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Assessment of the Water Quality in the Salt River Prior to Its Impoundment in Anderson and Spencer Counties, Kentucky

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Research Report No. 106

ASSESSMENT OF THE WATER QUALITY IN THE SALT RIVER PRIOR TO ITS IMPOUNDMENT IN ANDERSON AND SPENCER COUNTIES, KENTUCKY

by

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ABSTRACT

Monthly water samples were taken and analyzed to determine the water quality of the Salt River in Anderson and Spencer counties Kentucky prior to the river's impoundment. Sediments from the area watershed were analyzed to total acid digestion, barium chloride extraction, and aqueous extraction methods. Rainwater and runoff water were collected and analyzed for major cations and anions from two sites in the watershed.

The Salt River at Taylorsville is characterized by hard water with high levels of calcium (33.5-74.8 mg/l), bicarbonate (136-236 mg/l), specific conductance (200-535 μmhos/cm), and sulfate (16.5-71.5 mg/l). Nitrates (0.6-5.7 mg/l), phosphates (0.2-2.4 mg/l), sodium (3.2-20.3 mg/l), and potassium (1.3-5.6 mg/l), are moderate. Iron, manganese, copper, and nitrites are less than 0.5 mg/l. Suspended solids in the river (4.0-1,684.0 mg/l) are highly variable and directly related to fluctuations in discharge. Sediments from the Salt River Basin are high in potassium (12.4-213.3 mg/g) and iron (23.4-135.1 mg/g), with moderate levels of calcium (0.8-45.7 mg/g), sodium (4.5-10.5 mg/g), magnesium (3.2-6.3 mg/g), and phosphate (1.3-15.3 mg/g). Approximately 10% of the total ionic composition of these sediments is exchangeable and may be extracted with barium chloride. Calcium (309-3,292 μg/g), was the most readily adsorbed cation, with lower levels of potassium (17.6-490.5 μg/g), sodium (12.9-458.1 μg/g), and magnesium (89.4-266.2 μg/g). In the aqueous extractions, calcium (18-486 μg/g), potassium (16.6-69.5 μg/g), sodium (11.1-30.8 μg/g), and magnesium (6.6-68.7 μg/g) comprised about 10% of the exchangeable fraction.

Ranges of rainwater ions from the Salt River Basin were: sulfate (8.3-27.8 mg/l), calcium (0.3-10.7 mg/l), potassium (0.4-15.4 mg/l), sodium (0.0-0.7 mg/l), and magnesium (0.1-2.8 mg/l). Ionic composition and sediment yield of runoff water was variable and was related to magnitude of rainfall and runoff sampler placement. Ranges for selected constituents at the two samplers near Taylorsville were: suspended solids (44.0-8,808.0 mg/l), potassium (1.1-84.0 mg/l), magnesium (1.5-7.1 mg/l), calcium (9.5-33.0 mg/l), and sodium (0.6-3.0 mg/l).

Calcium and bicarbonate in the Salt River originate from weathering of calcite, although mole ratios of these two ions greater than 1:2 suggest that weathering of magnesium carbonates also contributes bicarbonate to the water. Carbonate equilibrium calculations using field pH and ionic strength suggest calcium is at saturation in the Salt River. High levels of sulfate in rainwater indicate some of this anion may be introduced into the area watershed by atmospheric precipitation.

KEYWORDS: Water Quality, Water Chemistry, Preimpoundments, Sediment, Rainfall, Runoff, Environmental Effects, Limnology

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INTRODUCTION

This report concludes the preimpoundment study begun in 1968 of the ecology of the Salt River Basin, Kentucky. This report summarizes the findings of previous reports on ecological studies of the Salt River Basin undertaken by the Water Resources Laboratory of the University of Louisville and sponsored by the Office of Water Resources Research and Development of the U. S. Department of the Interior. The earlier reports are from Project Nos. A-019-KY, B-005-KY, B-016-KY, B-022-KY, B-031-KY, and the current B-035-KY. Funding for those projects was continuous and extended on an annual or biennial basis from April 1968 through June 1975. Initially proposed as a study to include pre- and postimpoundment data, delays in construction on the Taylorsville Lake Project prevented continuing the study past the preimpoundment stage.

When the idea for such a long-range study was conceived in 1967, it was evident that the Congress of the United States either had authorized or was considering authorization of a flood control reservoir on each of the three principal parts of the Salt River system: Taylorsville Lake on the main stem of the Salt River, Camp Ground Lake on the Beech Fork, and Howardstown Lake on the Rolling Fork. At present, Taylorsville Lake has been authorized and funded, and construction is proceeding on the outlet works for the dam. Camp Ground Lake was authorized and funded only for Advanced Engineering and Design, which is under way; it has not been authorized nor funded for construction. Howardstown Lake has not been recommended for authorization, and at present there are no plans to do so. Locations and extents of those proposed bodies of water are shown in Fig. 1.

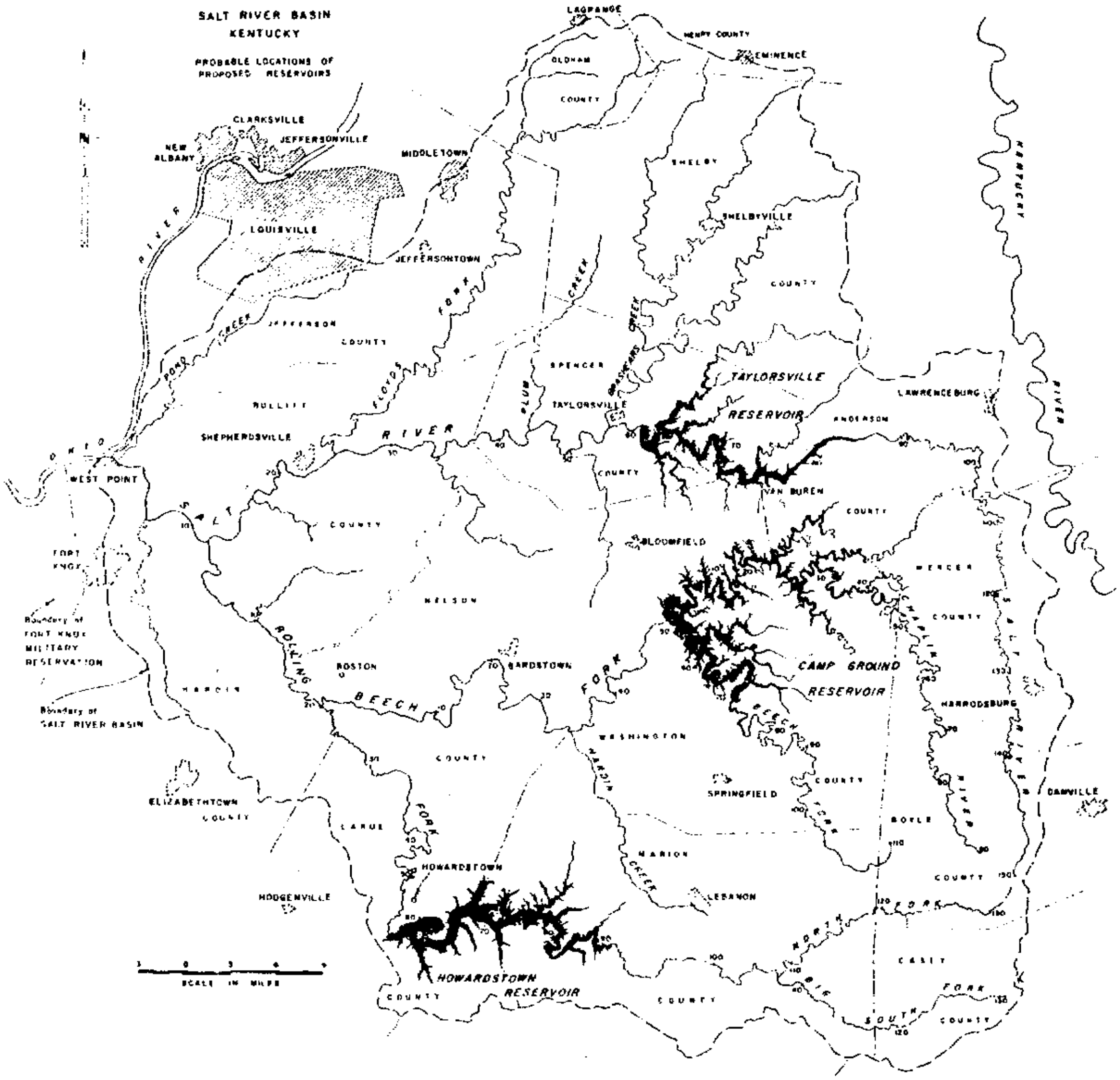

Figure 1. The Salt River Basin showing the Salt River, the Beech Fork, the Chaplin River, together with the sites for the proposed reservoirs. The plans for constructing Howardstown Reservoir have not been authorized.

Such a broad study includes gathering detailed ecological data from the areas to be impounded as well as the waters upstream and downstream. In addition, there must be detailed studies of the adjacent terrestrial areas. When land is flooded permanently, it is no longer available for agricultural or domestic purposes, and the areas surrounding the newly formed lake are subjected to conditions quite different from those prior to flooding.

Although socioeconomic studies were not a major portion of research performed by the Water Resources Laboratory, a preliminary assessment of the economic base in Spencer County was given by Neff and Krumholz (1973). Other studies were carried out by personnel of the University of Kentucky (Ludtke and Burdge 1970, Burdge and Ludtke 1970, Smith 1970, Smith and Drucker 1973, Drucker, et al 1974). Areas of socioeconomic interest are: (1) it is likely that recreational use of those bodies of water within 50 miles of populations that total more than a million people will cause an influx of large numbers of visitors each year, (2) suburban development of the area, especially the area nearest Louisville, only 35 miles (56 km) away, is most likely since many Louisvillians have already purchased property in the vicinity, (3) businesses oriented toward agricultural practices probably will be supplanted to a large extent by those that cater to an urban population and also to recreationists, and (4) with the urbanization of the area, the political structure of the community will be affected and the tax base will likely change quite markedly.

Previous reports on the Salt River have contained inventories of the algae and terrestrial plants of the basin (Krumholz 1971), the benthic arthropods, mollusks, fishes, amphibians, reptiles, birds, and mammals (Krumholz 1971, Krumholz and Neff, 1971, Neff and Krumholz 1972).

These surveys have been essential in establishing initial baseline conditions in the Salt River Basin. The paucity of data on the distribution and abundance of Kentucky flora and fanua made these collections and inventories necessary. Reports on the caddisflies (Insecta: Trichoptera) in Kentucky have accrued from the Salt River investigations (Resh 1975), along with production estimates of this important aquatic insect order (Resh et al. 1973, Resh 1977). Stonefly (Insecta: Plecoptera) distribution in the Salt River has been presented (White 1974). Other reports concerning the distribution of the Coleoptera and Diptera are in preparation.

Particular attention has been given to the fish populations inhabiting the Salt River, the Beech Fork, and the Chaplin River (Hoyt, et al. 1970). The Salt River fish fauna will be modified considerably both above and below the lake following impoundment. A detailed collection of this fauna is necessary to document and to assess these changes. Study of these fish samples is continuing as the community species diversity and collection methods are analyzed (Hoyt, et al. 1977).

Since water quality in Taylorsville Lake will change as impoundment proceeds, it was decided to monitor existing water quality in the part of the Salt River to be impounded, to assess surface runoff in that area, and to investigate potential sources of pollution that could influence the quality of the impounded waters. A dearth of information on the water chemistry of the Salt River and seasonal variation in important anions and cations made the collection and study of these data imperative. The U. S. Geological Survey gauging stations in Anderson County (Goodnight Bridge) and in Spencer County (U. S. 44 in Taylorsville) provided adequate data on annual river discharge, but offered little or no information on water quality in that portion of the Salt River.

In previous reports, we had conducted a broad survey of the water quality of the Salt River and its tributary, Brashears Creek (Krumholz 1971, Krumholz and Neff 1971, Neff and Krumholz 1973). From this survey, we had ascertained a general idea of the prevailing water quality in the Salt River Basin. Several problems appeared to warrant further investigation. For example, low correlation between discharge and specific conductance and higher correlations with sulfate anions encouraged more study. Sulfate in particular seemed to need additional analysis through surface runoff sampling. Certain cations, notably iron (Fe), were sometimes present in sufficient quantities to present subsequent problems in a lentic rather than lotic condition (Krumholz 1971, Krumholz and Neff 1971).

Several sources of potential pollution sources had been found. In 1969-70, Harrodsburg Sewage Treatment Plant appeared to be operating beyond its capacity and causing problems in the Salt River, while its receiving stream (Town Creek) was almost devoid of fish and benthic invertebrates.

The Lawrenceburg Sewage Treatment Plant uses Hammond Creek as its receiving stream, and the creek illustrated the classic characteristics of a degraded waterway. A reduced fauna consisting of pollution tolerant invertebrates were seen in Hammond Creek. Rat-tail maggots (*Eristalis*: Syrphidae) and oligochaete tubificid worms (*Tubifex*: Tubificidae) were the most common inhabitants of the creek. Some recovery of the stream was observed further downstream, particularly as discharge increased in the spring. This situation called for more detailed information. Hammond Creek enters the Salt River almost 30 miles upriver from the damsite. At low flow and after impoundment, the Lawrenceburg effluent seems to be a potential source of pollution for Taylorsville Lake.

Thus, we undertook to assess surface runoff in the area of the Salt River that is to be impounded and to analyze in detail the existing water quality variations in that portion of the river.

DESCRIPTION OF STUDY AREA, ITS PHYSIOGRAPHY AND CLIMATE

The Salt River Basin has an area of 2,920 square miles (7,563 km^2) and lies immediately southeast of the city of Louisville at approximately 37°25'-38°25' N and 84°46'-85°58' W. The extreme southern portion of the city lies within the basin. The basin occupies all or parts of 15 counties of Kentucky and makes up 7.23 percent of the total area of the Commonwealth. In their upper reaches, the Salt River and its tributaries flow through gently rolling hills over rock bottoms with loose rocks and gravel in the beds. As the streams become larger, they frequently flow over solid rock bottoms, and in the western part of the basin they leave the rolling limestone hills and enter the carboniferous shales and sandstones (McFarlan 1943).

Proceeding upstream from its mouth where it empties into the Ohio River at West Point, Kentucky (Ohio River Mile 629.9), the Salt River receives the following principal tributaries (Fig. 1): Pond Creek drains the southern portion of Jefferson County and enters the Salt River a few hundred meters upstream from its mouth; The Rolling Fork empties into the Salt River 11.6 miles (18.7 km) above its mouth and drains approximately the southern half of the entire drainage basin; Floyds Fork rises in Henry and Oldham counties, flows southwest through Jefferson and Bullitt counties, and empties into the Salt River at Shepherdsville, about 20.5 miles (33.0 km) above its mouth; Plum Creek rises in Shelby County, flows southwest through Bullitt and Spencer counties, and joins the Salt River near Waterford about 44 miles (71 km) above its mouth; and Brashears Creek, with several sources in Henry and Shelby counties, enters the Salt River at Taylorsville about 56 miles

(90 km) above its mouth and 3.5 miles (5.6 km) downstream from the damsite for Taylorsville Lake.

Brashears Creek deserves special mention since it has been the site of several detailed studies during the course of this investigation. Brashears Creek, the first tributary to the Salt River downstream from the damsite for Taylorsville Lake (Fig. 1), has its origin in three principal tributaries: (1) Bullskin Creek rises in Henry County about 2 miles (3.2 km) west of Eminence, near the source of the Little Kentucky River, and flows south-southwest through Shelby County to join Clear Creek about 4 miles (6.4 km) southwest of Shelbyville, (2) Clear Creek rises in north-central Shelby County near Pleasureville and flows southeast through Shelbyville to its union with Bullskin Creek to form Brashears Creek; just north of Shelbyville, Clear Creek is impounded to form Lake Shelby, and (3) Guist Creek rises near Bagdad in northeastern Shelby County and flows southwest to enter Brashears Creek near the community of Rivals in north-central Spencer County. From the union of Bullskin and Clear creeks, Brashears Creek flows southwest to enter the Salt River at Taylorsville.

Upstream from the damsite for Taylorsville Lake, and within the area to be impounded, several large tributaries enter the Salt River (Fig. 1). Beech Creek rises in southeastern Shelby County and flows west-southwest to enter the Salt River less than a mile (<1.6 km) above the damsite and about 60 miles (97 km) upstream from its mouth at West Point. Little Beech Creek rises in northeastern Spencer County and flows southwest to enter the Salt River about a mile (1.6 km) upstream from the mouth of Beech Creek, Crooked Creek rises about 3 miles (4.8 km) due south of the source of Beech Creek and flows southwest forming the boundary between Anderson and Shelby counties and Anderson and Spencer counties before joining the Salt River in Van Buren at the juncture of Anderson, Nelson, and Spencer counties. The mouth of Crooked Creek is about 76.5 miles (123 km) upstream from the mouth of the Salt River. Ashes Creek is the only principal tributary on the south side of the Salt River to receive any detailed study during this investigation. Ashes Creek rises from several sources in northeastern Nelson County about 4 miles (6.4 km) east of Bloomfield and flows northwest into Spencer County where it receives its two principal tributaries, Doe Run and Jacks Creek, before it empties into the Salt River about 2 miles (3.2 km) upstream from the damsite for Taylorsville Lake.

Upstream from the area to be impounded, the Salt River receives a single tributary, Hammond Creek (not shown in Fig. 1). Hammond Creek rises in the northwestern section of Lawrenceburg, flows west-southwest, and enters the Salt River about 91 miles (146 km) upstream from its union with the Ohio River. Hammond Creek receives the treated effluent from the sewage disposal system of Lawrenceburg. The only other known source of domestic pollution in the Salt River emanates from Harrodsburg where the effluent from the sewage treatment facility empties directly into Town Creek, a small tributary to the Salt River at Harrodsburg about 130 miles (209 km) upstream from its mouth and about 45 miles (72 km) upstream from the head of Taylorsville Lake.

The main stem of the Salt River, also known as the North Fork of the Salt River (Leverett 1929), rises as three separate sources in Boyle County about 7 miles (11.3 km) southwest of Danville, just south of Kentucky Highway 300 near the town of Parksville. From there, it flows due north for slightly more than 50 miles (80 km) through Boyle, Mercer, and

Anderson counties, and about 3 miles (4.8 km) south of Lawrenceburg it makes essentially a right angle turn and flows westward toward the damsite and to its union with the Ohio River. The overall length of the main stem of the Salt River is about 150 miles (424 km).

The Rolling Fork, the principal tributary to the Salt River, receives a large tributary, the Beech Fork, about 20.2 miles (32.5 km) above its union with the Salt River. The principal tributaries to the Beech Fork are Hardin Creek which rises in Marion County near Lebanon, flows northwest through Marion County and forms part of the county line between Marion and Washington counties, and empties into the Beech Fork at the juncture of Larue, Marion, Nelson, and Washington counties. By far the largest tributary to the Beech Fork is the Chaplin River which rises in Boyle County about 3 miles (4.8 km) northwest of the sources of the main stem of the Salt River (Fig. 1). The Chaplin River flows northwest through Boyle, Mercer, and Washington counties for about 60 miles (97 km), then west and southwest to form part of the southeastern border of Nelson County, and empties into the Beech Fork about 0.75 mile (1.2 km) upstream from the proposed damsite for Camp Ground Lake. The overall length of the Chaplin River is about 90 miles (150 km). The main stem of the Beech Fork rises in Boyle County about 5 miles (8 km) west of the source of the Chaplin River (Fig. 1) and flows northwest for about 60 miles (98 km) through Marion and Washington counties to where it receives the Chaplin River at the Nelson-Washington county line about 6 miles (9.8 km) southeast of Bloomfield. At that point, it turns abruptly and flows southwest for about 15 miles (24 km) forming the boundary between Nelson and Washington counties, then meanders in a westerly direction forming the rest of the southern border of Nelson County and enters the Rolling Fork near the village of Boston. The overall length of the Beech Fork is 110 miles (177 km).

The Rolling Fork has two main sources. The North Fork rises in Boyle County about a mile (1.6 km) south of the source of the main stem of the Salt River; the South Fork rises in Casey County about 7 miles (11.3 km) south of the origin of the North Fork. Both streams flow west and unite a few miles west of the Marion-Casey county line to form the main stem of the Rolling Fork. That stream flows almost due west for almost 50 miles (80 km) to a point about 3 miles (4.8 km) south of Howardstown in Larue County. That is the approximate location of the proposed dam for Howardstown Lake (Fig. 1). The Rolling Fork then flows north-northwest forming the border between Larue and Nelson counties and empties into the Salt River inside the Fort Knox Military Reservation. The overall length of the Rolling Fork is about 130 miles (210 km).

It was reported by Leverett (1929:8) that at one time the Salt River formed the headwaters of the Ohio River, and that all of the present Ohio River east of the mouth of the present Salt River drained in a more or less northerly direction into the area now occupied by the Great Lakes or into a stream that emptied into the present Wabash River drainage. Within the Salt River Basin, Leverett (1939:8) pointed out that "The north-flowing headwater part of the North Fork of the Salt River in Boyle and Mercer counties, is connected with the Kentucky River by a shallow valley carrying fluvial material, which was the former line of discharge of this stream into the Kentucky. But Salt River, probably because of a more direct course to the part of the Ohio River where it discharges, and one through weaker strata, has diverted this stream away from Kentucky." The area under discussion is near the point where the main stem of the Salt River makes its right angle turn a few miles south of Lawrenceburg. Recent geological work (Cressman 1968, 1972, 1973) in the Lawrenceburg, Salvisa, and McBrayer areas has disclosed high- and low-level fluvial deposits in the region of the stream piracy proposed by Leverett. The extent, depth (20-60'), and two terraces of these fluvial deposits was unknown to Leverett, but the composition and distribution of these deposits suggest that they were formerly much more widespread in the area than they are now (Cressman 1972).

Other workers (Fowke 1933; Janssen 1952, 1953) have presented other ideas and interpretations of the origin and source of the middle Ohio River.

Physiography

The Salt River Basin lies within three physiographic regions of Kentucky, the Outer Bluegrass, the Knobs, and the Ohio River Lowlands. The entire basin is gently rolling topography with the steepest areas near the headwaters and the more gently rolling areas toward the central part of the basin. Each of the proposed reservoir sites and their drainages lies within the Outer Bluegrass Region. The areas above the damsites are characterized by narrow, steep ridges and narrow valleys that form dendritic patterns for the proposed lakes. The valleys and slopes are usually heavily wooded, but the cleared areas are subject to heavy erosion.

The underlying strata consist principally of the Maysville and Clays Ferry Formations of the Upper Ordovician and the High Bridge and Lexington Formations of the Middle Ordovician. Bedrock formations are largely shale, limestone, and limestone interbedded with shale. The streams have cut bedrock channels that have been subsequently filled with alluvial deposits of clay, sand, and gravel. There are some sandstone beds in the Clays Ferry Member. The Eden-Lowell Association makes up the major portion of the soils in the upper portions of the basin. Because of the relatively impervious nature of the Clays Ferry shale member (Eden Shale of earlier workers), the runoff has been likened to that of rain on a "metal roof," and the streams are subject to great and sudden fluctuations (Hendrickson and Krieger 1964).

The topography of the basin is characterized by long, narrow ridges with steep or strongly sloping hillsides that frequently rise more than 200 feet (60 m) above the valley floors. There are small acreages of corn, tobacco, and alfalfa, along with other seasonal crops, grown on the ridges, but most of the acreage is in pasture or in pasturelands that have been abandoned and are in oldfield succession.

Although the average annual discharge of the Salt River and its tributaries is about 3,275 cfs (105.5 m^3/sec), the extremes range from a minimum of about 25 cfs (0.7 m^3/sec) in 1967 to a maximum of nearly 53,000 cfs (1,500 m^3/sec) in 1964. At its confluence with the Salt River, the Rolling Fork has an annual discharge of about 1,695 cfs (49 m^3/sec). Thus, the Rolling Fork carries more than half the total discharge of the basin. Such fluctuations in runoff are traceable directly to the topography of the basin and the impermeability of its soils. Whenever there is a heavy rainfall, the streams rise rapidly and there is a very marked increase in turbidity of the water. By the same token, when rainfall ceases, the river levels return to their previous levels rather quickly.

Climate

The climate of the Salt River Basin is continental with marked seasonal changes, rather wide extremes of temperature and precipitation, but is generally temperate, healthful, and conducive to a varied plant and animal life (Kendall 1941). Climatological data from the National Weather Service stations at Shelbyville, Taylorsville, and Bardstown, Kentucky, all within the basin, began in 1888, 1902, and 1901, respectively, and are believed to be representative for the entire basin. The mean annual rainfall is about 46 inches (117 cm) and is spread farily evenly throughout the year. Snow rarely remains on the ground for more than a few days at a time and rarely contributes to flooding. The mean annual temperature is about 56 F (13.5 C) and the frostfree period extends for about 180-185 days, from mid-April to mid-October. January usually is the coldest month and July is the hottest, with mean temperatures of 34 F (1 C) and 75 F (24.4 C), respectively. The highest and lowest temperatures recorded were 112 F (44.4 C) and -23 F (-30.6 C), respectively. Those extremes were recorded at Shelbyville.

THE LAKE SITE

The proposed damsite for Taylorsville Lake is about 3 miles (4.8 km) upstream from Taylorsville, 36.4 miles (56 km) above Shepherdsville, and about 60 miles (97 km) upstream from the juncture of the Salt River with the Ohio River. At seasonal pool, it is estimated that the lake will occupy about 3,600 acres (1,457 ha) in parts of Anderson, Nelson, and Spencer counties (Table 1), and at flood pool will cover 7,900 acres (3,197 ha). Thus, at flood pool, 25.3 miles (40.7 km) of stream will be inundated and at seasonal pool 20.6 miles (33.2 km), leaving 4.7 miles (7.6 km) of streambed exposed except at flood stage. The drainage area for Taylorsville Lake will be 354 square miles (917 km^2) or about 12.1 percent of the entire basin.

The maximum depth of Taylorsville Lake will be 73 feet (22.25 m) just upstream from the damsite. There will be no large expanse of water because of the hilly terrain. The lake will have a high shoreline development with a marked dendritic shape that includes several long, narrow embayments in areas now occupied by the lower reaches of Beech, Little Beech, Ashes, and Crooked creeks along with several smaller embayments. Most of the shoreline will be quite steep except near the upper end of the water body where the floodplain is fairly broad. The maximum width of the main water body will be little more than 0.5 mile (0.8 km) at the mouths of Ashes and Beech creeks. The high banks and narrow channel may impede wind action so effectively that there will be relatively little mixing of the waters, and may result in the accumulation of organic and inorganic compounds, especially in areas of limited flow.

Construction of Taylorsville Lake will require the relocation of about 100 families including the entire village of Van Buren. Also, all cemeteries within the confines of the flood pool must be relocated. Included will be the rather extensive cemetery at Van Buren.

In all likelihood, Taylorsville Lake will be quite productive during the first few years following impoundment because of the added fertility from the vegetation that remains in the impounded area. Even after that time, it should continue to be reasonably productive because of the nature of the soils in the watershed.

At the time of this writing, the outlet works for the dam for Taylorsville Lake are under construction, and acquisition of the land for the lake is well under way.

THE COLLECTING STATIONS

During the course of the study, 70 sites were selected as appropriate locations for collecting samples of water for analyses in the laboratory and for sampling the aquatic biota. These collecting sites have been described in detail in previous reports (Krumholz 1971, Krumholz and Neff, 1971, Neff and Krumholz 1973). Figure 2 includes only those portions of the Salt River Basin in Anderson, Boyle, Marion, Mercer, Nelson, Shelby, Spencer, and Washington counties that contain parts of the main stem of the Salt River and the Beech Fork and Chaplin River that are proposed to be impounded as Taylorsville and Camp Ground lakes.

In order to ascertain water quality variations in the Taylorsville impoundment area, four sampling stations were selected. Numerical designation of these stations follows Krumholz (1971). To facilitate discussion of results, these stations are described as follows:

Station 17. This station is at Goodnight Bridge, approximately 4.8 km (3 miles) east of the town of Van Buren in Anderson County, on State Highway 248. During periods of low flow, there was a riffle below the bridge and considerable growth of water willow. The north bank of the river is very steep and grades into a high hill. The south bank is low and flat and floods during high water. The substrate is bedrock, as well as small boulders, cobble, fine gravel, sand, and shells. The U. S. Geological Survey (U. S. Geological Survey 1971, 1972, 1973, Part I. Surface Water Records) maintains a continuous reading discharge station at the bridge. They publish daily averages, and make available bihourly readings of discharge and gage height.

