# WATER-QUALITY AND CHEMICAL LOADS OF THE SUSQUEHANNA RIVER AT HARRISBURG, PENNSYLVANIA, APRIL 1980 TO MARCH 1981

By David K. Fishel

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ILLUSTRATIONS

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## FACTORS FOR CONVERTING INCH-POUND UNITS TO INTERNATIONAL SYSTEMS OF UNITS (SI)

| Multiply inch-pound unit | By | To obtain SI unit |
|---|---|---|
| | **Length** | |
| inch (in) | 2.540 | centimeter (cm) |
| | 25.40 | millimeter (mm) |
| foot (ft) | 0.3048 | meter (m) |
| mile (mi) | 1.609 | kilometer (km) |
| | **Area** | |
| square mile ($mi^2$) | 2.590 | square kilometer ($km^2$) |
| | **Discharge** | |
| cubic foot per second ($ft^3/s$) | 0.02832 | cubic meter per second ($m^3/s$) |
| ton per day (short, 2000 pounds) | 0.9072 | megagram (Mg/d) |
| | **Volume** | |
| gallon (gal) | 3.785 | liter (L) |
| | 3,785 | milliliter (mL) |
| | **Mass** | |
| ton per square mile per year (($ton/mi^2$)/yr) | 0.3503 | megagram per square kilometer per year (($Mg/km^2$)/yr) |
| | **Specific conductance** | |
| micromhos per centimeter (μmho/cm) | 1.000 | microsiemens per centimeter (μs/cm) |
| | **Temperature** | |
| degree Fahrenheit (°F) | 5/9 (°F-32) | degree celsius (°C) |
| | **Velocity** | |
| foot per second (ft/s) | 0.3048 | meter per second (m/s) |

# WATER-QUALITY AND CHEMICAL LOADS OF THE SUSQUEHANNA RIVER AT HARRISBURG, PENNSYLVANIA, APRIL 1980 TO MARCH 1981

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## ABSTRACT

Water samples were analyzed for 42 chemical constituents to determine the water quality of the Susquehanna River at Harrisburg, Pennsylvania from April 1, 1980 to March 31, 1981. The investigation was part of the U.S. Environmental Protection Agency's (EPA) Chesapeake Bay Program's Fall Line Monitoring Project to provide information on the Susquehanna River's freshwater input to the Chesapeake Bay.

Streamflow and sediment discharge at Harrisburg during the study were 77 and 72 percent, respectively, of the average annual discharges. Precipitation was 16 percent lower than normal. Streamflow for February 1981 was 140 percent higher than the average monthly flow and transported 61 percent of the total annual sediment discharge.

Approximately 2,300,000 tons of suspended sediment and 2,990,000 tons of dissolved solids were transported during the study. About 76 percent of the 42,000-ton nitrogen load was dissolved. Nearly 84 percent of the 2,930-ton phosphorus load and 95 percent of the 111,000-ton iron, aluminum and manganese loads were associated with suspended sediment.

The herbicides atrazine and 2,4-Dichloro-phenoxyacetic acid (2,4-D) were the only pesticides measured in significant concentrations during the study period. Concentrations of 2,4-D varied throughout the year, and atrazine varied mostly during the spring and summer. Seasonal variations for other constituent concentrations and loads were directly related to streamflow.

The concentrations of many constituents varied with distance along the sampling cross-section. Maximum concentrations of suspended sediment differed between the east and west channels and fluctuated from one channel to the other. Specific conductance, dissolved nutrients, and dissolved major ions were consistently higher along the east and west banks. Dissolved nitrate concentrations were significantly higher in the vertical section closest to the west bank of the river.

Diel variations of water temperature, dissolved oxygen, pH, and specific conductance recorded for the period 1974 through 1978 were greatest during the months of June, July, August, and September. However, no trends in the amount of daily variation were determined for the five years of data. Regular diel variation patterns were observed for water temperature, dissolved oxygen, and pH for all streamflow conditions except peak flow and ice melt conditions. Specific conductance showed no regular diel variation, and was inversely related to streamflow. All four constituents were greatly influenced for short durations by melting ice.



page 3 follows

## INTRODUCTION

### Summary of Chesapeake Bay Program and Fall Line Monitoring Project

Interest in the processes of eutrophication and sedimentation in the Chesapeake Bay was initiated as part of a 25-million dollar study which Congress directed the Environmental Protection Agency (EPA) to coordinate in 1976. The Environmental Protection Agency requested the U.S. Geological Survey undertake a portion of the Chesapeake Bay Program study entitled "Fall Line Monitoring of the Potomac, Susquehanna, and James Rivers." This study of the fresh-water input to the Chesapeake Bay was begun in October 1978, and was directed by the U.S. Geological Survey, Maryland District.

In March 1980, the Maryland District requested the collection of additional data at the Susquehanna River at Harrisburg, Pennsylvania to aid in the determination of sediment and nutrient loadings downstream at Conowingo, Maryland. The station at Harrisburg was selected because of its long-term sediment records dating back to October 1963. The Pennsylvania Department of Environmental Resources also showed interest in the enlargement of the data base at Harrisburg for use in the development of sewage-treatment plant regulations. Thus, from March 21, 1980 until March 31, 1981, sampling at the Susquehanna River at Harrisburg was conducted by the U.S. Geological Survey, Harrisburg, Pa., Subdistrict office. This report presents results of the data collected during that period.

The primary concern of the Chesapeake Bay Program was to identify the extent and location of nutrient and sediment loadings entering the Bay. The Susquehanna River had previously been identified as the largest fresh-water contributor of nutrients to the Bay (Guide and Villa, 1972), and transports about 3.0 million tons of sediment annually to the Bay. However, much of the suspended sediment measured at the Susquehanna River at Harrisburg is trapped during low-flow conditions by three reservoirs downstream from Harrisburg before reaching the outfall of the power-generating dam at Conowingo, Maryland (Williams and Reed, 1972).

The three power-generating dams between Harrisburg, Pa., and Conowingo, Md., are the Safe Harbor, the Holtwood, and Conowingo dams (fig. 1). The Safe Harbor Dam is 33 miles upstream from the mouth of the Susquehanna River. It was constructed in 1931 creating a storage area of approximately 11.5 $mi^2$ and a total storage of about 150,000 acre-feet. The Holtwood Dam is about 25 miles upstream from the mouth of the Susquehanna River. It was constructed in 1910 with a storage area of 3.8 $mi^2$ and total storage of about 60,000 acre-feet. The Conowingo Dam is 10 miles upstream from the mouth of the Susquehanna River at Havre de Grace, Maryland. It was constructed in 1928 with a storage area of about 14.0 $mi^2$ and total storage of about 300,000 acre-feet.

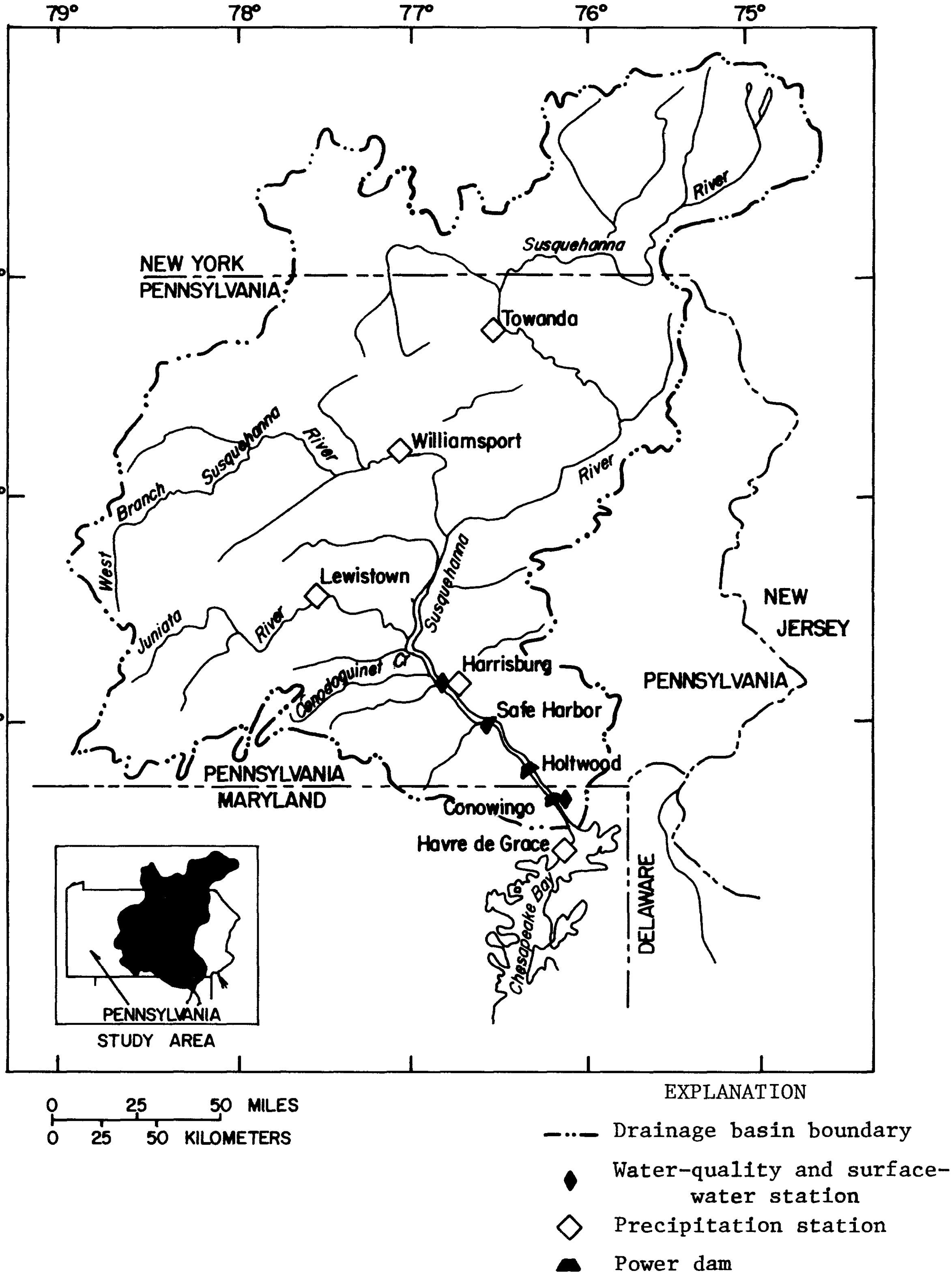


Figure 1.--Susquehanna River basin, water-quality and surface-water stations, precipitation stations and power-generating dams.

## Eutrophication

Eutrophication or nutrient enrichment in the Chesapeake Bay occurs when nitrogen and phosphorus compounds accumulate in the water or stream bed and stimulate plant growth to a point where plankton and algal blooms occur. These blooms produce toxic and low oxygen conditions, both of which are unfavorable for fish populations and aquatic vegetation. Nutrient enrichment is a serious concern in the immediate Chesapeake Bay area, but is also a concern upstream in fishing and recreational areas.

## Sedimentation

Sedimentation in the Chesapeake Bay is caused primarily by the deposition of suspended sediment transported into the Bay by its tributaries. This problem is compounded by the hydraulics of the Bay; a net inward flow of water from the lower layer of the Bay and a net outward flow of water near the surface creates a natural sediment trap (Pritchard, 1969). As a result, the Bay is becoming wider and decreasing in depth. Recent studies indicate that the trapped sediments contain nutrients, trace metals, and pesticides, which can reach toxic levels.

Much like the problem with eutrophication, the process of sedimentation is not limited to the Bay area. It too is of concern upstream where power-generating dams act as sediment traps during low flows, causing the deposition of approximately 40 percent of the annual sediment load carried by the Susquehanna River (Williams and Reed, 1972). During high flows a substantial part of this load can be flushed from the dams and transported to the Bay.

## Purpose and Scope

The primary purpose of this study is to provide quantitative and qualitative information on chemical, physical, and biological water-quality characteristics of the Susquehanna River at Harrisburg, Pa., measured during limited sampling from March 21, 1980 to March 31, 1981. The results of this study provide information for the Fall Line Monitoring study performed by the U.S. Geological Survey's Maryland office to determine the relationship between constituent loading at Harrisburg to the Susquehanna River's loading to Chesapeake Bay. Study results also provide information to evaluate the effects of existing and future land use, water use, and regional economic development in the Susquehanna River Basin on the water quality of the Chesapeake Bay.

This report provides information on the concentrations and loadings of suspended sediment, major ions, selected nutrient species, and trace metals. It also includes seasonal characterization of selected pesticides. The cross-sectional variation in concentrations of suspended sediment, major ions, selected nutrient species, and trace metals at Harrisburg is discussed. In addition, information on the diel variation of conductance, dissolved oxygen, pH, and water temperature for the period 1974 to 1978 is provided for trend analyses.

## Previous Studies of Water-Quality and Suspended-Sediment Characteristics of the Susquehanna River

Numerous studies report the water-quality characteristics of the Susquehanna River. A report discussing the variations of the chemical-quality of the Susquehanna River at Harrisburg by Anderson (1963) presents the causes for cross-sectional variation in water quality at this site. Clark, Guide, and Pheiffer (1974) report on a comprehensive nutrient survey performed between Northumberland, Pennsylvania and Conowingo, Maryland and the deposition of phosphorus in the Conowingo and Safe Harbor impoundments. The effects of land use on water quality in the Susquehanna River basin are reported by Lystrom and others (1978). Lang and Grason (1980) give statistical analyses of water-quality data collected at the Susquehanna River at Conowingo, Maryland, as part of the Fall-Line Monitoring Project of the Chesapeake Bay Program.

Various studies also provide information on transport and deposition of sediment in the Susquehanna River and its tributaries near Harrisburg. Williams and George (1968) describe sediment yields of the major tributaries of the Susquehanna using sediment data collected up to 1965. Williams and Reed (1972) report on sediment transported by the Susquehanna River to the head of the Chesapeake Bay.

## Acknowledgments

Support and assistance for this study were given by many individuals. Mr. Lonnie Moyer of the Harrisburg City Engineers office provided information on storm sewer drainage entering the river from the city of Harrisburg. The Pennsylvania Department of Environmental Resources, Bureau of Air Quality Control provided information on the air quality of the basin during the study. The National Oceanic Atmospheric Administration's River Forecasting Section provided prediction of river stage information during high-flow events. The U.S. Geological Survey's Maryland office and the Susquehanna River Basin Commission also helped to coordinate nutrient and pesticide sampling during July 1980. The Susquehanna River Basin Commission provided a compilation of 1980 census data.

## DESCRIPTION OF THE SUSQUEHANNA RIVER BASIN AND SAMPLING SITE

### Location

The Susquehanna River flows southerly through the eastern half of Pennsylvania draining about 24,100 $mi^2$ before reaching Harrisburg, Pa. (fig. 1) and 27,510 $mi^2$ before entering the Chesapeake Bay. Three major tributaries upstream of Harrisburg, the West Branch Susquehanna River, the Juniata River, and the Conodoguinet Creek drain into the river from the central portion of the state.

The sampling site in Harrisburg, Pa., is approximately 69 miles upstream from the mouth of the Susquehanna River and is divided into the west and east channels by City Island. The Walnut Street bridge, located at the sampling site, (fig. 2), joins the communities of Harrisburg, Dauphin County, on the eastern side of the river and Lemoyne, Cumberland County, on the western side. The sampling site cross section is divided into six verticals in the east channel and six verticals in the west channel, each 215 ft apart. Immediately upstream are numerous islands and several bridges which prevent lateral mixing of Harrisburg storm sewer drainage, entering the river from numerous pipes of various diameters in the east channel, with drainage from Conodoguinet Creek in the west channel.

Continuous records of specific conductance, pH, dissolved oxygen, and water temperature were collected for the Susquehanna River at Harrisburg from October 1974 to September 1978 using a water-quality monitor. The intake for the monitor was installed on the east side of City Island approximately 60 ft downstream of the Market Street bridge and projects into the river about 80 ft from the streamgaging station and 1 ft above the bed of the channel.

### Physiography and Geology

Although four physiographic provinces transect the Susquehanna River basin (Fenneman, 1938) only the Appalachian Plateau and the Valley and Ridge are found upstream of the sampling site at Harrisburg (fig. 3). The Blue Ridge and the Piedmont provinces are present just south of Harrisburg. However, drainage from these provinces does not contribute to the water quality at the Harrisburg sampling site.

The Appalachian Plateaus consists of two sections. The first section is the low plateau in the northeast which has well-rounded hills and broad flat valleys. The second section is the high plateau in the southwest characterized by flat-topped mountains and deeply incised narrow stream valleys.

Rocks in the Appalachian Plateau are nearly horizontal with alternating layers of shale, siltstone, sandstone, limestone and bituminous coal. Much of the bituminous coal is found in the unglaciated section of the Appalachian high plateau. Mine drainage from the bituminous coal, often having high sulfate concentrations and low pH, is neutralized and diluted by tributaries draining limestone areas before reaching Harrisburg.

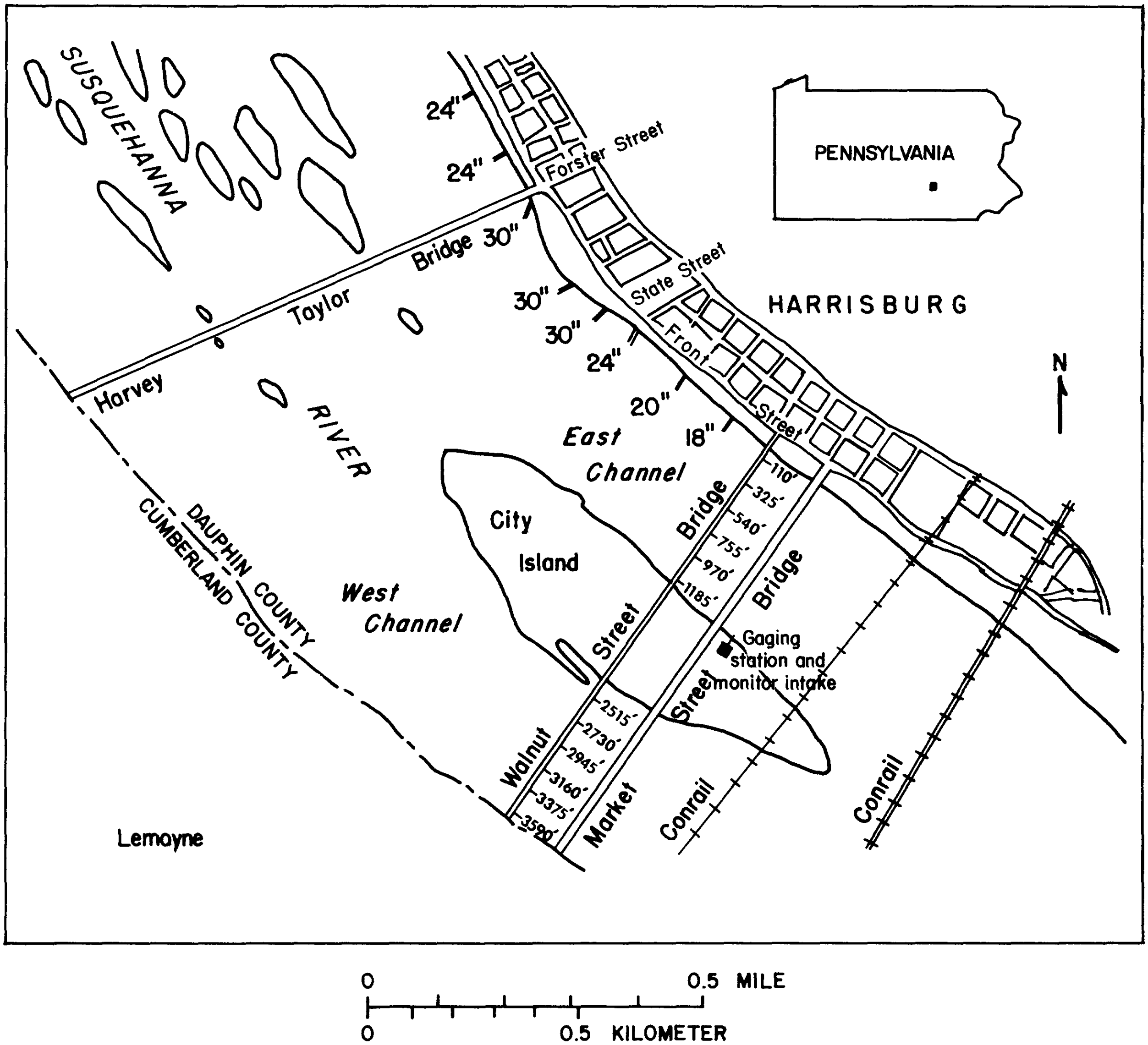


Figure 2.--Sampling verticals on Walnut Street Bridge and storm sewer drainage pipes from Harrisburg, Pennsylvania.

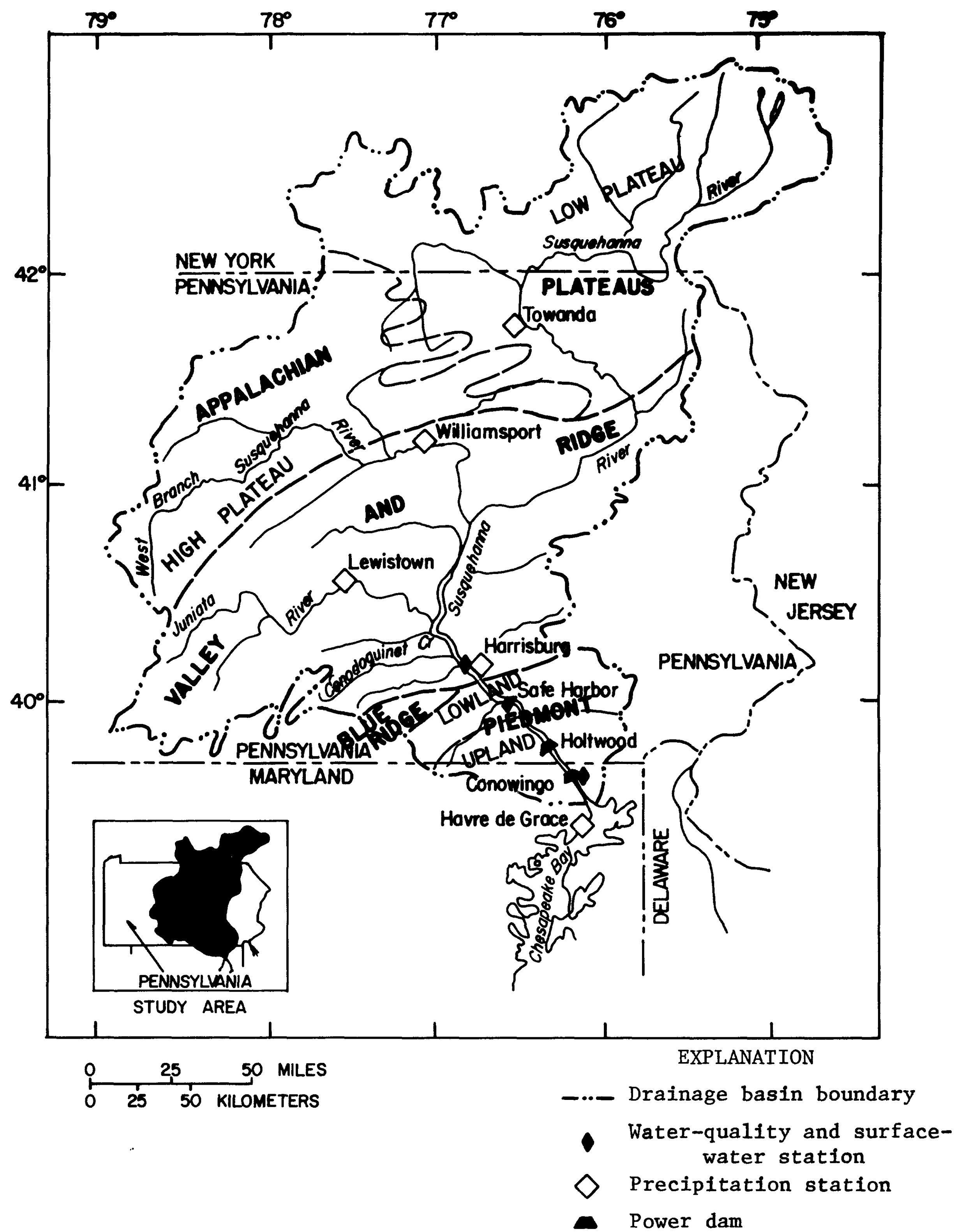


Figure 3.--Physiographic provinces of the Susquehanna River basin (from Fenneman, 1938).

Williams and Reed (1972) report that basins within the Appalachian Plateau province have the widest range of sediment yields with 40 tons/mi$^2$ in the Appalachian low plateau and 66 to 120 tons/mi$^2$ in the forested Appalachian high plateau.

The Valley and Ridge province comprises most of the middle third of the Susquehanna River basin, with steep mountains and ridges separated by broad valleys. The steep ridges are underlain by sandstone or conglomerate and have very shallow soils. The valleys are formed in limestone and shale and have deep well-developed soils. Anthracite fields are found east of the Susquehanna River in the Valley and Ridge province and may contribute drainage with high iron, manganese, aluminum, and sulfate concentrations. Basins within the Valley and Ridge provinces have sediment yields measured from 58 to 280 tons/mi$^2$.

A small part of the Blue Ridge province lies within the basin downstream of the Harrisburg sampling site. Rocks in this province are crystalline and soils are deep and well drained. Sediment yields in this province are believed to be similar to those of the Appalachian high plateau as the area is heavily forested.

The Piedmont province begins 10 miles south of Harrisburg and consists of gently rolling to hilly uplands and lowlands. The rocks in the uplands are crystalline and in the lowlands are limestone, sandstone, and shale. Soils in the Piedmont are deep and well drained. Sediment yields in the Piedmont Lowland range from 180 to 220 tons/mi$^2$, whereas yields in the Piedmont Upland have been measured as high as 715 tons/mi$^2$ for the Pequea Creek basin (Ward and Eckhardt, 1979).

## Climate and Air Quality

The basin's climate reflects temperate conditions that exist in the Middle Atlantic States. Seasonal climatic differences are evident in the basin with air temperature differences of more than 100 degrees Fahrenheit from winter to summer. During the study air temperatures ranged from -4°F (-20°C) to 100°F (38.8°C) with an average of 53°F (11.7°C) while the annual normal is 53.4°F (11.9°C). Freezing air and water temperatures commonly occur during December, January, February, and March. Winds usually come from the west-northwest with average speeds of 7.7 miles per hour. Precipitation is greatest during July with a mean of 3.70 in. and lowest during February with a mean of 2.42 in. during the study, precipitation was about 6 inches below the annual mean of 36.5 inches at Harrisburg. Mean annual concentrations of sulfur dioxide, nitrogen dioxide, and suspended particulates in the Susquehanna air basin measured by the Pennsylvania Department of Environmental Resources, Bureau of Air Quality and Noise Control are 0.01 ppm (parts per million), 0.22 ppm, and 62 ppm, respectively, (Pennsylvania Department of Environmetal Resources Bureau of Air Quality, 1980).

## Land Use

Land use characteristics are expected to shift in the Susquehanna River Basin from cropland to urban and to other nonagricultural uses in the future (Susquehanna River Basin Study, 1970). Land-use statistics for the Susquehanna River basin to Harrisburg for 1964 and projections for 1985 are given in table 1. These figures indicate an expected decrease of 10 percent (2,410 square miles) in cropland while nonagricultural uses such as highways, public buildings, and recreation included under the category Other, will increase 9 percent (2,220 square miles) by 1985.

Table 1.--Land-use characteristics for 1964, and projected figures for 1985 for the Susquehanna River basin to Harrisburg, Pennsylvania

| Land use | Year | Area ($mi^2$) | Percentage of basin area |
|---|---|---|---|
| Cropland | 1964 | 4,800 | 20 |
| | 1985 | 2,390 | 10 |
| Pasture | 1964 | 2,210 | 9 |
| | 1985 | 1,660 | 7 |
| Forest | 1964 | 14,110 | 60 |
| | 1985 | 14,580 | 62 |
| Urban | 1964 | 920 | 4 |
| | 1985 | 1,190 | 5 |
| Other (highways, public buildings, and recreation) | 1964 | 1,600 | 7 |
| | 1985 | 3,820 | 16 |

Although significant changes in land use characteristics are expected, population figures have not reflected these expected changes. In 1960 the population for the entire Susquehanna River basin was 3,179,000 and was expected to reach 5,210,000 by 1990 (Susquehanna River Basin Study Coordinating Committee, 1970). This increase was expected in most part from substantial urban development. However, 1980 census figures indicate the population for the entire Susquehanna River basin reached only 3,740,000 for an increase of about 15 percent. The 1980 population for the Susquehanna River basin to Harrisburg, Pa., was about 2,620,000.

## Hydrologic Conditions

Streamflow in the Susquehanna River is dependent upon precipitation, ground water outflow and regulation by reservoirs. The highest flows throughout the basin normally occur in March, April, and May as warming temperatures and Spring rains cause snow and ice in the northern part of the basin to melt. Floating slush or ice which covers the entire river channel is common from December through March. Average monthly streamflow is lowest in September when average precipitation is low and evapotranspiration is high. Figure 4 shows the monthly mean streamflow for the period of study compared to the entire period of record for Harrisburg. It indicates that below normal flows occurred from April 1980 through January 1981. However, the streamflow for February 1981 of 95,200 ft$^3$/s was 140 percent above the median monthly flow for February of 39,700 ft$^3$/s.

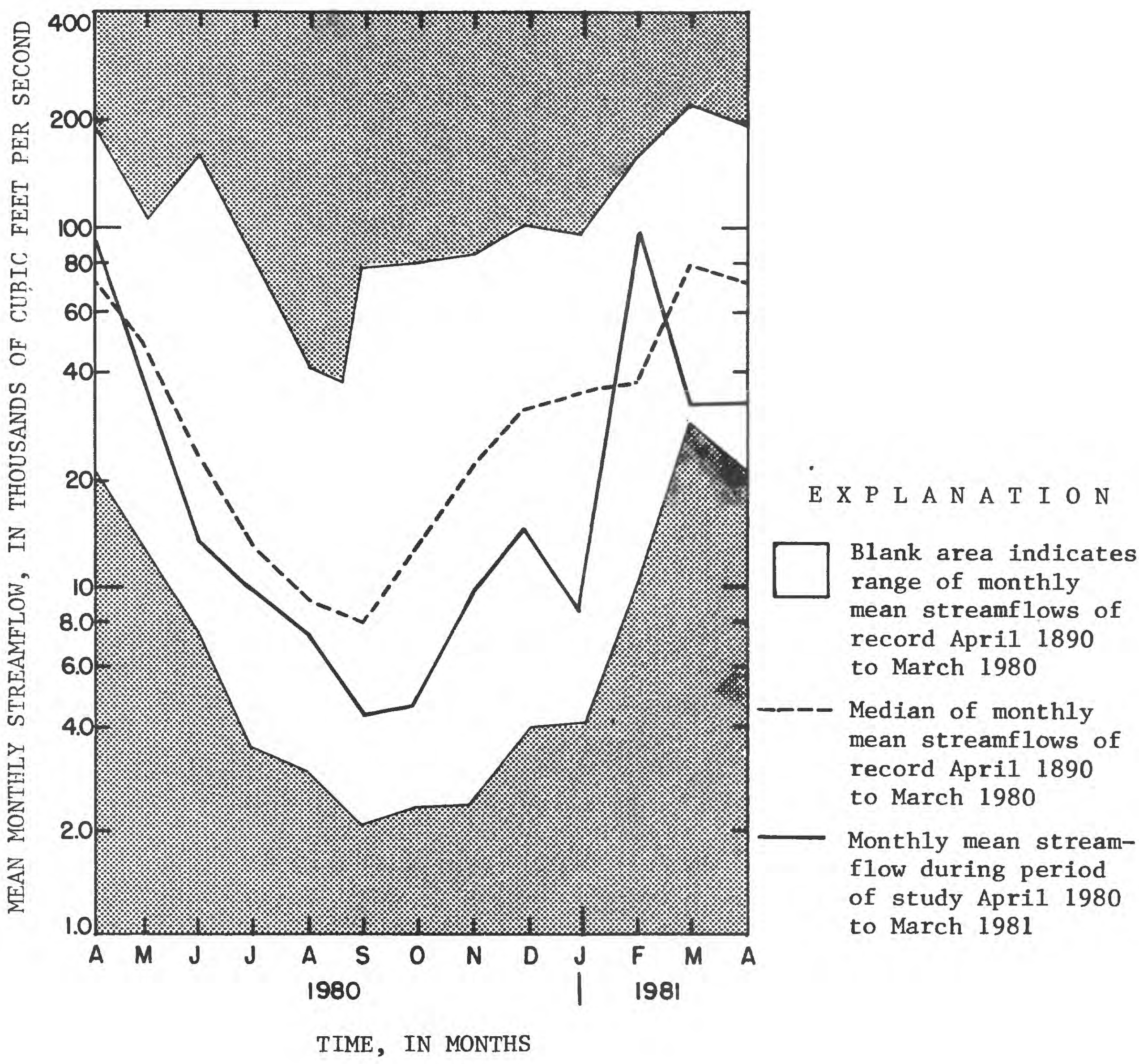


Figure 4.--Monthly mean streamflow for period of study, April 1980 to March 1981, and streamflow ranges for period April 1890 to March 1980.

