituents and properties detected in water samples from monitoring and supply wells--Continued*

Well (fig. 3)	Date (month-day-year)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Bicarbonate, calculated (mg/L as HCO_3)	Alkalinity, total field (mg/L as $CaCO_3$)	Alkalinity, total laboratory (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)
MW-1	09-13-88	110	14	59	2	650	530	400	30	22
MW-2	09-14-88	130	16	40	1	460	380	290	82	75
MW-3A	09-14-88	160	32	93	2	840	690	500	74	130
MW-3B	09-14-88	180	41	110	2	980	810	520	19	160
MW-4A	09-15-88	120	24	45	2	700	570	430	17	32
MW-4B	09-15-88	110	24	42	2	680	560	440	16	11
MW-5	09-15-88	140	24	41	2	550	450	330	38	120
MW-6	09-15-88	120	25	45	2	770	630	440	51	12
MW-7	09-16-88	120	23	45	2	730	600	390	46	41
MW-7-D[1]	09-16-88	120	23	45	2	730	600	390	45	42
MW-8A	09-15-88	110	23	71	2	650	530	390	54	60
MW-8B	09-15-88	160	32	66	2	710	590	450	91	100
MW-9	09-13-88	120	21	73	4	920	750	370	16	110
MW-10	09-14-88	110	21	75	2	650	540	380	88	56
S-1[2]	09-12-51	176	39	63[5]	--	364	--	--	338	55
Kansas drinking-water standards[3]										
Primary		--	--	--	--	--	--	--	--	--
Secondary		--	--	--	--	--	--	--	250	250
Federal primary drinking-water standards[4]		--	--	--	--	--	--	--	--	--

Table 7. *Inorganic constituents and properties detected in water samples from monitoring and supply wells*--Continued

Well (fig. 3)	Date (month-day-year)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Solids, sum of constituents, dissolved (mg/L)	Nitrogen, nitrate dissolved (mg/L as N)	Nitrogen, ammonia dissolved (mg/L as N)	Phosphorus, dissolved (mg/L as P)	Arsenic, dissolved (µg/L as As)	Barium, dissolved (µg/L as Ba)	Cadmium, dissolved (µg/L as Cd)
MW-1	09-13-88	0.3	12	497	<0.01	0.52	2.5	14	470	<1
MW-2	09-14-88	.2	24	568	5.1	<.01	.30	1	340	<1
MW-3A	09-14-88	.2	21	816	<.01	1.5	2.2	7	540	1
MW-3B	09-14-88	.3	29	860	<.01	1.2	1.9	10	590	1
MW-4A	09-15-88	.2	18	523	<.01	.50	1.5	5	270	<1
MW-4B	09-15-88	.3	17	498	<.01	.43	1.7	4	260	<1
MW-5	09-15-88	.2	16	580	<.01	.58	1.6	7	740	<1
MW-6	09-15-88	.3	14	535	<.01	.37	.98	14	280	<1
MW-7	09-16-88	.3	21	538	<.01	.23	1.3	6	360	<1
MW-7-D[1]	09-16-88	.3	21	538	<.01	.21	1.5	5	330	<1
MW-8A	09-15-88	.3	18	579	<.01	.57	.80	7	480	<1
MW-8B	09-15-88	.3	18	752	.37	.03	.73	2	400	<1
MW-9	09-13-88	.4	34	602	<.01	1.4	1.4	3	270	1
MW-10	09-14-88	.4	16	604	<.01	.37	1.8	8	240	<1
S-1[2]	09-12-51	.4	4.4	864	2.0	--	--	--	--	--
Kansas drinking-water standards[3]										
Primary		1.8	--	--	10	--	--	50	1,000	10
Secondary		--	--	500	--	--	--	--	--	--
Federal primary drinking-water standards[4]		1.4	--	--	10	--	--	50	1,000	10

Table 7. *Inorganic constituents and properties detected in water samples from monitoring and supply wells*--Continued