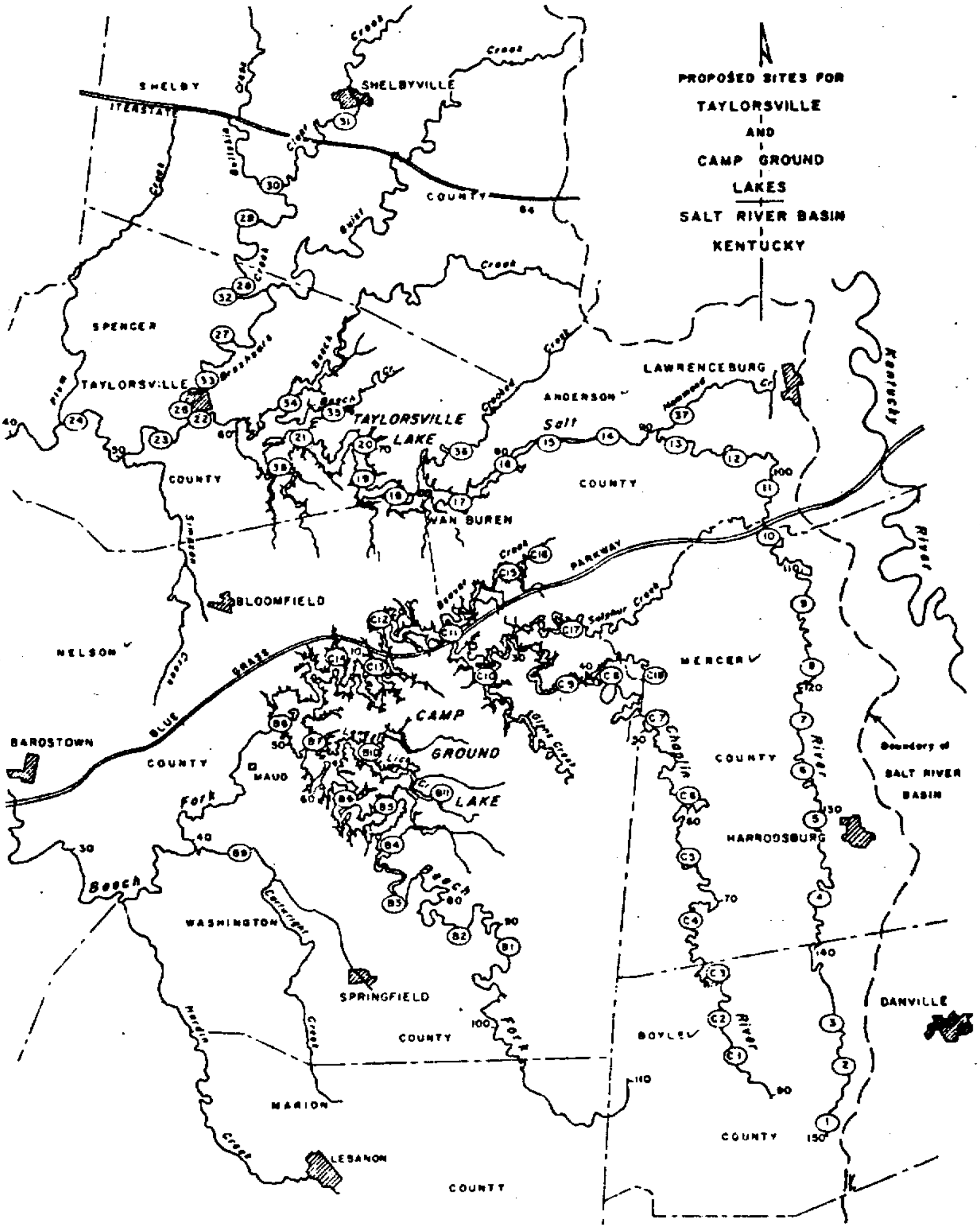

Figure 2. Sampling stations for water analysis, benthic fauna, and fishes on the mainstem of the Salt River, and its tributaries — Beech Fork (B-), Chaplin River (C-), Brashears Creek, Beech Creek, and others.

Station 22: Station 22 is in Taylorsville below the bridge on State Highway 55 that crosses the Salt River. Samples were taken either under the bridge or 20 m downstream on the property of the Taylorsville Water Company. About 15 m below the bridge a pair of storm sewers empty into the river. Care was taken to avoid collecting below these after a rain since they usually carried considerable concentrations of sodium, chloride, and sediment. At this site there is no bedrock but an assortment of small to large rocks and stands of water willow.

Station 23: Station 23 is about 2.2 km (1.4 miles) southwest of State Highway 55 near a gravel road which leads to Bloomfield. This station was chosen to contrast with Station 22 at Taylorsville since it is influenced to some extent by Brashears Creek. Brashears Creek joins the Salt River about 500 m below Taylorsville or 1 to 1.5 km upstream from Station 23. At times of low flow there are large numbers of pelecypod shells, small to medium rocks, coarse gravel, and considerable water willow present.

Station 26: Station 26 is on Brashears Creek approximately 100 m above its confluence with the Salt River. Access to the site is provided by a gravel road which runs along the west bank of the river. Both banks are very steep and in the summer months support a thick growth of giant ragweed, *Ambrosia trifida*. Brashears Creek is similar to the Salt River, with beds of water willow and the substrate composed of various-sized rocks, sand, and clay.

To determine the effects of domestic pollution of the Salt River and the impoundment area, the following stations were established on Hammond Creek in Anderson County:

Station H1: This site on Hammond Creek is approximately 300 m below a sewage outfall from Lawrenceburg. It is at U. S. Highway 127 west of the intersection of Highway 127 and State Highway 44. Below the outfall, the stream winds through bedrock and large cobblestones. The terrain is flat and generally lacking trees since it is overgrown farmland. The effects of the effluent are very noticeable at Highway 127. At low flow, there is considerable odor, sludge, muck, and many *Chironomus* and *Eristalis* (Syrphidae) larvae in the stream. Approximately 200 m below Highway 127 a tributary joins Hammond Creek and the sewage effluent is considerably diluted.

Station H2. This station is at a low water bridge next to a distillery close to the mouth of Hammond Creek. This site is less than 0.5 km from the Salt River. The bottom is composed of gravel, cobblestones, and sand.

Station H3. Station H3 is at low water bridge on the Salt River above the mouth of Hammond Creek. During the spring and summer of 1973, water samples were collected here to aid in assessing the effects of Hammond Creek on the Salt River. The low water bridge acts as a dam at times of low flow and creates a large pool. The bottom is composed of medium to large rocks, sand, and clay.

Station H4. This site is 300 m below the confluence of Hammond Creek with the Salt River. There is water willow growing in the area, although there are no conspicuous riffles. The bottom type and terrain at this station are similar to Station H2.

MATERIALS AND METHODS

Physical and chemical parameters of the waters of the Salt River and its tributaries were measured according to procedures outlined in Standard Methods for Examination of Water and Wastewater, 13th ed. (Amer. Pub. Health Assoc. 1971). Temperatures were measured with calibrated mercury stem thermometers and with the thermistor element of a Yellow Springs Model 54 Oxygen Meter. Readings for dissolved oxygen were taken with the same meter and checked against a standard determined by the Alsterberg modification of the Winkler method. Total hardness and alkalinity were determined using 0.020 N H_2SO_4 as described in Standard Methods (13th ed. 1971). Specific conductance was measured using a Beckman RB3 Solu-Bridge conductivity meter. Major anions were determined following accepted wet chemistry procedures (Environmental Protection Agency 1973) using a Bausch and Lomb Spectronic 20 and Perkin-Elmer Model 111 spectrophotometer. Major cations were determined with at atomic absorption spectrophotometer (Perkin-Elmer Model 303). Magnesium and calcium were determined in the nitrous oxide flame using 1,000 to 2,000 ppm KCl to suppress ionization (Bowman and Willis 1964). The four major cations, sodium, potassium, calcium, and magnesium were analyzed using a 2-inch burner head rotated 90 degrees to the light path. This adjustment facilitated reading high concentrations without dilution of the sample (Ediger 1973; Kahn 1967, 1968).

Suspended solids were measured by filtering 50 or 100 ml of raw water through Reeve-Angel Filters in Gooch Crucibles and then drying at 105° C. To determine total residue, 50 or 100 ml of water were evaporated to dryness at 105° C and weighed in a tared flask.

Besides bicarbonate, chloride was the only other anion determined by titrimetric means. A standard mercuric nitrate solution was used with diphenylcarbazonebromophenol blue as the indicator in a 100-ml sample in the laboratory (Standard Methods, 13th ed. 1971).

Sediment analysis. - Samples were collected with a small stainless steel spatula and returned to the laboratory in 100-ml Nalgene bottles. The samples were either 'wet' or 'dry', depending on whether they were taken above or below the water level. Of the latter, it was noted if they had been recently deposited by high water. In the laboratory, the samples were strained if necessary to remove large stones, sticks, and shells. The sediment samples were ground with a mortar and pestle and dried at 105° C.

Cations and anions were analyzed from the sediments using 3 different techniques. For total ionic concentration, the acid digestion procedure of Mackereth (1966) was employed. This consisted of dissolving the sediment in successive additions of concentrated nitric, hydrofluoric, and perchloric acids. This was warmed (but not boiled) and evaporated to dryness. The residue was dissolved in 2 ml of concentrated hydrochloric acid and brought to constant volume with demineralized water. Each cation and anion of interest was then analyzed using standard procedures (Standard Methods, 13th ed. 1971).

To determine the concentration of exchange cations, a 0.1 normal $BaCl_2$ extraction was used (Beck 1972). Approximately 0.5 grams of material were shaken in a 50-ml flask with 2 separate 25 ml washings of barium chloride. The 2 aliquots were separated from the sediment by filtration through Millipore 0.45-micron HA filters. If the washings were exceptionally turbid, an initial step of settling or centrifuging was necessary. The two 25-ml portions of barium chloride were then combined for atomic absorption analysis.

The third procedure was a distilled water extraction method. The same quantities and methods were used as with the $BaCl_2$ extraction. These water-extracted samples were then ready for analysis of cations and anions by spectrophotometric techniques. This last method will leach out only interstitial cations and will have minimal effects on exchange ions (Beck, pers. comm.).

Rainfall and Runoff Samplers. - In the fall of 1973, one rainfall and 3 runoff samplers were placed in the field to collect water for chemical analysis. The rainfall sampler was similar to one used by Likens et al. (1967) and consisted of a 5-cm polyethylene funnel connected by a loop of Tygon tubing to a 1-liter Nalgene bottle. The loop in the tubing kept out insects and prevented evaporation of the sample. The runoff collectors were plexiglass trays in the shape of a trapezoid with bases 10 and 40 cm and an altitude of 30 cm. The short base, and both sides of the tray, had a 2-cm high edge. The tray was set with the wide base into the hillside and tilted so runoff water was directed to the narrow base where a 2.5-cm funnel (covered with Nitex screen) was embedded in the plexiglass. The funnel was connected to a 1-liter bottle by a looped tube. The entire apparatus was covered with plywood to exclude rainwater. One runoff sampler was placed near Station 17, and 2 were set near Station 22 at Taylorsville.

Faunal Sampling. - Benthic samples were collected with Surber samplers, Ekman dredges, and nets in an effort to obtain qualitative information as well as sound data on the relative abundance and distribution of the various kinds of organisms. Such samples were preserved in ethyl alcohol and returned to the laboratory for sorting, counting, and identification. Fishes were collected by electroshocking, netting, seining, and with chemicals. All collections were fixed in 10 percent formalin, returned to the laboratory, washed, sorted, identified, weighed, and preserved in ethyl alcohol. Whenever possible, stations were visited on several occasions so that seasonal changes in the various elements of the biota could be documented. While in the field, records were kept of all amphibians, reptiles, birds, and mammals seen or heard in the study area. Birds were identified by song as well as by sighting. Complete lists of algae, vascular plants, benthic arthropods, mussels, fishes, amphibians, reptiles, birds, and mammals taken from the Salt River Basin or observed in the watershed have been presented in Krumholz (1971), Krumholz and Neff (1971), Neff and Krumholz (1973), Krumholz and Neff (1974). Some of that material has been published in the open literature (White 1974, Resh 1975) and will be referred to in appropriate sections of this report.

PHYSICAL FEATURES OF THE SALT RIVER IMPOUNDMENT AREA

Temperature. - The temperature of the air influences the temperature of natural waters on both a seasonal and diurnal basis. Changes in water temperature affect solubilities of gases and chemical compounds as well as growth rates and activities of various organisms. Water temperatures in the Salt River ranged from 0.50 to 28.0° C. Although ice has been reported along the bottom of flowing water (anchor ice) (Hynes 1970), the only ice observed during this study was along the edge of the river in shallow water. During the study period, the air temperature varied from -8.3 to 30.0° C. Maximum-minimum air temperatures are available from Shelbyville, Kentucky (U. S. Dept. Commerce, Climatological Data 1972, 1973, 1974), about 30 km northeast of Taylorsville. With the exception of 4 samples, all water temperatures recorded at Taylorsville were within the maximum-minimum air temperatures recorded at Shelbyville.

Discharge. - Variations in discharge in a river probably influence water quality more than changes in season or temperature. This is especially true in the Salt River area where the impervious substratum (Clays Ferry Formation) results in high surface runoff. The effect of rainfall is to dilute and decrease the concentrations of the chemical constituents in the water. Exceptions are suspended solids and turbidity, which increase as a result of overland flow. Dissolved gases and pH either are not affected or respond in an unpredictable manner. Increased turbulence should increase the concentration of dissolved oxygen, but this effect is usually overshadowed by the higher BOD or COD readings which result from increased quantities of silt and detritus. Since pH is a measure of ratios and concentrations of various chemical species in water, it is difficult to predict the effects of overland flow on this parameter.

Monthly averages for rainfall (at Taylorsville) and discharges at Van Buren (Station 17) and Harrodsburg, are depicted in Figure 3. The Harrodsburg station was terminated as a continuous discharge station in September 1973. The effect of season on rainfall and discharge is apparent, with periods of higher rainfall and discharge occurring in the winter months, typically December or January. Periods of low flow usually are in the late summer months, either August or September. The low flow during the summer is the result of decreased rainfall as well as higher evaporation and transpiration rates by plants.

The significant correlation between rainfall and discharge is due to the shale and limestone (covered with clay) which resists water infiltration. During 1972 and 1973, rainfall differed by only 1.72%, with a total of 139.8 cm (55 inches) falling the first year, and 137.4 cm (54.1 inches) falling the second. The annual discharge at Van Buren for these two calendar years differed by only 1.76%, being 4,243.5 m^3/sec (149.856 cfs), and 4,169.3 m^3/sec (147,236 cfs). The average discharge at Van Buren for the 1972 and 1973 calendar years was 11.6 m^3/sec (409 cfs) and 11.4 m^3/sec (403 cfs), respectively. These values are almost twice as high as the 35-year mean for Van Buren of 6.9 m^3/sec (244 cfs). The discharge at Van Buren was considerably less than that at Shepherdsville. From 1966 to the present time (1973 water year), the average yearly discharge at Van Buren varied from 15.7% to 18.0% of the average yearly discharge at Shepherdsville. During the same period, yearly discharge at the Harrodsburg station varied from 3.2 to 4.3% of the yearly average discharge at Shepherdsville.

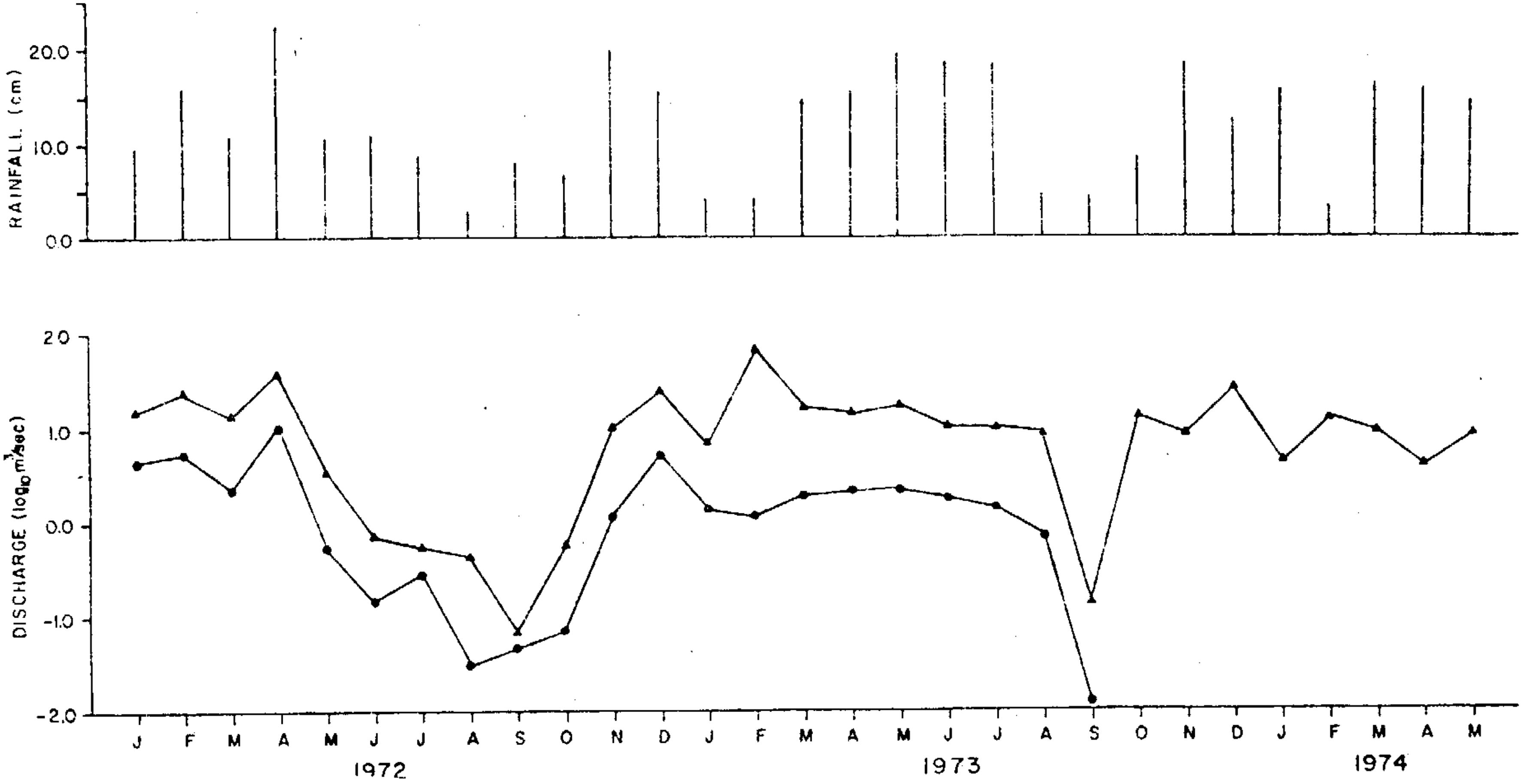

Figure 3. Rainfall at Taylorsville (cm), and discharge (m^3/sec) at Station 17, Anderson County, and at Harrodsburg, Mercer County, on the Salt River, June 1972 - May 1974. Harrodsburg (—●—●—) was not sampled after September 1973.

The use of means in discussing discharge in a river is not too instructive, since flow rates change readily. Even the monthly means in Figure 3 range through three (3) orders of magnitude. The U. S. Geological Survey bihourly discharge data for Station 17 show the minimum for the 1973 water year was 0.80 m^3/sec and the maximum was 302.9 m^3/sec. The record maximum at this station was 473 m^3/sec (16,740 cfs) on 4 March 1964. One of the heaviest rains and the resulting high discharge for the period of study came when 5 cm of rain fell between 15 March and 17 March 1972. The discharge increased from 5.5 m^3/sec to 196 m^3/sec, a 35-fold increase. The period of maximum change was from 0600 to 0800 hours on the 16th when the discharge increased 1.5 times, climbing from 38.5 to 57.8 m^3/sec.

It is an oversimplification to state that the effect of rain and high discharge is to dilute the soluble chemical constituents in water. Although the concentration in milligrams per liter may decrease, considering the tremendous increase in discharge the total amount of soluble materials increases. By multiplying the concentration in milligrams per liter by the flow in cubic meters per second times 10^3 ($1\ m^3 = 10^3$ liters) it is possible to calculate the actual quantity of an element being carried by the river.

Concentrations of sodium (mg/l) and the total amount of sodium (g/sec) flowing past a point are shown in Figure 4. These data were taken from a station (Station 28, Krumholz and Neff 1972) on Brashears Creek in conjunction with a study of invertebrate drift. The data were collected from 21 May to 10 August 1973. A total of 44 samples was taken including daily and hourly collections. The longest period between collections was 20 days, with the more frequent hourly samples taken during times of

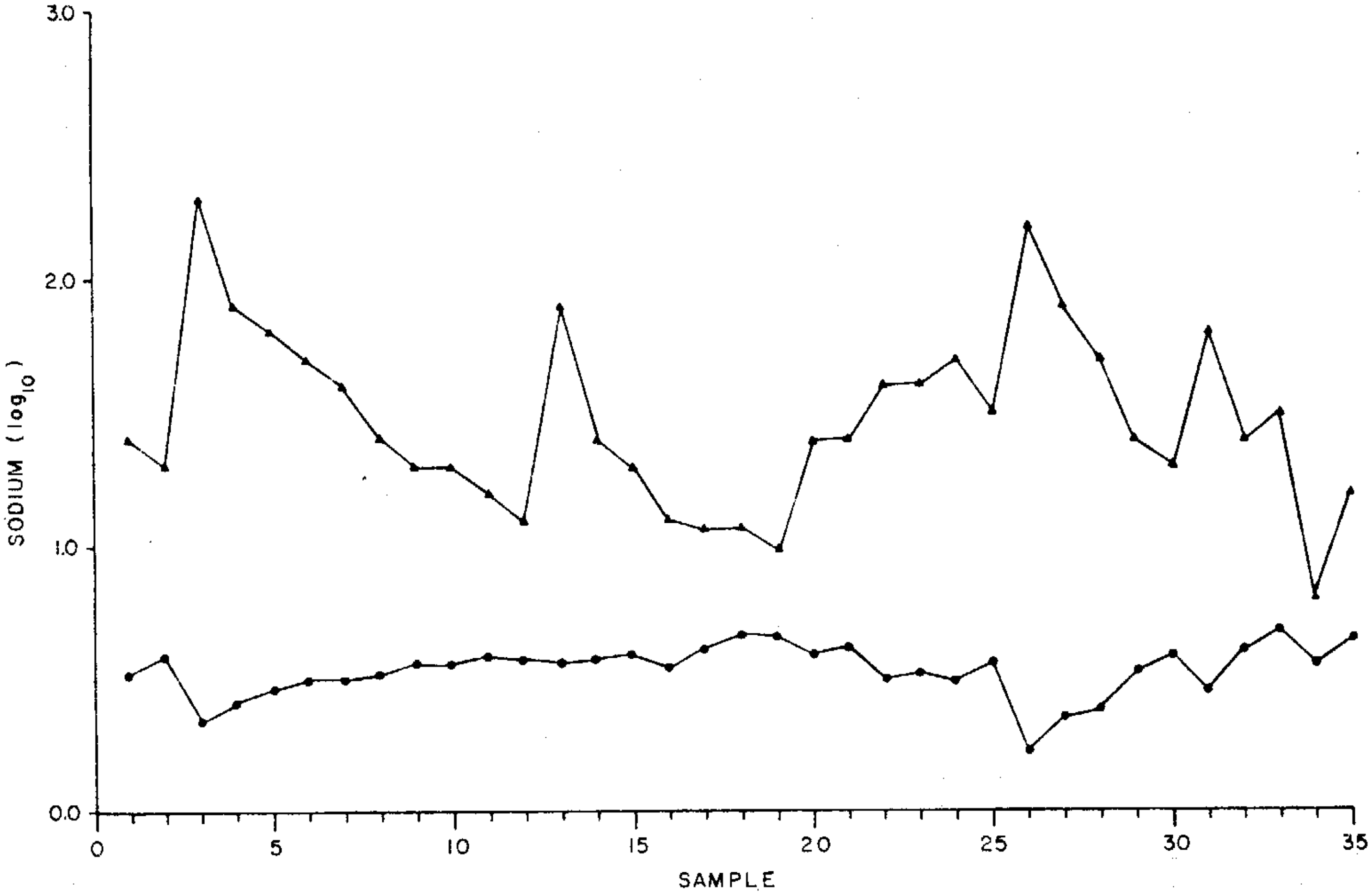

Figure 4. Sodium in mg/l and g/sec at Station 28 on Brashears Creek, Spencer County, 21 May 1973 - 10 August 1973. The upper line (—▲—▲—) is sodium in g/sec.

rain and change in discharge. The regression lines are inversely correlated (n = 44, r = -0.65), significant at the 99% level. The minimum flow for the study was 0.55 m^3/sec. On the day of minimum flow, sodium concentration was at maximum (6.3 mg/l). Combining, this gives 3.46 g of sodium passing per second, which was minimum for the study. The day of maximum flow (96.8 m^3/sec) corresponded to the second lowest reading for sodium concentration which was 2.2 mg/l (the lowest was 1.7 mg/l). These two values yield 212.9 g of sodium per second, the highest value recorded. Sodium ranged from 1.7 to 6.3 mg/l, a difference of 3.7 times. During the same period, the discharge ranged from a low of 0.55 to a high of 96.8 m^3/sec, a difference of 176 times. If dilution were the only process acting, these two measurements would exhibit the same magnitude of fluctuation.

CHEMICAL CHARACTERISTICS OF THE IMPOUNDMENT AREA

Sets of samples from the collection stations were taken at regular intervals for two years. These data were collected to ascertain seasonal variations and differences between stations on the river.

Major Cations. - Means and ranges for cations, anions, and the other parameters collected from Station 17, and Station 22 on the Salt River, and Station 26 on Brashears Creek are listed in Tables 1, 2, and 3. The cations are listed before the anions, and both are ranked in order of abundance. The most abundant cation was calcium. This ion averages more than 50 mg/l at all stations, which was 5 times the concentration of the next most abundant cation. Calcium originates from weathering of calcite ($CaCO_3$) or limestone. The solubility of calcium carbonate in water is dependent on pH as well as water temperature. Sodium and magnesium were the second and third most abundant cations with means between 4 and 10 mg/l.

In general, magnesium levels were higher than sodium. Magnesium in the water probably originates from magnesium carbonates. The sodium in solution may have a variety of origins, coming from halite (NaCl) or weathering of aluminosilicates ($NaAlSi_3O_8$).

Although specific differences among the stations on the Salt River and Brashears Creek will be discussed later on the basis of means and ranges of data, these three stations have much similarity. Average specific conductance at Station 17 was 832 μmhos. The four major cations range from 0.1 mg/l (potassium) to 1.7 mg/l (sodium), less at Station 26 on Brashears Creek than at Station 22 at Taylorsville on the Salt River. Average bicarbonate was higher at Station 26 than at Station 22 (192 mg/l compared with 183 mg/l) while average sulfate was lower at Station 26 than at Station 22 (27.4 mg/l compared with 35.7 mg/l). The greatest variation among these three stations was not in the chemical parameters but in total and suspended solids. Average values for suspended solids at Station 17 was 48 mg/l, for Station 22 was 159 mg/l, and for Station 26 was 63 mg/l.

Ranges and means for Station H1, below the Lawrenceburg sewage outfall on Hammond Creek, Anderson County, are listed in Table 4. The concentrations of ions at this site are greater than at the stations on the Salt River and Brashears Creek. The average value for sodium was 54.5 mg/l, for conductance was 619 μmhos/cm, and for dissolved oxygen was 5.4 mg/l. The high values for sodium and specific conductance, and low value for dissolved oxygen were due to chemicals added for the effluent treatment. The moderate values for calcium and magnesium were similar to the values obtained at Stations 22, 26, and 17.

Major Anions. - The major anion in the Salt River and Brashears

Creek is the bicarbonate ion. The major source of HCO_3^- is the weathering of calcite. Average readings for HCO_3^- are similar for Station 17 (188 mg/l), Station 22 (183 mg/l), and Station 26 (192 mg/l). The average for Station H1 on Hammond Creek was 279 mg/l, almost 100 mg/l greater than the previous three stations. In this case, the addition of sodium bicarbonate to the sewage effluent at Lawrenceburg caused the increased amounts.