## DATA COLLECTION AND METHODOLOGY

### Precipitation Data

Precipitation data tabulated from National Oceanic and Atmospheric Administration Climatological Data reports were used to determine the percentage difference from the normal precipitation for the period April 1980 to March 1981 at Harrisburg. Susquehanna River basin values are based on averages determined from data collected at over 100 stations. Climatological data for four stations, Harrisburg (southcentral), Lewistown (southwest), Williamsport (northwest), and Towanda (northeast), were used to identify areas where most precipitation occurred in the Susquehanna River basin for each high-flow event during the study.

### Streamflow Data

Ninety years of streamflow data (1890 to 1980) are available for the Susquehanna River at Harrisburg. Streamflow data for the period are published in Water Resources Data for Pennsylvania, Volume 2 and can be obtained from the U.S. Geological Survey, Harrisburg, Pa. The gaging station (figs. 5-6), about 60 ft downstream from the Market Street Bridge on the east bank of City Island, is equipped with an analog digital stage recorder and a continuous strip-chart stage recorder. Stage-discharge relationships for the period of study were defined by streamflow measurements from the Walnut Street Bridge made at various stages and by ice measurements made approximately 100 ft upstream from the Walnut Street bridge (fig. 7).

Stage-discharge relationships were used to obtain instantaneous streamflow values when water-quality samples were collected. Streamflow values were then used to compute instantaneous chemical constituent discharges.

A streamflow-duration curve was plotted to determine the percentage of time a particular streamflow value was equalled or exceeded. Mean streamflow for the period of study was then computed as the average of the 5 percent increments of the flow-duration table.

### Water-Quality Data

Water-quality samples were collected from March 21, 1980 to March 31, 1981 (figs.8-9) and were coordinated with ongoing data collection for the U.S. Geological Survey National Stream Quality Accounting Network. Water quality data are published in Water Resources Data for Pennsylvania, Volume 2. Depth-integrated samples were collected at the twelve verticals shown in figure 2, and composited using the equal-width increment sampling procedure (Guy and Norman, 1970), and analyzed for 79 chemical and physical constituents. The twelve verticals were selected so that representative samples of the entire river could be collected in a minimum of time during rapidly changing stages. Dissolved oxygen and water temperature values were measured at a location about 18 inches above the streambed and 600 ft from the east edge (Harrisburg side) of the Walnut Street Bridge. The frequency of sample collection and total number of samples for each constituent are listed in table 2. Analyses for additional constituents were included in the National Stream Quality Accounting Network.

Figure 5.--Susquehanna River at Harrisburg, Pa. gaging station located on City Island.

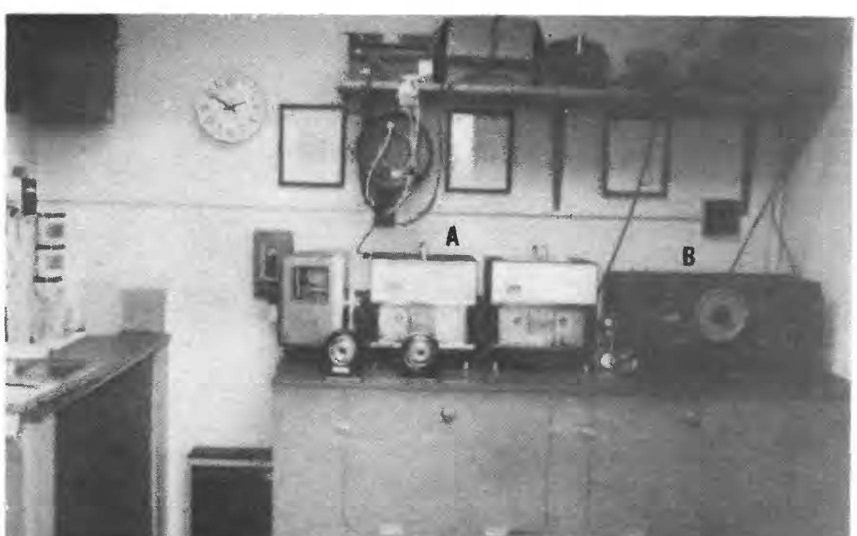


Figure 6.--Susquehanna River at Harrisburg, Pa. gaging station equipped with (A) analog digital stage recorder, and (B) a continuous strip-chart recorder.

Figure 7.--Streamflow measurement on January 19, 1981 when ice covered entire channel of Susquehanna River at Harrisburg.

Figure 8.--Depth-integrated sampling from Walnut Street Bridge on April 1, 1980.

Figure 9.--Depth-integrated sampling just upstream from Walnut Street Bridge during period of full ice cover on January 19, 1981.

Table 2.--Characteristics, frequency of collection, and total number of samples collected March 21, 1980 to March 31, 1981

| Characteristics | Frequency of collection [B, biweekly; W, weekly; M, monthly; S, storm] | Total number of samples collected | |
|---|---|---|---|
| | | Composite | Single vertical |
| **Physical parameters** | | | |
| Acidity (mg/L as $CaCO_3$) | W,S | 72 | 0 |
| Alkalinity (mg/L as $CaCO_3$) | W,S | 71 | 0 |
| Dissolved oxygen (mg/L) | W,S | 0 | 77 |
| pH (units) | W,S | 80 | 0 |
| Specific conductance (umhos/cm at 25°C) | W,S | 80 | 234 |
| Temperature (°C) | W,S | 0 | 80 |
| Turbidity (NTU) 1/ | W,S | 80 | 234 |
| Suspended sediment (mg/L) | W,S | 80 | 234 |
| **Nutrients and phytoplankton (mg/L except as noted)** | | | |
| Nitrogen, total | W,S | 80 | 60 |
| Nitrogen, dissolved | W,S | 80 | 24 |
| Nitrite, total | W,S | 80 | 60 |
| Nitrite, dissolved | W,S | 80 | 24 |
| Nitrate, total | W,S | 80 | 60 |
| Nitrate, dissolved | W,S | 80 | 24 |
| Nitrogen, Kjeldahl, total | W,S | 80 | 60 |
| Nitrogen, Kjeldahl, dissolved | W,S | 80 | 24 |
| Nitrogen, ammonia, total | W,S | 80 | 60 |
| Nitrogen, ammonia, dissolved | W,S | 80 | 24 |
| Phosphorus, total | W,S | 80 | 60 |
| Phosphorus, dissolved | W,S | 80 | 24 |
| Phosphorus, orthophosphate, total | W,S | 80 | 60 |
| Phosphorus, orthophosphate, dissolved | W,S | 80 | 24 |
| **Nutrients and Phytoplankton (mg/L except as noted)** | | | |
| Carbon, organic, total | S | 0 | 36 |
| Carbon, organic, dissolved | B,S | 57 | 0 |
| Carbon, organic, suspended | B,S | 55 | 0 |
| Carbon, inorganic, dissolved | B | 22 | 0 |
| Chlorophyl *a*, phytoplankton (µg/L) | B,S | 54 | 0 |
| Chlorophyl *b*, phytoplankton (µg/L) | B,S | 54 | 0 |

1/ Nephelometric turbidity unit.

Table 2.--Characteristics, frequency of collection, and total number of samples collected March 21, 1980 to March 31, 1981--(Continued)

| Characteristics | Frequency of collection [B,biweekly; W,weekly; M,monthly; S,storm] | Total number of samples collected | |
|---|---|---|---|
| | | Composite | Single vertical |
| Trace metals (µg/L) | | | |
| Aluminum, total | M,S | 50 | 36 |
| Aluminum, dissolved | M,S | 47 | 0 |
| Cadmium, total | M,S | 50 | 36 |
| Chromium, total | M,S | 50 | 36 |
| Copper, total | M,S | 50 | 36 |
| Iron, total | M,S | 56 | 36 |
| Iron, dissolved | M,S | 54 | 0 |
| Lead, total | M,S | 49 | 36 |
| Manganese, total | M,S | 56 | 36 |
| Manganese, dissolved | M,S | 54 | 0 |
| Mercury, total | M,S | 46 | 36 |
| Nickel, total | M,S | 50 | 36 |
| Zinc, total | M,S | 50 | 36 |
| Major ions (mg/L) | | | |
| Calcium | M,S | 50 | 0 |
| Magnesium | M,S | 50 | 0 |
| Sodium | M,S | 50 | 0 |
| Potassium | M,S | 50 | 0 |
| Chloride | M,S | 51 | 0 |
| Fluroide | M,S | 51 | 0 |
| Silica | M,S | 50 | 0 |
| Sulfate | M,S | 37 | 0 |
| Dissolved solids residue at 180°C | M,S | 49 | 0 |
| Pesticides | | | |
| (a) Herbicides (µg/L) | | | |
| Ametryne, total | M,S | 49 | 0 |
| Atratone, total | M,S | 49 | 0 |
| Atrazine, total | M,S | 49 | 0 |
| Cyanazine, total | M,S | 49 | 0 |
| Cyprazine, total | M,S | 49 | 0 |
| Prometone, total | M,S | 49 | 0 |
| Prometryne, total | M,S | 49 | 0 |
| Propazine | M,S | 49 | 0 |

Table 2.--Characteristics, frequency of collection, and total number of samples collected March 21, 1980 to March 31, 1981--(Continued)

| Characteristics | Frequency of collection [B,biweekly; W,weekly; M,monthly; S,storm] | Total number of samples collected: Composite | Total number of samples collected: Single vertical |
|---|---|---|---|
| Pesticides | | | |
| (a) Herbicides (μg/L) | | | |
| Simazine, total | M,S | 49 | 0 |
| Simetone, total | M,S | 49 | 0 |
| Simetryne, total | M,S | 49 | 0 |
| 2,4-D, total | M,S | 29 | 0 |
| 2,4-DP, total | M,S | 49 | 0 |
| 2,4,5-T, total | M,S | 29 | 0 |
| Silvex, total | M,S | 29 | 0 |
| (b) Insecticides (μg/L) | | | |
| Aldrin, total | M,S | 31 | 0 |
| Chlordane, total | M,S | 31 | 0 |
| DDD, total | M,S | 31 | 0 |
| DDE, total | M,S | 31 | 0 |
| DDT, total | M,S | 31 | 0 |
| Dieldrin, total | M,S | 31 | 0 |
| Endosulfan, total | M,S | 30 | 0 |
| Endrin, total | M,S | 31 | 0 |
| Heptachlor, total | M,S | 31 | 0 |
| Heptachlor epoxide, total | M,S | 31 | 0 |
| Pesticides | | | |
| (b) Insecticides (μg/L) | | | |
| Lindane, total | M,S | 31 | 0 |
| Mirex, total | M,S | 30 | 0 |
| Perthane, total | M,S | 30 | 0 |
| Toxaphene, total | M,S | 31 | 0 |
| Polychlorinated biphenyls, total | M,S | 31 | 0 |
| Polychlorindated napthalenes, total | M,S | 30 | 0 |

Samples were collected weekly during base-flow conditions and at selected stages during five storms to develop transport curves for selected constituents. Storms were selected whenever possible so that seasonal characterizations of pesticide concentrations could be made. Additional samples were collected at each of the twelve verticals and analyzed separately to determine the cross-sectional variation of suspended sediment, specific conductance, total nitrogen, phosphorus, carbon, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, and zinc at high flow conditions.

All water-quality samples were analyzed or preserved for analysis immediately after collection in the field. Field analyses included measurements of water temperature, pH, dissolved oxygen, specific conductance, alkalinity, and acidity. Samples analyzed for dissolved constituents were filtered in the field using a 0.45 micron membrane filter mounted in a peristaltic filter assembly. Samples for dissolved organic carbon were filtered through a 0.45 micron silver filter in a stainless steel pressure filtration unit. Samples requiring shipment to the U.S. Geological Survey Central Laboratory were packed on ice immediately after collection and kept at 4°C until analysis were completed.

Analysis for inorganics, organic carbon, pesticides, and phytoplankton were done in the U.S. Geological Survey Central Laboratory in Doraville, Georgia. Inorganic constituents were determined by procedures given by Skougstad and others (1979). Organic carbon and pesticide analysis were determined by methods described by Goerlitz and Brown (1972). Phytoplankton concentrations were determined using methods described by Greeson and others (1977) and (1979). Suspended-sediment analyses were done in the U.S. Geological Survey Sediment Laboratory in Harrisburg, Pa., by methods described by Guy (1969).

Water-quality data were analyzed using the computer package, Statistical Analysis System (Helwig, 1978). Basic univariate statistics, including maximum, minimum, and mean, were calculated for each water-quality constituent. Test statistics were computed to determine if the date approximated normal distributions. Tests were also done to determine if the means and variances were independent as required for statistical testing. Logarithmic transformation using log (x) or log (x+1) was performed to normalize the data and to create independent relationships between the means and variances. Chemical constituent hydrographs were plotted to determine seasonal trends. These plots were then used to show relationships between constituent concentrations and streamflow. Instantaneous constituent loads were calculated using the equation:

$$L = CQF \qquad (1)$$

where

L = constituent discharge in tons per day
C = measured concentration in milligrams per liter
Q = instantaneous streamflow in cubic feet per second
F = 0.0027

Constituent loads were then used to develop a transport curve for each constituent. Linear and geometric regression analyses were performed to determine the best relationship between constituent load and streamflow, suspended-sediment concentration, water temperature, and specific conductance. Transport curves were plotted and the t test performed to assure that the slope of the regression line was significantly different from 0 at the 95 percent confidence level. Regression equations were fitted analytically by the method of least squares. Regression statistics used in this report for constituent loads versus streamflow are listed in table 3. Relationships were considered good if the coefficent of determination ($r^2$) was greater than 0.64. Regressions in table 3 show coefficients of determination ($r^2$) were above 0.80 for 35 of the 40 constituents.

An estimated mean load and concentration was calculated as the average of the 5-percent increments of the duration tables using techniques described by Miller (1951) for constituents showing good relationships with streamflow. Table 13 lists the duration intervals used.

Daily, monthly and annual loads for selected chemical constituents were determined by three methods. The first method was to sum the daily constituent loads obtained by the subdivided-day method described by Porterfield (1972) using the U.S. Geological Survey, Wisconsin District's Water-quality loads program, and estimating missing periods of record using hydrograph comparisons and storm transport curves. This method was used only for constituents with sufficient samples to plot hydrographs. The second method was the flow-duration method as outlined by Miller (1951). This method was used for constituents for which transport curves could be developed. The last method was to sum the daily constituent loads computed by substituting the log of the mean daily streamflow into a regression equation relating the log of constituent load to the log of streamflow. This method was used by Lang (1982) to calculate loads for the Susquehanna River at Conowingo, Md station. Therefore, in order to make valid comparisons of data collected at Harrisburg with data from Conowingo the same technique was applied to Harrisburg data.

Duncan's multiple range was used to determine the significance in cross-sectional variation of suspended sediment, nutrient, major ion, and trace metal concentrations.

Daily values for suspended-sediment concentration and discharge were computed using techniques given by Porterfield (1972) (table 14)[2/]

Continuous water temperature, dissolved oxygen, pH and specific conductance data from October 1, 1973 through September 30, 1978 were analyzed to determine periods of greatest diel change, or the amount of change within a 24-hour period, and the effects of streamflow conditions on these parameters. Selected periods were then plotted and streamflow conditions for each period were identified.

2/ Table 14 at back of report (page 87).

Table 3.--Regression statistics for constituent loads versus streamflow

| Dependent variable (log of constituent load) | Intercept | Slope | Coefficient of determination ($r^2$) | Standard error of estimate (base e log units) |
|---|---|---|---|---|
| Aluminum, dissolved (load+1) | -2.2194 | 0.6503 | 0.82 | 0.174 |
| Aluminum, total (load+1) | -6.3757 | 1.7704 | .85 | .431 |
| Calcium, dissolved (load+1) | .2483 | .6700 | .98 | .052 |
| Carbon, organic dissolved (load) | -2.3868 | 1.0660 | .89 | .225 |
| Carbon, organic suspended (load) | -3.0318 | 1.1261 | .81 | .320 |
| Chloride, dissolved (load) | - .2966 | .7239 | .94 | .110 |
| Chromium, total (load+1) | -2.2899 | .6047 | .83 | .161 |
| Copper, total (load) | -6.2676 | 1.3530 | .93 | .220 |
| Iron, dissolved (load+1) | -2.9450 | .8503 | .83 | .230 |
| Iron, total (load+1) | -6.1444 | 1.8238 | .97 | .206 |
| Lead, total (load+1) | -2.9488 | .7403 | .66 | .311 |
| Magnesium, dissolved (load) | - .0151 | .6065 | .98 | .054 |
| Manganese, dissolved (load+1) | -3.9162 | 1.0778 | .88 | .241 |
| Manganese, total (load+1) | -4.6063 | 1.3400 | .91 | .252 |
| Mercury, total (load+1) | - .0581 | .0147*(T=14.73) | .83 | .004 |
| Nickel, total (load+1) | -2.7483 | .6065 | .79 | .212 |
| Nitrogen, ammonia dissolved as N (load+1) | -3.3431 | 1.0778 | .78 | .295 |
| Nitrogen, ammonia total as N (load+1) | -3.3984 | 1.3400 | .86 | .238 |
| Nitrogen, ammonia + organic dissolved as N (load) | -3.6762 | .0147*(T=27.97) | .91 | .211 |
| Nitrogen, ammonia + organic total as N (load) | -3.7086 | .7034 | .93 | .201 |
| Nitrogen, nitrate dissolved as N (load) | -3.9623 | .9228 | .91 | .250 |

* Slope determined to be significantly different from zero at 95 percent confidence level using t test.

Table 3.--Regression statistics for constituent loads versus streamflow--(Continued)

| Dependent variable (log of constituent load) | Intercept | Slope | Coefficient of determination ($r^2$) | Standard error of estimate (base e log units) |
|---|---|---|---|---|
| Nitrogen, nitrate total as N (load) | -3.9621 | 0.9603 | 0.92 | 0.236 |
| Nitrogen, nitrite dissolved as N (load+1) | -1.8842 | 1.1109 | .88 | .115 |
| Nitrogen, nitrite total as N (load+1) | -2.2456 | 1.1974 | .85 | .152 |
| Nitrogen, nitrate + nitrite dissolved as N (load) | -3.7868 | 1.2457 | .89 | .268 |
| Nitrogen, nitrate + nitrite total as N (load) | -3.9282 | 1.2842 | .92 | .232 |
| Nitrogen, organic dissolved as N (load+1) | -3.0604 | .9513 | .76 | .320 |
| Nitrogen, organic total as N (load+1) | -3.5040 | 1.1418 | .91 | .224 |
| Nitrogen, dissolved as N (load) | -3.5023 | 1.2162 | .95 | .167 |
| Nitrogen, total as N (load) | -3.4280 | 1.2285 | .97 | .139 |
| Phosphorus, dissolved as P (load+1) | -2.3112 | .6247 | .80 | .189 |
| Phosphorus, total as P (load+1) | -4.2296 | 1.1619 | .88 | .261 |
| Potassium, dissolved (load) | -1.8388 | .8919 | .97 | .090 |
| Sediment, suspended (load) | -5.7885 | 2.0399 | .93 | .332 |
| Silica, dissolved (load+1) | -4.5935 | 1.5170 | .93 | .246 |
| Sodium, dissolved (load) | - .1915 | .6575 | .95 | .086 |
| Solids, dissolved residue at 180°C (load) | .9006 | .6955 | .96 | .072 |
| Sulfate, dissolved (load) | .8236 | .6031 | .98 | .056 |
| Zinc, total (load) | -5.5275 | 1.3199 | .88 | .281 |

## RESULTS

### Precipitation

Precipitation records shown in table 4 for the Susquehanna River basin from Harrisburg indicate a wide range in total monthly precipitation during the study period. Total monthly precipitation ranged from 0.53 in. in January 1981 to 5.41 in. in February 1981. Total precipitation during the study period was approximately 6.0 in., or 16 percent, below the mean annual precipitation. Monthly precipitation was more than 1.0 in. below normal in May, August, September, and December 1980 and January and March 1981; no storm samples were collected from May 5 to November 24, 1980. The month of February 1981 was 133 percent wetter than normal, and 16 high-flow samples were collected during two storms that month.

The total precipitation during each storm varied across the Susquehanna River basin with the northwest portion of the basin having the heaviest rainfalls during three of the five storms sampled. Table 5 shows the total amount of precipitation for each storm at four stations in the basin. The heaviest precipitation occurred during February 20 to March 2, 1981. Precipitation for this storm ranged from 2.00 in. at Towanda in the northeast, to 3.76 in. at Williamsport in the northwest portion of the drainage basin.

### Streamflow

Streamflow in the Susquehanna River at Harrisburg during the study reached a minimum of 3,320 $ft^3/s$ on September 28, 1980 and a maximum of 289,000 $ft^3/s$ on February 25, 1981 (fig.10). The mean daily flow of 26,500 $ft^3/s$ during the study was 77 percent of the average annual flow of 34,500 $ft^3/s$ for Harrisburg.

Low-flow augmentation upstream of Harrisburg has caused recent low flows to be higher than those which occurred several years ago (Armbruster, 1977). Figure 11 shows the flow-duration curves for the Susquehanna River at Harrisburg for the entire period of record and for the period of study. The figure indicates low flows for the period of study are higher than those for the entire period of record, whereas the frequency of occurrence for flows in the medium and low range is much lower for the period of study. High flows and frequency of occurrence of high flows are nearly the same for both periods. Therefore, load calculations using the flow-duration method were based on the April 1980 to March 1981 curve.

Streamflows at which water-quality samples were collected are shown on figures 10 and 11, and indicate samples were collected at flow conditions representative of the entire flow-duration curve and during all seasons of the year.

Table 4.--Precipitation data for Susquehanna River basin upstream from Harrisburg, Pennsylvania tabulated from National Oceanic and Atmospheric Administration Climatological data

| | Basin average precipitation 1980 - 81 (inches) | Basin average for 1951-1980 (inches) | Differences (inches) | Percentage difference |
|---|---|---|---|---|
| April | 4.60 | 3.34 | 1.26 | 38 |
| May | 2.16 | 3.53 | -1.37 | -39 |
| June | 4.02 | 3.72 | .30 | 8 |
| July | 2.83 | 3.64 | - .81 | -22 |
| August | 2.24 | 3.43 | -1.19 | -35 |
| September | 1.90 | 3.48 | -1.58 | -45 |
| October | 3.17 | 2.98 | .19 | 6 |
| November | 2.82 | 3.11 | - .29 | - 9 |
| December | 1.30 | 2.88 | -1.58 | -55 |
| January | .53 | 2.56 | -2.03 | -79 |
| February | 5.41 | 2.32 | 3.09 | 133 |
| March | 1.18 | 3.22 | -2.04 | -63 |
| Total | 32.16 | 38.21 | -6.05 | -16 |

Table 5.--Summary of precipitation, snowfall, and snow on the ground at four National Oceanic and Atmospheric Administration stations in the Susquehanna River basin

| Storm | Dates | Precipitation (inches) | Snowfall (inches) | Snow on ground (inches) | Precipitation (inches) | Snowfall (inches) | Snow on ground (inches) |
|---|---|---|---|---|---|---|---|
| | | Harrisburg (south-central) | | | Lewistown (southwest) | | |
| 1 | March 21-26, 1980 | 2.02 | Trace | --- | 1.56 | --- | --- |
| 2 | April 27-May 5, 1980 | 2.33 | --- | --- | 1.40 | --- | --- |
| 3 | Nov. 24-Dec. 2, 1980 | 2.21 | Trace | --- | 1.29 | --- | --- |
| 4 | Feb. 10-Feb. 18, 1981 | 1.20 | 0.5 | 1 | 1.37 | --- | --- |
| 5 | Feb. 20-March 2, 1981 | 2.90 | Trace | --- | 3.08 | --- | --- |
| | | Williamsport (northwest) | | | Towanda (northeast) | | |
| 1 | March 21-26, 1980 | 2.26 | 0.9 | Trace | 1.21 | 0.5 | 1.0 |
| 2 | April 27-May 5, 1980 | 2.25 | --- | --- | 1.02 | --- | --- |
| 3 | Nov. 24-Dec. 2, 1980 | 1.16 | .4 | 2 | 1.09 | Trace | 2.0 |
| 4 | Feb. 10-Feb. 18, 1981 | 2.75 | Trace | 5 | 1.39 | 5.0 | 7.0 |
| 5 | Feb. 20-March 2, 1981 | 3.76 | --- | --- | 2.00 | --- | --- |

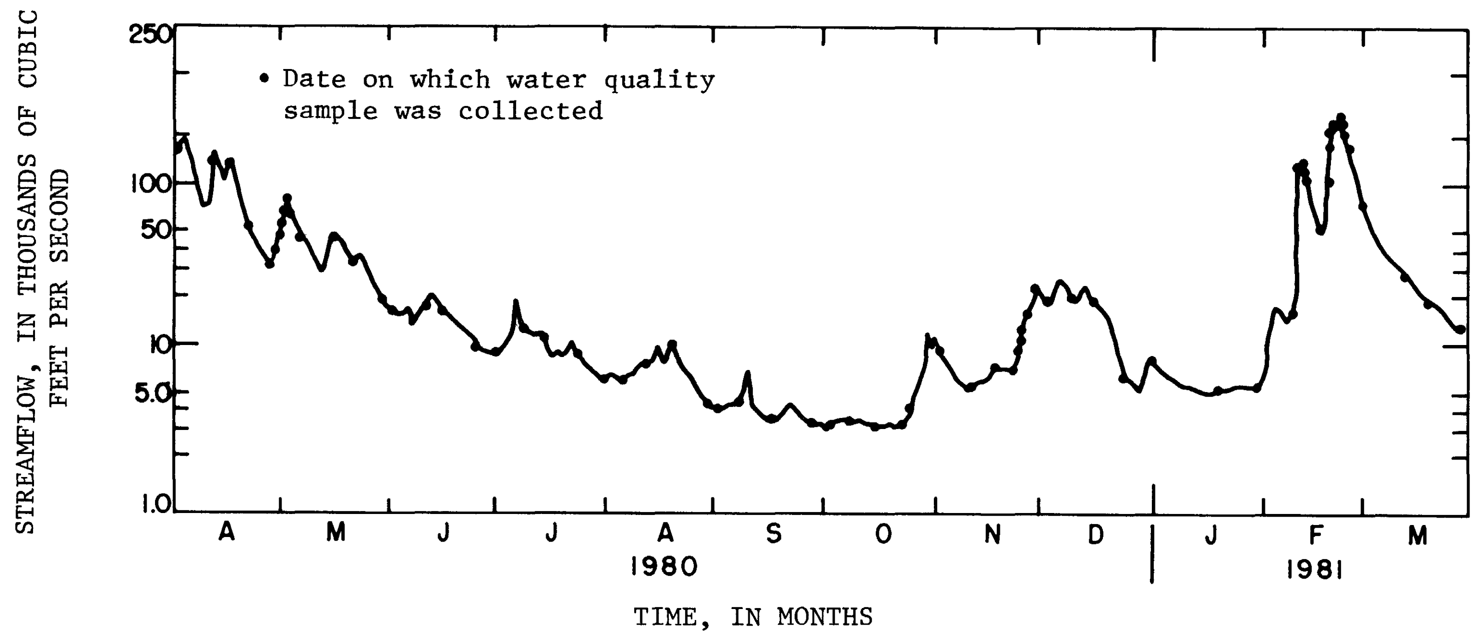


Figure 10.--Daily mean streamflow for April 1980 to March 1981.

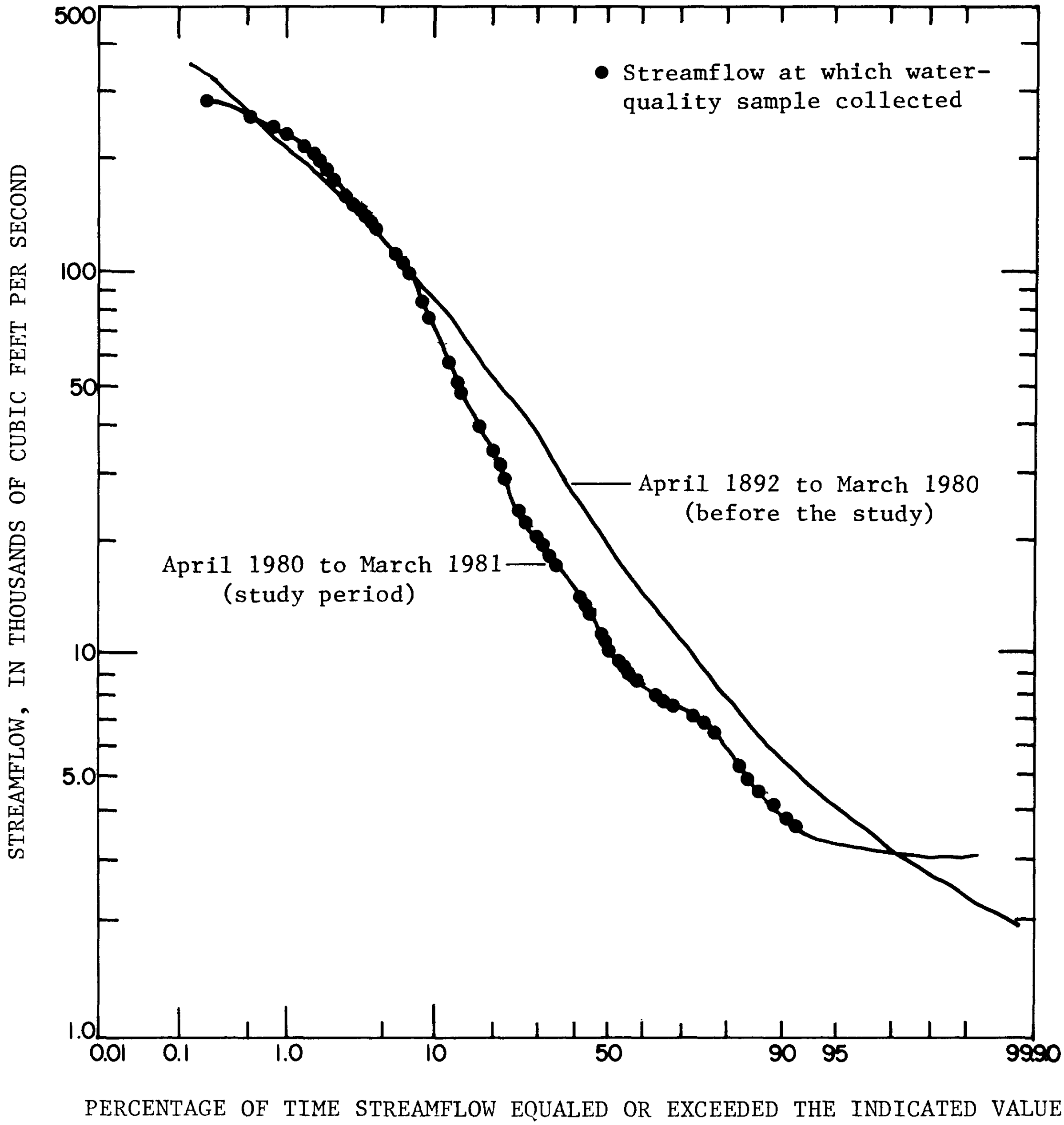


Figure 11.--Flow duration before and during the period April 1, 1980 to March 31, 1981.