Well number (fig. 3)	Date (month-day-year)	Chromium, dissolved (µg/L as Cr)	Copper, dissolved (µg/L as Cu)	Iron, dissolved (µg/L as Fe)	Lead, dissolved (µg/L as Pb)	Manganese, dissolved (µg/L as Mn)	Mercury, dissolved (µg/L as Hg)	Selenium, dissolved (µg/L as Se)	Silver, dissolved (µg/L as Ag)	Zinc, dissolved (µg/L as Zn)
MW-1	09-13-88	<10	<10	7,100	<1	950	<0.5	<1	<1.0	60
MW-2	09-14-88	<10	<10	50	<1	50	<.5	1	<1.0	50
MW-3A	09-14-88	<10	<10	1,400	<1	2,900	<.5	<1	1.0	170
MW-3B	09-14-88	<10	<10	2,200	<1	4,500	<.5	2	<1.0	150
MW-4A	09-15-88	<10	<10	2,500	<1	760	<.5	1	<1.0	70
MW-4B	09-15-88	<10	<10	580	<1	1,300	<.5	<1	2.0	150
MW-5	09-15-88	<10	<10	6,100	<1	1,300	<.5	<1	2.0	110
MW-6	09-15-88	<10	10	2,400	<1	490	<.5	<1	2.0	70
MW-7	09-16-88	<10	20	1,900	<1	1,300	<.5	<1	1.0	140
MW-7-D[1]	09-16-88	<10	<10	1,300	<1	1,300	<.5	<1	2.0	60
MW-8A	09-15-88	<10	10	1,400	<1	630	<.5	<1	2.0	80
MW-8B	09-15-88	<10	20	10	<1	260	<.5	<1	2.0	80
MW-9	09-13-88	<10	10	470	<1	830	<.5	<1	4.0	50
MW-10	09-14-88	<10	10	3,200	<1	1,500	<.5	3	<1.0	100
S-1[2]	09-12-51	--	--	60	--	--	--	--	--	--
Kansas drinking-water standards[3]										
Primary		50	--	--	50	--	2	10	50	--
Secondary		--	1,000	300	--	50	--	--	--	5,000
Federal primary drinking-water standards[4]		50	--	--	50	--	2	10	50	--

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[1] Duplicate sample.

[2] Data from O'Connor (1953a).

[3] Kansas Department of Health and Environment, 1986.

[4] U.S. Environmental Protection Agency, 1986.

[5] Concentration is for sodium plus potassium.

Table 8. *Ranges and median chemical-constituent concentrations and properties in water from upgradient and downgradient wells and wells MW-9 and MW-10, September 1988*

[Concentrations in milligrams per liter, except as noted]

Chemical constituent or property	Upgradient wells (MW-1, MW-2 MW-3A, MW-3B)		Downgradient wells (MW-4A, MW-4B, MW-5, MW-6, MW-7, MW-8A, MW-8B)		Wells MW-9 and MW-10	
	Range	Median	Range	Median	Range	Median
Specific conductance[1]	963-1,750	1,285	880-1,400	1,010	1,010-1,150	1,080
Dissolved oxygen	1.2-3.1	2.0	1.3-2.1	1.6	2.1-2.3	2.2
Hardness, as $CaCO_3$	330-610	465	380-540	400	370-380	375
Calcium	110-180	145	110-160	120	110-120	115
Magnesium	14-41	24	23-32	24	21-21	21
Sodium	40-110	76	41-71	45	73-75	74
Potassium	1-2	2	2[4]	2	2-4	3
Bicarbonate, as HCO_3	460-980	745	550-770	700	650-920	785
Sulfate	19-82	52	16-91	45	16-88	52
Chloride	22-160	102.5	11-120	41	56-110	83
Fluoride	0.2-0.3	.25	0.2-0.3	.25	0.4[4]	.4
Silica	12-29	22.5	14-21	18	16-34	25
Dissolved solids	497-860	692	498-752	538	602-604	603
Nitrate, as N	<0.01-5.1	<.01	<0.01-0.37	<.01	<0.01[4]	<.01
Ammonia, as N	<0.01-1.5	0.86	0.03-0.58	.43	0.37-1.4	.88
Iron[2]	50-7,100	1,800	10-6,100	[3]1,600	470-3,200	1,835
Manganese[2]	50-4,500	1,925	260-1,300	760	830-1,500	1,165
Total organic carbon	7.9-60	42.5	11-37	15	20-58	39

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[1] Concentrations in microsiemens per centimeter at 25 °C.
[2] Concentrations in micrograms per liter.
[3] Average of concentrations in water from wells MW-7 and MW-7-D.
[4] All concentrations are the same for these samples (see table 7).

