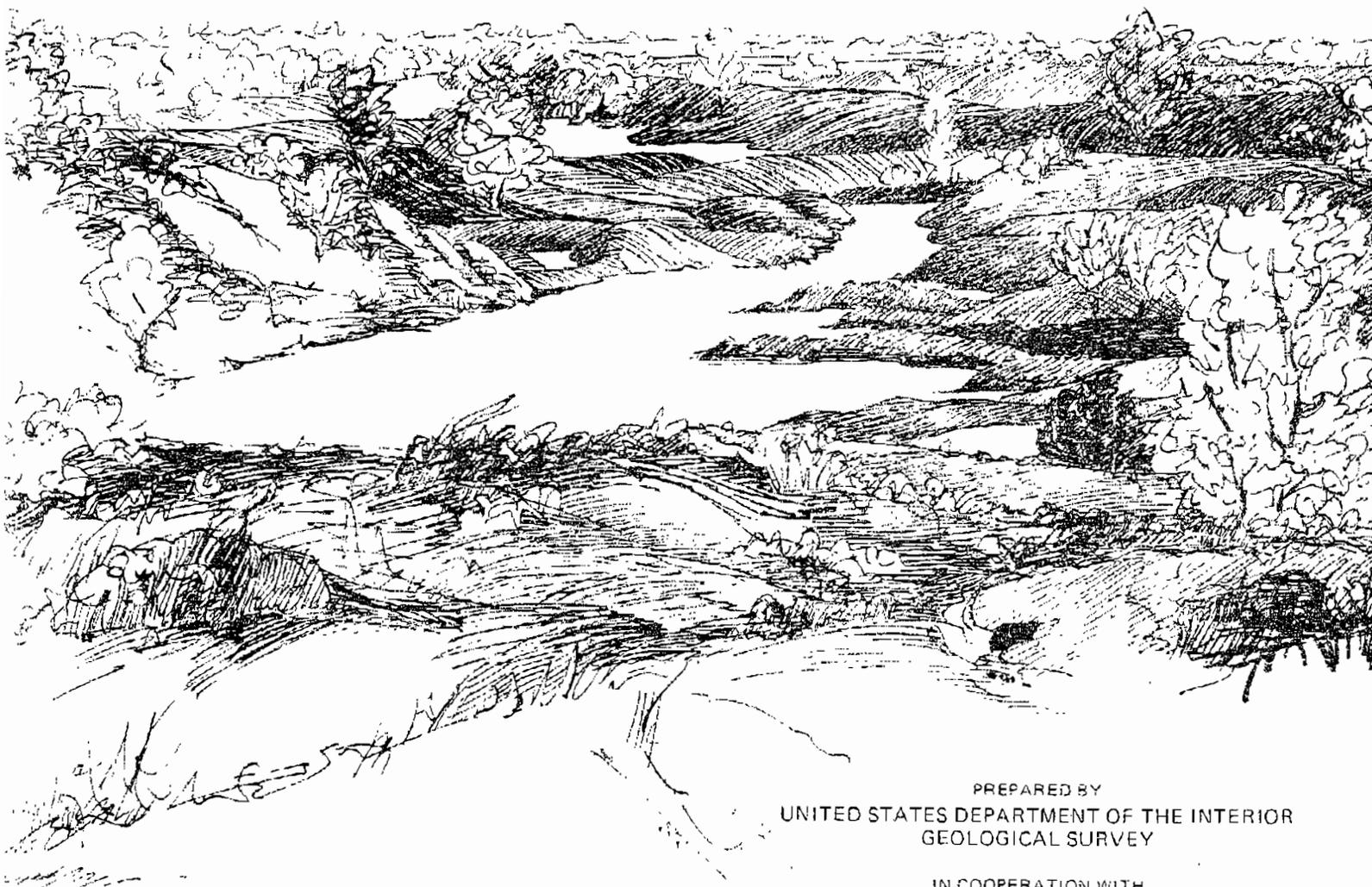


HYDROLOGIC CHARACTERISTICS OF SURFACE-MINED LAND RECLAIMED BY SLUDGE IRRIGATION, FULTON COUNTY, ILLINOIS



PREPARED BY
UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

IN COOPERATION WITH
THE METROPOLITAN SANITARY DISTRICT
OF GREATER CHICAGO

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LAND RECLAIMED BY SLUDGE IRRIGATION,
FULTON COUNTY, ILLINOIS**

G. L. PATTERSON, R. F. FUENTES, AND L. G. TOLER

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*Prepared in cooperation with the
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ABSTRACT

Analyses of water samples collected at four stream-monitoring stations in an area surface mined for coal and being reclaimed by sludge irrigation show the principal metals to be sodium, calcium, and magnesium and the principal non-metals to be chloride, sulfate, and bicarbonate. Comparisons of yearly mean chemical concentrations show no changing trends since the reclamation began, nor are there apparent differences, attributed to sludge, between stream stations upstream and downstream from the site. Yearly suspended-sediment loads and discharge relationships between stations upstream and downstream from the site also are not notably different. Discharge hydrographs of two tributary streams draining the site show a delayed response to precipitation compared with other streams, owing to the damping effect of several upstream strip-mine lakes.

The shape of the water-table surface generally follows the irregular topography. Monthly water-level fluctuations in wells were dependent on the surface material penetrated (mined or unmined) and their proximity to surface discharge. The largest fluctuations were in unmined land away from discharge, whereas the smallest were in mined land near discharge. The water table is closer to the surface in unmined land than in mined land.

The chemical characteristics of ground water are typical of those in mined areas as shown by high concentrations of sulfate, calcium, magnesium, chloride, iron, zinc, and manganese. However, no changes in ground-water quality attributable to reclamation were identified.

INTRODUCTION

The Metropolitan Sanitary District of Greater Chicago (MSDGC) produces more than 500 dry tons of sewage sludge per day through treatment of wastewaters from sanitary facilities (J. R. Peterson, written commun., 1979). Consequently, there is critical need for a safe, economical, and environmentally acceptable disposal method. The MSDGC began research into land application of digested sludge in the mid 1960's.

Sludge contains substantial quantities of nutrients, primarily phosphorus and nitrogen, and application to deficient soils could help restore agricultural productivity. Sludge may also contain potentially harmful constituents such as heavy metals, pesticides, and polychlorinated biphenyls (PCB's). The concentrations of these constituents in sludge may be high relative to those in natural soils and waters and thus may undesirably alter the water quality. In Illinois, more than 100,000 acres of land had been surface mined for coal before the enactment of reclamation laws in 1962 (Haynes and Klimstra, 1975, p. 18). It was suggested that the application of sludge as a soil conditioner and fertilizer might serve as an effective method of reclaiming this land. Thus, in 1970, the MSDGC began acquiring and recontouring surface-mined land about 25 miles west of Peoria, near the towns of Canton, Cuba, Bryant, and St. David in Fulton County, Illinois (fig. 1). Reclamation involved barging sludge approximately 200 miles down the Illinois River from Chicago to Liverpool, Illinois. The sludge is pumped 10 miles through pipelines to four sludge storage basins within the project area, and then pumped through a piped distribution system from the storage basins to the fields.

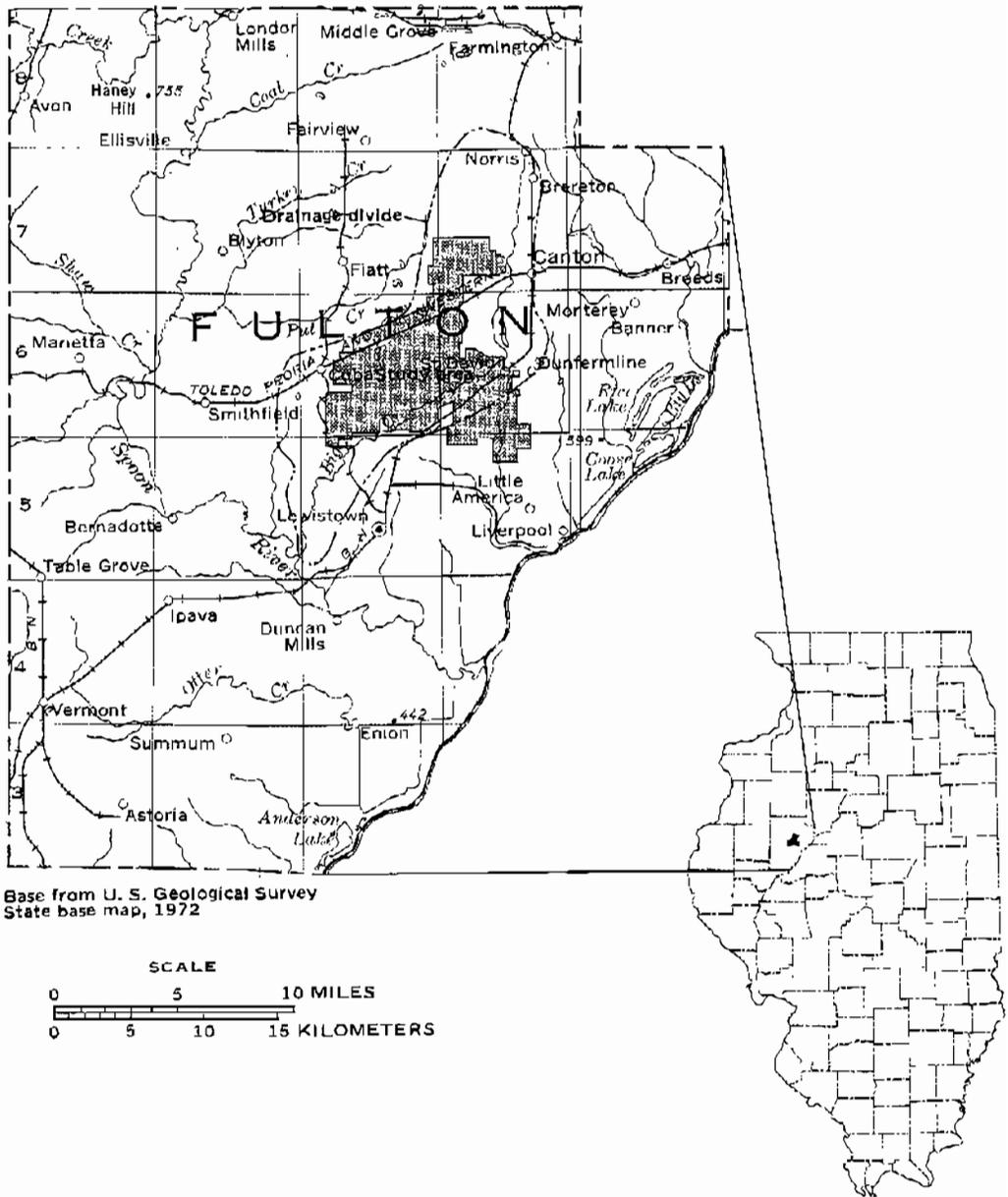


Figure 1. Location of study area.

In 1971, the U.S. Geological Survey (USGS) began a cooperative project with the MSDGC to measure stream discharge, suspended-sediment loads, and chemical constituents in surface water in the project area. Sludge application began on the 15,528 acre area in 1972 (Zenz, Peterson, Brooman, and Lue-Hing, 1976, p. 2333). In 1976, the cooperative project was expanded to include monitoring of shallow ground-water levels and ground-water quality.

The purpose of the cooperative project was to provide background data on surface-water quality and quantity and to establish and maintain stations to monitor changes or trends caused by site preparation and sludge application. In 1976, monitoring of ground-water quality was added to the project to acquire baseline data on concentrations of chemical constituents in ground water. Ground-water levels were measured and used to prepare a water-level contour map and to define temporal and spatial differences in water-levels.

This report contains a general description of the hydrology of the project site, summaries of the data collected during 1971 to 1978, and discusses some of the factors affecting the hydrology of the site. This information and the water-level contour map (Fuentes and Patterson, 1979) will be helpful in designing an effective ground-water monitoring program and will provide baseline hydrologic information from which future changes can be detected.

PHYSICAL SETTING

Fulton County is on the northwest flank of the Illinois Basin, a broad bedrock depression trending southeasterly from northern Illinois into Kentucky. Bedrock within the basin represents all of the Paleozoic systems through the Pennsylvanian (Wanless, 1957, p. 29). In Fulton County the dip on these beds is southeasterly at about 10 feet per mile. The Upper Pennsylvanian consists of several cyclical deposits of limestone, shale, sandstone, and coal. The surficial material consists of up to 50 feet of Pleistocene glacial deposits and 10 feet of wind-blown silt (Willman and Frye, 1970, p. 17 and plate 3). The material that was overlying the coal was stripped, mixed, and redeposited to leave a surficial material of unsorted sand, silt, and clay, with many large blocks of original bedrock.

The county is level to gently undulating, except where surface mining has left a varied surface. At the project site, conspicuous topographic features include rough unreclaimed areas of hills, ridges, and valleys composed of displaced overburden; steep valley walls along strip-mine lakes and drainage

channels; gentle slopes formed during reclamation; and, near the center of the site, a prominent mound formed by the construction of berms to form sludge-holding basins.

HYDROLOGIC ENVIRONMENT

The major stream draining the project area is Big Creek, which flows southwesterly through the area (figs. 1 and 2) to the Spoon River which in turn flows southeast to the Illinois River. Two tributaries to Big Creek (fig. 2), Slug Run and Evelyn Branch, originate from strip-mine lakes in the project area. Cripple Creek, a tributary to Evelyn Branch, originates on the site and is fed by drainage from underground coal mines. South of Highway 100 the site is drained by Big Sister and Little Sister Creeks, both tributaries to the Illinois River.

Ground water is obtained in Fulton County from unconsolidated glacial deposits or from deeper consolidated bedrock units. The glacial deposits commonly yield enough water from sand and gravel for domestic and farm purposes, but the quantity and quality of the water depend on local conditions (Horberg, 1950, p. 19). Other sources of domestic supplies are Pennsylvanian sandstones at depths from 50 to 300 feet (Bergstrom, 1956, p. 16), and Mississippian limestones at depths from 250 to 500 feet. Deeper water-bearing formations include Silurian and Devonian limestone, Ordovician sandstone, and Cambrian sandstone. Although these deeper formations yield large water supplies, in Fulton County the water is highly mineralized, which limits its use.

Many lakes formed by the surface mining are now integral parts of both the surface-water and ground-water systems. Most lakes are hydraulically connected with shallow ground water and their surfaces are continuous with the water table. Many of these lakes are connected by pipes or drainage channels, thereby forming several interconnected reservoirs that discharge into either Evelyn Branch or Slug Run. Some lakes have relatively impermeable bottom materials, which cause their surfaces to be perched above the local water table.