## Water Quality

As Feltz (1980) has aptly stated "Traditionally, water quality has been judged by the kinds and concentrations of materials found in solution; however, only a fraction of the chemical load transported by a stream at any given time might be in the dissolved phase, depending on the amount and nature of suspended sediment." Many investigators have established the strong association between nutrients, trace metals, pesticides, and sediment. Thus, in order to properly characterize the quality of the Susquehanna River at Harrisburg, constituent concentrations and loads were determined for both the dissolved and total phases of selected water samples. Concentrations quantify the constituent as its weight per unit volume of water, and loads quantify the total amount of material transported. Tables 6 and 7 list basic statistics for measured concentrations and calculated daily loads for contituents sampled during the study.

Annual loads and differences between the three methods used for calculating these loads are shown in table 8. Differences between the methods were less than five percent for each constituent except nitrite which had differences greater than ten percent. Regression statistics used for methods 2 and 3 are listed in table 3. Coefficients of determination ($r^2$) for the regressions were above 0.80 for 35 of the 40 constituents.

Mean loads used for discussion purposes for the remaining portion of the report are taken from table 13 which lists estimated daily flows and constituent load durations.

### Nutrient and Associated Constituents

Nitrogen and phosphorus are the major nutrients required for algal growth. Free-floating algae obtain nutrients from dissolved inorganic nitrogen and phosphorus. An indication of the amount of algae present in a body of water can be made by measuring the concentrations of photosynthetic pigments chlorophyll *a* and *b* in the water. An increase in chlorophyll *a* and *b* occurs when a sufficient supply of dissolved nitrogen and phosphorus coupled with proper light intensities and water temperatures promote algae growth. It has been suggested in the literature that 0.3 mg/L of inorganic nitrogen and 0.01 mg/L of phosphorus are critical values which, when exceeded, can stimulate excessive growth of algae (McKee and Wolf, 1963; Harms, Darnbush and Anderson, 1974). The U.S. Environmental Protection Agency (1976) recommends that total phosphorus should not exceed 0.05 mg/L in streams in order to prevent biological nuisances.

Nitrogen probably was not a limiting factor for algal growth during most of the study period. Inorganic nitrogen concentrations below the critical value of 0.3 mg/L were measured only during the summer when algal populations were already high, and the dissolved nitrogen load was ten times greater than the total phosphorus load. Total phosphorus was limiting from late spring through the summer except during brief periods of increasing streamflow. During these periods, additional phosphorus-containing particles were transported to the stream by surface erosion from storm runoff and scour of the streambed.

Maximum concentrations for all the nitrogen species occurred during high-flow conditions. The maximum concentration for any of the nitrogen determinations was 1.7 mg/L for total organic nitrogen as N on February 25, 1981. Other nitrogen species also reached maximum concentrations during high-flow conditions in April 1980 and February and March 1981. Differences between total and dissolved nitrite and nitrate nitrogen concentrations were small during high-flows. However, increases in both ammonia and organic nitrogen concentrations appeared to be associated with increases in suspended sediment. Maximum concentrations for total nitrate nitrogen and nitrite nitrogen were 1.6 mg/L and 0.04 mg/L respectively. Nitrite nitrogen concentrations showed the least variation of the nitrogen species, ranging from <0.01 mg/L to 0.04 mg/L (table 6).

The maximum daily load of any of the nitrogen species was 1,260 tons for total organic nitrogen as N, and the minimum load was 16.2 tons for dissolved nitrate nitrogen (table 7). The total nitrogen load transported during the study period was 42,000 tons, or a yield of 1.74 tons/$mi^2$ (5.4 pounds per acre). Seventy-six percent of the nitrogen load was dissolved. Figure 12 shows the composition of the nitrogen load by species and indicates that 63 percent of the nitrogen load, or 26,300 tons, was nitrate. Ninety-six percent of the nitrate nitrogen or about 25,200 tons, was dissolved.

Because most of the nitrogen is dissolved at Harrisburg it is available for transport to the Chesapeake Bay without being trapped by the reservoirs downstream from Harrisburg. Data collected by Lang (1982) for the period April 1980 to March 1981 support this assumption as an additional 3,100 tons of nitrogen was transported downstream from the reservoirs at the Susquehanna River at Conowingo than at Harrisburg, and most of the nitrogen was dissolved.

Mean concentrations for nitrogen species range from 0.01 mg/L for dissolved nitrite nitrogen to 1.00 mg/L for total nitrate nitrogen (table 5). Assuming a mean streamflow of 26,500 $ft^3/s$ and mean load of 90.1 tons/day and 123 tons/day for dissolved nitrogen and total nitrogen, respectively, corresponding mean concentrations of 1.3 mg/L and 1.7 mg/L were equaled or exceeded 22 percent of the time, based on load-duration table 13. The mean daily load of dissolved nitrate nitrogen, 68.7 tons per day, exceeded all other nitrogen species and was equaled or exceeded 21 percent of the time based on load-duration table 13 and shown in figure 13[3/].

Nitrogen concentrations and loads showed direct relationships with streamflow. However, peak concentrations generally occurred prior to streamflow peaks as seen in the storm hydrographs in figure 14. As a result, regressions between nitrogen concentrations and streamflow have poor correlation, and regressions between nitrogen discharges and streamflow generally have good correlation, with coefficients of determination ($r^2$) greater than 0.85 (table 8). Multiple variable regression analyses between constituent concentrations and the independent variables streamflow, suspended-sediment concentration, water temperature, and specific conductance also indicated poor correlation. This may be due to the fact that most of the nitrogen was transported in the dissolved rather than the suspended phase. Another contributing factor is that there were no storms during the summer, which biases the data base.

3/ Table 13 at back of report (page 80).

Table 6.--Ranges and means of water-quality characteristics and constituent concentrations from April 1, 1980 to March 31, 1981

| Characteristic or constituent | Number of Observations | Concentration Minimum | Maximum | Mean |
|---|---|---|---|---|
| Acidity (mg/L as $CaCO_3$) | 72 | 0.0 | 9.0 | 2.0 |
| Aldrin, total (µg/L) | 31 | <.01 | <.01 | <.01 |
| Alkalinity, (mg/L as $CaCO_3$) | 71 | 8.0 | 74 | 38 |
| Aluminum, dissolved (µg/L as Al) | 47 | 10 | 80 | 40* |
| Aluminum, susp. recov. (µg/L as Al) | 41 | 0 | 4,500 | 940 |
| Aluminum, total recov. (µg/L as Al) | 50 | 40 | 7,000 | 940* |
| Ametryne, total (µg/L) | 48 | <.1 | .1 | <.1 |
| Atratone, total (µg/L) | 48 | <.1 | .1 | <.1 |
| Atrazine, total (µg/L) | 48 | <.1 | 3.4 | .2 |
| Arsenic, dissolved (µg/L as As) | 3 | <1 | 1 | <1 |
| Arsenic, susp. (µg/L as As) | 3 | <1 | 1 | <1 |
| Arsenic, total (µg/L as As) | 3 | <1 | 1 | 1 |
| Barium, dissolved (µg/L as Ba) | 3 | <1 | 50 | 30 |
| Barium, total recov. (µg/L as Ba) | 3 | 50 | 50 | 50 |
| Cadmium, dissolved (µg/L as Cd) | 3 | <1 | <1 | <1 |
| Cadmium, susp. recov. (µg/L as Cd) | 3 | <1 | <1 | <1 |
| Cadmium, total recov. (µg/L as Cd) | 50 | <1 | 2 | <1 |
| Calcium, dissolved (mg/L as Ca) | 50 | 8.8 | 45 | 20* |
| Carbon, inorganic, dissolved (mg/L as C) | 22 | 5.1 | 19 | 12 |
| Carbon, organic, dissolved (mg/L as C) | 57 | 1.1 | 14 | 3 |
| Carbon, organic, suspended (mg/L as C) | 55 | .3 | 5.0 | 1.4 |
| Carbon, organic, total (mg/L as C) | 9 | 3.2 | 9.8 | 4.7 |
| Chlor-*a*, Phytoplankton Chromo Fluorum (µg/L) | 54 | .92 | 34.9 | 12.1 |
| Chlor-*b*, Phytoplankton Chromo Fluorum (µg/L) | 54 | .00 | 9.09 | 1.35 |
| Chlordane, total (µg/L) | 31 | <.1 | .1 | <.1 |
| Chloride, dissolved (mg/L as Cl) | 51 | 5.5 | 23 | 9.8* |
| Chromium, dissolved (µg/L as Cr) | 3 | 10 | 10 | 10 |
| Chromium, suspended recov. (µg/L as Cr) | 1 | <10 | <10 | <10 |
| Chromium, total recov. (µg/L as Cr) | 50 | 10 | 40 | 20* |
| Cobalt, dissolved (µg/L as Co) | 3 | <1 | <1 | <1 |
| Cobalt, susp. recov. (µg/L as Co) | 3 | <1 | 1 | 1 |
| Cobalt, total recov. (µg/L as Co) | 3 | <1 | 1 | 1 |
| Coliform, Fecal, 0.7 UM-MF (Cols./100 ML) | 11 | 7 | 240 | 79 |
| Copper, dissolved (µg/L as Cu) | 3 | 1 | 5 | 3 |
| Copper, susp. recov. (µg/L as Cu) | 3 | 0 | 14 | 6 |
| Copper, total recov. (µg/L as Cu) | 50 | 1 | 33 | 10* |
| Cyanazine, total (µg/L) | 48 | <.1 | .1 | <.1 |
| Cyprazine, total (µg/L) | 48 | <.1 | .1 | <.1 |

Table 6.--Ranges and means of water-quality characteristics and constituent concentrations from April 1, 1980 to March 31, 1981--(Continued)

| Characteristic or constituent | Number of Observations | Concentration Minimum | Maximum | Mean |
|---|---|---|---|---|
| DDD, total (μg/L) | 31 | <0.01 | <0.01 | <0.01 |
| DDE, total (μg/L) | 31 | <.01 | <.01 | <.01 |
| DDT, total (μg/L) | 31 | <.01 | <.01 | <.01 |
| Diazinon, total (μg/L) | 31 | <.01 | .02 | <.01 |
| Dieldrin, total (μg/L) | 31 | <.01 | <.01 | <.01 |
| Endosulfan, total (μg/L) | 30 | <.01 | <.01 | <.01 |
| Endrin, total (μg/L) | 31 | <.01 | <.01 | <.01 |
| Ethion, total (μg/L) | 31 | <.01 | <.01 | <.01 |
| Fluoride, dissolved (mg/L as F) | 51 | <.1 | .2 | .1* |
| Hardness, (mg/L as $CaCo_3$) | 50 | 34 | 170 | 78 |
| Heptachlor, total (μg/L) | 31 | <.01 | <.01 | <.01 |
| Heptachlor epoxide, total (μg/L) | 31 | <.01 | <.01 | <.01 |
| Iron, dissolved (μg/L as Fe) | 54 | <10 | 530 | 70* |
| Iron, susp. recov. (μg/L as Fe) | 50 | 20 | 13,000 | 2,800 |
| Iron, total recov. (μg/L as Fe) | 56 | 110 | 13,000 | 3,000* |
| Lead, dissolved (μg/L as Pb) | 3 | <1 | 2 | 1 |
| Lead, suspended recov. (μg/L as Pb) | 3 | <1 | 5 | 2 |
| Lead, total recoverable (μg/L as Pb) | 49 | <1 | 140 | 14* |
| Lindane, total (μg/L) | 31 | < .01 | <.01 | <.01 |
| Magnesium, dissolved (mg/L as Mg) | 50 | 2.6 | 15 | 5.5* |
| Malathion, total (μg/L) | 31 | <.01 | <.01 | <.01 |
| Manganese, dissolved (μg/L as Mn) | 54 | 3 | 390 | 90* |
| Manganese, susp. recov. (μg/L as Mn) | 49 | 10 | 1,700 | 260 |
| Manganese, total recov. (μg/L as Mn) | 56 | 50 | 1,900 | 390* |
| Mercury, total recov. (μg/L as Hg) | 46 | <.10 | 0.2 | .1* |
| Methoxychlor, total (μg/L) | 31 | <.01 | <.01 | <.1 |
| Methyl parathion, total (μg/L) | 31 | <.01 | <.01 | <.01 |
| Methyl trithion, total (μg/L) | 31 | <.01 | <.01 | <.01 |
| Mirex, total (μg/L) | 30 | <.01 | <.01 | <.01 |
| Nickel, total recov. (μg/L as Ni) | 50 | 1 | 52 | 16* |
| Nitrogen, ammonia diss. (mg/L as N) | 80 | <.01 | .36 | .06* |
| Nitrogen, ammonia total (mg/L as N) | 80 | <.01 | .36 | .08* |
| Nitrogen, ammonia + organic dis. (mg/L as N) | 80 | <.01 | .84 | .26 |
| Nitrogen, ammonia + organic total (mg/L as N) | 80 | .19 | 1.8 | .63* |
| Nitrogen, nitrate diss. (mg/L as N) | 80 | .06 | 1.6 | .96* |
| Nitrogen, nitrate total (mg/L as N) | 80 | .06 | 1.6 | 1.0 |
| Nitrogen, nitrite diss. (mg/L as N) | 80 | <.01 | .03 | .01* |
| Nitrogen, nitrite total (mg/L as N) | 80 | <.01 | .04 | .02* |
| Nitrogen, nitrite + nitrate diss. (mg/L as N) | 80 | .06 | 1.6 | .91* |
| Nitrogen, nitrite + nitrate total (mg/L as N) | 80 | .06 | 1.6 | 1.0 |
| Nitrogen, organic diss. (mg/L as N) | 80 | <.01 | .65 | .18* |
| Nitrogen, organic total (mg/L as N) | 80 | .12 | 1.7 | .54* |

Table 6.--Ranges and means of water-quality characteristics and constituent concentrations from April 1, 1980 to March 31, 1981--(Continued)

| Characteristic or constituent | Number of Observations | Concentration Minimum | Maximum | Mean |
|---|---|---|---|---|
| Nitrogen, dissolved (mg/L as N) | 80 | 0.26 | 2.1 | 1.3* |
| Nitrogen, total (mg/L as N) | 80 | .41 | 3.1 | 1.7* |
| Oxygen, dissolved (mg/L) | 77 | 5.2 | 16.8 | 11.0 |
| Parathion, total (μg/L) | 31 | <.01 | <.01 | <.01 |
| PCB, total (μg/L) | 31 | <.1 | <.1 | <.1 |
| Naphthalenes, polychlor total (μg/L) | 30 | <.1 | <.1 | <.1 |
| Perthane, total (μg/L) | 30 | <.01 | <.01 | <.01 |
| pH (units) | 80 | 7.2 | 8.9 | 7.9 |
| Phosphorus, dissolved (mg/L as P) | 80 | <.01 | .08 | .02* |
| Phosphorus, total (mg/L as P) | 80 | .01 | .59 | .12* |
| Phosphorus, orthophosphate diss. (mg/L) | 80 | <.01 | .06 | .01 |
| Phosphorus, orthophosphate total (mg/L) | 80 | <.01 | .11 | .02 |
| Phytoplankton, total (cells per ML) | 7 | 26 | 250,000 | 72,000 |
| Potassium, dissolved (mg/L as K) | 50 | 1.1 | 2.8 | 1.7* |
| Prometone, total (μg/L) | 48 | <.1 | <.1 | <.1 |
| Prometryne, total (μg/L) | 48 | <.1 | <.1 | <.1 |
| Propazine, total (μg/L) | 48 | <.1 | <.1 | <.1* |
| Sediment, suspended (mg/L) | 80 | 1 | 447 | 84 |
| Silica, dissolved (mg/L as $SiO_2$) | 50 | <.1 | 4.9 | 3.0* |
| Silver, dissolved (μg/L as Ag) | 3 | <1 | <1 | <1 |
| Silvex, total (μg/L) | 29 | <.01 | .01 | <.01 |
| Simazine, total (μg/L) | 48 | <.1 | .2 | <.1 |
| Simetone, total (μg/L) | 48 | <.1 | <.1 | <.1 |
| Simetryne, total (μg/L) | 48 | <.1 | <.1 | <.1 |
| Sodium, dissolved (mg/L as Na) | 50 | 3.1 | 16 | 6.2* |
| Solids, residue at 180°C dissolved (mg/L) | 49 | 75 | 280 | 110* |
| Solids, sum of constituents, diss. | 19 | 48 | 252 | 116 |
| Specific conductance (micromhos) | 80 | 101 | 443 | 241 |
| Streamflow, instantaneous ($ft^3/s$) | 80 | 3,320 | 289,000 | 26,500* |
| Streptococci fecal, KF AGAR (Cols./100 Ml) | 11 | 13 | 1000 | 210 |
| Sulfate dissolved (mg/L as $SO_4$) | 57 | 17 | 110 | 37 |
| Temperature, water (Deg C) | 80 | .0 | 29.5 | 10.5 |
| Toxaphene, total (μg/L) | 31 | <.1 | <.1 | <.1 |
| Trithion, total (μg/L) | 31 | <.01 | <.01 | <.01 |
| Turbidity | 80 | .4 | 180 | 26 |
| Zinc, dissolved (μg/L as Zn) | 3 | 4 | 10 | 6 |
| Zinc, susp. recov. (μg/L as Zn) | 2 | 6 | 10 | 8 |
| Zinc, total recov. (μg/L as Zn) | 50 | 10 | 160 | 40* |
| 2,4-D, total (μg/L) | 29 | <.01 | .41 | .11 |
| 2,4-DP, total (μg/L) | 29 | <.01 | .02 | <.01 |
| 2,4,5-T, total (μg/L | 29 | <.01 | <.01 | <.01 |

* Mean value determined from sum of the 5 percent increments of the load-duration table.

Table 7.--Ranges and means of daily water-quality constituent loads from April 1, 1980 to March 31, 1981

| Constituent | Number of Observation | Daily load in tons | | |
|---|---|---|---|---|
| | | Minimum | Maximum | Mean (From load duration table) |
| Aluminum, dissolved | 47 | 0.43 | 26.2 | 2.88 |
| Aluminum, total | 50 | 1.10 | 3,240 | 65.8 |
| Calcium, dissolved | 50 | 360 | 8,200 | 1,400 |
| Carbon, organic dissolved | 57 | 17.7 | 4,910 | 223 |
| Carbon, organic suspended | 55 | 9.88 | 2,620 | 98.0 |
| Chloride, dissolved | 51 | 185 | 5,900 | 700 |
| Chromium, total | 50 | .09 | 29.8 | 1.10 |
| Copper, total | 50 | .02 | 24.6 | .72 |
| Fluoride, dissolved | 51 | <.01 | 74.5 | 7.63 |
| Iron, dissolved | 54 | <.01 | 73.3 | 4.99 |
| Iron, total | 56 | .99 | 6,860 | 211 |
| Lead, total | 49 | <.01 | 104 | .99 |
| Magnesium, dissolved | 50 | 120 | 2,240 | 394 |
| Manganese, dissolved | 54 | .09 | 164 | 6.54 |
| Manganese, total | 56 | .54 | 1,410 | 27.4 |
| Mercury, total | 46 | .00 | .07 | .01 |
| Nickel, total | 50 | .03 | 38.6 | 1.09 |
| Nitrogen, ammonia dissolved (as N) | 80 | <.01 | 108 | 4.23 |
| Nitrogen, ammonia total (as N) | 80 | <.01 | 147 | 5.88 |
| Nitrogen, ammonia + organic dissolved (as N) | 80 | <.01 | 369 | 18.8 |
| Nitrogen, ammonia + organic total (as N) | 80 | 2.90 | 1,340 | 45.4 |
| Nitrogen, nitrate dissolved (as N) | 80 | .65 | 969 | 68.7 |
| Nitrogen, nitrate total (as N) | 80 | .65 | 1,040 | 71.8 |
| Nitrogen, nitrite dissolved (as N) | 80 | <.01 | 16.2 | .90 |
| Nitrogen, nitrite total (as N) | 80 | <.01 | 22.4 | 1.16 |

Table 7.--Ranges and means of daily water-quality constituent loads from April 1, 1980 to March 31, 1981--Continued

| Constituent | Number of Observation | Daily load in tons | | |
|---|---|---|---|---|
| | | Minimum | Maximum | Mean* (From load duration table) |
| Nitrogen, nitrate + nitrite dissolved (as N) | 80 | 0.65 | 891 | 65.0 |
| Nitrogen, nitrate + nitrite total (as N) | 80 | .65 | 1,040 | 72.2 |
| Nitrogen, organic dissolved (as N) | 80 | <.01 | 274 | 12.6 |
| Nitrogen, organic total (as N) | 80 | 2.53 | 1,260 | 38.3 |
| Nitrogen, dissolved (as N) | 80 | 2.84 | 1,190 | 90.1 |
| Nitrogen, total (as N) | 80 | 5.25 | 2,230 | 123 |
| Phosphorus, dissolved (as P) | 80 | <.01 | 44.6 | 1.43 |
| Phosphorus, total (as P) | 80 | .36 | 283 | 8.26 |
| Potassium, dissolved | 50 | 23.0 | 1,190 | 119 |
| Sediment, suspended | 80 | 19.8 | 220,000 | 6,020 |
| Silica, dissolved | 50 | <.01 | 3,580 | 27 |
| Sodium, dissolved | 50 | 131 | 2,900 | 445 |
| Solids, dissolved residue at 180°C | 49 | 1,950 | 43,700 | 8,180 |
| Sulfate, dissolved | 57 | 863 | 14,900 | 2,620 |
| Zinc, total | 50 | .17 | 86.4 | 2.7 |

* Mean value determined from the load-duration table.

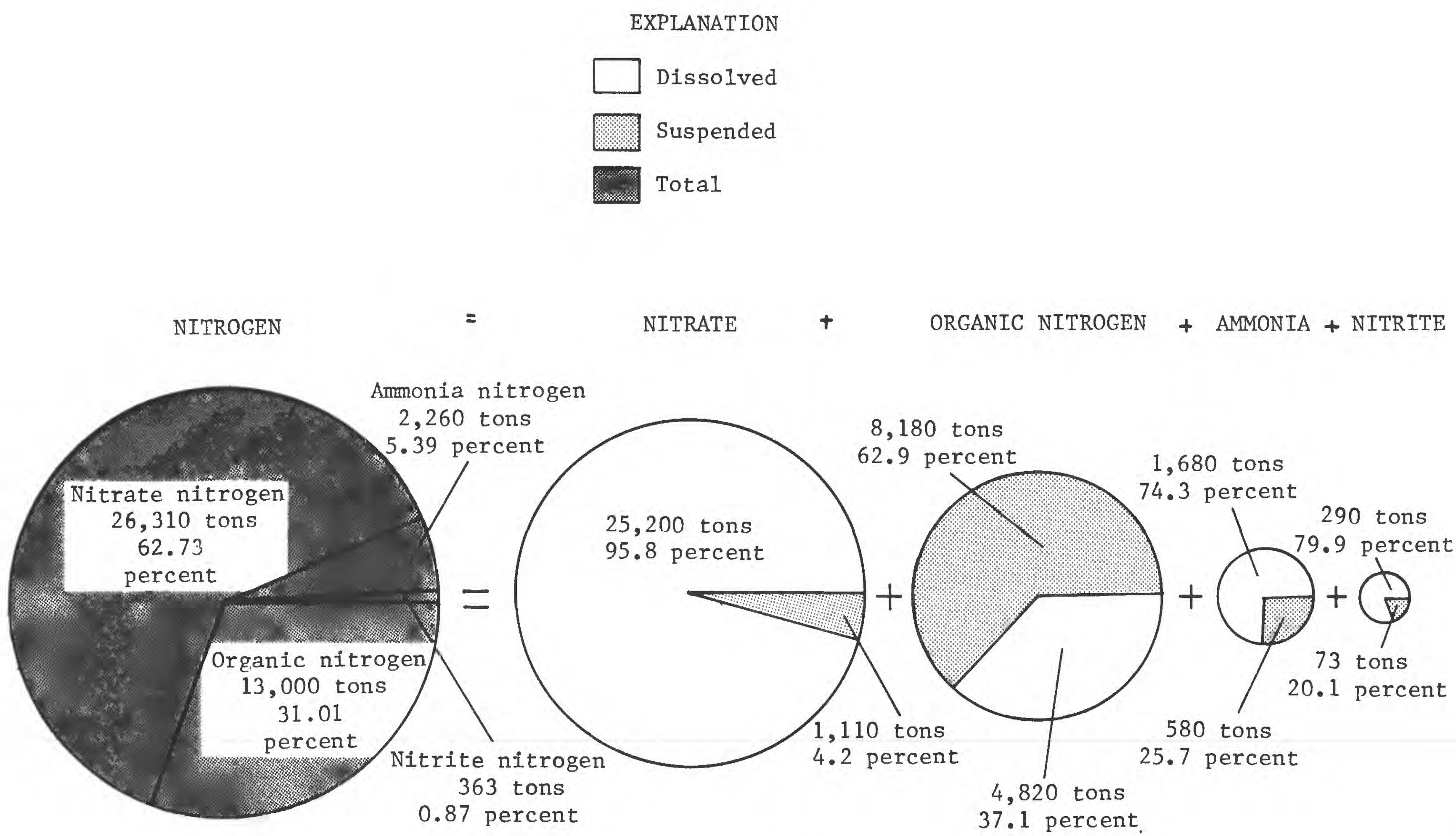


Figure 12.--Nitrogen constituent loads in tons, and percentage of total load, from April 1, 1981 to March 31, 1981.

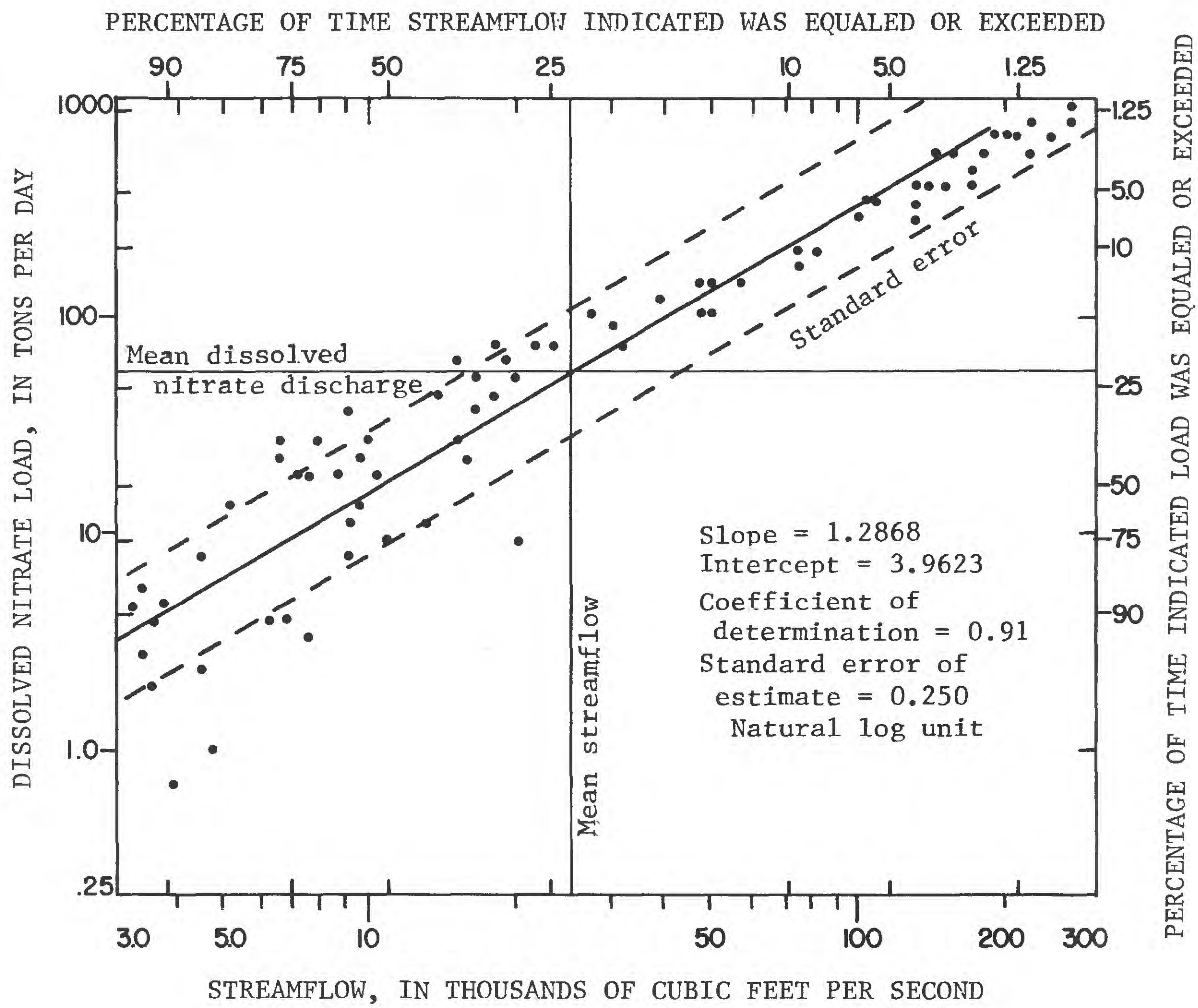


Figure 13.--Dissolved nitrate load as a function of streamflow.

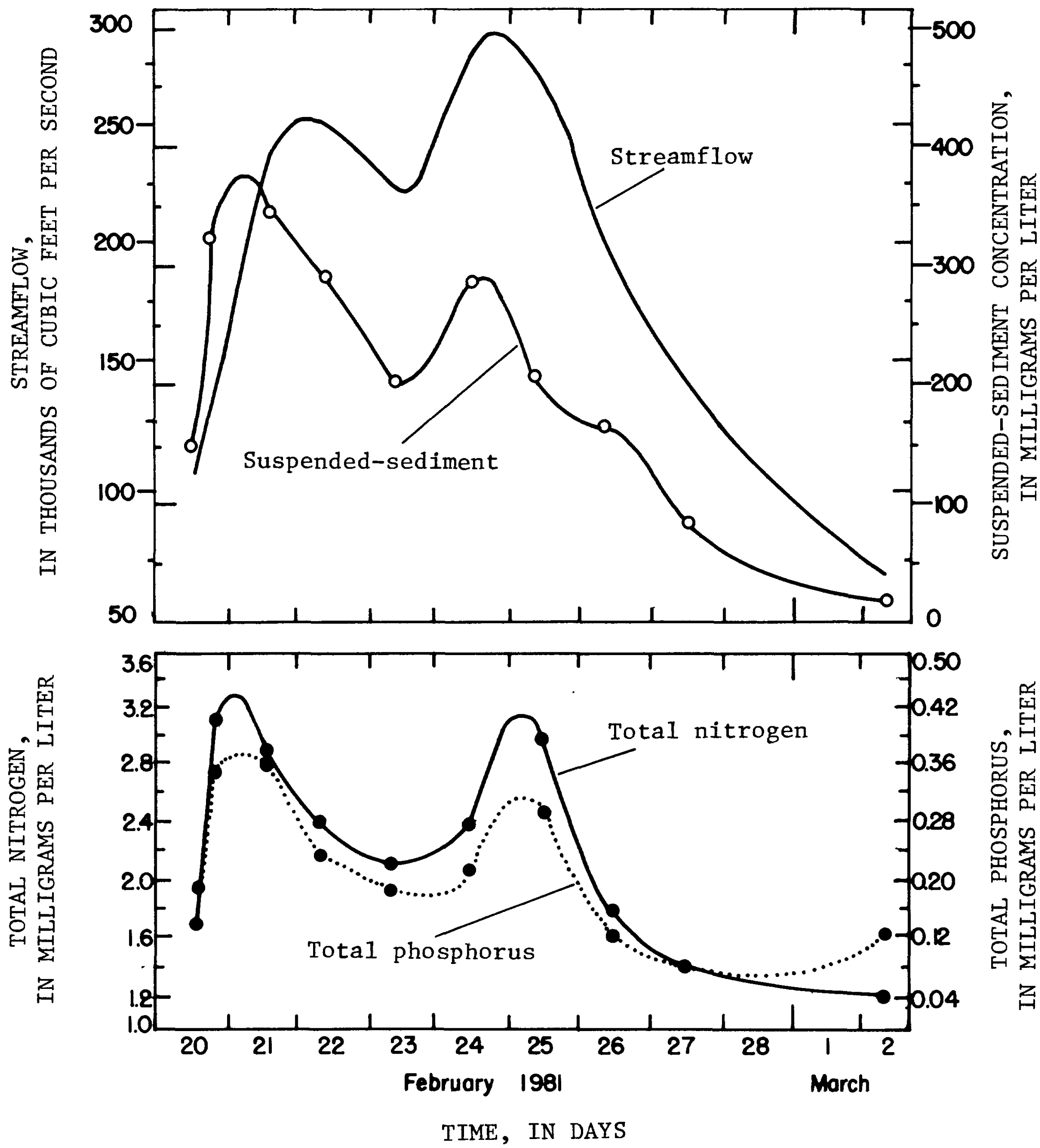


Figure 14.--Streamflow and constituent concentrations from February 20 to March 2, 1981.