The second most abundant anion in the Salt River Basin is sulfate. With average values of 35.7 ppm at Station 22, this anion was about 20% the value of bicarbonate. Sulfate can enter the water from the oxidation of SO_2 in the atmosphere (Junge 1960), or from the weathering of gypsum. Deposits of gypsum are common the Blue Grass Region, and probably originated from the reaction of H_2SO_4 with calcium carbonate (Hendrickson and Krieger 1964:58). Gypsum in its anhydrous form is 71% SO_4 and 29% Ca which will place additional calcium ions in solution.

The third most abundant anion in these waters is chloride which was similar at Station 22 (9.7 mg/l), Station 26 (10.7 mg/l), and Station 17 (11.1 mg/l). The weathering of halite (NaCl) produces free sodium and chloride in solution. Despite its name, the Salt River does not possess elevated concentrations of either sodium or chloride.

Nitrate and phosphate are the fourth and fifth most abundant anions in the Salt River and Brashears Creek. The sources of these two anions are natural wastes and processes, such as the decay of dead organisms or human influence, such as waste effluents and runoff from fertilized farmland. In addition, phosphate can come from snail and clam shells (Miller 1896), as well as the mineral apatite. The reported nitrate values are for actual NO_3^-, not nitrate nitrogen as is often reported.

These ranged from 0.48 to 15.95 mg/l at Station 17 with a mean of 4.43 mg/l. Converting to nitrate nitrogen, the range would be from 0.11 to 3.5 with a mean of 0.95 mg/l. At these stations on the Salt River and Brashears Creek, phosphate levels are about one-third or one-fourth of nitrate levels. At Goodnight Bridge (Station 17), the mean was 1.05 and the range 0.18 to 3.71 mg/l. These values were similar to those obtained at Station 26 on Brashears Creek (Table 3).

The Federal Water Pollution Control Administration (1968) proposed an optimum ratio for N:P of 10:1. When molecular phosphorus rises above 0.1 of molecular nitrogen, algal growth is likely to occur in standing water. At Station 17, the range in N:P ratios was from 0.3:1 to 13.7:1 with an average of 3.7:1. At Station 26, the range was from 0.6:1 to 9.4:1 with an average of 2.1:1. These high values for phosphorus indicate that once the Salt River is impounded there is the possibility of nutrient enrichment and eutrophic conditions. In contrast with these data, Bacon (1973) at Station I (surface water) on Doe Valley Lake found low values for phosphorus. The range in N:P for his data was from 4.2:1 to 56.0:1 with an average of 15.7:1. Clearly, these waters are phosphorus-poor in comparison with Salt River water. At the mouth of Beargrass Creek, Terhune (1975) found average nitrate was 25.7 mg/l and average phosphate was 8.0 mg/l, with N:P ratios of from 0.4:1 to 10.2:1, with an average of 3.9:1. These phosphate and nitrate levels at the mouth of Beargrass Creek are higher than those found in the Salt River, but since both nutrients are more concentrated in Beargrass Creek, the N:P ratios are similar in both rivers.

Nitrite was present (0.01-0.001 ppm) and was not in quantities to be significant. Aside from the mineral content of rocks and soils, nitrite may originate from the oxidation of ammonia (NH_3^-) or the reduction of nitrate (NO_3^-).

Carbonate ($CO_3^=$) results from the weathering of calcite and exists in appreciable quantities at pH readings greater than 8.2. Below 8.2 the anion is present as bicarbonate (HCO_3^-). Detectable carbonate was found on several occasions at the mouth of Hammond Creek (Station H2). These were in July, September, and November of 1972, and July of 1973. At this station, the nutrients from the effluent at Lawrenceburg, although diluted, caused high oxygen, alkalinity, and pH readings.

Silica is reported in terms of silicon dioxide, SiO_2. The silicon-oxygen bond is so strong that free silica does not occur in solution. The actual form found in natural waters is H_4SiO_4, which will dissociate depending on the pH of the water. Silica in water may come from granite or siliceous rocks. In this area, it is more likely to come from weathering of feldspars. With readings that ranged between 5 and 10 mg/l, silica was about as abundant as chloride or magnesium.

Hammond Creek (Table 4) had elevated readings for sulfate (59.8 mg/l) and bicarbonate (279 mg/l). Phosphate readings (26.4 mg/l) were almost double the average nitrate readings (15.6 mg/l). Ammonia nitrogen ranged from 1.2 to 47.3 mg/l with an average of 12.9 mg/l. No data are available for silica or chloride at this station, although the chloride levels probably would be elevated due to the sewage effluent.

Discussion of ions based on their concentrations in grams or milligrams is not as instructive as converting them to milliequivalents. This form is instructive because the ionic charge or combining capacity is considered with its determination (Hem 1971). The sum of all cations should equal the sum of all anions when converted to milliequivalents, which provides another means for checking the accuracy of the analyses. Discrepancies may arise if there are errors in the chemical procedures or if ions are present that are not assayed for in the analytical methods.

Data from 19 December 1973 for Stations 17 and 26 on the Salt River have been converted to milliequivalents and are depicted in Figure 5. For comparison, data collected in May 1974 from the Kentucky side of the Ohio River (Mile 762.1), about 250 km (155 miles) downstream from Louisville are shown. The Salt River had a higher concentration of ions than Brashears Creek, which in turn was higher than the Ohio River. Slightly higher sulfate amounts in the Salt River, when compared with Brashears Creek, are noticeable. The Ohio River in contrast with both streams has elevated sodium and sulfate levels. It cannot be ascertained from these data if these variations are due to differences in rock strata or effluent additions, although the latter is the most probable source. Milliequivalent data for Stations H1, H2, and H4 for 26 January 1973 are presented in Figure 6. The effluent from Lawrenceburg caused higher levels of sodium, nitrate, phosphate, and sulfate at Station H1. These ions are diluted substantially at Stations H2 and H4.

Results of chemical analyses can also be expressed in terms of millimoles. This does not take the ionic charge into account, so there is not a 1:1 combining ratio between cations and anions. Garrels and MacKenzie (1971) suggested that a mole ratio of calcium to bicarbonate of 1:2 was indicative of limestone waters (since each mole of $CaCO_3$ yields one mole of Ca^{++} and 2 moles of HCO_3^-). The average of all calcium to bicarbonate ratios for the Salt River at Station 17 was 1:2.1 and for Brashears Creek at Station 26 was 1:2.3. This high value for the bicarbonate indicated that this ion may be contributed from sources

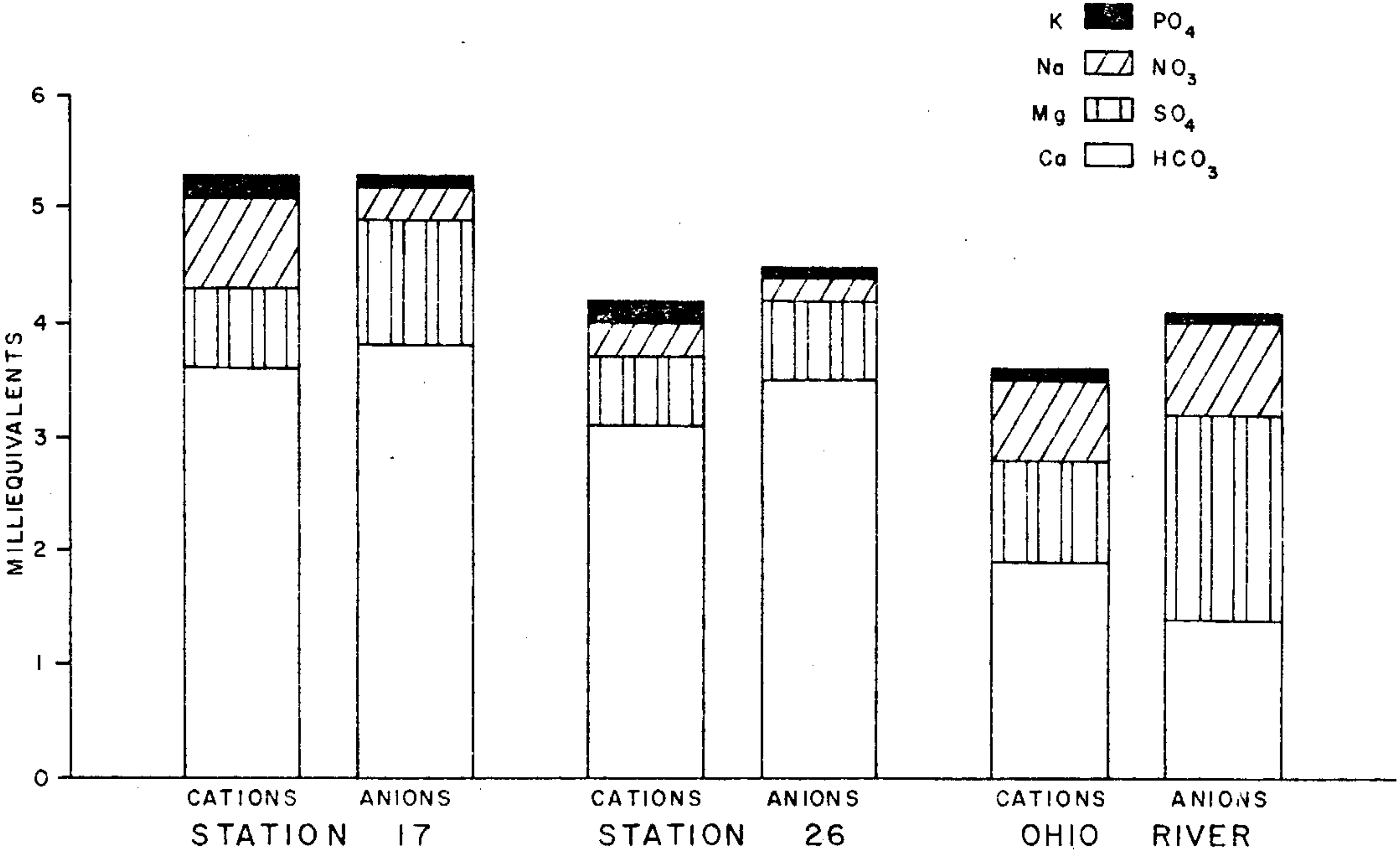

Figure 5. Milliequivalents of major ions at Station 17 on the Salt River, Anderson County, Station 26 on Brashears Creek, Spencer County (19 December 1973), and the Ohio River (Mile 762.1), 17 May 1974.

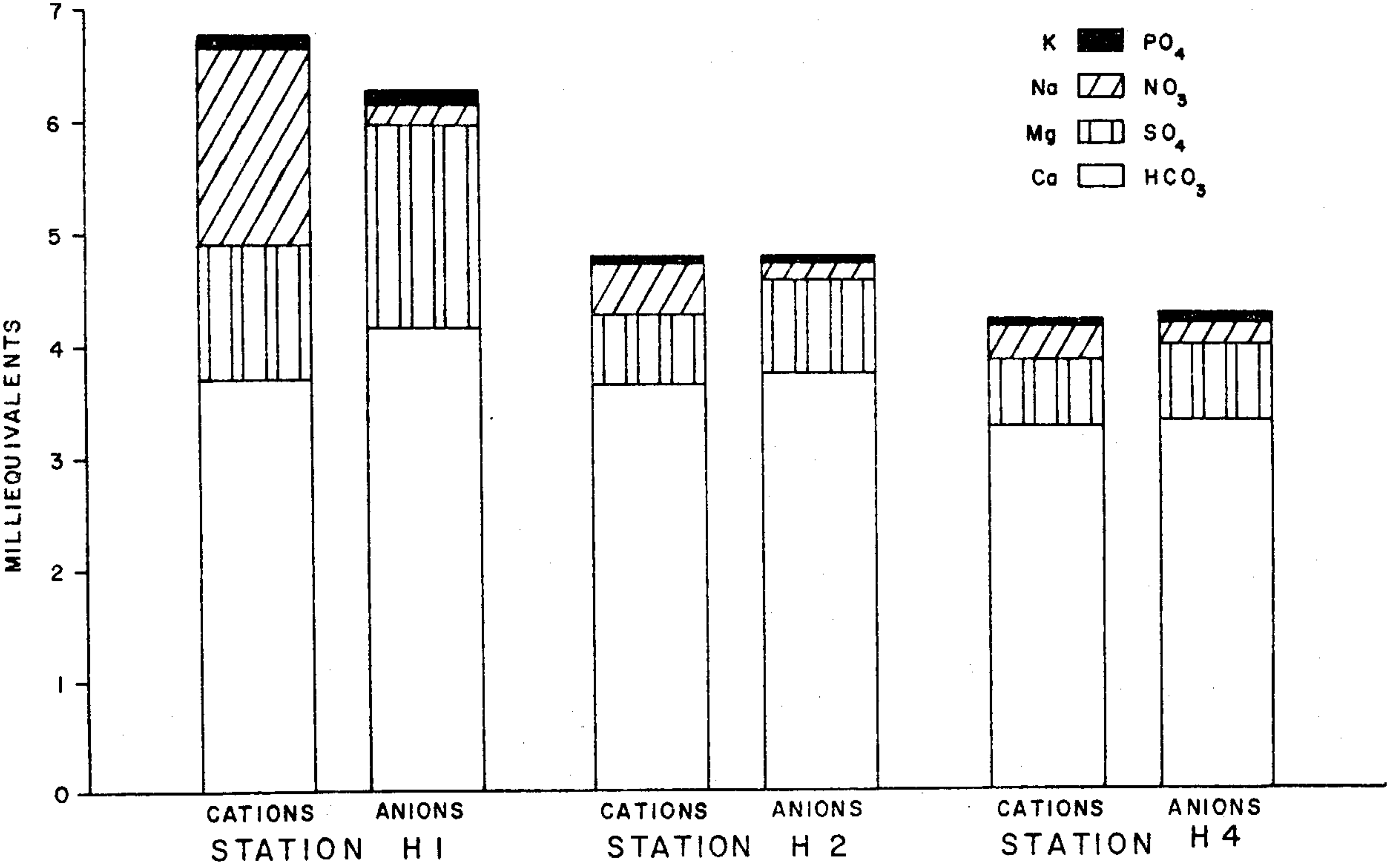

Figure 6. Millequivalents of major ions from Stations H1 and H2 on Hammond Creek and Station H4 on the Salt River, Anderson County, Kentucky 26 January 1973.

other than calcite. Dolomite waters have a calcium to magnesium to bicarbonate ratio of 1:1:4. There is also the possibility of magnesium carbonate ($MgCO_3$) deposits within limestone. Evidently these are predominantly calcium carbonate waters, with additional carbonate in the form of magnesium carbonate.

Livingstone (1963) compiled water chemistry data from rivers all over the world. Table 5 presents the averages of Livingstone's data for his concept of the typical world river. When comparing Livingstone's values with the data in Tables 1, 2, and 3, we find calcium, bicarbonate, sulfate, magnesium, and nitrate levels are greater, sodium and potassium levels similar, and silica slightly less in the Salt River than in the 'average' river.

Milligram ratios for various chemical constituents are listed for Station H1 on Hammond Creek (Table 6), and Station 17 on the Salt River (Table 7). A low coefficient of variation for a milligram ratio indicates that the two ions are related and could have originated from the same source. The coefficient of variation for calcium to bicarbonate is 20.1% for Station H1 and 20.0% for Station 17. Sodium to magnesium and calcium to magnesium concentrations were poorly correlated at Station H1, while these two pairs of ions exhibited a much closer relationship at Station 17 on the Salt River. The high coefficients of variation at Station H1 seem due to the Lawrenceburg sewage wastewater's effect on the water quality. If solid NaCl is dissolved in water the milligram ratio of sodium to chloride is 0.648. The sodium to chloride ratio for Station 17 was 0.8, which indicates sodium originates from sources other than halite, perhaps in this case sodium bicarbonate. The calcium to bicarbonate ratio for pure calcite is 0.328. Milligram ratios for these ions at both stations were less than 0.328, indicating that bicarbonate in solution also originates from weathering of magnesium and sodium carbonates.

Hydrogen Ion Concentration. - Hydrogen ion concentration was determined at all the stations during this survey. Precise knowledge of pH can aid in equilibrium calculations concerning calcite, dolomite, and various forms of iron, manganese, and silicates. Hydrogen ion concentration is related to the solubilities and concentrations of all cations and anions and carbon dioxide in water. Hydrogen ion concentration is influenced by photosynthesis and time of day it is sampled, so its use for the comparison of different sampling stations is rather limited. Since pH is a logarithmic quantity, the difference between a tenth of a pH unit can often be a full unit on the concentration scale. For example, a pH of 7.6 is 2.5×10^{-8} moles of hydrogen ions and a pH of 7.5 is 3.16×10^{-8} moles of hydrogen ions, or a difference of 21%. Between 7.50 and 7.51 there is a difference of 2.3%. Even in the laboratory with a good meter and judicious care with temperatures, buffers, and wash solutions, it is very difficult to obtain such accuracy. To calculate means for pH measurements, values must be converted to hydrogen ion concentration, the mean determined, and the mean reconverted to pH.

The ranges of from 6.8 to 7.9 (average 7.5) for Station 17, and 7.1 to 8.2 (average 7.6) at Station 26 are typical for natural waters. Station 22, at Taylorsville, had an average of 7.1, which was less than the average readings at Station 17. There were no predictable seasonal fluctuations in pH for any of the stations on the Salt River; higher pH values were encountered at times of low flow in the summer months. The slightly higher average readings for Station 26 on Brashears Creek and for the mouth of Hammond Creek, Station H2, were the results of high photosynthetic rates in shallow water. Because of the effluent at Station H1, pH values at this site were several tenths below typical Salt River water. At this station, the average of all pH determinations was 6.4 and the range was from 5.5 to 7.7.

Specific Conductance. - The conductivity of a solution at 25° C, is a measurement similar to pH in that it is related to the concentration and solubilities of all ions. Specific conductance is determined in order to approximate the concentration of all dissolved ions. Very high values can indicate hard water, mine drainage, effluents, industrial wastes, or domestic sewage.

At Taylorsville, specific conductance ranged from 200 to 535 micromhos (μmhos). The average reading was 368. The higher readings were observed during high discharge when the concentration of most ions in solution was more dilute. Hammond Creek near the effluent had higher specific conductance than either the Salt River or Brashears Creek. At this station (H1) the maximum was 1300 and the average of 17 readings was 619 μmhos. High specific conductance values may be found in acid mine drainage which is free of sewage. In a study of Paint Creek in eastern Kentucky, Krumholz et al. (1974) reported specific conductance values greater than 10,000 μmhos. In these samples, sodium and chloride were as high as 1 g/l, indicating that saline brines were the source of the high readings.

Since the conductivity of a solution is related to the concentration of all ions, there is usually a significant correlation between specific conductance and quantities of ions present. In Figure 7,

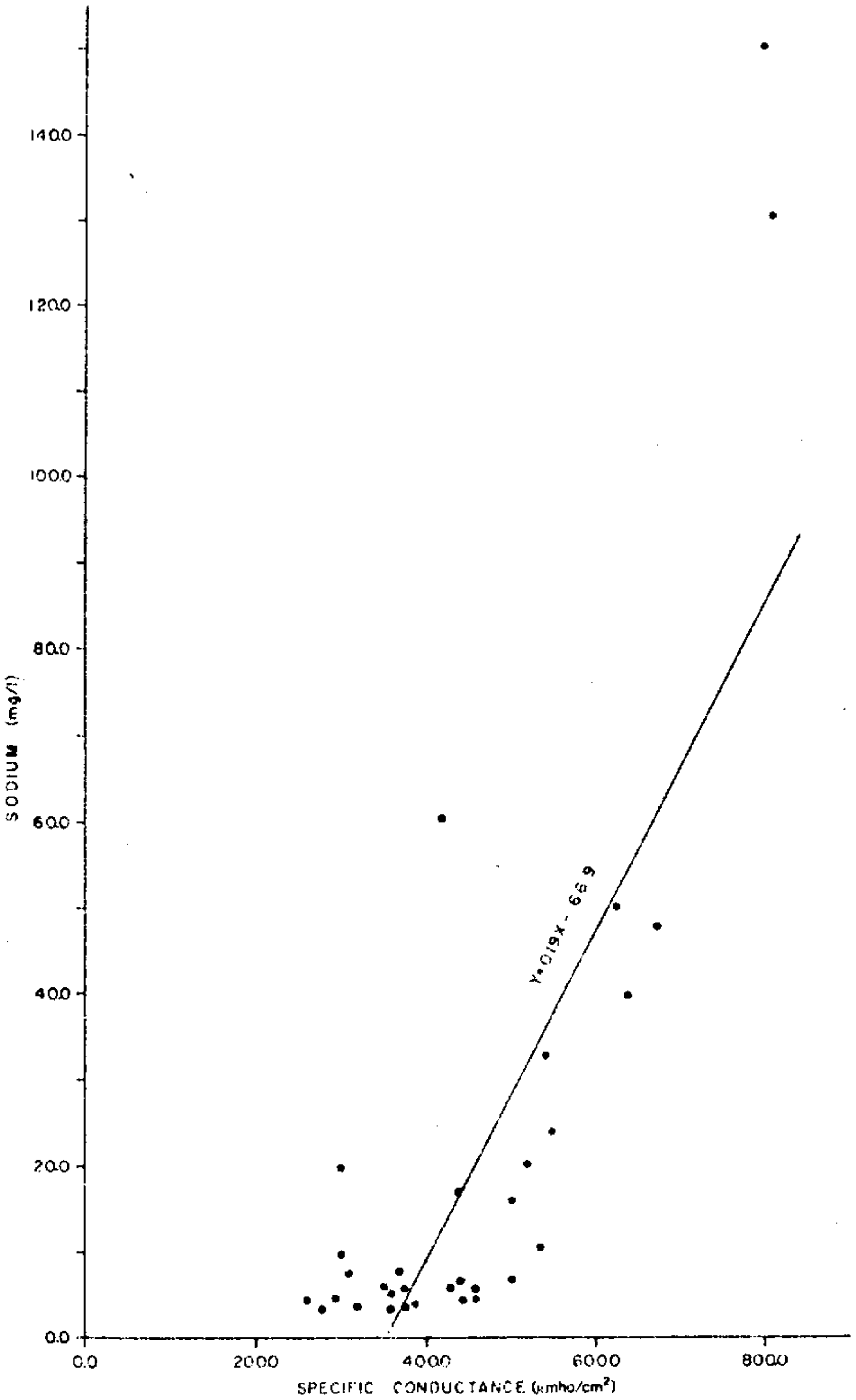

Figure 7. Relationship between sodium and specific conductance at Station 17 on the Salt River, Anderson County, and Station H1 on Hammond Creek, Anderson County, Kentucky.

sodium concentration is plotted against specific conductance for two stations, H1 near the source of Hammond Creek and Station 17 on the Salt River. The relationship between the variables is linear, and the equation $y = 0.19x - 66.9$ accounts for 82.4% of the variation in variable 2. If the concentration of each ion is multiplied by a conversion factor (from Hem 1971 or American Public Health Association 1971), then summed, it is possible to predict the specific conductance of a solution from the analytical concentration of its ions.

Dissolved Oxygen. - From a biological point of view, dissolved oxygen is one of the most important parameters measured in water. In general, amounts of less than 4.0 mg/l are detrimental to most aquatic fauna (FWPCA 1968). At Station 17 on the Salt River, the oxygen levels ranged from 2.7 to 14.4 mg/l, which was 18.5% to 101% saturation. The minimum reading of 2.7 at this station, and a minimum of 1.8 mg/l at Station 22, were both on 28 September 1972 when the discharge was at its lowest during the study, 0.07 m^3/sec (2.6 cfs). The next highest readings for these stations were 5.6 and 5.2 mg/l, respectively. Readings of less than 5.0 mg/l are atypical for the Salt River.

At Station H1 near the source of Hammond Creek, 7 of the 16 readings were less than 4.0 mg/l. The range was from 0.2 to 10.1 with an average of 5.4 mg/l. Hammond Creek exhibited the classical case of recovery below a polluted zone (Hynes 1960). At the mouth of Hammond Creek, some 10 km below the effluent, the maximum oxygen recorded was 17.0 mg/l, with 9 of the 16 readings equal to or greater than 10 mg/l.

Suspended Solids. - One of the most significant features of the Salt River is the large variation in turbidity and suspended solids. At Station 17 the range was from 2 to 194 mg/l of unfilterable solids.

Farther downstream (Taylorsville, Station 22) the range was from 4 to 1,684 mg/l. There is no doubt that the solids exhibit the widest range and often the highest concentration of any constituent in the stream's water. The effects of silt and increasing turbidities on flora and fauna in a stream have been discussed by the Federal Water Pollution Control Administration (1968) and Hynes (1960, 1970). Light penetration is reduced, and aquatic plants and benthic animals may be covered and destroyed by silt. The feeding and foraging activities of fish may be reduced and feeding activities of filtering organisms such as clams, mollusks, zooplankton, and crayfish become less efficient. The effects are both chemical and physical and can lead to problems such as disease, lack of oxygen, and difficulty in obtaining food. The Ohio River Basin Commission (1977) has recommended a limiting value of 100 mg/l for total suspended solids.

There are positive effects from suspended sediments in water. Spring floods convey nutrients and fresh soil which may aid crop production. Since clay particles are negatively charged, they may adsorb cations which may otherwise be toxic. In fact, it has even been suggested that brine may be added to farm ponds to reduce turbidity (Keeton 1959). The neutralization of strong negative charges makes the silt flocculate and settle faster. Hutchinson (1957), Ruttner (1953), Welch (1952), and Stumm and Morgan (1970), discussed the incorporation of iron and phosphorus into lake sediments and the migration of these ions in relation to overturn.

There was a significant positive correlation (at the 95% level) between suspended solids and discharge, and between turbidity and discharge. There was no positive correlation between dissolved solids and discharge, or between dissolved solids and turbidity (see Table 8). Although high water carries more suspended material than low water, increased flow rates do not uniformly dilute all soluble ions. Regression lines relating turbidity and suspended solids have been published for specific types of water (Duchrow and Everhart 1971). These are of limited use in other areas since turbidity can be caused by different types of clay, coal dust, wood pulp, or organic matter, all of which will affect light penetration in varying degrees.

In Figure 8, discharge is plotted against suspended solids. Using the equation $y = 0.11x + 1.4$, it is possible to predict suspended solids from discharge data. If suspended sediments are multiplied by discharge and 10^3, the resulting value is the amount of suspended material per cubic meter of water per second. This value can then be multiplied by 86,400 (the number of seconds in a day) to determine the daily sediment load. Using the above relationships, the amount of suspended solids for the 1972 and 1973 calendar year was calculated for Station 17 on the Salt River. For 1972, the annual total was 3.3×10^9 kg (3.6×10^6 tons) and for 1973 the value was 2.8×10^9 kg (3.1×10^6 tons) of material. These values can be compared to the Jordan River for 1968-1969 (Serruya 1971) which carried 1.2×10^5 tons. The Colorado River, before construction of Hoover Dam, was estimated to carry 2.2×10^8 tons (Vetter 1953). This last value is about 100 times the amount of sediment carried by the Salt River during this study period.