SLUDGE AND SUPERNATANT

Composition

The term "sludge", as used in this report, refers to a fluid mixture, resulting from sewage treatment, that contains about 5 percent solid matter. During storage in holding basins at the project site, the solid matter settles to the bottom; the solution left is the supernatant. Sludge is applied to fields as a fertiliz-

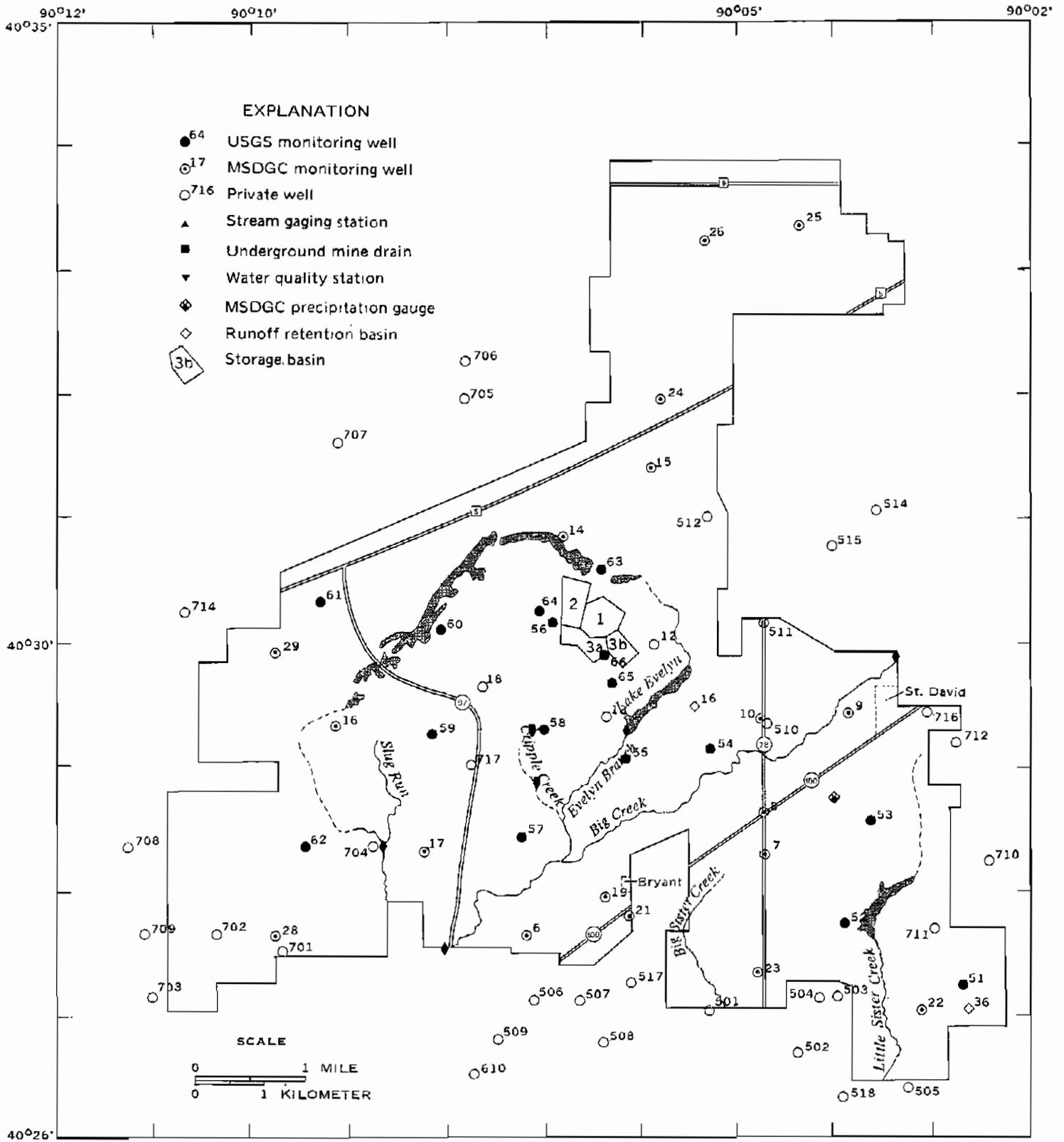


Figure 2. Location of data collection sites.

er and soil conditioner and the supernatant is applied as an irrigant and fertilizer.

The MSDGC maintains records of the sludge and supernatant applied to the project site and reports this information regularly to the Illinois Environmental Protection Agency. Table 1 lists analyses of sludge and supernatant summarized from Peterson (1973-78). The analyses indicate that most of the chemical constituents are associated with the solids.

Sludge applied during 1977 (table 1) contained concentrations of many chemical constituents several times greater than usual concentrations in soils and water in Illinois. On a mass basis, the major constituents were bicarbonate, ammonia, organic nitrogen, iron, phosphorus, and calcium, aluminum, and magnesium. Zinc and chromium generally found in low concentrations (less than 1 mg/L) in soils and water, were present in mean concentrations of 208 and 190 mg/L, respectively. Concentrations of other trace elements were also several

times higher than those usual in water in Illinois.

In 1977, one sludge sample was analyzed for synthetic organic compounds. Of 22 insecticides, herbicides, and polychlorinated biphenyls (PCB), only PCB and chlordane had noticeably high concentrations, 2,740 and 420 $\mu\text{g/g}$, respectively.

Supernatant applied during 1977 contained much lower concentrations of chemical constituents than sludge (table 1). The principal constituents were bicarbonate, potassium, and phosphorus. Other significant constituents were sodium, calcium, and magnesium. Minor elements detected were present in concentrations below 1.0 mg/L, which is not uncommon in water in Illinois.

Application

Sludge was applied to the fields by pumping it through a series of pipes to a hose attached to a field disk, which directly incorporated it into the soil. Application rates during 1977 ranged from 0.6 to

Table 1. Chemical analyses and application of sludge and unfiltered supernatant during 1977.

Constituent or property	SLUDGE		Application Rate ² (lb/acre)	SUPERNATANT		Application Rate ⁴ (lb/acre)
	Mean Concentrations ¹ (mg/L)	(lb/ton, dry)		Units	Concentration	
Total phosphorus, as P	1,700	68.4	1,900	mg/L	100	95
Kjeldahl nitrogen, as N	2,400	97.1	2,700	--	--	--
Ammonia, as N	1,100	43.1	1,200	--	--	--
Alkalinity, as CaCO ₃	3,350	137	3,790	mg/L	372	354
Bicarbonate ³ (HCO ₃)	4,090	183	5,060	mg/L	432	--
Chloride (Cl)	370	15.2	420	--	--	--
Iron (Fe)	2,470	101	2,790	--	--	--
Zinc (Zn)	208	8.49	235	mg/L	0.1	0.10
Copper (Cu)	88.6	3.62	100	mg/L	0.05	0.05
Nickel (Ni)	20	0.82	23	--	--	--
Manganese (Mn)	17.6	0.71	20	mg/L	0.05	0.05
Potassium (K)	177	7.22	200	mg/L	104	99
Sodium (Na)	105	4.28	118	mg/L	66	63
Magnesium (Mg)	484	19.8	548	mg/L	9	9
Calcium (Ca)	1,580	64.6	1,790	mg/L	37	35
Lead (Pb)	45.5	1.86	51	mg/L	0.03	0.03
Chromium (Cr)	190	7.76	215	mg/L	0.05	0.05
Cadmium (Cd)	16	0.65	18	-- ⁵	0	--
Aluminum (Al)	732	29.9	827	--	--	--
Mercury (Hg)	0.283	0.011	0.3	--	--	--

¹ Peterson, J. R., 1978, Environmental Protection System Report for Fulton, County, Illinois, December 1977.

² Calculated using the mean application rate of 27.7 tons/acre (dry).

³ Bicarbonate was calculated by dividing alkalinity (in milligrams per liter) by 0.8202 (Hem, 1970, p. 84).

⁴ Based on application rate of 124,000 gallons per acre.

⁵ Not detected.

56.1 dry tons per acre, with a mean of 27.7 (Peterson, 1978). At these rates a range of from 0.1 to 9.9 inches of water was applied to the fields with a mean of 4.9 inches.

Supernatant was pumped to the fields and allowed to flow over the surface from perforated pipe and percolate into the ground. During 1977, supernatant was applied at rates from 82,600 to 160,000 gallons per acre, with a mean rate of 124,000 (Peterson, 1978). Supernatant irrigation provided an average of 4.6 inches of water in 1977 and ranged from 3.0 to 5.8. Mean application rates of individual chemical constituents, as reported by MSDGC for both sludge and supernatant, are shown in table 1.

DATA NETWORK

Surface Water

Three stream-gaging stations were installed in 1971 (fig. 2), two on Big Creek, one upstream and one downstream from the project site, and one on Evelyn Branch near the center of the site. A fourth was installed in 1975 on Slug Run, which drains the western part of the site. Continuous records of daily discharge were obtained at each station from recorded stage data and stage-discharge relationships defined by current-meter measurements of discharge.

Daily suspended-sediment discharges were calculated for the two Big Creek stations and for the Slug Run station. Samples for determination of suspended-sediment concentrations were collected at least twice weekly and more often during storms. Suspended-sediment concentrations were determined at the USGS laboratory in Iowa City, Iowa. Suspended-sediment discharges were calculated from the concentrations and discharge records. Field procedures were those described by Guy and Norman (1970), and laboratory and computation procedures were those described by Porterfield (1972).

Continuous records of specific conductance and water temperature were obtained at each of the four gaging stations. Grab samples were collected monthly at each gaging station and analyzed for a variety of chemical constituents at the MSDGC laboratory. Other lakes and ponds not included in the routine network were sampled intermittently to better determine areal distributions of specific constituents.

Samples of streambed materials were collected annually at each gaging station for chemical analyses of nutrients, metals, and synthetic com-

pounds. Bed materials within and downstream from two runoff-retention basins were sampled once and analyzed for nutrients and metals.

Ground Water

The ground-water monitoring network consisted of 70 wells (fig. 2); 22 wells installed by the MSDGC during 1971 and 1973, 16 wells installed by the USGS in 1977, and 32 privately owned wells on property adjacent to the site. Water levels were obtained by using a graduated steel tape and measuring the depth to water from a point of known altitude at land surface. Water samples were obtained from the wells by one of the following methods:

- The MSDGC network wells were sampled monthly by using permanently installed submersible pumps.
- The USGS network wells were sampled by using a bailer or by using compressed air to pressurize the casing and force water up through an inner sampling line. Each well was bailed or pumped and allowed to recover before sampling, thus assuring a representative sample. Field measurement of pH, specific conductance, and temperature of the water were taken; and the samples were immediately filtered through a 0.45-micrometer filter.
- The private wells were sampled by using a hand pump or bailer, or from a faucet before any storage or water-treatment systems. The samples were then treated as in number 2 above.

Upon collection, part of each sample was acidified to keep dissolved metals in solution and the raw and acidified samples were shipped to the MSDGC laboratory for analysis.

All water samples were routinely analyzed for pH, total phosphorus, chloride, sulfate, Kjeldahl nitrogen, ammonia nitrogen, nitrate plus nitrite, alkalinity (as calcium carbonate), specific conductance, potassium, sodium, calcium, magnesium, zinc, cadmium, copper, nickel, manganese, lead, iron, aluminum, and mercury. In 1977-78, water samples from 65 wells were analyzed for dissolved boron.

RESULTS

Surface Water

Discharge hydrographs for the 1976 and 1977 water years for the four gaging stations closely resemble the precipitation hydrographs (fig. 3), except for winter months, when below freezing

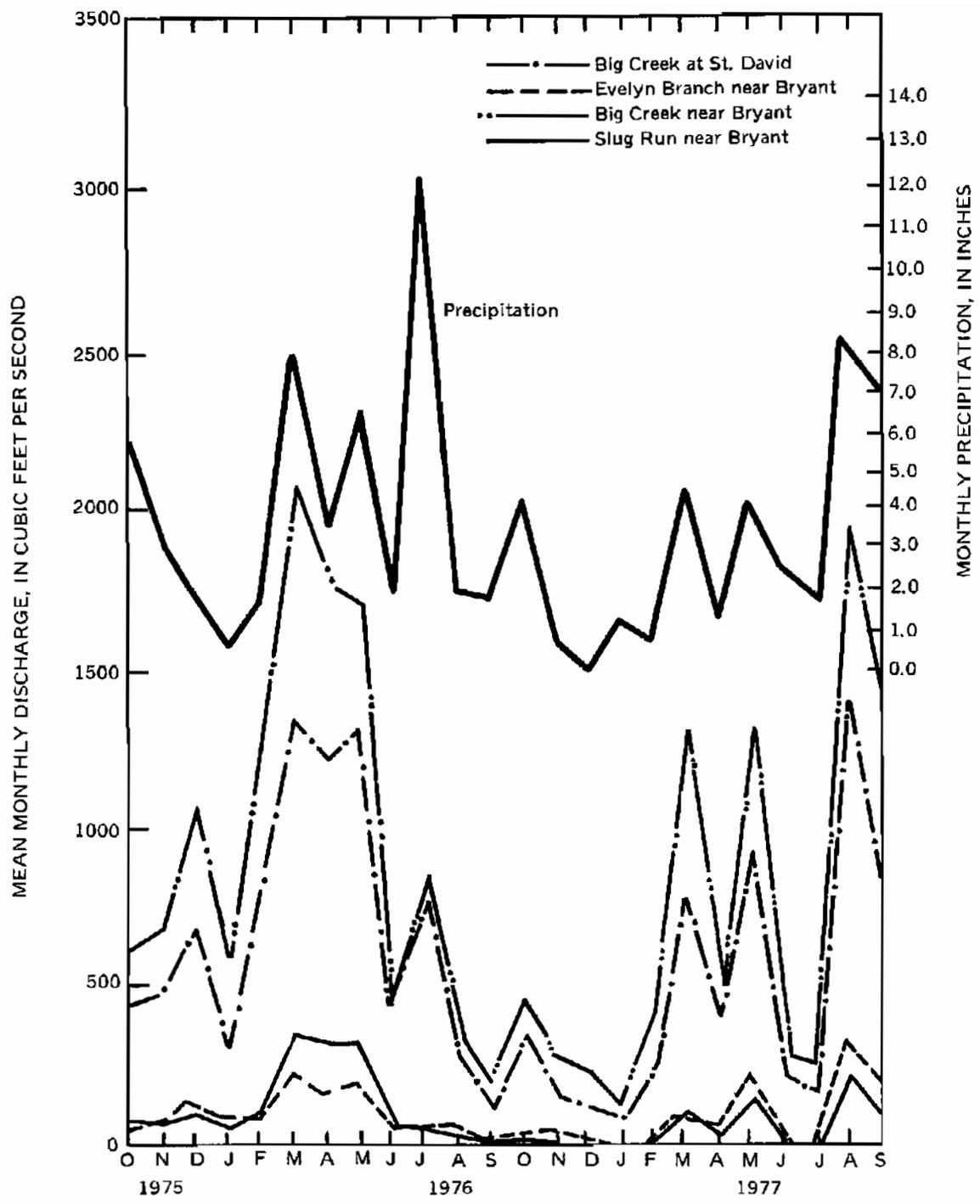


Figure 3. Discharge and precipitation for the 1976 and 1977 water years.

