

HYDROGEOLOGY AND EFFECTS OF LANDFILLS ON GROUND-WATER QUALITY,
SOUTHERN FRANKLIN COUNTY, OHIO

By Jeffrey T. de Roche

U.S. GEOLOGICAL SURVEY

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UNITED STATES DEPARTMENT OF THE INTERIOR

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C O R R E C T I O N S

- p. 10, 5th paragraph; line 3 should read: "have low volatility and are not easily degraded..."
- p. 11, 4th paragraph, line 3; the word "or" should be deleted from end of line.
- p. 33, 2d paragraph; line 6 should read: "concentrations of potassium and flouride generally are less than 4 mg/L."
- , 5th paragraph; lines 3 and 4 should read: "Levels of carbon dioxide range from 30 to 101 mg/L with a median concentration of 51.5 mg/L."
- p. 35, 6th paragraph; line 2 should read: "(17 to 720 µg/L)...."
- , 7th paragraph; line 2 should read: "530 mg/L ..."
- , 8th paragraph; line 2 should read: "...820 mg/L..."
- p. 36, last column, 6th line from top; maximum value for dissolved solids, residue at 180 deg. C, should be 1970 mg/L.
- p. 38, 2d paragraph; line 1 should read: "Ammonia, which has a median concentration of 15 mg/L..."
- , 2d paragraph; line 6 should read: "...(0.0 to 2.0 mg/L)..."
- , 4th paragraph; line 6 should read: "to 330 mg/L..."
- , 8th paragraph; lines 2 and 3 should read: "...range from 0.5 to 2.7 mg/L with a median of 1.2 mg/L..."

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CONVERSION FACTORS

For the convenience of readers who prefer to use metric (International System) units, conversion factors for terms used in this report are listed below:

<u>Multiply Inch-Pound Units</u>	<u>By</u>	<u>To Obtain Metric Units</u>
inch (in)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
acre	0.4047	square hectometer (hm ²)
mile (mi)	1.609	kilometer (km)
square mile (mi ²)	2.590	square kilometer (km ²)
cubic yard (yd ³)	0.7646	cubic meter (m ³)
cubic foot per second (ft ³ /s)	43.81	liter per second (L/s)

ABBREVIATIONS AND SYMBOLS

<u>Abbreviation</u>	<u>Description</u>
°C, deg. C	degrees Celsius
ft ³ /s	cubic feet per second
mg/L	milligrams per liter
µg/L	micrograms per liter
µg/kg	micrograms per kilogram
µm	micrometer
µS/cm	microsiemens per centimeter at 25°C
ND	constituent not detected
--	constituent not analyzed
ppm	parts per million

U.S. ENVIRONMENTAL PROTECTION AGENCY (USEPA) DESIGNATIONS FOR CHEMICAL SUBSTANCES

HS	hazardous substance
HW	hazardous waste
HWC	hazardous waste constituent
PTP	priority toxic pollutant

Specific information on these designations can be found in works listed in the Selected References section of this report (U.S. Environmental Protection Agency, 1978a, 1978b, 1979, 1980a, 1980b).

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ABSTRACT

Hydrogeology and water quality were evaluated near five landfills along a 5-mile segment of the Scioto River valley south of Columbus, Ohio. Heterogeneous surficial deposits of sand, gravel, and till up to 160 feet thick are hydraulically connected to the underlying Devonian limestone, the landfills, and Scioto River, which has been leveed with 12 to 35 feet of refuse. Ground-water withdrawals caused a maximum 21-foot decline in ground-water levels from 1979 to 1982. The study reach of Scioto River within the influence of ground-water pumping is a losing stream, except for a small segment adjacent to one landfill.

Analysis of variance indicated significant differences in ground-water quality between wells upgradient of landfills, downgradient of landfills, and wells penetrating refuse. Elevated specific conductance and concentrations of total dissolved solids, ammonia, carbon dioxide, and dissolved organic carbon in water from wells downgradient from and penetrating landfills indicate leachate production and migration is occurring.

Analysis of bed-material samples from Scioto River and Scioto Big Run revealed concentrations of polynuclear aromatic hydrocarbons ranging from 220 to 9,440 micrograms per kilogram of sediment ($\mu\text{g}/\text{kg}$) and concentrations of toxic metals ranging from 1 to 720 $\mu\text{g}/\text{kg}$. Samples from an upstream control station on Scioto River contained no organic compounds and lower concentrations of metals (ranging from 1 to 260 $\mu\text{g}/\text{kg}$). Because of multiple land uses within the study area, organic compounds recovered from the streambed sediments cannot be attributed to any single source.

The generation of hydrogen sulfide and methane gases, presence of a zone of increased hardness, elevated concentrations of common ionic species, and dominance of ammonia over other nitrogen species indicate that leachate is being produced and is migrating from four landfills and the river levee. Based on hydraulic relationships between ground water and surface water, it is highly probable that ground water contaminated by leachate from the levee and from one of the landfills is discharging to Scioto River. Leachate-enriched ground water from other landfills also may begin to discharge to the river if water-withdrawal patterns in the study area change.

INTRODUCTION

The City of Columbus, Ohio, has constructed an induced-infiltration water-supply system in the highly permeable glacial outwash aquifer between Scioto River and Big Walnut Creek (fig. 1). The sources of supply for the water system are the sand-and-gravel aquifer and water percolating through the streambeds of Scioto River and Big Walnut Creek. The presence of several large landfills adjacent to Scioto River (2 miles upstream from the well-field) could adversely affect the quality of the water supply.

The U.S. Geological Survey began a study in 1981, in cooperation with the City of Columbus, Division of Water, to obtain hydrogeologic and chemical-quality information in the vicinity of the landfill area. This study will further understanding of the potential impacts of solid-waste disposal on glacial outwash aquifers. The use of statistical methods to investigate variations in ground-water quality demonstrates a valuable tool that can be used in future studies of aquifers affected by solid-waste disposal.

Purpose and Scope

The primary objectives of this report are to: (1) Describe the geologic and hydrologic setting in which the landfills are located, (2) characterize the ground-water and surface-water quality in the vicinity of the landfills, and (3) determine the effect of landfills on ground-water quality.

Data for evaluating the hydrogeology of the study area were obtained from 37 wells, 4 surface-water sites, and 1 seep. Two continuous ground-water level recorders and a precipitation gage were installed near an existing surface-water gage (site FR-266, Scioto River at Columbus, Ohio) to aid in evaluation of ground-water/surface-water relationships. Gain/loss studies conducted on Scioto River and on a tributary provided additional information on aquifer-stream relationships.

Water-quality samples were obtained from 21 ground-water wells and from 2 surface-water sites. Water-quality samples were analyzed for field-measured properties, major anions and cations, trace metals, nutrients, and base/neutral- and acid-extractable organic compounds. Aquifer materials from two wells and streambed sediments from three sites were analyzed for base/neutral- and acid-extractable organic compounds. Streambed sediments also were analyzed for trace metals. Hydrogeologic relationships and statistically significant water-quality variations are used to illustrate the effects of landfills on water quality.

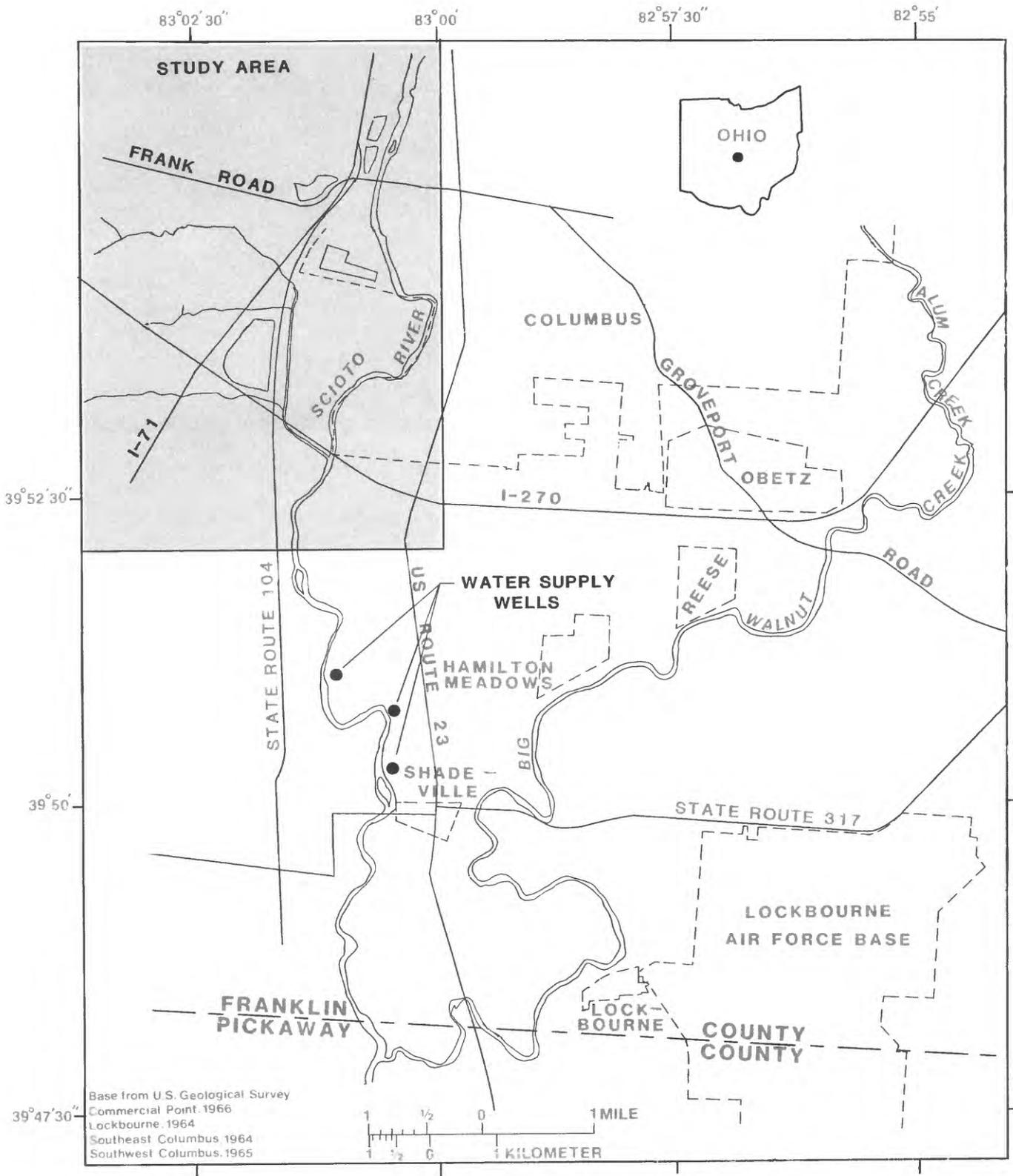


Figure 1.--Location of study area.

Physical Setting and Land Use

The 15-mi² study area is located in central Ohio in the southern part of Franklin County just south of Columbus. The five landfills investigated (fig. 2) are located within a 6-mi² area near Scioto River. Descriptions of the landfills as of 1982 are summarized in table 1.

Single-family residences, commercial buildings, and manufacturing establishments are located in the western half of the study area. A rendering plant is located south of landfill 3, and sewage-treatment facilities for the City of Columbus are immediately north of landfill 4. South of landfill 4 is a trash-burning powerplant that began operating on a limited basis in 1983. The remainder of the study area is occupied by several sand, gravel, and limestone quarries.

The study area is drained by Scioto River and its tributaries. The topography in the study area is generally flat; slopes are 50 to 70 feet per mile towards Scioto River. The land-surface elevation ranges from 770 feet above sea level in the western part of the study area to 680 feet near Scioto River.

Previous Investigations

The Scioto River valley in southern Franklin County has been studied extensively in recent years. A report by Schmidt and Goldthwait (1958) provides information on the geology and ground-water resources of Franklin County. A study by Stowe (1979) discusses the hydrogeology of the Scioto River valley in south-central Franklin County. A series of U.S. Geological Survey reports by Weiss and Razem (1980), Razem (1983), and de Roche and Razem (1984), discuss the hydrogeology and water quality of the Scioto River valley immediately south of the landfill area.

Site-specific studies of one landfill prior to its expansion were done by the Ohio Environmental Protection Agency (1974) and Emcon Associates (1975). A series of geotechnical studies to determine foundation requirements in the study area were done by Alden E. Stilson and Associates (written commun., 1975-81). A preliminary investigation by de Roche and Razem (1981) provided background data on ground-water quality in the vicinity of the landfill sites.

Acknowledgments

The author acknowledges the cooperation of the City of Columbus, Division of Water and Division of Sewerage and Drainage, Alden E. Stilson and Associates (for providing borehole logs and technical information), and American Aggregates Corporation (for providing data and allowing observation wells to be drilled on their property). The author also expresses thanks to area businesses and homeowners for permitting access to their wells.

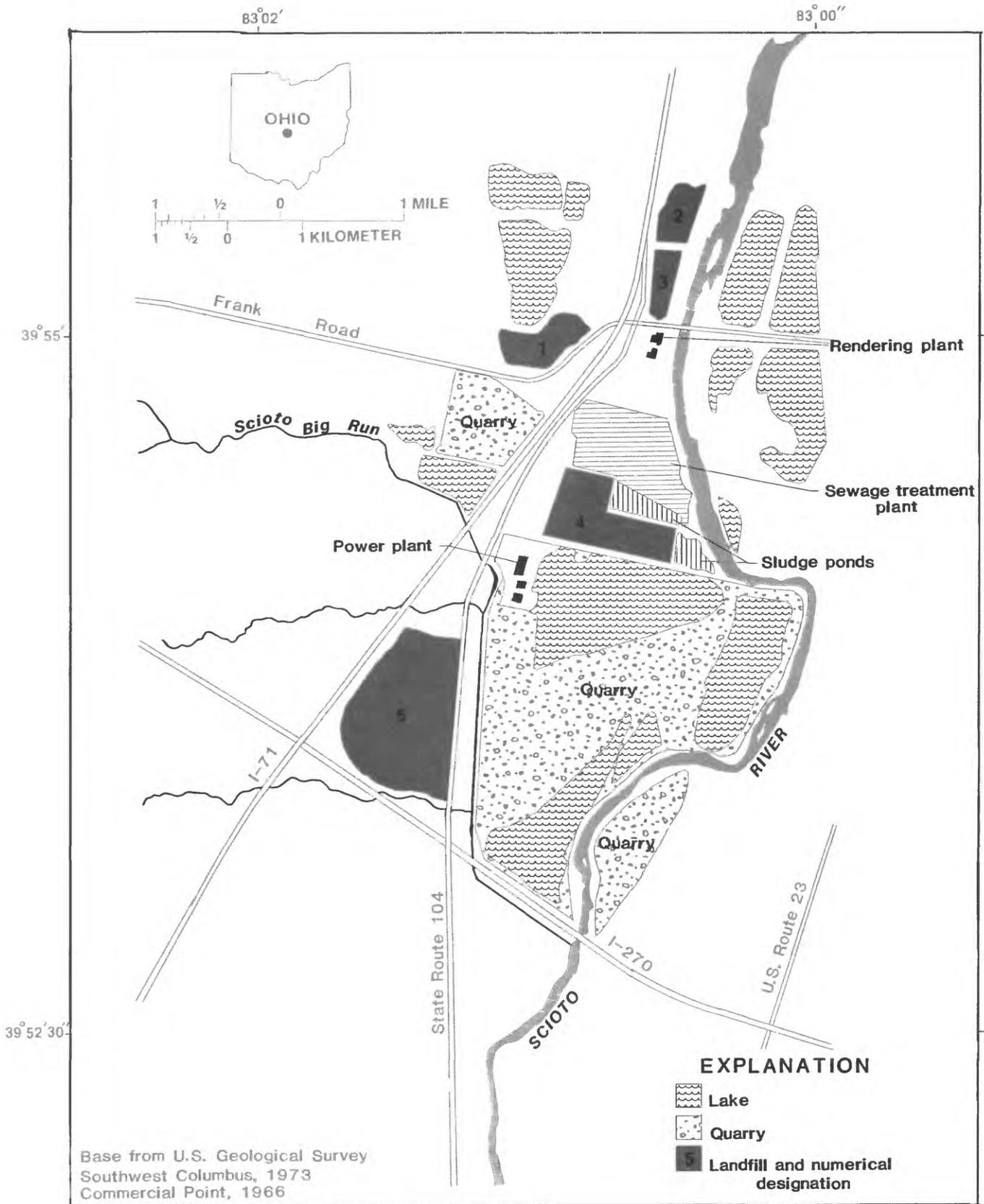


Figure 2.--Location of study area, landfills, industrial sites, quarries, and lakes.