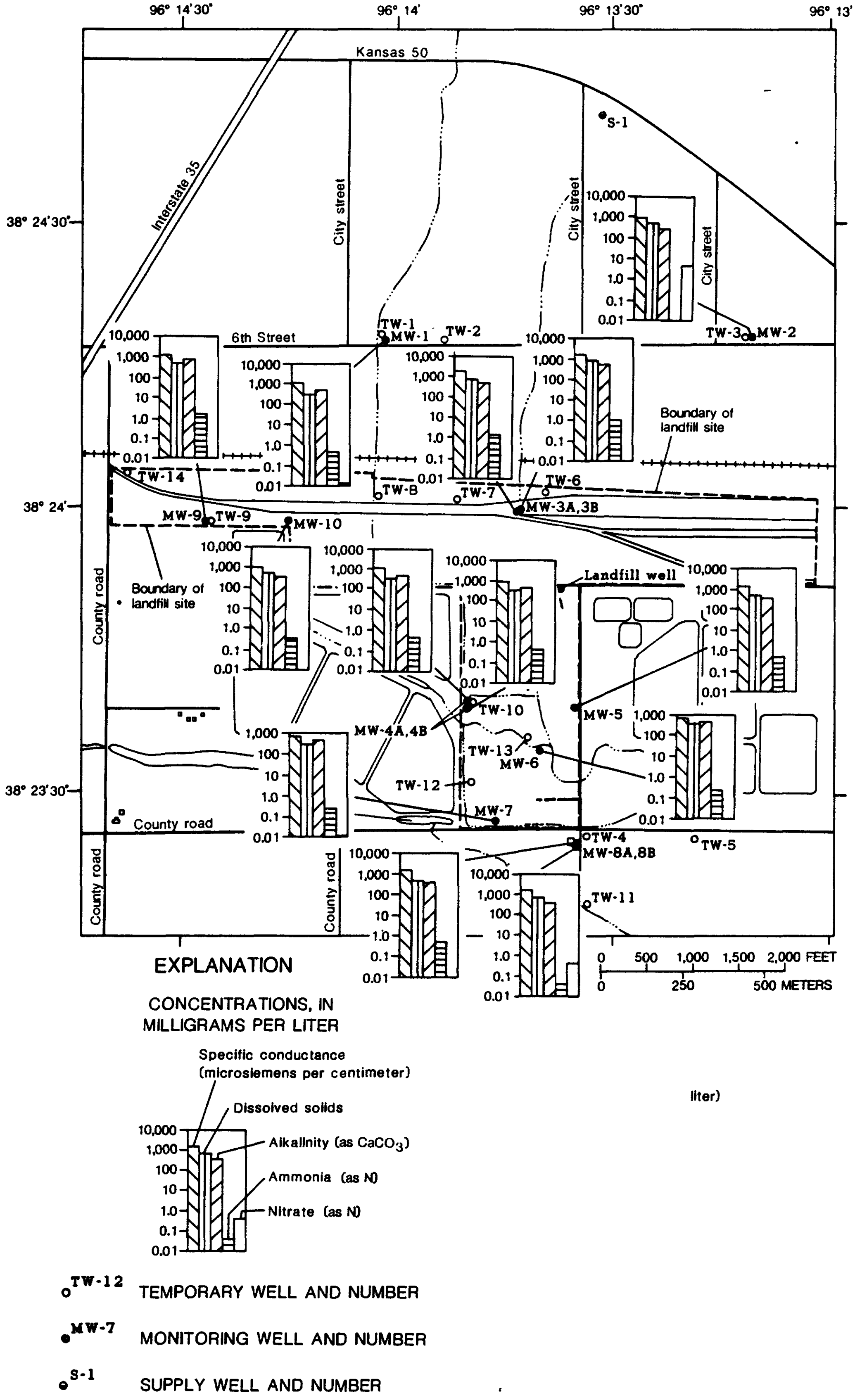

Figure 12. Values of specific conductance and concentrations of dissolved solids, total alkalinity, ammonia, and nitrate in water from monitoring wells, September 1988.