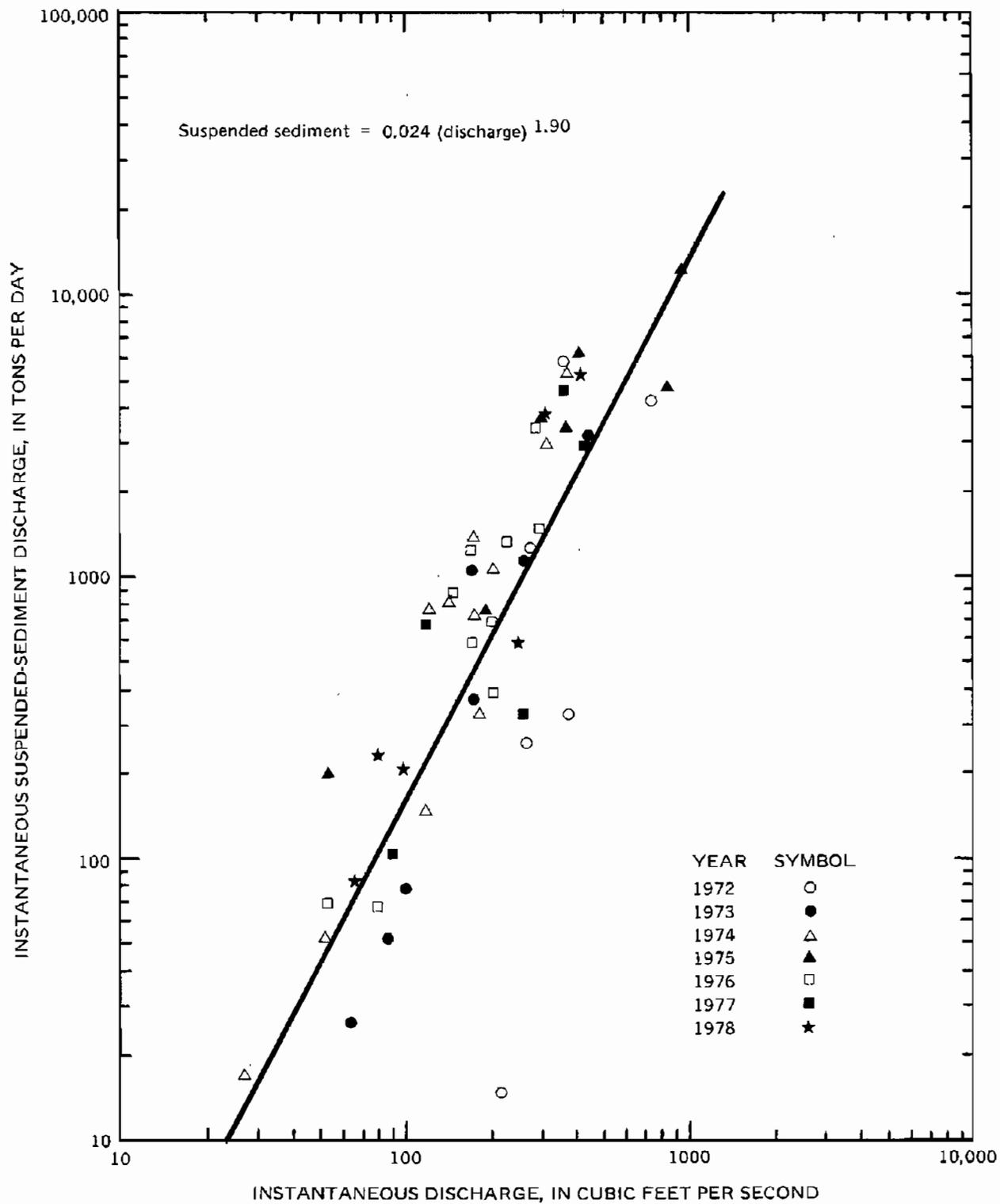


Figure 4. Suspended-sediment transport curve for Big Creek at St. David.

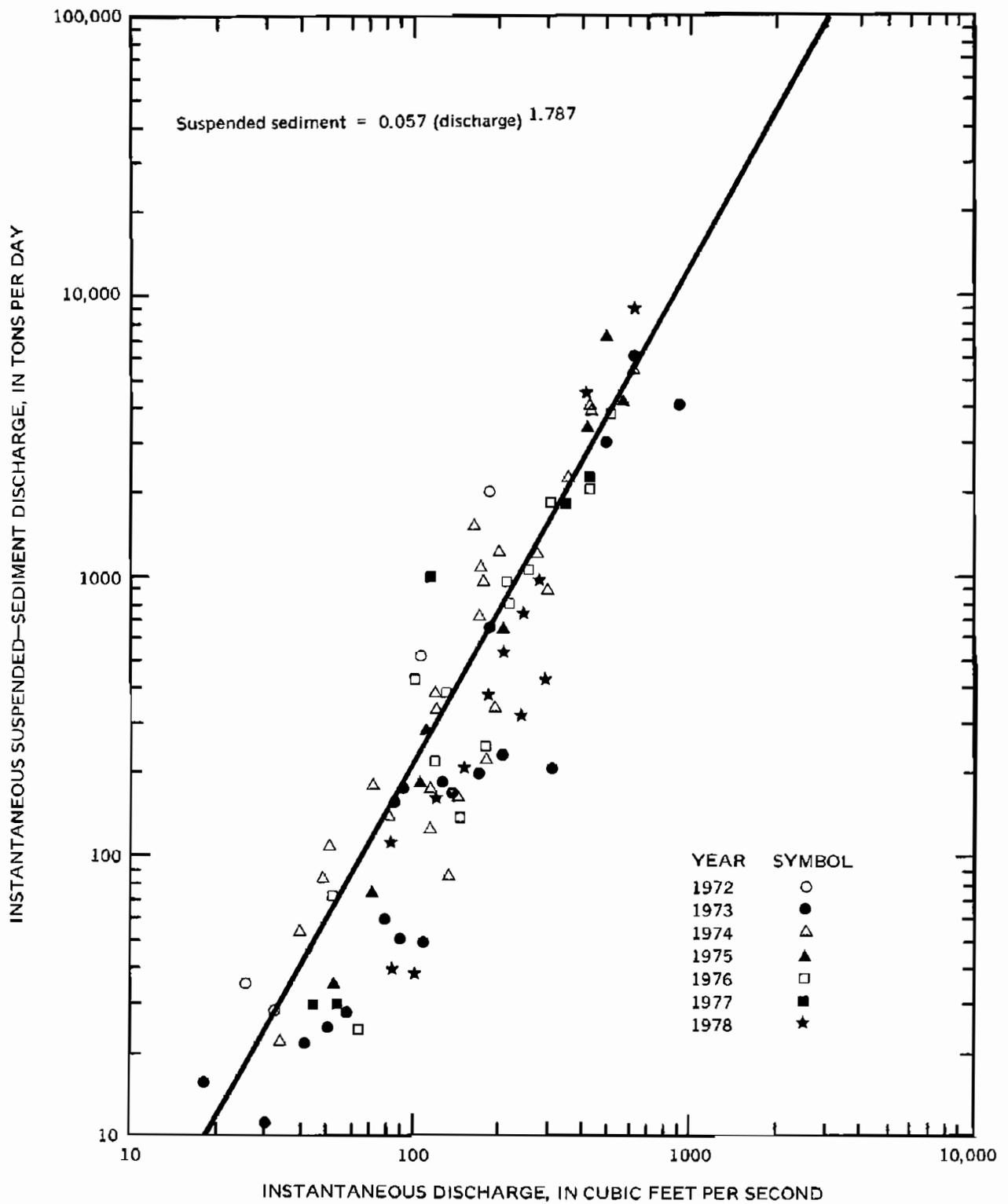


Figure 5. Suspended-sediment transport curve for Big Creek near Bryant.

temperatures decrease infiltration and increase runoff. All four stream hydrographs have the same relative shape and coincidental peaks; however, the peaks are much less pronounced for Evelyn Branch and Slug Run because the large storage capacity of upstream mine lakes decreases the peak storm runoff for low order floods. This difference is most pronounced after long dry periods, when Big Creek rises significantly in response to rainfall, but both Evelyn Branch and Slug Run remain relatively unaffected.

The ratio of annual runoff per square mile for Big Creek at St. David to that for Big Creek at Bryant ranged from 0.98 to 1.06 and showed no trend. The averages of runoff per square mile for the two stations for the 1971 to 1978 period were sufficiently similar that, given the assumed accuracy of streamflow measurements, no difference could be attributed to conditions in the intervening area.

Regression lines calculated by the least square method (figs. 4 and 5) define sediment transport curves for discharges greater than 10 ft³/s for each of the Big Creek stations. Some of the scatter about the transport curves is caused by differences in sediment-concentrations during the rising and falling limbs of the discharge hydrographs. The dis-

charge and sediment concentration graphs do not peak together, and the suspended-sediment concentration is different for a given value of discharge on the falling limb of the discharge hydrograph than for the same discharge on the rising limb. This is illustrated by the stage and suspended-sediment concentration graphs for the storm of April 9-11, 1978 (fig. 6), at Big Creek near Bryant. This "advanced" sediment concentration peak is the most common of all sediment-concentration hydrographs (Colby, 1956, p. 133) and is typical of both the St. David and Bryant stations. This displacement of peaks occurs because the readily available sediment for erosion and transport is flushed away before peak runoff occurs.

Some of the scatter about the transport curves may also be caused by seasonal factors affecting availability of sediment for transport. The factors include freezing in winter, construction and farming activities in the summer, and the amount of vegetation.

The data points in figures 4 and 5 do not indicate any apparent time trends by years for the period of record. Annual suspended-sediment yields calculated for the Big Creek basin upstream of St. David and for the basin upstream of Bryant

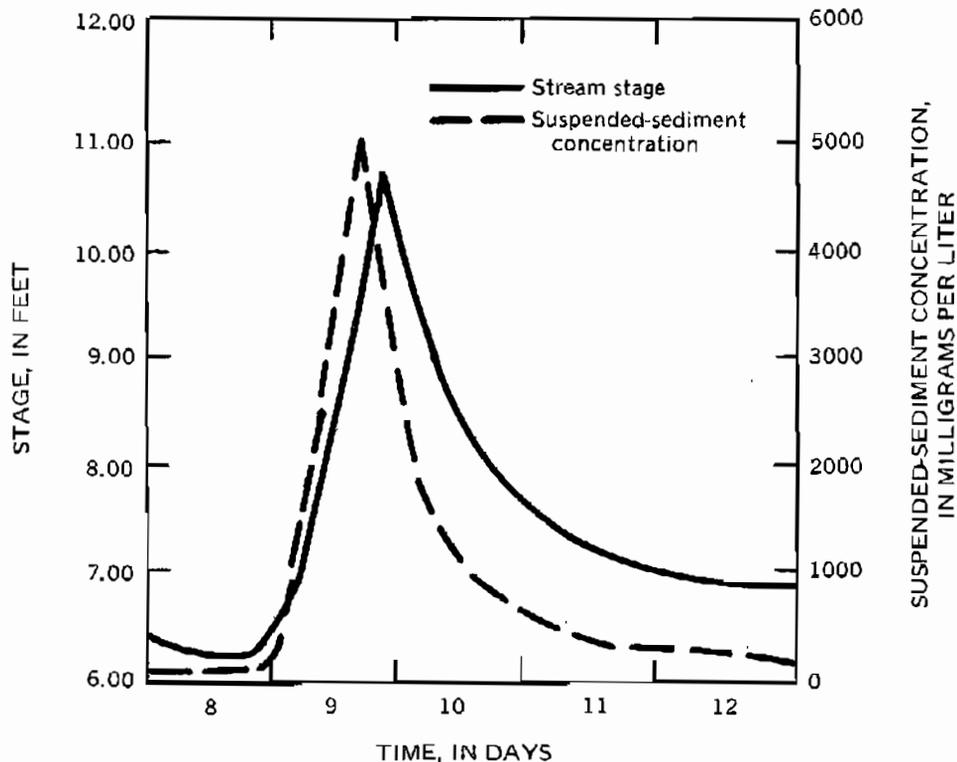


Figure 6. Suspended-sediment concentration and stream stage at Big Creek near Bryant April 8-12, 1978.

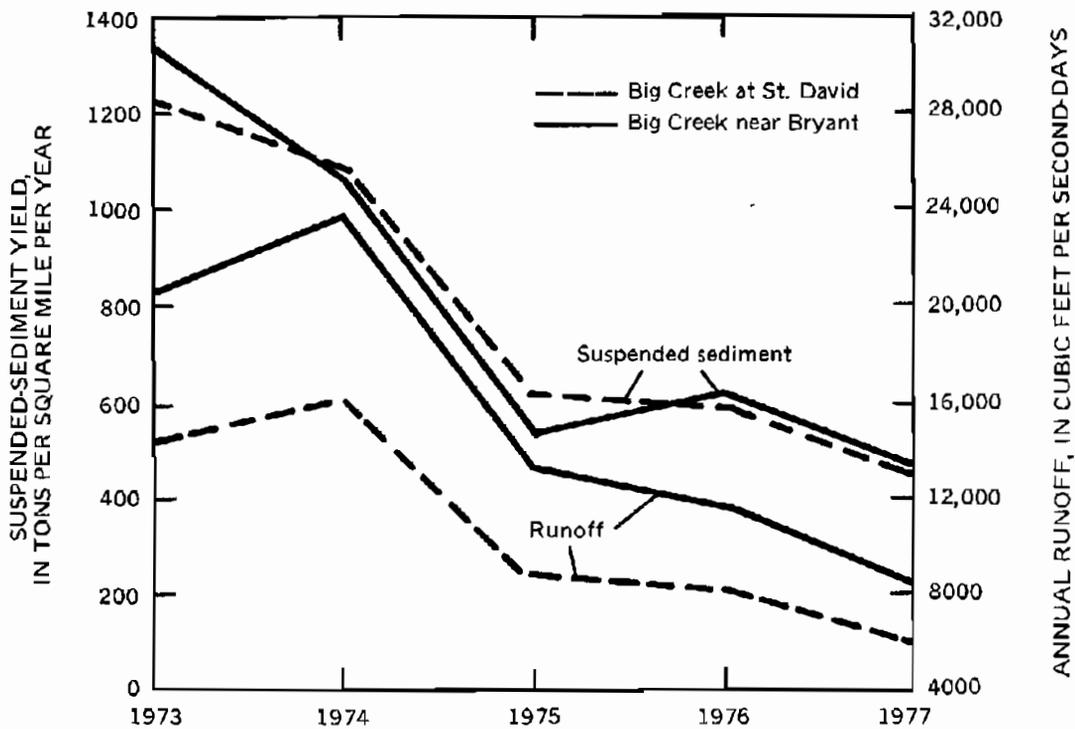


Figure 7. Suspended-sediment yields and stream runoff for Big Creek stations.