Table 1.--Status of landfill operations in southern Franklin County, Ohio

[D, demolition waste; GW, ground water; S, solid waste; SW, surface water]

Land-fill site	Size (acres)	Waste type	Previous use of site	Began operating	Operating in 1982	Method of operation	Environmental protection and monitoring
1	41	D	Gravel pit	1968	Yes	Area-fill	SW
2	22.5	DS	Gravel pit	1975	No	None	None
3	16.5	DS	Gravel pit	1973	Yes	Area-fill	None
4	38	S	Unknown	1969	No	Trench, area-fill	None
5	174	S	Gravel pit	Mid - 1960's	Yes	Area-fill	SW, GW, clay liner, leachate-collection system

METHODS OF INVESTIGATION

Well Installation

The data-collection network (fig. 3, table 2) consists of 37 wells, 4 surface-water sites, and 1 seep. In addition to existing wells, 12 monitoring wells were drilled by means of a hollowstem, continuous-flight auger. Special methods and cleaning agents were chosen to minimize the effect of well installation on the ambient chemical quality of the aquifers being studied.

To avoid the addition of any liquid not native to the aquifers, all wells were augered without the use of a drilling fluid whenever possible. Before going downhole, all augers were cleaned with hexane¹ and flushed with distilled water. Upon removal from the hole, augers were scrubbed with tap water, cleaned with hexane, and flushed with distilled water.

Wells were cased with 2-inch threaded, flush-fit polyvinyl chloride (PVC) casing and screens, thereby eliminating the need for organic PVC solvents. Wells were screened with 0.010-inch continuous-slot, PVC well screen. Gravel packs were not used. The formation was allowed to collapse around the screen.

In wells that penetrated the base of a landfill, the well screen was packed with silica sand, and a cement-bentonite grout was installed from the first impermeable strata below the landfill base upwards to above the base of the landfill. The annular space above the grouted interval was filled with drill cuttings from the hole. A cement collar was installed at land surface to prevent infiltration of surface water, and protective, locking steel casings were installed over the PVC casings. All wells were developed with compressed air.

Field-Sampling Procedures

Sampling procedures for observation wells were designed to obtain a representative sample from the aquifer and to minimize the introduction of any foreign substance that might affect ambient water quality. All observation wells were pumped until a minimum of five casing volumes were purged from the well. Domestic wells were pumped until the volume of the pressure tank plus five casing volumes had been purged. After purging the wells, samples were collected when specific conductance and temperature readings became stable.

¹Hexane (C₆H₁₄) is an organic solvent commonly used in the analysis of nonvolatile organic constituents by gas chromatography. Because the water samples were analyzed for nonvolatile organic constituents by gas chromatography, the use of hexane as a solvent and cleaning agent was consistent throughout drilling, sample collection, and analysis.

Table 2.--Records of selected wells in southern Franklin County, Ohio

[Aquifer: S&G, sand and gravel; LS, limestone. Casing type: S, steel; P, pvc. Double dash indicates data are not available. Water levels measured August 1982]

Well number	Latitude	Longitude	Aquifer	Year completed	Casing diameter (inches)	Elevation of land surface (feet)	Depth of well (feet)	Altitude of water (feet)
FR-109	395157	830035	S&G	1975	6	702	92	683
FR-133	395218	830239	S&G	1977	2	765	82	705
FR-201	395314	830156	S&G	1968	4.25	731	84	658
FR-202	395314	830219	LS	1977	4	752	220	679
FR-204	395238	830155	S&G	1969	5.5	740	92	688
FR-209	395206	830145	S&G	--	4.25	700	--	685
FR-210	395206	830149	S&G	--	4.25	707	--	685
FR-212	395213	830221	S&G	1978	4.25	752	--	685
FR-213	395313	830200	S&G	1981	5	732	97	659
FR-217	395409	830132	S&G	1976	4	712	92	655
FR-223 ¹	395334	830128	LS	--	--	620	--	--
FR-224	395409	830150	S&G	1979	5.5	721	78	658
FR-227	395348	830227	LS	1978	5	748	260	678
FR-230	395350	830300	S&G	--	6	760	--	684
FR-234	395413	830213	LS	1977	4	733	108	664
FR-236	395250	830141	S&G	1975	4	718	95	660
FR-237	395407	830215	LS	1981	5	735	114	660
FR-242	395319	830128	S&G	1979	4	705	70	650
FR-244	395351	830137	S&G	1979	4	700	75	642
FR-246	395331	830139	LS	1979	4	722	142	609
FR-247	395451	830050	S&G	1964	26	695	83	676
FR-248	395458	830116	S&G	1966	4.25	698	--	660
FR-253	395254	830107	S&G	1982	2	688	60	665
FR-254	395344	830041	S&G	1982	2	691	35	660
FR-255	395403	830003	S&G	1982	2	714	80	655
FR-256	395523	830031	S&G	1982	2	710	40	685
FR-257	395509	830037	S&G	1982	2	700	38	675
FR-258	395448	830042	S&G	1982	2	713	50	682
FR-259	395417	830050	S&G	1982	2	725	51	678
FR-260	395413	830029	S&G	1982	2	713	60	671
FR-261	395426	830102	S&G	1982	2	720	45	681
FR-262	395255	830030	S&G	1982	2	692	49	676
FR-263	395324	830015	S&G	1982	2	691	50	675
FR-264	395329	830131	LS	1980	4	659	140	601
FR-268	395321	830057	S&G	1982	2	680	64	659
FR-269	395330	830039	S&G	1982	2	695	62	658
FR-270	395327	830038	S&G	1982	2	692	63	660
FR-271	395308	830100	S&G	1982	2	679	63	659

¹Seep

A Johnson-Keck¹ SP-81 submersible pump with interchangeable EPDM and Viton stators was used for sampling all 2-inch diameter (I.D.) observation wells. When sampling for inorganic constituents, 10 percent acetone solution and distilled water were used to clean the pump. The acetone solution was pumped through the pump and sample lines, and was followed by distilled water to flush the acetone. The power line, pump housing, and exterior of the sample line also were cleaned before being lowered into the well.

When sampling for base/neutral- and acid extractable organic compounds, a solution of 75 percent hexane and 25 percent alcohol was used to clean the interior and exterior parts of the sampling pump. Pump materials for organic sampling were limited to Teflon, Viton, and stainless steel. For all observation-well sampling, the pump was cleaned before it was lowered into the well and immediately after it was removed.

Aquifer materials were sampled for base/neutral- and acid-extractable organic compounds by surging the wells after water sampling. All sampling equipment was cleaned with a solution of 75 percent hexane and 25 percent alcohol, and flushed with distilled water prior to sample collection. The water-sediment mixture was pumped from the wells and wet sieved in the field through 45- and 25- μ m stainless steel sieves. The <25- μ m fraction that passed through the sieves was collected in a stainless steel vessel and transferred to 1-gallon glass jugs. In the laboratory, 3 gallons of water-sediment mixture was decanted and centrifuged to yield approximately 250 grams of sediment, which was submitted for analysis.

Scioto River and Scioto Big Run are heavily influenced by human activity within the study area. Because of the variable and artificial flow in these two streams due to industrial sources, the streambed sediments were chosen for intensive sampling as opposed to the water column. Analysis of streambed sediments generally provides a good record of many dissolved or suspended constituents that have previously traveled downstream.

Recovery of organic compounds and trace metals from streambed sediments is somewhat restricted to compounds that are hydrophobic, have a low volatility, and are now easily degraded. Physical factors such as grain size, surface charge and area, and cation-exchange capacity affect a sediment's capacity to attract and concentrate compounds. To increase the amount of recovery, only sediments with a high ratio of surface area to grain size (silt and clay) were submitted for analysis.

¹Use of trade names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

Bed material was obtained from local streams and analyzed for organic constituents and trace metals. To increase the recovery of fine sediments, pools and low-velocity reaches of the streams were chosen as sampling sites. Streambed penetration during sampling was generally 4 inches or less.

Bed-material samples for trace-metal analysis were collected with a U.S. Geological Survey BMH60 sampler or a plastic scoop. All sampling equipment and containers were cleaned with a 10 percent nitric acid solution, followed by distilled water, and then by a native-water rinse. Samples were wet sieved with native water through 63- and 38- μm nylon cloth sieves. Samples were further separated by column settling, and the <20- μm fraction was analyzed.

Bed-material samples for organic constituents were collected with a BMH60 sampler with Teflon seals, a stainless-steel scoop, and stainless-steel sieves. All sampling equipment was cleaned with a 75 percent hexane and 25 percent alcohol solution, followed by distilled water and native-water rinses. Samples were wet sieved in the field through 90-, 45-, and 25- μm sieves, and the <25- μm fraction (medium silts and smaller) was analyzed.

Analysis of organic constituents in water and sediments was done by gas chromatography/mass spectrometry. Samples were analyzed quantitatively for base/neutral- and acid-extractable or organic compounds and qualitatively for all other methylene-chloride-extractable organics. All samples were analyzed at the U.S. Geological Survey National Water-Quality Laboratory in Atlanta, Georgia.

Statistical Procedures

A statistical analysis of ground-water quality data was used to determine if landfills had significantly affected ambient ground-water quality. All statistical tests were performed using a statistical software package called Statistical Analysis System, or SAS (Helwig and Council, 1974). Variables that had several missing values or many values assigned at the instrumental detection limit were not used in the analysis and do not appear in the statistical summary tables.

The ground-water quality data were separated into three groups: Upgradient ("up"), downgradient ("down"), and penetrating refuse ("in"), based on the well's position in the ground-water flow system with respect to the landfills. Data were then ranked within the respective groups and nonparametric statistical procedures were used. Analysis was completed using the general linear-model (GLM) procedure, which is specifically designed for unbalanced situations and tests for intergroup differences.

To determine if there were significant variations in ground-water quality among wells in position groups "up," "down," and "in," an analysis of variance was done on the ranked water-quality data. Residuals generated by the analysis of variance were tested for normality using the Shapiro-Wilk W statistic, and only models whose residuals were normally distributed at a 95-percent significance level were used in the analysis.

Because analysis of variance does not indicate specifically which groups differ from each other, Tukey's studentized range test was used to determine the differences between the groups. Tukey's test computes the smallest difference required between mean values for two groups to be considered different, then compares all group combinations to determine which are different.

HYDROGEOLOGY

Unconsolidated Deposits

The unconsolidated deposits in southern Franklin County consist of interbedded sand, gravel, cobbles, and till deposited during the Wisconsin stage of glaciation. The glacial deposits are overlain by a thin veneer of alluvium from Scioto River. The glacial deposits are heterogeneous and have a maximum thickness of 160 feet in the study area.

Geologic-boring data indicate that highly permeable glacial deposits directly overlie fractured limestone in some areas. Reported values of hydraulic conductivity for the glacial deposits range from 190 to 960 feet per day. Weiss and Razem (1980) and de Roche and Razem (1981) classified the deposits as having an average hydraulic conductivity of 200 feet per day. In other areas, the limestone is capped by a low-permeability, sandy gray silt. A geologic cross section through the study area (fig. 4) illustrates the heterogeneity of the surficial deposits, their relationship to the limestone, and the altitude of the water table in August 1982.

The original flood plain of Scioto River was modified in the early 1900's by the construction of levees to prevent flooding. Once such levee extends from Interstate 270 (fig. 3), in the southern part of the study area, northwards past landfills 2 and 3. The levee is on both banks of the river and averages 30 feet in height above the base of the channel.

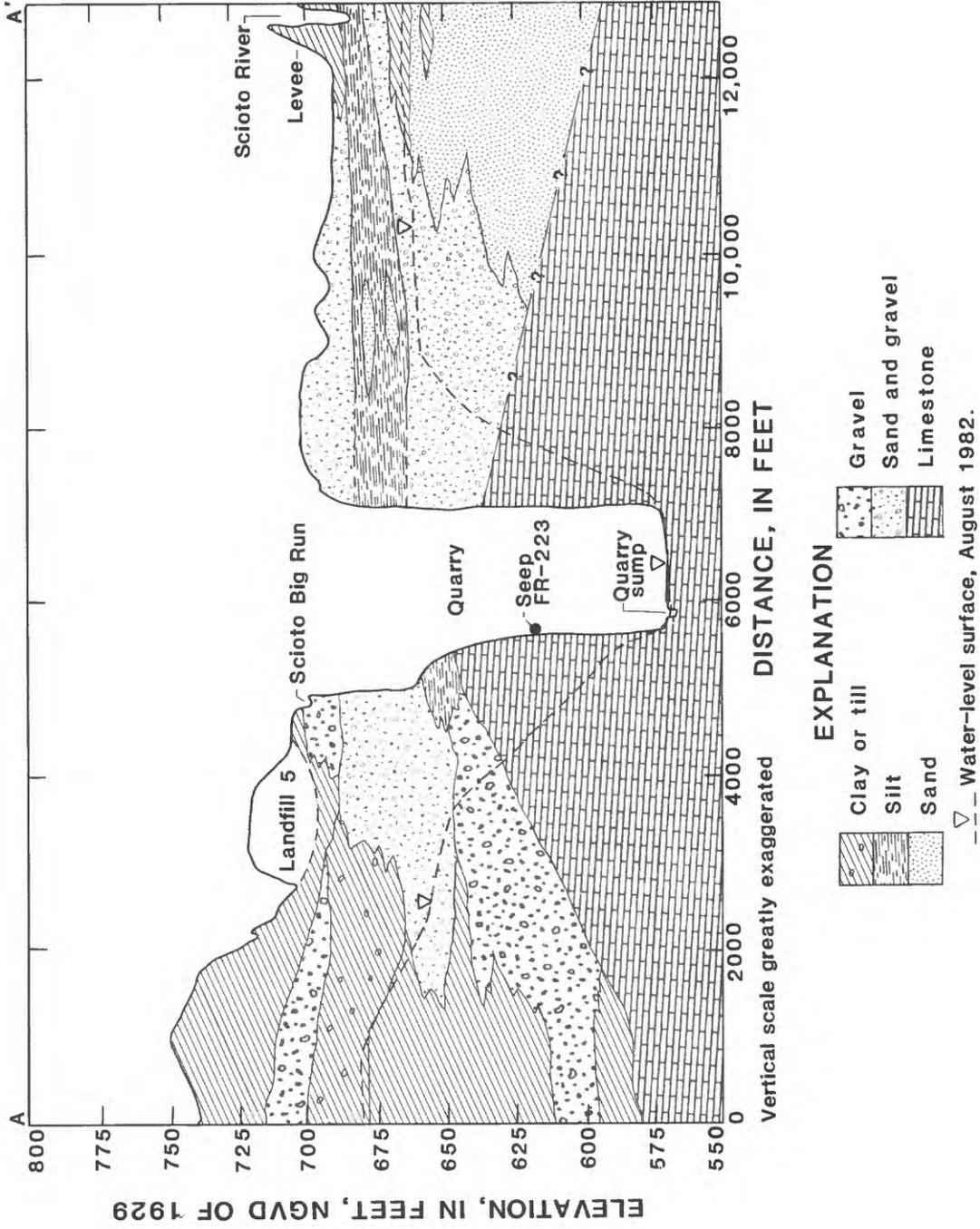


Figure 4.--Geologic section A-A'.

The composition of the levee east of Scioto River was not determined. The western levee is composed of a variety of materials including demolition waste and domestic refuse. The segment of the western levee between I-270 and well FR-260 is constructed primarily of silty clay fill containing some sand and gravel. The depth of fill, as determined from geologic borings and historical data, ranges from 15 to 25 feet. The segment of the levee from just north of well FR-260 to a point just north of landfill 2 (fig. 3) is composed almost entirely of domestic refuse with small amounts of demolition waste. According to geologic borings and historical data, the depth of fill in this area ranges from 20 to 35 feet. The thickness of refuse in the western levee ranges from 12 to 35 feet and averages 22 feet.

Bedrock

The Columbus Limestone of Devonian age underlies the entire study area. Geologic borings indicate the limestone is fractured in some areas at the contact with the overlying glacial deposits. A map of the bedrock surface (fig. 5) constructed from drillers' logs, geologic borings, and surface exposures, shows a highly eroded surface with bedrock valleys trending west to east. The trend of the bedrock valleys coincides with the preglacial drainage system known as the "Teays Stage," which was described by Stout and others (1943) and modified by Goldthwait (Schmidt and Goldthwait, 1958).

