Distribution and Transport of Trace Substances in the Schuylkill River Basin from Berne to Philadelphia, Pennsylvania

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By J. K. STAMER, T. H. YORKE,
and G. L. PEDERSON

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PREFACE

In 1973, the U.S. Geological Survey began a series of intensive river-quality assessments designed to demonstrate the use of river-quality studies in basin planning and water-resources management. The first of these assessments was conducted in the Willamette River basin, Oregon. Others have been completed in the Yampa River basin, Colorado and Wyoming; the Chattahoochee River basin, Georgia; the Apalachicola River basin, Florida; the Truckee and Carson River basins, California and Nevada; and the Potomac River basin, Maryland and Virginia. Objectives of the assessments were to define the types and amounts of data required to assess various river-quality problems and to develop and document methods for assessing planning alternatives in terms of potential impacts on river quality.

The assessments were a result of recommendations from the Advisory Committee on Water Data for Public Use. This committee was established to help implement Office of Management and Budget Circular A-67, which designated the U.S. Department of the Interior responsible for coordinating Federal water-data acquisition and the U.S. Geological Survey responsible for acquiring the data. In 1971, the Advisory Committee was concerned because suitable information on river-basin planning and on water-quality management of major rivers was not available. The concern resulted from the inadequacy of water data to address problems that demanded legislative action. Major problems included (1) definition of water quality of the Nation's rivers, (2) analysis of water-quality trends, especially the effectiveness of pollution-control programs in improving water quality, (3) determination of whether advanced waste-water treatment was desirable or necessary on a national, State, or river-basin basis, and (4) definition of the interrelation of land use and water quality. The committee recommended that the Geological Survey assess these problems, using the Willamette River basin for the pilot study.

This water-supply series, Water-Supply Paper 2256-A, consists of the two primary reports. The reports present the results of the Schuylkill River Quality Assessment, which is the first to address river-quality problems associated with trace metals and trace organic substances. The Schuylkill River was chosen for study because of heavy use of the river for municipal water supplies and a history of accidental spills and discharges of trace substances in the heavily industrialized reach of the river between Reading and Philadelphia, Pa.

The Schuylkill River Quality Assessment was divided into three components on the basis of results of review of water-quality conditions in the basin by the project staff and officials from local, State, and Federal agencies. The first component was a review of the methods of conducting trace substance studies and a determination of the most appropriate methods of sampling and analyzing water, sediment, and biota to define ambient conditions in the aquatic environment. The second component was a determination of the distribution and transport of trace metals and organic substances in the basin. The third component was a determination of the effects of the low dams in the lower part of the basin on the transport of sediment, trace metals, and organic substances. The first component of the assessment is addressed in both parts A and B of this series. The second and third components are presented in parts A and B, respectively.

Part A presents the analyses and interpretations of data collected in the Schuylkill River basin from Berne to the Fairmount Dam at Philadelphia. The purpose of the study was to determine (1) the distribution of trace substances in the Schuylkill River and its tributaries through analyses of streambed sediments, (2) the average annual transport of trace substances, including dissolved and total trace metals, from major tributaries and reaches of the river, and (3) the frequency at which concentrations of selected constituents exceed Federal and State water-quality.

Part B presents the analyses of information collected in part of the lower basin between Pottstown and Philadelphia, particularly in or near the pools formed by the six low dams on the river. The objectives for this part of the study were to determine (1) the sediment transport characteristics of the Schuylkill River and the major tributaries in the lower basin, (2) the sediment-deposition rates, the spatial and temporal deposition patterns, and the trap efficiency of the six pools, and (3) the transport characteristics of trace metals and organic substances in the river and the distribution and magnitude of trace substances deposited in the pools.

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Distribution and Transport of Trace Substances in the Schuylkill River Basin from Berne to Philadelphia, Pennsylvania

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Abstract

During the period from October 1978 to March 1981, the U.S. Geological Survey assessed the river quality of the Schuylkill River basin in Pennsylvania from the headwaters to the Fairmount Dam at Philadelphia (river mile 8.4). The assessment focused on the distribution and transport of trace metals and organic substances (trace substances). Trace metals included were arsenic, beryllium, cadmium, copper, lead, mercury, nickel, and zinc; trace organic substances included organochlorine insecticides and polychlorinated biphenyls.