(fig. 7) show a general decrease related to a decline in runoff from 1973 to 1977. The slightly higher sediment yield at Bryant in 1976 and 1977 is coincident with bridge construction on roads between the stations. The curves show a range from under 500 to over 1,300 tons of suspended sediment per square mile of drainage area; however, the similarity of the two curves indicates that the sediment contribution to streams from the project site is similar to that from upstream sources.

The quality of water in Big Creek and its tributaries is characterized by relatively high concentrations of dissolved solids, generally greater than 500 mg/L, of which about 50 to 60 percent by mass is sulfate.

Variations in dissolved-solids concentrations are principally related to changes in discharge. Increased discharge results from direct runoff, which is generally lower in dissolved-solids concentration than water discharging to the stream from the ground-water system. Specific conductance is a reliable indicator of the concentration of dissolved solids and sulfate and is similarly related to discharge. The relation between specific conductance and dissolved solids or sulfate (fig. 8) for Slug Run near Bryant can be used with continuously measured specific conductance to estimate changes and

extremes in concentrations of these constituents. Figure 9 shows how conductance decreases as discharge increases in Big Creek at Bryant and figure 10 indicates that the inverse relationship is similar for the Big Creek and Slug Run stations. The discharge-concentration relation for Evelyn Branch is less obvious because of storage and mixing of water in Lake Evelyn.

Analyses of selected chemical constituents in monthly water samples at each of the four surface-water stations are summarized in table 2. The principal cations were sodium, calcium, and magnesium; annual mean concentrations of 12 monthly samples ranged from 68 to 200 mg/L, 100 to 220 mg/L, and 43 to 140 mg/L, respectively. The principal anions were chloride, sulfate, and bicarbonate; annual mean concentrations of 12 monthly samples ranged from 10 to 50 mg/L, 240 to 840 mg/L, and 270 to 420 mg/L, respectively.

Heavy metals and other constituents were generally present in low concentrations, within the recommended Illinois Pollution Control Board general surface-water standards and U.S. Environmental Protection Agency (USEPA) domestic water-supply limits (table 3). Noteworthy exceptions were maximum cadmium concentrations of 400 and 800 mg/L in Big Creek at St. David and Bryant, respec-

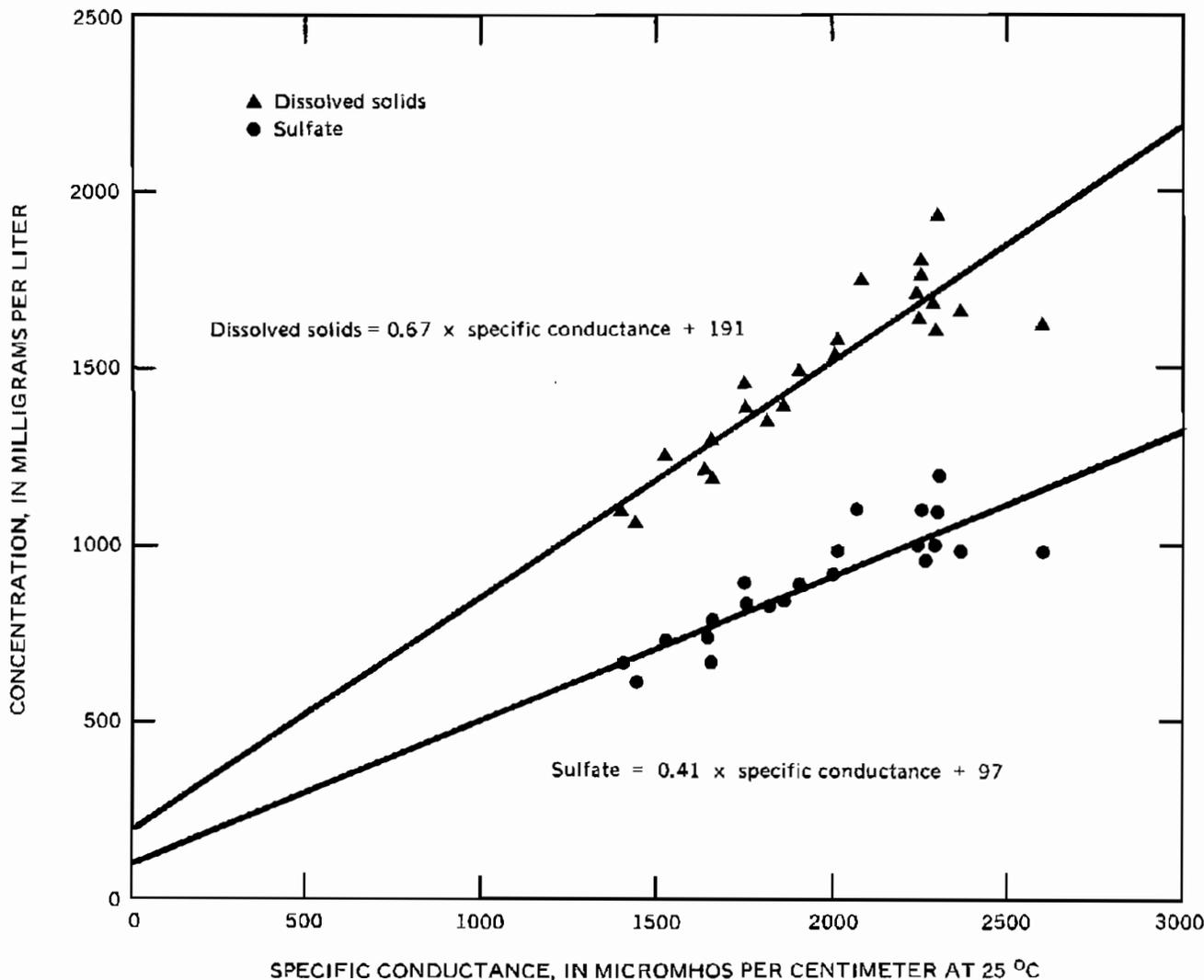


Figure 8. Relation of specific conductance to dissolved solids and sulfate at Slug Run near Bryant.

tively, in 1976. Although these concentrations are high, the means (table 2) for cadmium determinations at the two sites were less than or only slightly higher than surface-water standards (table 3).

Dissolved solids graphs for the four gaging stations (fig 11) show that Big Creek at St. David had the lowest concentrations of dissolved solids and that both Evelyn Branch and Slug Run had relatively high concentrations. The apparent effect of the high concentrations of dissolved solids from Evelyn Branch was to cause higher concentrations downstream from its confluence with Big Creek as shown by the concentration graph for Big Creek near Bryant.

The concentration graphs of sulfate (fig 11) have the same general patterns as the graphs of dissolved solids and indicate that nearly half the dissolved solids, by mass, is attributable to sulfate. Toler (1980) showed that high sulfate concentrations are common in drainage from surface-mined lands. The high concentrations of sulfate in Big Creek and its tributaries are probably similarly related to the surface mining which has been done in the Big Creek drainage basin.

Some of the common constituents do not follow concentration patterns shown by the sulfate and dissolved solids graphs. The concentrations of chlo-

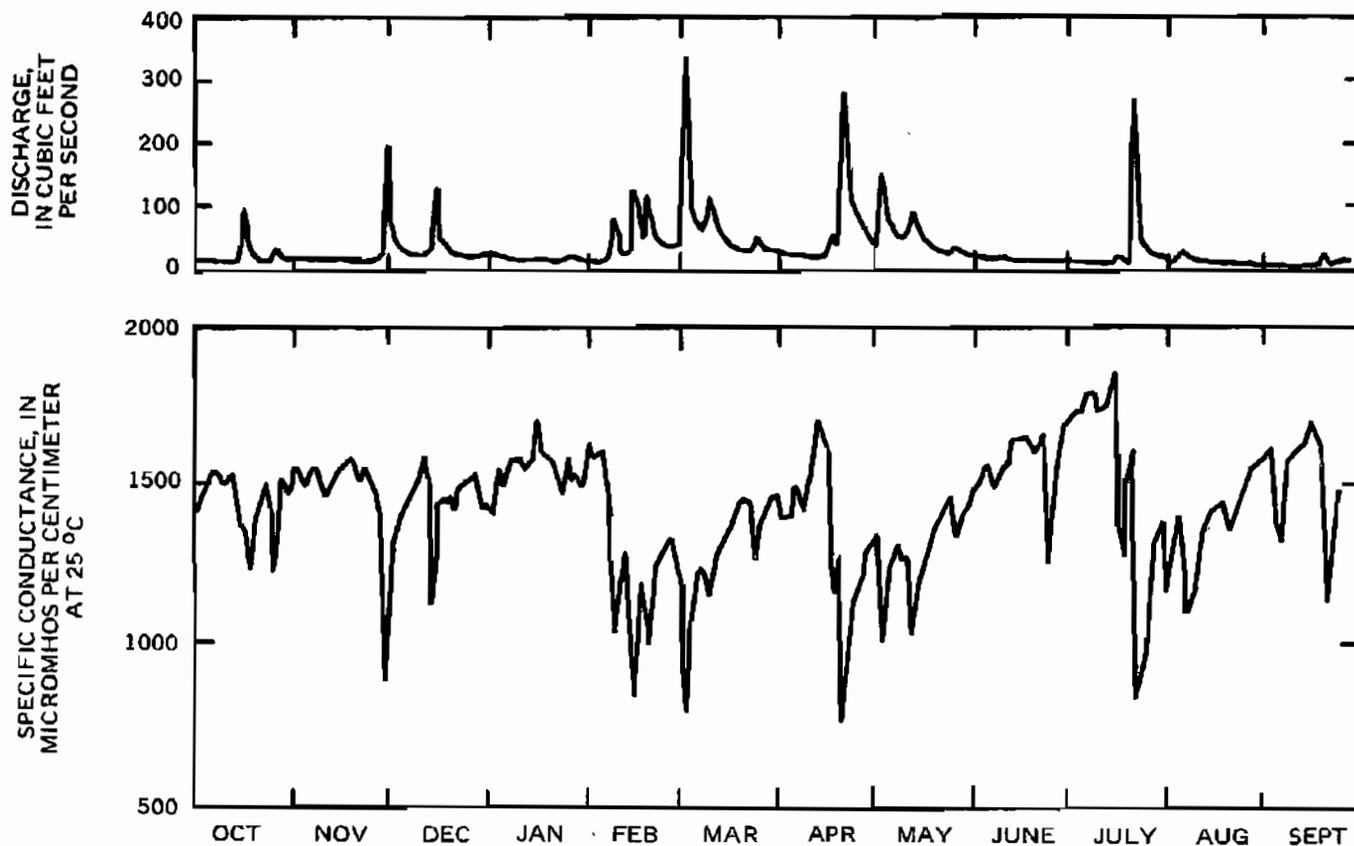


Figure 9. Specific conductance and discharge for Big Creek and Bryant, 1976 water year.

ride (table 2) are generally highest at Big Creek at St. David, probably because of the use of chloride salts for street deicing, water softening, and industrial purposes.

The relative concentrations of sodium for the samples collected at the gaging stations also contrast to the relative concentrations of dissolved solids and sulfate. The concentrations of sodium are 2 to 3 times as high at Evelyn Branch near Bryant as at the other three sites (table 2). This is apparently due in part to the movement of ground water with high sodium concentrations into the lake, and possibly to solution and exchange of sodium from bottom materials in the lake. Sodium concentrations in the sludge and supernatant are too low to be considered a cause of high sodium concentrations in Evelyn Branch. Other constituents are generally higher at the Big Creek stations, both upstream and downstream from the project area. The high concentration and high discharge in Big Creek make it extremely difficult to assess any changes caused by tributary inflow from monthly samples. No effects on Big Creek attributable to the sludge application can be detected with the available data.

Stream bottom sediments were sampled annually at each gaging station during low-flow periods for analyses of selected constituents (table 4). Most nutrient and minor element concentrations decreased or remained constant between 1975 and 1977. Increases in the concentrations of phosphorus were noted between 1975 and 1977 in Big Creek both at St. David and near Bryant and at Slug Run near Bryant. The most significant increases in phosphorus were from 370 to 2,000 mg/kg at the St. David station, upstream from the reclamation activities. Concentration of manganese increased from 410 to 620 $\mu\text{g/g}$ at St. David, but decreased at all other stations.

Bottom materials were sampled within, at the outlet, and downstream from two runoff-retention basins that collect surface runoff from sludge application fields 16 and 36 (fig. 2). The concentration of all constituents (table 4) are of the same magnitude, or less, than the concentrations of bottom materials at the stream sites, including the Slug Run site, where no sludge was applied.