Total and Dissolved Residue. - At Station 22, total residue ranged from a low of 193 mg/l to a maximum of 1900 mg/l, and the range in dissolved ions was from 14% to 98% of the total residue. At Station 17, the range was from 224 mg/l to 482 mg/l, and the dissolved solids comprised

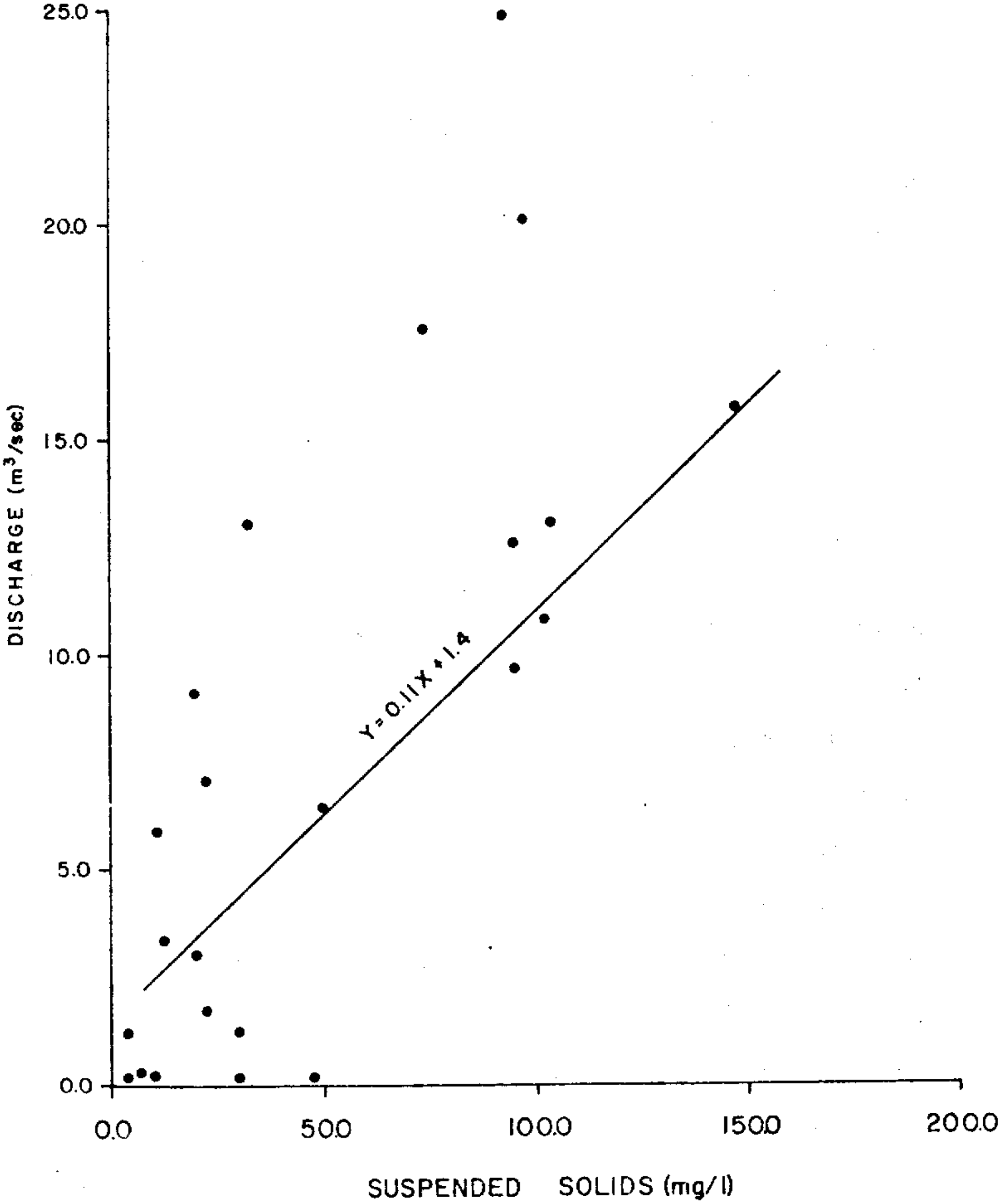

Figure 8. Relationship between suspended solids (mg/l), and discharge (m^3/sec), at Station 17, Anderson County, Kentucky on the Salt River.

from 58% to 99% of the total residue. In this study, dissolved residue was determined by subtracting the suspended solids from the total residue. A factor may be experimentally determined (American Public Health Association 1971), which, when multiplied by the specific conductance, will estimate the dissolved residue. For Station 17, this factor was 0.675 and for Station H1 it was 0.670. Using the factor from Station 17, dissolved residues were predicted using specific conductance for all samples collected from Stations 22 and 23. The range in error and mean error for these two stations was:

Station	Minimum	Maximum	Mean
22	-14%	36%	9.5%
21	-16%	30%	4.4%

Some of the errors are high, although the mean values are below 10%. As calibrated, the specific conductance meter read approximately 5% low, so these predictions are from 3% to 5% too high. This is a convenient, acceptable method for determining filterable residue if a 5.0 to 10.0% error can be tolerated.

It is also possible to predict the dissolved residue from the sum of analytically determined cations and anions. The weight of bicarbonate must be multiplied by 0.494 to account for its approximate 50% loss in weight as a portion is released as CO_2 during drying. A simple factor does not exist for determining the amount of water picked up by sulfate. This amount is quite variable and not easily predicted (Hem 1971).
Below is the range and average error for the differences between analytically determined and calculated dissolved residue for three stations on the Salt River:

Station	Minimum	Maximum	Mean
17	-13.0%	33.0%	9.8%
22	-20.6%	28.7%	5.8%
23	-18.0%	42.2%	5.3%

Considering the many opportunities for error, the average values for these stations are within an acceptable range.

Correlation coefficients for selected ions at Station 17 on the Salt River and Station H2 on Hammond Creek are listed in Tables 9 and 10, respectively. Chemical parameters exhibit significant relationships if they are uniformly diluted and concentrated by changes in season or flow rate. The correlations (significant at the 95% level) between calcium and bicarbonate and among bicarbonate, phosphate, and sulfate at both stations are examples. Calcium and magnesium demonstrate significant relationships at Station 17, indicating that these two ions originate from ground water in close proximity to one another. At Station H1, these two ions are not correlated at the 95% level, because of the influence of sewage effluent. At Station H1, sodium and potassium as well as potassium and phosphate are significantly related. The small drainage area and the proximity of the discharge caused these more significant correlations between the parameters than were observed at Station 17.

Turbidity. - The American Public Health Association, the Environmental Protection Agency, and the U. S. Geological Survey have adopted the nephelometer as the standard instrument for measuring turbidity. The nephelometer does not measure absorbance, as a spectrophotometer does, but rather the amount of light reflected from a water sample. Standards are prepared from a polymer of formazin, chosen because of its stability, small molecular size, and ease of making up reproducible concentrations. Results using the nephelometer should be expressed as a Nephelometric Turbidity Unit (NTU) (Hanna, pers. comm.), although the term Jackson Turbidity Unit (JTU) is still in use. The adoption of nephelometers and formazin standards has come after more than 50 years of a variety of instrumentation and standards. Instruments used in the past include the Jackson Candle Turbidimeter, absorption spectrophotometers, and visual comparisons with standards. Standard solutions have been prepared from different types of clay, Fuller's earth, and silicon dioxide. The silicon dioxide standard has been abandoned because of the difficulties involved in preparing uniform concentrations (Hach 1968). For years, Hellige sold a standard solution which was actually kaolin, standardized by optical methods, and calibrated in terms of silicon dioxide (Caplan, pers. comm.).

The term 'turbidity' is a qualitative, not a quantitative description of water. Speaking of turbidity is much like referring to warmth or cold and not to specific temperatures (Pijanowski 1974). Not much in the way of specifics can be said or predicted with turbidity figures. Unlike ionic concentration, pH, and specific conductance, which are related in a theoretical manner, the turbidity of water is highly variable. For this reason, adoption of easily prepared, reliable standards is justified.

The majority of the turbidity measurements for this study were done with a Coleman 111 Spectrophotometer at 450 nanometers (nm) (Hach Chemical Co. 1969). Standards were prepared from silicon dioxide (from Hellige Inc., New York, N. Y.). In this study when turbidity is discussed it will be as parts per million of silicon dioxide (ppm SiO_2), and this is done with the knowledge that ppm SiO_2 is now outdated. These readings are comparable to readings from other laboratories. Considering the nature of the measurement and the rather limited use of the measurement, they are adequate for current work.

The range of turbidity was from 5.0 to 174.0 ppm SiO_2 at Station 17 on the Salt River. Downriver at Station 22 (Taylorsville), the range was from 5.0 to 816.0. This progressive increase in turbidity or suspended material moving downriver is not uncommon (Hynes 1970). This is due to the river attaining larger size, to its affecting more surface area, and to addition of more water quantity from runoff and tributaries. At the mouth of Brashears Creek (Station 26), the range was from 2 to 148 ppm SiO_2, and was less than turbidity at Station 22 on the Salt River. The effect of Brashears Creek was to dilute and decrease the turbidity of the Salt River below Brashears Creek.

Hardness and Alkalinity. - The American Public Health Association (1971) has developed identical procedures for the tests for alkalinity and hardness. Both tests call for 0.02 normal titrant, and the calculations make use of the equivalent weight of calcium carbonate. Results of both hardness and alkalinity determination are expressed as mg/l of calcium carbonate. EDTA, the hardness titrant, forms ligands with all divalent cations, so in addition to calcium and magnesium, other ions such as iron, manganese, or zinc may be determined by this procedure. In our area, the sum of all divalent cations other than calcium and magnesium is less than 1.0 mg/l so there is little error in this regard. Because the equivalent weight of calcium carbonate is used in these calculations, 40 mg (1 millimole) of calcium in solution (calcium bicarbonate, or any salt of calcium) will be reported as 100 mg of calcium carbonate.

The EDTA will chelate 1 millimole of any divalent cation and the results would be reported as 100 mg of calcium carbonate. Thus, 24 mg of magnesium, 1 millimole, in solution would yield a hardness of 100 mg expressed as calcium carbonate.

In this study, most of the calcium and magnesium was determined by atomic absorption spectrophotometry. To make the results of this study comparable with other works, these values were converted to hardness expressed as calcium carbonate. This was done by multiplying calcium by 2.50 and magnesium by 4.12 to obtain equivalent weights of calcium carbonate. Comparisons showed that these two methods of determining hardness differed by no more than 1%, which may be attributed to experimental error. The value obtained by EDTA titration should be slightly higher, since the titrant is also reacting with the minute quantities of other divalent cations.

If a liter of water contains 100 mg of calcium carbonate, then an EDTA titration for hardness and a sulfuric acid titration for alkalinity will yield identical results. The former would be reported as 100 mg of hardness as calcium carbonate; the latter would be reported as 100 mg of alkalinity as calcium carbonate. If calcium sulfate (gypsum) were added to the water, the alkalinity would be unaffected, but the value for hardness (because of the reaction between EDTA and calcium) would increase. In much of Kentucky's natural waters, hardness exceeds alkalinity because of calcium sulfate. This difference between hardness and alkalinity should provide a method for estimating the sulfate concentration. In a liter of distilled water with 100 mg of calcium carbonate and 100 mg of calcium sulfate, the concentration of the cations and anions in milligrams would be:

	Total	Cation	Anion
$CaCO_3$	100	40.07	60.00
$CaSO_4$	100	29.43	70.56

The total calcium in solution is 40.07 + 29.43 or 69.5 mg. Converting this to calcium carbonate (as the hardness titration does) would be 173.7 mg. Since the alkalinity is 100 mg then the noncarbonate hardness would be 173.7 - 100 or 73.7 mg. This is sulfate, but it is expressed as calcium carbonate. To convert this reading to actual sulfate, 73.7 must be multiplied by 0.9598 (MW SO_4/MW $CaCO_3$). The result is 70.7 mg which differs by only a few tenths from the amount determined from the percentage composition of $CaSO_4$.

This procedure was used to estimate sulfate content from 13 samples when the noncarbonate hardness ranged from 61.5 to 68.0 mg/l. The range in predicted sulfates was from 59 to 65.3 mg/l. The actual sulfate concentration determined by the turbidimetric procedure was from 63.3 to 76 mg/l. The average error for these 13 samples was 10.7%. This error can be reduced somewhat if the original system is considered, and another aspect is discussed. If 100 mg of sodium carbonate is added to the calcite-gypsum water, the hardness would be unaffected, but the alkalinity would increase. In the hypothetical system, this could be accounted for by 1) determining sodium by atomic absorption and converting to sodium carbonate, then 2) subtracting this calculated value from the alkalinity value determined by titration.

Dissolved oxygen, total alkalinity, and total hardness from Station H1 for the period of study are depicted in Figure 9. During the summer months, when the dissolved oxygen dropped below 2 or 3 mg/l, the alkalinity measurements usually climbed above the hardness (which will give

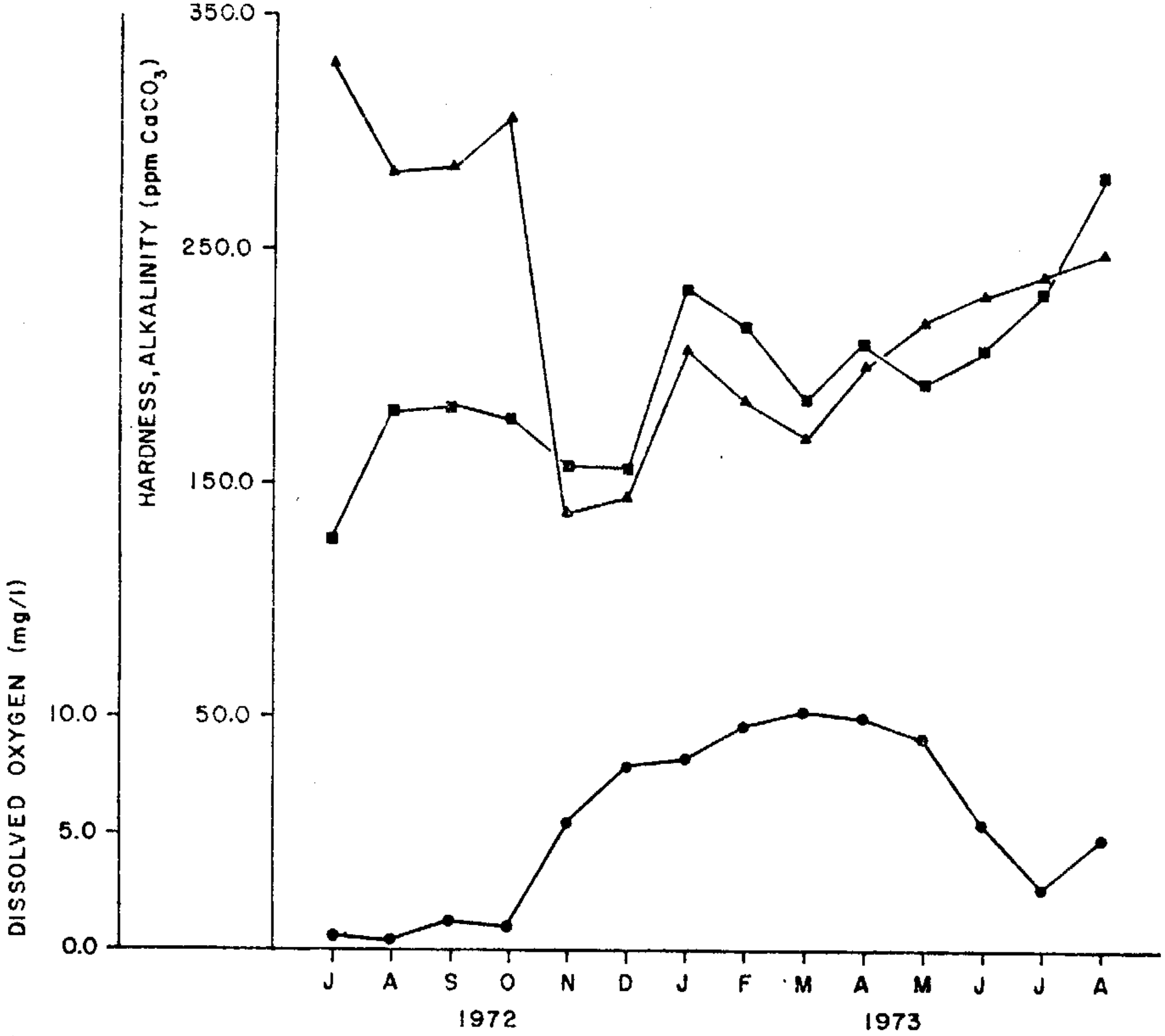

Figure 9. Dissolved oxygen in mg/l (–●–●–), total alkalinity (–▲–▲–), and total hardness (–■–■–), as mg/l $CaCO_3$ at Station H1 on Hammond Creek, Anderson County, Kentucky, July 1972 - August 1973.

negative values for noncarbonate hardness). In 7 out of 15 samples, there was negative noncarbonate hardness, with some values less than -100 mg/l. The sodium and potassium levels were very high in these samples, indicating that some bicarbonate originated from these ions.

SEASONAL CHANGES IN THE WATER CHEMISTRY OF THE SALT RIVER

In the summer and fall, decreased rainfall and high evapotranspiration rates cause a lowering of the water table and a diminished flow rate in the stream of the Salt River Basin. Discharge at Station 17 on the Salt River often drops to zero, and the smaller streams may dry completely. By mid-October, leaves and plant material accumulate in the fairly warm, slow-moving or still waters creating low oxygen levels and high quantities of dissolved solids. In the winter and spring, when precipitation is greater, the discharge increases, and flowing waters are more dilute, although they may transport greater quantities of ions and sediment. Gases are more soluble in cooler waters, and dissolved oxygen levels approach and usually surpass 100% saturation.

Amounts of suspended solids at Stations 17 and 22 for the period of study are shown in Figure 10. The peaks and troughs correspond to periods of high and low discharge at Station 17. Suspended solids at Station 22 were usually greater than at Station 17, except in May and June, 1973, and were even more pronounced at times of high discharge. At Station 22, the periods of maximum suspended sediments occurred on 13 June 1973 (1,684 mg/l) and 3 May 1974 (912 mg/l). For these two samples, the percentage of suspended solids was 88.6% and 86.0%, respectively, of the total residue. The minimum suspended solids at this station were 24 Oct 1972 (4 mg/l, 2% of the total residue) and 19 Dec 1973 (4 mg/l, 1.2% of the total residue).

Oxygen saturation values for August, 1972 and May and July, 1973 are

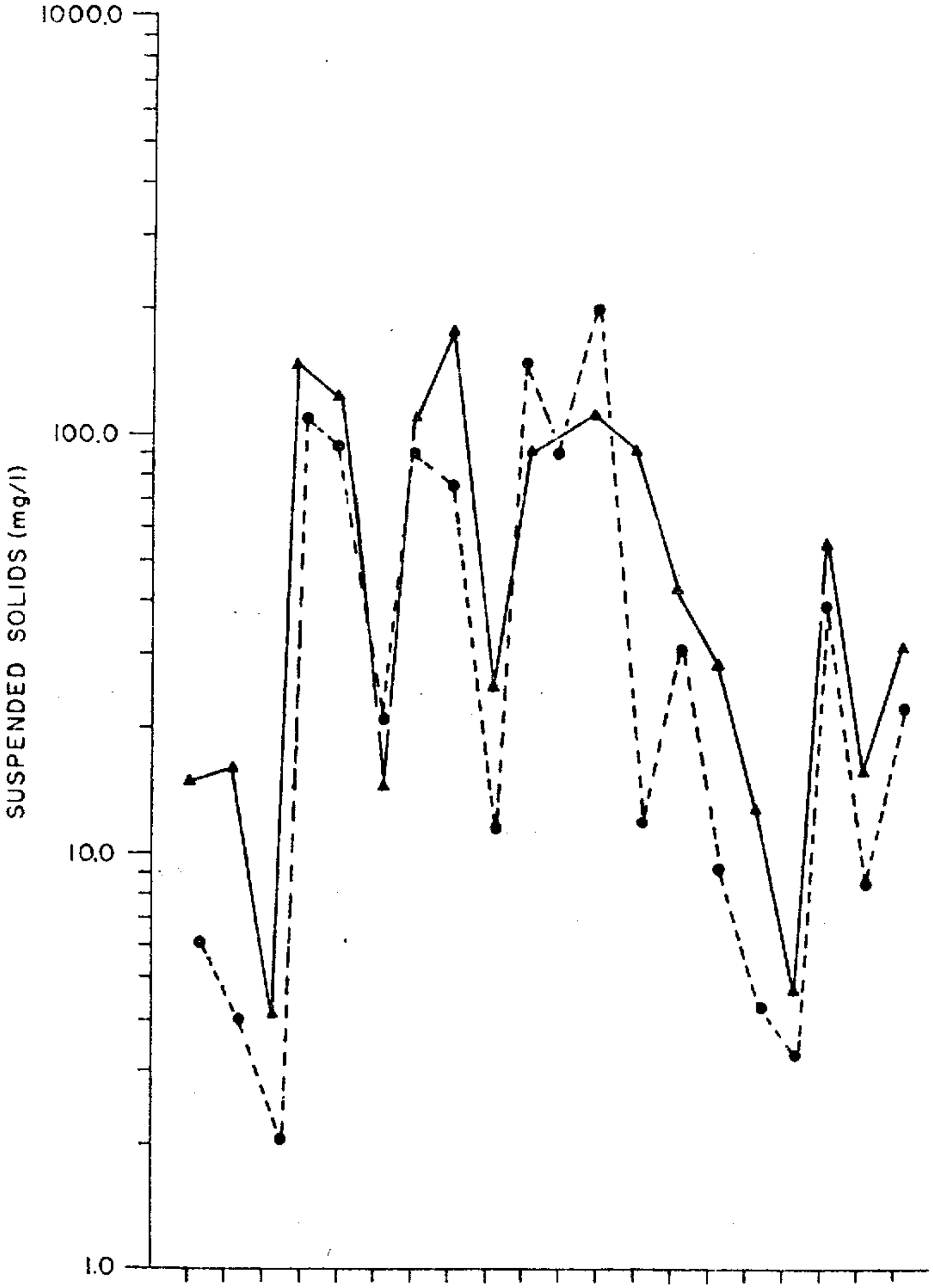

Figure 10. Suspended solids in mg/l at Station 17 (-●-●-), Anderson County, and Station 22 (-▲-▲-), Spencer County, on the Salt River, Kentucky. August 1973 - March 1974.

depicted in Figure 11. The effects of the sewage effluent at Lawrenceburg on Station H1 were greatest during the summer months when water temperatures were high and flow rates were low. For July and August, the average saturation values were 32% and 2.2%; for May, they were 94%. For the same dates, the water at Station H2, the mouth of Hammond Creek, was either at saturation or supersaturation. Evidently, the nutrients were high enough to increase the photosynthetic rates but were not high enough to cause a significant biological oxygen demand (BOD). Brashears Creek (Station 26) exhibited slightly higher saturation levels than the Salt River at Taylorsville.

Dissolved oxygen fluctuated on a seasonal basis (Figure 12), with saturation levels diminished during periods of low flow in the fall. Only 3 times did the oxygen saturation exceed 100% at Station 17, during May 1973, January 1974, and February 1974. Typical saturation values were 80 to 90%, with the exception of 28 September, 1972, when the oxygen was 2.7 mg/l and the percentage saturation was 29.3%. There were no specific differences between Stations 17 and 22, with respect to dissolved oxygen as there were with suspended solids. The differences between these two sites were variable and unpredictable.

Nitrate nitrogen, dissolved residue, and total phosphate at the seven stations are shown in Figures 13, 14, and 15, respectively. For all three parameters, the effects of the sewage effluent at Lawrenceburg were greatest during the summer months when temperatures were high and discharge was low. The influence of the effluent during late July or August was not noticeable in the Salt River directly below Hammond Creek (Station H3), or at Station 17 on the Salt River. Of all the parameters, nitrate nitrogen levels exhibited the greatest fluctuation

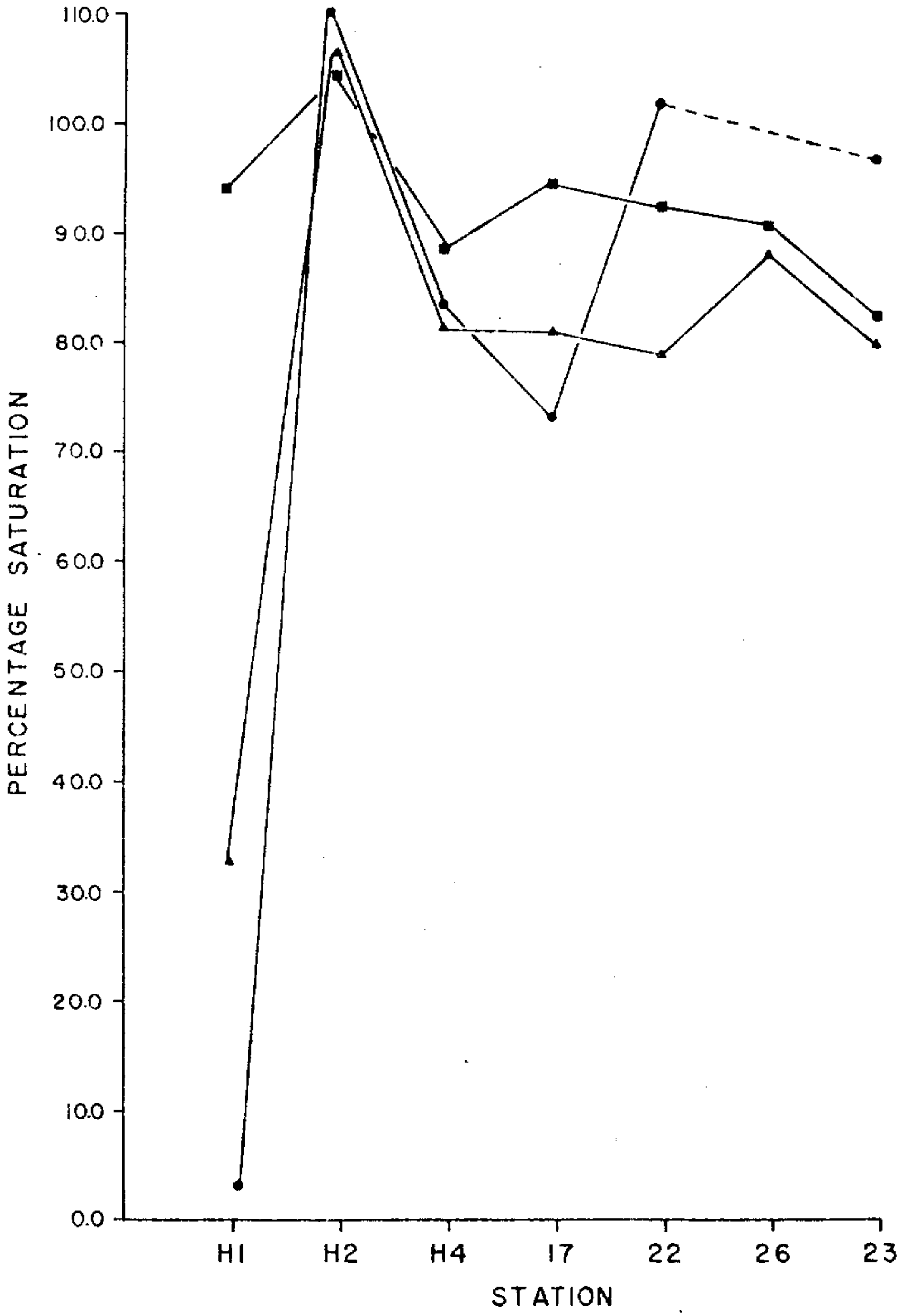

Figure 11. Percentage saturation of dissolved oxygen for 10 August 1972 (-●-●-), 31 July 1973 (-▲-▲-), and 29 May 1973 (-■-■-), for the 7 stations on the Salt River and Hammond Creek, Anderson and Spencer counties, Kentucky.