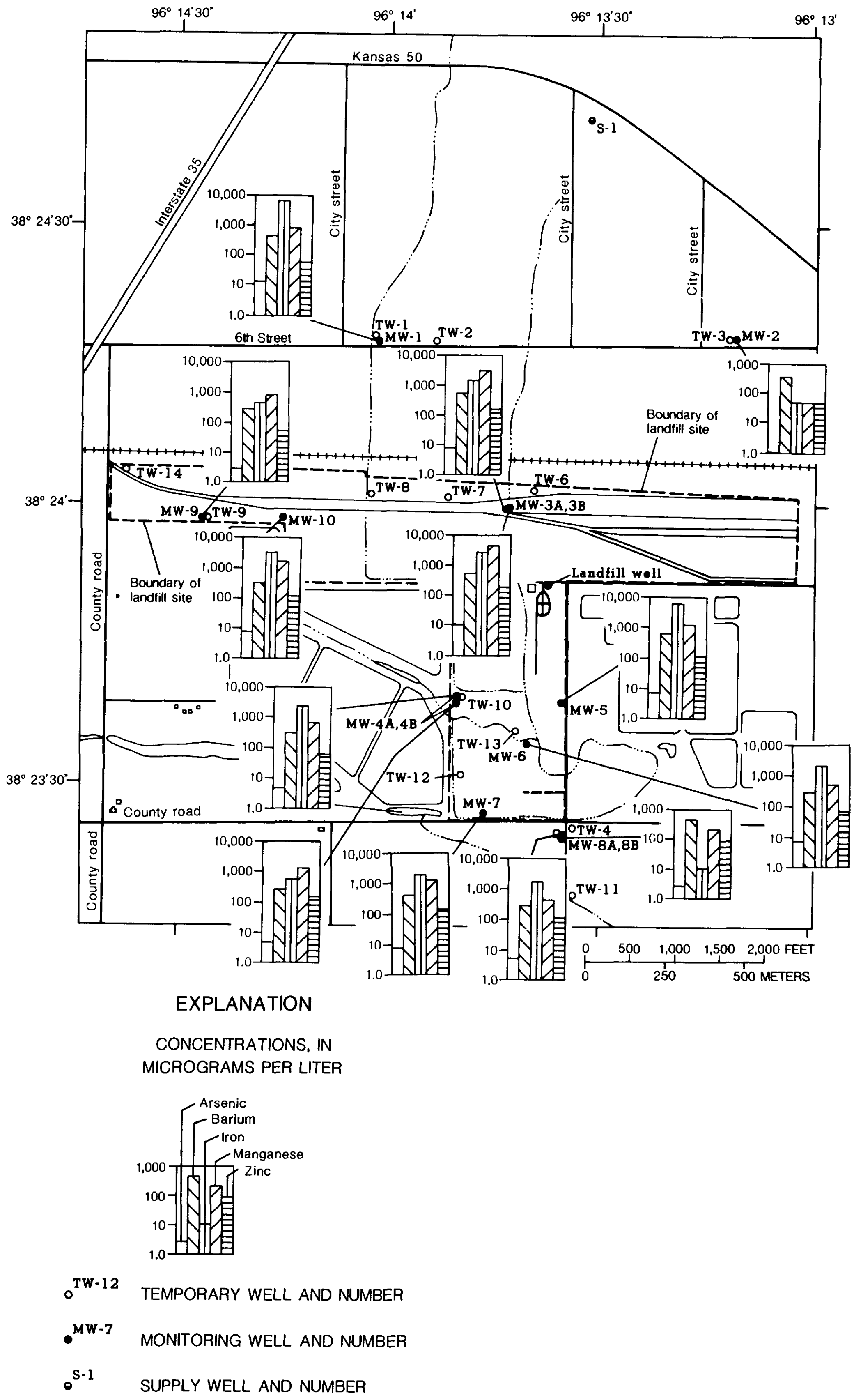

Figure 13. Concentrations of arsenic, barium, iron, manganese, and zinc in water from monitoring wells, September 1988.