**Table 2. Summary of chemical analyses of whole water samples
of surface water from 1975 to 1977.
(means are an arithmetic average of 12 monthly samples)**

Big Creek at St. David

Constituent or Property	Units	1975			1976			1977		
		Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.
pH	--	--	8.3	7.6	--	8.3	7.3	--	8.0	6.2
Phosphorus, as P	mg/L	0.70	1.1	0.11	1.20	2.2	.47	0.68	1.6	.29
Chloride (Cl)	mg/L	41	110	22	35	47	20	50	140	31
Sulfate (SO ₄)	mg/L	360	550	130	320	460	160	240	600	1108
Nitrogen, Kjeldahl, as N	mg/L	2.5	3.9	1.0	1.5	3.5	.70	1.3	2.8	<1.0
Ammonia, as N	mg/L	1.7	3.1	.50	.76	1.8	0	.50	2.2	<1.0
Nitrite + Nitrate, as N	mg/L	2.0	3.2	.94	2.6	3.7	1.3	3.4	9.2	.88
Alkalinity as CaCO ₃	mg/L	250	300	170	310	1,030	200	220	300	160
Bicarbonate ¹ as HCO ₃	mg/L	310	370	210	380	1,250	250	270	370	190
Specific Conductance	µmhos/cm	970	1,250	700	840	1,140	210	820	1,000	600
Potassium (K)	mg/L	4	5	3	5	7	3	5	6	4
Sodium (Na)	mg/L	72	96	51	68	97	40	68	110	47
Calcium (Ca)	mg/L	110	150	84	130	170	57	110	200	81
Magnesium (Mg)	mg/L	59	83	42	55	65	39	43	53	35
Zinc (Zn)	µg/L	0	0	0	0	100	0	<100	100	<100
Cadmium (Cd)	µg/L	0	0	0	40	400	0	<10	<10	<10
Copper (Cu)	µg/L	10	40	0	0	40	0	<10	<10	<10
Chromium (Cr)	µg/L	0	20	0	0	10	0	<20	<20	<20
Nickel (Ni)	µg/L	20	200	0	0	0	0	<10	<10	<10
Manganese (Mn)	µg/L	2,000	18,000	390	520	740	340	470	710	210
Lead (Pb)	µg/L	070	0	40	110	0	30	100	<30	
Iron (Fe)	µg/L	2,000	10,800	500	1,600	5,400	600	1,500	3,200	200
Aluminum (Al)	µg/L	2,800	21,000	0	2,000	8,000	0	2,000	9,000	<1,000
Mercury (Hg)	µg/L	0.08	0.06	0	0	0	0	<.1	.2	<.1
Dissolved Solids	mg/L	1,100	2,250	790	968	1,160	634	821	918	640

Evelyn Branch near Bryant

Constituent or Property	Units	1975			1976			1977		
		Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.
pH	--	--	8.3	7	--	8.5	7.7	--	10	7
Phosphorus, as P	mg/L	.18	.80	0.05	.14	.28	.05	.08	.15	.04
Chloride (Cl)	mg/L	20	36	13	22	40	15	37	140	16
Sulfate (SO ₄)	mg/L	720	960	270	620	1,100	21	628	1,300	300
Nitrogen, Kjeldahl, as N	mg/L	1.2	2.2	0	1.0	1.5	.30	1.1	2.6	.50
Ammonia, as N	mg/L	.42	1.1	.10	.24	.80	0	.20	1.4	<.10
Nitrite + Nitrate, as N	mg/L	1.3	3.8	.02	1.3	4.3	0	1.6	2.9	.05
Alkalinity as CaCO ₃	mg/L	340	900	200	290	490	150	280	390	200
Bicarbonate ¹ as HCO ₃	mg/L	410	1,100	240	350	500	190	340	480	240
Specific Conductance	µmhos/cm	1,450	2,000	500	1,580	2,900	1,250	1,270	2,000	900
Potassium (K)	mg/L	8	10	3	9	11	7	9	12	8
Sodium (Na)	mg/L	190	220	150	200	240	150	170	260	98
Calcium (Ca)	mg/L	150	200	96	150	180	110	130	190	83
Magnesium (Mg)	mg/L	110	140	89	100	130	41	88	140	63
Zinc (Zn)	µg/L	0	0	0	0	100	0	<100	<100	<.1
Cadmium (Cd)	µg/L	0	0	0	0	20	0	<10	<10	<10
Copper (Cu)	µg/L	10	20	0	80	150	20	70	180	<10
Chromium (Cr)	µg/L	10	40	0	0	0	0	<20	<20	<20
Nickel (Ni)	µg/L	20	300	0	0	0	0	<100	<100	<100
Manganese (Mn)	µg/L	220	410	70	230	570	80	210	420	50
Lead (Pb)	µg/L	20	130	0	20	50	0	40	130	<10
Iron (Fe)	µg/L	320	600	100	300	80	0	300	800	<100
Aluminum (Al)	µg/L	400	1,000	0	500	2,000	0	<1,000	2,000	<1,000
Mercury (Hg)	µg/L	0.03	0.2	0	0	0.5	0	<.1	<.1	<.1
Dissolved Solids	mg/L	1,620	2,190	1,040	1,740	2,050	1,510	1,420	2,290	998

¹ HCO₃ as calculated by dividing alkalinity (in mg/L) by 0.8202 (Hem, 1970, p. 84).

Table 2. Summary of chemical analyses of whole water samples of surface water from 1975 to 1977--Continued.
(means are an arithmetic average of 12 monthly samples)

Big Creek near Bryant

Constituent or Property	Units	1975			1976			1977		
		Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.
Ph	--	-	8.3	7.4*	--	8.3	7.6	--	8.3	6.9
Phosphorus, as P	mg/L	.48	.87	.13	.70	1.6	.20	.45	.85	.23
Chloride (Cl)	mg/L	32	50	18	31	48	20	44	150	20
Sulfate (SO ₄)	mg/L	550	800	420	430	600	260	340	590	140
Nitrogen, Kjeldahl, as N	mg/L	1.6	2.5	.70	.88	1.4	0	.90	1.7	<1.0
Ammonia, as N	mg/L	.90	1.9	.30	.30	.80	0	.30	1.1	<.10
Nitrite + Nitrate, as N	mg/L	1.9	3.4	.25	1.8	4.4	0	2.5	3.5	.81
Alkalinity as CaCO ₃	mg/L	290	480	200	350	1,250	220	250	530	140
Bicarbonate ¹ , as HCO ₃	mg/L	350	590	240	420	1,520	270	300	640	
Specific Conductance	µmhos/cm	1,140	1,650	870	1,040	1,490	515	843	1,100	575
Potassium (K)	mg/L	5	6	3	6	8	4	5	6	1
Sodium (Na)	mg/L	84	100	61	88	120	50	75	120	54
Calcium (Ca)	mg/L	140	170	110	160	200	130	120	150	90
Magnesium (Mg)	mg/L	71	91	58	70	82	54	50	62	39
Zinc (Zn)	µg/L	0	0	0	20	100	0	<100	<100	<100
Cadmium (Cd)	µg/L	0	0	0	70	800	0	<10	<10	<10
Copper (Cu)	µg/L	10	30	0	0	20	0	<10	<20	<10
Chromium (Cr)	µg/L	0	20	0	0	10	0	20	20	20
Nickel (Ni)	µg/L	20	300	0	0	0	0	<100	<100	<100
Manganese (Mn)	µg/L	1,950	17,000	360	550	1,070	320	460	870	110
Lead (Pb)	µg/L	40	120	0	30	100	0	100	60	<30
Iron (Fe)	µg/L	2,020	11,900	600	1,550	6,400	500	1,300	--	100
Aluminum (Al)	µg/L	2,400	20,000	0	1,400	9,000	0	1,300	4,000	<1,000
Mercury (Hg)	µg/L	0.08	0.40	0	0	0	0	<0.1	<0.2	<0.1
Dissolved Solids	mg/L	1,290	2,610	1,000	1,220	1,660	912	880	1,130	624

Slug Run near Bryant

Constituent or Property	Units	1975			1976			1977		
		Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.
Ph	--	--	8.5	7.7	--	8.3	7.8	--	8.3	7.4
Phosphorus, as P	mg/L	.16	.89	.05	.11	.22	.01	.06	.17	.02
Chloride (Cl)	mg/L	17	56	7	16	52	9	10	12	8
Sulfate (SO ₄)	mg/L	810	1,550	110	720	1,730	190	840	1,680	590
Nitrogen, Kjeldahl, as N	mg/L	0.86	3.4	0	.63	1.7	.10	.60	2.1	<1.0
Ammonia, as N	mg/L	.41	3.3	0	.10	.40	0	<1.0	.20	<.10
Nitrite + Nitrate, as N	mg/L	.10	.25	.04	.07	.14	0	.15	.59	<.01
Alkalinity as CaCO ₃	mg/L	290	380	210	290	360	220	260	360	190
Bicarbonate ¹ , as HCO ₃	mg/L	350	460	260	360	440	270	310	440	230
Specific Conductance	µmhos/cm	1,530	1,800	1,250	1,410	1,800	1,180	1,360	2,600	150
Potassium (K)	mg/L	6	7	5	7	8	5	6	8	5
Sodium (Na)	mg/L	70	88	61	77	140	59	73	96	50
Calcium (Ca)	mg/L	190	260	40	220	280	160	210	310	150
Magnesium (Mg)	mg/L	130	150	110	140	200	110	130	180	98
Zinc (Zn)	µg/L	0	0	0	0	0	0	<100	<100	<100
Cadmium (Cd)	µg/L	0	0	0	0	30	0	<10	<10	<10
Copper (Cu)	µg/L	10	20	0	0	10	0	<10	<10	<10
Chromium (Cr)	µg/L	0	20	0	0	0	0	<20	<30	<20
Nickel (Ni)	µg/L	0	0	0	0	0	0	<100	<100	<100
Manganese (Mn)	µg/L	500	760	210	570	1,100	220	640	1,280	320
Lead (Pb)	µg/L	30	70	0	30	80	0	20	80	<30
Iron (Fe)	µg/L	500	1,100	0	700	2,400	200	800	1,600	180
Aluminum (Al)	µg/L	600	2,000	0	400	1,000	0	<1,000	2,000	<1,000
Mercury (Hg)	µg/L	0.06	0.24	0	0	0	0	<0.1	<0.2	<0.1
Dissolved Solids	mg/L	1,580	1,980	848	1,900	2,160	1,540	1,890	3,320	1,190

¹ HCO₃ was calculated by dividing alkalinity (in mg/L) by 0.8202 (Hem, 1970, p. 84).

Table 3. Recommended water quality standards and criteria.

Constituent or Property	Units	Illinois	USEPA Criteria
		Pollution Control Board Standards for Surface Waters ¹	for Domestic Water Supply ²
Arsenic (total)	µg/L	1,000	50
Boron (total)	µg/L	1,000	--
Cadmium (total)	µg/L	50	10
Chloride	mg/L	500	--
Chromium (total hexavalent)	µg/L	50	50
Chromium (total trivalent)	µg/L	1,000	--
Copper (total)	µg/L	20	1,000
Dissolved solids	mg/L	1,000	--
Iron (total)	µg/L	1,000	300
Lead (total)	µg/L	100	50
Manganese (total)	µg/L	1,000	50
Mercury (total)	µg/L	50	2.0
Nitrogen, ammonia	mg/L	1.5	--
Nitrogen, nitrate	mg/L	--	10
Nitrogen, nitrite	mg/L	--	1
Nickel	µg/L	1,000	--
pH	--	6.5-9.0	--
Phosphorus (as P)	mg/L	0.05	--
Sulfate	mg/L	500	--
Zinc	µg/L	1,000	5,000

¹ Illinois Pollution Control Board, 1977, p. 7.

² U.S. Environmental Protection Agency, 1976.

Stream bottom materials were also analyzed for synthetic organic compounds. Those compounds detected at trace concentrations were chlordane, DDD, DDE, Dieldrin, PCB's, parathion, methyl parathion, silvex, trithion, and methyl trithion, most of which were not detected in analyses of the sludge.

Ground Water

Water levels from 70 wells and several lakes within and adjacent to the project site were used to prepare a water-table contour map (fig. 12) (Fuentes and Patterson, 1979). The water-table contours generally reflect the local topography.

Hydrographs of monthly water levels for representative monitoring wells in unmined and mined areas (fig. 13) reflect some effects of differences in the material in which the wells are finished. Based on the type of material (mine spoil or unmined material) and the location of the well with respect to the nearest ground-water discharge area (such as abrupt topographic depressions, streams or strip-mine lakes), the wells can be separated into

four categories: (1) wells in **unmined material away from discharge areas**, (2) wells in **mine spoil away from discharge areas**, (3) wells in **unmined material near discharge areas**, and (4) wells in **mine spoil near discharge areas**.

Water level data for wells which are representative of the four categories are summarized in table 5. Wells in unmined material away from discharge areas show the largest fluctuations; wells in mine spoil away from discharge areas show the next largest fluctuations, just slightly greater than wells in unmined material near discharge areas. Wells in mine spoil near discharge areas show the smallest fluctuations. The mean depth to water is also related to the above physical conditions, being greater in mine spoil than in unmined material and greater near discharge areas (table 5).

Figure 14 helps to illustrate the probable causes of the differences in the above categories. For a given amount of precipitation, the water level rises in the shallow aquifer by an amount dependent on the infiltration characteristics and porosity of the aquifer materials. The disturbed nature of the mine spoil causes it to be less compacted, and therefore

Table 4. Nutrient and trace-element concentrations

		Nitrite plus Nitrate (mg/kg)	Ammonia, (mg/kg)	Nitrogen, Kjeldahl, (mg/kg)	Phosphorus (mg/kg)	Arsenic ($\mu\text{g/g}$)	Cadmium ($\mu\text{g/g}$)
Big Creek at St. David	May 1, 1975	34	37	1,000	370	11	4
	June 9, 1976	20	20	520	560	14	0
	June 15, 1977	2.4	32	2,900	2,000	11	<10
Evelyn Branch near Bryant	April 30, 1975	35	62	1,400	290	12	1
	June 10, 1976	35	55	770	660	26	0
	June 15, 1977	1.8	50	1,400	310	19	<10
Big Creek near Bryant	May 1, 1975	16	33	1,100	320	10	1
	June 9, 1976	30	28	580	420	11	0
	June 15, 1977	2.3	8.7	970	700	13	<10
Slug Run near Bryant	April 30, 1975	26	28	1,100	210	17	1
	June 9, 1976	28	34	880	480	10	0
	June 15, 1977	2.1	33	4,200	480	19	<10
Field 16, April 15, 1977	Retention Basin	16	24	1.0	760	--	2
	Below Outlet	0	12	0.7	360	--	1
	Downstream	4.9	6.3	0.4	570	--	0
Field 36, April 15, 1977	Retention Basin	0.9	71	2.0	1,000	--	12
	Below Outlet	11	--	4.3	1,300	--	0
	Downstream	0.9	5.4	0.5	360	--	0

both the infiltration rates and the porosity are increased. Although more water infiltrates the mine spoil for a given amount of precipitation, the greater porosity results in a smaller rise in ground-water levels than that in less porous unmined material. The disturbed materials also have a greater permeability than the undisturbed material; therefore, the water moves more quickly to a discharge area.