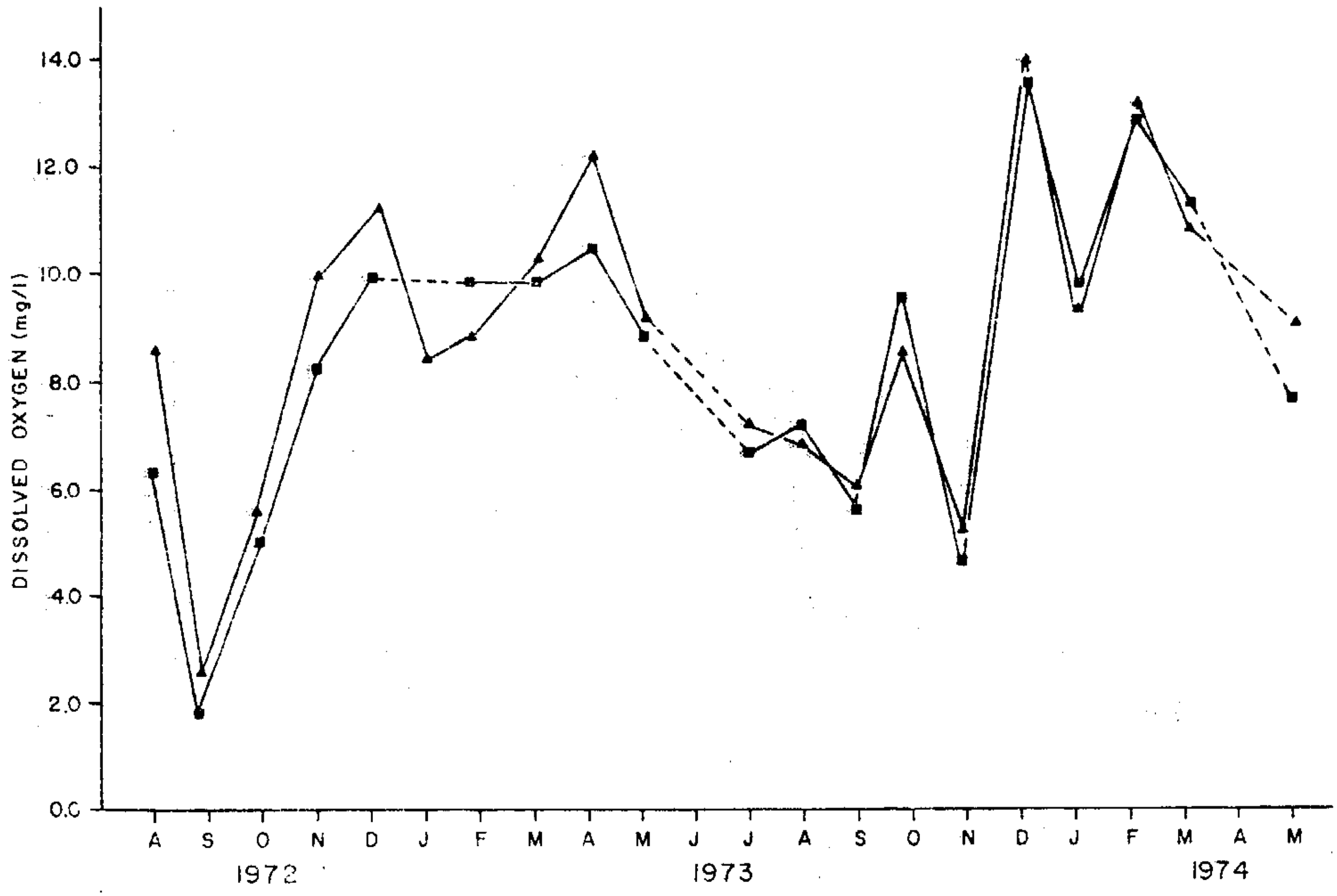

Figure 12. Dissolved oxygen in mg/l at Station 17 (—▲—▲—), and Station 22 (—■—■—), on the Salt River in Anderson and Spencer counties, Kentucky, July 1972 - July 1974.

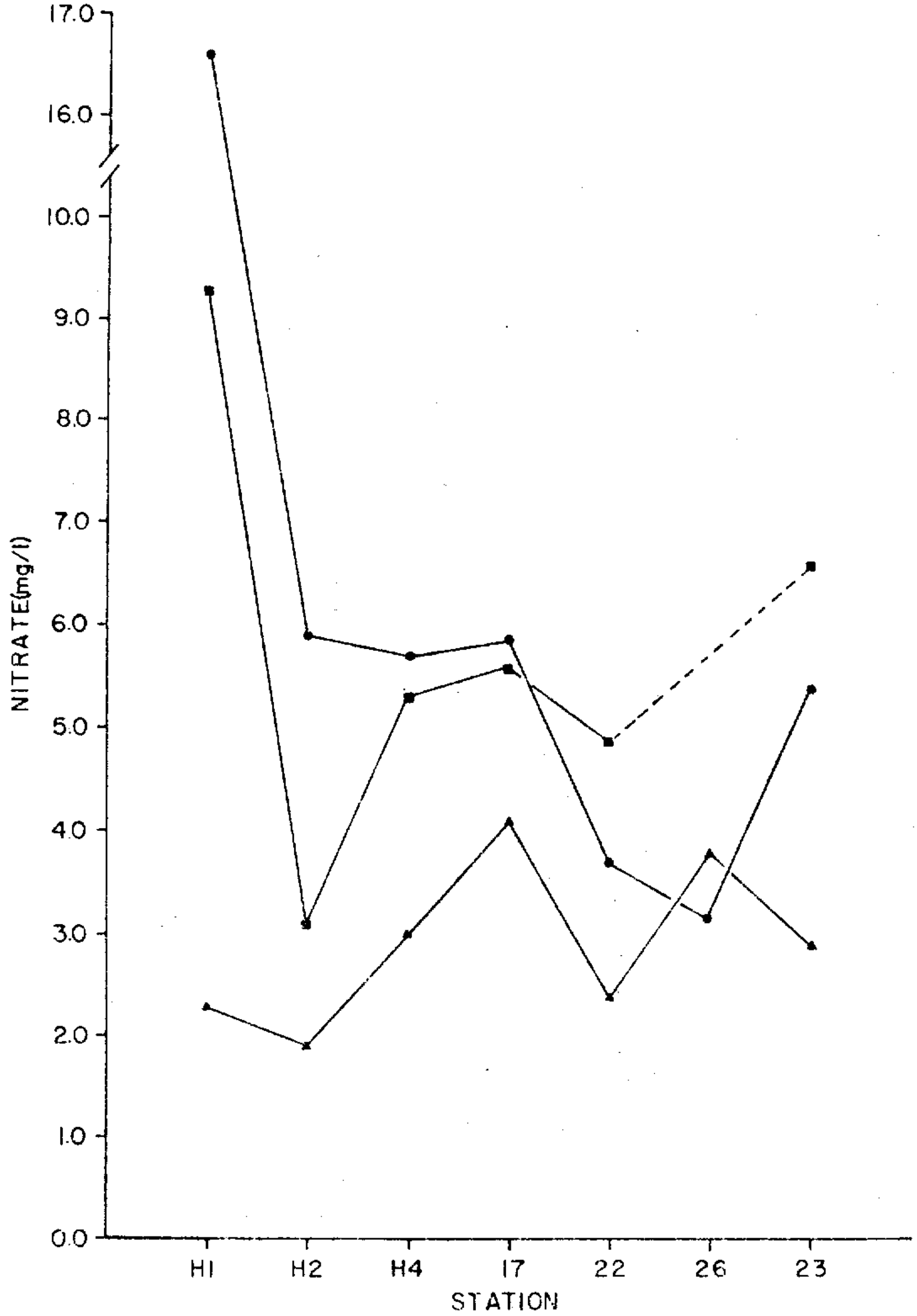

Figure 13. Nitrate nitrogen in mg/l at 7 stations on the Salt River and Hammond Creek, Anderson and Spencer counties, Kentucky, for 31 July 1972 (-●-●-), 13 December 1972 (-■-■-), and 13 April 1972 (-▲-▲-).

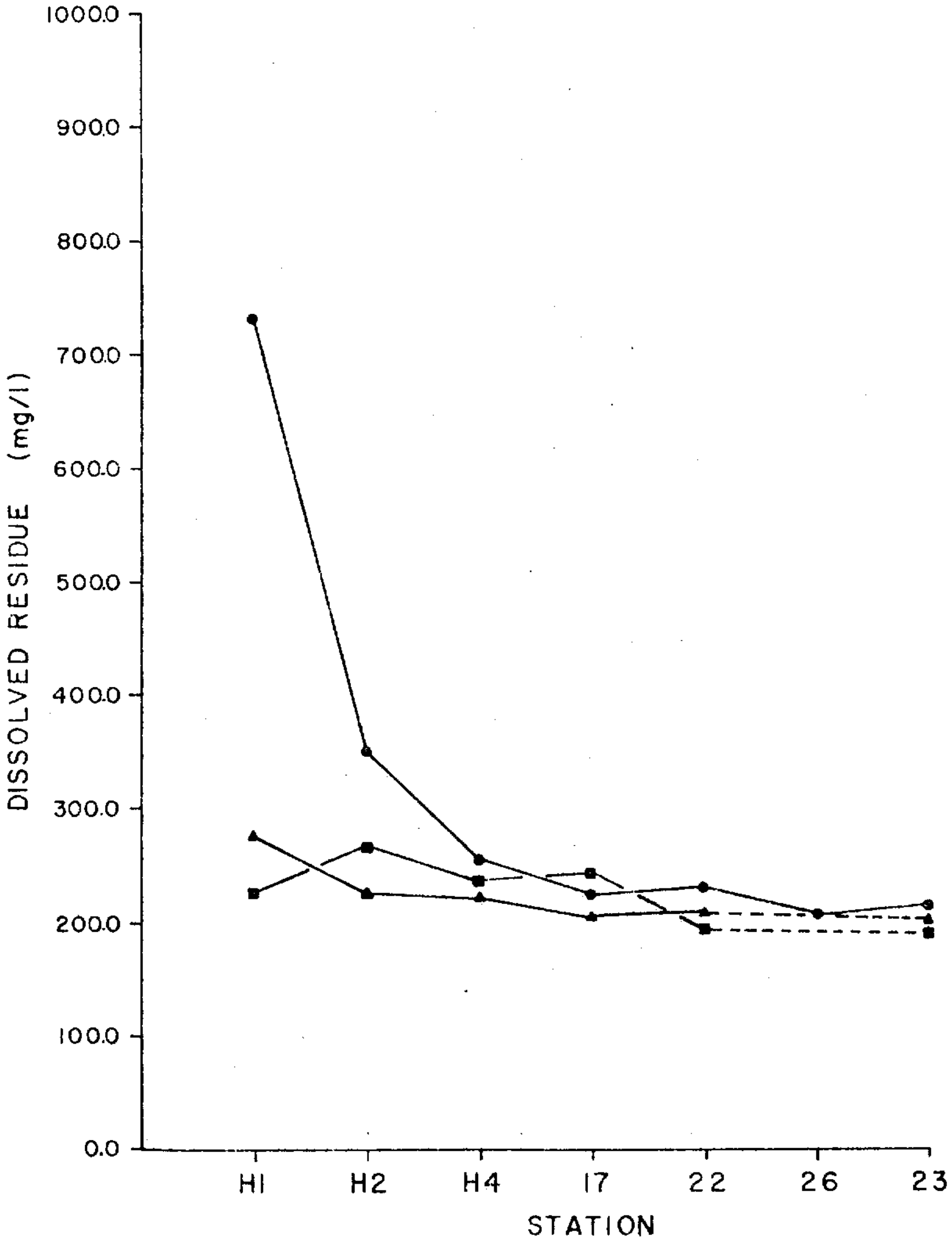

Figure 14. Dissolved residue in mg/l at 7 stations on the Salt River and Hammond Creek in Anderson and Spencer counties, Kentucky, for 10 August 1972 (-■-■-), 16 February 1973 (-▲-▲-), and 31 July 1973 (-●-●-).

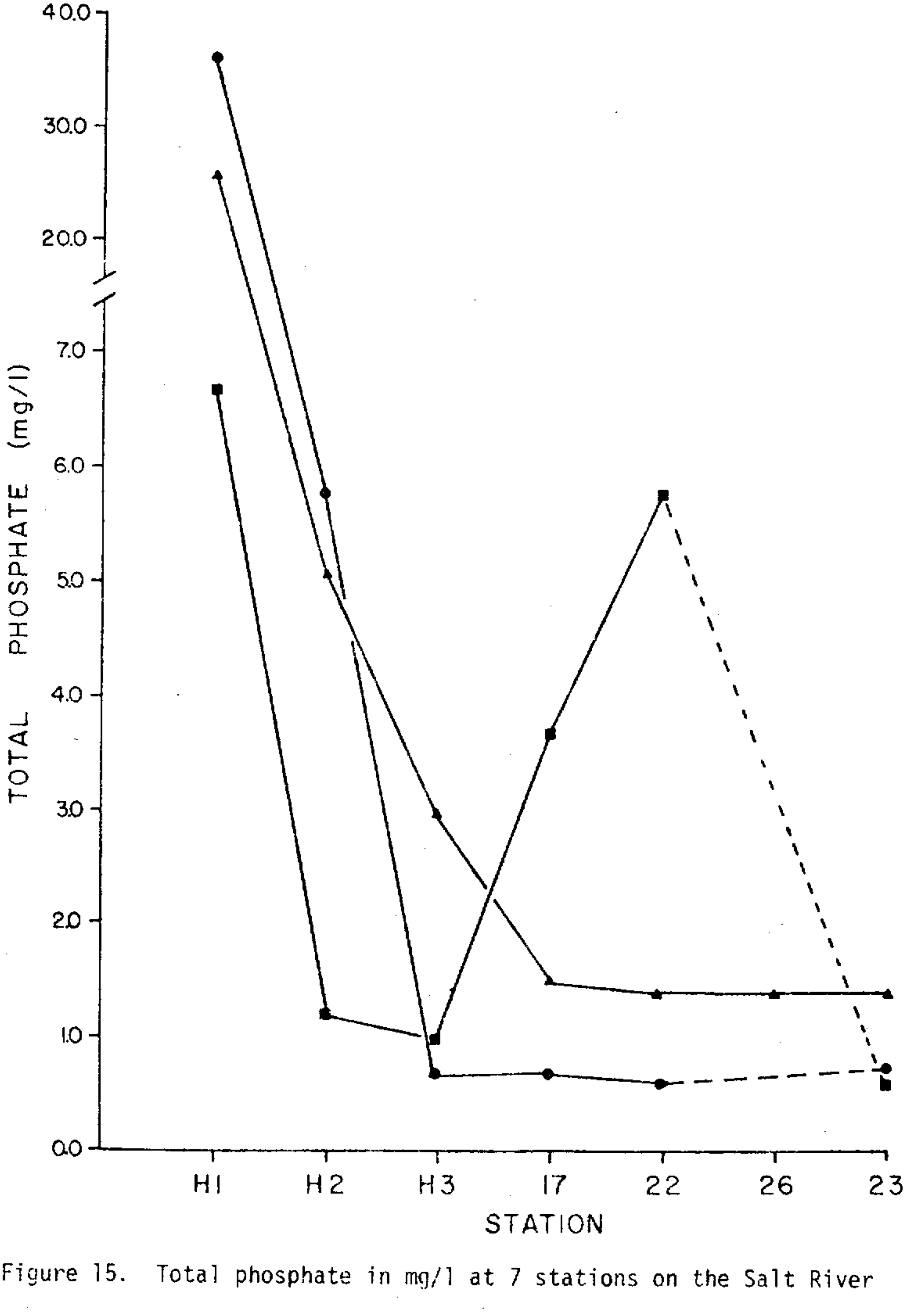

Figure 15. Total phosphate in mg/l at 7 stations on the Salt River and Hammond Creek, Anderson and Spencer counties, Kentucky, for 10 August 1972 (-●-●-), 16 February 1973 (-■-■-), and 31 July 1973 (-▲-▲-).

from station to station. On the other hand, phosphate levels illustrated the influence of enriched effluent wastewater on Hammond Creek, but elsewhere differed by only a few tenths of a milligram per liter, and dissolved residue differed by no more than 20 or 30 mg/l.

Concentrations of sulfate, bicarbonate, and calcium at the seven stations are given in Figure 16. These samples were taken on 31 July 1973 when the discharge was 1.85 m^3/sec (65.0 cfs). Bicarbonate and sulfate, unlike calcium, were elevated in Hammond Creek, at Station H1. As with suspended solids, values for these ions from Brashears Creek (Station 26) were slightly lower than those at Station 22.

Values for the four major cations at the same seven stations are depicted in Figure 17. These data were obtained on 29 May 1973 when the discharge was 15.7 m^3/sec (554.4 cfs). Sodium and potassium levels were high at Station H1, while calcium and magnesium concentrations were similar to the Salt River water at Station 17 or 22.

Values for hardness, alkalinity (as mg/l $CaCO_3$), and specific conductance (Figure 18) show the same relationships among sampling stations as the previously mentioned parameters. Hardness was greater than alkalinity, and the specific conductance values at Station H1 were higher than at the mouth of Hammond Creek. Dissolved ions at Station 26 (the mouth of Brashears Creek) were from 0.5 to 3.0 ppm less than those in the Salt River at Taylorsville, giving this water slightly lower readings for hardness and specific conductance. There were no marked differences in alkalinity between Station 22 and 17 for the period of study (Figure 19). Variations in flow caused these differences in this parameter. The low readings in May were taken when the discharge at Station 17 was 10.87 m^3/sec (384 cfs); the elevated readings in July were taken when the discharge was 0.052 m^3/sec (1.84 cfs).

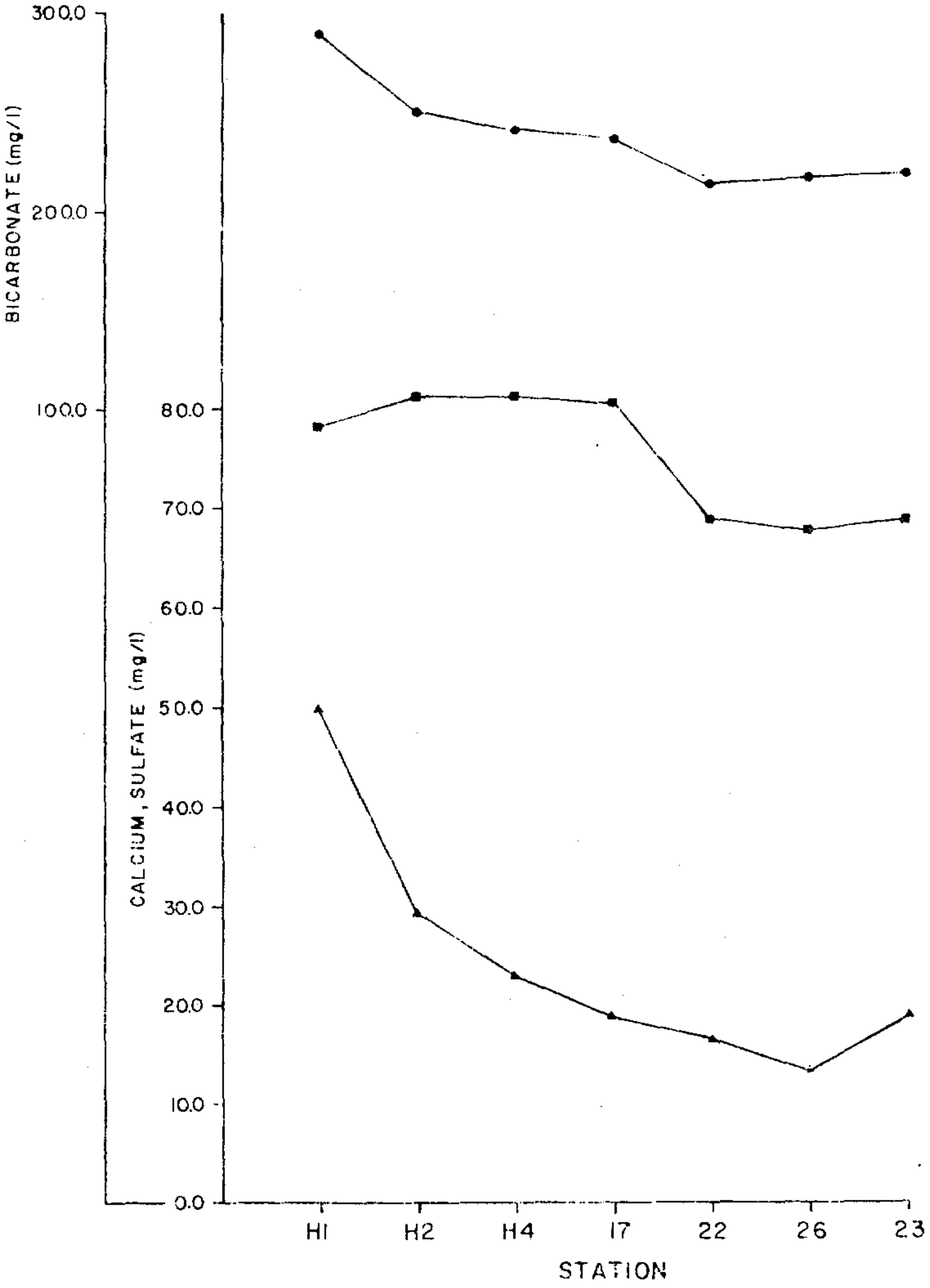

Figure 16. Bicarbonate (-●-●-), calcium (-■-■-), and sulfate (-▲-▲-), in mg/l on the Salt River and Hammond Creek in Anderson and Spencer counties, Kentucky, for 31 July 1973.

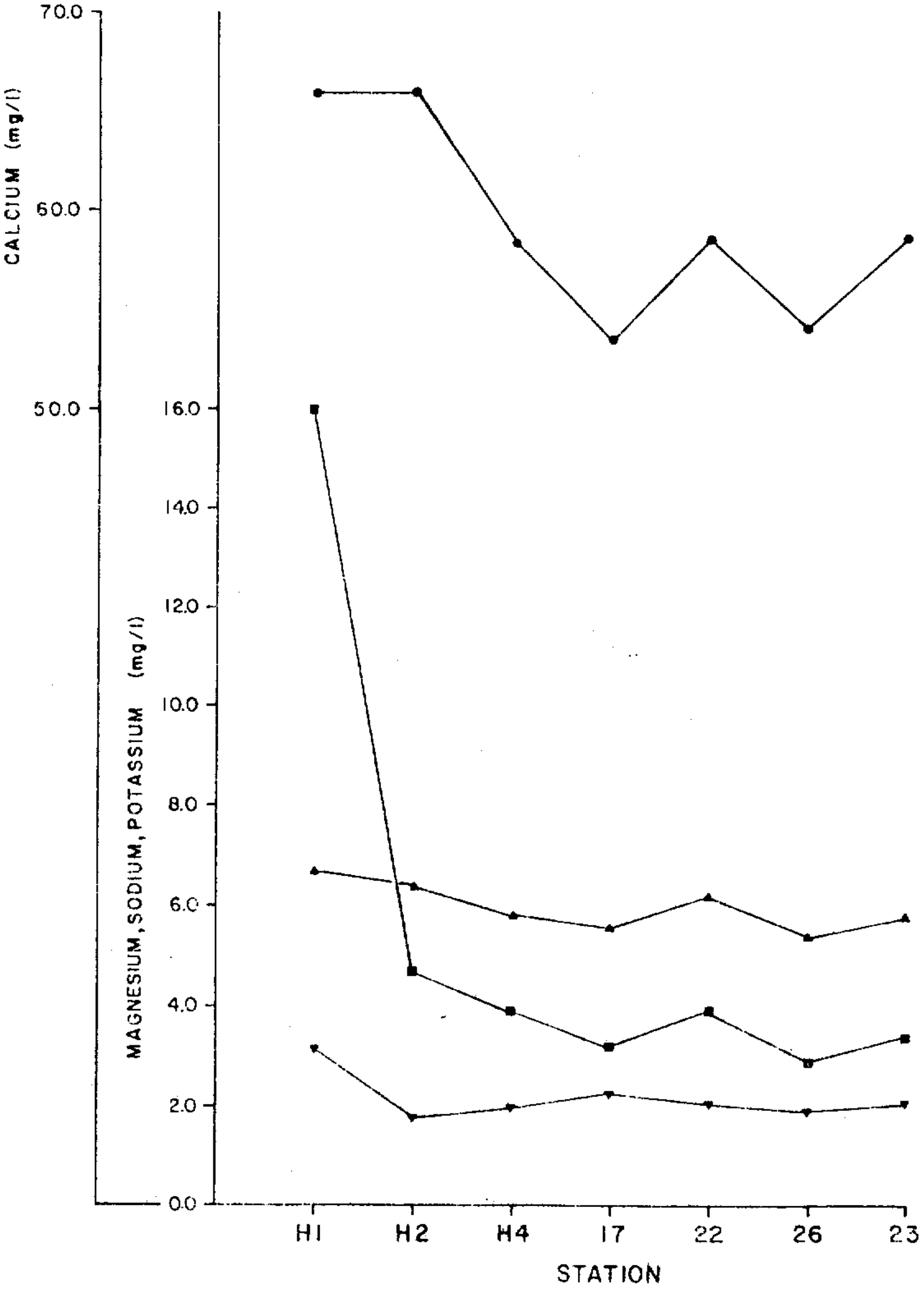

Figure 17. Calcium (—●—●—), magnesium (—▲—▲—), sodium (—■—■—), and potassium (—▼—▼—), in mg/l at the 7 stations on the Salt River and Hammond Creek, Anderson and Spencer counties, Kentucky, 29 May 1973.

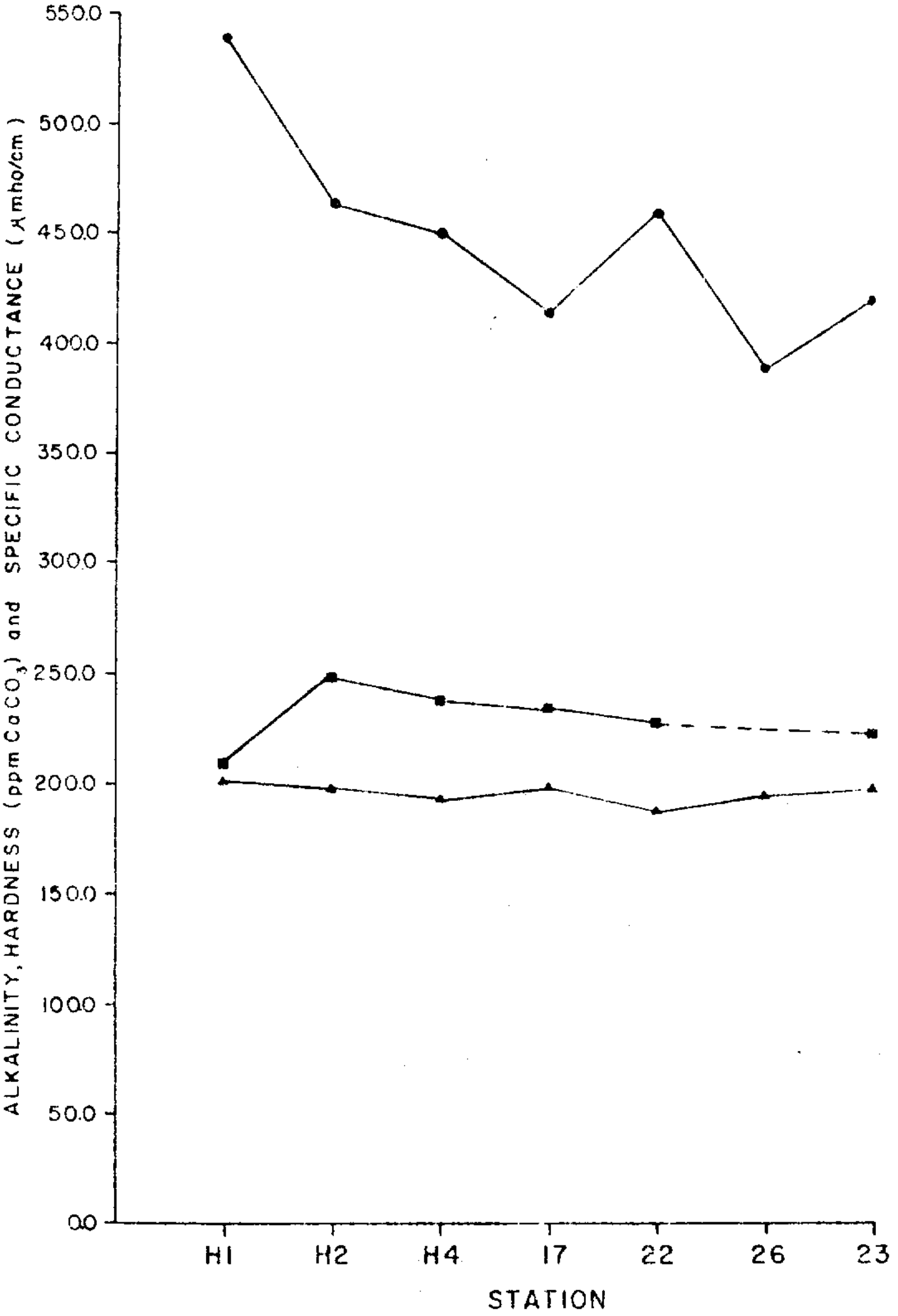

Figure 18. Specific conductance (-●-●-), µmhos/cm total hardness (-■-■-), and total alkalinity (-▲-▲-), as mg/l $CaCO_3$, at the 7 stations on the Salt River and Hammond Creek, Anderson and Spencer counties, Kentucky, 13 April 1973.