Ground Water

The configuration of the ground-water surface is important when considering the effects of landfills on ground-water quality. Migration direction of many contaminants introduced into the ground-water system will coincide with present directions of ground-water flow. The direction of ground-water flow may be estimated from a water-level contour map. Assuming isotropic conditions, ground water moves from areas of higher hydraulic head to areas of lower hydraulic head along paths perpendicular to water-level contours.

Of equal importance are factors that influence the configuration of the ground-water surface and thus affect migration of any contaminant. Factors such as ground-water withdrawals, recharge from surface impoundments, and stream-aquifer relationships can have major impacts on direction of ground-water flow.

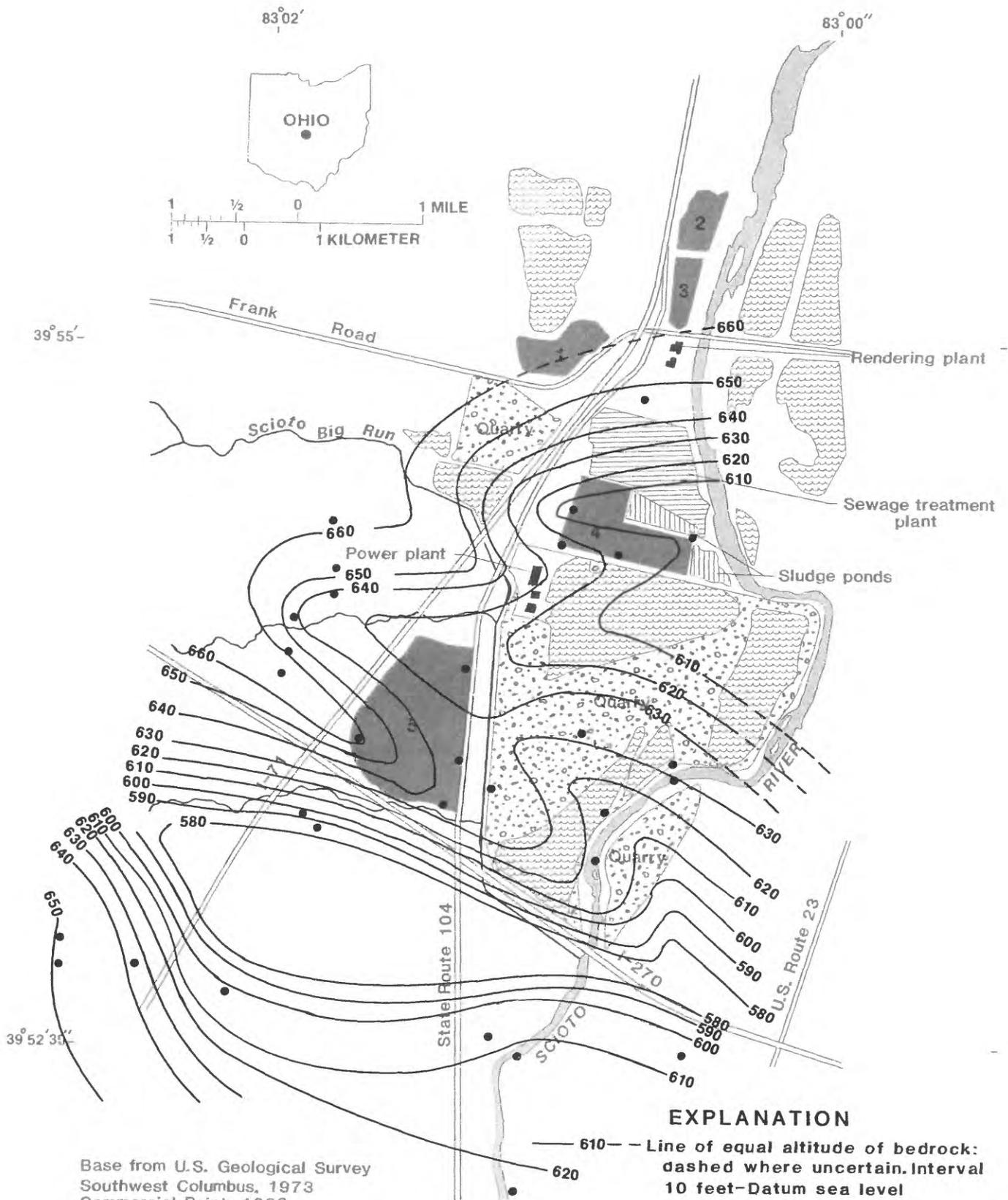


Figure 5.--Altitude and configuration of bedrock surface. (Quarries not shown.)

Ground-water conditions in the landfill area were evaluated on the basis of water-level measurements from domestic, industrial, and observation wells; lake and river mean pool elevations; drillers' logs; and geologic-boring data. The unconsolidated glacial deposits and the underlying limestone were treated as one semiconfined unit, on the basis of geologic data (fig. 4) and similarities in water levels and water quality. A map showing the ground-water level contours and direction of ground-water flow (fig. 6) was constructed from water-level measurements made in August 1982. The map shows a large, asymmetrical cone of depression centered on a limestone quarry.

The long axis of the cone of depression trends roughly north-south, and ground-water flow converges on the sump of the limestone quarry, which is the lowest topographic point of ground-water withdrawal in the study area. Ground water is removed from the aquifer at the sump, used for aggregate processing, and pumped into the lake north of the quarry. Ground water removed at the sump is ultimately discharged to Scioto River just south of well FR-260. Ground-water withdrawal at the quarry sump has created a thick unsaturated zone beneath landfill 5 (fig. 4).

The configuration of water-level contours in the northern section of the study area indicate the cone of depression has not advanced equally in all directions. The contours also indicate the presence of a ground-water mound near landfill 4. Comparison of the configuration of the bedrock surface (fig. 5) with that of the water table (fig. 6) show that bedrock topography is not the control on the shape of the cone of depression. The asymmetry of the cone may be caused by other factors such as differences in hydraulic conductivity, recharge from Scioto River and (or) quarry lakes, or ground-water withdrawals.

Drillers' logs of observation wells FR-258, FR-259, FR-260, and FR-261 near landfill 4 (fig. 3) show the presence of multiple zones of high hydraulic conductivity sands and gravels at elevations ranging from 657 to 688 feet. These permeable zones coincide with the nearby channel base of Scioto River at an elevation of 683 feet. Geologic borings show 57 feet of vertically continuous sands and gravels beneath landfill 4 that would allow direct and unimpeded flow from the landfill to the underlying limestone bedrock. Based on additional borings, this zone of high conductivity can be extended to encompass the aquifer beneath the power-plant and the quarry lake south of landfill 4.

Considering the extent, proximity to surface water, and high hydraulic conductivity of these deposits, it is highly probable that recharge to the aquifer in this area is occurring where intervening clays and tills are not present and the surface alluvium has been removed. The recharge may be originating from Scioto River, landfill 4, the quarry lake, or a combination of these three sources. The effect of the recharge would be to retard cone advancement and create a ground-water mound near the sewage-treatment plant, landfill 4, and the adjacent quarry lake. Drillers' logs of wells FR-254 and FR-255, southeast of landfill 4, also indicate high-conductivity zones that would facilitate recharge from the intervening quarry lake or Scioto River.

Other irregularities in the water-level surface may be caused by the additive effect of water users throughout the study area. Figure 7 shows the decline of water levels for the 3-year period between August 1979 and August 1982. All major ground-water withdrawals are ultimately discharged to Scioto River within the study area by way of Scioto Big Run, the sewage treatment plant, and several discharge pipes near FR-255 and FR-268.

Comparison of water-level and log data shows that refuse in landfill 4 and part of the river levee is beneath the water table. During the study, the water table varied from 1 to 5 feet above the base of the refuse near well FR-256. In landfill 4 near wells FR-259 and FR-261, the water table varied from 5 feet below to 8 feet above the base of the refuse.

Most water levels in the study area have declined steadily. The decline is greatest west of State Route 104 between Interstate 270 and Frank Road. In this area, ground-water pumping is the primary control on water levels. Aquifer response to seasonal recharge is varied (fig. 8). Some wells (such as FR-201) show no reaction at all, whereas other wells (such as FR-224) indicate a reduction in the rate of water-level decline. In wells where the hydrograph indicates a response to recharge (such as FR-227), the yearly maximum water level is consistently lower than for previous years. Historic water-level data (Emcon Associates, 1975) indicate that ground-water levels in 1967 were 680 feet above sea level in the vicinity of landfill 5 and State Route 104. In August 1982, water levels for the same location were 610 to 620 feet above sea level--a decline of 60 to 70 feet.

Surface Water

The study area is drained by Scioto Big Run and Scioto River. A gaging station designated FR-266 (shown as SR3 on fig. 9) is located on Scioto River (fig. 9) downstream of the sewage treatment plant. Scioto River is regulated by a series of reservoirs located 10.4, 20.4, and 35 miles upstream from the gaging station.

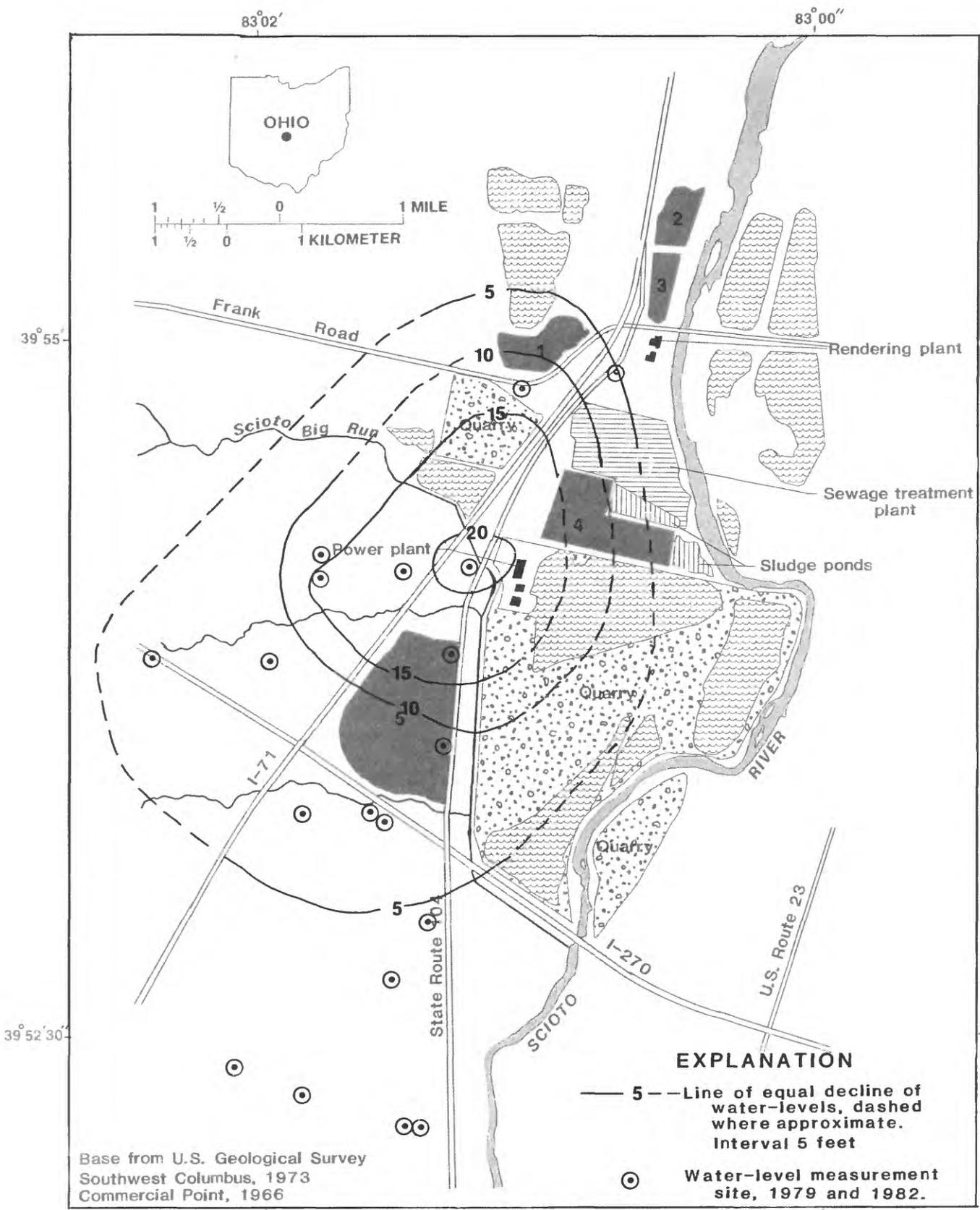


Figure 7.--Decline of water-levels in study area from August 1979 through August 1982.

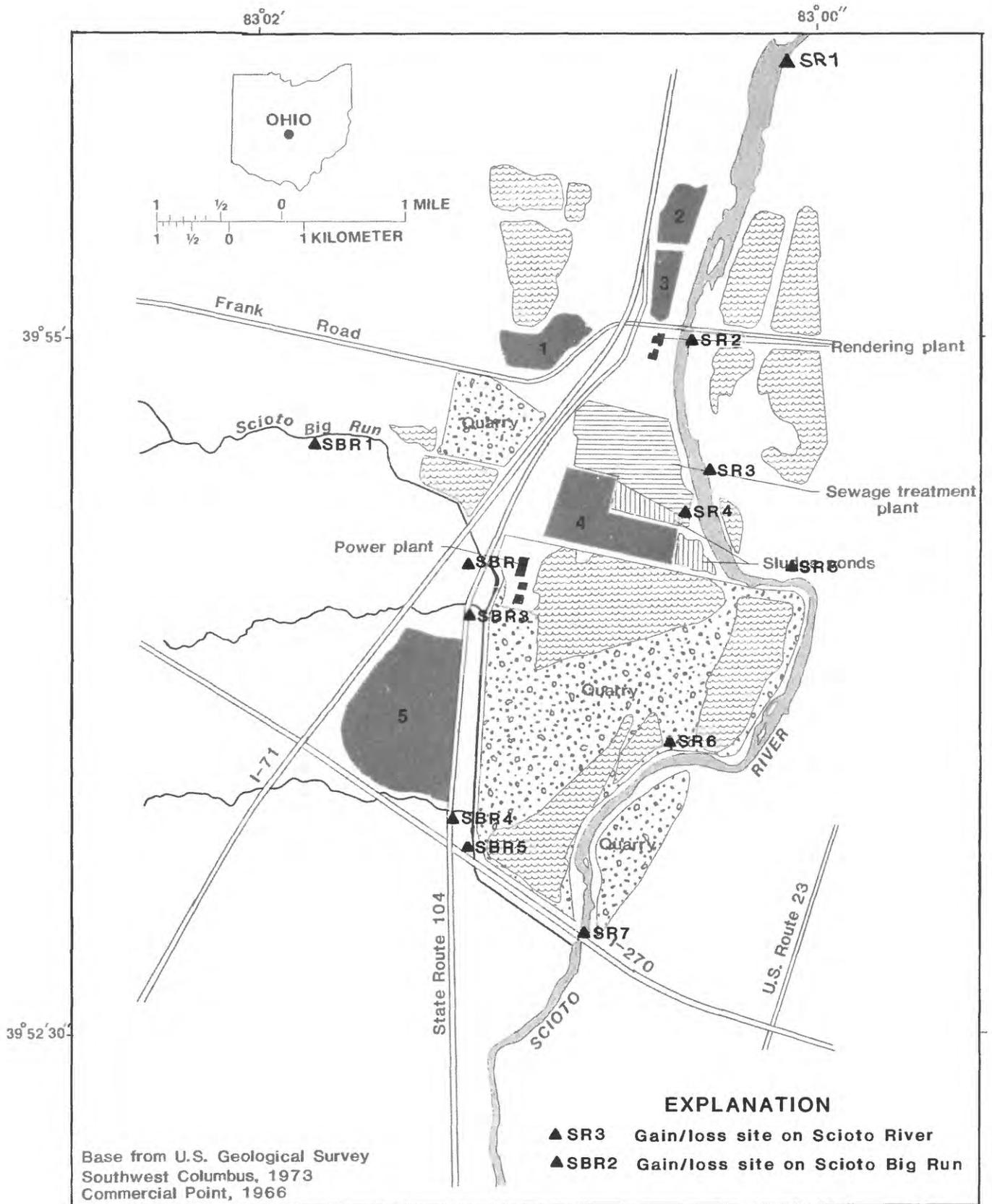


Figure 9.--Map showing location of gain/loss sites on Scioto River and Scioto Big Run.