Table 8.--Estimated annual loads of water-quality constituents from April 1, 1980 to March 31, 1981

| Constituent | Load, in tons: Method 1 Hydrograph and sub-divided day | Load, in tons: Method 2 Flow duration | Load, in tons: Method 3 Regression equation and mean daily discharge | Percentage difference between: Method 1 and Method 2 | Percentage difference between: Method 1 and Method 3 | Percentage difference between: Method 2 and Method 3 |
|---|---|---|---|---|---|---|
| Aluminum, dissolved | -- | 1,050 | 1,040 | -- | -- | 1 |
| Aluminum, total | -- | 24,000 | 25,300 | -- | -- | 5 |
| Calcium, dissolved | -- | 510,000 | 506,000 | -- | -- | 1 |
| Carbon, organic dissolved | -- | 81,600 | 82,100 | -- | -- | 1 |
| Carbon, organic suspended | -- | 35,800 | 36,100 | -- | -- | 1 |
| Chloride, dissolved | -- | 255,000 | 254,000 | -- | -- | 0 |
| Chromium, total | -- | 401 | 392 | -- | -- | 2 |
| Copper, total | -- | 262 | 267 | -- | -- | 2 |
| Fluoride, dissolved | -- | 2,790 | 2,780 | -- | -- | 0 |
| Iron, dissolved | -- | 1,820 | 1,820 | -- | -- | 0 |
| Iron, total | -- | 76,800 | 81,200 | -- | -- | 5 |
| Lead, total | -- | 360 | 353 | -- | -- | 2 |
| Magnesium, dissolved | -- | 144,000 | 143,000 | -- | -- | 1 |
| Manganese, dissolved | -- | 2,390 | 2,400 | -- | -- | 0 |
| Manganese, total | -- | 9,990 | 10,200 | -- | -- | 2 |
| Mercury, total | -- | 3.46 | 3.26 | -- | -- | 6 |
| Nickel, total | -- | 396 | 390 | -- | -- | 2 |
| Nitrogen, ammonia dissolved (as N) | 1,680 | 1,540 | 1,540 | 8 | 8 | 0 |
| Nitrogen, ammonia total (as N) | 2,260 | 2,150 | 2,150 | 5 | 5 | 0 |
| Nitrogen, ammonia + organic dissolved (as N) | 6,500 | 6,860 | 6,920 | 5 | 6 | 1 |
| Nitrogen, ammonia + organic total (as N) | 15,260 | 16,600 | 16,800 | 8 | 9 | 1 |
| Nitrogen, nitrate dissolved (as N) | 25,200 | 25,100 | 25,600 | 0 | 2 | 2 |
| Nitrogen, nitrate total (as N) | 26,300 | 26,200 | 26,700 | 0 | 1 | 2 |
| Nitrogen, nitrite dissolved (as N) | 290 | 330 | 322 | 12 | 10 | 2 |
| Nitrogen, nitrite total (as N) | 363 | 422 | 413 | 14 | 12 | 2 |
| Nitrogen, nitrate + nitrite dissolved (as N) | 25,500 | 23,700 | 24,100 | 7 | 5 | 2 |

Table 8.--Estimated annual loads of water-quality constituents from April 1, 1980 to March 31, 1981--Continued

| Constituent | Load in tons: Method 1 Hydrograph and sub-divided day | Load in tons: Method 2 Flow duration | Load in tons: Method 3 Regression equation and mean daily discharge | Percentage difference between: Method 1 and Method 2 | Percentage difference between: Method 1 and Method 3 | Percentage difference between: Method 2 and Method 3 |
|---|---|---|---|---|---|---|
| Nitrogen, nitrate + nitrite total (as N) | 26,700 | 26,400 | 26,800 | 1 | 0 | 1 |
| Nitrogen, organic dissolved (as N) | 4,820 | 4,600 | 4,600 | 5 | 5 | 0 |
| Nitrogen, organic total (as N) | 13,000 | 14,000 | 14,100 | 7 | 8 | 1 |
| Nitrogen, dissolved (as N) | 31,900 | 32,900 | 33,300 | 3 | 4 | 1 |
| Nitrogen, total (as N) | 42,000 | 44,700 | 45,400 | 6 | 7 | 2 |
| Phosphorus, dissolved (as P) | 484 | 522 | 512 | 7 | 5 | 2 |
| Phosphorus, total (as P) | 2,930 | 3,010 | 3,040 | 3 | 4 | 1 |
| Phosphorus, orthophosphate dissolved (as P) | 243 | -- | -- | -- | -- | -- |
| Phosphorus, orthophosphate total (as P) | 579 | -- | -- | -- | -- | -- |
| Potassium, dissolved | -- | 43,600 | 43,500 | -- | -- | 0 |
| Sediment, suspended | 2,300,000 | 2,200,000 | 2,360,000 | 4 | 3 | 7 |
| Silica, dissolved | -- | 79,200 | 81,800 | -- | -- | 3 |
| Sodium, dissolved | -- | 163,000 | 161,000 | -- | -- | 1 |
| Solids, dissolved residue at 180°C | -- | 2,990,000 | 2,770,000 | -- | -- | 7 |
| Sulfate, dissolved | -- | 958,000 | 950,000 | -- | -- | 1 |
| Zinc, total | -- | 990 | 1,010 | -- | -- | 2 |

Maximum concentrations measured for phosphorus were 0.59 mg/L for total phosphorus and 0.08 mg/L for dissolved phosphorus on February 13, 1981. Maximum concentrations of total and dissolved orthophosphate phosphorus were 0.11 and 0.06 mg/L, respectively, and were measured on February 23 and February 25, 1981. The maximum load for total phosphorus as P was 285 tons per day as compared to the maximum load of 44.6 tons/day for dissolved phosphorus as P.

The mean concentration of 0.12 mg/L for total phosphorus as P was equaled or exceeded at least 22 percent of the time based on load-duration table 13 and shown in figure 15. It was six times greater than the mean concentration of 0.02 mg/L for dissolved phosphorus (table 5). The mean daily load for total phosphorus as P was 8.26 tons as compared to the mean daily load for dissolved phosphorus as P of 1.43 tons.

The total phosphorus load for the study was 2,930 tons or a yield of 0.12 tons per square mile (0.38 pounds per acre). Eighty-four percent of the phosphorus load or 2,450 tons was suspended, and about 20 percent of the phosphorus load, or 579 tons, was orthophosphate phosphorus. About 58 percent of the orthophosphate load was suspended. It is estimated that nitrogen and phosphorus constitute 0.4 percent and 0.1 percent respectively of the annual suspended-sediment load at Harrisburg.

Unlike nitrogen much of the phosphorus load is suspended and may be trapped by the three reservoirs before reaching the Bay. Results from Lang (1982) support this conclusion as 34 percent less phosphorus was transported downstream at Conowingo than at Harrisburg.

Like nitrogen, phosphorus showed a direct relationship with streamflow but peak concentrations occurred earlier than streamflow peaks (fig. 14) and regressions between phosphorus concentrations and streamflow were poorly correlated. Regression results between phosphorus load and streamflow resulted in coefficient of determinations of 0.80 for dissolved phosphorus and 0.88 for total phosphorus. Although most of the phosphorus transported was suspended, multiple variable regressions did little to improve the statistics obtained between constituent loads and streamflow. Poor relationships resulted for orthophosphate phosphorus concentrations and loads versus streamflow using both the bivariable and multiple variable regression techniques.

Concentrations of chlorophyll *a* and *b* may be influenced by physical factors such as water temperature and ice cover in addition to available nutrients and herbicides in the water. Time-series plots in figure 16 show chlorophyll *a* and *b* concentrations increased from April to July 14, 1980 when measured concentrations peaked at 34.9 and 9.09 μg/L respectively. These excellent growing conditions were due to increased water temperatures and light penetration due to low streamflow conditions. Stream depths were often less than four feet, and mean stream velocities were as low as 0.55 feet per second.

A downward trend in chlorophyll concentration began in September. Immediately prior to this occurrence water temperatures dropped from 28.0°C

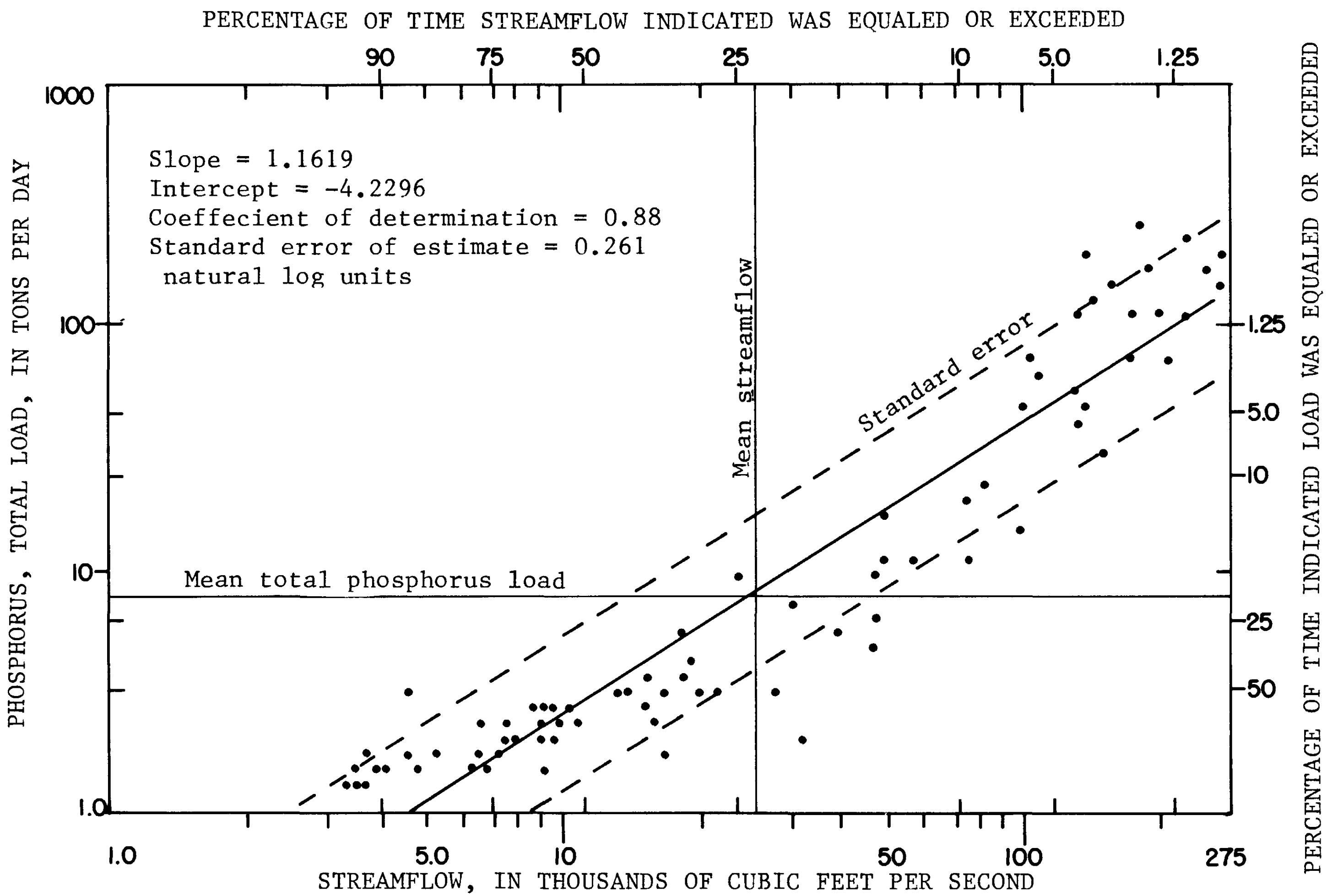


Figure 15.--Total phosphorus load as a function of streamflow.

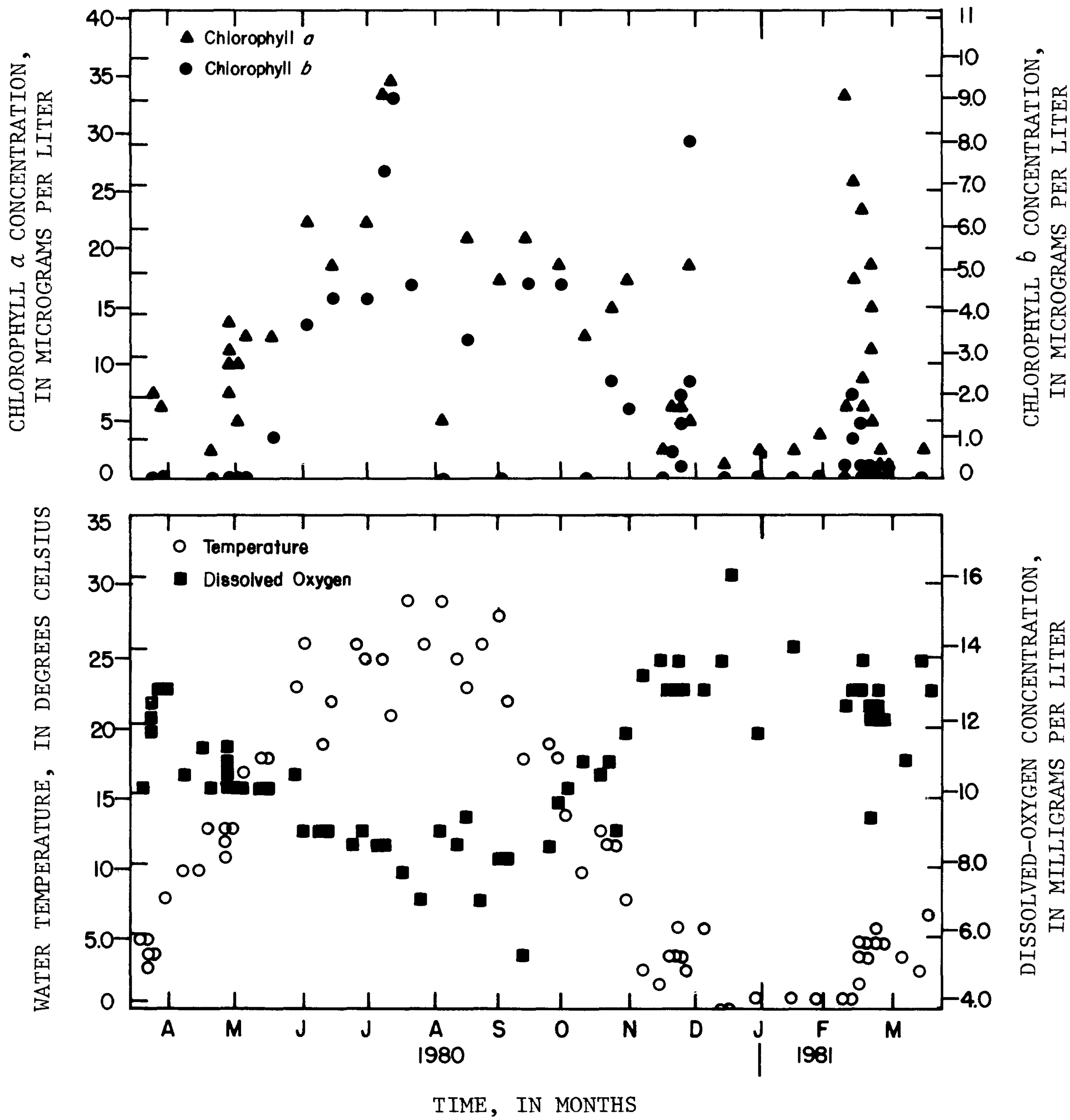


Figure 16.--Time-series of chlorophyll *a* and *b* concentrations, water temperature, and dissolved-oxygen from March 21, 1980 to March 31, 1981.

on September 2, 1980, to 18.0°C on September 16, 1980. Corresponding dissolved-oxygen concentrations decreased from 8.0 mg/L to 5.2 mg/L, which was the low for the period of study. Percent saturation values also decreased during this period from 100 percent on September 2, 1980 to 52 percent on September 16, 1980. Increases in chlorophyll observed in November 1980 and February 1981 were probably due to the flushing and scouring of both phytoplankton and periphyton during periods of rapidly increasing streamflow as chunks of ice moved downstream. Only chlorophyll *a* showed a slight increase in concentration from December 22 to February 12 when ice covered the entire stream channel. This may have resulted from an increase in diatoms in which chlorophyll *b* may be absent altogether or present in very minute quantities (Hill and others, 1967) and which have often been found to be the predominent component of phytoplankton in cold water or under the ice (McCoy, 1978).

## Suspended Sediment

Suspended sediment is the most visible constituent transported in the Susquehanna River and is directly related to the tubidity. The coefficient of determination between suspended-sediment concentration and turbidity for samples collected at Harrisburg is 0.89 (figure 17). Major sources of suspended sediment in the Susquehanna River basin include areas of mining, agriculture, urbanization, and road construction.

Suspended-sediment concentrations ranged from 1 mg/L on July 8, 1980 to 447 mg/L on February 12, 1981. The maximum daily suspended-sediment load was 220,000 tons per day and the minimum was 19.8 tons/day. The total suspended-sediment load transported during the study was 2,300,000 tons which is an annual yield of 95.4 tons/mi$^2$ or 0.15 tons/acre. The suspended-sediment load was 72 percent of the average annual suspended-sediment load of 3,180,000 tons. Lang (1982) reports that 1,270,000 tons of suspended sediment was transported from the Susquehanna River at Conowingo from April 1980 to March 1981. Therefore at least 1,030,000 tons of suspended sediment was trapped in the reservoirs between Harrisburg and the Chesapeake Bay during the study period.

The mean suspended-sediment concentration was 84 mg/L. The mean daily suspended-sediment load was 6,020 tons/day and was equaled or exceeded about 14 percent of the time shown in figure 18. Daily mean suspended-sediment discharges and concentrations determined by the sub-divided day method are listed in table 14.

Suspended-sediment concentration hydrographs were similar to those for the nutrients (fig. 14). Peak concentrations occurred before streamflow peaks and two peaks often occurred during a storm. Regression analyses between suspended-sediment concentration and streamflow were poor. However, the relationship between suspended-sediment load and streamflow was good as the coefficient of determination was 0.93 (table 3 and fig. 18).

A double-mass curve of annual suspended-sediment discharge versus annual streamflow often can be used to show trends in sediment yield and to detect the effects of watershed practices on sediment yield. Searcy and Hardison

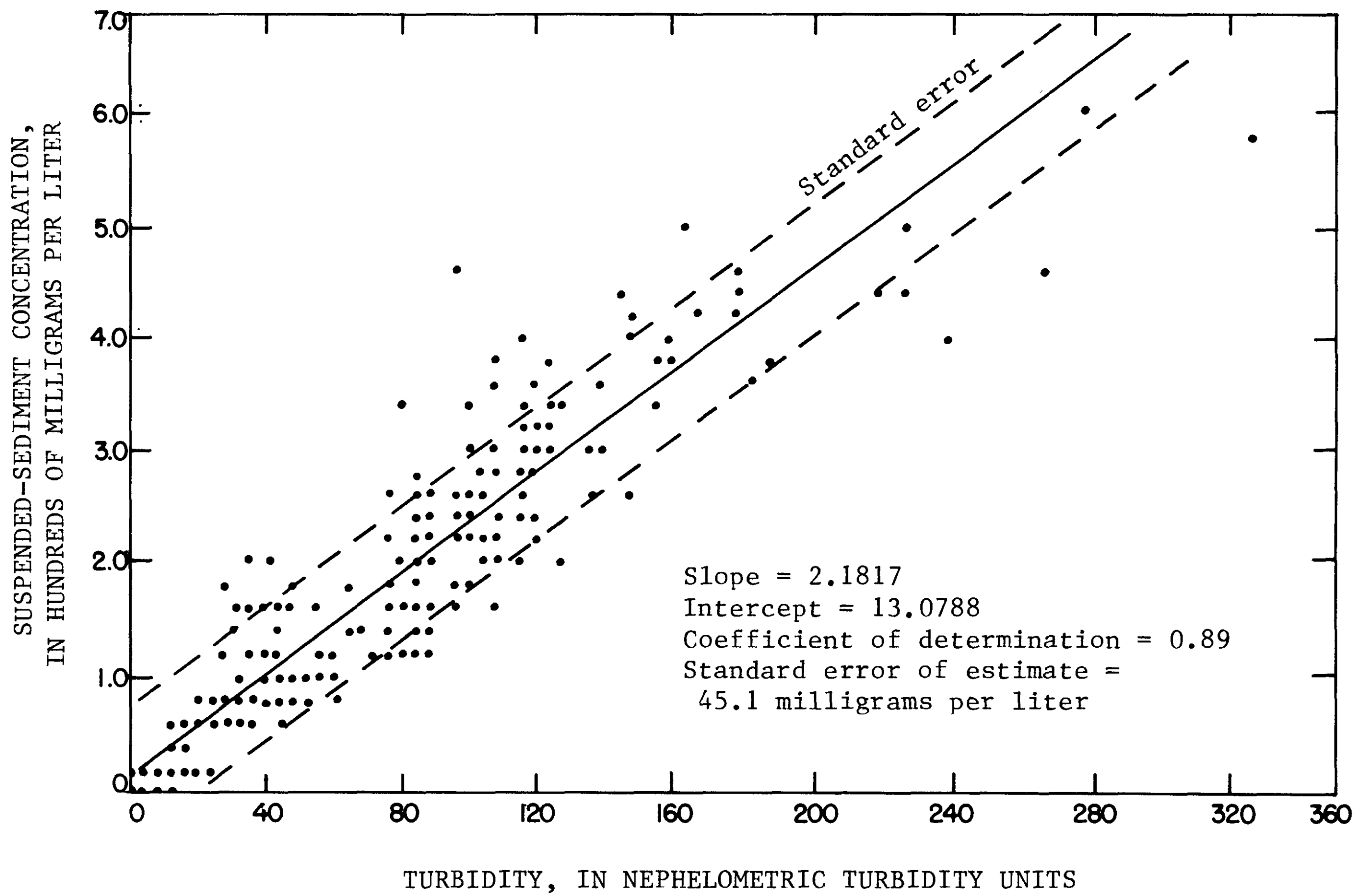


Figure 17.--Suspended-sediment concentration as a function of turbidity.

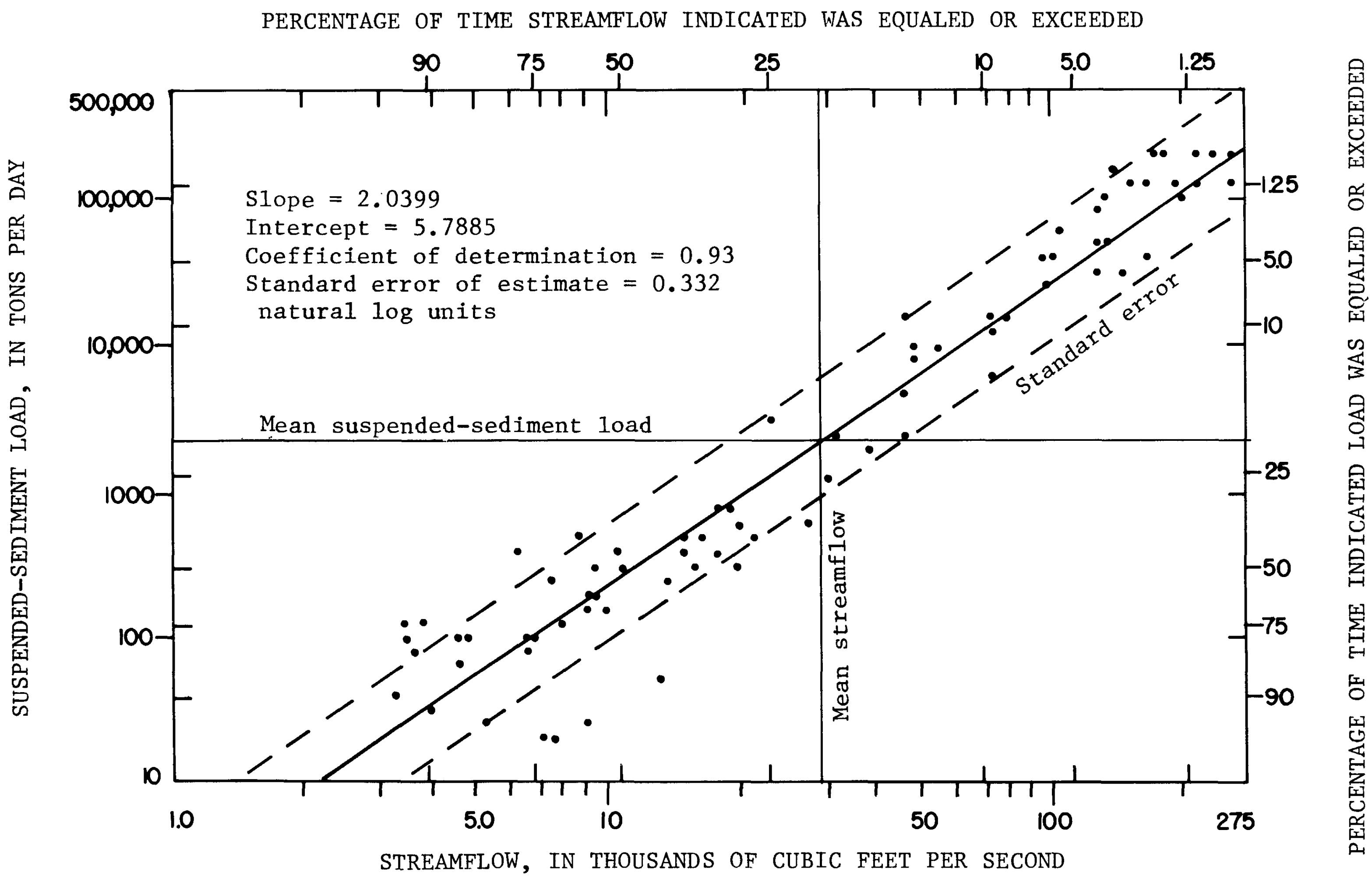


Figure 18.--Suspended-sediment load as a function of streamflow.

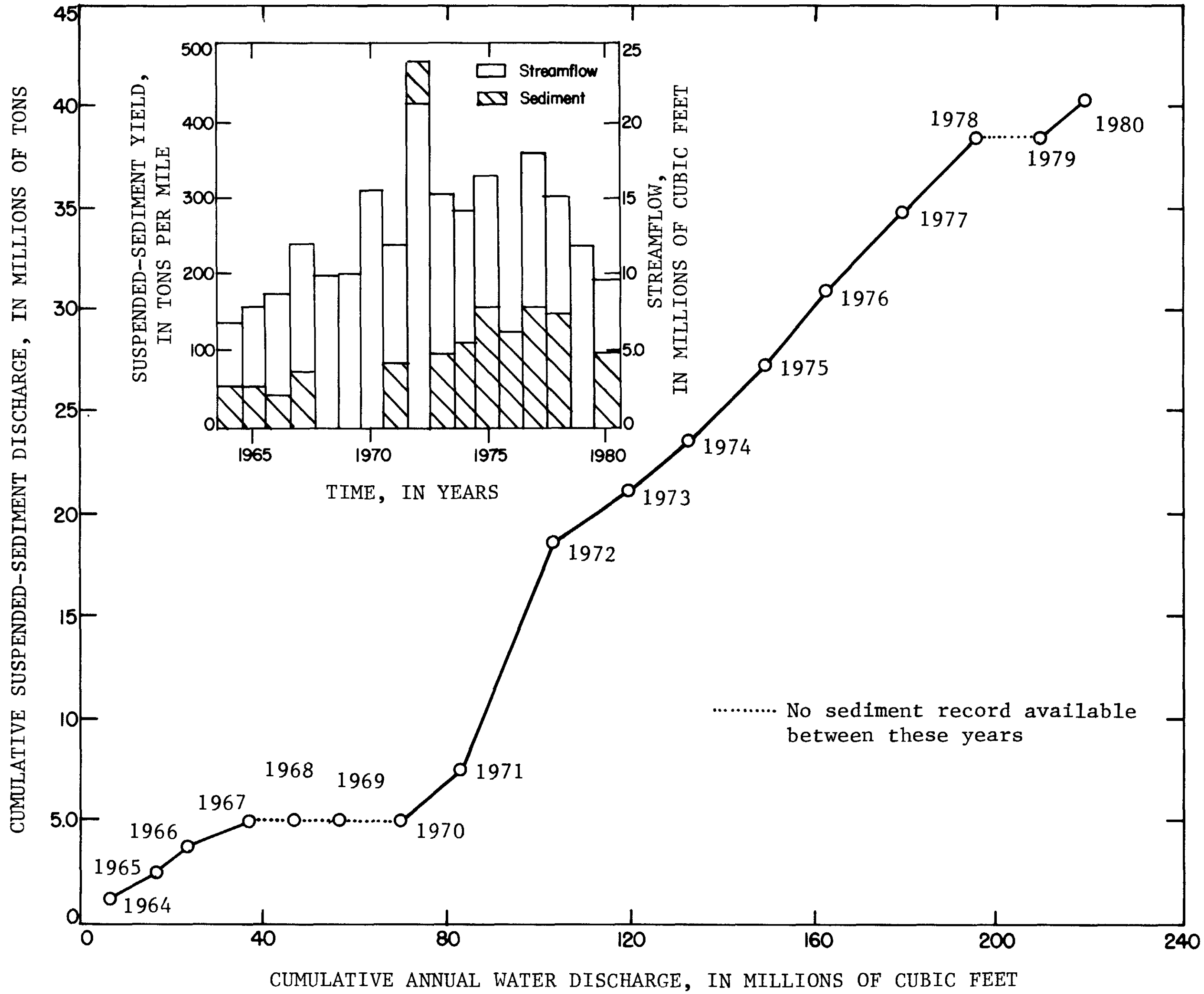


Figure 19.--Double-mass accumulation of annual suspended-sediment discharge as a function of annual water discharge (based on the climatic year beginning April 1 and ending March 31.

(1960) state, "...that year to year breaks in the slope of the double-mass curve are recognized as being due to chance and, thus, ignore any break that persists for less than five years." Figure 19, a double-mass curve for the Susquehanna River at Harrisburg, indicates two different times since 1970 that the rate of sediment transport varied from the average rate, and both were due to chance events. The change in slope of the double-mass curve between 1971 and 1972 was caused by very high suspended-sediment loads transported by Hurricane Agnes. A small change in slope occurred between 1974 and 1975 and probably resulted from Hurricane Eloise. Since that time there have not been any marked changes in the rate of sediment transport. Therefore, changes in watershed practices such as reservoir construction and operation, mining, and urbanization which may have affected local transport and deposition of sediment upstream of Harrisburg, have had little long term effects on sediment transport at Harrisburg.

The bar chart insert in figure 19 shows the variability in annual suspended-sediment yield, expressed in tons per square mile and the corresponding annual streamflow in millions of cubic feet. The flood during Hurricane Agnes in 1972 resulted in an annual suspended-sediment yield of nearly 480 tons/$mi^2$. A slight increasing trend in suspended-sediment yield appears from 1959 to 1977 as correponding streamflow increases. Since that time both suspended-sediment yield and annual streamflow have decreased.

Selected suspended-sediment samples collected near the peak of storms were also analyzed for particle size. Samples near the peak were chosen since most of the suspended sediment is transported during high flows. The data in table 9 indicates an average distribution of 13 percent sand, 48 percent silt and 39 percent clay in suspended-sediment during high flows, which is similar to those determined by Williams and Reed (1972). Therefore, approximately 308,000 tons of the suspended-sediment load for the period of study at Harrisburg was sand, 1,138,000 tons was silt and 924,000 tons was clay.