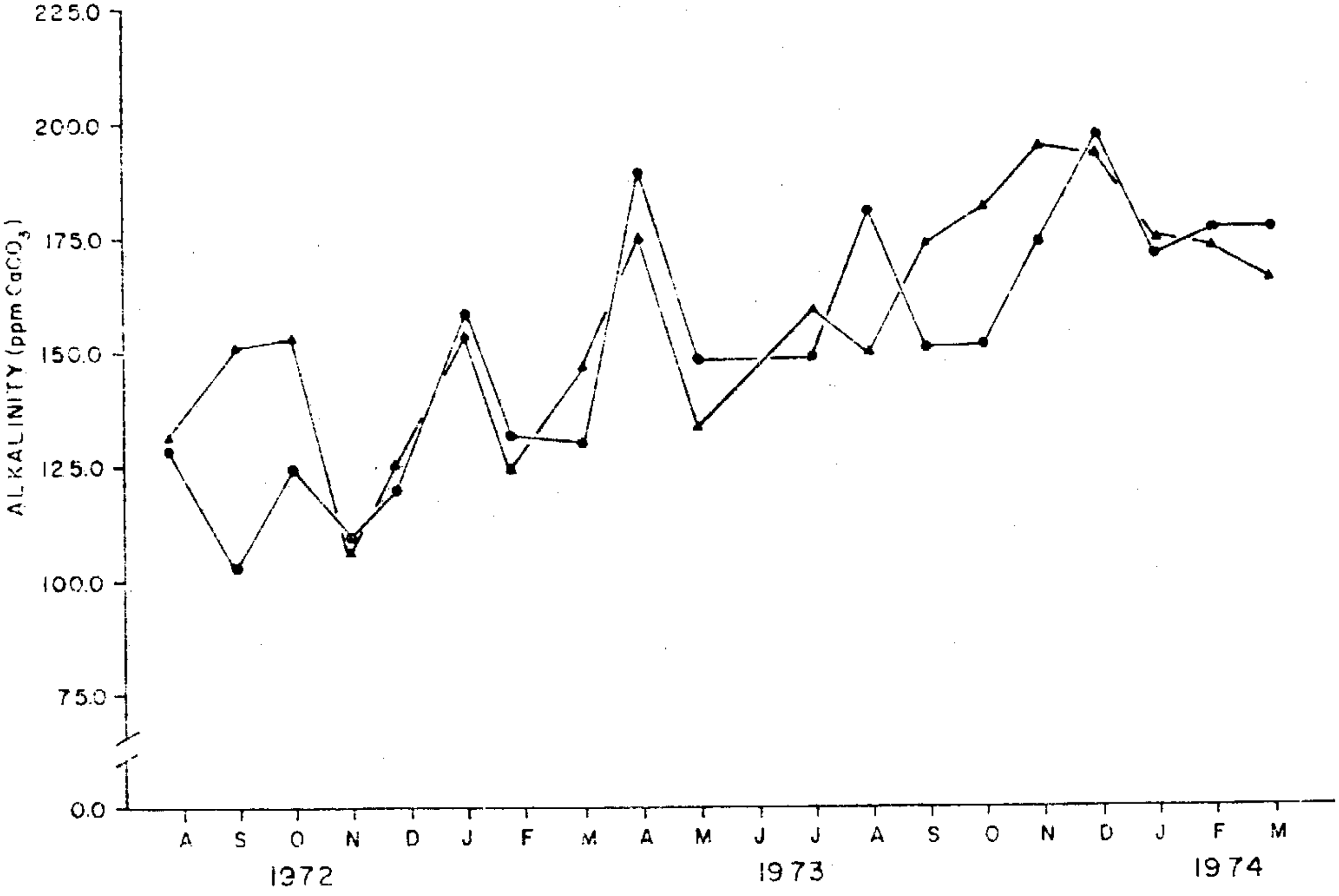

Figure 19. Total alkalinity as mg/l CaCO$_3$ at Station 17 (—▲—▲—), Anderson County, and Station 22 (—●—●—), Spencer County, Kentucky, August 1972 - March 1974.

Concentrations of sodium and magnesium for Station 22 (Taylorsville) are presented in Figure 20. Although it was mentioned above (Figure 17) that magnesium levels tended to be higher than sodium, this was not true for all samples. For the majority of the collections, magnesium concentrations did exceed sodium by at least 1 mg/l. The periods when sodium exceeded magnesium usually occurred in the fall. Probably the sodium originated from organic material (leaves) which fell into the river and accumulated at times of low discharge. During the spring when discharge was higher, the leaves were washed away and magnesium levels were increased by the action of water on the sediments, rocks, and soils in the watershed.

Data from Station 17 for phosphate, sulfate, and suspended solids for the period of study are shown in Figures 21, 22, and 23, respectively. Each figure has both actual concentration (mg/l, lower line) and concentration times discharge times 10^3 (g/m^3/sec, upper line). To facilitate presentation all values were converted to $\log_{10}$. The two means of expression illustrate for both phosphate and sulfate an inverse relationship. When the concentration drops (usually due to higher discharge and subsequent dilution), the total amount of the particular ion carried by the river increases, showing that the Salt River transports far more sulfate and phosphate during times of high discharge (usually the winter) than during the summer. This is not apparent solely from the examination of concentrations; discharge must be considered also. The maximum phosphate transported by the Salt River during the study period was 19.2 g/m^3/sec on 13 December 1972. For a 24-hour period this would be 1.65×10^6 g or 1.8 tons. The minimum was on 28 September 1972 when the discharge was 0.07 m^3/sec and 49 mg/m^3/sec of phosphate was carried

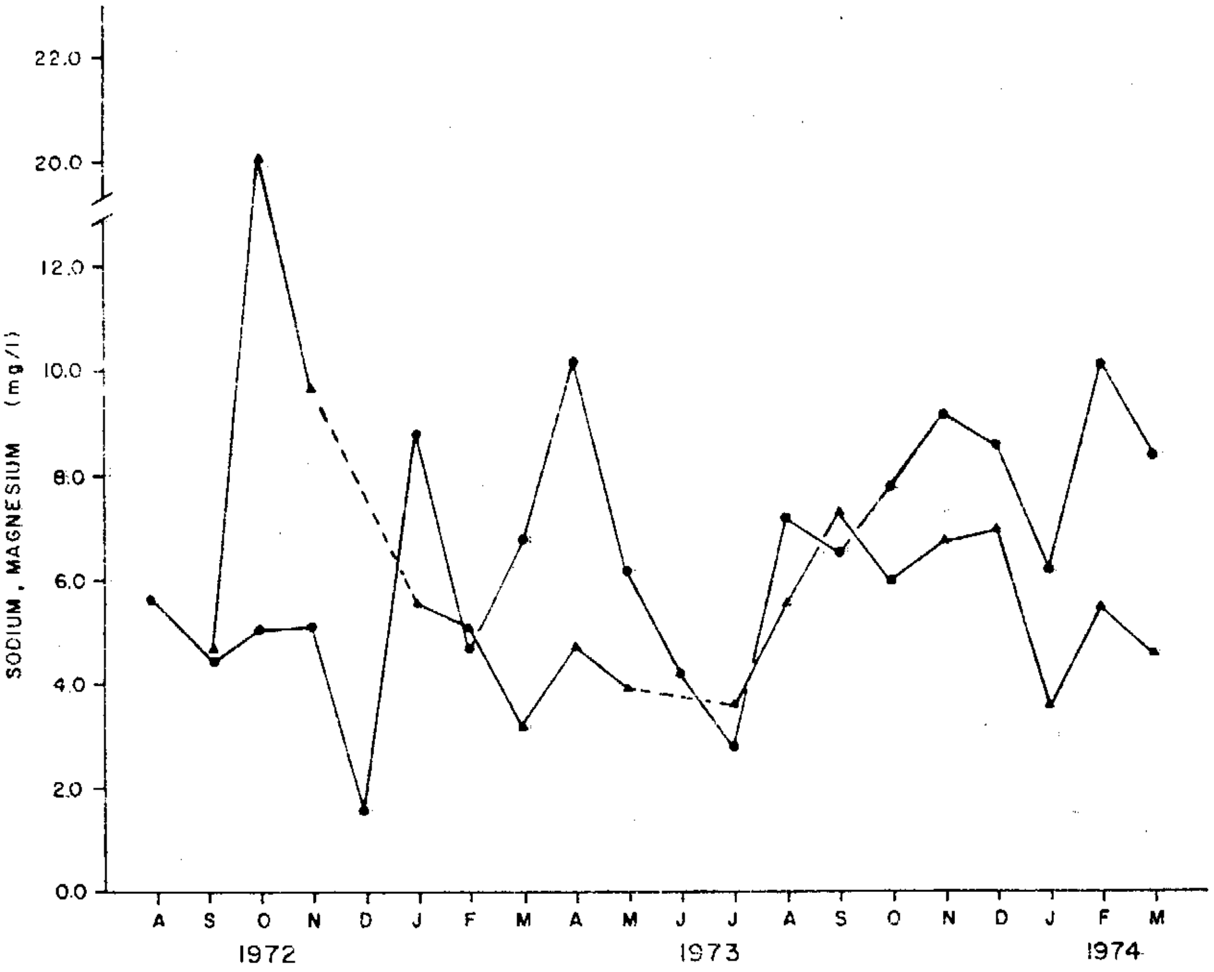

Figure 20. Sodium (—▲—▲—) and magnesium (—●—●—), in mg/l, at Station 22, Spencer County, Kentucky, on the Salt River. August 1972 - March 1974.

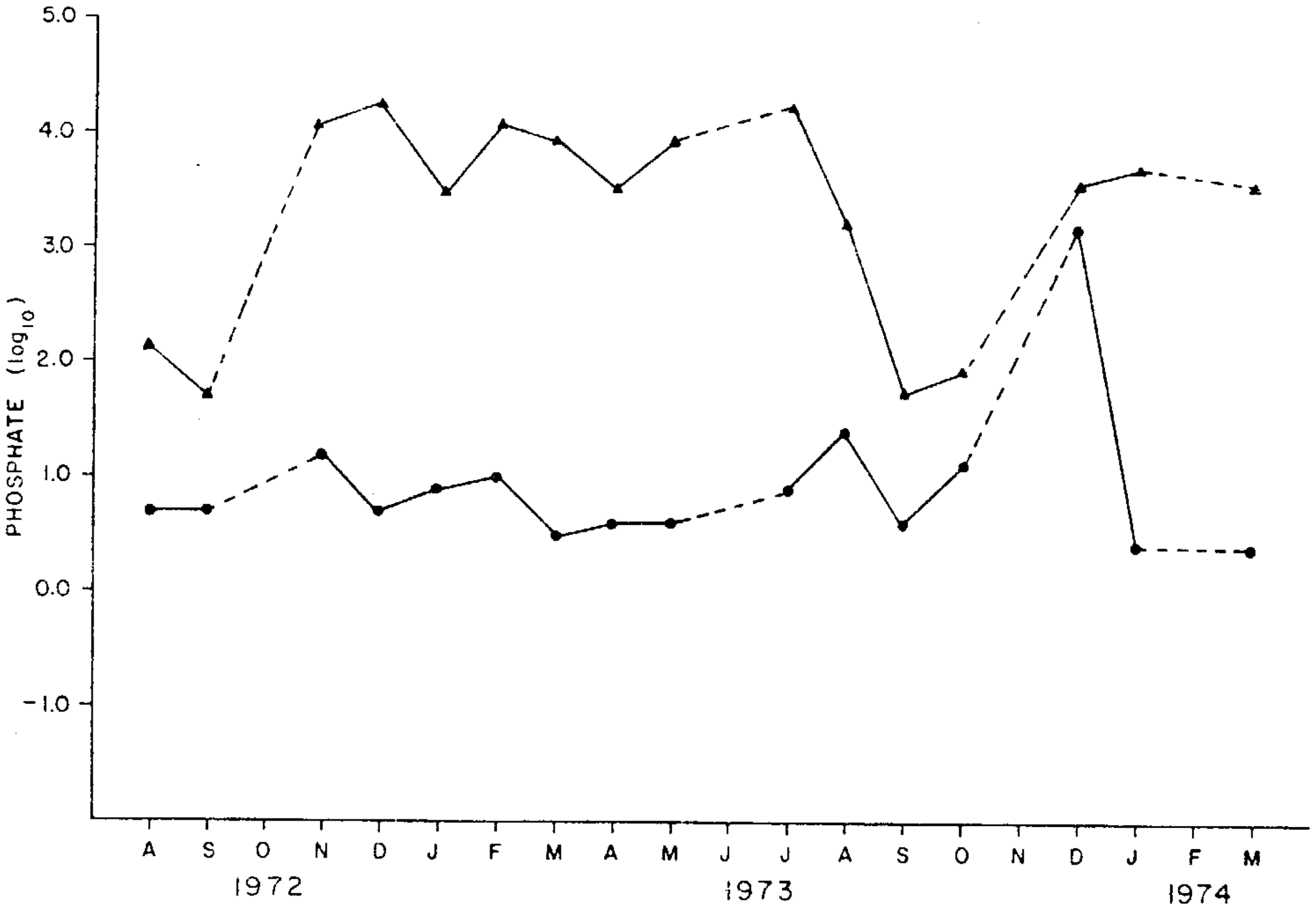

Figure 21. Phosphate in mg/l (-●-●-), and g/sec (-▲-▲-), at Station 17, Anderson County, Kentucky, on the Salt River, August 1972 - March 1974.

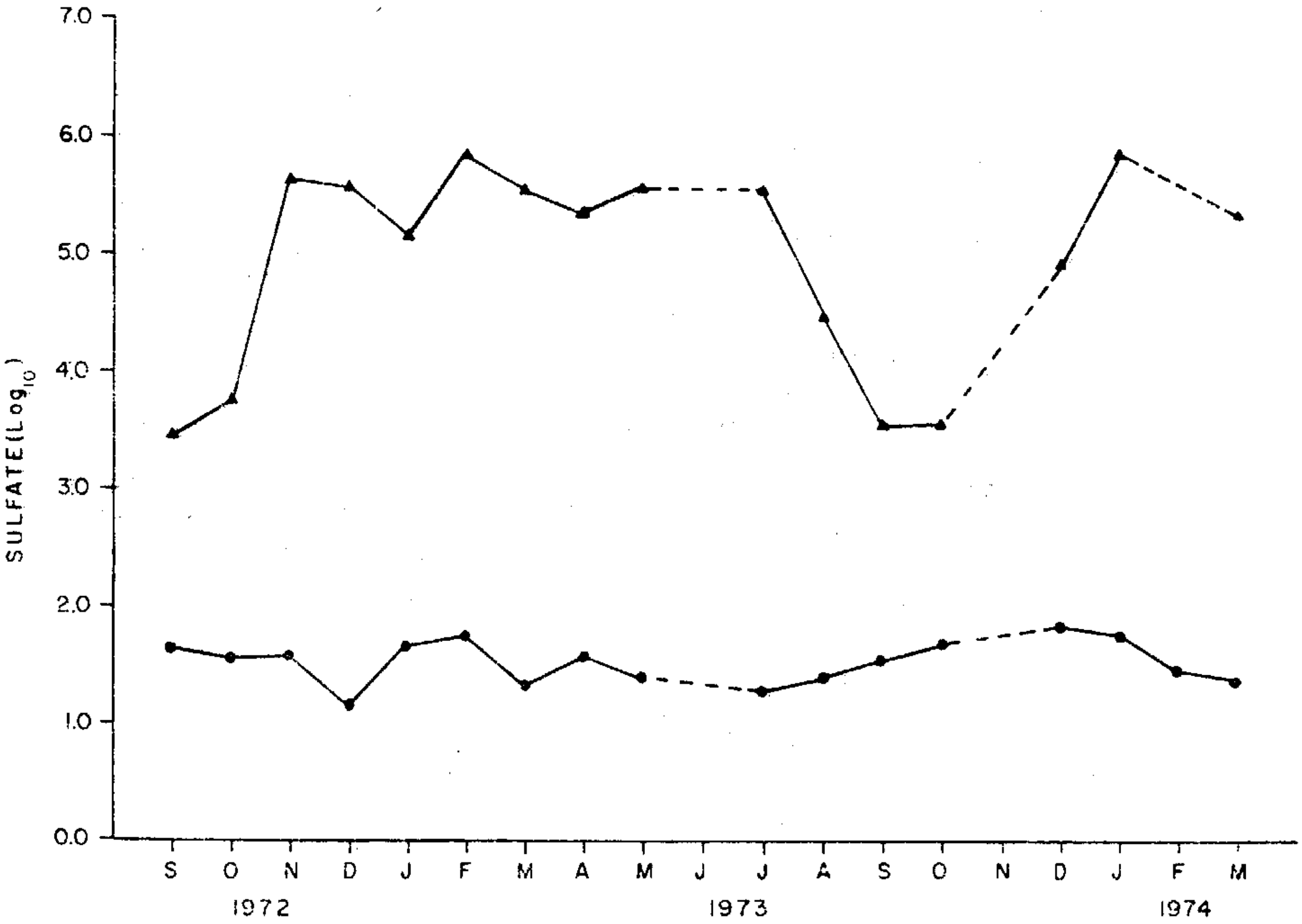

Figure 22. Sulfate in mg/l (–●–●–), and g/sec (–▲–▲–), at Station 17, Anderson County, Kentucky on the Salt River, September 1972 - March 1974.

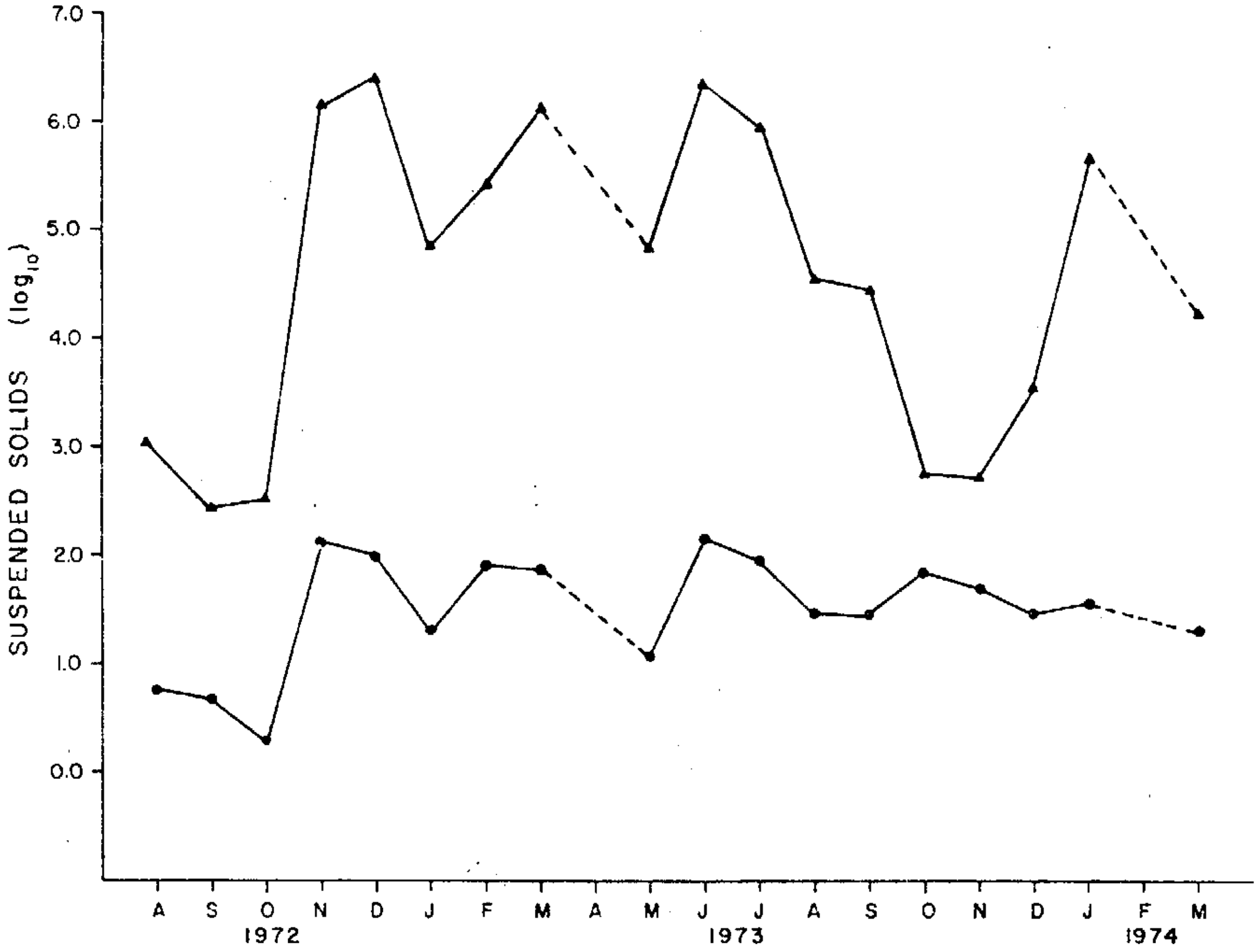

Figure 23. Suspended solids in mg/l (-●-●-), and g/sec (-▲-▲-), at Station 17, Anderson County, Kentucky, on the Salt River, August 1972 - March 1974.

by the Salt River. Because of these variations in discharge, there is no specific influence of season on the concentration of phosphate in the Salt River. Although fertilization of fields typically occurs in spring, this nutrient material may not enter the river until later in the year, depending on rainfall and runoff.

SEDIMENT ANALYSIS

An understanding of sediments, soil, and rock types is relevant to an assessment of water quality. One approach to a study of soils and sediments is to dissolve all material in appropriate acids, dilute the residue to a suitable volume, and perform the chemical analyses. The results will give concentration of the element per unit of material (see Mackereth 1966). Shells, sand, and organic material will contribute to the results since most sediments are a heterogeneous mixture of biotic and abiotic materials. A problem with this type of total analysis is that it provides no indication of how such material will influence water quality. Trace elements such as iron, manganese, and copper are insoluble at neutral pH values, and their presence in sediments does not indicate they will be detectable in water samples.

A barium chloride extraction will remove all ions chelated within the sediment matrix (see Beck 1972). Insoluble portions of the sediments such as iron, phosphate, or silicate will not be extracted. Since chelated ions were once dispersed in water, this extraction should provide some insight into the chemical characteristics of water. An extraction with distilled water will not remove chelated ions, but it will leach ions associated with the sediment particles. The aqueous extraction approximates rain or runoff water coming into contact with soil or clay. Both of these extractions should provide useful information concerning water quality and the impact of interactions between sediments and water.

Sixteen sediment samples were analyzed by total acid digestion, barium chloride extraction, and aqueous extraction for comparison and interpretation (Table 15). Nine samples were from the sampling stations on the Salt River and Brashears Creek. These include sand, clay, and topsoil, collected in the river bed or on the river bank above high water. The remaining seven sediment samples were: a settling pond at the Fischer Packing Company in Louisville (10), a sulfur spring at Doe Run, Meade County (11), Lake Michigan sand (12), Ohio River marl (13), and 3 samples from Paint Creek in eastern Kentucky.

Concentrations of sodium, potassium, calcium, magnesium, iron, and total phosphate for the sixteen sediment samples are listed in Table 16. For the Salt River samples, potassium exhibited the greatest variation of any ion, indicating that the principal source of this cation is mineral fertilizer. Magnesium exhibited the least variation, and often differed by no more than a few tenths of a milligram per gram. Iron exhibited little variation in Salt River samples, with the exception of the red clay sample (No. 6). Average values for potassium for Salt River sediments (see also Table 19), were greater than for any other ion. This is opposite from the chemical composition of river water, where potassium levels were less than the other three cations. The highest sodium level from Salt River sediments was No. 5, the storm sewer. Elevated levels of sodium were recorded from the water in the storm sewer following a rain. The marl from the Ohio River was high in calcium, although the monovalent ions were similar to levels in Salt River sediments. Paint Creek samples were low in calcium and magnesium, when compared with Salt River sediment samples. Paint Creek water was low in calcium and magnesium, and at times of low flow had elevated concentrations of sodium, potassium, and iron (Krumholz et al. 1974). Salt River sediments contained more calcium than magnesium, which is similar to chemical composition of the water. In the sediments, sodium levels were less than magnesium levels, while in water samples these two ions were equal or within 1 or 2 ppm of one another.

Sixteen sediment samples were also analyzed by barium chloride and aqueous extractions. Standard procedure (Beck 1972), specified combining two separate 25-ml washings of the sediment for ion analysis. Quantities of the four major cations removed from the 16 sediment samples by a 0.1 normal barium chloride solution are listed in Table 17. These values, in micrograms per gram of material, are approximately 1,000 times less than the total ionic composition of the sediments. In the Salt River samples, calcium was the major cation released by the sediments, even though potassium was the most abundant cation. With the barium chloride extraction, only soluble and adsorbed material is removed, so the feldspar particles and clay minerals did not contribute to the overall potassium concentration. Calcium concentrations were greater than magnesium, and attest that calcite is the major rock type in the Salt River Basin. Since sodium levels did not exceed the potassium levels in the sediments, this indicates sodium reached the water from sources other than the sediments. The high sodium and potassium, and low calcium levels from the Paint Creek area, (14-16) demonstrate again that the characteristics of the water are reflected in the sediment characteristics. The sand from Lake Michigan (12) exhibited reduced ion levels, while the sample from Fischer Packing Company's settling pond (10) had elevated levels of the 4 cations.

Data for the sixteen sediments extracted with distilled water are listed in Table 18. The barium chloride removed 5-10 times as much material as the distilled water. For the Salt River material, calcium is the major cation, potassium second in abundance, with magnesium and sodium in lesser quantities. There were high values for sodium and potassium from the Paint Creek samples, and low values for ions from the Lake Michigan sand. The ion levels from the soil around Fischer's Pond (10) were high, demonstrating that this was a nutrient-rich area. The aqueous extraction yielded proportionally higher concentrations than the barium chloride procedure. This indicates that much material was associated with clay particles, but not actively adsorbed. When analyzed by acid digestion, sediment samples from the Salt River had nearly equal quantities of iron and potassium. The aqueous extraction removed more potassium than iron, because of differences in solubilities of these elements. Because of the quality of the sediments, Salt River water has the potential for elevated iron concentrations that could be detrimental when the impoundment is established.

Mean ion values for total composition, barium chloride, and aqueous extractions for sediment samples from the Salt River (Numbers 1 through 9) are listed in Table 19. For the 4 major cations, the relationship K > Ca > Mg > Na holds for total ion concentration. This is because of high quantities of potassium-containing clays and feldspars in the Salt River Basin. For both barium chloride and the aqueous extraction these 4 cations are in the order Ca > K > Mg > Na. High calcium concentrations in the river water evidently saturated adsorption sites on sediment particles.

Milligram ratios for the Salt River sediments analyzed by total acid digestion, barium chloride, and aqueous extractions, are in Tables 20, 21, and 22. Sodium to potassium ratios for total analysis were low when compared with the extraction analyses and the water samples collected at Station 17 (Table 7). Although potassium levels were high in Salt River sediments, this ion was tightly adsorbed and not readily released. Sodium concentrations were greater than magnesium in the sediments, although these ions were approximately equal in water samples at Station 17 and the aqueous extractions. Barium chloride removed almost twice as much magnesium as sodium from sediment samples than did the aqueous extractions. This indicates that magnesium, like potassium, was strongly held to the clay particles. Calcium concentrations were greater than magnesium concentrations in water samples and all sediment samples.

The percentage of organic matter in these sediments is listed in Table 23. The average for the Salt River samples was 7.2% with a range of 4.1-14.1%.

Concentrations of magnesium and potassium in filtered and unfiltered water samples are shown in Figure 24. With small quantities of suspended solids, the ratio between filtered and unfiltered cations approached unity, since both samples are practically identical. With higher levels of suspended solids, the concentrations of cations in the unfiltered sample increase and the ratio of filtered ions to unfiltered samples are more significant with potassium than with magnesium. At suspended solids levels of 100 mg/l, potassium is at least twice as high in the unfiltered samples as it is in the filtered samples. Calcium and sodium were identical in filtered and unfiltered samples of Salt River water.