other wells, and the next to smallest concentration of iron (table 7). A water sample collected in 1951 from well S-1 had a larger concentration of nitrate, smaller concentrations of bicarbonate, and the third smallest iron concentration (table 7). Water samples from wells MW-2 and S-1 are probably representative of uncontaminated upgradient water quality. Because of changing of directions of ground-water flow (fig. 7), other monitoring wells (MW-1 and MW-3A through MW-10) probably have been downgradient of the landfill and surrounding waste lagoons at one time or another, and thus have water with small nitrate concentrations and increased concentrations of bicarbonate, alkalinity, ammonia, and trace metals.

Changes in concentrations of ions and trace metals in ground water may be caused by several factors. A change in the amount of a specific mineral or minerals present in aquifer material can cause changes in ion concentrations. For example, the solution of halite (sodium chloride) causes an increase in sodium and chloride concentrations. Sorption or ion-exchange processes in clay materials in aquifers may decrease cation concentrations or decrease one cation concentration while increasing another. A change in the pH of water may affect the solubility of minerals and thus the concentrations of ions present.

The addition of wastes to ground water can change the oxidation-reduction characteristics of water, which may change the concentrations of ions present. Oxidation of organic matter can use up the available oxygen (Freeze and Cherry, 1979, p. 117-118). The depletion of oxygen as the primary oxydizing agent may lead to sulfate, nitrate, manganese oxides, iron oxides, and water acting as oxidizing agents (table 9). In the process of oxidizing organic matter, the oxidizers themselves are reduced to forms that are more soluble and thus are detected in larger concentrations under reducing conditions, except that nitrate nitrogen is reduced to ammonia nitrogen (Baedecker and Back, 1979; Freeze and Cherry, 1979, p. 118). In the oxygen-depleted landfill environment, the oxidation of organic matter also may lead to the production of methane gas (Freeze and Cherry, 1979, p. 118).

It is evident from the small nitrate concentrations and the increased bicarbonate, ammonia, iron, and manganese concentrations in water from all monitoring wells except MW-2 that ground-water quality downgradient of well MW-2 has been affected by increased concentrations of inorganic and organic compounds. However, it is not clear what the source or sources of the inorganic and organic compounds may be. The industrial nature of the area near the landfill suggests that there may be many sources of wastes that have accumulated in the soil and ground water over the years. The possibility of multiple waste sources, the changing directions of ground-water flow, and the large cation-exchange capacity of the clayey soil in the area may be masking any effect of the landfill on ground-water quality.

Organic Compounds

Water samples from landfill monitoring wells were analyzed for 109 organic compounds (table 10). Total organic carbon (TOC) was detected in water from all wells at concentrations ranging from 7.9 to 60 mg/L (table 11). Bis (2-ethylhexyl) phthalate, chloroform, prometon, and toluene were detected also in water samples from landfill monitoring wells. Bis (2-ethylhexyl) phthalate was detected in water from well MW-9 at 42.6 µg/L. Chloroform was detected in water from well MW-2 at 0.8 µg/L, from well MW-4B at 2.3 µg/L, from well MW-7 at 0.7 µg/L, from well MW-9 at 0.9 µg/L, and from well MW-10 at 1.8 µg/L. Prometon was detected in water from well MW-3A at 0.1 µg/L. Toluene was detected in water from well MW-1 at 0.6 µg/L.

Kansas primary drinking-water standards have not been established for the organic compounds detected. Kansas action levels and Kansas notification levels have been established for chloroform and toluene, but none of the concentrations of chloroform or toluene exceeded these levels (table 11). In addition to the organic compounds just discussed, natural gas was detected by a combustible-gas indicator in wells MW-3A and MW-3B.