Table 9.--Suspended-sediment particle-size distribution

| Date sample collected | Streamflow ($ft^3/s$) | Particle-size distribution (percent) Sand (2.0-0.062 mm) | Silt (0.062-0.004 mm) | Clay (<0.004 mm) |
|---|---|---|---|---|
| March 21, 1980 | 108,000 | 7 | 49 | 44 |
| March 23, 1980 | 200,000 | 13 | 46 | 41 |
| May 14, 1980 | 48,700 | 11 | 32 | 57 |
| February 20, 1981 | 101,000 | 21 | 54 | 25 |
| February 21, 1981 | 231,000 | 18 | 48 | 34 |
| February 23, 1981 | 224,000 | 11 | 53 | 36 |
| February 24, 1981 | 276,000 | 10 | 47 | 43 |
| February 25, 1981 | 275,000 | 15 | 52 | 37 |
| Average | | 13 | 48 | 39 |

## Major Dissolved Inorganic Constituents

The major dissolved inorganic constituents for which chemical analyses were made include calcium, chloride, fluoride, magnesium, potassium, silica, sodium, and sulfate. The sum of these constituents is sometimes referred to as dissolved solids residue in freshwater systems such as the Susquehanna River and as dissolved salts or a related term, salinity, in oceanographic or estuarine systems like the Chesapeake Bay.

The highest concentration measured for any of the inorganic constituents was 110 mg/L for sulfate on October 1, 1980. Maximum calcium and chloride concentrations were 45.0 and 23.0 mg/L, and the maximum for dissolved solids residue was 280 mg/L (table 5). All measured concentrations for chloride and sulfate were below the EPA criterion of 250 mg/L in domestic water supplies. Fluoride concentrations showed little variation with a minimum of $<0.01$ mg/L and a maximum of 0.20 mg/L. The maximum load for any of the inorganics was 8,200 tons/day for calcium, and the minimum was $<0.01$ tons per day for fluoride (table 7).

Mean concentrations for the dissolved inorganics ranged from a high of 36.6 mg/L for sulfate to a low of 0.11 mg/L for fluoride (table 6). Mean daily loads were also highest for sulfate, 2,620 tons, and lowest for fluoride, 7.63 tons/day. The mean daily load for sulfate of 2,620 tons is equaled or exceeded 30 percent of the time (table 13).

The total sulfate load transported during the study was 958,000 tons, or 39.8 tons/mi$^2$. About 510,000 tons of calcium, 25,500 tons of chloride and a total load of 2,990,000 tons of dissolved solid residue were transported for yields of 21.2, 1.06, and 124 tons/mi$^2$, respectively.

Concentrations for each of the dissolved inorganic constituents showed an indirect relationship with streamflow similar to the plot of dissolved calcium concentration versus streamflow in figure 20. Regression analysis for all major inorganic constituent loads as a function of streamflow resulted in coefficient of determinations greater than 0.93 as shown in table 8. Regression analysis between inorganic constituent concentrations and specific conductance also showed good relationships, and results are listed in table 10. These relationships were used to estimate inorganic constituent concentrations for cross-sectional samples collected at each of the twelve verticals. A minimum of 49 observations were used to develop the regression statistics in table 10; however, users of the table should note that these regression equations should not be used to extend relationships beyond the range of data used to develop the relationships.

Dissolved solids loads were 21 percent higher than suspended-sediment loads at Harrisburg for the study period, and much of the dissolved solids may be transported to the Bay without being trapped in the reservoirs. This is substantiated by Lang (1982) who reported 24 percent more dissolved solids transported at Conowingo than at Harrisburg during the study period.

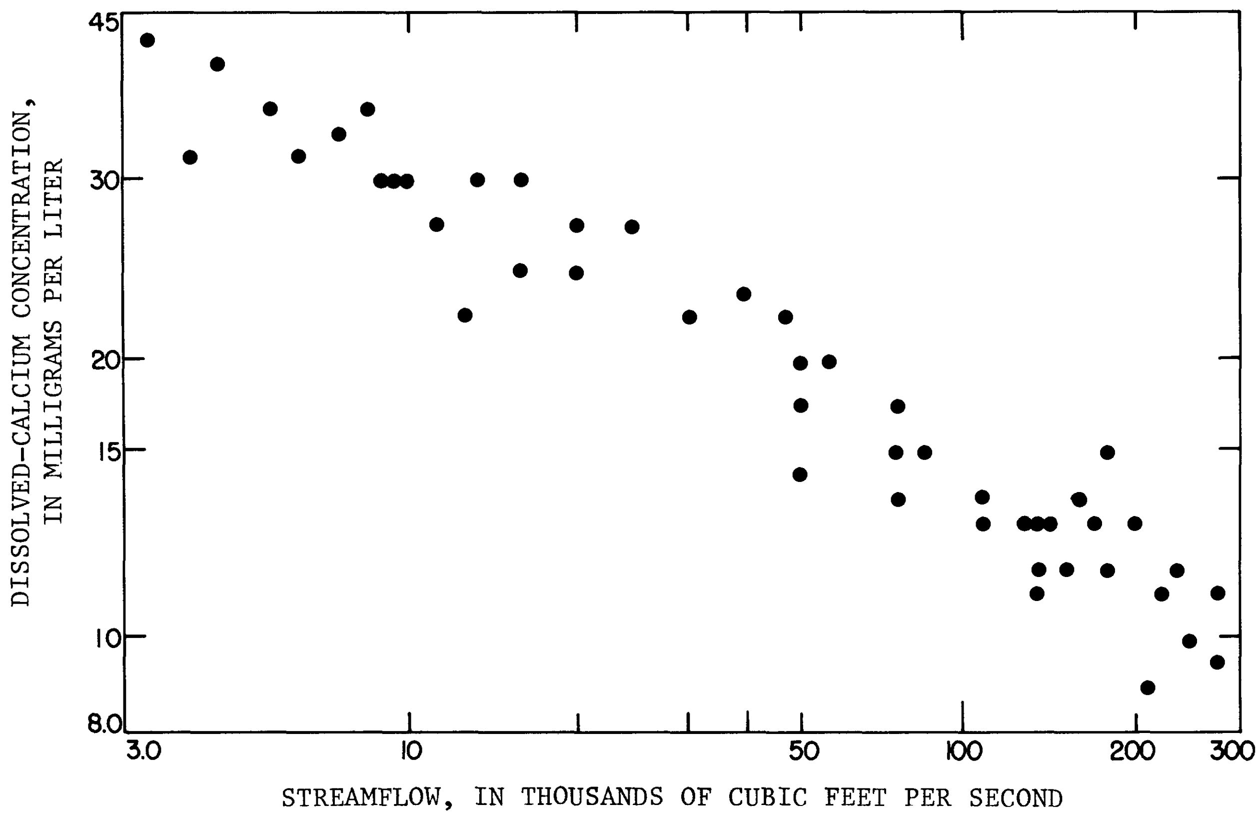


Figure 20.--Dissloved-calcium concentration as a function of streamflow.

Table 10.--Linear regression statistics for constituent concentration as a function of specific conductance

| Constituent (mg/L) | Intercept | Slope | Coefficient of determination ($r^2$) | Standard error of dependent variable |
|---|---|---|---|---|
| Calcium, dissolved | 0.3361 | 0.0995 | 0.96 | 2.02 |
| Chloride, dissolved | .6218 | .0484 | .79 | 2.45 |
| Magnesium, dissolved | -1.2234 | .0350 | .96 | .69 |
| Silica, dissolved | 6.0460 | -.0143 | .83 | .63 |
| Sodium, dissolved | -.8583 | .0370 | .91 | 1.13 |
| Sulfate, dissolved | -10.00 | .2455 | .96 | 5.31 |
| Solids, residue dissolved | 8.1456 | .5709 | .82 | 24.51 |

## Metals

Metals for which analyses were performed included total recoverable and dissolved aluminum, iron, and manganese, and total recoverable chromium, copper, lead, mercury, nickel, and zinc. Ninety-five percent of the 113,000 ton of iron, aluminum, and manganese load was associated with suspended sediment. Results from this study indicate these three metals constitute nearly 5 percent of the annual suspended sediment load transported by the river. Maximum concentrations of dissolved metals were much lower than corresponding total concentrations. Because much of the suspended material is trapped by the three major reservoirs before reaching the Bay, concentrations and loads obtained for Harrisburg may be higher than those measured near the Bay. Again, Lang (1982) substantiates these assumptions as loads measured at Conowingo for total iron, aluminum, and manganese were 51, 9, and 19 percent lower, respectively, than the loads measured at Harrisburg. In view of this, the following discussion applies only for the Susquehanna River at Harrisburg, Pa.

The maximum concentration measured for total recoverable iron was 13,000 μg/L measured on February 20, 1981. The maximum concentration for total recoverable mercury was 0.20 μg/L measured July 1, 1980. The range in loads for total recoverable iron was from 0.99 to 6,860 tons/day. Dissolved iron ranged from 0 to 73.3 tons/day (table 6).

Regression analyses showed good relationships between constituent metal loads and streamflow. Coefficients of determination ($r^2$) were above 0.82 for all metals except total recoverable lead (table 8).

Mean concentrations for total recoverable iron were higher than any of the other metals (table 5) and exceeded the EPA criterion of 300 μg/L for domestic water supplies and 1,000 μg/L for freshwater aquatic life (U.S. Environmental Protection Agency, 1976). The mean daily concentration for iron of 3,000 μg/L was three times greater than the criteria for freshwater aquatic life and is equaled or exceeded 15 percent of the time at Harrisburg (table 13). Although iron levels in water used for domestic purposes can be treated to remove iron, concentrations of iron in the Susquehanna River and their effects on aquatic vegetation and fish populations may be much more complex.

The mean concentration for total recoverable manganese was 390 μg/L and was equaled or exceeded about 20 percent of the time. The EPA criteria for manganese is 50 μg/L for domestic water supplies and 100 μg/L for the protection of consumers of marine mollusks. Like iron, manganese may be removed from domestic water at treatment plants and poses no human health hazard. However, if manganese concentrations entering the Bay are as high as those at Harrisburg, they may have an adverse affect on the shellfish industry.

The mean concentration for total recoverable lead was 14 μg/L and is equaled or exceeded about 25 percent of the time based on load-duration table 13. The criterion listed by the EPA for total recoverable lead is 50 μg/L for domestic water supplies and was exceeded only during periods of high streamflow when instantaneous concentrations of 110, 85, and 140 μg/L were measured on February 14, 18, and 24, 1981, respectively.

Mean loads for total recoverable metals were substantially higher than those for dissolved metals (table 13). The mean daily loads for total recoverable iron, aluminum, and manganese were 211, 65.8, and 27.4 tons/day, respectively, and corresponding dissolved loads were 4.99, 2.88, and 6.54 tons/day, respectively. Only two percent of the total iron load of 76,800 tons was dissolved. Four percent of the total aluminum load of 24,000 tons was dissolved. Approximately 24 percent of the total manganese load of 9,900 tons was dissolved. Annual yields for total iron, aluminum, and manganese were about 0.01, 0.003, and 0.001 tons/mi$^2$ respectively.

## Seasonal Characterization of Pesticides and Other Constituents

Characterization of constituent concentrations and loads can sometimes be made for particular seasons of the year. These seasons may occur during different periods of time in different parts of the country. However, for this report the seasons are referred to as spring (March-April-May), summer (June-July-August), autumn (September-October-November), and winter (December-January-February).

Pesticides for which seasonal characterization was attempted are listed in table 2. The only pesticides detected in significant concentrations during the study were the herbicides atrazine and 2,4-Dichloro-phenoxyacetic acid (2,4-D). Maximum, minimum, and mean pesticide concentrations are listed in table 5.

Seasonal characterization of pesticide and other chemical constituents is often dependent on precipitation events and streamflow conditions. Because there were no storms between May 5 and November 24, 1980, there were no high-flow samples collected when pesticide applications usually occur.

Time-series plots (fig. 21) indicate 2,4-D concentrations varied the most throughout the study while atrazine concentrations were relatively constant except during the spring and summer when applications are used to control weed growth in cornfields. The maximum concentration detected for atrazine was 3.4 µg/L which occurred for a short duration near the peak streamflow of the study on February 24, 1981.

No direct relationship was observed between any of the pesticides and streamflow, suspended-sediment concentration or particle-size. Variations in measured pesticide concentrations may have been the result of runoff from local showers which occurred soon after periods of application, and did not significantly affect streamflow or sediment concentrations in the Susquehanna River.

Seasonal variation of chemical constituent loads was largely dependent on streamflow and can be seen in bar charts of the monthly streamflow and loads for selected constituents (figs. 22 to 24). Sixty-seven percent of the total streamflow occurred in the spring and winter months of April 1980 and February and March of 1981. Ninety-two percent of the suspended-sediment load and 72, 85, and 75 percent of the loads of dissolved nitrate, and total and dissolved phosphorus, respectively, were transported during these three months.

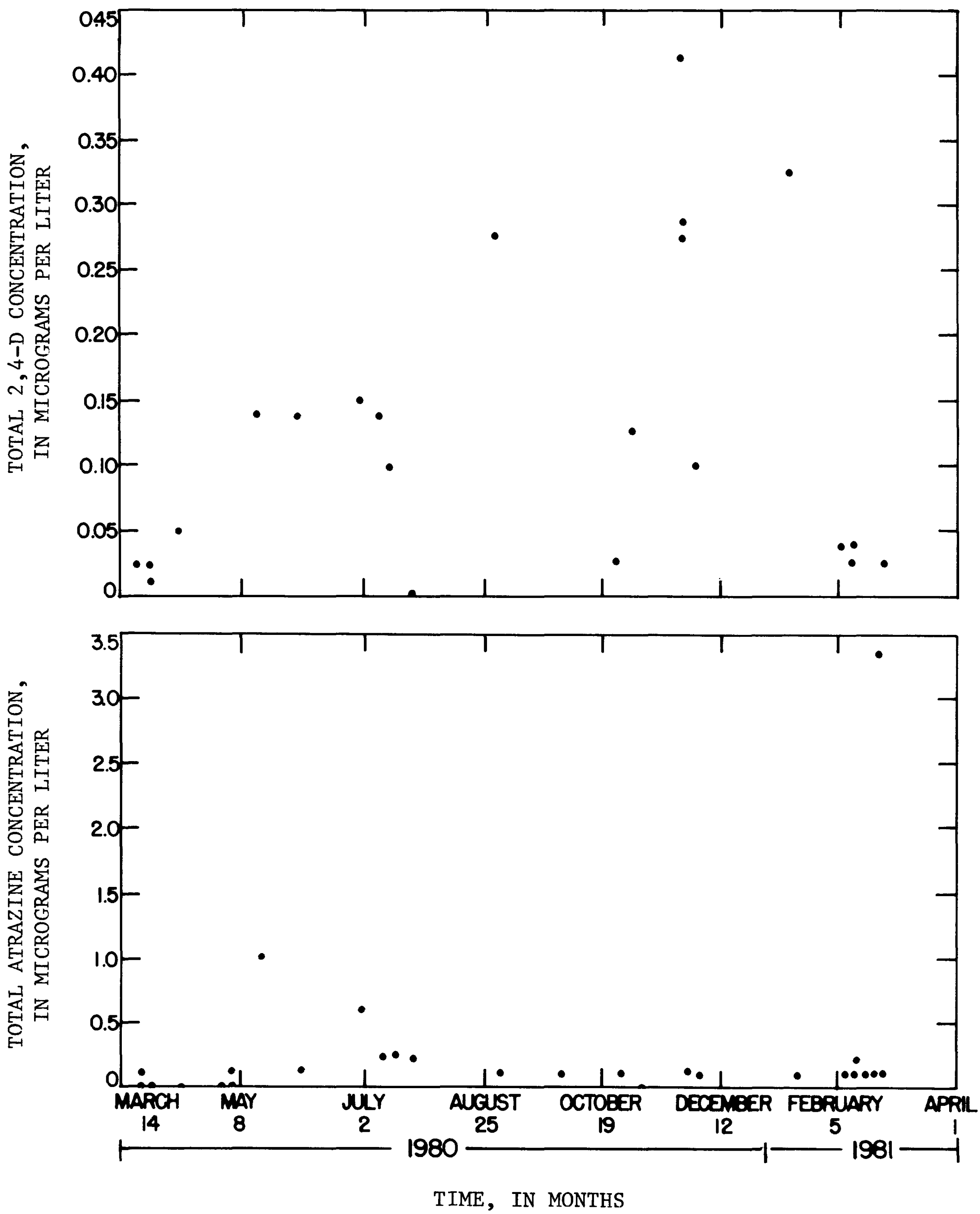


Figure 21.--Time-series of instantaneous 2,4-Dichloro-phenoxyacetic acid (2,4-D) and atrazine concentrations, March 1980 to March 1981.

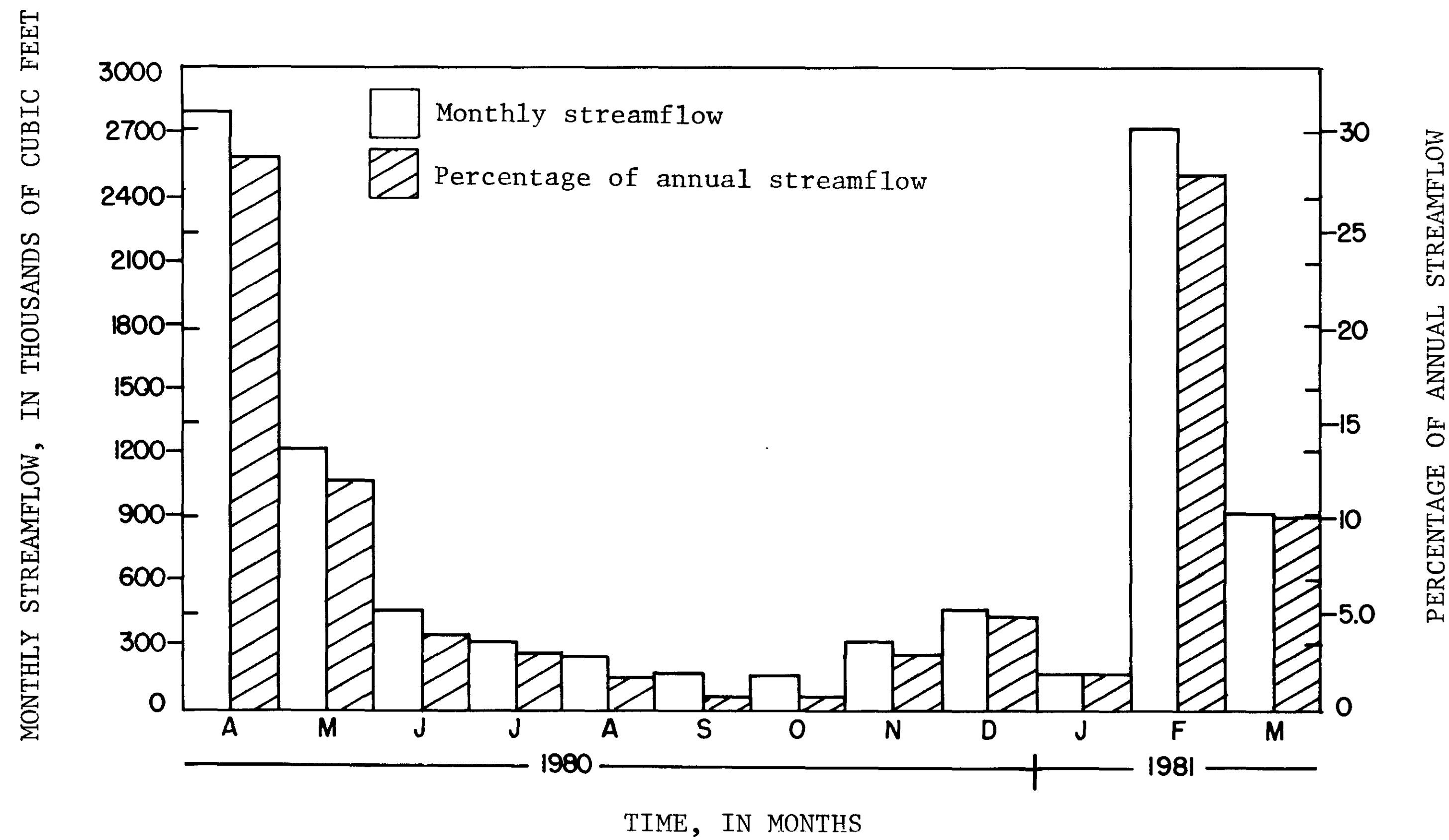


Figure 22.--Monthly streamflow and percentage of annual streamflow.

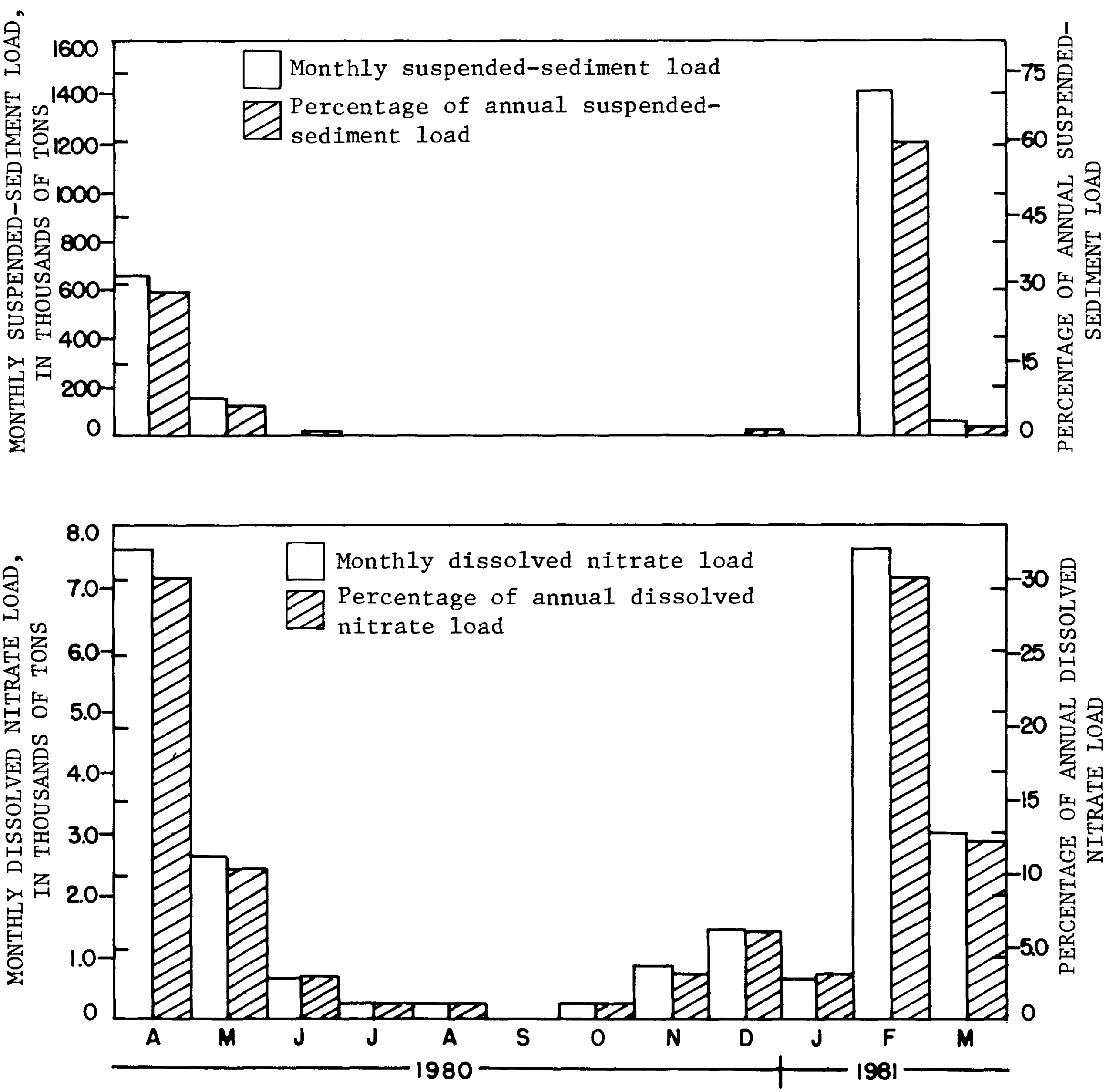


Figure 23.--Monthly suspended-sediment and dissolved nitrate loads, and percentage of annual loads.

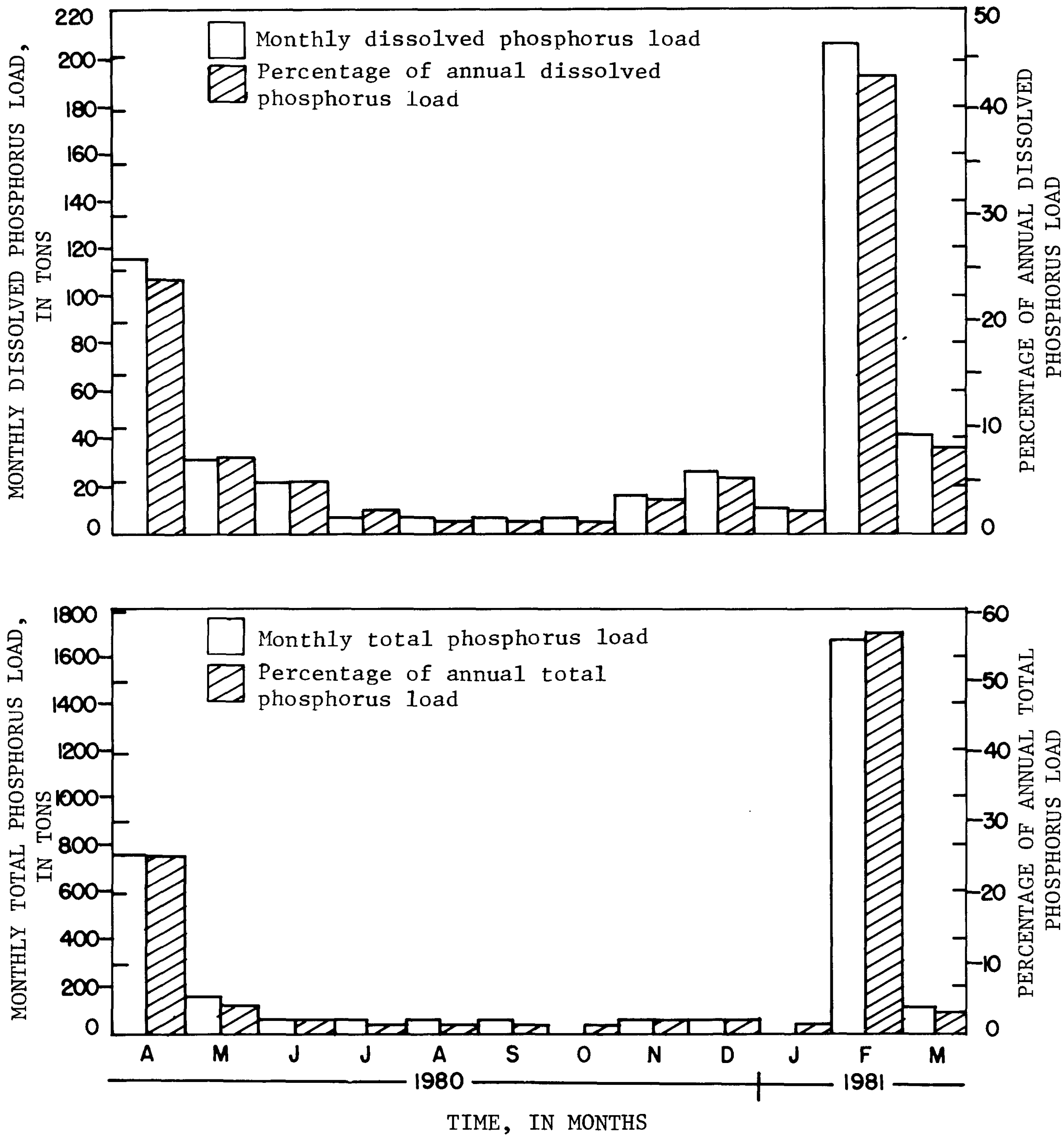


Figure 24.--Monthly dissolved and total phosphorus loads, and percentage of annual loads.

## Cross-sectional Variation of Chemical Constituents

Variation of chemical constituent concentrations and loads at the Harrisburg cross-section results from the lack of lateral mixing of the water. Lateral mixing of the water is prevented by the river's relatively shallow depth, large channel width, slow velocity, gentle slope, and numerous islands. Figure 25 illustrates cross-sectional depths of the east and west channels at a streamflow of 19,400 $ft^3/s$. Notice that if the vertical scale were the same as the horizontal scale the cross-section plot would be a line no more than 0.05 inches thick. Streamflow and corresponding depths during the study were equal or less than those indicated approximately 69 percent of the time. The graph shows that the deepest point in the east channel was 10 feet, which is about 3 feet more than the deepest point in the west channel. The total width of the river is approximately 3,650 feet. The east and west channels are about 1,340 and 1,250 feet, respectively. Mean stream velocities at a flow slightly higher than the long term mean of 34,500 $ft^3/s$ are about 2.42 ft/s for the east channel and 2.20 ft/s for the west channel. The slope of the thalweg between the points 10 percent and 85 percent of the distance from Harrisburg to the basin divide is only 2.06 ft/mi.

The percentage of total flow in the east and west channels of the Susquehanna River at Walnut Street is dependent upon the total flow of the river. About 59 and 41 percent of the total flow occurs in the east and west channels, respectively at the mean flow, of 34,500 $ft^3/s$. Figure 26 illustrates changes in the percentage of total streamflow in the east and west channels as the total streamflow of the river increases. If the regression line were extended, the percentage of flow in the east channel would decrease until both channels reached equal flows at about 400,000 $ft^3/s$.

Maximum concentrations of constituents constantly differed between the east and west channels and fluctuated from one to the other, especially during high-flow conditions. These fluctuations are due to the different rates at which runoff enters the Susquehanna River from source areas, the different travel times for runoff to reach Harrisburg from source areas, and the poor lateral mixing of runoff from the east and west. Figure 27 illustrates the changes in instantaneous suspended-sediment concentrations and specific conductance at each vertical from February 20 to March 2, 1981. Over the course of the storm, maximum suspended-sediment concentrations fluctuated between the west and east channels as runoff from the source areas reached Harrisburg. Specific conductance values were consistently higher along the banks of the river with progressively lower values towards the center of the river, indicating poor lateral mixing of the dissolved ions.

In addition to the variations in instantaneous concentrations for each vertical, mean concentrations also showed significant differences between verticals. Mean concentrations for each vertical were determined from samples collected at high-flow conditions. Means were determined as the sum of the log of the concentrations divided by the number of high-flow samples. Seventeen samples were used for each vertical for suspended sediment, specific conductance, and major ions. Five samples were used for nitrogen and phosphorus species, and three samples for total organic carbon and total metal concentrations. Values used for major ion concentrations were esti-

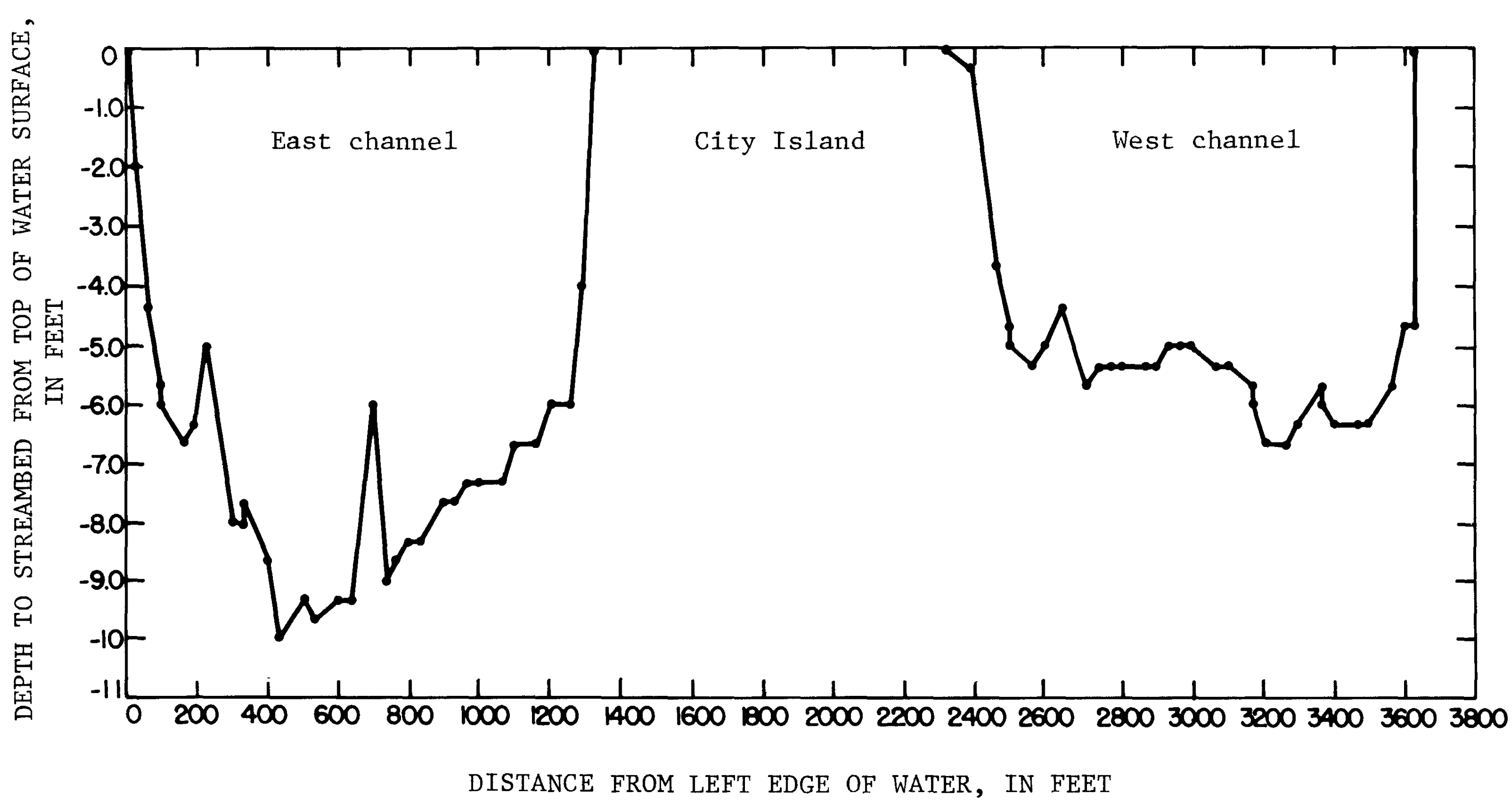


Figure 25.--Cross-section of Susquehanna River at Harrisburg at Walnut Street Bridge on December 9, 1980 at streamflow of 19,400 cubic feet per second.