The above characteristics, along with the direction of ground-water movement inferred from the water-table contour map (fig. 12), must be considered in designing the effective placement and spacing of a well network for monitoring ground-water quality.

Samples of water from private wells near the site were used to represent baseline ground-water quality before either mining or sludge irrigation. Wells in mine spoil but isolated from sludge irrigation provided samples for use in assessing the wa-

ter-quality effects of surface mining. Comparison of these analyses (table 6) reveals significant differences in the chemical characteristics of water from mined and unmined land and supports the conclusions of Pietz, Peterson, and Lue-Hing (1974, p. 142). They state that, "the significantly higher electrical conductivity (E.C.) and concentrations of Cl^- , SO_4 , Kjeldahl-N, K, Na, Ca, Mg, Zn, Cd, Cr, Ni, Mn, Pb, and Fe observed in mine-spoil ground waters were a reflection of the altered chemical-physical composition of heterogeneous mine-spoil materials." They also reported that some constituents exceeded public supply recommendations and that ground water in mined areas had greater monthly and seasonal chemical changes than in unmined areas. Comparing concentrations of chemical constituents in ground-water (table 6) with the water-quality standards and criteria (table 3) shows that water from both unmined and mined land exceeded USEPA domestic water-supply criteria for zinc, manganese, lead, and iron.

In bottom sediments in Big Creek basin.

Chromium ($\mu\text{g/g}$)	Cobalt ($\mu\text{g/g}$)	Copper ($\mu\text{g/g}$)	Iron ($\mu\text{g/g}$)	Lead ($\mu\text{g/g}$)	Manganese ($\mu\text{g/g}$)	Mercury ($\mu\text{g/g}$)	Zinc ($\mu\text{g/g}$)
23	18	16	15,000	19	410	.0	70
6	6	8	20,000	24	430	.0	56
10	<10	10	4,500	<10	620	.0	50
30	10	14	13,000	20	1,300	.0	59
4	9	7	22,000	32	1,100	.0	56
<10	<10	<10	1,000	<10	350	.0	20
32	10	16	16,000	22	680	.0	110
4	7	7	21,000	11	970	.0	65
<10	<10	<10	2,000	<10	620	.0	30
26	11	14	18,000	29	950	.0	--
9	14	14	31,000	26	1,400	.0	--
10	<10	10	5,000	<10	880	.0	--
27	--	20	12,000	21	520	--	70
27	--	15	6,800	17	420	--	50
18	--	10	8,800	20	1,200	--	50
180	--	100	14,000	62	390	--	360
9	--	20	13,000	18	930	--	290
5	--	10	8,200	14	870	--	20

The chemical constituents in water samples collected monthly from January to December 1977 (table 6) were from wells representative of four hydrologic environments categorized by land type and proximity to sludge application fields:

- **unmined land isolated** from sludge application fields;
- **unmined land near** sludge application fields;
- **surface-mined land isolated** from sludge application fields;
- **surface-mined land near** sludge application fields.

Most of the sludge fields are located on mined land, and wells therein can be expected to show effects of both mining and sludge application. However, some of the wells near sludge fields on

unmined land may also be affected by nearby mine spoil. Concentrations of iron and manganese were highest in surface-mined land isolated from sludge application, with mean concentrations of 80,300 and 3,000 $\mu\text{g/L}$, respectively. Lowest mean concentrations of iron and manganese were 1300 and 60 $\mu\text{g/L}$ respectively, in unmined land isolated from sludge application. Concentrations of zinc and aluminum were highest in unmined land near sludge application, with mean concentrations of 5,300 and 3,800 $\mu\text{g/L}$, respectively. Lowest mean concentrations of zinc and aluminum were 100 $\mu\text{g/L}$ zinc, in unmined land isolated from sludge application, and 30 $\mu\text{g/L}$ aluminum, in surface-mined land isolated from sludge application.

Mean concentrations of cadmium, copper, chromium, nickel, and mercury in all four environments were within the suggested USEPA limits for domestic supplies (table 3); however, the maximum concentrations sometimes exceeded these standards.

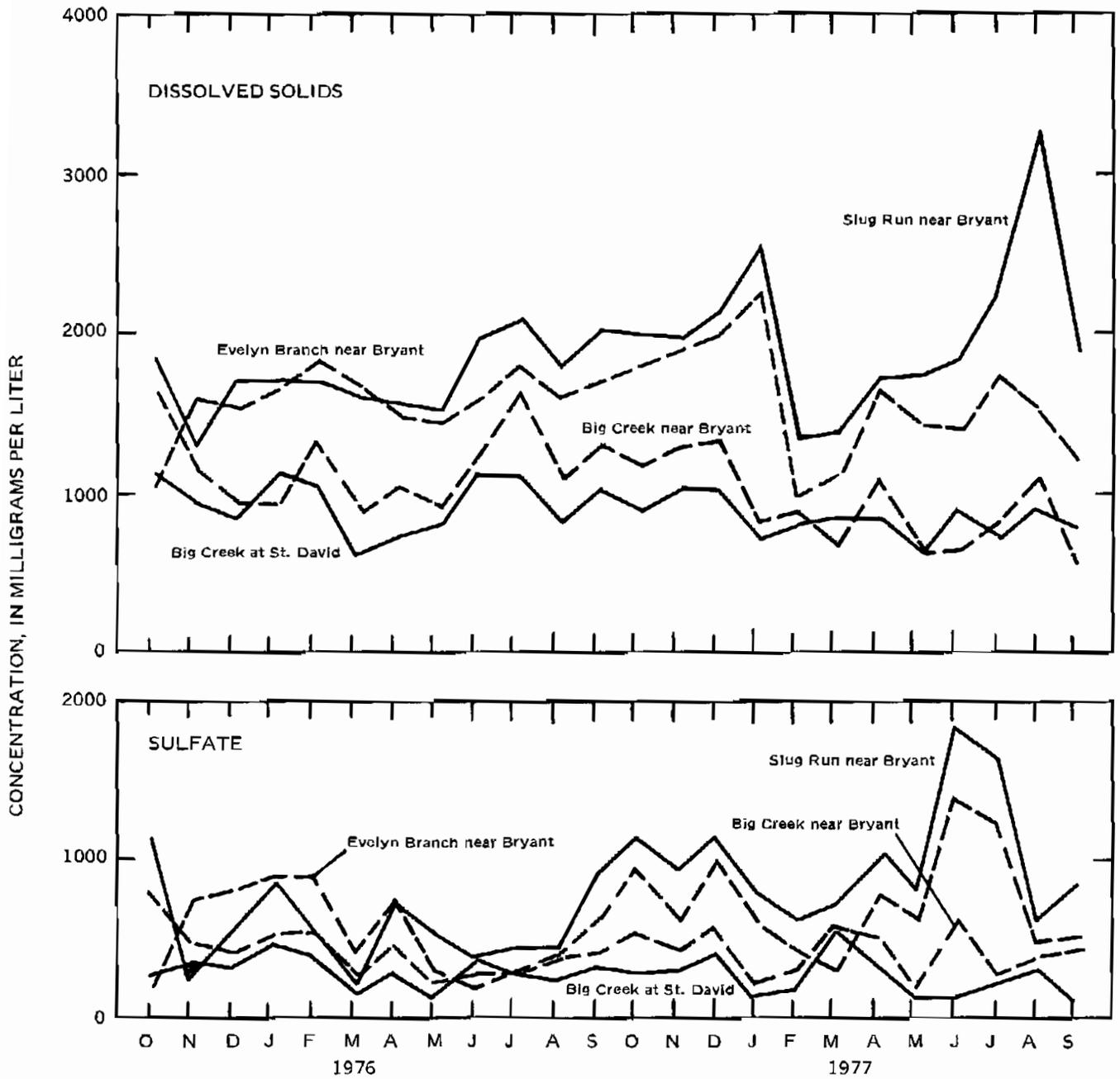


Figure 11. Dissolved-solids and sulfate concentrations and gaging stations in Big Creek drainage basin.

Table 5. Mean monthly water-table fluctuations and depth from February 1977 to May 1978.

Parameter	Unmined land			Mined land			Total Wells	
	All wells (16 wells)	Near discharge (7 wells)	Far from discharge (9 wells)	All wells (9 wells)	Near discharge (11 wells)	Far from discharge (8 wells)	All wells far from discharge (17 wells)	All wells near discharge (18 wells)
Mean monthly fluctuation (in feet)	1.65	1.21	2.00	0.92	0.61	1.33	1.67	0.91
Mean maximum fluctuation (in feet)	4.48	3.72	4.82	2.81	1.93	4.02	4.42	2.83
Percent of monthly fluctuations greater than 2 feet	32.6	16.2	40.2	13.5	3.3	23.2	31.7	9.8
Mean depth to water (in feet)	14.98	22.00	9.50	29.51	31.38	27.08	18.29	25.69

Mean concentrations of lead exceeded the USEPA limits in all environments except unmined land isolated from sludge fields.

Phosphorus and nitrogen generally occurred in low concentrations; however, concentrations of phosphorus, up to 2.5 mg/L, and nitrogen, up to 23 mg/L, were found in some samples. High phosphorus concentrations occurred in well 16 during the winter of 1976-77, before sludge or supernatant was applied to the adjacent field. The highest concentrations of nitrogen occurred as nitrate plus nitrite in wells in unmined land, both near and isolated from sludge. The high values found in many of the farm wells were probably due to surface contamination from nearby animal pens.

In all four hydrologic environments, calcium, magnesium, and sodium were the principal cations, and sulfate and bicarbonate were the principal anions. The concentration of calcium and magnesium was 3 to 5 times greater and the concentration of sulfate was 10 to 15 times greater in mined land than in unmined land. Magnesium and calcium sulfate was the predominant water type in mined land, and calcium bicarbonate was the predominate type in unmined land.

Concentrations of sulfate in monthly samples during 1976-78 are shown in figure 15 for wells in each of the four land-use types. The high variability of sulfate concentrations in water from wells in surface-mined land is one of the more pronounced effects of mining on water quality. Concentrations

of dissolved solids (table 6) are also higher in the mined area, and changes in dissolved solids are largely caused by changes in the concentration of sulfate.

Trilinear diagram plots of analyses of water samples (fig 16) collected in November 1977 suggest four water types related to source: (I) water with low concentrations of dissolved solids from unmined lands; (II) water with high concentrations of dissolved solids from surface-mined lands; (III) water with high concentrations of dissolved solids and relatively high percentages of sodium and chloride from deep bedrock wells; and (IV) waters with high concentrations of dissolved solids, from mined and unmined lands, and intermediate in cation composition between group I or II or III.

Analyses of various mixtures of two different waters should plot along a straight line within the trilinear diagram (Hem, 1970, p. 268). The graphs suggest a possibility of mixing: (1) between groups I and II, where water analyses from both mined land and unmined land plot along a common line and (2) between groups II and IV where water from mined and unmined lands seem to be mixing with water containing a lower concentration of calcium and magnesium. Although sorption and exchange of ions between the water and the aquifer materials may cause some scatter of data points, the graph suggests that water moves from one environment to another.

Table 6. Summary of chemical analyses of ground water, 1977.
(includes data for filtered and whole-water samples)

Unmined Land							
Constituent or Property	Units	Isolated from sludge fields ¹			Near sludge fields ²		
		Mean	Max.	Min.	Mean	Max.	Min.
ph	--	--	7.9	7.3	--	8.1	6.9
Phosphorus, as P	mg/L	.09	.15	.02	.15	2.5	0
Chloride (Cl)	mg/L	19	61	2.0	26	170	4.0
Sulfate (SO ₄)	mg/L	62	170	0	62	400	0
Nitrogen,							
Kjeldahl, as N	mg/L	.32	1.2	0	.76	5.0	<.01
Ammonia, as N	mg/L	.04	.80	<.1	.30	.90	<.01
Nitrite + Nitrate,							
as N	mg/L	4.7	12	.07	2.0	23	0
Alkalinity as CaCO ₃	mg/L	340	460	300	380	560	170
Bicarbonate ⁵ , as HCO ₃	mg/L	410	560	370	460	680	210
Specific Conductance	μmhos/cm	--	850	450	--	770	450
Potassium (K)	mg/L	2	20	0	2	8	1
Sodium (Na)	mg/L	17	57	7.0	30	150	3.0
Calcium (Ca)	mg/L	110	190	88	88	180	28
Magnesium (Mg)	mg/L	51	98	37	44	62	31
Zinc (Zn)	μg/L	100	600	0	5,300	105,000	0
Cadmium (Cd)	μg/L	0	0	0	0	40	0
Copper (Cu)	μg/L	60	310	0	0	290	0
Chromium (Cr)	μg/L	0	30	0	0	60	0
Nickel (Ni)	μg/L	0	0	0	0	100	0
Manganese (Mn)	μg/L	60	280	0	560	2,600	0
Lead (Pb)	μg/L	20	150	0	100	910	0
Iron (Fe)	μg/L	1,300	6,000	0	21,500	282,000	0
Aluminum (Al)	μg/L	100	1,000	0	3,800	84,000	0
Mercury (Hg)	μg/L	0	.1	0	0	.4	0

Analysis of the variance was done to determine if statistically significant differences could be found between waters from mined and unmined land and between water near and away from sludge fields. The items tested were: sulfate, kjeldahl nitrogen, ammonia, alkalinity, potassium, sodium, calcium, magnesium, manganese, iron, total phosphorus, chloride, zinc, and lead. A computer program developed by SAS Institute Incorporated (1979) was used to do the analyses.

The 0.01 level of significance was selected as the criterion for assigning a statistical difference between the mined and unmined waters and between the waters near and away from sludge fields. The selection of the more restrictive significance level (0.01) as opposed to a lesser one was made for the following reasons:

- There was uncertainty about the areal extent of the effects of mining (see page 42).

- Some of the data available for analysis did not rigorously meet the assumptions underlying the analysis (the data did not have an approximately normal distribution in many cases).

- The mine spoils were of varying age and thus varying chemical composition.