A gain/loss study was done on Scioto River in October 1982. The flow duration at Scioto River at the start of the study was 90 percent (1950-78 period of record). During the study, there were no withdrawals from the river between stations SR1 and SR7 (fig. 9). The only artificial inflow was from the treatment-plant outlet SR4. The low-water control for the stream gage SR3 is a rock riffle located at SR5, and discharge from the treatment-plant outlet is included in the gage record at SR3.

Measurements made at stations SR1 (36 ft³/s) and SR2 (44 ft³/s) indicate that the river gained 8 ft³/s of flow in this segment, which is adjacent to landfills 2 and 3 and not affected by treatment-plant discharge. An analysis of gain/loss between stations SR2 and SR7 was difficult because inflow from the sewage treatment plant was variable (70 to 126 ft³/s) during the study. In addition, long time of travel because of low-flow conditions made prediction of the downstream advancement of flow from the treatment plant difficult. Nevertheless, on the basis of travel-time data (Janet Hren, U.S. Geological Survey, written commun., 1981) and the variation in treatment-plant outflow, the minimum net loss from stream to aquifer in segment SR2/SR7 (3.3 miles long) is approximately 6 ft³/s.

When aquifer head is lowered beneath the base of a stream, the volume of leakage becomes a function of head in the stream and streambed conductivity and area. Model simulation showed a 10-ft³/s loss for a 3.28-mile segment just south of SR7 in which aquifer head was lowered beneath the base of the streambed during simulated pumpage (A. C. Razem, U.S. Geological Survey, oral commun., 1984). Presuming the streambed area and conductivity of the simulated segment and SR2/SR7 to be similar, a 6-ft³/s loss for SR2/SR7 is a realistic estimate.

Several measurements made simultaneously determined the amount of streamflow that was contributed to Scioto River by the sewage-treatment plant. A comparison of flows at stations SR1, SR4, and SR5 indicates that treated effluent contributed about 70 percent of total flow in the stream at the time of measurement:

<u>Station</u>	<u>Discharge (in ft³/s)</u>	<u>Source of data</u>
SR1	36	Discharge measurement
SR4	80	Treatment-plant flowmeter
SR5	115	Gage height and flow rating

In 1982, average daily discharge from the treatment plant was 124 ft³/s, whereas the median daily discharge (1950 to 1978) at the gaging station (SR3) was 450 ft³/s.

Large variations in the ratio of treated effluent to total streamflow occur throughout the year, primarily because of local weather conditions and their effect on runoff (daily effluent discharge remains relatively constant). The ratio is highest during the summer months when natural streamflow is very low. It is presumed that the high ratio during summer months has a significant effect on low-flow characteristics and water quality of Scioto River.

Scioto Big Run, which drains the western part of the study area, receives most of its flow from a large quarry lake located just west of I-71. The levee between the lake and the stream has been breached and allows the lake to flow into the stream. Upstream of the breach, the channel is dry and has no natural flow except for periods of heavy precipitation and spring runoff.

A gain/loss study was conducted during low-flow conditions on a small section of Scioto Big Run in October 1982 at stations SBR1, SBR2, SBR3, SBR4, and SBR5 (fig. 9). The resulting measurements were:

<u>Station</u>	<u>Discharge (in ft³/s)</u>
SBR1	0 (channel dry)
SBR2	10.2
SBR3	0
SBR4	0
SBR5	9.60

The data show that flow originates between stations SBR1 and SBR2, and that the segment between SBR2 and SBR5 is losing 0.60 ft³/s to the the aquifer. An analysis of error on the measurements indicates the loss could vary from a maximum of 1.11 ft³/s to a minimum of 0.40 ft³/s.

Ground Water/Surface-Water Relationships

Figure 10 illustrates the relationship among precipitation, streamflow, and water levels in the aquifer. Well FR-263 is completed in the outwash deposits 500 feet east of Scioto River. Well FR-264 is completed in the underlying limestone 2,500 feet west of the river (fig. 3). Both wells are approximately 1.5 miles from the river gage.

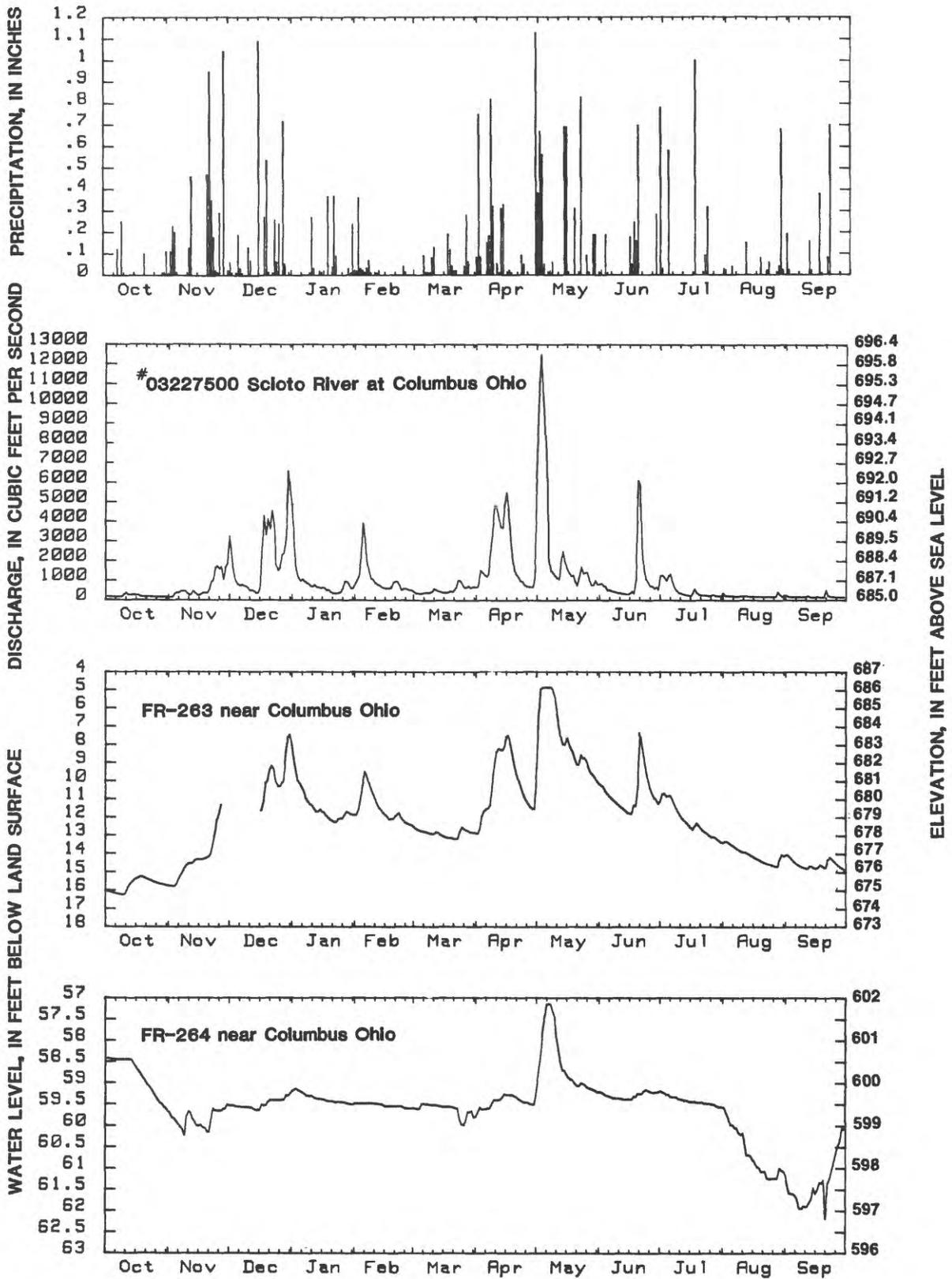


Figure 10.—Hydrographs showing relationship between water levels in wells FR-263 and FR-264, discharge of Scioto River, and precipitation for the 1983 water year.

Graphs of precipitation, stage of Scioto River, and water level in well FR-263 are very similar in shape. The bed of the river is composed of cobbles and gravel in a matrix of sand and silt. The hydrograph of FR-263 shows relatively instantaneous response to even a small rise in stage of Scioto River, perhaps reflecting the permeable nature of the riverbed.

The reaction of FR-264 to river stage is much more subdued due to horizontal and vertical distance from the river, effects of ground-water withdrawal, or a combination of both. The elevation of water in well FR-264 is approximately 80 feet lower than the mean pool elevation of Scioto River due to dewatering in the vicinity of the well. The water level in the quarry is maintained by pumping at an elevation of approximately 565 feet.

Although the reaction of FR-264 is somewhat masked, there are certain similarities between its hydrograph and the other graphs. The rising and falling trends exhibited by the river and FR-263 appear in the record for FR-264, but in less detail. Events that are distinctive, such as the storm of late April and early May, are shown by all three hydrographs. This suggests that a hydraulic connection exists between the stream, glacial deposits, and underlying limestone. It is probable that water-level fluctuations in FR-264 are a complex function of precipitation and river stage superimposed upon deeper regional flow and further modified by dewatering. Water levels also may be affected by leakage from Scioto Big Run.

The ground-water and surface-water data presented indicate that stream-aquifer relations are characterized by leakage from Scioto Big Run and Scioto River to the underlying glacial deposits. Figure 10 shows that water-level elevation in the recorder wells is consistently below the channel base of Scioto River. Comparison of mean pool and streambed elevations for Scioto River with ground-water-level contours indicate that almost the entire study reach of the stream is losing water to the underlying aquifer. Only in the vicinity of FR-256, downgradient of landfill 2, do hydraulic gradients indicate ground-water discharge into Scioto River.

WATER AND SEDIMENT QUALITY

Water quality of the aquifer, Scioto River, and Scioto Big Run was evaluated from 37 water-quality samples--34 from ground-water sites and 3 from surface-water sites (fig. 11). To provide continuity and to detect changes in water quality, wells that were sampled previously (de Roche and Razem, 1981) also were used in this study. Table 3 presents results of analyses of ground water and surface water.

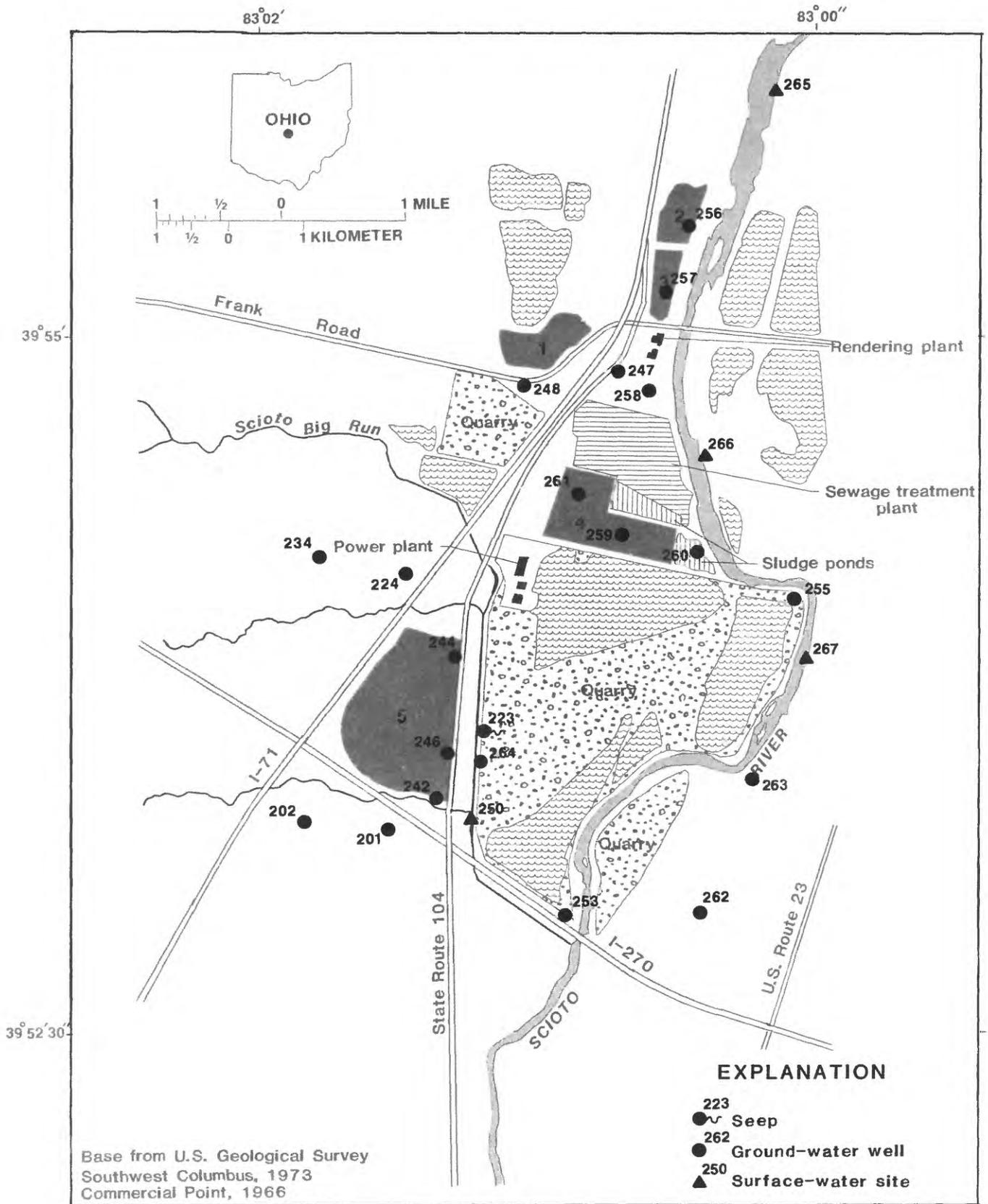


Figure 11.--Sites at which water-quality and/or sediment-quality data were obtained. (The county code prefix, FR-, has been deleted from site numbers.)

Table 3.--Water-quality analyses of ground water and surface water in southern Franklin County, Ohio

[$\mu\text{s}/\text{cm}$, microsiemens per centimeter at 25°C; mg/L, milligrams per liter; ND, not detected; $\mu\text{g}/\text{L}$, micrograms per liter. A dash indicates "data not obtained" or "not applicable."]]