In general, concentrations of trace substances in the streambed sediments were greater in the main stem of the Schuylkill River than in its tributaries and exceeded the background concentrations in the study area. Concentrations of most trace metals in the sediments were lowest in the Berne area (river mile 95) and highest in the urban-industrial area of Reading (river mile 76). Concentrations generally decreased from Reading downstream to Philadelphia (river mile 10.2). Concentrations of the organochlorine insecticides chlordane, DDT and its metabolites, and dieldrin generally increased gradually from Berne to Philadelphia. Average concentrations of trace metals in the main stem of the Schuylkill River in the sediment-sized fraction, less than 0.063 millimeters, were: zinc, 603 µg/g (micrograms per gram); lead, 284 µg/g; copper, 252 µg/g; nickel, 119 µg/g; chromium, 96 µg/g; beryllium, 8.2 µg/g; arsenic, 0.64 µg/g; and mercury, 0.002 µg/g. Average concentrations of trace organic substances in sediments of the main stem of the river were: polychlorinated biphenyls, 152 µg/kg (micrograms per kilogram); chlordane, 24 µg/kg; DDT and its metabolites, 18 µg/kg; and dieldrin, 1.8 µg/kg.

The average annual transport of trace substances by the river was computed for chromium, copper, lead, nickel, and zinc. Concentrations of other trace substances in the sediment-water mixtures were generally undetectable. Of the trace metals, average annual transport of zinc was the greatest, and that of nickel was the least. Transport of trace metals in the river is closely associated with and related to suspended-sediment transport. About 71 percent of the average annual total metal transport is particulate material.

Yields, in tons per square mile per year, of copper, lead, zinc, and total organic carbon in the Schuylkill River basin were compared with yields in the Chattahoochee River basin (Georgia). The comparison indicates that yields, by constituent, were of the same order of magnitude. Both basins lie in the Piedmont province, and both have about the same percentage of urban land use.

The frequency of occurrence of concentrations of copper, lead, and zinc in the sediment-water mixture at Manayunk in Philadelphia were compared with domestic water-supply criteria of the U.S. Environmental Protection Agency. The criteria are exceeded less than 1 percent of the time, or about 4 days per year.

INTRODUCTION

In the last 200 years, the use of the Schuylkill River (fig. 1) has undergone considerable evolution. Philadelphia began using the river for water supply in 1801. From 1824 to 1928, the river was used to barge coal from the Southern Anthracite coal fields. Commercial mining of coal had begun in about 1820, with production peaking in the 1920's and 1940's. The mining and processing of coal resulted in discharge of acidic waters and large quantities of coal fines into the Schuylkill. By the early 1940's, the river's channel was so clogged with coal fines that the Schuylkill became known as the river that was "too thick to navigate and too thin to cultivate." In 1945, by authority of the Clean Streams Act, the Commonwealth of Pennsylvania ordered that municipal and industrial wastewaters discharged into the basin's waters be treated.

In 1947, under authority of the Clean Streams Act and the Desilting Act, restoration of the Schuylkill began with construction of desilting basins and dredging. By 1954, the State and Federal governments together had removed 54 million cubic yards of sediment from the river. In 1972, by authority of Public Law 92-500, wastewater-treatment facilities were upgraded, and plans to assess nonpoint-source discharges were studied. In 1978, a 226-foot-long fish ladder was constructed at Fairmount Dam to permit anadromous fish such as alewife, blueback herring, and shad to enter a 6-mile reach of the river. In 1979, the Governor of Pennsylvania designated the Schuylkill from the Little Schuylkill River