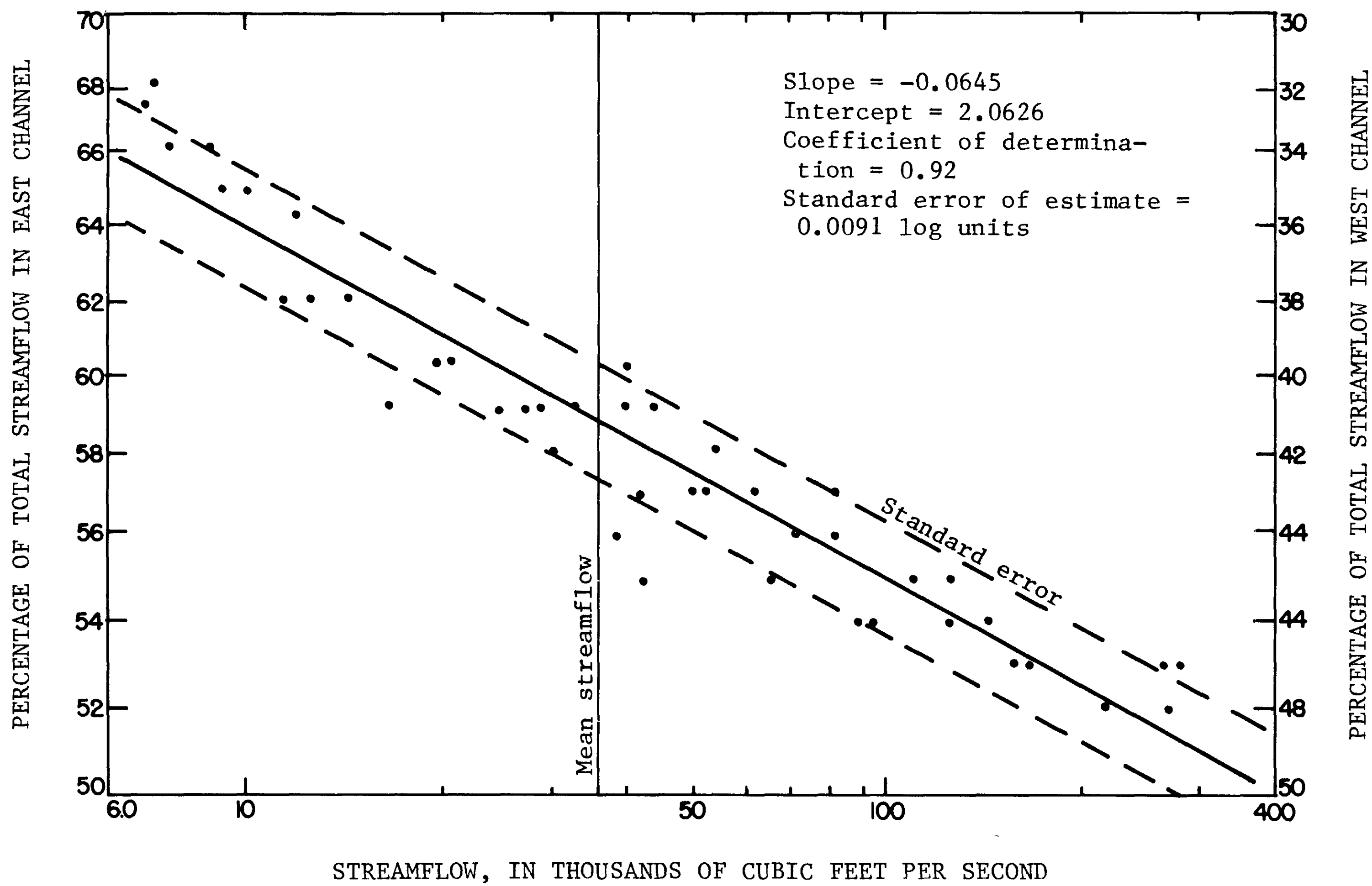


Figure 26.--Relation of percentage of total streamflow in east and west channel of Susquehanna River at Walnut Street.

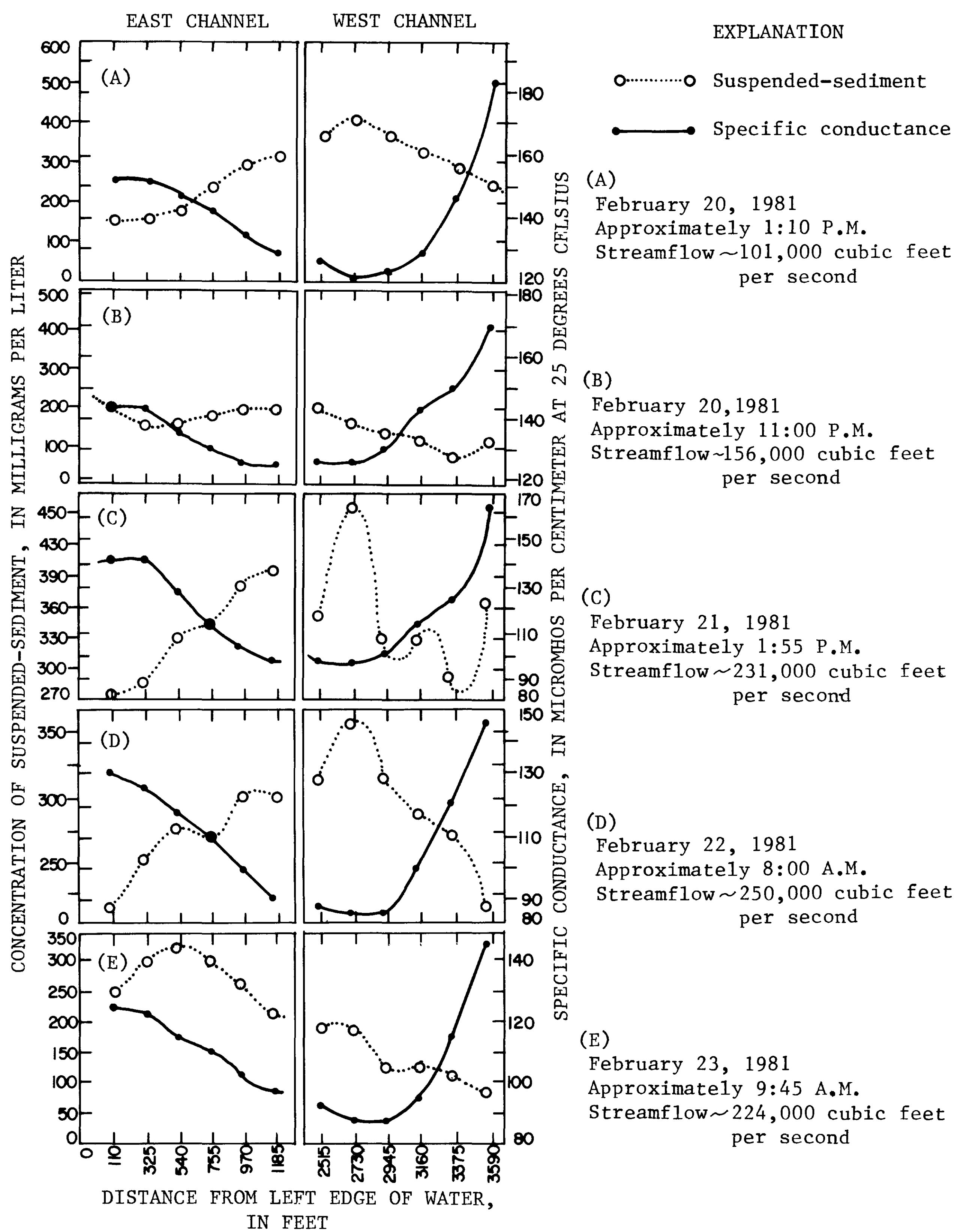


Figure 27.--Cross-sectional variation of suspended-sediment concentration and specific conductance from February 20 to March 2, 1981.

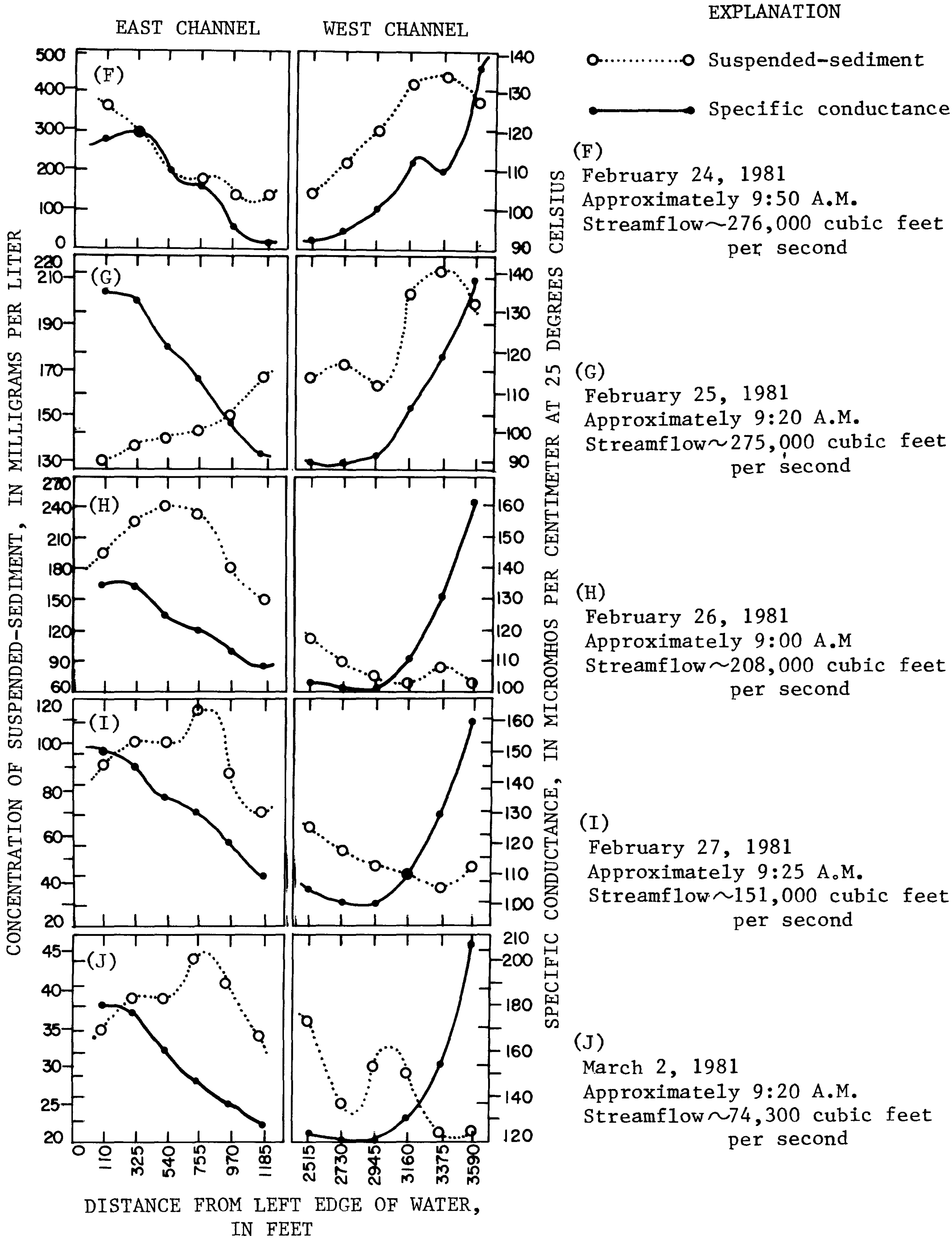


Figure 27.--Cross-sectional variation of suspended-sediment concentration and specific conductance from February 20, to March 2, 1981 -- continued.

mated using regression equations in table 9. Although few nitrogen, phosphorus, and metal analyses were available, the analysis of variance test was performed among 12 verticals and is valid for periods of high-flow.

Bar charts of selected constituents, figures 28-31, show mean concentrations for each vertical and groups of verticals not significantly different represented by the letters A thru E. Verticals having the same letter are not significantly different at the 95 percent confidence level.

Although figure 28 indicates mean concentrations of suspended sediment in the east channel verticals were higher than those in the west channel, differences between all the verticals were not found significant.

All constituents with significant differences among verticals were transported primarily in the dissolved phase. The highest mean values occurred along the east and west banks of the river. Results for specific conductance (fig. 28) indicate the mean at vertical 3590 is significantly different from the other verticals in the west channel but not from the two verticals closest to the east bank. Similar results were found for parameters determined by regression from specific conductance such as dissolved calcium, chloride, magnesium, potassium, sodium, sulfate, and dissolved solid residue as shown in figures 29-31. The total nitrate nitrogen mean concentration at vertical 3,590, shown in figure 31, was significantly higher than for all other verticals. The highest mean concentrations for nitrate, like those for total nitrogen and major ions, were along the banks of the Susquehanna River with progressively lower values occurring near the verticals closest to City Island. Mean concentrations of orthophosphate phosphorus at vertical 3,590 were significantly higher than any of the other verticals except 3,375 (fig. 31). Orthophosphate phosphorus was also predominantly dissolved.

None of the metals showed significant differences between verticals, however, mean concentrations were higher in the east channel for iron and lead, higher in the west channel for aluminum, and higher near the center of the river for manganese, zinc and nickel.

Anderson (1963) found variations similar to those in figures 28-31 existed for data collected at both high and low flow conditions during October 1956 to September 1960. In his report, he stated "the cross-section variations in chemical composition of the water at the Harrisburg station are retained at Columbia, several miles downstream from Harrisburg." Few data are available showing cross-section variations of chemical concentrations and their effects in the reservoirs downstream of Harrisburg. Although mixing should occur in the reservoirs, cross-sectional studies of the reservoirs and lower river should be done. If dissolved nitrate and orthophosphate concentrations continue to be higher in the shallow areas along the banks than the deep areas in the center of the river, underlying causes should be determined as increased algal growth can be expected in the shallow water along the edges of the reservoirs and the Chesapeake Bay.

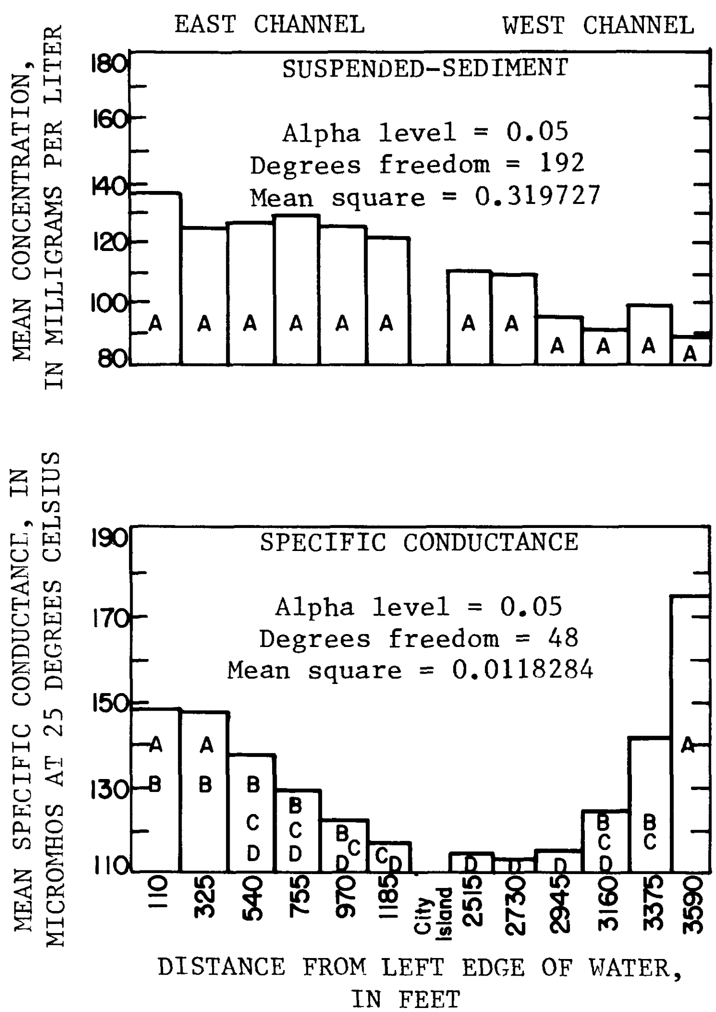


Figure 28.--Duncan's multiple range results for suspended-sediment concentrations and specific conductance.

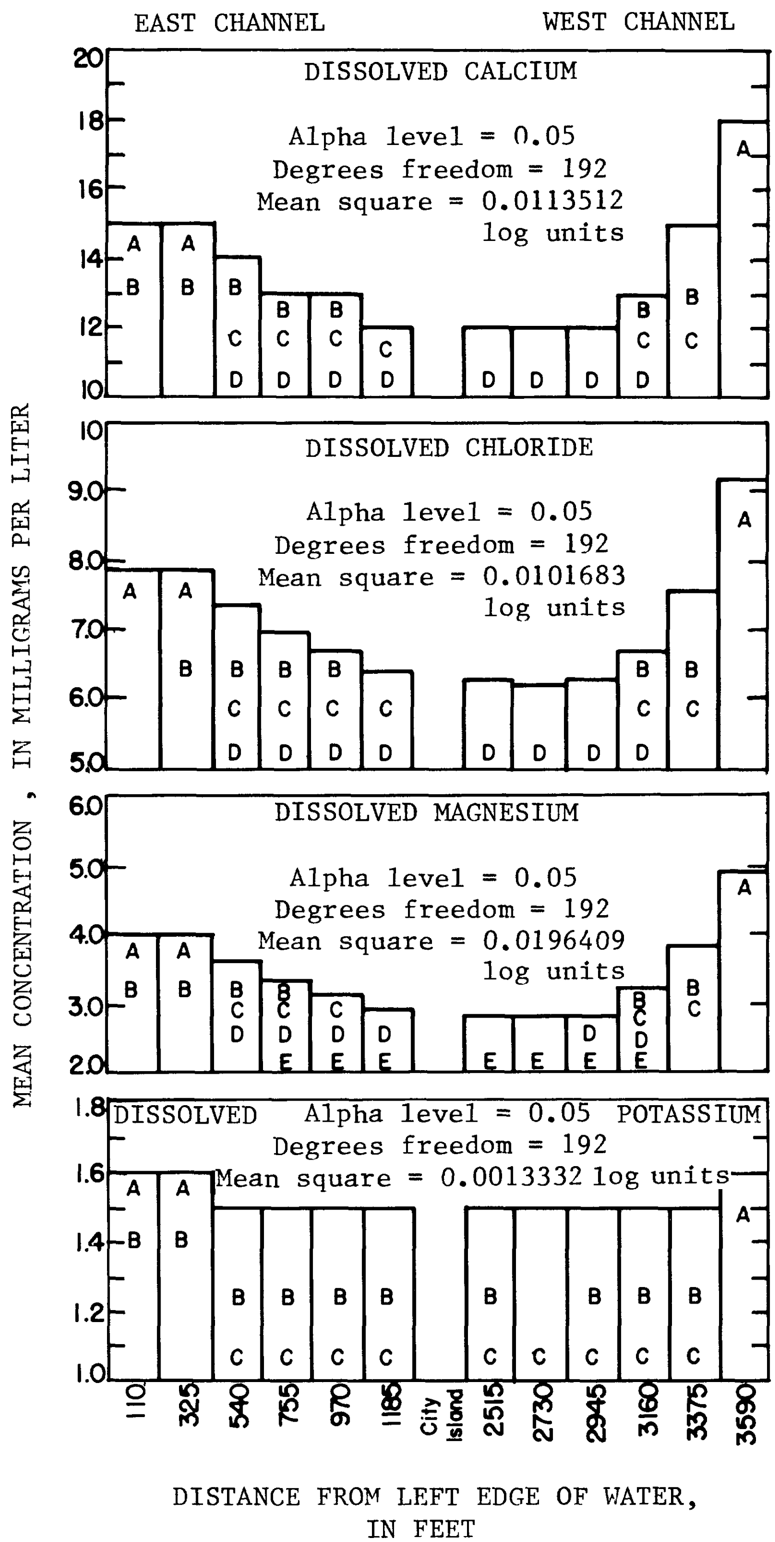


Figure 29.--Duncan's multiple range results for dissolved calcium, chloride, magnesium, and potassium concentrations.

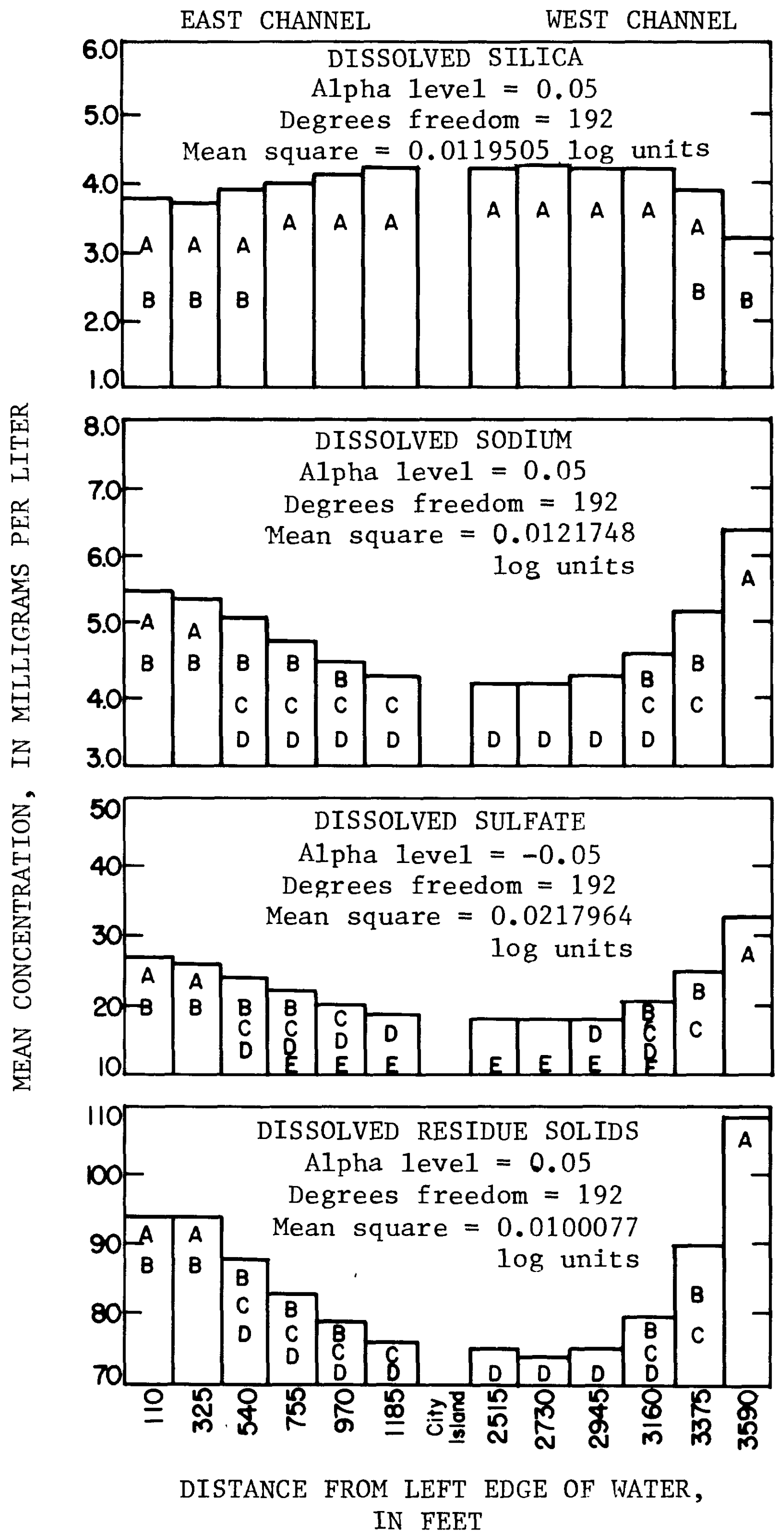


Figure 30.--Duncan's multiple range results for dissolved silica, sodium, sulfate, and solid-residue concentrations.

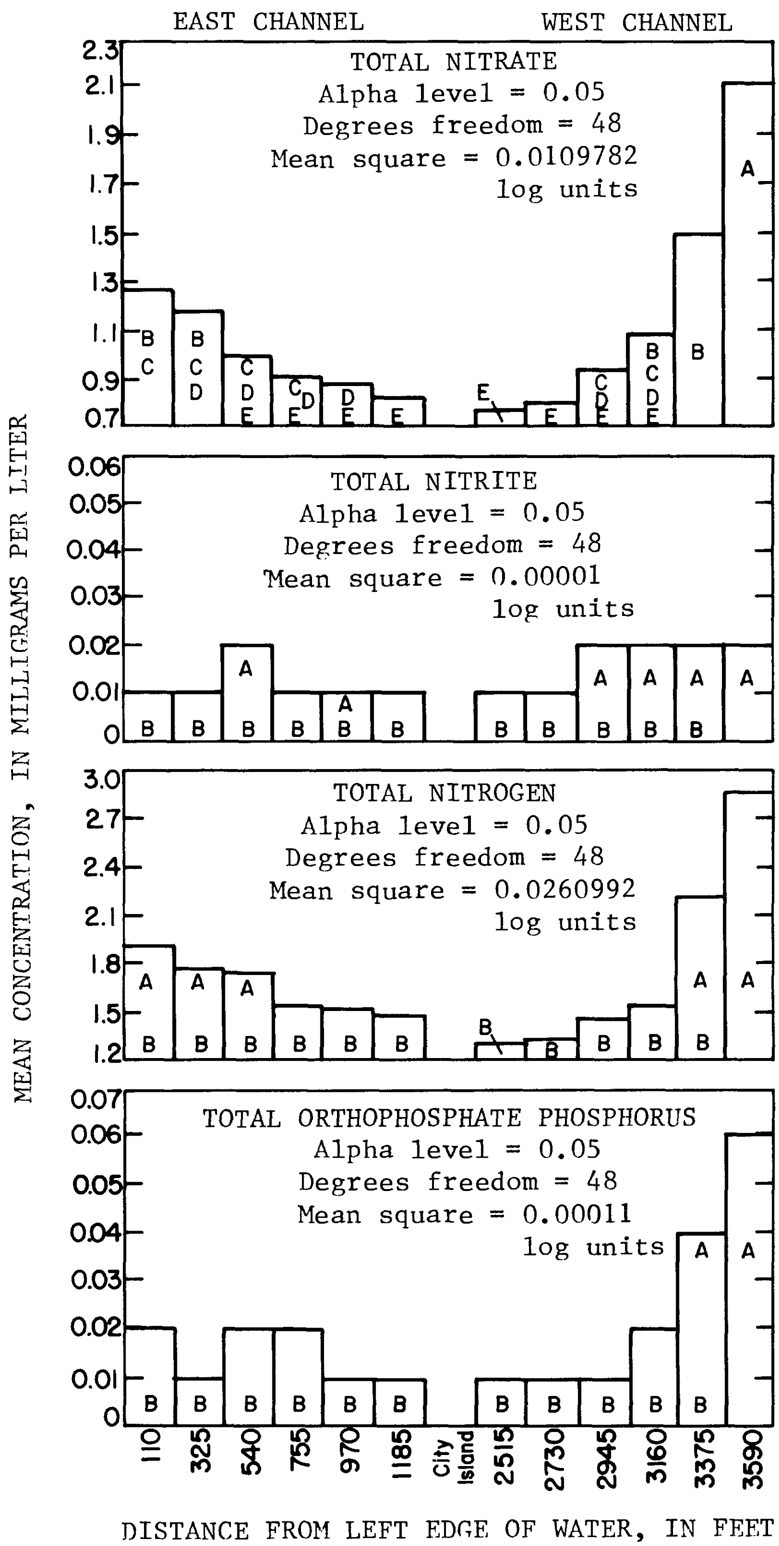


Figure 31.--Duncan's multiple range results for total nitrate, nitrite, nitrogen, and orthophosphate phosphorus concentrations.

## Extremes and Diel Variation of Historical Monitor Data

Many aquatic organisms in both the Susquehanna River and the Chesapeake Bay may be able to adapt to a range of environmental conditions. However, the organisms may not be able to adapt when extreme levels and rapid variations of particular constituents occur.

Extreme values and diel variations of water temperature, dissolved oxygen, pH, and specific conductance are influenced by factors such as air temperature, sunlight, and inflows from point and non-point source discharges. Water temperature is largely controlled by air temperature, but also can be influenced by point source discharges from treatment plants or releases from reservoirs. Dissolved-oxygen concentrations are affected by water temperature, photosynthesis, respiration, and decomposition. Dissolved oxygen concentrations typically increase in the daytime as photosynthesis increases, peak near mid-afternoon, and decline through the night as photosynthesis decreases and respiration consumes the oxygen. The pH is also affected by water temperature, photosynthesis, and inflows such as mine drainage. Increases in pH often occur during the day when algae consume $CO_2$, which when present in water forms carbonic acid. Specific conductance is affected by the increase or decrease of dissolved ions in the water and usually has an indirect relationship with streamflow.

Because continuous monitoring of the river's water temperature, dissolved oxygen, pH and specific conductance for the entire cross section is difficult, monitoring is often accomplished at a fixed point representative of the entire stream. However, since lateral variations are significant at the Susquehanna River at Harrisburg, fixed point measurements are not representative of the entire stream. Table 11 lists the maximum and minimum values and dates of occurrence for data collected continuously from May 1974 to September 1978 at a fixed point in the river, and measurements made during the study from April 1980 to March 1981. Little difference was observed between the time of occurrence for maximum and minimum historical values and values obtained during the study. Daily maximum dissolved-oxygen concentrations for historical data usually occurred during the winter months as did the maximum for the period of study when ice covered the entire channel on January 29, 1981. Minimum dissolved-oxygen concentrations were similar for the periods 1974 to 1978 and 1980 to 1981, and frequently occurred in July, August, and September when water temperatures were high and flows were low. Maximum values for pH often occurred during the warm months and corresponded to maximum photosynthetic activity. An exceptionally high pH of 11.9 occurred December 28, 1977 and lasted for eight hours with simultaneous increases of dissolved oxygen, water temperature, and specific conductance. This may have resulted from a slug of warm water as air temperatures rose from 24°F to 54°F, melting ice in the river channel on December 26, 1977. Maximum specific conductance values from 1974 to 1976 and 1980 to 1981 occurred in September and October during low-flow conditions; in 1977 and 1978, maximum values were recorded during periods when ice covered the river channel.