Local number	Date of sample	Specific conductance, field (us/cm)	pH, field (units)	Water temperature (°C)	Biochemical oxygen demand (mg/L)	Chemical oxygen demand (mg/L)	MBAS, total (mg/L)	Organic carbon, dissolved (mg/L) as C	Organic carbon suspended (mg/L) as C	Bicarbonate field (mg/L as HCO ₃) ¹	Alkalinity, field (mg/L as CaCO ₃)	Hardness (mg/L as CaCO ₃)
Wells upgradient of landfills ("up")												
201	4-09-82	860	7.1	12.0	ND	12	ND	1.3	0.3	440	361	430
202	4-09-82	901	6.8	11.5	ND	25	ND	1.1	.2	400	328	430
224	4-08-82	730	7.0	11.0	ND	45	ND	1.0	.1	320	270	270
234	4-08-82	764	7.1	12.5	ND	47	ND	.5	.1	410	336	330
253	6-30-82	690	7.1	8.4	ND	42	.02	2.5	.2	270	221	330
255	6-29-82	775	7.2	11.0	.2	34	.03	2.7	.1	300	246	350
262	7-01-82	744	7.1	11.5	ND	48	ND	.9	.1	380	312	380
263	7-01-82	811	6.9	12.5	ND	150	ND	1.5	1.2	348	285	430
Wells downgradient of landfills ("down")												
242	4-13-82	1,530	6.3	13.0	ND	ND	.1	1.1	.6	520	427	560
242	7-27-83	1,530	6.5	12.5	ND	ND	.04	1.8	.5	480	394	560
244	4-13-82	801	7.0	13.5	ND	ND	ND	.4	.1	340	279	330
244	7-27-83	931	6.8	15.0	ND	15	.02	2.0	.4	320	262	400
246	4-12-82	1,020	6.7	12.5	ND	ND	ND	1.6	.1	590	484	510
247	4-13-82	2,710	7.2	17.0	ND	73	.2	5.7	.1	700	574	560
248	4-07-82	771	7.4	12.5	ND	23	.1	3.1	.2	360	295	320
260	6-29-82	1,100	6.9	15.0	ND	50	.08	6.8	.2	501	411	390
260	7-27-83	915	7.0	14.5	.3	43	.08	5.3	.2	420	344	290
264	11-08-82	1,510	6.7	12.5	12	11	.04	6.5	.1	650	533	680
Wells penetrating refuse ("in")												
256	6-28-82	1,950	6.9	18.0	8.5	120	.20	36	.1	950	779	460
256	7-26-83	1,520	6.8	17.0	4.2	73	.13	21	.1	790	648	440
257	6-28-82	1,240	6.9	16.0	.9	13	.07	12	3.0	844	692	530
257	1-26-83	1,450	6.7	14.0	2.0	97	.15	12	.4	900	738	530
257	7-26-83	1,530	6.6	15.5	2.2	50	.08	12	.4	820	672	620
258	6-23-82	1,320	7.1	17.0	.4	35	.03	4.5	4.0	640	525	510
258	7-26-83	954	6.7	15.5	.2	16	.02	3.9	4.3	520	426	380
259	6-30-82	1,640	6.7	17.0	ND	63	.07	6.3	.4	484	397	580
261	7-01-82	18,400	7.7	22.5	67	2,800	2.4	420	24	10,400	8,330	550
Seep and surface-water sites												
223	4-12-82	920	7.3	12.5	ND	17	ND	1.3	.2	440	361	470
250	11-09-82	935	--	12.0	.4	ND	.04	3.4	.5	390	320	430
266	10-19-82	724	7.6	18.0	3.2	68	.21	--	--	180	148	250
Ohio EPA drinking water standards ²												
Laboratory detection limit		--	7.0-10.5	--	--	--	.5	--	--	--	--	--

Table 3.--Water-quality analyses of ground water and surface water in southern Franklin County, Ohio--Continued

Local number	Date of sample	Non-carbonate hardness (mg/L)	Carbon dioxide, dis-solved (mg/L as CO ₂)	Hydrogen sulfide, dis-solved (mg/L as H ₂ S)	Calcium, dis-solved (mg/L as Ca)	Magnesium, dis-solved (mg/L as Mg)	Sodium, dis-solved (mg/L as Na)	Potassium, dis-solved (mg/L as K)	Chloride, dis-solved (mg/L as Cl)	Fluoride, dis-solved (mg/L as F)	Sulfate, dis-solved (mg/L as SO ₄)	Silica, dis-solved (mg/L as SiO ₂)	phenol, total (µg/L)
Wells upgradient of landfills ("up")													
201	4-09-82	70	56	ND	100	42	27	2.1	3.6	1.6	200	14	ND
202	4-09-82	100	101	.3	100	43	28	2.4	2.3	1.8	220	11	1
224	4-08-82	10	51	ND	71	23	45	3.0	60	3	81	11	ND
234	4-08-82	0	52	ND	73	35	18	1.8	27	.8	97	9.2	ND
253	6-30-82	110	34	ND	94	23	22	2.5	35	.5	120	7.3	ND
255	6-29-82	100	30	ND	98	25	29	4.0	39	.4	140	7.3	ND
262	7-01-82	70	48	ND	100	32	7.9	.9	41	.2	75	9.9	ND
263	7-01-82	140	70	ND	110	37	8.9	2.0	35	.8	110	16	ND
Wells downgradient of landfills ("down")													
242	4-13-82	130	414	ND	160	36	78	3.1	110	.2	100	16	ND
242	7-27-83	170	241	ND	150	46	110	2.9	240	.8	130	14	ND
244	4-13-82	51	54	ND	89	26	51	3.1	67	.2	74	10	1
244	7-27-83	140	81	ND	110	30	41	3.8	91	.2	130	9.6	ND
246	4-12-82	25	187	ND	140	41	32	2.6	18	1.0	190	16	1
247	4-13-82	0	70	ND	140	51	380	15	520	.3	82	11	1
248	4-07-82	24	23	ND	73	33	43	2.5	36	.8	100	11	ND
260	6-29-82	0	100	ND	98	36	55	13	64	.6	38	17	ND
260	1-27-83	0	67	ND	73	27	44	10	68	.8	72	17	ND
264	11-08-82	150	206	.5	190	50	57	3.1	93	.6	180	15	ND
Wells penetrating refuse ("in")													
256	6-28-82	0	190	.5	72	67	260	49	270	.4	16	21	3
256	7-26-83	0	199	ND	75	62	84	34	130	.4	48	21	1
257	6-28-82	17	124	.5	100	67	48	11	73	.5	96	12	2
257	1-26-83	0	285	.7	120	55	52	22	76	.5	33	17	ND
257	7-26-83	0	327	.7	130	72	61	16	81	.6	140	13	ND
258	6-23-82	0	81	ND	130	46	86	14	130	.5	170	13	1
258	7-26-83	0	165	ND	96	34	53	8.3	42	.6	110	13	ND
259	6-30-82	190	153	.7	150	51	57	33	90	.5	380	17	5
261	7-01-82	0	330	26	7	130	1400	1600	1800	.8	52	7.3	130
Seep and surface-water sites													
223	4-12-82	110	35	ND	120	41	24	2.4	37	.4	190	12	ND
250	11-09-82	140	ND	ND	100	43	46	4.0	70	.3	130	7.6	ND
266	10-19-82	100	7.2	ND	64	22	56	7.0	69	1.0	130	5.6	ND
Ohio EPA drinking-water standards ²													
Laboratory detection limit													
		--	--	--	--	--	--	--	250	--	250	--	1
		--	--	.1	--	--	--	--	--	--	--	--	1

Table 3.--Water-quality analyses of ground water and surface water in southern Franklin County, Ohio--Continued

Local number	Date of sample	Nitro- gen, NO ₂ +NO ₃ , dis- solved (mg/L as N)	Nitro- gen, NH ₄ , dis- solved (mg/L as N)	Nitro- gen, organic, dis- solved (mg/L as N)	Phos- phorus, dis- solved (mg/L as P)	Arsenic, dis- solved (ug/L as As)	Cadmium, dis- solved (ug/L as Cd)	Chrom- ium, hexa- valent (ug/L as Cr)	Copper, dis- solved (ug/L as Cu)	Cyanide, total (mg/L as Cn)	Iron, dis- solved (ug/L as Fe)	Lead, dis- solved (ug/L as Pb)
201	4-09-82	0.10	0.61	ND	0.01	7	ND	8	1	ND	1,600	1
202	4-09-82	.10	.74	ND	.01	1	ND	ND	1	ND	1,300	3
224	4-08-82	.10	.06	.06	ND	1	ND	ND	1	ND	1,880	3
234	4-08-82	.10	.38	ND	.04	3	ND	ND	ND	ND	1,500	1
253	6-30-82	ND	.50	.10	.20	2	ND	ND	6	ND	220	ND
255	6-29-82	ND	.35	.25	.06	1	ND	ND	6	ND	4,400	ND
262	7-01-82	ND	.05	2.0	ND	2	ND	ND	3	ND	110	ND
263	7-01-82	ND	.17	5.0	.04	2	ND	ND	3	ND	2,000	45
Wells downgradient of landfills ("down")												
242	4-13-82	ND	.48	.05	ND	2	ND	ND	2	ND	800	7
242	7-27-83	ND	.49	.01	ND	6	2	ND	4	ND	3,700	5
244	4-13-82	ND	.03	---	ND	2	ND	ND	4	ND	410	1
244	7-27-83	ND	.22	.18	ND	3	ND	ND	5	ND	220	3
246	4-12-82	.1	.81	ND	.01	3	ND	ND	1	ND	3,200	1
247	4-13-82	ND	.19	ND	ND	1	1	ND	2	ND	580	1
248	4-07-82	.10	.15	.06	.01	1	ND	ND	8	ND	2,000	4
260	6-29-82	ND	23	ND	ND	2	ND	ND	3	ND	1,600	2
260	1-27-83	ND	19	.7	ND	1	1	ND	2	ND	1,300	2
264	11-08-82	ND	.55	.45	.01	3	ND	ND	1	ND	3,100	4
Wells penetrating refuse ("in")												
256	6-28-82	ND	22	ND	.02	11	ND	ND	16	ND	6,200	ND
256	7-26-83	ND	19	2.0	.02	9	2	ND	170	ND	7,600	8
257	6-28-82	ND	3.7	.5	.02	3	ND	ND	11	ND	430	ND
257	1-26-83	---	---	---	---	1	ND	ND	1	ND	430	1
257	7-26-83	ND	11	1.0	.04	1	2	ND	7	ND	260	3
258	6-23-82	3.7	3.7	1.2	ND	3	ND	ND	2	ND	370	5
258	7-26-83	ND	2.1	.60	ND	4	2	ND	3	ND	410	1
259	6-30-82	ND	41	ND	.01	11	ND	ND	6	ND	16,000	2
261	7-01-82	.54	1,600	ND	.87	67	ND	ND	52	.19	4,000	28
Seep and surface-water sites												
223	4-12-82	.10	.12	.08	ND	1	ND	ND	1	ND	470	2
250	11-09-82	.22	.03	.37	.03	1	ND	ND	5	ND	26	5
266	10-19-82	4.2	2.5	.90	2.8	2	ND	ND	7	.01	19	5
Ohio EPA drinking-water standards ²												
		---	---	---	---	50	10	50	1,000	---	300	50
Laboratory detection limit												
		.1	---	.1	.1	1	1	1	1	.01	---	1

Table 3.--Water-quality records for ground water and surface water in southern Franklin County, Ohio--Continued

Local number	Date of sample	Manganese, dissolved (µg/L as Mn)	Mercury, dissolved (µg/L as Hg)	Mercury, total (µg/L as Hg)	Nickel, dissolved (µg/L as Ni)	Zinc, dissolved (µg/L as Zn)	Dissolved solids, sum of constituents (mg/L)	Dissolved solids, residue at 180 °C (mg/L)
Wells upgradient of landfills ("up")								
201	4-09-82	35	--	0.1	3	36	610	637
202	4-09-82	11	--	.1	2	5	610	661
224	4-08-82	75	--	.1	ND	82	450	451
234	4-08-82	44	--	.1	3	9	470	494
253	6-30-82	51	--	.1	ND	5	440	507
255	6-29-82	95	--	ND	ND	ND	500	518
262	7-01-82	170	--	ND	ND	ND	450	558
263	7-01-82	72	--	.2	ND	16	490	592
Wells downgradient of landfills ("down")								
242	4-13-82	100	--	.1	11	21	770	1,320
242	7-27-83	190	.2	.4	8	16	930	1,230
244	4-13-82	170	--	ND	2	8	490	494
244	7-27-83	64	.2	.1	5	6	570	740
246	4-12-82	390	--	.1	3	29	730	765
247	4-13-82	720	--	ND	9	10	1,600	1,970
248	4-07-82	69	--	.1	1	14	480	490
260	6-29-83	17	--	ND	1	6	600	568
260	7-27-83	18	.2	.3	5	6	540	600
264	11-08-82	340	ND	--	ND	ND	910	945
Wells penetrating refuse ("in")								
256	6-28-82	50	--	.1	ND	30	1,300	1,230
256	7-26-83	25	.2	.3	18	8	880	1,000
257	6-28-82	79	--	.4	8	ND	720	794
257	1-26-83	120	ND	--	9	ND	820	796
257	7-26-83	100	.2	.2	6	ND	930	1,100
258	6-23-83	640	--	.6	7	21	910	948
258	7-26-82	450	ND	.2	7	8	620	687
259	6-30-82	67	--	ND	2	ND	1,100	1,090
261	7-01-82	20	--	.3	490	350	12,000	7,150
Seep and surface-water sites								
223	4-12-82	93	--	.1	2	6	650	675
250	11-09-82	30	.1	--	2	121	580	514
266	10-19-82	27	--	.4	12	200	450	462
Ohio EPA drinking-water standards ²		50	2	2	--	5,000	500	500
Laboratory detection limit		--	.1	.1	1	4	--	--

¹Fixed-endpoint titration

²Ohio Environmental Protection Agency (1978, p. 36-7)

Ground Water

Well-Position Classification

For purposes of discussion and statistical analysis, all wells sampled to determine water quality were assigned a position of "up," "down," or "in." The assignment of position was based strictly upon the location of the well with respect to the landfills and ground-water flow system (fig. 6), and whether refuse was encountered during drilling. The three well-position groups are defined as follows:

- (1) up - wells located upgradient from any landfill in the project area.
- (2) down - wells located downgradient from any landfill in the study area.
- (3) in - wells penetrating a landfill or refuse.

The seep, FR-223, was not assigned a position based upon its relationship in the ground-water flow system (fig. 4). Flow from the seep is considered to originate from precipitation, return flow of process waters (truck washing, dust control), and pipe leakage in the dewatering system. These waters discharge to the seep through a series of limestone and outwash benches leading downward into the main quarry pit.

The group "up" consists of wells FR-201, FR-202, FR-224, FR-234, FR-253, FR-255, FR-262, and FR-263 (fig. 12). Of this group, wells FR-201, FR-202, FR-224, and FR-234 were used in a previous study (de Roche and Razem, 1981) to reflect ambient water quality in the landfill area. The group as a whole is composed of wells presumed not to be affected by waste disposal.

The group "down" consists of wells FR-242, FR-244, FR-246, FR-247, FR-248, FR-260, and FR-264. Of this group, FR-242 and FR-247 were previously shown to have significant departures from ambient water-quality that may have indicated contamination by leachate (de Roche and Razem, 1981). This group, as a whole, is presumed to be within the influence of waste-disposal sites.

The group "in" consists of wells FR-256, FR-257, FR-258, FR-259, and FR-261. Initially, these wells were designed and located specifically to obtain water-quality and water-level information in data-deficient areas. Before installation, the composition of the Scioto River levee was not apparent. The wells in this group penetrate 12 to 30 feet of refuse.

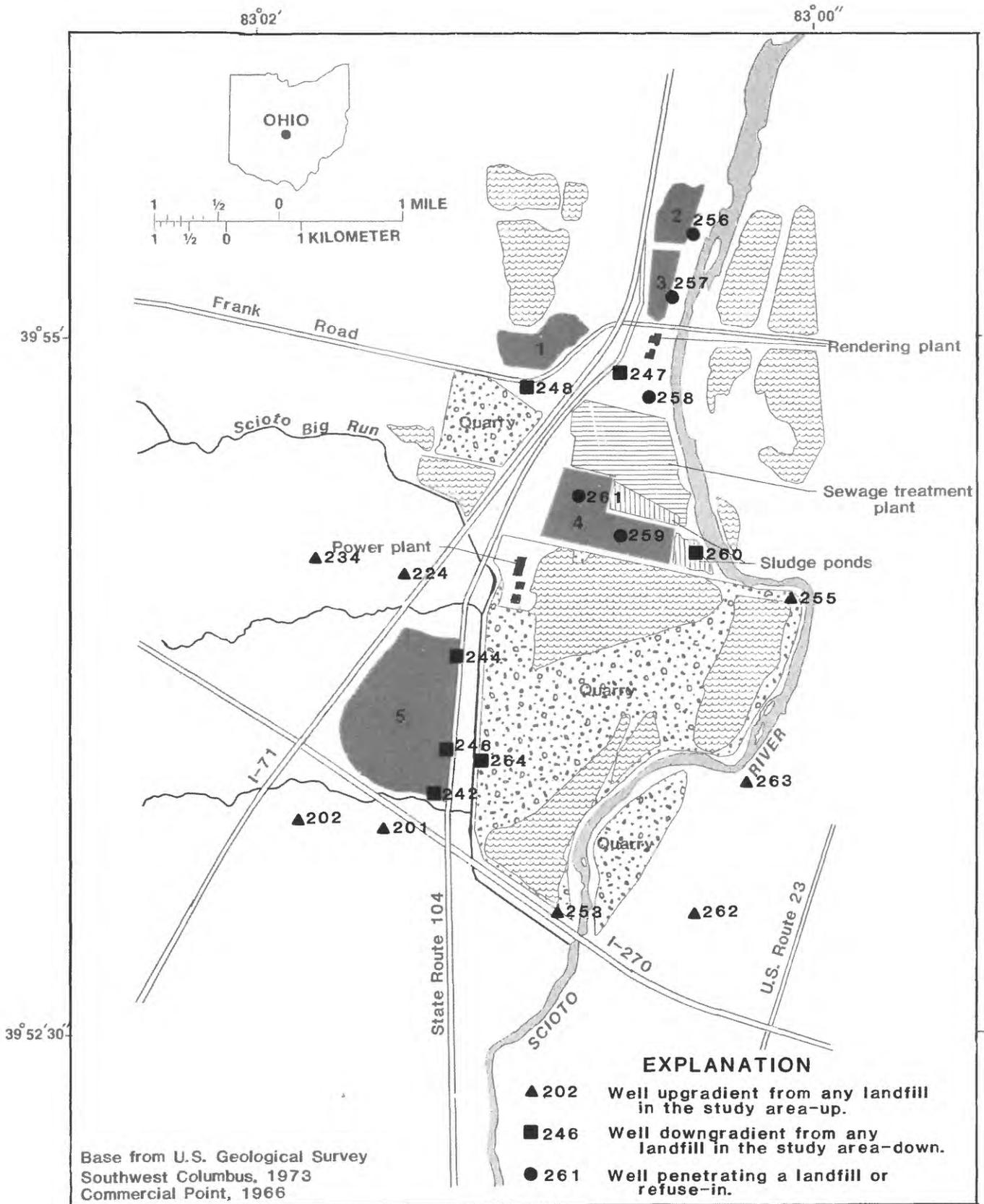


Figure 12.--Map showing location of wells sampled and their assigned position group.