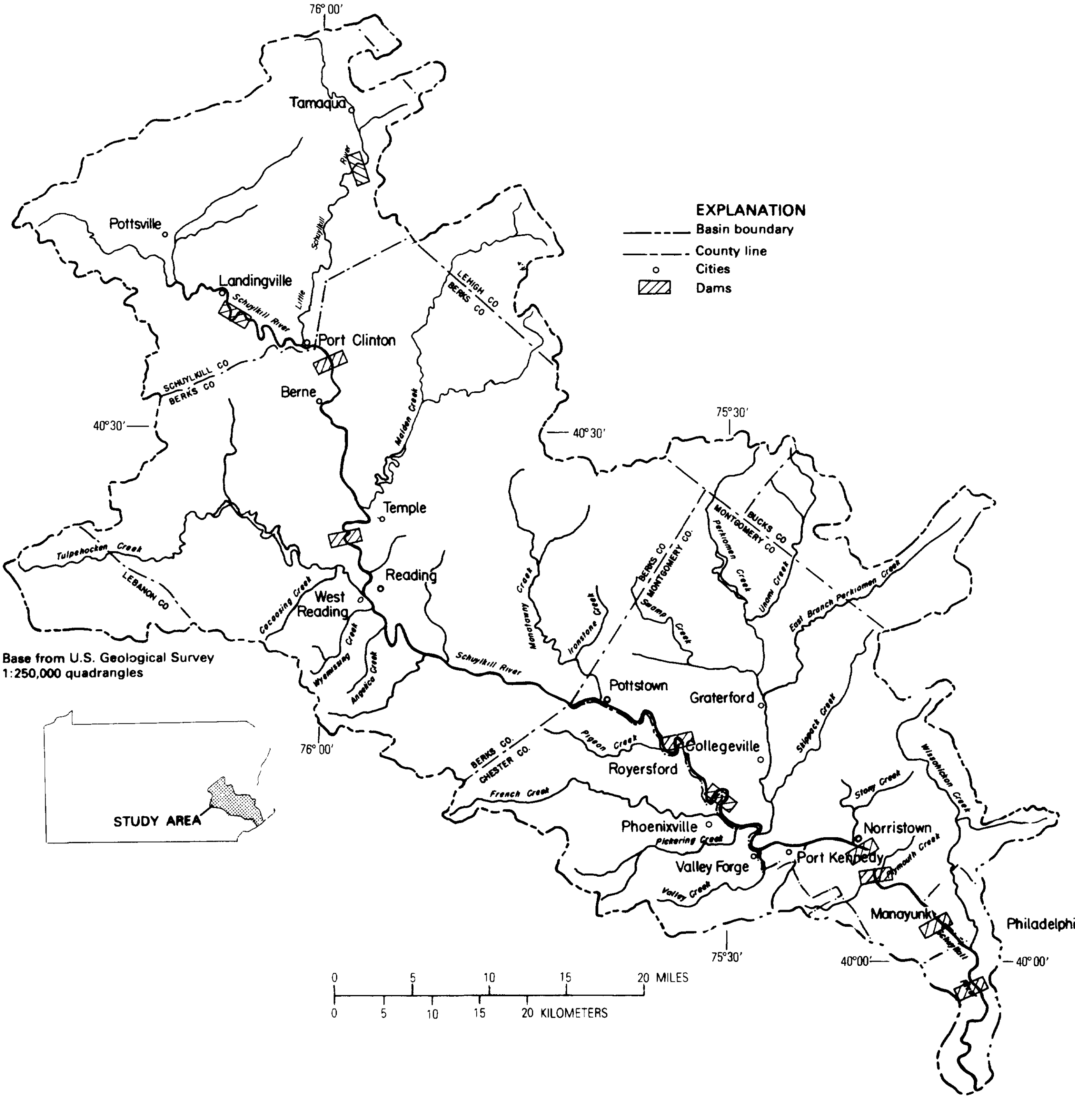

Figure 1. Schuylkill River basin.

confluence to Philadelphia's Fairmount Dam the first river segment to be included in the Pennsylvania Scenic Rivers System, thus culminating efforts to commit the river for recreation. The designation is largely in the "recreation" classification, with several reaches in urban areas designated "modified recreation."

The Schuylkill is one of the most extensively used rivers in the country. Its waters and those of its tributaries are used for municipal and industrial supply, waste assimilation, and recreation. The river and its tributaries are the primary source of public-water supply in the basin, and withdrawals average 700 ft^3/s per day. The largest public user is the city of Philadelphia, which withdraws an average of 290 ft^3/s. Other major withdrawals for municipal water supply are made by the Philadelphia Suburban Water Company, which withdraws water from Pickering and Perkiomen Creeks and from the Schuylkill, and the Keystone Water Company in Norristown, the Pottstown Water Authority, and the Borough of Phoenixville, all of which withdraw water exclusively from the Schuylkill. The Reading Bureau of Water withdraws water from Maiden Creek, and the Western Berks Water Authority withdraws water from Tulpehocken Creek. Industry, however, is the largest water user, with an average daily withdrawal of 810 ft^3/s, of which 760 ft^3/s is used to cool the condensers of two thermoelectric plants. Other significant industrial users include steel, coal, and paper producers. About 240 ft^3/s of municipal wastewater is discharged into the basin, with 68 percent of the total discharged downstream from Norristown. Most industrial wastewater discharges are from Reading downstream and, with the exception of discharges from cooling uses, are small compared with municipal discharges.