Months with the greatest average diel variation in water temperature, dissolved oxygen, pH, and specific conductance for years 1974 through 1978

Table 11.--Maximum and minimum water temperature, dissolved-oxygen, pH, and specific conductance values measured by water-quality monitor from 1974 to 1978 and manual samples collected from April 1980 to March 1981

| Year | Water temperature (°C) | | Dissolved Oxygen (mg/L) | | pH | | Specific conductance (µmho/cm at 25°C) | |
|---|---|---|---|---|---|---|---|---|
| | Maximum | Minimum | Maximum | Minimum | Maximum | Minimum | Maximum | Minimum |
| 1974 | 29.5 | 11.5 | 11.9 | 5.1 | 10.3 | 6.5 | 350 | 106 |
| date | June,July,Aug Several days | May 7* | May 8 | Sept. 2 | June 22 | Dec. 10 | Sept. 1 | July 4,5 |
| 1975 | 32.0 | 1.0 | 14.9 | 5.9 | 10.4 | 6.8 | 356 | 77 |
| date | Aug. 2,3 | Jan.18,21 | Jan. 21 | Aug. 5 | Aug. 27 | May 5, Sept.27,28 | Sept. 2 | Sept. 27 |
| 1976 | 29.0 | 0.5 | 17.1 | 5.8 | 9.3 | 6.6 | 291 | 95 |
| date | Aug. 24 | Jan.-Feb. Several days | Dec. 21 | June 17,19,20 | May 9 | June 22,23 | Sept. 15,30 | Feb. 20,21 |
| 1977 | 30.0 | 0.0 | 17.7 | 5.6 | 11.9 | 6.4 | 1070 | 92 |
| date | July 16,17 | Jan.-Feb. Several days | Dec. 28 | July 7 | Dec. 28 | Sept. 30 | Dec. 9 | March 6 |
| 1978 | 29.5 | 0.0 | 17.4 | 5.9 | 10.9 | 6.1 | 727 | 80 |
| date | Aug. 19 | Feb.-March Several days | Feb. 1 | Aug. 31 | Feb. 1 | May 17 | Feb. 1 | May 16 |
| April 1980 to March 1981 | 29.5 Aug. 5 | 0.0 Dec. 15,22 | 16.8 Jan. 29 | 5.2 Sept. 16 | 8.9 July 14 | 7.2 Feb. 24 | 443 Oct. 7 | 101 Feb. 24 |

* Water-quality monitor operation began in May.

Table 12.--Months with greatest average diel variations of water-quality data from 1974 to 1978

| | Average Diel Variation | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Year | Month | Water temperature (°C) | Month | Dissolved oxygen (mg/L) | Month | Specific conductance (μmho/cm at 25°C) | Month | pH |
| 1974 | June | 2.5 | June | 2.1 | June | 14 | June | 1.3 |
| | July | 2.5 | July | 3.4 | July | 12 | July | .9 |
| | August | 2.5 | August | 3.1 | August | 19 | August | 1.0 |
| 1975 | June | 2.0 | July | 2.2 | August | 19 | June | .7 |
| | July | 2.5 | August | 3.4 | September | 22 | July | 1.1 |
| | August | 2.5 | September | 1.8 | October | 22 | August | .8 |
| 1976 | May | 2.0 | July | 1.8 | June | 16 | July | 1.0 |
| | June | 2.0 | August | 2.1 | July | 17 | August | .8 |
| | July | 2.0 | September | 2.3 | December | 18 | September | .7 |
| 1977 | June | 2.5 | June | 2.4 | January | 33 | June | .9 |
| | July | 2.0 | July | 2.1 | February | 22 | July | 1.0 |
| | August | 2.0 | August | 1.7 | July | 16 | August | 1.2 |
| 1978 | June | 2.0 | July | .9 | July | 24 | July | .8 |
| | July | 3.0 | August | 2.6 | August | 11 | August | .8 |
| | August | 2.5 | September | 1.8 | September | 17 | September | .8 |

are shown in table 12. Maximum diel variations for each constituent occurred in June, July, August, or September, except for specific conductance which sometimes had large diel variations in the winter during periods of snow and ice melts. Little difference was found in the average diel variation from one year to the next and no trends in the amount of diel variation were determined for the five years of data.

Figure 32 represents a near base-flow condition from September 9 through 15, 1976. Streamflow for this period ranged from 7,470 to 8,190 $ft^3/s$ and significant diel variations were measured for water temperature, dissolved oxygen, and pH. Specific conductance increased during the period as corresponding streamflows dropped. A sharp decrease of nearly 6.0°C in water temperature occurred from September 9 through 11 as air temperatures dropped from a high of 90°F to a low of 49°F in the same period. Regular diel variations in water temperature began on September 11, 1976 with minimum temperatures occurring between 6:00 to 8:00 a.m. Minimum dissolved oxygen occurred near 4:00 to 6:00 a.m. as expected during periods of reduced photosynthetic activity. Values for pH varied up to 0.8 units during 24-hour periods with minimums occurring near 8:00 a.m. and maximums near 10:00 p.m.

Figure 33 represents a period of rising stage from September 1 to 4, 1975. Daily mean streamflow increased from 8,370 $ft^3/s$ to 15,200 $ft^3/s$. Again there were significant diel variations for water temperature, dissolved oxygen, and pH. However, specific conductance decreased steadily as streamflow increased. Maximum and minimum values for each constituent occurred at times similar to those for the base-flow condition. The rising stage appeared to have little effect on the occurrence or timing of the maximums or minimums.

Figure 34 shows a period of peak and falling stage from July 5 to 8, 1978. Daily mean streamflow peaked near 22,700 $ft^3/s$ then fell to 15,300 $ft^3/s$. Water temperature continued to show daily variations with minimums between 6:00 to 8:00 a.m. and maximums near 6:00 p.m. that lasted up to six hours on July 6. Dissolved oxygen values showed little variation on July 5 as the storm peaked, but as the stage fell dissolved oxygen values began to show regular diel variations of 0.6 to 1.0 mg/L, beginning about 10:00 a.m. on July 7. There was little variation in pH during the peak streamflow, but as the stage continued to drop pH values returned to a regular diel variation. Specific conductance again showed no clear diel variation but was inversely related to streamflow.

Figure 35 represents a period of ice melt in the river from December 27 to 29, 1977 and shows significant variations for all four constituents for 10 hours on December 28, 1977. Daily mean streamflow fell from 58,000 $ft^3/s$ to 50,000 $ft^3/s$. Water temperatures ranged from a low of 0.5 to 3.9°C, dissolved oxygen from 13.6 to 17.6 mg/L, pH from 7.1 to 11.9 and specific conductance from 148 to 1001 μmhos. Similar conditions of shorter duration were observed during ice melt conditions on December 9, 1977 and February 1, 1978.

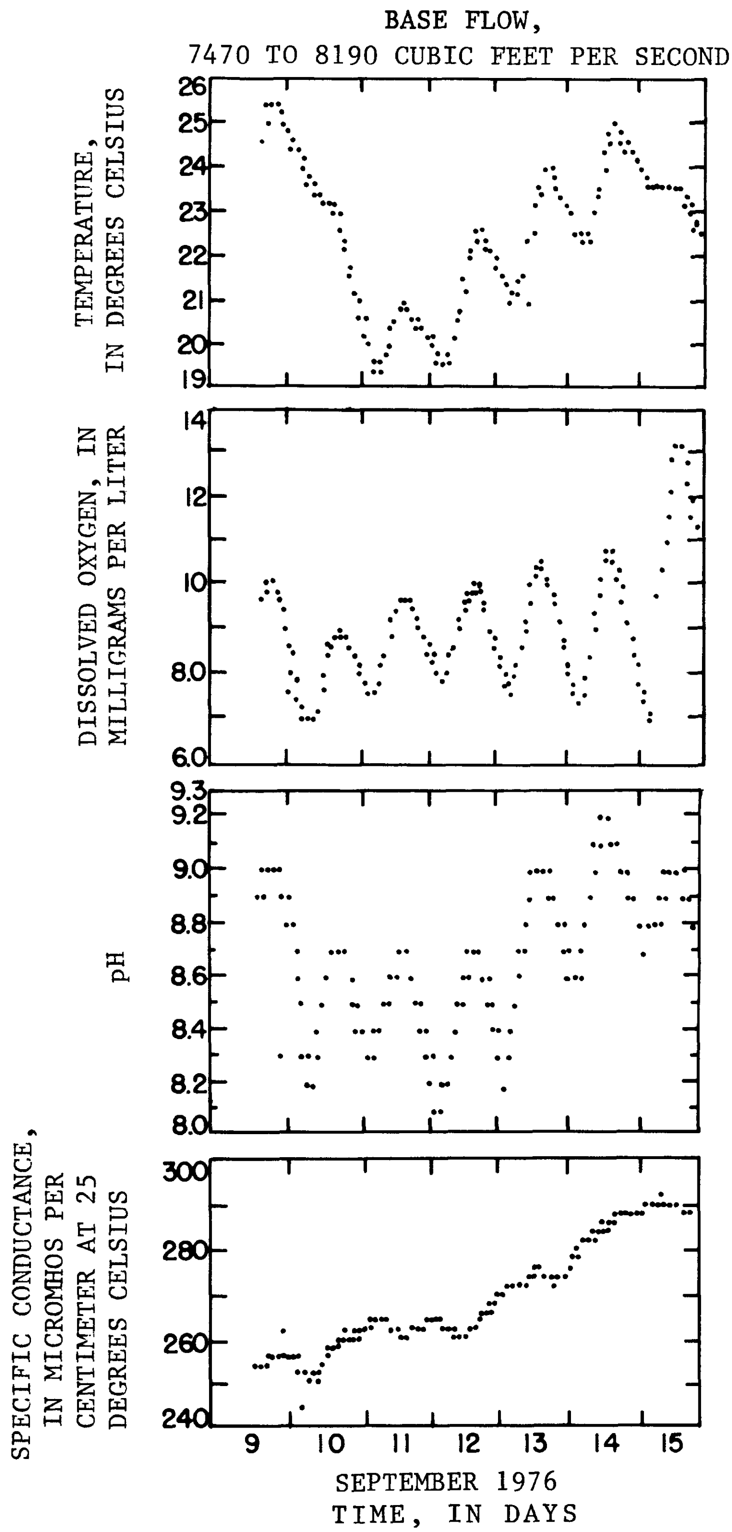


Figure 32.--Diel variation of water temperature, dissolved oxygen, pH and specific conductance during baseflow condition, September 9 to 15, 1976.

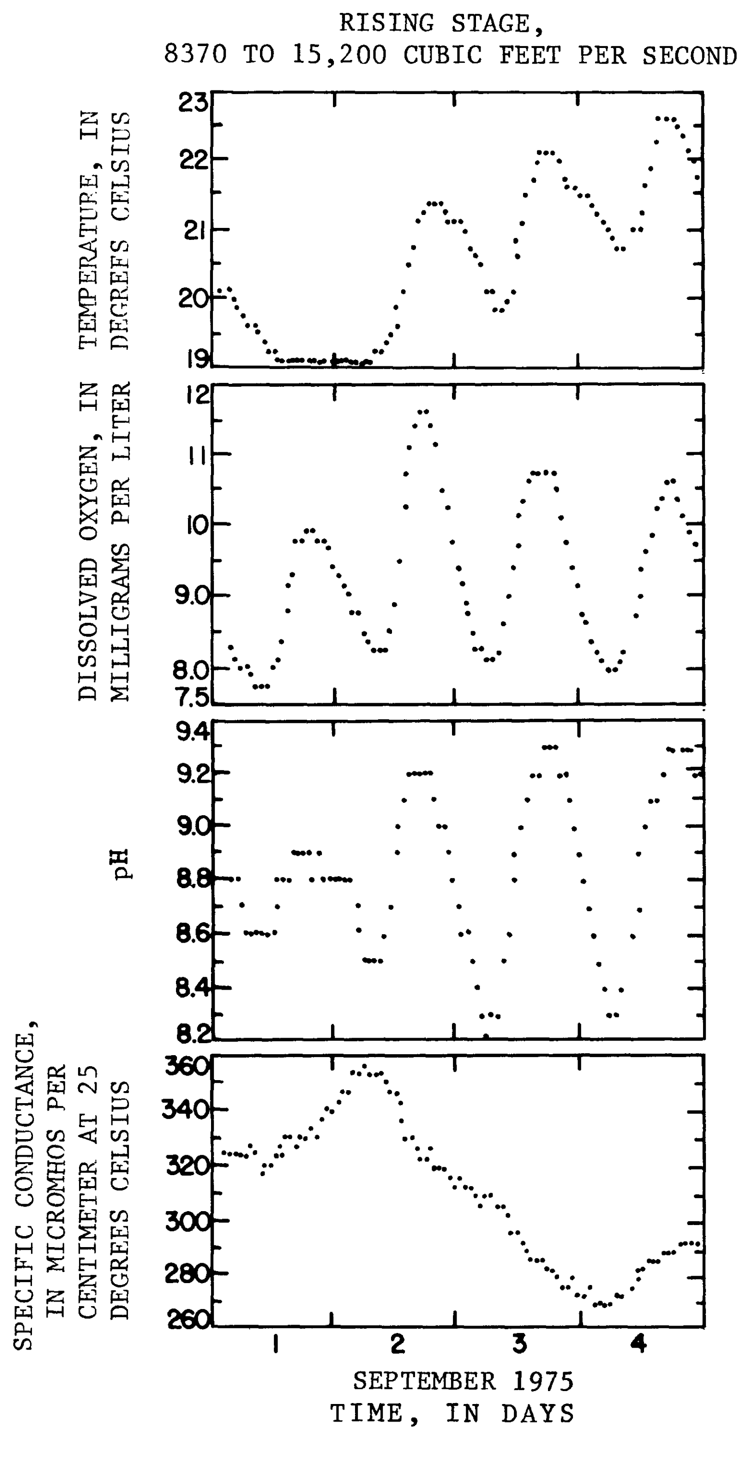


Figure 33.--Diel variation of water temperature, dissolved oxygen, pH, and specific conductance during rising stage, September 1 to 4, 1975.

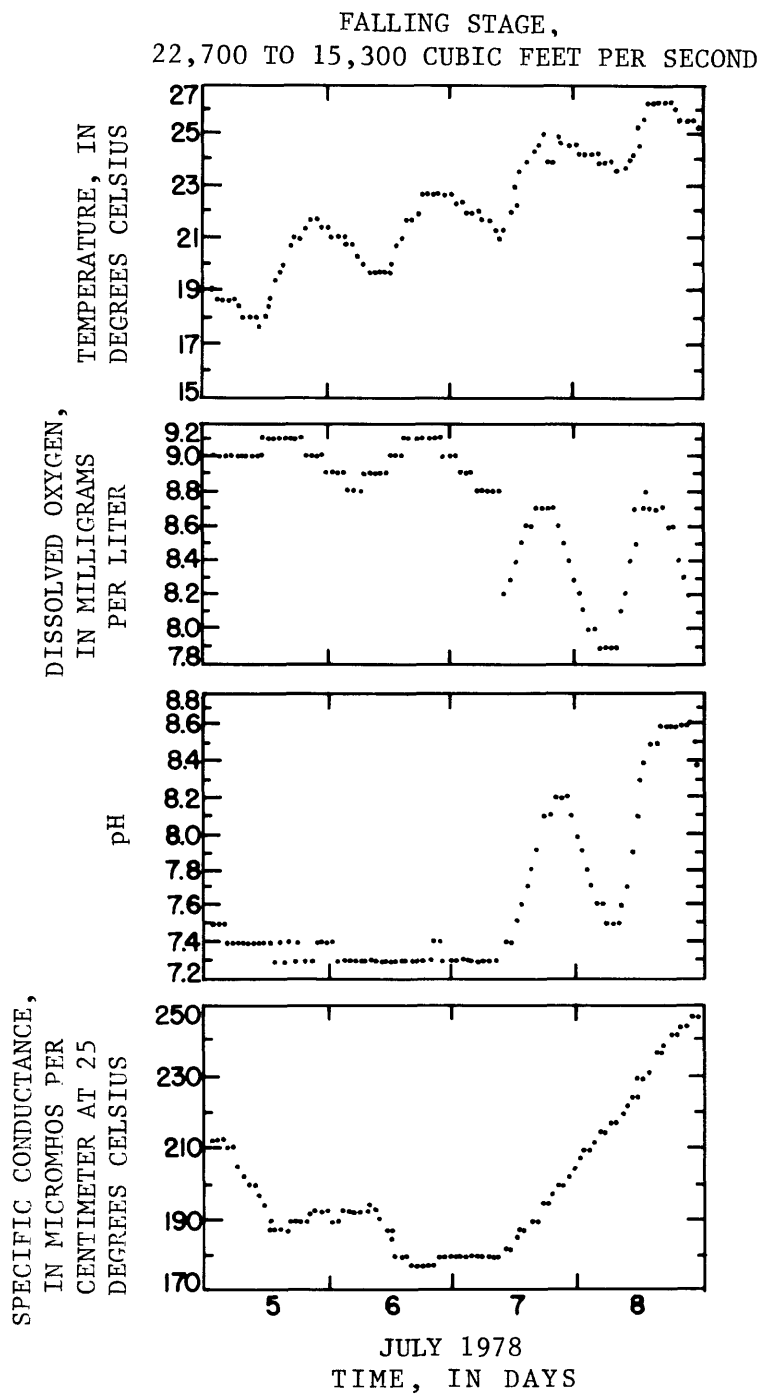


Figure 34.--Diel variation of water temperature, dissolved oxygen, pH, and specific conductance during falling stage, July 5 to 8, 1978.

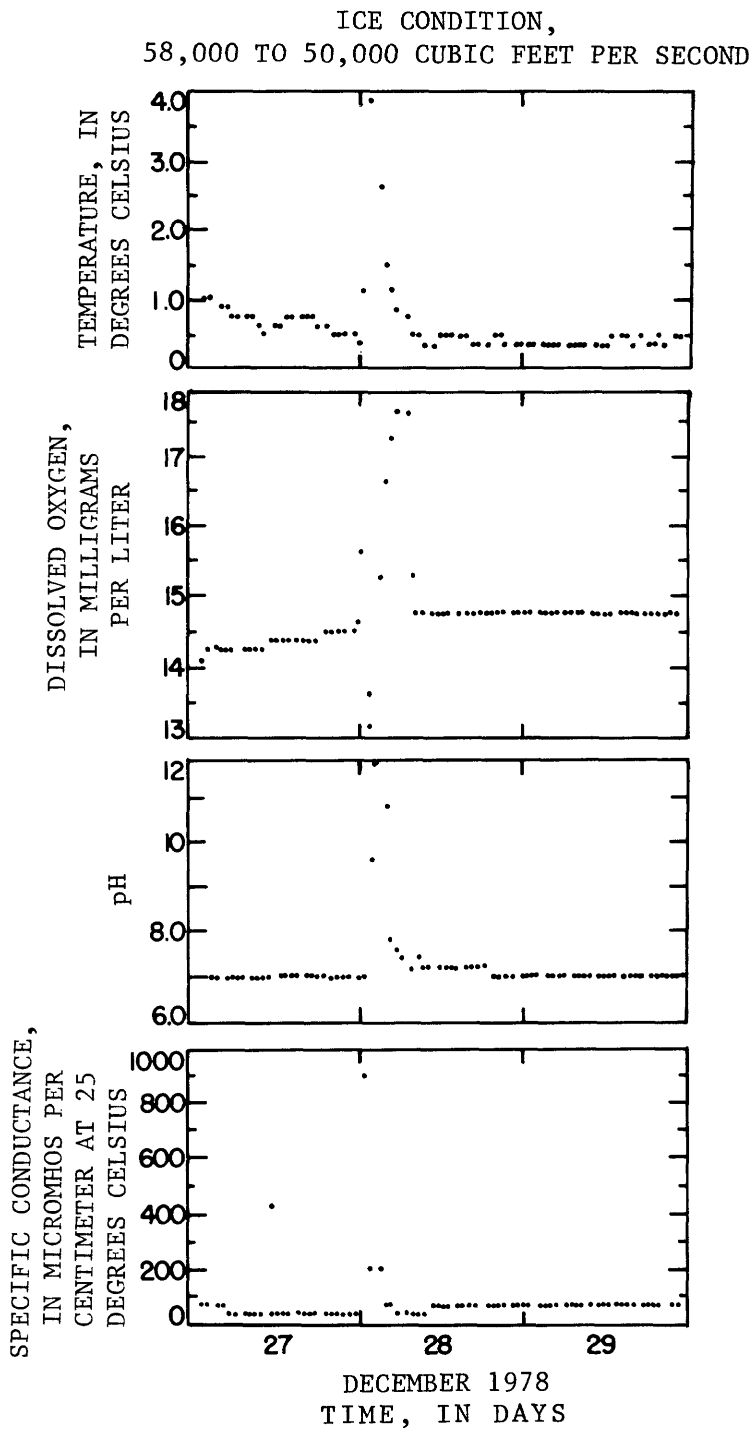


Figure 35.--Diel variation of water temperature, dissolved oxygen, pH, and specific conductance during period of melting ice, December, 27 to 29, 1978.

# SUMMARY

1. Precipitation during the study was 6.0 inches below the normal of 38.21 inches, but the month of February 1981 was 133 percent above normal.

2. The average mean daily streamflow of 26,500 ft$^3$/s was 23 percent below the long term mean of 34,500 ft$^3$/s. Total streamflow for the period was 77 percent of the average annual flow.

3. Regression analyses show that constituent loads and streamflow are directly related and have coefficients of determination greater than 0.80 for 35 of the 42 constituents sampled.

4. Annual loads of chemical constituents were computed using three methods; hydrograph and subdivided day, flow-duration, and regression equation with mean daily discharge; differences in results using the three methods was usually less than 5 percent.

5. The nitrogen load in tons for the period of study was composed of:

| | Dissolved | Suspended | Total |
|---|---|---|---|
| Ammonia as N | 1,680 | 580 | 2,260 |
| Nitrite as N | 290 | 73 | 363 |
| Nitrate as N | 25,200 | 1,110 | 26,300 |
| Organic as N | 4,820 | 8,180 | 13,000 |
| Total nitrogen | 31,990 | 9,933 | 41,923 |
| Percentage | 76 | 24 | 100 |

6. The phosphorus load in tons for the period of study was composed of:

| | Dissolved | Suspended | Total |
|---|---|---|---|
| Orthophosphate as P | 243 | 336 | 579 |
| Phosphorus as P | 484 | 2,446 | 2,930 |
| Total phosphorus | 484 | 2,446 | 2,930 |
| Percentage | 17 | 83 | 100 |

7. The suspended-sediment load transported during the study was 2,300,000 tons for a yield of 95.4 tons/mi$^2$. These results are believed to be comparable to previous records because streamflow for the period of study was 23 percent below normal, and the suspended-sediment load was 72 percent of the average annual load.

8. About 21 percent more dissolved solids was transported than suspended-sediment.

9. The amount of dissolved sulfate, calcium, and chloride transported was 32, 17, and less than 1 percent of the total dissolved solid load, respectively.

10. The mean daily concentration for total recoverable iron was 3,000 µg/L and was three times greater than the EPA criterion for freshwater aquatic life. The mean daily concentration will be equaled or exceeded about 15 percent of the time.

11. The mean concentration for total recoverable manganese was 390 µg/L and will be equaled or exceeded 20 percent of the time. Since EPA criteria for manganese is 100 µg/L for protection of consumers of marine mollusks, adverse affects on the shellfish industry may occur if concentrations for manganese entering the Bay are as high as those at Harrisburg.

12. Instantaneous concentrations for total recoverable lead exceeded the EPA criteria of 50 µg/L for domestic water supplies on February 14, 18, and 24, 1981, when concentrations were 110, 85, and 140 µg/L, respectively.

13. Ninety-five percent of the 111,000 ton iron, aluminum and manganese load was associated with the suspended sediment.

14. Of all the pesticides analyzed, 2,4-D varied the most throughout the study, and atrazine varied mostly during the spring and summer seasons.

15. Seasonal variation of constituent loads was largely dependent on streamflow as 67 percent of the total streamflow occurred during April 1980 and February and March of 1981. Ninety-two percent of the suspended-sediment load, and 73, 85, and 74 percent of the loads for dissolved nitrate and total and dissolved phosphorus occurred during the same period.

16. Maximum concentrations of suspended sediment differed between the east and west channels and fluctuated from one channel to the other. Specific conductance, dissolved nutrients, and major ion values were higher along the east and west banks than those in the center of the River.

17. Dissolved nitrate and orthophosphate concentrations were significantly higher closest to the west bank of the River.

18. Diel variations of water temperature, dissolved oxygen, pH, and specific conductance were greatest during the months of June, July, August, and September from 1974 to 1978. Diel variations were observed for water temperature, dissolved oxygen, and pH during all streamflows except peak flow and ice melt. Specific conductance showed no regular diel variation pattern, and was inversely related to streamflow. All four constituents were greatly influenced for short durations by melting ice.

## SUGGESTIONS FOR FURTHER STUDIES

Further investigation into the reason that dissolved constituents have significantly higher concentrations along the east and west banks than in the center of the Susquehanna River needs to be undertaken. A study of the cross-sectional variation of the river upstream and downstream of Harrisburg may help to identify point sources of dissolved nutrients, especially nitrate, as well as constituents such as calcium, chloride, and sulfate. Data also need to be collected to determine if dissolved metal concentrations are higher along the east and west banks of the river than in the center of the river. Contributions made by urban runoff entering the Susquehanna River from the numerous storm sewers in Harrisburg and from the Conodoguinet Creek drainage also needs to be evaluated.

Because of the relatively low streamflow conditions during the spring and summer of 1980, seasonal characterization of pesticides was difficult. Additional data collection need to be initiated to quantify the amount of pesticides being transported by the Susquehanna River at Harrisburg. Because previous studies have already identified 2,4-D and atrazine as the principal pesticides transported, intensive sampling should be limited to these two herbicides. Differences in the herbicide load in the east and west channels needs to be quantified.

Since much of the phosphorus and metal load at Harrisburg was determined to be suspended and is believed to deposit within the three major reservoirs downstream from Harrisburg, a detailed study of the deposition of these materials needs to be made.

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Table 13.--Durations of estimated daily streamflow and constituent loads

| Duration (percent) | Daily streamflow, in cubic feet per second, and daily constituent load, in tons | | | | | |
|---|---|---|---|---|---|---|
| | Streamflow | Aluminum dissolved | Aluminum total | Calcium dissolved | Carbon organic dissolved | Carbon organic suspended |
| 1.25 | 212,000 | 16.6481 | 1,148.56 | 6,597.81 | 1,972.33 | 933.927 |
| 5.00 | 116,000 | 10.7793 | 381.41 | 4,350.11 | 1,016.62 | 463.731 |
| 10.00 | 70,000 | 7.6011 | 161.46 | 3,146.30 | 607.16 | 269.020 |
| 15.00 | 43,800 | 5.2805 | 68.02 | 2,275.62 | 362.61 | 156.064 |
| 20.00 | 33,900 | 4.3267 | 43.08 | 1,920.44 | 276.81 | 117.336 |
| 25.00 | 24,000 | 3.2551 | 22.91 | 1,523.70 | 191.55 | 79.528 |
| 30.00 | 20,100 | 2.7748 | 16.26 | 1,346.79 | 157.40 | 64.629 |
| 35.00 | 17,500 | 2.4504 | 12.51 | 1,227.72 | 135.84 | 55.318 |
| 40.00 | 15,600 | 2.2015 | 10.02 | 1,136.58 | 120.15 | 48.591 |
| 45.00 | 13,200 | 1.8829 | 7.29 | 1,020.23 | 101.19 | 40.526 |
| 50.00 | 11,000 | 1.5575 | 4.98 | 901.78 | 83.15 | 32.934 |
| 55.00 | 9,130 | 1.2688 | 3.32 | 797.08 | 68.32 | 26.764 |
| 60.00 | 8,270 | 1.1369 | 2.67 | 749.38 | 61.93 | 24.127 |
| 65.00 | 7,840 | 1.0430 | 2.24 | 715.48 | 57.54 | 22.322 |
| 70.00 | 7,400 | .9827 | 1.99 | 693.75 | 54.78 | 21.194 |
| 75.00 | 6,700 | .8675 | 1.54 | 652.23 | 49.66 | 19.106 |
| 80.00 | 5,940 | .7070 | .99 | 594.57 | 42.86 | 16.353 |
| 85.00 | 4,700 | .4696 | .32 | 509.57 | 33.53 | 12.618 |
| 90.00 | 3,900 | .3037 | .00 | 450.40 | 27.55 | 10.254 |
| 95.00 | 3,500 | .2097 | .00 | 416.97 | 24.37 | 9.007 |
| 98.75 | 3,320 | .1740 | .00 | 404.30 | 23.20 | 8.552 |
| Mean | 26,500 | 2.88 | 65.8 | 1,400 | 223 | 98.0 |
| Annual total | 9,680,000 | 1,050 | 24,000 | 510,000 | 81,600 | 35,800 |

Table 13.--Durations of estimated daily streamflow and constituent loads-Continued

| Duration (percent) | Daily streamflow, in cubic feet per second, and daily constituent load, in tons | | | | | | |
|---|---|---|---|---|---|---|---|
| | Stream-flow | Chloride dissolved | Chromium total | Copper total | Fluoride dissolved | Iron dissolved | Iron total |
| 1.25 | 212,000 | 3,645.75 | 7.57336 | 8.78800 | 54.5063 | 37.6455 | 3,769.98 |
| 5.00 | 116,000 | 2,324.52 | 4.88684 | 3.78948 | 30.8428 | 21.7781 | 1,212.47 |
| 10.00 | 70,000 | 1,638.00 | 3.39435 | 1.96993 | 19.8068 | 14.0992 | 501.38 |
| 15.00 | 43,800 | 1,154.24 | 2.28026 | 1.02405 | 12.7197 | 9.0090 | 206.98 |
| 20.00 | 33,900 | 960.88 | 1.81443 | .72693 | 10.0862 | 7.0697 | 130.04 |
| 25.00 | 24,000 | 748.31 | 1.28395 | .45555 | 7.3509 | 5.0161 | 68.80 |
| 30.00 | 20,100 | 654.89 | 1.04320 | .35506 | 6.2097 | 4.1439 | 48.88 |
| 35.00 | 17,500 | 592.57 | .87944 | .29452 | 5.4716 | 3.5737 | 37.77 |
| 40.00 | 15,600 | 545.18 | .75304 | .25204 | 4.9240 | 3.1472 | 30.43 |
| 45.00 | 13,200 | 485.14 | .59024 | .20266 | 4.2482 | 2.6161 | 22.42 |
| 50.00 | 11,000 | 424.58 | .42262 | .15795 | 3.5887 | 2.0918 | 15.74 |
| 55.00 | 9,130 | 371.57 | .27266 | .12311 | 3.0315 | 1.6436 | 10.96 |
| 60.00 | 8,270 | 347.61 | .20372 | .10868 | 2.7863 | 1.4444 | 9.11 |
| 65.00 | 7,840 | 330.65 | .15447 | .09899 | 2.6155 | 1.3050 | 7.92 |
| 70.00 | 7,400 | 319.81 | .12277 | .09301 | 2.5075 | 1.2165 | 7.20 |
| 75.00 | 6,700 | 299.18 | .06194 | .08211 | 2.3046 | 1.0495 | 5.93 |
| 80.00 | 5,940 | 270.71 | .00000 | .06811 | 2.0307 | .8223 | 4.39 |
| 85.00 | 4,700 | 229.15 | .00000 | .04988 | 1.6446 | .4983 | 2.54 |
| 90.00 | 3,900 | 200.54 | .00000 | .03887 | 1.3893 | .2811 | 1.53 |
| 95.00 | 3,500 | 184.50 | .00000 | .03327 | 1.2502 | .1616 | 1.05 |
| 98.75 | 3,320 | 178.45 | .00000 | .03126 | 1.1986 | .1170 | .89 |
| Mean | 26,500 | 700 | 1.10 | .72 | 7.63 | 4.99 | 211 |
| Annual total | 9,680,000 | 255,000 | 401 | 262 | 2,790 | 1,820 | 76,800 |