Inorganic Constituents

Upgradient ("up") wells

There has been virtually no change in the ambient water quality as defined by control wells in a previous study (de Roche and Razem, 1981). Ambient ground-water quality in the study area as defined by position group "up" is a very hard, calcium bicarbonate-type water with a median pH of 7.1 (table 4). Specific conductance ranges from 690 to 901 microsiemens per centimeter at 25°C ($\mu\text{S}/\text{cm}$) with a median value of 770 $\mu\text{S}/\text{cm}$. Total dissolved-solids concentrations range from 451 to 651 mg/L, with a median of 538 mg/L.

The most abundant anions are bicarbonate and sulfate, with median concentrations of 364 mg/L and 115 mg/L, respectively. The major cations are calcium and magnesium, with median concentrations of 99 mg/L and 34 mg/L, respectively. Median concentrations of sodium and chloride are 24 mg/L and 35 mg/L, respectively, and concentrations of potassium and fluoride are less than 4 mg/L.

The combined concentration of all nitrogen species is generally less than 1 mg/L, except for water from wells FR-262 and FR-263, which contain 2.0 mg/L and 5.0 mg/L, respectively, of organic nitrogen. Nitrate and nitrite nitrogen are present in all upgradient wells except for FR-253, FR-255, FR-262, and FR-263, which are adjacent to and receive recharge from Scioto River. Generally, ammonia is the major nitrogen species; its mean concentration is 0.58 mg/L.

Chemical oxygen demand (COD) ranges from 12 to 150 mg/L, and has a median concentration of 44 mg/L. Concentrations are highest in water from wells near Scioto River and in areas where drawdown in the aquifer has been greatest. Biochemical oxygen demand (BOD) was detected in one upgradient well at a concentration of 0.2 mg/L.

Methane was not detected in any "up"-position wells. Hydrogen sulfide was present in one well at a concentration of 0.3 mg/L. Levels of carbon dioxide range from 81 to 330 mg/L with a median concentration of 190 mg/L.

Concentrations of iron (110 to 4,400 $\mu\text{g}/\text{L}$) and manganese (11 to 170 $\mu\text{g}/\text{L}$) routinely exceed Ohio Environmental Protection Agency (OEPA) drinking-water standards (1978) of 300 and 50 $\mu\text{g}/\text{L}$, respectively. Trace metals arsenic, copper, lead, nickel, and zinc were present in concentrations generally less than 5 $\mu\text{g}/\text{L}$. Cadmium and cyanide were not detected in any "up"-position wells.

Table 4.--Statistical summary of ground-water-quality data, upgradient-position ("up") category

Constituents or properties	Unit	Number of observations	Mean	Median	Minimum value	Maximum value
Specific conductance	µS/cm	8	784	770	690	901
pH		8	7	7.1	6.8	7.2
Carbon dioxide, dissolved	mg/L	8	55.2	51.5	30	101
Hardness, as CaCO ₃	mg/L	8	369	365	270	430
Hardness, noncarbonate	mg/L	8	75	85	0	140
Solids, residue at 180 deg. C, dissolved	mg/L	8	552	538	451	661
Solids, sum of constituents, dissolved	mg/L	8	502	480	440	610
Calcium, dissolved	mg/L	8	94	99	71	110
Magnesium, dissolved	mg/L	8	32	34	23	43
Sodium, dissolved	mg/L	8	23	24	7.9	45
Potassium, dissolved	mg/L	8	2.3	2.2	.9	4.0
Bicarbonate	mg/L	8	358	364	270	440
Chloride, dissolved	mg/L	8	30	35	2.3	60
Sulfate, as SO ₄ , dissolved	mg/L	8	130	115	75	220
Fluoride, dissolved	mg/L	8	.80	.65	.2	1.80
Silica, dissolved	mg/L	8	11	10	7.3	16
Nitrogen, organic, as N, dissolved	mg/L	8	.93	.08	0	5.0
Nitrogen, ammonia, as N, dissolved	mg/L	8	.36	.58	.05	0.74
Arsenic, dissolved	µg/L	8	2.4	2	1	7.0
Copper, dissolved	µg/L	8	2.8	2	1	6.0
Iron, dissolved	µg/L	8	1500	1400	110	4400
Lead, dissolved	µg/L	8	7	1	1	45
Manganese, dissolved	µg/L	8	69	62	11	170
Mercury, total recoverable	µg/L	8	.11	.1	.10	.20
Nickel, dissolved	µg/L	8	1.6	1	1	3.0
Zinc, dissolved	µg/L	8	20	7	4.0	82
Oxygen demand, chemical (high level)	mg/L	8	50	44	12	150
Carbon, organic, dissolved	mg/L	8	1.4	1.2	.5	2.7
Carbon, organic, suspended total	mg/L	8	.29	.2	.10	1.2
Methylene blue active substance	mg/L	8	.28	.07	.01	1.0

Downgradient ("down") wells

Water from wells classified "down" is very hard, has a wide range of ionic water types, and has a median pH of 6.8 (table 5). Specific conductance ranges from 771 to 2,710 $\mu\text{S}/\text{cm}$ with a median value of 1,060 $\mu\text{S}/\text{cm}$. Total dissolved solids concentrations range from 490 to 1,970 mg/L, with a median of 752 mg/L.

The major anions are bicarbonate and sulfate, with median concentrations of 490 mg/L and 100 mg/L, respectively. The most abundant cations are calcium, with a median concentration of 123 mg/L, and sodium, with a median concentration of 53 mg/L. Chloride concentrations show a wide range (18 to 520 mg/L), with a median value of 80 mg/L. Magnesium has a median concentration of 36 mg/L, and concentrations of potassium range from 2.5 to 15 mg/L.

The dominant nitrogen species in this group is ammonia, which ranges in concentration from 0.03 to 23 mg/L with a median value of 0.52 mg/L. Nitrate plus nitrite was detected only in FR-248 at a concentration of 0.1 mg/L. Organic nitrogen has a median concentration of 0.05 mg/L.

Levels of COD in water from "down"-position wells range from 10 to 73 mg/L, with a median concentration of 13 mg/L. BOD was detected at concentrations of 12 mg/L in well FR-246 and 0.3 mg/L in well FR-260. No other wells in this group had detectable amounts of BOD.

Methane gas was detected in well FR-260 at concentrations >1,000 ppm. Hydrogen sulfide was detected only in well FR-264 at a concentration of 3.5 mg/L. Carbon dioxide concentrations range from 23 to 414 mg/L, with a median of 90.5 mg/L.

Concentrations of iron (220 to 3,700 mg/L) and manganese (17 to 1,000 $\mu\text{g}/\text{L}$) commonly exceed OEPA drinking-water standards. Arsenic, copper, lead, nickel, and zinc were detected in most of the wells in trace amounts. Cyanide was not detected in any wells, and cadmium was detected in wells FR-242, FR-247, and FR-260 in trace amounts.

Wells penetrating refuse ("in")

Water from wells penetrating refuse has a median hardness of 630 mg/L and a median pH of 6.8 (table 6). These waters show a wide range of ionic water type; specific conductance ranges from 954 to 18,400 $\mu\text{S}/\text{cm}$. Total dissolved solids concentrations range from 687 to 7,150 mg/L, with a median of 1,000 mg/L.

The most abundant anion is bicarbonate, with a median concentration of 715 mg/L. Chloride and sulfate are present in approximately equal amounts, with median concentrations of 90 mg/L and 96 mg/L, respectively. Calcium is the most abundant cation, and ranges from 7 to 150 mg/L, with a median of 100 mg/L.

Table 5.---Statistical summary of ground-water-quality data, downgradient-position ("down") group

Constituents or properties	Unit	Number of observations	Mean	Median	Minimum value	Maximum value
Specific conductance	µS/cm	10	1280	1060	771	2710
pH		10	6.8	6.8	6.3	7.4
Carbon dioxide, dissolved	mg/L	10	144	90.5	23	414
Hardness, as CaCO ₃	mg/L	10	460	455	290	680
Hardness, noncarbonate	mg/L	10	69	38	.00	170
Solids, residue at 180 deg. C, dissolved	mg/L	10	912	752	490.	970
Solids, sum of constituents, dissolved	mg/L	10	762	665	480	1600
Calcium, dissolved	mg/L	10	122	123	73	190
Magnesium, dissolved	mg/L	10	38	36	26	51
Sodium, dissolved	mg/L	10	89	53	32	380
Potassium, dissolved	mg/L	10	5.9	3.1	2.5	15
Bicarbonate	mg/L	10	488	490	320	700
Chloride, dissolved	mg/L	10	130	80	18	520
Sulfate, as SO ₄ , dissolved	mg/L	10	110	100	38	190
Fluoride, dissolved	mg/L	10	.55	.6	.2	1.0
Silica, dissolved	mg/L	10	14	14	9.6	17
Nitrogen, organic, as N, dissolved	mg/L	9	.86	.05	.0	7.0
Nitrogen, ammonia, as N, dissolved	mg/L	10	6.4	.52	.03	23
Arsenic, dissolved	µg/L	10	2.4	2.0	1.0	6.0
Copper, dissolved	µg/L	10	3.2	2.5	1.0	8.0
Iron, dissolved	µg/L	10	1700	1400	220	3700
Lead, dissolved	µg/L	10	3.0	2.5	1.0	7.0
Manganese, dissolved	µg/L	10	207	135	17	720
Mercury, total recoverable	µg/L	9	.16	.10	.10	.40
Nickel, dissolved	µg/L	10	4.6	4.0	1.0	11
Zinc, dissolved	µg/L	10	12	9	4	29
Oxygen demand, chemical (high level)	mg/L	10	26	13	10	73
Carbon, organic, dissolved	mg/L	10	3.4	2.6	.4	6.8
Carbon, organic, suspended total	mg/L	10	.25	.2	.1	.6
Methylene blue active substance	mg/L	10	.08	.08	.01	.20

Table 6.--Statistical summary of ground-water-quality data, in-position ("in") group

Constituents or properties	Unit	Number of observations	Mean	Median	Minimum value	Maximum value
Specific conductance	µS/cm	9	3,330	1,520	954	18,400
pH		9	6.9	6.8	6.6	7.7
Carbon dioxide, dissolved	mg/L	9	206	190	81.0	330
Hardness, as CaCO ₃	mg/L	9	511	530	380	620
Hardness, noncarbonate	mg/L	9	23	.0	.0	190
Solids, residue at 180 deg. C, dissolved	mg/L	9	1,640	1,000	687	7,150
Solids, sum of constituents, dissolved	mg/L	9	2,140	910	620	12,000
Calcium dissolved	mg/L	9	98	100	7.0	150
Magnesium dissolved	mg/L	9	65	62	34	130
Sodium, dissolved	mg/L	9	230	61	48	1,400
Potassium, dissolved	mg/L	9	200	22	8.3	1,600
Bicarbonate	mg/L	9	1,820	820	484	10,400
Chloride, dissolved	mg/L	9	300	90	42	1,800
Sulfate, as SO ₄ , dissolved	mg/L	9	120	96	16	380
Fluoride, dissolved	mg/L	9	.53	.50	.40	.80
Silica, dissolved	mg/L	9	15	13	7.3	21
Nitrogen, Organic, as N, dissolved	mg/L	8	.66	.55	.0	2.0
Nitrogen, Ammonia, as N, dissolved	mg/L	8	210	15	2.1	1,600
Arsenic, dissolved	µg/L	9	12	4.0	1.0	67
Copper, dissolved	µg/L	9	30	7.0	1.0	170
Iron, dissolved	µg/L	9	4,000	430	260	16,000
Lead, dissolved	µg/L	9	5.6	2.0	1.0	28
Manganese, dissolved	µg/L	9	170	79	20	640
Mercury, total recoverable	µg/L	8	.28	.25	.1	.60
Nickel, dissolved	µg/L	9	61	7.0	1.0	490
Zinc, dissolved	µg/L	9	48	8.0	3.0	350
Oxygen demand, chemical (high level)	mg/L	9	360	63	13	2,800
Carbon, organic, dissolved	mg/L	9	59	12	3.9	420
Carbon, organic, suspended total	mg/L	9	4.1	.4	0.10	24
Methylene blue active substance	mg/L	9	.35	.08	.02	2.4

Median levels of magnesium and sodium are approximately equal at 62 mg/L and 61 mg/L, respectively. Potassium ranges from 8.3 to 1,600 mg/L and has a median of 22 mg/L.

Ammonia, which has a median concentration of 19 mg/L and a range in concentrations of 2.1 to 1,600 mg/L, is the most prominent nitrogen species. Levels of ammonia are generally 30 times higher than concentrations in other well-position groups. Low concentrations of nitrate plus nitrite (0.1 to 3.7 mg/L) and organic nitrogen (0.08 to 2.0 mg/L) were observed in several wells.

Levels of COD range from 13 to 2,800 mg/L, with a mean concentration of 63 mg/L. BOD was detected in five "in"-position wells as compared with two "down"-position wells and one "up"-position well. Concentrations of BOD range from 0.2 to 67 mg/L for "in"-position wells.

Methane concentrations exceeding 100 ppm were detected in FR-256, FR-257, and FR-258, and levels greater than 1,000 ppm were detected in wells FR-259 and FR-261. Concentrations of hydrogen sulfide ranging from 0.3 to 26 mg/L were detected in wells FR-257, FR-259, and FR-261. Carbon dioxide concentrations range from 81 to 300 mg/L, with a median of 190 mg/L.

Concentrations of iron differ substantially in this group (from 260 to 16,000 µg/L) and all analyses (except one from FR-257) exceed OEPA drinking-water standards. Concentrations of manganese range from 20 to 640 µg/L. Cyanide was not detected; however, trace amounts of cadmium were found in wells FR-242, FR-256, FR-257, and FR-258. Arsenic, copper, lead, nickel, and zinc were found in all wells in trace amounts.

Organic Constituents

Methylene blue active substances (MBAS), foaming agents found in detergents, were detected in "up"-position wells FR-201, FR-253, and FR-255 at concentrations ranging from 0.02 to 1.0 mg/L. All "down"-position wells except FR-246 contained MBAS, which ranged in concentration from 0.02 to 1.0 mg/L. MBAS were found in all "in"-position wells at concentrations ranging from 0.02 to 2.4 mg/L.

Phenol was found in one upgradient well (FR-202) at a concentration of 1 mg/L. "Down"-position wells, FR-244, FR-246, and FR-247 contained 1 mg/L of phenol. Concentrations of phenol ranging from 1 to 130 mg/L were detected in wells penetrating refuse.

Concentrations of dissolved organic carbon (DOC) in upgradient wells range from 0.1 to 2.0 mg/L with a median of 0.2 mg/L. DOC concentrations for downgradient wells range from 0.4 to 6.8 mg/L with a median of 2.6 mg/L. Wells penetrating refuse show DOC concentrations ranging from 3.9 to 420 mg/L with a median of 12 mg/L.

On the basis of a study to determine background levels of DOC in ground water, Leenheer and others (1974) recommended 5 mg/L as a threshold concentration for DOC in ground water. The 5-mg/L limit, if exceeded, would indicate ground-water contamination by organics. Water from "in"-position wells FR-256, FR-257, FR-258, FR-259, and FR-261 exceed the 5-mg/L threshold limit.