At the selected level of significance (0.01) no differences could be attributed to sludge application. On the other hand, several constituents and alkalinity showed differences attributed to effects of mining. Those showing effects of mining at the 0.01 significance level were: sulfate, kjeldahl nitrogen, alkalinity, potassium, sodium, calcium, magnesium

Table 6. Summary of chemical analyses of ground water, 1977--Continued.
(includes data for filtered and whole-water samples)

Constituent or Property	Units	Mined Land					
		Isolated from sludge fields ³			Near sludge fields ⁴		
		Mean	Max.	Min.	Mean	Max.	Min.
pH	--	--	7.9	6.5	--	8.8	6.8
Phosphorus, as P	mg/L	.05	.22	7.0	.05	.30	0
Chloride (Cl)	mg/L	17	25	7.0	16	29	4.0
Sulfate (SO ₄)	mg/L	1,600	2,700	<1	990	3,200	<1
Nitrogen, Kjeldahl, as N	mg/L	1	4.6	<.1	1.3	5.0	<.10
Ammonia, as N	mg/L	.66	2.8	.1	.94	3.9	.1
Nitrite + Nitrate as N	mg/L	.31	6.8	0	.11	1.61	0
Alkalinity as CaCO ₃	mg/L	450	620	84	600	1,260	57
Bicarbonate ⁵ , as HCO ₃	mg/L	550	760	100	730	1,540	69
Specific Conductance	µmhos/cm	--	3,800	2,000	--	4,400	450
Potassium (K)	mg/L	6.7	12	1	8	27	1
Sodium (Na)	mg/L	92	260	31	200	620	15
Calcium (Ca)	mg/L	450	680	130	250	600	15
Magnesium (Mg)	mg/L	260	650	47	160	430	31
Zinc (Zn)	µg/L	3,300	20,100	0	3,400	66,000	0
Cadmium (Cd)	µg/L	<10	40	0	0	30	0
Copper (Cu)	µg/L	9	70	0	30	170	0
Chromium (Cr)	µg/L	0	20	0	0	120	0
Nickel (Ni)	µg/L	0	200	0	0	400	0
Manganese (Mn)	µg/L	3,300	12,000	110	2,200	7,700	<10
Lead (Pb)	µg/L	70	190	0	70	500	0
Iron (Fe)	µg/L	80,300	177,000	0	20,900	445,000	0
Aluminum (Al)	µg/L	30	103,000	0	2,700	78,000	0
Mercury (Hg)	µg/L	0	.4	0	<.1	.4	0

¹ 21 analyses from 21 wells.

² 53 analyses from 6 wells.

³ 30 analyses from 4 wells.

⁴ 107 analyses from 14 wells.

⁵ HCO₃ was calculated by dividing alkalinity (in milligrams per liter) by 0.8202 (Hem, 1970, p. 84).

and manganese. All of the above except alkalinity are included in list of constituents for which differences between mined and unmined land were found by Pietz, Peterson and Lue-Hing (1974, p. 142).

All constituents found significantly different at the 0.01 level (between mined and unmined land) were higher in mined land (table 6) except chloride which was higher in unmined land.

Many components of sludge are thought to be selectively sorbed onto soil or spoil particles. Therefore, a mobile and conservative tracer was sought to detect water-quality differences attributa-

ble to sludge application. Boron was considered for this purpose because it is present in the sludge, is thought to move more rapidly through soil than most other trace elements (Page, 1974, p. 67), and is thought not to be present in appreciable amounts in any naturally occurring earth materials in Illinois (Nienkirk and Flemal, 1976, p. 16). Fourteen wells were sampled for boron analyses during November 1977 (table 7), four of which greatly exceeded the expected low concentrations and prompted further sampling in February, March, and April 1978. The samples collected in April 1978, including those from Big Creek near Bryant and Slug Run, had high boron concentrations exceeding Illinois Pollution

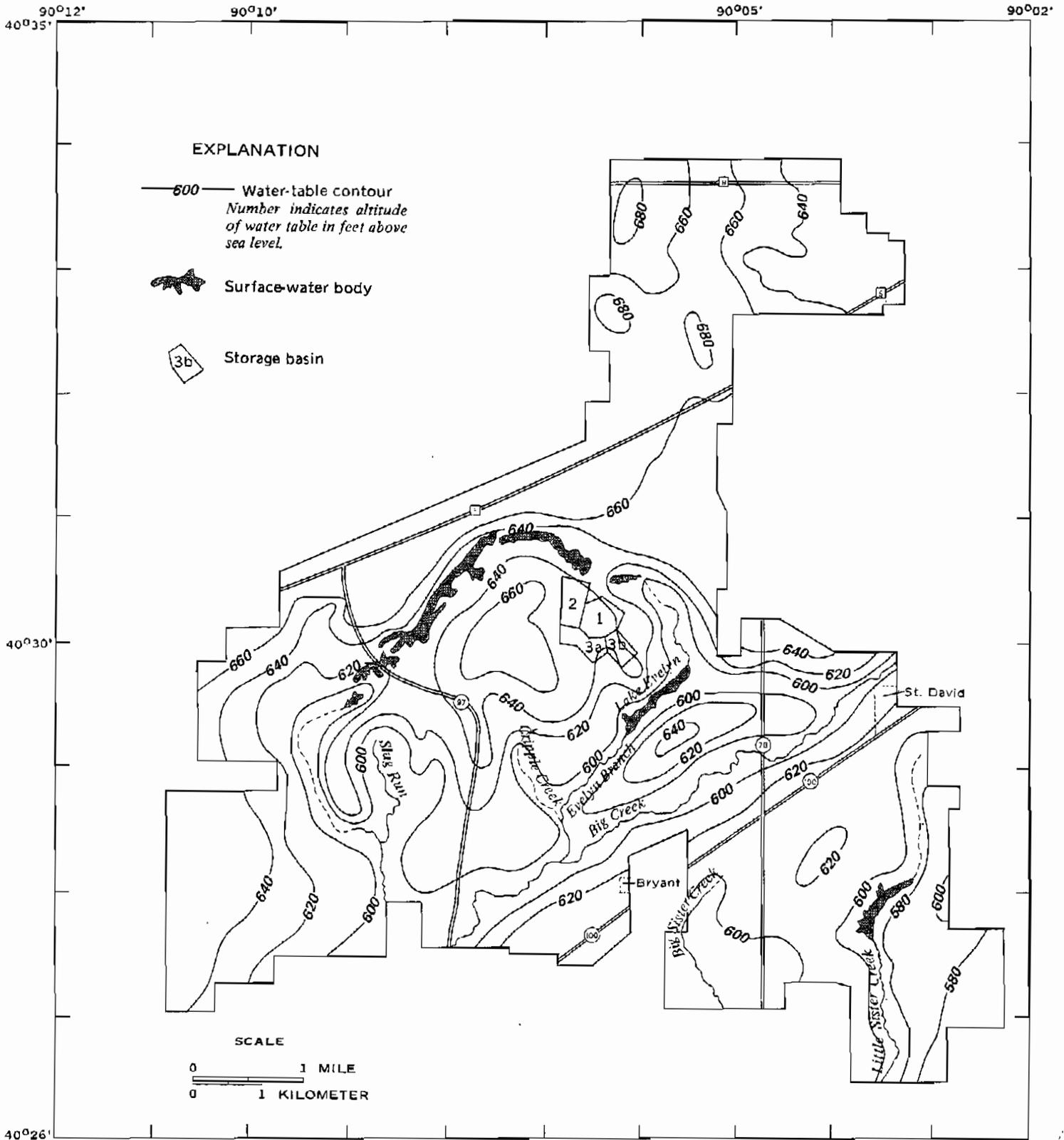


Figure 12. Generalized water-table contour map, November 1977 (modified from Fuentes and Patterson, 1979).

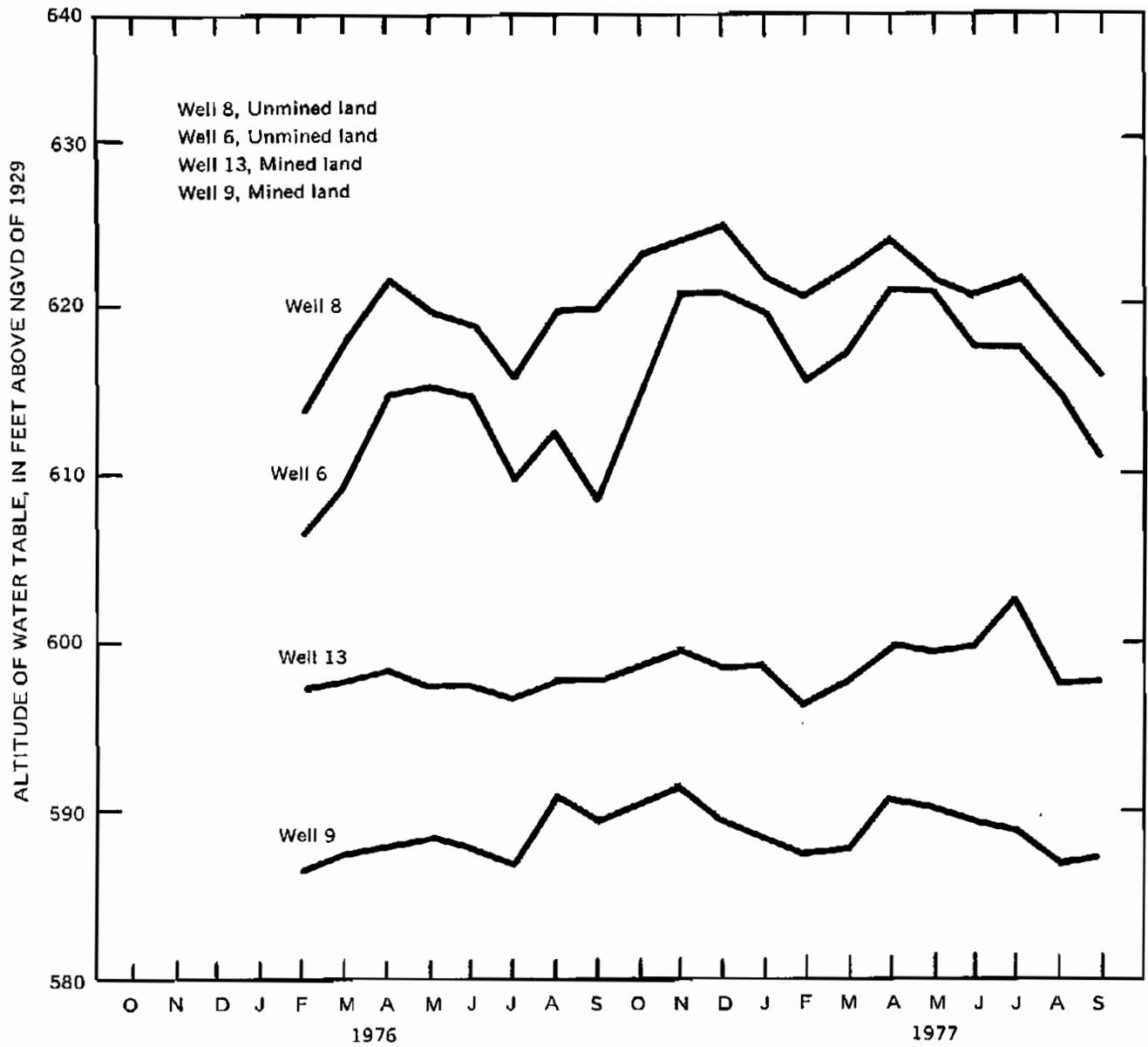


Figure 13. Monthly ground-water levels in wells located in mined and unmined areas.

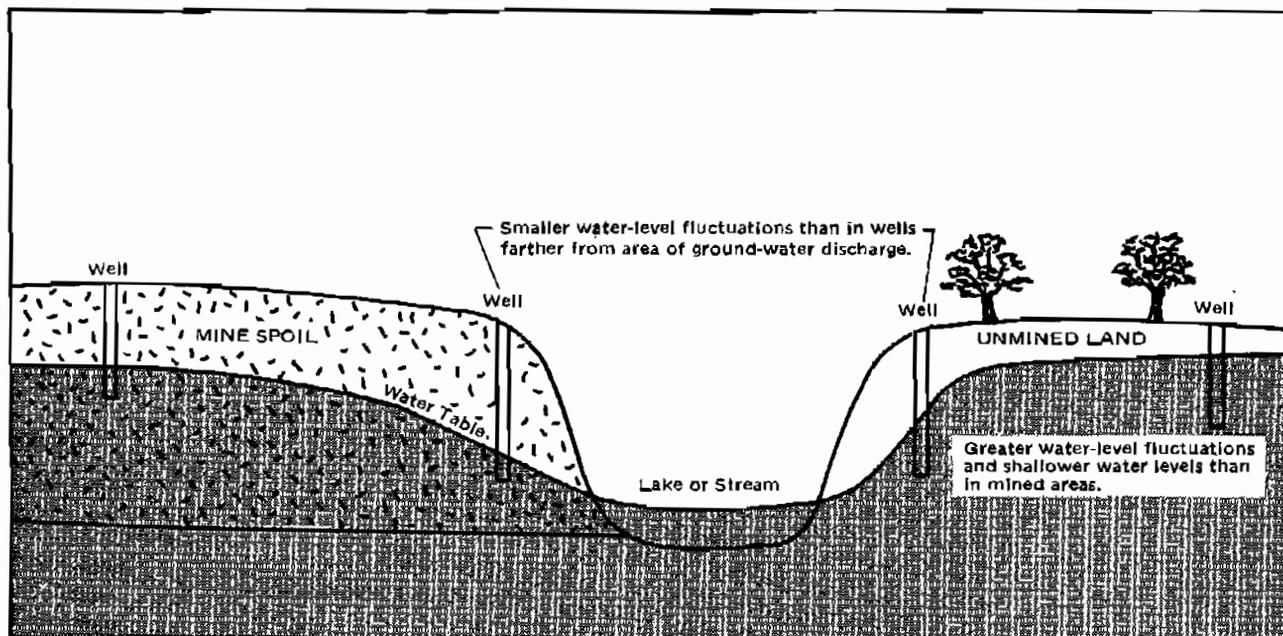


Figure 14. Relative depths to ground water with respect to land use and proximity to areas of ground-water discharge.

Control standards. It seems that the presence of high boron concentrations is due to sources in the spoil, rather than in the sludge, because high concentrations of dissolved boron were widespread regardless of proximity to sludge application fields and because most concentrations were higher than those found in the sludge or supernatant.

SUMMARY AND CONCLUSIONS

Since 1972 the Metropolitan Sanitary District of Greater Chicago has been applying digested sewage sludge as a fertilizer and soil conditioner to a 15,528-acre recontoured surface-mine area in Fulton County, Illinois. In 1971, the U.S. Geological Survey began a cooperative project with the MSDGC to measure stream discharge, suspended-sediment loads, and chemical constituents in surface water in areas affected by the reclamation. In 1976, the project was expanded to include a study of the shallow ground water.