The Schuylkill River and its tributaries are used for powerboating, canoeing, sculling, water skiing, and fishing. Interest in water-oriented recreation has been increasing steadily since the Schuylkill River restoration project of the 1950's. The former navigation pools of the Schuylkill, formed by low dams such as Fairmount and Flat Rock Dams in Philadelphia, Norristown and Black Rock Dams near Phoenixville, and Felix Dam near Reading, are centers for boating and water skiing. The Pennsylvania Fish Commission anticipates that other fish ladders, in addition to the one at Fairmount Dam, will be built at five low dams between Philadelphia and Reading.

The Schuylkill River restoration project, upgraded treatment of municipal and industrial wastewaters, and inclusion of the Schuylkill in the Pennsylvania Scenic Rivers System have resulted in increased emphasis on recreation and establishment of an anadromous fish population. The Safe Drinking Water Act of 1974 and the Toxic Substances Control Act of 1976 have increased the emphasis on protection of public-water supplies and aquatic biota.

To address the new emphasis, the U.S. Geological Survey assessed the Schuylkill River from Berne to Philadelphia. The $2\frac{1}{2}$-year study, begun October 1, 1978, was part of a series of studies by the Survey to assess the quality of some of the Nation's major rivers. The studies were to provide water-quality information to basin planners. Studies have been completed on the Willamette River in Oregon, the Upper Chattahoochee River in Georgia, and the Yampa River in Colorado and Wyoming. Concurrent with the Schuylkill River study were studies of the Potomac River from Washington, D.C., to Chesapeake Bay, the Apalachicola River in Florida, and the Truckee and Carson Rivers in California and Nevada.

The Schuylkill River assessment had three work elements. The element discussed in this report focused on the distribution and transport of trace substances (trace metals and organic substances); the second element evaluated the effects of low dams on the distribution of trace substances; the third evaluated methodologies for trace-substance studies.

The occurrence of trace substances in the basin is well documented. Trace substances have been identified and quantified in the sediments, fish, and, to a lesser extent, streamwaters. Trace substances are commonly associated with sediments for several reasons: (1) trace metals are absorbed onto iron and manganese hydrous oxides (Jenne, 1968); (2) most trace substances are sparingly soluble in water; and (3) most trace substances persist in the environment (for example, the production and specified uses of PCB's and DDT are prohibited in the United States, but residuals of both compounds have been identified in the sediments). Anomalously high concentrations of lead have been observed by Brezina and others (1974) in the Schuylkill River and are attributed to a storage-battery reclamation plant and to a lagoon containing high concentrations of lead that spilled into the river during Hurricane Agnes. Since 1973, the Pennsylvania Department of Environmental Resources has been analyzing fish samples for selected compounds, including lead and PCB's. The highest concentrations of PCB's observed in Pennsylvania were in the edible part of carp (7.5 mg/kg) (milligrams per kilogram) and American eels (6.1 mg/kg) taken from the Schuylkill (Brezina and Arnold, 1976). The Pennsylvania Department of Environmental Resources expressed concern at the time because these concentrations exceeded the Food and Drug Administration's "Action Level" of 5 mg/kg. Concentrations in excess of 5 mg/kg were also measured in white sucker fillets in 1977. Followup sampling in 1979 indicated a decrease in concentrations of PCB's in fish from the Schuylkill (E. Brezina and R. Frey, Pennsylvania Department of Environmental Resources, written commun., 1981).

Objectives and Scope

This report is part of the Schuylkill River quality assessment. The study had three objectives: (1) to determine the distribution of trace substances in the Schuylkill River and its tributaries through analyses of streambed sediments; (2) to determine the average annual transport of trace substances, including dissolved and total trace metals, from major tributaries and reaches of the river; and (3) to determine the frequency with which concentrations of selected constituents exceed Federal and State water-quality criteria. The study area included the entire drainage of the Schuylkill River between the headwaters and Fairmount Dam at Philadelphia (RM 10.2[1]). Some data initially were collected in the reach of the river from the headwaters to Fairmount Dam; however, the main emphasis of the study was the main stem of the river from Berne (RM 95.5) to Fairmount Dam and the tributaries entering the river downstream from Berne. Specific tasks of the study included: (1) collecting and analyzing streambed sediments and suspended-sediment-water mixtures for trace substances; (2) collecting and analyzing streamflow data at gaged and ungaged stations; (3) collecting and analyzing suspended-sediment data over a wide range of streamflows and climatic conditions; and (4) analyzing trace-substance data from records collected by the U.S. Geological Survey, the Pennsylvania Department of Environmental Resources, municipal water- and wastewater-treatment plants, and privately owned water-treatment plants.