Table 13.--Durations of estimated daily streamflow and constituent loads-Continued

| | Daily streamflow, in cubic feet per second, and daily constituent load, in tons | | | | | | |
|---|---|---|---|---|---|---|---|
| Duration (percent) | Stream-flow | Lead total | Magnesium dissolved | Manganese dissolved | Manganese total | Mercury total | Nickel total |
| 1.25 | 212,000 | 8.93114 | 1,650.23 | 66.3712 | 342.479 | 0.0477339 | 9.02125 |
| 5.00 | 116,000 | 5.26784 | 1,131.85 | 33.4721 | 148.314 | .0382023 | 5.47149 |
| 10.00 | 70,000 | 3.38182 | 844.16 | 19.4706 | 77.109 | .0308489 | 3.60564 |
| 15.00 | 43,800 | 2.06332 | 629.59 | 11.1560 | 39.860 | .0235475 | 2.27775 |
| 20.00 | 33,900 | 1.53956 | 539.94 | 8.2520 | 28.100 | .0197436 | 1.74285 |
| 25.00 | 24,000 | .96659 | 437.90 | 5.3762 | 17.319 | .0145793 | 1.15126 |
| 30.00 | 20,100 | .71589 | 391.61 | 4.2281 | 13.312 | .0118357 | .88982 |
| 35.00 | 17,500 | .54907 | 360.13 | 3.5048 | 10.893 | .0097829 | .71481 |
| 40.00 | 15,600 | .42252 | 335.84 | 2.9791 | 9.193 | .0080754 | .58142 |
| 45.00 | 13,200 | .26251 | 304.57 | 2.3445 | 7.213 | .0056897 | .41191 |
| 50.00 | 11,000 | .10157 | 272.37 | 1.7423 | 5.417 | .0029701 | .24033 |
| 55.00 | 9,130 | .00000 | 243.58 | 1.2485 | 4.013 | .0002579 | .08959 |
| 60.00 | 8,270 | .00000 | 230.35 | 1.0360 | 3.431 | .0000000 | .02124 |
| 65.00 | 7,840 | .00000 | 220.89 | .8899 | 3.039 | .0000000 | .00000 |
| 70.00 | 7,400 | .00000 | 214.81 | .7984 | 2.798 | .0000000 | .00000 |
| 75.00 | 6,700 | .00000 | 203.14 | .6284 | 2.357 | .0000000 | .00000 |
| 80.00 | 5,940 | .00000 | 186.81 | .4032 | 1.789 | .0000000 | .00000 |
| 85.00 | 4,700 | .00000 | 162.46 | .0948 | 1.049 | .0000000 | .00000 |
| 90.00 | 3,900 | .00000 | 145.29 | .0000 | .601 | .0000000 | .00000 |
| 95.00 | 3,500 | .00000 | 135.49 | .0000 | .372 | .0000000 | .00000 |
| 98.75 | 3,320 | .00000 | 131.76 | .0000 | .290 | .0000000 | .00000 |
| Mean | 26,500 | .99 | 394 | 6.54 | 27.4 | .009 | 1.09 |
| Annual total | 9,680,000 | 360 | 144,000 | 2,390 | 9,990 | 3.46 | 396 |

Table 13.--Durations of estimated daily streamflow and constituent loads-Continued

Daily streamflow, in cubic feet per second, and daily constituent load, in tons

| Duration (percent) | Streamflow | Nitrogen ammonia dissolved | Nitrogen ammonia total | Nitrogen ammonia+ Org.dissolved | Nitrogen ammonia+ Org.total | Nitrogen nitrate dissolved | Nitrogen nitrate total |
|---|---|---|---|---|---|---|---|
| 1.25 | 212,000 | 36.6205 | 51.4806 | 175.751 | 471.565 | 787.669 | 825.654 |
| 5.00 | 116,000 | 20.1967 | 27.8880 | 88.096 | 223.998 | 353.922 | 370.114 |
| 10.00 | 70,000 | 12.5669 | 17.1575 | 51.483 | 125.542 | 189.968 | 198.294 |
| 15.00 | 43,800 | 7.6834 | 10.4128 | 30.087 | 70.362 | 101.965 | 106.239 |
| 20.00 | 33,900 | 5.8736 | 7.9487 | 22.708 | 51.954 | 73.604 | 76.616 |
| 25.00 | 24,000 | 3.9976 | 5.4226 | 15.472 | 34.357 | 47.194 | 49.060 |
| 30.00 | 20,100 | 3.2164 | 4.3813 | 12.609 | 27.556 | 37.234 | 38.679 |
| 35.00 | 17,500 | 2.7117 | 3.7127 | 10.815 | 23.355 | 31.170 | 32.363 |
| 40.00 | 15,600 | 2.3376 | 3.2195 | 9.516 | 20.347 | 26.878 | 27.894 |
| 45.00 | 13,200 | 1.8763 | 2.6144 | 7.956 | 16.776 | 21.843 | 22.655 |
| 50.00 | 11,000 | 1.4267 | 2.0284 | 6.484 | 13.455 | 17.233 | 17.862 |
| 55.00 | 9,130 | 1.0473 | 1.5374 | 5.284 | 10.792 | 13.597 | 14.082 |
| 60.00 | 8,270 | .8805 | 1.3226 | 4.770 | 9.665 | 12.077 | 12.504 |
| 65.00 | 7,840 | .7644 | 1.1735 | 4.418 | 8.898 | 11.050 | 11.438 |
| 70.00 | 7,400 | .6910 | 1.0795 | 4.197 | 8.421 | 10.414 | 10.778 |
| 75.00 | 6,700 | .5532 | .9035 | 3.789 | 7.541 | 9.250 | 9.570 |
| 80.00 | 5,940 | .3673 | .6670 | 3.250 | 6.391 | 7.743 | 8.007 |
| 85.00 | 4,700 | .1055 | .3363 | 2.517 | 4.851 | 5.758 | 5.948 |
| 90.00 | 3,900 | .0000 | .1196 | 2.051 | 3.891 | 4.543 | 4.690 |
| 95.00 | 3,500 | .0000 | .0024 | 1.805 | 3.390 | 3.917 | 4.042 |
| 98.75 | 3,320 | .0000 | .0000 | 1.715 | 3.208 | 3.692 | 3.809 |
| Mean | 26,500 | 4.23 | 5.88 | 18.8 | 45.4 | 68.7 | 71.8 |
| Annual total | 9,680,000 | 1,540 | 2,150 | 6,860 | 16,600 | 25,100 | 26,200 |

Table 13.--Durations of estimated daily streamflow and constituent loads-Continued

Daily streamflow, in cubic feet per second, and daily constituent load, in tons

| Duration (percent) | Streamflow | Nitrite dissolved | Nitrite total | Nitrate+ nitrite dissolved | Nitrate+ nitrite total | Nitrogen organic dissolved | Nitrogen organic total |
|---|---|---|---|---|---|---|---|
| 1.25 | 212,000 | 5.40301 | 7.73388 | 712.494 | 825.251 | 101.336 | 380.763 |
| 5.00 | 116,000 | 3.67830 | 5.02246 | 328.429 | 371.409 | 55.647 | 186.719 |
| 10.00 | 70,000 | 2.66505 | 3.51040 | 179.823 | 199.604 | 34.761 | 107.076 |
| 15.00 | 43,800 | 1.87126 | 2.37797 | 98.457 | 107.272 | 21.575 | 61.223 |
| 20.00 | 33,900 | 1.52664 | 1.90327 | 71.816 | 77.486 | 16.741 | 45.597 |
| 25.00 | 24,000 | 1.12238 | 1.36158 | 46.705 | 49.727 | 11.773 | 30.411 |
| 30.00 | 20,100 | .93393 | 1.11529 | 37.129 | 39.252 | 9.720 | 24.453 |
| 35.00 | 17,500 | .80365 | .94758 | 31.258 | 32.871 | 8.400 | 20.739 |
| 40.00 | 15,600 | .70181 | .81803 | 27.082 | 28.353 | 7.425 | 18.061 |
| 45.00 | 13,200 | .56883 | .65100 | 22.156 | 23.052 | 6.227 | 14.857 |
| 50.00 | 11,000 | .42953 | .47882 | 17.613 | 18.196 | 5.065 | 11.849 |
| 55.00 | 9,130 | .30259 | .32460 | 14.001 | 14.363 | 4.090 | 9.412 |
| 60.00 | 8,270 | .24341 | .25363 | 12.484 | 12.760 | 3.663 | 8.373 |
| 65.00 | 7,840 | .20080 | .20290 | 11.454 | 11.677 | 3.367 | 7.662 |
| 70.00 | 7,400 | .17321 | .17023 | 10.816 | 11.007 | 3.180 | 7.218 |
| 75.00 | 6,700 | .11991 | .10753 | 9.643 | 9.779 | 2.829 | 6.398 |
| 80.00 | 5,940 | .04447 | .01972 | 8.119 | 8.189 | 2.357 | 5.318 |
| 85.00 | 4,700 | .00000 | .00000 | 6.094 | 6.093 | 1.697 | 3.857 |
| 90.00 | 3,900 | .00000 | .00000 | 4.845 | 4.809 | 1.263 | 2.936 |
| 95.00 | 3,500 | .00000 | .00000 | 4.197 | 4.148 | 1.029 | 2.451 |
| 98.75 | 3,320 | .00000 | .00000 | 3.963 | 3.910 | .942 | 2.274 |
| Mean | 26,500 | .904 | 1.16 | 65.0 | 72.2 | 12.6 | 38.3 |
| Annual total | 9,680,000 | 330 | 422 | 23,700 | 26,400 | 4,600 | 14,000 |

Table 13.--Durations of estimated daily streamflow and constituent loads-Continued

| Duration (percent) | Daily streamflow, in cubic feet per second, and daily constituent load, in tons | | | | | | |
|---|---|---|---|---|---|---|---|
| | Stream-flow | Nitrogen dissolved | Nitrogen total | Phosphorus dissolved | Phosphorus total | Potassium dissolved | Sediment suspended |
| 1.25 | 212,000 | 955.094 | 1317.97 | 9.43400 | 90.9024 | 822.294 | 121,386 |
| 5.00 | 116,000 | 448.407 | 614.06 | 6.07591 | 43.6287 | 472.296 | 34,150 |
| 10.00 | 70,000 | 249.041 | 339.02 | 4.23112 | 24.4457 | 306.842 | 12,735 |
| 15.00 | 43,800 | 138.315 | 187.17 | 2.86730 | 13.5083 | 199.350 | 4,749 |
| 20.00 | 33,900 | 101.645 | 137.12 | 2.30135 | 9.8095 | 159.040 | 2,833 |
| 25.00 | 24,000 | 66.781 | 89.71 | 1.66064 | 6.2364 | 116.875 | 1,400 |
| 30.00 | 20,100 | 53.378 | 71.54 | 1.37143 | 4.8421 | 99.168 | 962 |
| 35.00 | 17,500 | 45.122 | 60.37 | 1.17534 | 3.9757 | 87.671 | 726 |
| 40.00 | 15,600 | 39.226 | 52.41 | 1.02438 | 3.3527 | 79.115 | 574 |
| 45.00 | 13,200 | 32.244 | 43.00 | .83048 | 2.6093 | 68.522 | 413 |
| 50.00 | 11,000 | 25.772 | 34.29 | .63150 | 1.9139 | 58.140 | 284 |
| 55.00 | 9,130 | 20.599 | 27.34 | .45416 | 1.3525 | 49.331 | 195 |
| 60.00 | 8,270 | 18.416 | 24.42 | .37285 | 1.1137 | 45.441 | 161 |
| 65.00 | 7,840 | 16.932 | 22.43 | .31487 | .9507 | 42.726 | 140 |
| 70.00 | 7,400 | 16.010 | 21.20 | .27758 | .8491 | 41.007 | 128 |
| 75.00 | 6,700 | 14.314 | 18.93 | .20615 | .6614 | 37.773 | 106 |
| 80.00 | 5,940 | 12.100 | 15.98 | .10642 | .4150 | 33.394 | 80 |
| 85.00 | 4,700 | 9.144 | 12.04 | .00000 | .0829 | 27.194 | 50 |
| 90.00 | 3,900 | 7.309 | 9.60 | .00000 | .0000 | 23.074 | 34 |
| 95.00 | 3,500 | 6.354 | 8.33 | .00000 | .0000 | 20.822 | 27 |
| 98.75 | 3,320 | 6.008 | 7.88 | .00000 | .0000 | 19.984 | 25 |
| Mean | 26,500 | 90.1 | 123 | 1.43 | 8.26 | 119 | 6,020 |
| Annual total | 9,680,000 | 32,900 | 44,700 | 522 | 3,010 | 43,600 | 2,200,000 |

Table 13.--Durations of estimated daily streamflow and constituent loads-Continued

| Daily streamflow, in cubic feet per second, and daily constituent load, in tons | | | | | | |
|---|---|---|---|---|---|---|
| Duration (percent) | Stream-flow | Silica dissolved | Sodium dissolved | Solids dissolved | Sulfate dissolved | Zinc total |
| 1.25 | 212,000 | 3,104.35 | 2,055.77 | 40,514.9 | 10,917.5 | 32.1786 |
| 5.00 | 116,000 | 1,208.26 | 1,366.00 | 26,292.4 | 7,503.9 | 14.1643 |
| 10.00 | 70,000 | 579.70 | 993.97 | 18,783.4 | 5,605.8 | 7.4820 |
| 15.00 | 43,800 | 277.86 | 723.27 | 13,419.0 | 4,187.8 | 3.9522 |
| 20.00 | 33,900 | 188.89 | 612.32 | 11,251.6 | 3,594.5 | 2.8291 |
| 25.00 | 24,000 | 111.45 | 487.92 | 8,848.9 | 2,918.6 | 1.7933 |
| 30.00 | 20,100 | 84.04 | 432.26 | 7,784.8 | 2,611.7 | 1.4063 |
| 35.00 | 17,500 | 67.96 | 394.73 | 7,071.6 | 2,402.9 | 1.1719 |
| 40.00 | 15,600 | 56.91 | 365.95 | 6,527.5 | 2,241.8 | 1.0067 |
| 45.00 | 13,200 | 44.35 | 329.15 | 5,835.3 | 2,034.1 | .8137 |
| 50.00 | 11,000 | 33.29 | 291.61 | 5,133.6 | 1,820.2 | .6381 |
| 55.00 | 9,130 | 24.93 | 258.34 | 4,516.3 | 1,628.8 | .5004 |
| 60.00 | 8,270 | 21.55 | 243.16 | 4,236.0 | 1,540.8 | .4431 |
| 65.00 | 7,840 | 19.31 | 232.37 | 4,037.3 | 1,477.9 | .4045 |
| 70.00 | 7,400 | 17.94 | 225.44 | 3,910.1 | 1,437.5 | .3806 |
| 75.00 | 6,700 | 15.47 | 212.19 | 3,667.5 | 1,359.8 | .3371 |
| 80.00 | 5,940 | 12.35 | 193.76 | 3,331.5 | 1,251.1 | .2809 |
| 85.00 | 4,700 | 8.42 | 166.54 | 2,838.5 | 1,088.9 | .2073 |
| 90.00 | 3,900 | 6.12 | 147.55 | 2,497.2 | 974.4 | .1625 |
| 95.00 | 3,500 | 4.98 | 136.79 | 2,305.0 | 909.0 | .1396 |
| 98.75 | 3,320 | 4.58 | 132.71 | 2,232.3 | 884.1 | .1314 |
| Mean | 26,500 | 217 | 445 | 8,180 | 2,620 | 2.71 |
| Annual total | 9,680,000 | 79,200 | 163,000 | 2,990,000 | 958,000 | 990 |

Table 14.--Daily mean suspended-sediment concentrations and loads, April 1980 to March 1981
[Mean daily streamflow, in cubic feet per second: mean concentration, in milligrams per liter: sediment load, in tons]

| | April | | | May | | | June | | |
|---|---|---|---|---|---|---|---|---|---|
| Day | Mean streamflow | Mean concen-tration | Sediment load | Mean streamflow | Mean concen-tration | Sediment load | Mean streamflow | Mean concen-tration | Sediment load |
| 1 | 166,000 | 82 | 37,000 | 83,200 | 73 | 16,400 | 15,900 | 8 | 341 |
| 2 | 190,000 | 94 | 48,400 | 74,500 | 67 | 13,400 | 16,100 | 7 | 305 |
| 3 | 169,000 | 81 | 37,100 | 64,300 | 47 | 8,110 | 16,600 | 7 | 313 |
| 4 | 135,000 | 71 | 25,700 | 55,200 | 31 | 4,690 | 16,200 | 7 | 318 |
| 5 | 111,000 | 65 | 19,500 | 49,400 | 22 | 2,920 | 16,900 | 8 | 365 |
| 6 | 95,200 | 61 | 15,700 | 44,400 | 19 | 2,320 | 17,300 | 8 | 374 |
| 7 | 84,600 | 64 | 14,600 | 40,100 | 18 | 1,920 | 12,800 | 6 | 213 |
| 8 | 74,500 | 68 | 13,700 | 36,400 | 16 | 1,610 | 15,600 | 7 | 315 |
| 9 | 74,400 | 74 | 15,000 | 33,200 | 15 | 1,360 | 15,500 | 10 | 406 |
| 10 | 104,000 | 96 | 27,400 | 30,400 | 14 | 1,140 | 17,100 | 12 | 557 |
| 11 | 152,000 | 145 | 59,600 | 28,200 | 13 | 972 | 20,800 | 14 | 781 |
| 12 | 150,000 | 144 | 58,900 | 28,300 | 15 | 1,110 | 20,600 | 15 | 835 |
| 13 | 117,000 | 110 | 35,000 | 38,500 | 46 | 4,960 | 19,000 | 14 | 722 |
| 14 | 97,100 | 96 | 25,200 | 48,700 | 98 | 12,800 | 17,800 | 14 | 673 |
| 15 | 108,000 | 116 | 34,000 | 46,300 | 96 | 11,900 | 16,100 | 13 | 577 |
| 16 | 138,000 | 133 | 49,500 | 45,900 | 83 | 10,300 | 15,100 | 13 | 530 |
| 17 | 130,000 | 117 | 41,300 | 43,200 | 64 | 7,450 | 14,100 | 12 | 459 |
| 18 | 105,000 | 100 | 28,200 | 40,200 | 49 | 5,230 | 13,800 | 11 | 424 |
| 19 | 82,200 | 85 | 18,900 | 36,800 | 37 | 3,610 | 13,100 | 11 | 383 |
| 20 | 67,300 | 72 | 13,100 | 34,300 | 29 | 2,630 | 12,100 | 10 | 327 |
| 21 | 58,000 | 61 | 9,620 | 34,500 | 27 | 2,480 | 11,300 | 9 | 290 |
| 22 | 50,700 | 51 | 7,010 | 34,600 | 26 | 2,390 | 11,200 | 9 | 272 |
| 23 | 45,100 | 39 | 4,700 | 35,100 | 25 | 2,320 | 11,200 | 8 | 249 |
| 24 | 40,900 | 29 | 3,190 | 32,200 | 22 | 1,910 | 10,800 | 8 | 233 |
| 25 | 37,900 | 22 | 2,210 | 28,400 | 19 | 1,490 | 10,100 | 7 | 200 |
| 26 | 34,600 | 16 | 1,490 | 26,700 | 17 | 1,240 | 9,370 | 7 | 177 |
| 27 | 32,600 | 13 | 1,120 | 24,600 | 15 | 1,010 | 9,260 | 7 | 180 |
| 28 | 32,900 | 15 | 1,340 | 22,400 | 14 | 818 | 9,050 | 8 | 195 |
| 29 | 41,300 | 25 | 2,820 | 20,400 | 12 | 661 | 8,920 | 8 | 192 |
| 30 | 60,600 | 57 | 9,440 | 17,800 | 10 | 503 | 8,920 | 9 | 211 |
| 31 | --- | --- | --- | 16,400 | 9 | 406 | --- | --- | --- |
| TOTAL | 2,784,900 | --- | 660,740 | 1,194,600 | --- | 130,060 | 422,620 | --- | 11,417 |

Table 14.--Daily mean suspended-sediment concentrations and loads, April 1980 to March 1981-Continued
[Mean daily streamflow, in cubic feet per second: mean concentration, in milligams per liter: sediment load, in tons]

| | July | | | August | | | September | | |
|---|---|---|---|---|---|---|---|---|---|
| Day | Mean streamflow | Mean concen-tration | Sediment load | Mean streamflow | Mean concen-tration | Sediment load | Mean streamflow | Mean concen-tration | Sediment load |
| 1 | 8,660 | 9 | 218 | 6,870 | 10 | 193 | 4,040 | 4 | 39 |
| 2 | 8,920 | 12 | 296 | 6,430 | 12 | 213 | 4,070 | 3 | 33 |
| 3 | 11,100 | 15 | 440 | 6,320 | 15 | 253 | 4,200 | 4 | 41 |
| 4 | 13,500 | 16 | 588 | 6,320 | 18 | 298 | 4,380 | 4 | 48 |
| 5 | 18,500 | 18 | 898 | 6,320 | 21 | 356 | 4,440 | 5 | 60 |
| 6 | 14,600 | 14 | 554 | 6,650 | 23 | 405 | 4,480 | 6 | 71 |
| 7 | 13,000 | 13 | 457 | 7,200 | 24 | 479 | 4,370 | 7 | 81 |
| 8 | 12,300 | 13 | 432 | 7,200 | 23 | 447 | 4,480 | 8 | 96 |
| 9 | 11,700 | 12 | 389 | 7,920 | 20 | 437 | 7,400 | 12 | 250 |
| 10 | 11,400 | 12 | 367 | 7,810 | 18 | 384 | 5,530 | 10 | 150 |
| 11 | 12,100 | 11 | 367 | 7,740 | 16 | 340 | 3,980 | 8 | 87 |
| 12 | 12,000 | 11 | 357 | 7,810 | 14 | 305 | 3,880 | 8 | 84 |
| 13 | 12,700 | 10 | 352 | 7,940 | 13 | 288 | 3,830 | 8 | 85 |
| 14 | 10,500 | 10 | 284 | 9,680 | 15 | 382 | 3,650 | 9 | 89 |
| 15 | 9,570 | 10 | 257 | 8,440 | 14 | 308 | 3,590 | 9 | 87 |
| 16 | 8,790 | 10 | 239 | 8,450 | 12 | 283 | 3,700 | 9 | 90 |
| 17 | 9,180 | 10 | 246 | 7,880 | 11 | 241 | 3,600 | 9 | 88 |
| 18 | 8,790 | 10 | 236 | 7,330 | 10 | 206 | 3,590 | 9 | 87 |
| 19 | 8,530 | 10 | 231 | 10,300 | 14 | 388 | 3,700 | 9 | 89 |
| 20 | 9,050 | 10 | 249 | 9,420 | 14 | 349 | 4,240 | 9 | 102 |
| 21 | 10,700 | 11 | 319 | 8,230 | 13 | 282 | 4,260 | 8 | 96 |
| 22 | 8,920 | 9 | 221 | 7,330 | 12 | 230 | 4,090 | 8 | 89 |
| 23 | 7,920 | 8 | 170 | 6,820 | 11 | 196 | 3,960 | 8 | 86 |
| 24 | 7,800 | 7 | 154 | 6,340 | 10 | 168 | 3,860 | 8 | 84 |
| 25 | 7,320 | 7 | 133 | 5,880 | 9 | 143 | 3,720 | 8 | 81 |
| 26 | 7,320 | 6 | 118 | 5,480 | 8 | 121 | 3,590 | 8 | 76 |
| 27 | 7,090 | 5 | 105 | 5,170 | 8 | 106 | 3,360 | 9 | 81 |
| 28 | 6,760 | 5 | 93 | 4,800 | 7 | 89 | 3,320 | 10 | 88 |
| 29 | 6,430 | 6 | 106 | 4,600 | 6 | 72 | 3,440 | 11 | 100 |
| 30 | 6,210 | 7 | 123 | 4,430 | 5 | 60 | 3,420 | 12 | 109 |
| 31 | 6,430 | 9 | 149 | 4,320 | 4 | 47 | --- | --- | --- |
| TOTAL | 307,790 | --- | 9,148 | 217,430 | --- | 8,069 | 122,170 | --- | 2,647 |

Table 14.--Daily mean suspended-sediment concentrations and loads, April 1980 to March 1981-Continued
[Mean daily streamflow, in cubic feet per second: mean concentration, in milligams per liter: sediment load, in tons]

| | October | | | November | | | December | | |
|---|---|---|---|---|---|---|---|---|---|
| Day | Mean streamflow | Mean concen-tration | Sediment load | Mean streamflow | Mean concen-tration | Sediment load | Mean streamflow | Mean concen-tration | Sediment load |
| 1 | 3,400 | 13 | 119 | 11,100 | 25 | 748 | 21,300 | 20 | 1,160 |
| 2 | 3,330 | 13 | 116 | 9,980 | 23 | 611 | 18,900 | 14 | 705 |
| 3 | 3,400 | 13 | 120 | 8,660 | 20 | 479 | 16,800 | 11 | 518 |
| 4 | 3,650 | 12 | 122 | 7,680 | 16 | 332 | 18,500 | 17 | 848 |
| 5 | 3,480 | 12 | 114 | 7,090 | 12 | 234 | 22,700 | 34 | 2,120 |
| 6 | 3,570 | 12 | 115 | 6,320 | 9 | 162 | 24,200 | 25 | 1,630 |
| 7 | 3,650 | 12 | 115 | 5,800 | 7 | 114 | 24,300 | 17 | 1,120 |
| 8 | 3,650 | 10 | 99 | 5,600 | 6 | 83 | 21,800 | 12 | 685 |
| 9 | 3,480 | 9 | 81 | 5,400 | 4 | 63 | 18,900 | 8 | 423 |
| 10 | 3,480 | 7 | 69 | 5,200 | 3 | 46 | 17,500 | 8 | 356 |
| 11 | 3,650 | 6 | 62 | 5,100 | 3 | 35 | 17,500 | 7 | 340 |
| 12 | 3,480 | 5 | 51 | 5,300 | 2 | 29 | 19,600 | 11 | 605 |
| 13 | 3,330 | 5 | 42 | 5,900 | 2 | 32 | 22,900 | 17 | 1,070 |
| 14 | 3,330 | 4 | 36 | 6,100 | 2 | 31 | 21,800 | 11 | 647 |
| 15 | 3,400 | 5 | 44 | 6,320 | 1 | 17 | 19,600 | 6 | 339 |
| 16 | 3,400 | 6 | 51 | 6,320 | 1 | 17 | 17,700 | 6 | 283 |
| 17 | 3,400 | 6 | 60 | 6,650 | 1 | 18 | 15,900 | 5 | 215 |
| 18 | 3,480 | 8 | 71 | 7,320 | 1 | 20 | 14,700 | 5 | 198 |
| 19 | 3,480 | 9 | 82 | 7,200 | 1 | 19 | 13,800 | 5 | 186 |
| 20 | 3,260 | 10 | 93 | 7,320 | 1 | 20 | 11,000 | 4 | 119 |
| 21 | 3,260 | 12 | 101 | 7,320 | 1 | 20 | 9,200 | 4 | 99 |
| 22 | 3,260 | 10 | 84 | 7,090 | 1 | 19 | 7,400 | 4 | 80 |
| 23 | 3,330 | 8 | 70 | 7,090 | 1 | 19 | 6,700 | 6 | 109 |
| 24 | 3,400 | 6 | 59 | 8,040 | 1 | 22 | 6,300 | 7 | 119 |
| 25 | 4,120 | 5 | 58 | 10,300 | 5 | 132 | 5,900 | 8 | 127 |
| 26 | 4,830 | 6 | 84 | 14,000 | 8 | 304 | 5,600 | 5 | 84 |
| 27 | 5,500 | 9 | 129 | 15,600 | 9 | 396 | 5,200 | 6 | 96 |
| 28 | 8,160 | 11 | 254 | 17,800 | 17 | 871 | 5,900 | 6 | 113 |
| 29 | 11,200 | 13 | 410 | 23,800 | 39 | 2,520 | 7,000 | 6 | 159 |
| 30 | 9,700 | 13 | 346 | 22,700 | 30 | 1,860 | 8,400 | 7 | 157 |
| 31 | 10,800 | 21 | 604 | --- | --- | --- | 8,300 | 7 | 172 |
| TOTAL | 136,860 | --- | 3,861 | 270,100 | --- | 9,273 | 455,300 | --- | 14,882 |

Table 14.--Daily mean suspended-sediment concentrations and loads, April 1980 to March 1981-Continued
[Mean daily streamflow, in cubic feet per second: mean concentration, in milligams per liter: sediment load, in tons]

| | January | | | February | | | March | | |
|---|---|---|---|---|---|---|---|---|---|
| Day | Mean streamflow | Mean concen-tration | Sediment load | Mean streamflow | Mean concen-tration | Sediment load | Mean streamflow | Mean concen-tration | Sediment load |
| 1 | 8,200 | 7 | 155 | 5,700 | 5 | 77 | 91,300 | 39 | 9,730 |
| 2 | 8,100 | 7 | 153 | 6,000 | 8 | 130 | 73,300 | 33 | 6,450 |
| 3 | 8,000 | 6 | 130 | 10,000 | 10 | 270 | 61,600 | 28 | 4,590 |
| 4 | 6,500 | 6 | 105 | 15,000 | 12 | 486 | 55,100 | 23 | 3,490 |
| 5 | 7,000 | 5 | 94 | 18,000 | 14 | 680 | 49,100 | 20 | 2,650 |
| 6 | 6,600 | 5 | 89 | 16,000 | 13 | 561 | 44,800 | 17 | 2,050 |
| 7 | 6,200 | 6 | 100 | 15,000 | 11 | 445 | 40,300 | 14 | 1,560 |
| 8 | 6,000 | 6 | 97 | 14,500 | 12 | 470 | 36,300 | 12 | 1,200 |
| 9 | 5,900 | 7 | 111 | 14,000 | 17 | 643 | 32,300 | 10 | 908 |
| 10 | 5,800 | 7 | 110 | 16,000 | 15 | 648 | 29,500 | 9 | 722 |
| 11 | 5,700 | 6 | 92 | 25,000 | 20 | 1,350 | 28,100 | 9 | 685 |
| 12 | 5,600 | 6 | 91 | 142,000 | 284 | 127,000 | 27,200 | 9 | 659 |
| 13 | 5,500 | 6 | 89 | 147,000 | 315 | 128,000 | 26,200 | 9 | 636 |
| 14 | 5,300 | 6 | 86 | 110,000 | 164 | 49,400 | 25,500 | 8 | 569 |
| 15 | 5,200 | 7 | 98 | 83,200 | 103 | 23,300 | 23,200 | 8 | 503 |
| 16 | 5,200 | 7 | 98 | 65,400 | 81 | 14,300 | 23,200 | 8 | 502 |
| 17 | 5,200 | 6 | 84 | 54,300 | 70 | 10,300 | 22,700 | 8 | 492 |
| 18 | 5,400 | 6 | 87 | 49,500 | 68 | 9,100 | 22,100 | 8 | 476 |
| 19 | 5,600 | 6 | 91 | 54,100 | 86 | 12,800 | 22,000 | 8 | 490 |
| 20 | 5,500 | 6 | 89 | 106,000 | 179 | 56,200 | 20,100 | 9 | 488 |
| 21 | 5,500 | 5 | 74 | 214,000 | 339 | 196,000 | 19,400 | 9 | 471 |
| 22 | 5,600 | 5 | 76 | 247,000 | 274 | 183,000 | 18,800 | 10 | 497 |
| 23 | 5,600 | 5 | 76 | 228,000 | 206 | 127,000 | 17,800 | 10 | 482 |
| 24 | 5,600 | 5 | 76 | 274,000 | 267 | 199,000 | 17,100 | 11 | 489 |
| 25 | 5,600 | 5 | 76 | 268,000 | 195 | 142,000 | 16,500 | 11 | 489 |
| 26 | 5,700 | 5 | 77 | 202,000 | 141 | 78,400 | 15,700 | 11 | 469 |
| 27 | 5,800 | 5 | 78 | 149,000 | 74 | 30,200 | 15,300 | 10 | 415 |
| 28 | 5,900 | 5 | 80 | 116,000 | 50 | 15,800 | 15,200 | 10 | 412 |
| 29 | 5,800 | 5 | 78 | --- | --- | --- | 15,000 | 10 | 407 |
| 30 | 5,600 | 5 | 76 | --- | --- | --- | 15,200 | 10 | 389 |
| 31 | 5,600 | 5 | 76 | --- | --- | --- | 15,900 | 9 | 386 |
| TOTAL | 184,800 | --- | 2,892 | 2,664,700 | --- | 1,407,560 | 935,800 | --- | 43,756 |