No significant changes from 1971 to 1978 were found in runoff per square mile for Big Creek between stations upstream and downstream from the reclamation site. Discharge hydrographs of two tributary streams draining the reclamation site show that, after periods of precipitation, the discharge of

the tributaries does not increase at the same rate as discharge in Big Creek. The delayed response of the tributaries is owing to the damping effect of several strip-mine lakes.

Yearly suspended-sediment yields calculated for the upstream and downstream stations on Big Creek range from under 600 to over 1,200 tons per square mile of drainage area at each station. The two stations show no apparent differences between the sediment yield from the reclamation site and the yield from upstream sources.

The analyses of water samples collected at four stream-monitoring stations show the principal cations to be sodium, calcium, and magnesium. The principal anions were chloride, sulfate, and bicarbonate. The chemical composition of the surface water varies greatly from month to month; however, comparison of yearly mean concentrations show no changing trends at any station, nor are there any apparent differences attributable to sludge between stations upstream and downstream from the reclamation site.

The shape of the water table is irregular and generally follows the topography. Monthly water-level fluctuations depend upon two factors: (1) the type of land (mined or unmined), and (2) proximity

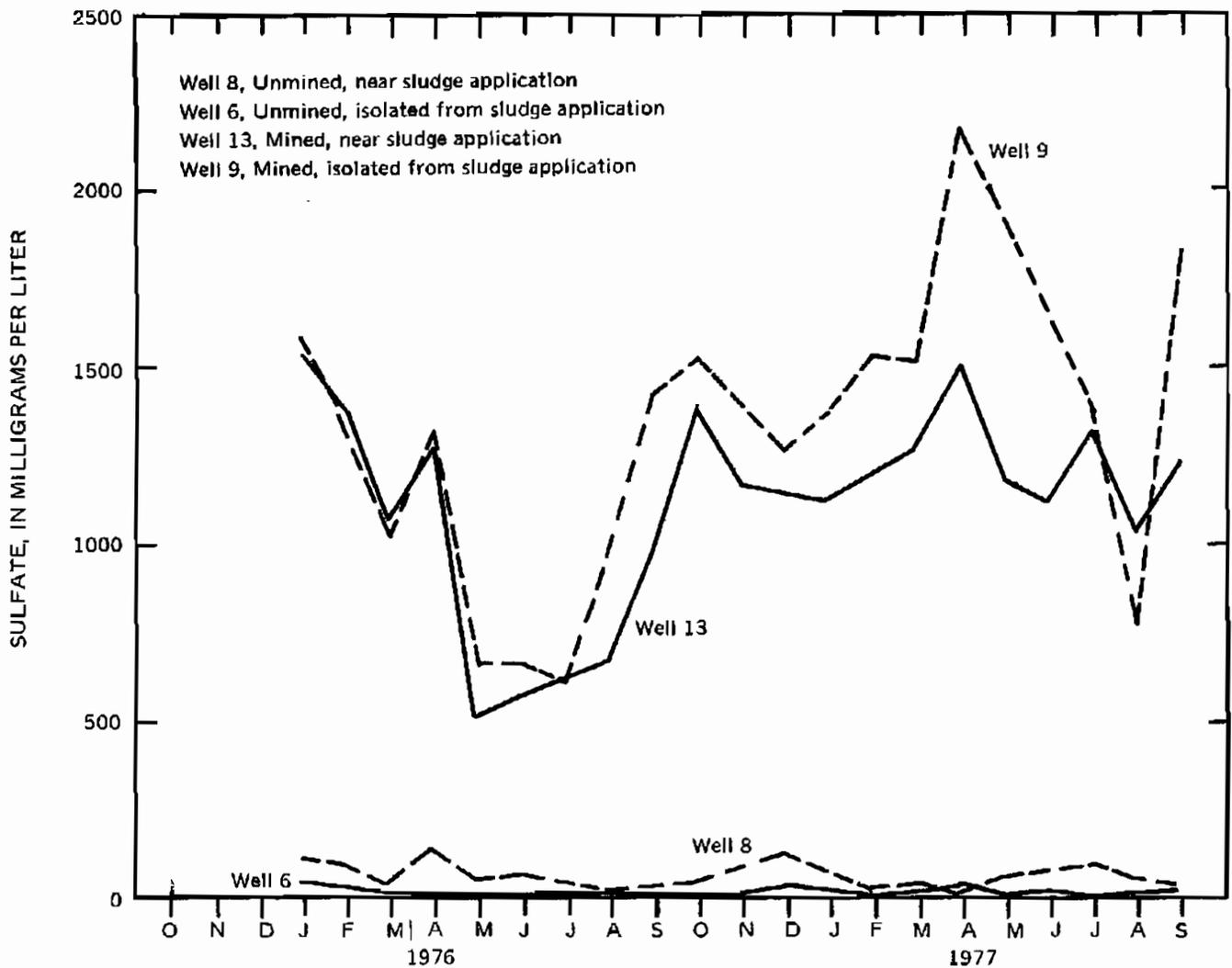


Figure 15. Sulfate concentration in wells located in mined and unmined land (data from Peterson, 1973-78).

to surface discharge. The largest fluctuations were in wells in unmined land away from discharge (monthly mean of 2 feet); the smallest fluctuations were in wells in mined land near discharge (monthly mean of 0.61 ft). The water table was closer to the surface in unmined land (mean depth to water 29.51 ft). The chemical characteristics of ground water seem to have been altered by surface mining, as indicated by high concentrations of sulfate, calci-

um, magnesium, chloride, iron, zinc, and manganese in water from wells in surface-mined lands and by statistical comparisons of chemical data for wells in unmined areas with those for wells in mined areas. Comparisons between ground water isolated from sludge application sites and that near sludge application sites, within the same land type, indicate no changes attributable to sludge application.

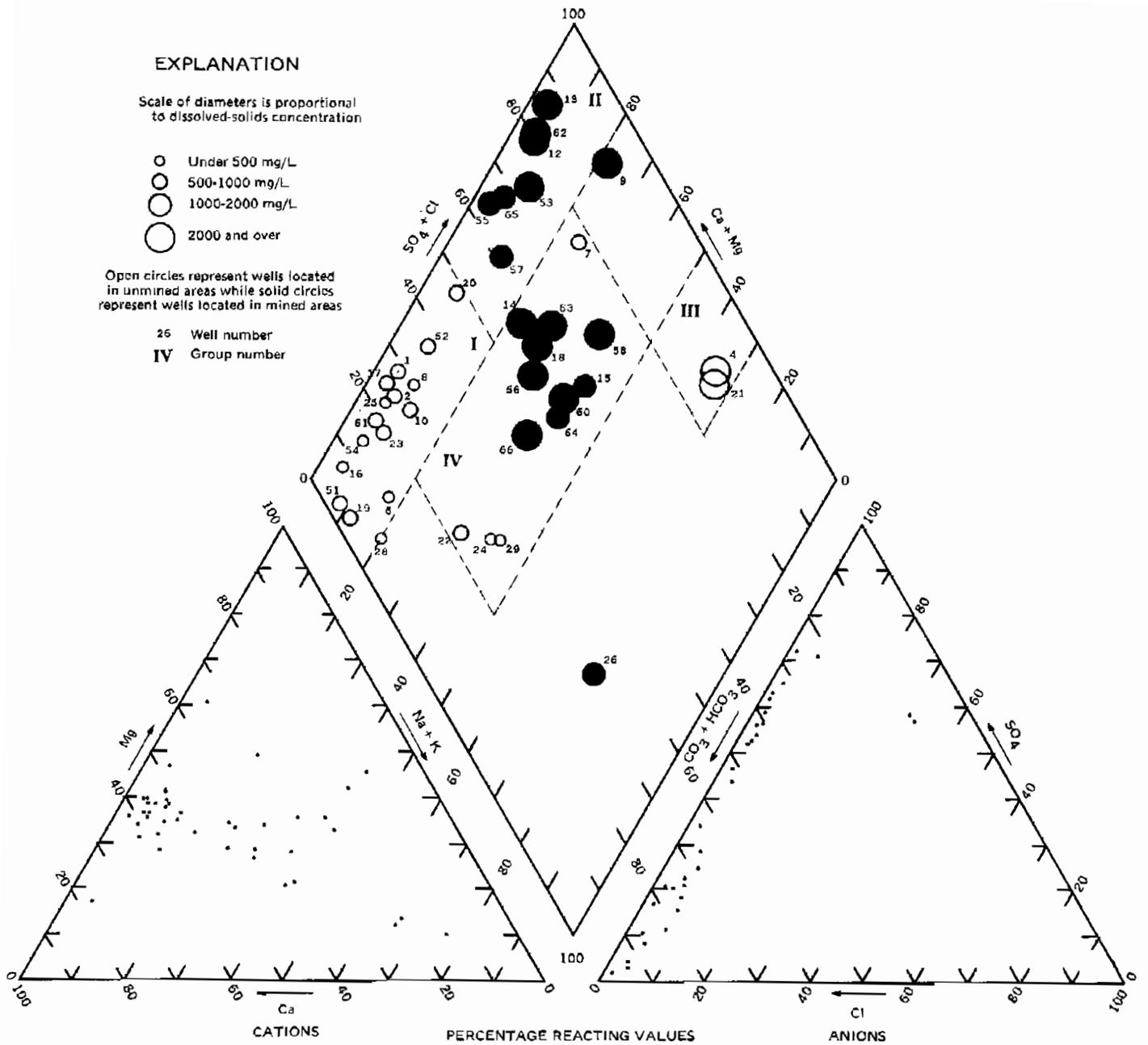


Figure 16. Trilinear graph of chemical analyses of ground water.

Table 7. Chemical analyses of boron in filtered water samples from Big Creek Basin (concentrations in micrograms per liter).

Well	Land Type*	Proximity to Sludge Field	November 1977	February 1978	March 1978	April 1978
51	UL	near	100	--	--	--
52	UL	do	30	--	40	--
53	M	do	490	--	400	--
54	UL	do	30	--	40	--
55	M	do	40	--	--	--
56	M	far	1,400	1,200	1,100	920
57	M	near	300	--	190	--
58	M	do	590	2,000	--	510
60	M	do	3,300	2,800	2,500	1,800
61	UL	do	40	--	50--	--
62	M	do	260	--	400	--
63	M	do	--	1,800	1,700	2,600
64	M	far	1,800	1,600	1,500	1,900
65	M	near	300	300	280	--
66	M	near	3,000	2,300	--	1,700
W-12	M	far	--	470	--	--
W-18	M	far	--	2,300	--	--
Streams						
Big Creek at St. David			--	--	--	610
Evelyn Branch			--	--	--	680
Big Creek near Bryant			--	--	--	1,600
Slug Run near Bryant			--	--	--	1,300
Underground Mine Drain 1			--	--	1,400	880
Underground Mine Drain 2			--	--	1,100	690
22 Lakes						
Maximum			--	--	--	2,300
Minimum			--	--	--	60
Average value			--	--	--	731

* UL = Unmined land

M = Mined land

REFERENCES

- Bergstrom, R.E., 1956, Ground water geology in western Illinois, north part: Illinois State Geological Survey Circular 222, 21 p.
- Colby, B. R., 1956, Relationship of sediment discharge to streamflow: U.S. Geological Survey Open-File Report, 170 p.
- Fuentes, R. F., and Patterson, G. L., 1979, Water-table contour map of land reclamation site Fulton County, Illinois: U.S. Geological Survey Open-File Report 79-210, 1 p.
- Guy, H. P., and Norman, V. W., 1970, Field methods for measurements of fluvial sediment: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 3, Chapter C2, 59 p.
- Haynes, R. J., and Klimstra, W. D., 1975, Illinois lands surface-mined for coal: (Cooperative Wildlife Research Laboratory), Southern Illinois University, 201 p.
- Hem, J. D., 1970, Study and interpretation of the chemical characteristics of natural water: U.S. Geological Survey Water-Supply Paper 1473, 363 p.
- Hinesly, T. D., Braids, O. C., and Molina, J. E., 1971, Agricultural benefits and environmental changes resulting from the use of digested sewage sludge on field crops: U.S. Environmental Protection Agency, 62 p.
- Horberg, Leland, 1950, Bedrock topography of Illinois: Illinois State Geological Survey Bulletin 73, 111 p.
- Illinois Pollution Control Board, 1977, Illinois Pollution Control Board Rules and Regulations, Chapter 3, Water pollution: Springfield Illinois Pollution Board, 54 p.
- Nienkirk, M. M., and Flemal, R. C., 1976, Regional distribution of the major dissolved solids in the streams of Illinois: University of Illinois, Urbana, Water Resources Center Research Report 109, 56 p.
- Page, A. L., 1974, Fate and effects of trace elements in sewage sludge when applied to agricultural lands—A literature and review study: University of California, Riverside, Department of Soil Science and Agricultural Engineering, 96 p.
- Peterson, J. R., 1973-1978, Environmental protection system reports for Fulton County, Illinois: The Metropolitan Sanitary District of Greater Chicago Department of Research and Development, December 1973; April, July, October 1974; October, December 1975; January-December 1976, January-December 1977; January, February, March 1978.
- Pietz, R. L., Peterson, J. R., and Lue-Hing, Cecil, 1974 Ground water quality at a strip-mine reclamation area in west central Illinois, in Second Research and Applied Technology Symposium on Mined-Land reclamation, Louisville, Kentucky, 1974, Proceedings: Washington, D.C., National Coal Association, October 1974, p. 124-144.
- Porterfield, George, 1972, Computation of fluvial-sediment discharge: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 3, Chapter C3, 66 p.
- Helwig, J. T., and Council, K. A., editors, 1979, SAS User's Guide 1979 Edition, SAS Institute Inc., 494 p.
- Toler, L. G., 1980, Some chemical characteristics of mine drainage in Illinois: U.S. Geological Survey Open-File Report 80-416, 47 p.
- U.S. Environmental Protection Agency, 1977, Quality Criteria for Water: U.S. Environmental Protection Agency, 256 p.
- Wanless, H. R., 1957, Geology and mineral resources of the Beardstown, Glasford, Havana, and Vermont quadrangles: Illinois State Geological Survey Bulletin 82, 233 p.
- Willman, H. B., and Frye, J. C., 1970, Pleistocene stratigraphy of Illinois: Illinois State Geological Survey Bulletin 94, 204 p.
- Zenz, D. R., Peterson, J. R., Brooman, D. L., Lue-Hing, Cecil, 1976, Environmental impacts of land application of sludge: Journal of Water Pollution Control Federation, v. 48, no. 10, p. 2332-2342.