Previous Studies

The Delaware Valley Regional Planning Commission (1978), in cooperation with the Pennsylvania Department of Environmental Resources, developed an areawide plan for managing waste treatment to protect surface water and ground water from contamination. Wood and MacLachlan (1978) described the geology and ground water of northern Berks County, and McGreevy and Sloto (1978) described the ground water of Chester County. Flippo (1977) prepared a manual for estimating the magnitude and frequency of floods in Pennsylvania, and Page and Shaw (1977) described the low-flow characteristics of Pennsylvania streams. Brezina and Arnold (1977) reported on the concentrations of heavy metals in Pennsylvania fish. Brezina and Arnold (1976) reported the results of a statewide monitoring program to determine the concentrations of PCB's and other persistent chlorinated hydrocarbons in fish. Brezina and others (1974) described the chemical and biological characteristics of the basin. A. W. Martin Associates, Inc. (1973) presented a plan for abating acid mine drainage into the Little Schuylkill River. Biesecker and others (1968) described the quality and quantity of water resources of the Schuylkill River basin. Parker and others (1964) described the water resources of the Delaware River basin. White and Lindholm (1950) described the flow and water quality of the Schuylkill River as related to the Schuylkill River restoration project. A more complete listing of publications on the water resources of the Delaware River basin is given in Biesecker and others (1968) and in Subitzky and others (1964).

Acknowledgments

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DESCRIPTION OF THE SCHUYLKILL RIVER BASIN

The Schuylkill River (fig. 1) lies entirely in southeastern Pennsylvania. The downstream boundary of the study area is at Philadelphia, where the river drains 1,893 mi^2. The largest tributaries of the Schuylkill are Perkiomen (362

[1]Zero river mile (RM 0.0) is defined as the confluence of the Schuylkill and Delaware Rivers at Philadelphia, Pa. The RM of a tributary to the Schuylkill River is designated as the RM on the Schuylkill River at the tributary confluence.

mi²), Tulpehocken (219 mi²), and Maiden (216 mi²) Creeks. Collectively, they drain 42 percent of the study area. Principal municipalities, in downstream order, are Pottsville, Reading, Pottstown, Phoenixville, Norristown, and Philadelphia; Philadelphia and Reading are the most populous.

Physiography, Topography, and Geology

The Schuylkill flows through four physiographic provinces (Fenneman, 1938)--the Valley and Ridge, New England, Piedmont, and Coastal Plain provinces (fig. 2). The Valley and Ridge province is characterized by mountains in the