On the basis of dissolved organic carbon (DOC) concentrations exceeding 10 mg/L, three wells were chosen to be tested for organic constituents. Water and sediment from wells FR-256 (36 mg/L DOC) and FR-257 (12 mg/L DOC) were tested for base/neutral- and acid-extractable organic constituents. FR-261 (420 mg/L DOC) was scheduled for testing, however, shifting of refuse within the landfill caused the well casing to warp, thereby preventing access to the well.

Water from wells FR-256 and FR-257 was analyzed for a total of 57 organic constituents. Analysis of water from FR-257 indicates that no base/neutral- or acid-extractable organics were detected. Four organic compounds were detected in the analysis of water from FR-256:

Compound	USEPA designation (see p. v)	Concentration (µg/L)	Origin or use
Diethyl-phthalate	HW PTP	1	Solvent for cellulose esters; vehicle for pesticide sprays; alcohol denaturant.
Di-n-butyl phthalate	HS HW PTP	1	Plasticizing agent; insect repellent.
Isophorone	PTP	5.7	Industrial chemical-solvent/cosolvent for finishes, laquers, resins, pesticides, fats, oils, and gums.
Naphthalene	HS HW PTP	2	Moth repellent; chemical feedstock for compounds used to manufacture dye; used in the manufacture of resins, lampblack, smokeless powder, and celluloid.

These four organic compounds were detected in trace amounts at or near the lower limit of instrumental detection. Low levels of phthalate esters are considered to be widespread in the environment (Mayer and others, 1972) because of their extensive use as plasticizing agents. Phthalate esters may also appear as artifacts in organic analysis because of low-level contamination of items used in the laboratory process. Because of these factors, the organic compounds identified in water from well FR-256 cannot be considered significant in terms of denoting organic contamination.

Aquifer Materials

Aquifer materials from FR-256 and FR-257 were analyzed for 57 base/neutral-extractable and acid-extractable organic constituents. Results of the analysis indicate none of the constituents tested for were present at a detection level of 20 µg/kg.

Surface Water

Inorganic Constituents

For comparison with earlier data on stream-water quality (de Roche and Razem, 1981), Scioto River and Scioto Big Run were each sampled at one site. The water quality of Scioto River at Site FR-266 (fig. 11, table 3) is consistent with past analyses at similar flows. The water quality of Scioto Big Run at station FR-250 (fig. 11, table 3) is consistent with the previous data and closely resembles the ambient ground-water quality in the study area. The close similarity of water quality between the stream and local ground water is not unusual because the entire flow was being generated from the breached quarry lake, which is essentially ground water except for its residence time in the lake.

Organic Constituents

Because the source of streamflow in Scioto Big Run is relatively constant, although artificial, a water sample was analyzed for 57 base/neutral- and acid-extractable organic compounds. Two compounds were identified:

Compound	USEPA designation (see p. v)	Concentration (µg/L)	Origin or use
Napthalene	HS, HW, PTP	2.7	Moth repellent; chemical feedstock for compounds used in the manufacture of dye; used in the manufacture of resins, lampblack, smokeless powder, and celluloid.
di(2-ethylhexyl) phthalate	HW, PTP	31.4	Commercially produced chemical used as a plasticizer for resins and in the manufacture of organic pump fluids.

Di(2-ethylhexyl)phthalate exceeds the recommended criterion of 3 µg/L for protection of freshwater aquatic life (U.S. Environmental Protection Agency, 1976). Low-level environmental occurrence and laboratory contamination may account for part of the total phthalate analyzed. However, the elevated concentration may indicate Scioto Big Run has been affected from a source within the basin.

Streambed Sediments

Inorganic Constituents

Sediment samples were collected from sites FR-265 and FR-267 on Scioto River and site FR-250 on Scioto Big Run. Samples were analyzed for 14 trace elements, 8 of which are designated Priority Toxic Pollutants by the U.S. Environmental Protection Agency. The trace elements analyzed for and their concentrations are as follows:

Constituent	USEPA designation (see p. v)	Concentration (µg/kg)		
		FR-265	FR-267	FR-250
Aluminum	None	450	2300	1900
Arsenic	HS ¹ ,HW,PTP	1	1	4
Boron	None	ND ²	ND	ND
Cadmium	HS ¹ ,HW,PTP	4	5	3
Chromium	HS ¹ ,HW,PTP	20	80	10
Cobalt	HS ¹	10	20	50
Copper	HS ¹ ,HW ¹ ,PTP	48	49	23
Iron	None	4500	7000	6200
Lead	HS ¹ ,HW,PTP	180	180	50
Manganese	None	150	260	380
Mercury	HW ¹ ,HS ¹ ,PTP	ND	ND	ND
Selenium	HW,HWC,PTP	ND	ND	ND
Strontium	None	170	190	120
Zinc	HS ¹ ,PTP ¹	260	720	78

¹Only certain compounds of parent element qualify.

²Not detected.

Many trace metals and their compounds are not soluble in water under relatively neutral pH conditions, as in Scioto River. Concentrations would be expected to decrease in the downstream direction as the metals are removed from the water column by gravity settling and adsorption on silts and clays. However, of the two sites on Scioto River, sediment from the downstream site (FR-267) has consistently higher concentrations of toxic metals than the upstream site, FR-265.

The downstream increase in toxic-metal concentration between sites FR-265 and FR-267 indicates a source of toxic metals may be present in the stream segment between these two stations. Possible sources could be incinerator ash, land spreading of sewage sludge on landfill 4, or treated effluent from the sewage-treatment plant.

Organic Constituents

Streambed sediments were collected at two sites on Scioto River and at one site on Scioto Big Run. Site FR-265 on Scioto River north of landfill 2 (fig. 11) is representative of streambed sediment before entering the study area. Site FR-267, on Scioto River south of well FR-255, receives drainage from the eastern section of the study area including commercial and industrial sites and landfills 1, 2, 3, and 4. Site FR-250 on Scioto Big Run provides drainage for the western section at the study area including landfill 5.

Analysis of sediment from site FR-265 on Scioto River (table 7) indicated that no base/neutral- or acid-extractable organic compounds were present. However, sediment from site FR-267 just downstream contains high concentrations (2,980 to 9,440 $\mu\text{g}/\text{kg}$) of polynuclear aromatic hydrocarbons (PNAs). PNAs in low concentrations are considered to be common to the environment.

The presence of various PNAs at site FR-267 and their high concentration in the sediment relative to site 265 suggests that the source is nearby, upstream, and concentrated. Possible sources found that are capable of generating such high concentrations of PNAs in such a short distance are fallout from an incinerator or ash ponds. There do not appear to be any other sources in this segment of Scioto River that could have generated concentrations of this magnitude.

Concentrations of the PNAs fluoranthene and pyrene (table 7), found in sediment from site FR-250 on Scioto Big Run, are low in comparison to levels at site 267. However, sediment at site 250 contains a wide range of organic compounds (including solvents) not common to the environment. Many compounds that were tentatively identified appear to be byproducts of other organic compounds, and laboratory standards were not available for confirmation. Although identification was only tentative, the varied nature of the chemicals present--and their concentrations--indicate an organic chemical source in the basin of Scioto Big Run. A source of the organic compounds found in the sediment of Scioto Big Run was not determined.

EFFECTS OF LANDFILLS ON WATER QUALITY

The analysis of variance (table 8) shows that there are significant (greater than 98-percent likelihood) water-quality differences between the well-position groups for 12 water-quality variables. Tukey's test was performed on the ranked data and was used to indicate which position groups are different from each other based upon 12 water-quality variables. Table 9 indicates which groups were determined to be different at the 95-percent confidence level, and the water-quality variables that are responsible for the difference. In all variables except for COD, the well position group mean values increase in order of "up" < "down" < "in."

Because of the differing conditions (both in hydrology and waste content) among the landfills in the study area, it was presumed that only water-quality properties and constituents that are collective or aggregate in nature would be significant. However, several constituents that are specifically related to chemical processes within landfills also are significant. These constituents relate to the chemical generation of leachate and the degradation of the leachate as it moves away from the landfills.

Table 7.--Records of organic compounds recovered from streambed sediment of Scioto River and Scioto Big Run, and their origin or use

[For explanation of EPA designation, see p. v. ND indicates the substance was not detected.]

Organic compound	USEPA designation	Total concentration at each site, in micrograms per kilogram		Origin or use of compound ¹
		FR-265	FR-267 FR-250	
Fluoranthene	HW, PTP	ND	3990	270
Pyrene	HW, PTP	ND	6760	220
Benzo(a)anthracene	HW, PTP	ND	2980	ND
Chrysene	HW, PTP	ND	9440	ND
Benzo(b)fluoranthene	HW, PTP	ND	7410	ND
Benzo(k)fluoranthene	HW, PTP	ND	4420	ND
Indeno(1,2,3-c,d)pyrene	HW, PTP	ND	3750	ND
Benzo(g,h,i)perylene	HW, PTP	ND	3420	ND
BIS(2-ethylhexyl)phthalate	HW, PTP	ND	2730	ND
Mesityl oxide	None	ND	ND	1000 ²
2,4-dimethylheptane	None	ND	ND	630 ²
2,6-dimethylheptane	None	ND	ND	770 ²
2-cyclohexen-1-ol	None	ND	ND	400 ²

A group of compounds known collectively as polynuclear aromatic hydrocarbons (PNAs). PNAs are produced from the pyrolytic processing of organic raw materials, such as coal and petroleum, at high temperatures. As the combustion process becomes less efficient, higher levels of PNAs are produced. Heat and power generation, refuse burning, coal heaps, and emissions from coke ovens are major sources.

Commercially produced chemical used as a plasticizer for resins, and in the manufacture of organic pump fluids.

Solvent for cellulose esters, ethers and other resins in lacquers and inks. Used in paint and varnish removers and as an insect repellent.

Table 7--Records of organic compounds recovered from streambed sediment of Scioto River and Scioto Big Run, and their origin or use--Continued

Organic compound	USEPA designation	Total concentration at each site, in micrograms per kilogram			Origin or use of compound ¹
		FR-265	FR-267	FR-250	
Methyl ethyl ketone	HW	ND	ND	3200 ³	Solvent in nitrocellulose coating and vinyl film manufacture and in smokeless powder manufacture. Used in cements and adhesives and in the dewaxing of lubricating oils.
2,5-dimethyl hexane	None	ND	ND	390 ³	?
Hexamethylcyclo-trisiloxane	None	ND	ND	340 ³	?
2-cyclohexen-1-one	None	ND	ND	510 ³	?
2-chloronaphthalene	HW, PTP	ND	ND	90 ⁴	Used in production of electric condensers, in the insulation of electric cables and wires, as additives to extreme pressure lubricants, supports for storage batteries, and as a coating in foundry use.
4,7-dimethyl undecane	None	ND	ND	140 ³	?
3,3-dimethyl hexane	None	ND	ND	440 ³	?
2,7-dimethyl octane	None	ND	ND	230 ³	?
Oxetane	None	ND	ND	620 ³	?

¹Information on organic compounds obtained from Sittig (1981) and Bennett (1947).

²Compound identified by National Bureau of Standards library search. No standard available. Concentration is semiquantitative.

³Tentative identification, not confirmed. No standard available. Concentration is semiquantitative.

⁴Tentative identification, not confirmed.

Table 8.--Results of analysis of variance on rank-transformed ground-water-quality data

Property or constituent	F value (variance ratio)	P*
Specific conductance -----	17.06	0.0001
Carbon dioxide, dissolved -----	10.10	0.0007
Sodium, dissolved -----	18.84	0.0001
Potassium, dissolved -----	30.19	0.0001
Chloride, dissolved -----	12.22	0.0002
Magnesium, dissolved -----	12.06	0.0002
Hardness, dissolved (as CaCO ₃) -----	4.84	0.0172
Organic carbon, dissolved -----	18.48	0.0001
Dissolved solids, residue at 180°C -----	9.47	0.0009
Dissolved solids, sum of constituents -----	13.85	0.0001
Chemical oxygen demand -----	4.62	0.0200
Ammonia, dissolved (as N) -----	9.85	0.0008

*Probability of statistically determining groups to be different when they actually are not.

Table 9.--Results of Tukey's studentized range test for statistical differences between well-position groups

[T, Tukey's test; X, mean of individual well-position groups; N, number of samples. Means with the same letter under the "T" columns are not significantly different at the 0.05 level]

Well-position group	Property or constituent											
	Specific conductance			Dissolved solids (residue at 180°C)			Dissolved solids (sum of constituents)			Carbon dioxide		
	T	X	N	T	X	N	T	X	N	T	X	N
Up	A	784	8	A	552	8	A	502	8	A	55.2	8
Down	B	1,280	10	B	912	10	B	762	10	B	144	10
In	B	3,330	9	B	1,640	9	B	2,140	9	B	206	9

Well-position group	Sodium						Potassium						Chloride						Magnesium					
	Dissolved organic carbon		Nitrogen, ammonia		Hardness (as CaCO ₃)		Chemical oxygen demand		Dissolved organic carbon		Nitrogen, ammonia		Hardness (as CaCO ₃)		Chemical oxygen demand		Dissolved organic carbon		Nitrogen, ammonia		Hardness (as CaCO ₃)		Chemical oxygen demand	
	T	X	N	T	X	N	T	X	N	T	X	N	T	X	N	T	X	N	T	X	N	T	X	N
Up	A	23	8	A	2.3	8	A	30	8	A	32	8												
Down	B	89	10	B	5.9	10	B	130	10	B	38	10												
In	B	230	9	C	200	9	B	300	9	B	65	9												

The most noticeable effect of the landfills on ground-water quality is increased mineralization and higher concentrations of most common ions in wells downgradient from and penetrating landfills (fig. 13). The increase in dissolved-ion constituents, although not statistically significant on an individual ion basis, is significant in terms of specific conductance and total dissolved solids, which are aggregate properties expressing the ionic concentration of a water. These variables are significant in distinguishing the "up" group from the "down" and "in" groups because they are indicators of a common landfill effect--that is, the increased concentration of common ions and metals in receiving waters.

The water-quality variables sodium (Na) and chloride (Cl) indicate significant variance between position "up" and positions "down" and "in." Of the common ions, Na and Cl have the lowest attenuation (decrease in concentration with distance) except for calcium (Ca), which exhibits negative attenuation or elution. The significance of Na and Cl as discriminators relates to leachate production and relatively low attenuation by clay minerals in the aquifer. Other ionic species may not have been significant between these positions because of their moderate to high attenuation or adsorption by clays, which quickly lowers enrichment to background levels within short distances downgradient of the landfill.

Concentrations of magnesium (Mg) in the "in" wells were significantly different from concentrations in positions "up" and "down." Magnesium is considered to be a major constituent in leachate-affected waters (Garland and Mosher, 1975) and exhibits moderate attenuation by clays. It appears that higher concentrations of Mg generated by decomposition of refuse are rapidly lowered as the leachate migrates away from the source.

Carbon dioxide (CO_2) is significantly different between the "up" position and the "down" and "in" positions, whereas ammonia (NH_4) can separate "in" from the "up" and "down" positions. The increase in CO_2 is a common effect of landfill leaching and results from degradation of organic matter in the landfill. The increase in concentration of NH_4 within the landfills is also characteristic of leachate production. As microbial degradation of organic compounds proceeds, CO_2 , CH_4 , NH_4 , and sometimes H_2S and H_2 are produced as end products (Baedecker and Back, 1979). The group means for CO_2 and NH_4 reflect this process; means are highest for "in"-position wells and lowest for "up"-position wells. In addition, H_2S was detected in four wells in the "in" group, and CH_4 was detected in all "in" wells.