If organic compounds are being released from the landfill, these should be detected in larger concentrations in water from

Table 9. *Typical chemical processes and water chemistry upgradient, in, and downgradient of a waste source*

[Freeze and Cherry, 1979, p. 117-118]

	Upgradient	In waste source	Downgradient	Transition zone
Chemical process	Chemical equilibrium (ambient conditions)	Rapid change in chemical equilibria. Oxidation of organic matter. Depletion of oxygen. Nitrate reduced to ammonia. Iron and manganese reduced to more soluble forms. Production of methane gas.	Meta-stable chemical equilibria.	Gradual transition to ambient chemical conditions. Increasing oxygen and nitrate concentrations. Decreasing ammonia and total organic-carbon concentrations. Iron and manganese oxidized to less soluble forms.
Water chemistry	Oxygenated. Nitrate present. Small ammonia and total organic-carbon concentrations. Iron and manganese in less soluble forms.	Rapidly changing water chemistry.	Oxygen depleted. Small nitrate concentrations. Ammonia present. Large total organic-carbon concentrations. Iron and manganese in more soluble forms.	Gradually changing water chemistry.

Table 10. *List of organic compounds for which analyses were done*

Volatile Organic Compounds

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

Semivolatile, Acid Extractable

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

Semivolatile, Base-Neutral Extractable

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

Table 10. *List of organic compounds for which analyses were done*--Continued

Pesticides and Polychlorinated Biphenyls (PCB's)

alachlor	aldrin
alpha BHC (benzene hexachloride)	ametryn
aroclor 1016	aroclor 1221
aroclor 1232	aroclor 1242
aroclor 1248	aroclor 1254
aroclor 1260	atrazine
beta BHC	chlordane
cyanazine	delta BHC
dieldrin	endosulfane sulfate
endosulfan II	endosulphan I
endrin	gamma BHC
heptachlor	heptachlor epoxide
metolachlor	metribuzin
p,p' DDD	p,p' DDE
p,p' DDT	prometon
prometryn	propazine
simazine	simetryn
toxaphene	trifluralin

downgradient wells as compared to upgradient wells. Bis (2-ethylhexyl) phthalate was detected in water from well MW-9. Bis (2-ethylhexyl) phthalate is a liquid used in vacuum pumps. Chloroform was detected in water from upgradient well MW-2, downgradient wells MW-4B, and MW-7, and in water from wells MW-9 and MW-10. Chloroform is used as a refrigerant, an aerosol propellant, in the synthesis of fluorinated resins, as a solvent, in fire extinguishers, and as a pesticide (National Research Council, 1977, p. 713). The U.S. Environmental Protection Agency has found chloroform to be present in 95 to 100 percent of finished chlorinated drinking water, the mean concentration being 20 µg/L (National Research Council, 1977, p. 713). Prometon was detected in water from upgradient well MW-3A. Prometon is a triazine herbicide used to control weeds. Toluene was detected in water from upgradient well MW-1. Toluene is used in the production of benzene derivatives, saccharin, perfumes, dyes, medicines, solvents, TNT, and detergent, and is used as a gasoline component (National Research Council, 1977, p. 770). Toluene has been reported in finished drinking-water supplies at concentrations of 11 µg/L (National Research Council, 1977, p. 770). Natural gas, primarily methane, is a byproduct in the decomposition of organic wastes in a reducing environment (Freeze and Cherry, 1979).

There are several possible sources for the organic compounds detected in water from monitoring wells. Chloroform and toluene are contained in a number of products for residential and commercial use and may originate from the landfill. Alternatively, industrial and urban areas of Emporia could be the source of these compounds. Both compounds have been detected in finished drinking water and could have been present in the finished drinking water used during well construction. Prometon may have originated from application of this herbicide in the vicinity of the landfill. The source of bis (2-ethlyhexyl) phthalate is uncertain; it could have come from buried wastes or field or laboratory contamination of the sample. Future analyses of water from well MW-9 would indicate if the source of this compound is in situ or is from post-sampling contamination.

Total organic carbon (TOC) was detected in water from all monitoring wells (table 11).