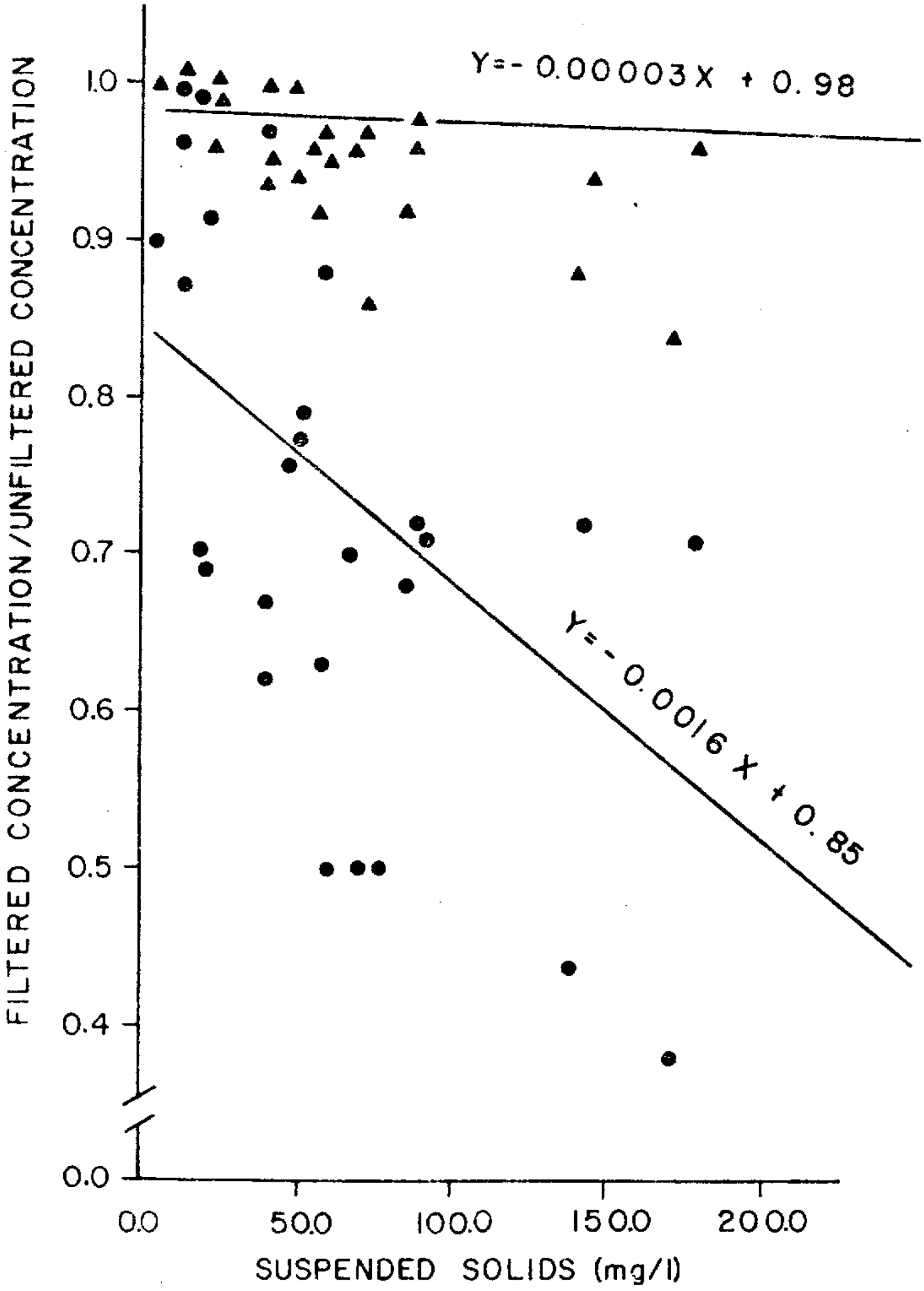

Figure 24. Relationship between suspended solids, potassium (-●-●-) and magnesium (-▲-▲-) levels from filtered and unfiltered water samples from the Salt River in Anderson and Spencer counties, Kentucky.

Analyses of phosphate from filtered and unfiltered water samples for the seven stations in the Salt River area are shown in Figure 25. Both fractions of water were analyzed for orthophosphate (H_3PO_4, which is soluble) and for total phosphate. Total phosphate includes orthophosphate plus the insoluble metaphosphate (HPO_4), and pyrophosphate ($H_4P_2O_7$) (Moeller 1952). Total phosphates from filtered samples were approximately 25% less than total phosphates from unfiltered samples. The magnitude of this variation depends on both the phosphate levels in water and the quantity of suspended sediments. The test for orthophosphate on filtered water and the test for total phosphate on filtered water are nearly identical. This is to be expected, since the insoluble phosphate forms are generally removed by filtration.

There is a significant difference between ion concentrations in filtered and unfiltered water samples. With ions such as sodium and calcium, there was little difference, while with phosphate, magnesium, and potassium the differences can be as high as 50 or 100%. If a study is designed to report differences between sites on a body of water or waterway, it is not too important how samples are treated as long as the procedures are consistent. The differences in phosphate concentrations between the seven stations in Figure 26 could have been recognized from any of the four methods.

ANALYSIS OF RAINWATER AND RUNOFF WATER IN THE SALT RIVER BASIN

Rainwater collected near Station 17 during the fall and spring of 1973 through 1974 was analyzed for major cations and anions (Table 24). The water from these eighteen collections ranged from 32 ml to over 1,000 ml when the sample bottle overflowed. The most prevalent ion in the water was sulfate which ranged from 8.3 to 27.8 mg/l. This ion

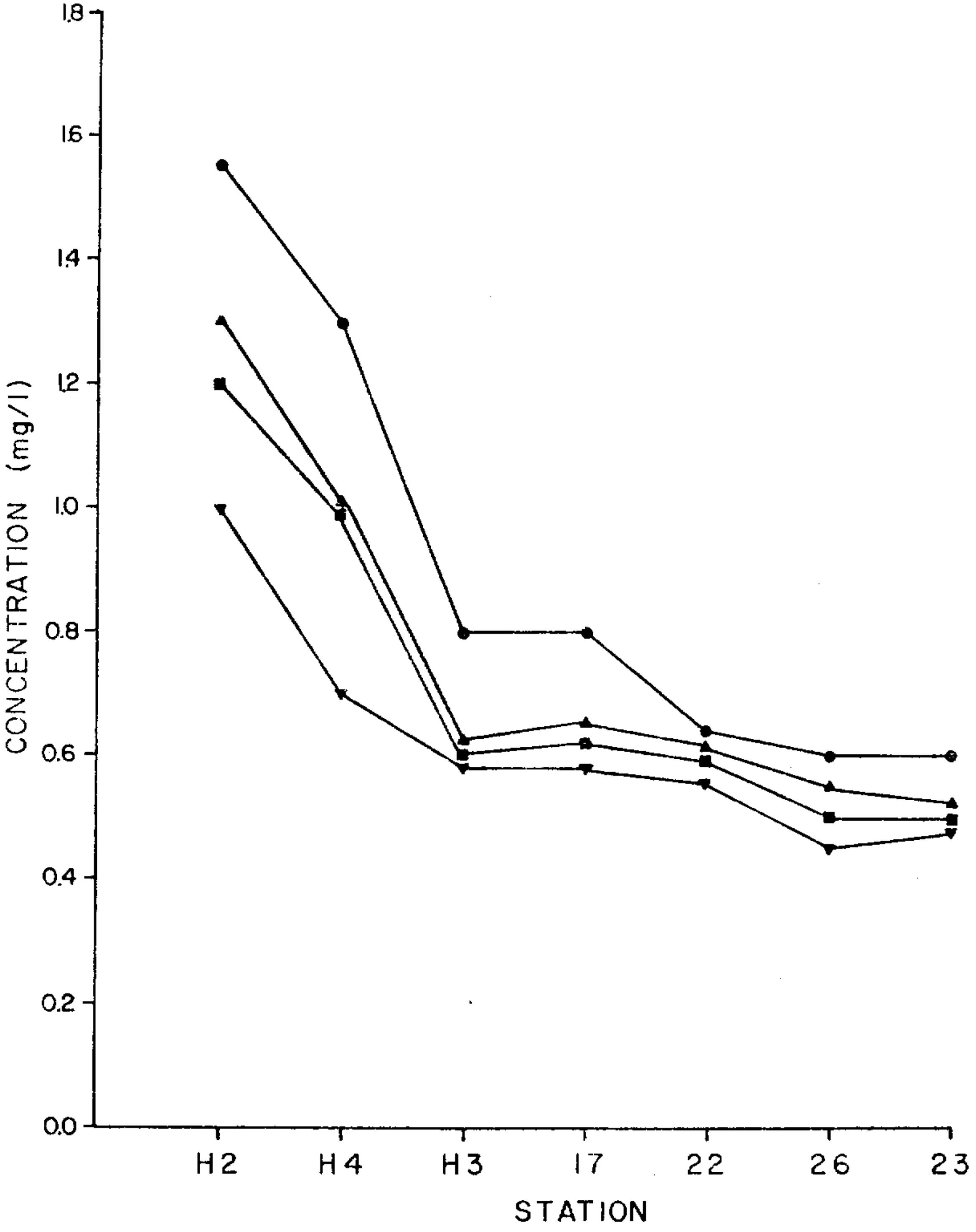

Figure 25. Total phosphate unfiltered (—●—●—), orthophosphate unfiltered (—▲—▲—), total phosphate filtered (—■—■—), and orthophosphate filtered (—▼—▼—), at 7 stations on the Salt River and Hammond Creek, Anderson and Spencer counties, Kentucky, 13 April 1973.

probably originated from oxidation of sulfur dioxide in the atmosphere (Junge 1960, Masterson and Slowinski 1973). High sulfate levels in rainwater are an indication that atmospheric input may account for a substantial proportion of this anion in the Salt River. Prevailing winds generally move from the Louisville metropolitan area toward this area of the basin. Sodium and magnesium concentrations usually were less than 1 mg/l, and potassium and calcium levels were usually between 1 and 3 mg/l. The high potassium (15.4 mg/l on 16 May 1974) and calcium (10.7 mg/l on 20 February 1974) were probably caused by airborne dust and were not typical of the majority of samples.

Chemical analyses of runoff water collected from Station 17 are listed in Table 25. This runoff sampler was located in a wooded area with substantial ground cover and little unexposed soil. These water samples had no suspended sediments. The blank spots in the table (--) indicate precipitation was high enough to collect rainwater, but not high enough to produce runoff.

The predominant cation in runoff water was sodium, which usually was more concentrated than potassium. This can be contrasted with the data from sediments, when sodium from aqueous extracts (Table 18) was less than any of the other 3 cations. Much of the dissolved sodium in the Salt River may originate from interactions of runoff water with organic matter prior to entering the river. Calcium and magnesium, which originate from interactions of water with underground strata, were low, usually less than concentrations of the monovalent ions.

Two other runoff samplers were placed near Taylorsville (Station 22). Data for the cations, anions, and suspended solids are in Tables 26 and 27. These samplers were in open areas with uncovered soil, so the runoff water carried more suspended solids than the sampler at Station 17. Suspended sediments ranged from 440 to more than 9,000 mg/l. Most of this sediment will either settle quickly, or become dispersed when the runoff water enters the river. It is, however, not unusual for a liter of runoff water to carry more than 10 times the sediment load found in turbid river water. In comparison to the runoff sampler at Station 17, these two samplers collected water with elevated calcium and magnesium, and diminished potassium and sodium levels. In these Taylorsville samples, the nitrate, phosphate, and silica levels are within typical limits for the Salt River. The sulfate readings are less than the 'typical' values for the water. Comparing these sulfate values with those in rainfall, they are similar and indicate that little additional sulfate was carried by surface runoff.

DISCUSSION

The Salt River is a relatively clean, hardwater stream draining productive farm and pasture land and receiving only a few sources of man-made pollution. Durfor and Becker (1964) classified water between 121 and 180 mg/l of hardness as 'very hard'. With the range in hardness at Taylorsville from 134 to 236 mg/l, there is little doubt that the river carries hard water by any standards. In contrast, surface water in New England had a 6-year average for calcium of 1.58 mg/l and bicarbonate levels were below detection limits (Johnson et al. 1973). Brucker et al. (1972) found hardness values of from 27.8 to 209.4 mg/l in groundwater from limestone caves in southern Kentucky.

Mole ratios of calcium to bicarbonate in the Salt River water were greater than 2:1, indicating that small amounts of bicarbonate originate from weathering of magnesium carbonates as well as calcium carbonates. Hardness was greater than alkalinity in the majority of the Salt River and Brashears Creek samples. The difference between hardness and alkalinity (noncarbonate hardness) was due to calcium sulfate (gypsum) in the Salt River Basin (Hendrickson and Krieger 1964), and in most limestone depoists (Richardson 1923). The concentration of sulfate can be predicted (with an average 10% error) from noncarbonate hardness by converting sulfate as calcium carbonate to milligrams of sulfate.

Noncarbonate hardness was zero at Station H1 on Hammond Creek during times of low flow and warm temperatures. This was caused by large quantities ot sodium bicarbonate from wastewater treatment which increased alkalinity, but produced no effect on hardness.

Phosphate concentrations were less than 1.0, and nitrate concentrations were less than 5.0 mg/l at the sites on the Salt River and Brashears Creek. Nitrogen to phosphorus ratios average 3.7:1 at Station 17 and 2.1:1 at Station 26. These ratios were less than 10:1, the N:P ratio that was suggested to control objectionable algal growth in natural waters (FWPCA 1968), indicating that phosphorus will not be a limiting factor for algal growth when the impoundment is completed. Indeed, phosphorus may be present in sufficient quantity for the first few years after the lake fills to cause algal 'blooms' that may be adverse to the lake's recreational objectives. This would also be affected by the continued introduction of nitrates and phosphates entering the lake from above or upriver.

Nitrate and phosphate levels were higher at Station H1 on Hammond Creek than for the stations on the Salt River and Brashears Creek. At this station, average N:P ratios were 0.7:1, which were considerably less than ratios on either Brashears Creek or the Salt River. Nitrite levels were less than 0.2 mg/l at stations on the Salt River, Brashears Creek, and Hammond Creek, and may be considered insignificant. Carbonate as calcium carbonate was below detection limits in most of the samples since the pH rarely rose above 8.2. On the occasions when the pH was above 8.2, the carbonate alkalinity was no more than 10.0 mg/l.

With the exception of sodium, potassium, and silica, the Salt River has higher levels of major ions than are found in Livingstone's data (1963) on the world average river (Table 5). Silica is a product of weathering of granite, feldspars, and sedimentary rocks (Hem 1971). The low levels of these ions in the Salt River is due to the dominance of calcite in the watershed. For most of the samples, dissolved calcium was 3 to 5 times the concentration of any other cation. Magnesium and sodium levels were within 1 or 2 mg/l of each other. During low discharge, sodium exceeded magnesium, which was probably the result of the influence of fallen leaves and organic matter (Slack and Feltz 1968).

These features mentioned above apply to the entire study area, but they do not take into account variations due to seasonal changes or differences between sampling stations. During the summer when discharge was low, the elevated nutrient levels at Station H1 were detectable at the mouth of Hammond Creek and also in the Salt River directly below the confluence of the creek. Even at low flow, these nutrient levels did not significantly elevate the nutrient concentration of the river water at any of the stations in the impoundment area. During the winter months when temperatures were lower and discharge usually greater, the elevated levels of nitrate and phosphate were undetectable at the mouth of Hammond Creek and at the site directly below Hammond Creek in the Salt River. With the change to a standing-water or lentic condition, assimilation of these nutrients could be reduced and they could accumulate in the impoundment with adverse effects.

There was significant positive correlations between related parameters such as calcium and bicarbonate, calcium and magnesium, calcium and specific conductance, and sulfate and bicarbonate. Ions in low levels, such as nitrate, potassium, and sodium usually did not show significant realtionships to one another. Discharge was significantly related to turbidity and suspended solids, but not to concentrations of various dissolved ions. In general, the variations in discharge did not uniformly concentrate and dilute cations and anions in the Salt River.

Rainfall patterns were variable over the entire watershed, and some ions (calcium and magnesium) originated from groundwater, while other ions originated in part from surface runoff (potassium, nitrates, and phosphates) or rainwater (sulfate).

Johnson et al. (1972) reported that upland streams in New England receive most, if not all, of the dissolved sulfate from atmospheric input. Average sulfate for these streams in New Hampshire was 6.4 mg/l and average sulfate in rain and snow was 3.1 mg/l. In the Salt River Basin, average sulfate in rain water was 13.8 mg/l, while average sulfate in the river at Station 22 was 35.7 mg/l. Atmospheric input of this ion accounted for only part of the dissolved sulfate load in the river; the remainder is probably derived from weathering of gypsum or sulfur deposits in limestone.

Nitrate ranged from 5.1 to 33.2 mg/l in runoff water collected near Station 22. Although this ion may originate from domestic, organic effluents and from crop fertilization, oxidation of atmospheric nitrogen by soil bacteria cannot be discounted. Calcium and magnesium, which are constituents of groundwater, were less than sodium and potassium levels in runoff water. Sodium and potassium are the result of interactions of surface water with organic material and, to some extent, groundwater input. Calcium, magnesium, bicarbonate, and some sulfate are the result of rock dominance. Sodium to magnesium ratios were higher in runoff water than in river water at Station 17 (Table 7), or the ionic composition of sediments (Table 16). The organic matter on the surface of the soil caused the higher sodium to magnesium readings for runoff water. Sodium to potassium ratios for the runoff water at Station 22 were less than these ionic ratios at Station 17. The increased sediment loads collected by the samplers near Station 22 were the cause of the elevated potassium levels.

Likens et al. (1967) calculated ionic budgets for the Hubbard Brook experimental forest by monitoring the chemical composition of rainfall and river water. They found that output exceeded input for calcium, magnesium, and sodium, but input exceeded output for potassium. This last finding was not totally explained, although uptake by soils and the biota was suggested. The strong association of potassium (and to some extent magnesium) with the Salt River sediments can explain how potassium may be adsorbed and retained in a watershed. Chemical data for runoff and nutrient budgets is often contradictory in the literature. Johnson and Needham (1966) reported no effect of a fire on concentrations of major cations, nitrates, bicarbonate, and chloride in runoff water. Evidently the ions freed by burning were either in low levels, or were taken up immediately by the sediments or plant material. Hobbie and Likens (1973) experimentally burned an area in the Hubbard Brook Forest and found elevated concentrations of phosphate and organic material in runoff from the burned area.

In Salt River water, major cations were in the following order: Ca > Na > Mg > K. Total ionic concentration of sediments (Table 16) has these ions in the following order: K > Ca > Na > Mg. The inference is that potassium, while available, is either tightly adsorbed or an integral part of the sediment matrix and is not easily removed by solution to influence the water quality. For the aqueous and barium chloride sediment extractions, these four ions are in the order: Ca > K > Mg > Na. Calcium dominates potassium, evidently due to the high levels of this cation in the river water. Although potassium is the dominant ion in sediments, its tendency to become incorporated into the sediment matrix causes it to be least concentrated of all ions in the Salt River water. For this reason, the extraction procedures yield a better indication of water quality than the total sediment analysis. Runoff water carrying considerable potassium and sodium loses its potassium to the sediment, but most of the sodium is retained in solution.

Beck (1972) used the barium chloride extraction in a study of sediments from soft water streams in Georgia. The four major ions from the sediments were Ca > Mg > K > Na. Dissolved ions from the Georgia waters were considerable less than typical levels observed in the Salt River. In Beck's water samples, calcium was rarely more than 10.0 mg/l and sodium, magnesium, and potassium concentrations were less than 5.0 mg/l. Exchangeable sodium and potassium in Salt River sediments were double those reported by Beck. Exchangeable magnesium in the Salt River sediment was 10% less, but calcium in Salt River sediments was approximately seven times the level of the cation from the soft water samples. Hem (1971) also discussed sodium-calcium adsorption ratios and their effect on soil quality and plant nutrition. If sodium concentrations are greater than 50% of the total ionic load, there is danger of this ion replacing calcium on soil and sediment particles. This is of little consequence in the Salt River where calcium levels are about five to ten times those of sodium.

There has been recent interest in the possibility that sediments and soils accumulate trace metals and nutrients far above levels found in water. Wali et al. (1972) and Perhac (1972) have described situations where heavy metals were undetectable in water, but they were found in high concentrations in surrounding sediments. Williams et al. (1973)

reported a fish kill in the Black Warrior River in Alabama following a rain that brought toxic sediments to the surface. Purves (1972) found concentrations of copper, zinc, boron, and lead, from 2 to 8 times higher in urban than in rural soils in Scotland. On the basis of weight, particulate matter can carry a higher percentage of heavy metals than water (Perhac and Whelan 1972). The data on total phosphate and cation concentration from sediments in the Salt River area (Table 16) are recorded in milligrams per gram or parts per thousand, and are roughly 1,000 times concentrations typically found in natural waters. This nutrient potential of sediments in standing water is not always fully realized. Weiler (1973) and Mortimer (1971) reported studies where diffusion of ions from sediments had minimal effects on water quality when compared with ionic input from groundwater and river water.

Impounding the Salt River above Taylorsville will cause a number of biological, physical, and chemical changes in the waterway and basin. A productive lotic environment will be transformed rather suddenly into a lentic habitat. The scouring action of the river in the transport of debris and sediment will be lost. The ability of the river to assimilate excess nutrients will be greatly reduced as a basin which encourages accumulation is created. Riffle inhabitants such as darters (Percidae) Psephenidae, and Plecoptera will be replaced by bluegill, bass, Culicidae, and Chironomidae. The new reservoir will support diatoms, algae, and rooted aquatics. During the summer months, the new body of water will be deep enough to stratify, and the deep water (hypolimnion) may become oxygen deficient (Churchill 1958, Minckley and Tindall 1965). Water fowl that are attracted to the large surface area probably will add to the nutrient loading with their wastes. Neel (1963) pointed out that the increased surface area of the impounded river causes increased evaporation rates, and the total flow of the river below the impoundment may be decreased.

Neel (1963) has also observed that impoundments, unlike lakes, begin their existence in a nutrient-rich condition due to the leaching of inundated soils and vegetation but they gradually lose this fertility later in time. Mullan and Applegate (1965) compared a new and a 14-year-old reservoir and found that the former had lower specific conductance and slightly elevated NO_3^-, PO_4^-, and dissolved organics when compared to the older body of water. The present study has demonstrated that elevated phosphate, nitrate, sulfate, and sodium levels from Hammond Creek were diluted by Salt River water. There was not a significant influence on the water quality of Station 17 (which will be in the impoundment) by the water from the effluent at Lawrenceburg. It is possible that over a long period of time phosphate and trace metals, from the effluent or agricultural input, could accumulate in the hypolimnion of the reservoir. In a 12-year study, Prochazkova et al. (1973a) reported significant positive correlations between agricultural fertilization and nitrate levels in an impoundment. Nelson and Romkens (1970) pointed out that conventional tillage (when the soil is completely plowed under) can reduce phosphate in runoff water by as much as 75%, although the quantity of suspended sediments in runoff water increases. Soltero et al. (1973) in a study of Bighorn Lake, a reservoir in Montana, found that 25% of the nitrate and 85% of the phosphate which entered the lake was not detectable in the outflow. Hetling and Sykes (1973) in a study of Canadarago Lake in New York reported that only 80% of the incoming phosphorus passed through the lake. The nutrients that were retained were presumably taken up by the sediments or by the biota.

With respect to hardness and alkalinity in the river below a reservoir, data in the literature is often contradictory. Neel (1963) stated that these parameters usually decrease in outfall water directly below an impoundment. Straskrabova et al. (1973) reported these ions increase and Prochazkova et al. (1973b) studied an impoundment where these ions were virtually unaffected. From this study, there were no significant differences between alkalinity (or any chemical parameters) between Stations 22 and 17. After construction of the impoundment, it will be interesting to observe if there are significant differences in any of the chemical measurements at these two collection sites.

One of the most important considerations in the construction of the reservoir on the Salt River is the high suspended sediment load following a rain. The turbidity of the river increases moving downstream because of increased surface runoff and entrance of tributaries. Previous authors (Vetter 1953, Neel 1963) have discussed some of the unforeseen problems which may arise due to sediment accumulation. This material is usually deposited at the upper end of the man-made lake, forming a delta which becomes longer through time. Sediment can be carried to the front of a reservoir by formation of density currents (Weibe 1939). These currents are caused by viscosity differences between the cooler, more turbid incoming water and the impounded water. The utility of an impoundment for flood control, power generation, and recreation can be diminished considerably by this partial filling.

Traditionally, much of the chemical analysis of natural waters has been done by biologists. Initially, this was a way of furthering knowledge about the effects of chemical constituents on a particular group of organisms, e.g. fishes. Later, as aquatic biologists shifted their interests to quantitative ecology, chemical studies were initiated in an attempt to characterize more accurately specific types of habitats. With the increased interest in pollution problems, the concept of 'indicator organism' proved to be the focal point of many aquatic studies. This search for an organism which, by its very presence, could indicate types and concentrations of pollutants has been described as 'tantalizing' (Hart and Fuller 1974). Hynes (1960) carried this even farther by pointing out that certain toxic materials are often detectable for only a short period of time, and that only by studying the aquatic community could one understand the true character of natural waters.

Many investigators have done rather extensive biological-chemical studies of aquatic systems in order to relate species composition with physio-chemical characteristics. Roback (1962, 1974) Curry (1962), Leonard (1962), Patrick et al. (1967), and Gaufin (1962) have published species lists and concentrations of various chemical parameters under which the organisms were collected. These data are not from controlled laboratory experiments on toxicity, but represent ranges of chemical data from habitats where the individuals were collected. For example, the caddisfly (Trichoptera), *Chimarra obscura*, which is found in the Salt River and the Philadelphia area, shows little similarity between these Salt River data and the published chemical ranges for the species (Roback 1974). *Chimarra obscura* exists under higher levels of alkalinity, dissolved oxygen, phosphate, and turbidity, and lower levels of chloride, calcium, magnesium and pH in the Salt River than in Roback's (1974) data. With the midge (Diptera) *Chironomus attenuatus*, Salt River individuals of the species inhabit water with higher levels of dissolved oxygen, calcium, phosphate, and turbidity, and tolerate lower levels of dissolved oxygen, chloride, and magnesium than those reported by Roback. Distribution of these individuals probably is governed more by bottom sediments and geologic conditions than by subtle differences in the major ions found in the waters of their habitat.

Nearly 300 different species of benthic organisms representing 80 families of insects have been collected and identified from the Salt River (Krumholz and Neff 1972). These include mostly clean water forms (Hynes 1960), such as Plecoptera, Ephemeroptera, Elmidae, and Trichoptera. Dipterous larvae include ceratopogonids, simuliids, and many chironomids such as *Tanytarsus* spp., *Microtendipes pedellus*, *Glyptotendipes* sp., *Polypedilum illinoense*, and *Stichtochironomus* sp., plus many species in the Orthocladiinae. In addition, the freshwater sponge, *Spongilla lacustris*, and the Asiatic clam, *Corbicula manilensis*, have been collected. A number of these lotic species will disappear or be greatly reduced as lacustrine conditions develop following impoundment.

Hoyt et al. (1970) studied the fishes in the lower (from just below Taylorsville to just above Hammond Creek) and upper Salt River including several of its tributaries. They collected 51 species representing 11 different families. The five most numerous fish in order of their abundance were longear sunfish, bluntnose minnow, rosefin shiner, green sunfish, and stoneroller. They found the lower portion of the river yielded about 90 pounds of fish per acre (16.5 kg/ha), while the upper stretch, with more intermittent water levels, yielded only about 48 pounds per acre (8.8 kg/ha). Of all the tributaries, Brashears Creek was the most productive with a yield of 80 pounds per acre (14.7

kg/ha). According to their data, there are more forage fish (darters, shad, and minnows), than either rough fish (gar, suckers, and carp) or game fish (sunfish, black bass, and crappie). The game fish predominated in the upper reaches of the river, while the rough fish were more numerous in the lower portion of the river.

On the basis of the biological studies on the Salt River, a picture of a lotic community with rather numerous and diversified species emerges. Both the number and variety of organisms indicates clean, free-flowing, unpolluted water. The continued presence of the crayfish, *Orconectes* sp., the freshwater sponge, *Spongilla lacustris*, as well as Ephemeroptera, Plecoptera, and Orthocladiinae suggests that the high siltation as the result of rain does not produce long-term detrimental effects. It is evident that in the area of the Salt River which is to be impounded, significant changes in the lotic community will occur.