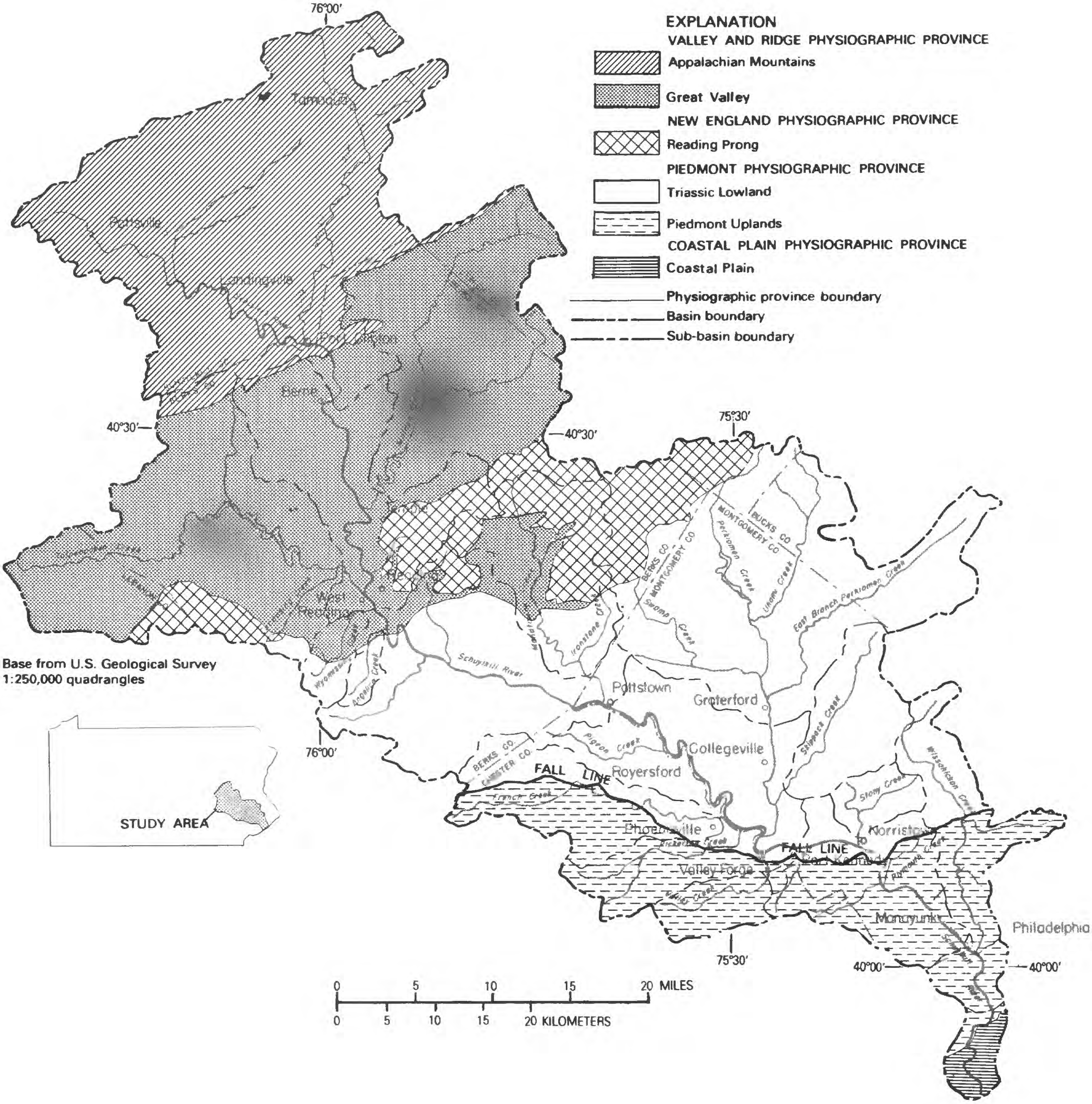

Figure 2. Physiographic provinces in the Schuylkill River basin.

Appalachian section and by open, rolling farmlands in the Great Valley section. Principal streams draining the Appalachian section are the Schuylkill and Little Schuylkill Rivers. Principal streams draining the Great Valley section are Maiden and Tulpehocken Creeks. The small mountains east of Reading, known as the Reading Prong, are part of the New England province. Manatawny Creek is the principal stream that rises in the Reading Prong. The Piedmont province is characterized by rich farmland on low, rolling hills in the Triassic Lowland section and by an urban area on steep hills in the Piedmont Uplands section. Principal streams draining the Triassic Lowland section are French and Perkiomen Creeks. Pickering, Valley, and Wissahickon Creeks are the principal streams in the Piedmont section. In Philadelphia, the fall line separates the Piedmont and Coastal Plain provinces. The Coastal Plain province, which has extremely low relief, is drained by several small tributaries to the Schuylkill.

Rocks in the Schuylkill River basin range in age from Precambrian to Quaternary. The Appalachian section of the Valley and Ridge province is composed primarily of coal, sandstone, and shale of Pennsylvanian age. The Great Valley section is composed chiefly of shale and carbonate rocks also of Pennsylvanian age. The Reading Prong of the New England province consists mostly of dolomite and sandstone of Precambrian and Cambrian age. Red shale and sandstone intruded by diabase predominate in the Triassic Lowland section of the Piedmont province. The Piedmont Uplands section of the Piedmont province is underlain by shale, limestone, gneiss, and schist, ranging in age from Precambrian to Ordovician. The Coastal Plain province is characterized mostly by sand and gravel deposits of Quaternary age.

Climate and Hydrology

Annual air temperatures average about 52°F in the study area and range from 55°F in the relatively flat Coastal Plain to 49°F in the mountainous headwaters. The coldest months are January and February, and the warmest are July and August. Precipitation averages about 42 inches per year and ranges from about 40 inches in the Coastal Plain to about 49 inches in the headwaters area. Precipitation is generally greatest in July and August and least in January and February, although it is fairly evenly distributed throughout the year. During December, January, and February, precipitation commonly is in the form of freezing rain, sleet, or snow.