Table 11. *Summary of organic compounds detected, September 1988*

[Concentrations in micrograms per liter except where noted]

Compound	Monitoring well (fig. 3)														Drinking-water standard		
	MW-1	MW-2	MW-3A	MW-3B	MW-4A	MW-4B	MW-5	MW-6	MW-7	MW-7-D[1]	MW-8A	MW-8B	MW-9	MW-10	KPDWS[2]	KAL[3]	KNL[4]
Total organic carbon[5]	60	7.9	60	25	11	13	29	37	23	23	13	15	58	20	--	--	--
Bis(2-ethylhexyl) phthalate	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	42.6	<10	--	--	--
Chloroform	<.5	.8	<.5	<.5	<.5	2.3	<.5	<.5	.7	.8	<.5	<.5	.9	1.8	--	[6]100	[6]100
Prometon	<.1	<.1	.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	--	--	--
Toluene	.6	<.4	<.4	<.4	<.4	<.4	<.4	<.4	<.4	<.4	<.4	<.4	<.4	<.4	--	240	3.5

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[1] Duplicate sample.
[2] KPDWS, Kansas primary drinking-water standard (Kansas Department of Health and Environment, 1986).
[3] KAL, Kansas action level (Kansas Department of Health and Environment, 1986).
[4] KNL, Kansas notification level (Kansas Department of Health and Environment, 1986).
[5] Concentration in milligrams per liter.
[6] Total of trihalomethane compounds.

TOC is a measure of the amount of organic carbon that is dissolved and suspended in water and can be an indicator of the presence of organic compounds in water. The largest TOC concentrations were detected in water from wells MW-1, MW-3A, and MW-9, in which toluene, prometon, and bis (2-ethlyhexyl) phthalate were detected, respectively. TOC concentrations in water from other wells indicate the presence of unidentified organic compounds.

Organic compounds were detected in monitoring-well water samples in the vicinity of the landfill. Organic compounds in wells MW-1, MW-3A, and MW-9 may have originated from a source north, northwest, or northeast of the landfill, or from the landfill, or from adjacent waste lagoons. Movement of contaminants from the landfill or waste lagoons could be caused by pumpage from nearby supply wells or by high river stages changing the direction of ground-water flow. Natural gas, detected in wells MW-3A and MW-3B, probably migrated laterally through the unsaturated zone to the wells from nearby buried trash.

SUMMARY AND CONCLUSIONS

A cooperative study of the ground-water quality in the vicinity of the Emporia-Lyon County Landfill near Emporia, Kansas, was undertaken during April 1988 to April 1989. Fourteen temporary wells were installed to determine the direction of ground-water movement, then 13 monitoring wells were installed in positions upgradient, in, and downgradient of the landfill.

Chemical analyses of water samples from monitoring wells indicate the presence of organic compounds in upgradient and downgradient wells. The distribution of organic and inorganic compounds indicates that these compounds may originate from sources other than the landfill. Variations in the direction of ground-water flow may have caused upgradient wells, except MW-2, to be contaminated by landfill or lagoon wastes. None of the concentrations of inorganic constituents detected in water from landfill-monitoring wells exceeded Kansas or Federal primary drinking-water standards. However, Kansas secondary drinking-water standards were equaled or exceeded for dissolved solids in water from all monitoring wells except MW-1 and MW-4A; for total hardness in water from wells MW-2, MW-3A, MW-3B, MW-4A, MW-6, and MW-8B; for iron in water from all monitoring wells except MW-2 and MW-8B; and for manganese in water from all monitoring wells. Kansas primary drinking-water standards have not been established for the organic compounds detected. Kansas action levels and Kansas notification levels have been established for chloroform and toluene, but none of the concentrations of chloroform or toluene exceeded the levels established for these compounds.

To further define the sources of ground-water contaminants near the landfill, additional wells would need to be installed north of the landfill, water levels and samples taken from waste lagoons and waste-lagoon monitoring wells, and pumpage rates established for nearby wells. In addition, yearly analyses of inorganic and volatile organic constituents would provide long-term information on the effect of the landfill on water quality. Quarterly water-level measurements and short-term continuous water-level measurements would provide a better understanding of seasonal fluctuations in ground-water levels and direction of water movement.

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