SUMMARY

The Salt River at Taylorsville is characterized by high specific conductance (200-535 μmhos/cm) and dissolved solids (166-316 mg/l), elevated concentrations of calcium (33.5-74.8 mg/l), bicarbonate (126-236 mg/l), sulfate (16.5-71.5 mg/l), and magnesium (1.6-12.7 mg/l), and moderate levels of chloride (4.2-15.3 mg/l), sodium (3.2-20.3 mg/l), potassium (1.3-5.6 mg/l), and silicon dioxide (2.1-12.4 mg/l). Nitrates and phosphates are rarely greater than 1 mg/l. Carbonates, nitrites, and heavy metals such as iron, manganese, and copper are all less than 0.5 mg/l. Brashears Creek at its mouth is similar to that of the Salt River at Taylorsville, except that the former has slightly lower turbidity, and total residue. The effect of Brashears Creek on the Salt River is that of dilution; Station 23 which is below the mouth of Brashears Creek has slightly lower levels of dissolved ions and suspended solids, than the station in the Salt River above the mouth of Brashears Creek (Station 22).

The Student's *t*-test shows that none of the stations on the Salt River or Brashears Creek are significantly different from one another (at the 5% level). There are significant differences at greater than the 5% level between Station H1 near the source of Hammond Creek, and the other stations studied in the Salt River area.

The sewage effluent of Lawrenceburg, Ky., near the source of Hammond Creek, contributes high levels of sodium (16.2-152.3 mg/l), potassium (3.1-19.4 mg/l), bicarbonate (168-402 mg/l), and sulfate (21.0-142.0 mg/l) to the creek. Under conditions of low flow and warm temperatures, the effect of these nutrients may be detected in the mouth of Hammond

Creek, in the Salt River below Hammond Creek, but not in the Salt River at Station 17, about 13 km downriver.

Following a rain, the Salt River can carry a suspended sediment load equal to 50% of the total residue. During the 1972 water year, about 3.3×10^9 kg of sediment which corresponds to 2.42×10^6 m^3 was carried by the river.

Total ion concentrations of Salt River soils and sediments indicated that potassium (12.4-213.3 mg/g) and iron (23.4-135.1 mg/g) are in the highest concentrations, with fairly high levels of calcium (0.81-45.7 mg/g) and reduced levels of sodium (4.6-10.5 mg/g), magnesium (3.2-6.3 mg/g), and phosphate (1.3-15.3 mg/g). In general, the sediments carry more than 1,000 times the nutrient load of an equal mass of water. About 10% of the total ions on sediments can be considered exchangeable ions. Calcium (309-3,292 μg/g) was the most prevalent extractable ion, followed by potassium (17.6-409.5 μg/g), then sodium (12.9-458.1 μg/g) and magnesium (89.4-266.2 μg/g). About 10% of the exchangeable ions were soluble in distilled water. Calcium (18-486 μg/g) and potassium (16.6-69.4 μg/g) were in the highest concentrations, followed by sodium (11.1-30.8 μg/g) and magnesium (6.6-68.7 μg/g). Salt River sediments contained high quantities of iron (0-6.7 μg/g) and phosphate (0.6-41.6 μg/g) which were on sediments, and not readily removed by distilled water treatment.

Rainwater analysis near Station 17 indicated sulfate was greater than 10 mg/l, while calcium and potassium were less than 5 mg/l, and sodium and magnesium were less than 1 mg/l. The high sulfate levels are an indication that some sulfate ion may enter the river from oxidation of sulfur dioxide in the atmosphere. Runoff analysis showed variation in suspended sediment depending on location of the samplers. In general, the sodium and potassium from runoff water was about 10 mg/l, while calcium was half this value, and magnesium was less than 1 mg/l. This may indicate that sodium and potassium enter the watershed by way of overland flow and interaction with organic material.

Calcium and bicarbonate in the river come from solution of calcite. Mole ratios of calcium to bicarbonate tend to be greater than 2:1 in the Salt River and Brashears Creek. The solution of calcium carbonate with water and dissolved carbon dioxide are the predominant reactions in the Salt River, and are responsible for maintaining the pH, high specific conductance, and dissolved residue in the water. Noncarbonate hardness in these unpolluted waters is almost entirely sulfate, expressed as parts per million of calcium carbonate. Sulfate can be predicted from the noncarbonate hardness with an average error of 10%. In an area such as Hammond Creek the noncarbonate hardness becomes negative, due to high levels of sodium or potassium bicarbonate, which raise alkalinity above hardness. In a theoretical system, all the concentration of ions can be accounted for on the basis of the hardness and alkalinity calculations; the difficulty comes in not knowing which cations are associated with which anions.

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Table 1. Means, maxima, and minima (mg/l unless noted otherwise), for chemical parameters at Station 17 on the Salt River, Anderson County, Kentucky, 10 August 1972 - 2 July 1974.

Parameter	No. of Determinations	Mean	Min	Max
Calcium	22	60.6	34.5	81.0
Sodium	22	9.1	3.1	32.4
Magnesium	24	6.5	2.1	13.2
Potassium	23	3.2	1.2	7.8
Bicarbonate	23	188	107	239
Sulfate	22	36.7	13.4	78.0
Chloride	11	11.1	6.6	14.9
Silicon Dioxide	11	6.9	2.9	12.0
Nitrate	16	4.43	0.48	15.95
Phosphate	22	1.05	0.18	3.71
Nitrite	20	0.140	0.006	0.029
Carbonate	24	--	--	--
Hardness	23	178	134	235
Alkalinity	23	154	88	196
Specific Conductance (μmhos/cm)	23	382	250	520
pH	22	7.5	6.8	7.9
Dissolved Oxygen	23	8.8	2.7	14.4
Turbidity (mg/l SiO_2)	24	38	5	174
Total Residue	24	291	224	482
Suspended Solids	24	48	2	194
Water Temperature (°C)	23	14	1	25

Table 2. Means, maxima, and minima (mg/l unless noted otherwise) for chemical parameters at Station 22 on the Salt River, Spencer County, Kentucky, 10 August 1972 - 2 July 1974.

Parameter	No. of Determinations	Mean	Min	Max
Calcium	21	55.8	33.5	74.8
Sodium	21	6.3	3.2	20.3
Magnesium	24	6.7	1.6	12.7
Potassium	22	2.9	1.3	5.6
Bicarbonate	23	183	126	236
Sulfate	22	35.7	16.5	71.5
Chloride	11	9.7	4.2	15.3
Silicon Dioxide	11	8.2	2.1	12.4
Nitrate	15	2.6	0.6	5.7
Phosphate	22	0.9	0.2	2.4
Nitrite	20	0.008	0.005	0.030
Carbonate	23	--	0	6.0
Hardness	21	174	134	236
Alkalinity	23	151	103	194
Specific Conductance (μmhos/cm)	23	368	200	535
pH	20	7.1	6.0	8.1
Dissolved Oxygen	22	8.7	1.8	14.2
Turbidity (mg/l SiO_2)	24	103	5	816
Total Residue	24	389	193	1900
Suspended Solids	24	159	4	1684
Water Temperature (°C)	23	14	1	28

Table 3. Means, maxima, and minima (mg/l unless noted otherwise) for chemical parameters at Station 26 on Brashears Creek, Spencer County, Kentucky, 13 April 1973 - 2 July 1974.

Parameter	No. of Determinations	Mean	Min	Max
Calcium	14	56.7	43.0	66.0
Sodium	14	4.6	2.8	8.8
Magnesium	15	6.4	3.0	8.2
Potassium	15	2.8	1.0	6.5
Bicarbonate	13	192	141	234
Sulfate	13	27.4	11.0	38.8
Chloride	10	10.7	6.6	19.3
Silicon Dioxide	10	5.7	2.0	11.3
Nitrate	7	2.16	0.75	7.08
Carbonate	13	--	0	4
Hardness	14	172	150	196
Alkalinity	13	158	116	192
Specific Conductance (µmhos/cm)	14	378	310	480
pH	12	7.6	7.1	8.2
Dissolved Oxygen	14	10.0	7.4	14.4
Turbidity (mg/l SiO_2)	15	42	2	148
Total Residue	15	291	194	628
Suspended Solids	15	63	2	396
Water Temperature (°C)	14	16	2	27

Table 4. Means, maxima, and minima (mg/l unless noted otherwise) for chemical parameters at Station H1 on Hammond Creek, Anderson County, Kentucky, 10 July 1972 - 14 August 1973.

Parameter	No. of Determinations	Mean	Min	Max
Calcium	13	68.5	50.5	98.3
Sodium	11	54.5	16.2	152.3
Magnesium	14	8.4	2.0	20.4
Potassium	11	7.6	3.1	19.4
Bicarbonate	13	279	168	402
Sulfate	13	59.8	21.0	142.0
Ammonia Nitrogen	10	12.9	1.2	47.3
Nitrate	12	15.6	2.3	57.6
Phosphate	13	26.4	3.5	75.0
Nitrite	11	0.05	0.02	0.20
Carbonate	14	--	--	--
Hardness	14	193	126	282
Alkalinity	14	228	138	330
Specific Conductance (μmhos/cm)	14	619	320	1300
pH	13	6.4	5.5	7.7
Dissolved Oxygen	14	5.4	0.2	10.1
Turbidity (mg/l SiO_2)	13	33	10	59
Total Residue	14	522	248	1105
Suspended Solids	13	108	10	420
Water Temperature (°C)	14	17	1	30

Table 5. Major ions from the 'World Average River' (Livingstone 1963).

Ion	mg/l
Ca	15.0
Mg	4.0
Na	6.3
K	2.3
Fe	0.67
SiO_2	13.1
HCO_3	58.4
SO_4	11.2
Cl	7.8
NO_3	1.0

Table 6. Milligram ratios of various chemical parameters at Station H1 on Hammond Creek, Anderson County, Kentucky, 15 September 1972 - 14 August 1973. n = number of samples, $\overline{x}$ = mean, and CV = coefficient of variation.

Date	Ca/HCO_3	Na/K	Ca/Mg	Ca/SO_4	Na/Mg	Na/HCO_3
15 Sep 72	0.2	-	35.2	0.5	-	-
10 Oct 72	0.2	7.8	5.6	0.5	15.4	0.41
2 Nov 72	0.3	9.4	10.9	2.2	12.5	0.07
13 Dec 72	0.3	-	13.5	1.8	-	-
26 Jan 73	0.3	8.3	5.1	0.8	2.7	0.16
16 Feb 73	0.3	6.1	9.0	2.0	2.6	0.90
30 Mar 73	0.3	5.4	9.0	3.0	2.4	0.80
13 Apr 73	0.3	6.1	9.4	1.7	4.3	0.13
29 May 73	-	5.1	9.9	-	2.4	-
31 Jun 73	0.3	4.2	18.6	2.5	5.7	0.08
31 Jul 73	0.3	5.7	8.7	1.6	5.3	0.16
14 Aug 73	0.3	6.4	11.2	2.2	5.9	0.17
n	11	10	12	11	10	9
$\overline{x}$	0.3	6.5	12.2	1.7	5.9	.18
CV	20.1	24.9	66.3	14.1	75.6	65.60

Table 7. Milligram ratios of various chemical parameters at Station 17 on the Salt River, Anderson County, Kentucky, 15 August 1973 - 2 July 1974. n = number of samples, $\overline{x}$ = mean, and CV = coefficient of variation.

Date	Discharge (m^3/sec)	Ca/HCO_3	Na/K	Ca/Mg	Na/Cl	Ca/SO_4	Na/Mg	Na/HCO_3
15 Aug 73	1.22	0.3	1.8	8.7	1.0	2.4	1.0	0.04
24 Sep 73	0.10	0.3	2.1	6.3	0.7	1.9	1.0	0.05
22 Oct 73	0.08	0.3	2.4	5.4	1.4	1.5	1.0	0.06
16 Nov 73	0.13	0.3	2.8	8.2	1.8	-	2.3	0.09
19 Dec 73	1.22	0.3	3.4	9.9	0.6	1.1	1.1	0.40
23 Jan 74	13.22	0.3	2.4	8.7	0.4	1.0	0.6	0.02
15 Mar 74	9.17	0.2	3.1	6.8	0.5	2.4	0.6	0.02
3 May 74	10.87	0.4	2.4	7.9	0.6	0.8	0.8	0.05
30 May 74	4.59	0.2	3.7	4.5	0.8	0.6	1.1	0.06
2 Jul 74	0.57	0.2	1.6	6.9	0.6	2.6	1.2	0.04
n	10	10	10	10	10	9	10	10
$\overline{x}$	4.11	0.3	2.6	7.3	0.8	1.6	1.1	0.05
CV	123.3	20.0	26.3	22.6	53.8	48.6	44.0	40.07

Table 8. Correlation coefficients between discharge, suspended solids, dissolved solids, and turbidity for Station 17 on the Salt River, Anderson County, Kentucky. Values marked with an asterisk (*) are significant at the 95% level with 20 degrees of freedom. The lower half of the matrix is r^2, or percentage variation.

	Discharge	Dissolved Solids	Suspended Solids	Turbidity
Discharge	1	-.02	.78*	.59*
Dissolved Solids	0.04%	1	-.41	-.37
Suspended Solids	61.8%	16.8%	1	.83*
Turbidity	35.8%	7.2%	68.9%	1

Table 9. Correlation coefficients for selected chemical parameters from Station 17 on the Salt River in Anderson County, Kentucky. Numbers marked with an asterisk (*) are significant at the 95% level with N = 30.

	Specific Conductance	Na	K	Ca	Mg	SO_4	PO_4	HCO_3
Specific Conductance	1.	0.28	0.04	0.13	0.09	0.44*	0.36	0.51*
Na		1.	0.76*	0.37*	0.40	0.29	0.26	0.18
K			1.	0.37*	0.14	0.16	0.19	0.16
Ca				1.	0.46*	0.16	0.26	0.43*
Mg					1.	0.22	-0.21	0.23
SO_4						1.	0.45*	0.43*
PO_4							1.	0.41*
HCO_3								1.

Table 10. Correlation coefficients for selected chemical parameters from Station H1 on Hammond Creek, Anderson County, Kentucky. Numbers marked with an asterisk (*) are significant at the 95% level with N = 19.

	Specific Conductance	Na	K	Ca	Mg	SO_4	PO_4	HCO_3
Specific Conductance	1.	0.35	0.23	0.48*	0.12	0.81*	0.67*	0.68*
Na		1.	0.95*	0.22	0.32	0.44	0.68	0.52*
K			1.	0.18	0.33	0.31	0.58*	0.42
Ca				1.	0.32	0.41	0.21	0.66*
Mg					1.	0.37	0.28	0.54*
SO_4						1.	0.80*	0.83*
PO_4							1.	0.78*
HCO_3								1.

Table 11. Flow weighted averages for dissolved residue, sodium, phosphate, and sulfate from Station 17, Anderson County, on the Salt River, August 1972 to July 1974.

Date	N	Average Discharge (m^3/sec)	Dissolved Residue	Sodium	Phosphate	Sulfate
Jan-Mar	6	12.0	232	4.1	1.1	40.3
Apr-Jun	5	9.3	219	5.0	0.7	43.8
Jul-Sep	7	3.4	280	4.3	1.1	19.3
Oct-Dec	6	7.0	156	7.5	1.3	22.7

Table 12. Chemical composition and activity coefficients of various ions at Station 17, Anderson County, on the Salt River, 31 July 1973.

Ion	mg/liter	Activity Coefficient
Ca	81.0	.71
Mg	5.8	.72
Na	5.0	.91
K	2.0	.91
PO_4	1.5	.45
SO_4	19.0	.70
NO_3	5.9	.91
HCO_3	238.9	.91
CO_3	0	.70

Table 13. Predicted levels for the ions in the calcite equilibria corresponding to the pH and ionic strength of the July 31 sample at Station 17, Anderson County, on the Salt River.

Ion	$\log_{10}$ Activity	mg/liter
H	-7.29	5.06×10^{-5}
OH	-6.63	3.94×10^{-3}
Ca	-2.73	73.74
CO_3	-5.27	0.32
HCO_3	-2.43	223.85
H_2CO_3	-3.43	23.05

Table 14. pH, predicted calcium, and laboratory determination of calcium from Station 17, Anderson County, on the Salt River.

Date	pH	Predicted Calcium	Laboratory Determination of Calcium
10 Aug 72	7.7	46	51
29 Sep 72	7.6	52	59
24 Oct 72	7.4	66	71
21 Nov 72	7.4	64	49
26 Jan 73	7.7	47	72
16 Feb 73	7.8	41	59
29 Mar 73	7.6	51	54
2 Jul 73	7.8	41	64
21 Jul 73	7.3	74	81
22 Sep 73	7.7	47	71
16 Oct 73	6.8	131	72
23 Jan 74	7.7	46	55
29 Feb 74	7.8	41	55
30 Mar 74	7.6	52	48
2 Jul 74	7.8	40	34
$\bar{x}$	-	56	60

Table 15. Sample number, location, type, and collection date for sediments analyzed by total acid, barium chloride, and aqueous extraction.

Sample	Location	Type	Collection Date
1	Salt River, 23	Dry Clay	15 Mar 73
2	Salt River, 23	Wet Clay	29 May 73
3	Salt River, 23	Dry Sand	15 Mar 73
4	Brashears Creek, 26	Wet Silt	29 May 73
5	Storm Sewer, 22	Wet Silt	2 Jul 73
6	Mouth of Salt River	Dry, Red Clay	27 Mar 73
7	Hill, Salt River	Dry Clay	5 May 73
8	Hill, Salt River	Dry Topsoil	5 May 73
9	Hill, Salt River	Dry Topsoil	9 Jul 73
10	Fischer Pond	Dry Sludge	29 May 73
11	Sulfur spring, Doe Run	Wet Silt	18 Jul 73
12	Lake Michigan	Dry Sand	20 June 73
13	Ohio River	Marl	Aug 73
14	Paint Creek	Wet Sand	Oct 73
15	Paint Creek	Wet Clay	14 Jul 73
16	Open Fork, Paint Creek	Wet Sand	14 Jul 73

Table 16. Ion concentrations of various sediments. Sample numbers refer to locations specified in Table 15. All values are in milligrams per gram of dry sediment.

Sample	Na	K	Ca	Mg	PO_4	Fe
1	5.0	28.1	12.5	4.2	8.2	24.1
2	7.1	213.3	12.4	6.1	5.7	29.9
3	4.7	12.4	45.7	4.7	4.1	99.8
4	7.1	18.6	16.8	5.7	15.3	28.7
5	10.5	24.3	7.1	6.3	3.4	28.5
6	4.6	14.7	2.4	3.4	3.3	135.1
7	6.2	39.8	0.8	3.2	1.3	25.9
8	8.7	18.7	1.9	3.9	1.5	23.4
9	4.9	127.0	3.9	3.7	3.7	31.3
10	6.5	12.4	46.5	6.9	6.6	25.4
11	6.3	14.9	6.1	3.2	1.2	17.9
12	4.5	9.9	5.9	2.7	0.1	4.5
13	5.2	5.2	247.6	22.9	1.4	12.5
14	8.3	19.6	1.3	2.8	1.4	78.7
15	9.2	18.6	0.6	3.9	1.2	25.8
16	6.6	19.0	1.5	2.7	0.6	18.1

Table 17. Cations extracted from sediments with 0.1 normal barium chloride. Sample numbers refer to locations specified in Table 15. All values are in micrograms per gram of dry sediment.

Sample	Na	K	Ca	Mg
1	458.1	381.7	3292	152.7
2	19.1	363.6	3018	118.2
3	47.9	204.1	2706	124.2
4	20.3	388.2	3144	135.8
5	26.9	409.5	3164	111.7
6	67.6	368.6	1187	266.2
7	28.5	17.6	309	98.3
8	32.2	22.2	1291	232.1
9	12.9	28.8	1169	89.4
10	95.4	360.3	3583	116.8
11	126.6	82.7	1811	194.7
12	18.6	4.8	45	9.7
13	443.2	144.0	1351	66.5
14	461.7	147.9	--	47.3
15	611.7	61.2	132	61.2
16	277.6	61.6	262	46.2

Table 18. Ions extracted from sediments with distilled water. Sample numbers refer to locations specified in Table 15. All values are in micrograms per gram of sediment. Sample No. 14 (-) was not analyzed.

Sample	Na	K	Ca	Mg	Fe	PO_4
1	15.7	46.8	435	20.0	6.7	12.3
2	14.1	68.7	481	68.7	6.5	30.4
3	12.3	16.6	192	6.6	6.6	12.3
4	20.4	68.1	486	29.1	3.2	39.2
5	22.2	69.4	678	33.1	6.6	41.6
6	11.1	39.3	54	12.1	3.0	0.6
7	30.8	35.0	18	9.5	0	0.6
8	27.7	26.9	151	33.8	6.2	3.4
9	10.3	55.4	370	38.1	3.5	27.3
10	76.6	79.9	945	53.2	6.6	6.6
11	56.5	43.1	863	132.8	9.9	2.3
12	5.6	9.9	0	0	0	9.9
13	56.2	125.8	950	29.8	6.6	0
14	-	-	-	-	-	-
15	23.2	23.2	39	13.2	6.6	0.6
16	13.1	29.5	52	9.8	6.5	0.3

Table 19. Average ion values for the Salt River sediments analyzed by total acid analysis (mg/g), barium chloride extraction (μg/g) and aqueous extraction (μg/g).

Ion	Total Acid Analysis	$BaCl_2$	Aqueous
Na	6.5	79.3	18.3
K	55.2	242.7	48.5
Ca	11.5	2197	318.3
Mg	4.6	147.6	27.9
Fe	47.4	---	4.7
PO_4	5.2	---	18.6

Table 20. Milligram ratios for selected ions from sediments 1-9, collected from the Salt River Basin, Kentucky. The sediment samples were analyzed by total acid digestion.

Sample	Na/K	Ca/Mg	Fe/PO_4	Na/Mg
1	0.2	3.0	2.9	1.2
2	0.0	2.0	5.3	1.2
3	0.4	9.7	24.3	1.0
4	0.4	2.9	1.9	1.2
5	0.4	1.1	9.1	1.7
6	0.3	0.7	8.4	1.4
7	0.2	0.2	40.1	1.9
8	0.5	0.5	15.6	2.2
9	0.0	1.0	8.5	1.3
n	9	9	9	9
$\bar{x}$	0.3	2.3	25.8	1.4
CV	62.6	125.8	71.3	27.9

Table 21. Milligram ratios for selected ions from sediments 1-9, collected from the Salt River Basin, Kentucky. The sediment samples were analyzed by distilled water extraction.

Sample	Na/K	Ca/Mg	Fe/PO_4	Na/Mg
1	0.3	21.7	0.5	0.8
2	0.2	7.0	0.2	0.2
3	0.7	29.1	0.5	1.9
4	0.3	16.7	0.8	0.7
5	0.3	20.5	0.2	0.7
6	0.3	4.5	5.0	0.9
7	0.9	1.9	0	3.2
8	0.8	4.5	1.8	0.8
9	0.2	9.7	0.1	0.3
n	9	9	9	9
$\overline{x}$	0.4	12.8	1.0	1.0
CV	61.0	75.2	1.5	90.2

Table 22. Milligram ratios for selected ions from sediments 1-9, collected from the Salt River Basin, Kentucky. The sediment samples were analyzed by barium chloride extraction.

Sample	Na/K	Ca/Mg	Na/Mg
1	1.20	21.6	3.0
2	0.05	25.5	0.2
3	0.23	21.8	0.4
4	0.05	23.2	0.1
5	0.06	28.3	0.2
6	0.18	4.5	0.3
7	1.62	3.1	0.3
8	1.45	5.6	0.1
9	0.45	18.7	0.1
n	9	9	9
$\bar{x}$	0.59	16.9	0.5
CV	110.8	57.8	187.1

Table 23. Percentage of organic material from sediments described in Table 15.

Sample No.	Location	Percentage Organic Material
1	Salt River, 23	5.9
2	Salt River, 23	7.8
3	Salt River, 23	9.0
4	Brashears Creek, 26	7.6
5	Storm Sewer, 22	7.2
6	Mouth of Salt River	4.1
7	Hill, Salt River	4.3
8	Hill, Salt River	4.6
9	Hill, Salt River	14.1
10	Fischer Pond	13.8
11	Sulfur spring, Doe Run	4.5
12	Lake Michigan	1.3
13	Ohio River	25.7
14	Paint Creek	1.9
15	Paint Creek	4.2
16	Open Fork, Paint Creek	1.8

Table 24. Chemical analysis of rainwater near Station 17 on the Salt River, Anderson County, Kentucky, 21 November 1973 - 3 June 1974. All measurements are in milligrams per liter. ml = number of milliliters in sample.

Date	ml	Residue	Na	K	Ca	Mg	SO_4	PO_4
21 Nov 73	259	--	0.1	1.07	1.3	0.33	--	--
28 Nov 73	>1000	--	0.2	0.4	0.32	0.7	--	--
5 Dec 73	71	9	0.5	2.6	3.3	0.4	--	--
14 Dec 73	32	--	0.6	1.0	6.1	0.65	--	--
26 Dec 73	948	18	0.06	0.5	0.4	0.1	--	--
8 Jan 74	133	--	0.16	0.7	0.7	0.1	--	--
23 Jan 74	306	--	0.10	1.32	1.4	0.15	--	--
24 Jan 74	312	--	0.14	1.44	1.4	0.2	--	--
28 Jan 74	--	--	0.4	1.22	1.9	0.3	--	--
8 Feb 74	134	--	0.32	0.68	3.6	0.45	--	--
20 Feb 74	193	196	0.7	2.2	10.7	1.0	27.8	1.0
29 Feb 74	177	18	0.2	0.7	0.2	0.2	10.8	0.07
15 Mar 74	319	28	0.1	0.5	1.5	0.2	10.1	0.29
13 May 74	--	32	0	1.3	1.5	0.3	12.6	0.16
16 May 74	9.6	--	0.3	15.4	4.0	2.8	--	--
23 May 74	98.2	102	0.2	7.3	5.5	1.8	--	--
30 May 74	243	44	0	1.6	3.2	0.6	13.4	0.29
3 Jun 74	>1000	14	0	0.4	0.7	0.3	8.3	0.11

Table 25. Chemical analysis of runoff water collected near Station 17 on the Salt River, Anderson County, Kentucky, 21 November 1973 - 3 June 1974. All measurements are in milligrams per liter. ml = number of milliliters in sample.

Date	ml	Residue	Na	K	Ca	Mg
21 Nov 73	78	--	9.2	40.8	7.4	1.9
28 Nov 73	86	--	20.2	11.0	3.9	0.3
5 Dec 73	--	--	--	--	--	--
19 Dec 73	--	--	--	--	--	--
26 Dec 73	1020	80	9.1	1.9	0.4	0.05
8 Jan 74	32	--	19.6	5.0	1.7	0.25
23 Jan 74	48	--	12.1	3.3	1.4	0.25
24 Jan 74	--	--	--	--	--	--
28 Jan 74	739	42	3.7	1.8	0.13	0.05
8 Feb 74	--	--	--	--	--	--
20 Feb 74	--	--	--	--	--	--
29 Feb 74	--	--	--	--	--	--
15 Mar 74	--	--	--	--	--	--
13 May 74	13	--	14.6	12.0	8.0	1.6
23 May 74	--	--	--	--	--	--
30 May 74	--	--	--	--	--	--
3 Jun 74	11	--	5.3	5.0	9.0	1.4

Table 26. Chemical analyses of runoff water from collection site #1, near Station 22, Spencer County, Kentucky, on the Salt River. All data were collected in 1974. All measurements are in milligrams per liter, except specific conductance which is in micromhos per centimeters.

Parameter	7 Mar	15 May	30 May	3 Jun
Total ml	>1000	970	70	1049
Residue	9962	2392	---	532
Suspended Solids	9808	2396	---	440
Na	2.2	1.0	1.1	1.7
K	1.7	1.3	84.0	6.6
Ca	9.5	10.0	13.0	11.5
Mg	1.7	1.9	5.8	2.2
SiO_2	1.3	2.2	---	3.6
SO_4	20.2	17.6	---	16.8
PO_4	0.62	1.14	---	1.25
NO_3	5.1	7.9	---	7.1
Specific Cond.	70	70	---	70

Table 27. Chemical analyses of runoff water from collection site #2, near Station 22, Spencer County, Kentucky, on the Salt River. All data were collected in 1974. All measurements are in milligrams per liter except specific conductance which is in micromhos per centimeters.

Parameter	7 Mar	15 May	30 May	3 Jun
Total ml	880	1378	90	953
Residue	1840	772	---	2732
Suspended Solids	1470	680	---	---
Na	.6	1.1	3.0	1.0
K	4.7	1.1	21.7	3.9
Ca	11.7	21.7	33.0	16.7
Mg	1.5	3.9	7.1	2.5
SiO_2	2.8	---	---	5.3
SO_4	15.1	---	---	17.6
PO_4	1.26	---	---	1.25
NO_3	33.2	---	---	7.9
Specific Cond.	79	130	---	95