Average annual streamflow (table 1) in the Schuylkill River basin is dependent on the amount

Table 1. Hydrologic data for selected stations in the Schuylkill River basin

Station name	Drainage area (mi^2)	Average discharge (ft^3/s)	7-day, 10-year minimum streamflow (ft^3/s)	Period of record (years)	Average water yield (cubic feet per second per square mile)
Schuylkill River at Landingville	133	303	41	12	2.28
Little Schuylkill River at Tamaqua	42.9	94	5.1	59	2.19
Schuylkill River at Berne	355	722	83	31	2.03
Maiden Creek tributary at Lenhartsville	7.46	12	0.07	13	1.61
Tulpehocken Creek near Reading	211	315	48	28	1.49
Schuylkill River at Reading	880	1,409	160	13	1.69
Schuylkill River at Pottstown	1,147	1,910	259	52	1.66
French Creek near Phoenixville	59.1	97	12	10	1.64
Pickering Creek near Chester Springs	5.98	11	1.7	11	1.84
Perkiomen Creek at Graterford	279	389	18	64	1.39
Skippack Creek near Collegeville	53.7	83	1.4	12	1.55
Wissahickon Creek at Mouth, Philadelphia	64.0	95	13	13	1.48
Schuylkill River at Philadelphia	1,893	2,910	[1]69	47	1.54

[1]Does not include diversion by city of Philadelphia.

of precipitation, soils, geology, and topography. Maximum streamflow per unit area occurs in the upper basin, where precipitation and land-surface altitudes are highest; minimum streamflow occurs in the lower basin, where precipitation and land-surface altitudes are lowest. Monthly streamflow is highest from February to April and lowest from August to October. Although precipitation is less in the cooler months than in the warmer months, streamflow is higher in the cooler months because of the increased runoff due to saturated soils, near-maximum ground-water storage, and periodic snowmelts. In the warmer months, the lesser streamflow results from decreased runoff due to higher rates of evaporation and transpiration, increased infiltration, and unsaturated soils.

Ground-water availability in the Schuylkill River basin is dependent on the physiography, geology, and distribution of precipitation. In general, ground-water levels are highest in the winter and decline from March through late fall. Although precipitation is greater in summer than winter, much of the summer precipitation is evaporated from the soil surface and transpired by plants. The influence of physiography and geology is represented by the high ground-water yields from the carbonate rocks in the Great Valley section and from unconsolidated deposits in the Coastal Plain section. In contrast, crystalline rock and shale of the Triassic Lowland section have the lowest ground-water yields. The low ground-water discharge in drainage basins in the Triassic Lowland section results in the unusually low 7-day, 10-year minimum streamflow of Perkiomen and Skippack Creeks (table 1) relative to their drainage areas.

Land Use

Land use in the study area (table 2) is approximately 15 percent urban, 51 percent agricultural, 31 percent forested, and 3 percent "other." Urban use includes residential, commercial, and industrial activities. Agricultural land includes cropland, pastureland, and confined feedlot operations. Forested land includes coniferous and deciduous forests and wetlands, and the "other" category includes water and mining activities. From table 2, the largest percentage of urban land is from Port Kennedy to Philadelphia, the largest percentage of agricultural land is from Berne to Reading, and the largest percentage of forested land is from Reading to Pottstown.

Land use along the tributaries included in the transport study is shown in figure 3. The diameter of each pie diagram is in proportion to the drainage area. Agriculture is the dominant land use in the basins of the four largest tributaries in the study area, Perkiomen, Tulpehocken, Maiden, and Manatawny Creeks. Urban land use is dominant in the Wissahickon Creek basin.

METHODS OF DATA COLLECTION, LABORATORY PROCEDURES, AND DATA ANALYSIS

From December 1978 to August 1980, samples of streambed sediments and sediment-water mixtures were collected to determine the distribution and transport of trace substances in the Schuylkill River basin.

Table 2. Land use in the study area

Basin from	Drainage area (square miles)	Land use: Urban, Square miles	Urban, Percentage	Agriculture, Square miles	Agriculture, Percentage	Forest, Square miles	Forest, Percentage	Other, Square miles	Other, Percentage
Berne to Reading	525	31.0	5.9	395	75.2	96.0	18.3	3.0	0.6
Reading to Pottstown	267	26.6	10.0	118	44.2	120	45.0	2.4	0.8
Pottstown to Port Kennedy	544	64.8	11.9	341	62.8	133	24.5	5.2	0.8
Port Kennedy to Manayunk	120	86.0	70.7	21.0	17.3	10.0	8.2	3.0	3.8
Manayunk to Philadelphia	82	58.0	70.6	14.0	17.1	9.0	11.0	1.0	1.3