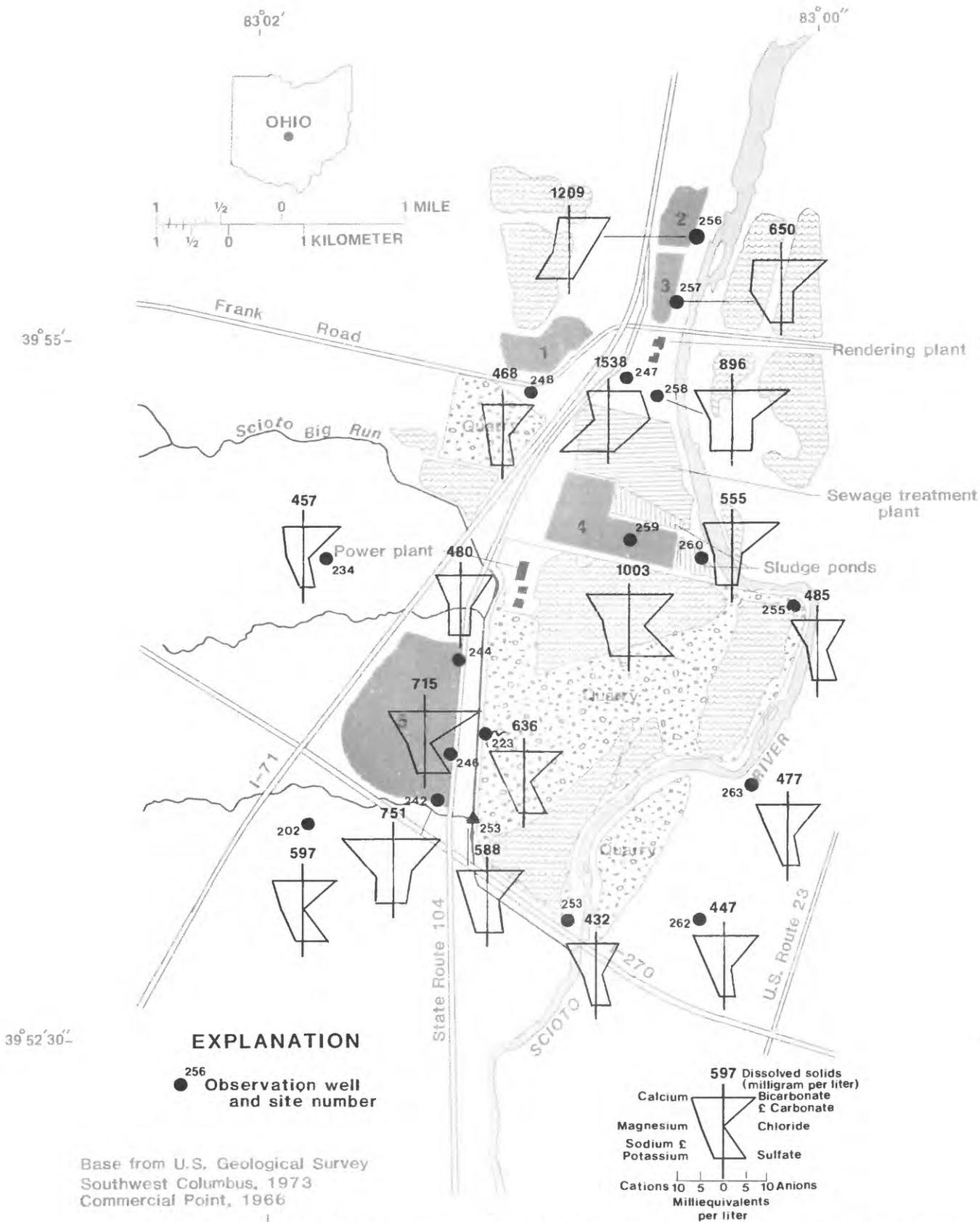


Figure 13.--Stiff diagrams showing the variation in concentration of the common ions in ground water throughout the study area. (The county code prefix, FR-, has been deleted from well numbers. Scale for FR-247 and FR-256 is 2X.)

Another effect of the landfills is the dominance of ammonia as the major nitrogen species in all wells downgradient from the landfills. In almost all of the upgradient wells, organic nitrogen or nitrate plus nitrite are the dominant nitrogen species. The dominance of ammonia in the downgradient wells is caused by reduction, decomposition, and ammonification of other nitrogen species in the landfills and subsequent migration of the water. The only downgradient well in which nitrate and nitrite were not completely converted to ammonia is FR-248.

Potassium (K) is significantly different between all groups, perhaps because it is normally a very conservative constituent and has very little variability in concentration in stable ground-water systems. Potassium, which is ranked medium with respect to attenuation and mobility (Griffin and others, 1976), is the only variable that could separate all group combinations at the 95-percent confidence interval. The group means for K increase from position "up" to position "down," and reach a maximum of 200 mg/L for wells penetrating refuse. The group mean concentration of the "down" wells is approximately 36 times less than for the "in" wells, which reflects adsorption to clays as leachate migrates away from the landfills.

The significance of hardness (mg/L as CaCO_3) is related to a condition termed "hardness halo," which can be observed in ground water near landfills 2, 3, 4, and 5 and is described below. The mechanics and existence of the hardness halo near other landfills has been documented by Griffin and others (1976). Hardness halo results from the displacement of Ca from clays exposed to landfill leachate. Data also indicate Ca is displaced from clay cation-exchange positions by Na, K, NH_4 , and Mg. The significant variation of K, Mg, and NH_4 between certain positions, as discussed earlier, may be related to the hardness-halo phenomenon.

The halo process begins with a relatively pure (undiluted) leachate in which Ca concentration is low, such as in samples from FR-261 (Ca = 7 mg/L). As the leachate moves away from the source, Ca concentrations increase, then decrease to background levels with distance from the refuse. Because of ground-water flow convergence and well placement in the study area, not all of the stages are seen.

The flow path defined by wells FR-258, FR-247, and FR-248 (figs. 3 and 6) illustrates the general chemical process and development of the hardness halo:

Well	Hardness (mg/L as CaCO ₃)	Calcium (mg/L)	Process
FR-258	510	96	Leachate being produced by refuse penetrated by well FR-258. Leachate begins migration and elution of Ca is already occurring.
FR-247	560	140	Concentration of hardness increases as Ca is eluted from clays in greater amounts.
FR-248	320	73	Concentration of hardness and Ca in well FR-248 falls to background levels as defined by control wells FR-224 and FR-234.
FR-224	270	71	
FR-234	330	73	

The flow path defined by FR-201, FR-242, and FR-246 also indicates this process; however, FR-201 represents ambient concentrations before leachate enters the system. The increase in Ca and hardness occurs between leachate entry, FR-242, and FR-264. It should be noted that, in the first example, FR-247 has higher levels of Na and NH₄ than FR-258, the upgradient well, which may indicate another, closer source of contamination.

COD, a measure of oxidizable-material load, is a relative indicator of the pollution load of a natural water. Levels of COD are significantly higher in wells penetrating refuse than in down-gradient wells. Levels of COD were not significantly different between position "up" and positions "down" and "in." The lack of difference may be caused by the large thicknesses of aquifer exposed to the atmosphere by drawdown in the vicinity of the upgradient wells. Since 1979, levels of COD have increased 20 to 1,200 percent in "up" wells that have been affected by dewatering. The dewatering in these areas encourages decomposition of aquifer materials that were previously in equilibrium with the ground-water system, thereby creating increased oxygen demand.

Although not presented statistically because of many values at the instrumental detection level, BOD (table 3), also an indicator of pollution load, varies significantly between position groups. BOD was detected in one "up"-position well and two "down"-position wells. However, all "in"-position wells except for FR-259 contained BOD, the concentration of which ranged from 0.2 to 67 mg/L.

Increase in DOC concentration is characteristic of waters affected by solid-waste disposal. DOC is significantly different between position "up" and positions "in" and "down." The group mean (59 mg/L) for "in" wells exceeded the recommended threshold limit value of 5 mg/L, which indicates contamination by organic compounds.

The effects discussed thus far are common to most landfills that generate a leachate, and specifically to landfills 2, 3, 4, and 5 in the study area. No degradation of ambient water quality is noted in well FR-248, which lies directly downgradient of landfill 1. The similarity between water quality in FR-248 and control wells FR-224 and FR-234 indicates that landfill 1 apparently has little or no effect on ambient ground-water quality.

The quality of water from well FR-261, completed in sand and gravel beneath the base of landfill 4, is the most degraded in the study area. This water contains very high concentrations of most constituents analyzed for, and has chemical characteristics common to most leachates (Garland and Mosher, 1975). Water from well FR-259, also in landfill 4, and well FR-260, completed in the levee between landfill 4 and Scioto River, are similarly degraded, but not to the extent of FR-261.

Ground water from well FR-256 near landfill 2 and adjacent well FR-257 near landfill 3 is similar in many respects, and contains elevated concentrations of most of the common ions and heavy metals. Concentrations of DOC are 10 to 35 times higher than in wells unaffected by refuse. Elevated concentrations of methane and carbon dioxide, the presence of hydrogen sulfide, and the dominance of ammonia as the major nitrogen species reflect reducing conditions in the aquifer near landfills 2 and 3. All these factors indicate that ground water near landfills 2 and 3 has been affected by leachate.

From well FR-256 south to well FR-260, ground water in the vicinity of the river levee has been similarly affected. Because the composition of the levee and the landfills are essentially the same, it is not possible to determine which is the primary source of contamination. It is probable that both the levee and landfills contribute to the degradation of ground-water quality.

Waste disposal in landfill 5 began at the southern edge and proceeded north. The ground-water quality reflects the filling sequence; water from FR-242 at the southern edge is the most degraded and water from FR-244 at the northern edge shows the least effect. Ground water from well FR-244 is similar to that of control wells FR-224 and FR-234 just north of landfill 5, except for presence of methane and slightly higher concentrations of the common ions and metals. Although landfill 5 affects the aquifer near FR-244, the degradation of ground water is more pronounced near wells FR-242 and FR-246. In this area, elevated levels of calcium, manganese, and hardness indicate that elution of calcium and manganese occurs as leachate evolves and migrates towards the ground-water surface.

The effect of leachate generated from landfill 5 on ground-water quality in the underlying aquifer is diminished by the thick unsaturated zone created by local dewatering. If not for the decomposition, dissolution, ion exchange, and biological decay taking place in this zone, the contamination would be much higher. At present, all ground-water flow from landfill 5 is towards the quarry sump.

Organic compounds present in the sediments of Scioto River and Scioto Big Run cannot be attributed directly to the landfills because of a number of other possible sources in the study area. Likewise, the organic compounds in water from Scioto Big Run cannot be attributed to a specific source. It should be noted that most of the compounds present are considered persistent and accumulative, and may have been in the sediment for a long time.

SUMMARY AND CONCLUSIONS

Hydrogeology and water quality were evaluated in the vicinity of five landfills located in the Scioto River valley in southern Franklin County, Ohio. Surficial deposits, which are actively mined, consist of interbedded glacial sand, gravel, and till that attain a maximum thickness of 160 feet within the study area. A 30-foot-high levee constructed in the early 1900's parallels the Scioto River on both banks; a section of the western levee is composed of refuse ranging from 12 to 35 feet in thickness.

The Columbus Limestone of Devonian age, which also is actively mined, underlies the entire study area. In some places, the limestone is fractured and jointed at the contact with the glacial deposits. The surface was highly eroded during glaciation and exhibits east-west trending valleys. Water-level and geologic boring data indicate good communication between the limestone and overlying glacial deposits.

A large cone of depression that affects ground-water flow throughout the entire study area is centered on a heavily pumped limestone quarry located between landfill 5 and Scioto River. The dewatering has created a thick unsaturated zone beneath landfill

5, and has converted a 4-mile segment of Scioto River to a losing stream. The maximum water-level decline in the study area for a 3-year period is 21 feet.

Seepage data indicate that Scioto River receives ground-water inflow near landfill 2, but loses water to the aquifer as it becomes influenced by ground-water withdrawals. Data also indicate that effluent from a sewage-treatment plant is a major component of streamflow during low-flow conditions. In Scioto Big Run--a losing stream--the entire flow originates at a breach in a levee, to a large lake fed by quarry dewatering. Upstream of the levee breach, the stream has no flow except during periods of heavy rainfall.

Analysis of water from well FR-256 identified very low concentrations of four organic compounds: diethyl-phthalate, di-n-butyl phthalate, isophorone, and naphthalene. However, the presence of the compounds identified--industrial chemicals, plasticizing agents, and solvents--cannot be considered significant because of low concentrations and possible interferences in the analytical process. Results of analysis of aquifer sediments for the same compounds were negative.

Analysis of dissolved constituents in the water column of the streams is consistent with past results, however, a phthalate ester was detected in Scioto Big Run at a concentration of 31.4 ug/L--10 times the USEPA recommended limit for protection of freshwater aquatic life.

Because streamflow and water quality in Scioto Big Run and the Scioto River are highly variable and heavily influenced by human activity, more emphasis was placed on analysis of streambed sediments as an indicator of past and present water quality. Polynuclear aromatic hydrocarbons (PNAs) ranging from 2,980 to 9,440 micrograms per kilogram of sediment from Scioto River indicate a segment of the streambed (at site FR-267) is heavily degraded compared to upstream sediment (at site FR-265), which did not contain any of the compounds. Nearby ash ponds or an incinerator may have produced these high concentrations of PNAs. Streambed sediment from Scioto Big Run contains various organic compounds at concentrations ranging from 90 to 3,200 micrograms per kilogram. Identification of some compounds was only tentative; however, the total organic load and varied nature of the compounds may indicate degradation from several sources. Analyses of toxic metals in streambed sediments of Scioto River also show higher concentrations at site FR-267 than at FR-265. Concentrations of toxic metals in streambed sediment from Scioto Big Run are intermediate between those from the two Scioto River sites.

Organic compounds detected in the water and sediments from Scioto Big Run and in the sediment of Scioto River cannot be directly attributed to the landfills because other sources may be present in the area. Most of the organic compounds identified are accumulative, and may have been in the sediment for a long time.

All wells sampled for water quality were separated into the groups "up" (upgradient), "down" (downgradient), or "in," (penetrating refuse) on the basis of their position with respect to the landfills and the ground-water flow system, and whether refuse was encountered during drilling. Ambient ground water as defined by "up" wells is a hard, calcium bicarbonate type, with a median pH of 7.1; this value has not changed significantly since an earlier report (de Roche and Razem, 1981). Concentrations of iron and manganese routinely exceed OEPA drinking-water standards.

Analysis of variance on the rank-transformed ground-water-quality data indicates there are significant (greater than 98-percent likelihood) water-quality differences between the three position groups for 12 water-quality variables. Tukey's test was used to determine which variables cause the groups to be different at the 95-percent confidence level. Most variables were statistically different between group "up" and groups "down" and "in"; five variables showed a difference between groups "down" and "in."

Wells located in and downgradient of landfills have higher concentrations of most chemical constituents than upgradient wells. Increases in concentrations of the common ionic species, (statistically significant in terms of specific conductance and dissolved solids), are the most noticeable effect of the landfills on ground water. The significance of sodium, chloride, potassium, and magnesium is related to decomposition of refuse and attenuation processes as leachate is formed and migrates away from the landfills.

Elevated concentrations of dissolved organic carbon are related to the decomposition of refuse in the levee and landfills. Downgradient wells FR-247 and FR-264 exceed a recommended threshold concentration of 5 mg/L for dissolved organic carbon, which indicates contamination by organic compounds. All "in" wells exceed this threshold except for FR-258.

Carbon dioxide, chemical oxygen demand, and ammonia show between-group differences based upon chemical and biological reactions occurring in and downgradient of the landfills and levee. Concentrations are generally highest in water from wells penetrating landfills, intermediate for downgradient wells, and lowest for upgradient wells. Carbon dioxide is generated through decomposition of organic compounds in the refuse, whereas chemical oxygen demand indicates an oxygen deficit and high pollution load.

The predominant nitrogen species in and downgradient of landfills 2, 3, 4, and 5 is ammonia. This results from biological reduction and decomposition of other nitrogen species in the refuse and the subsequent migration of leachate.

Water samples from wells FR-259, FR-260, and FR-261 indicate that ground water beneath landfill 4 is the most degraded in the study area. Similar chemical conditions exist near landfills 2 and 3 where ground-water quality also is heavily affected. The

refuse in landfill 4 and in the levee near landfill 2 is saturated. Water-level and stream-stage data indicate that flow between Scioto River and the aquifer is occurring near landfill 2 and that the direction of flow is controlled by head relationships between the aquifer and stream. It is probable that both the refuse-containing levee and landfills 2, 3, and 4 contribute to the degradation of ground-water quality in the study area.

Water from wells FR-242, FR-244, and FR-246, downgradient from landfill 5, has elevated concentrations of the common ions, ammonia, and heavy metals, and also generates methane. The production of methane gas and the presence of a "hardness halo" are evidence of leachate production. The degradation of ground water beneath landfill 5 is less than at landfills 2, 3, and 4, because of the thick unsaturated zone that allows for increased dissolution, attenuation, and biological decay of leachate produced by the refuse.

At present, ground-water flow in the study area is directed towards the quarry sump east of landfill 5, which represents the base of the cone of depression. Ground-water levels continue to decline; however, if current patterns of water use change, there may be significant changes in the hydraulic relationship among the levee, landfills, aquifer, and streams. Any modification of these relationships will affect the production and ultimate destination of leachate being produced by the landfills.

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