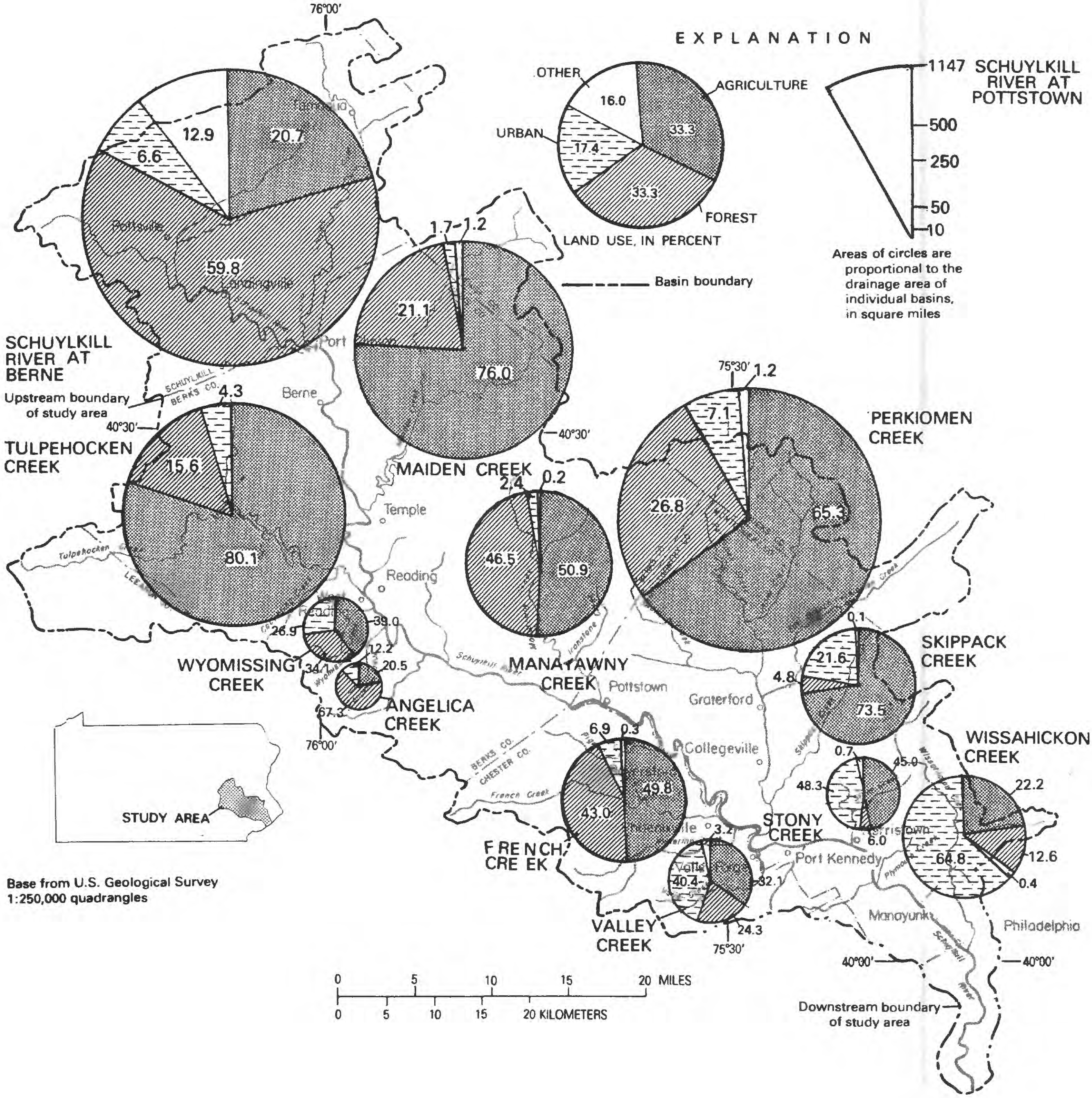

Figure 3. Land use in the Schuylkill River basin.

During a low-flow period in December 1978, streambed material was sampled at 51 sites in the Schuylkill River basin and analyzed for trace metals, particle-size distribution, and, at most of the 51 sites, organochlorine insecticides and PCB's. Of the 51 sites sampled, 19 were on the main stem of the river and 32 were on tributaries. The main stem was sampled from RM 124.9 to RM 10.2 at intervals of about 5 river miles. Tributaries having drainage areas of at least 20 mi^2, or about 1 percent of the total drainage area at Fairmount Dam, were sampled; smaller tributaries were sampled if they drained urban areas. The upper 10 mm of bed material was sampled with a nylon spoon. The sediment was placed in a glass jar and chilled to about 40°F. The gravel and cobbles in the streambeds precluded the use of a standard bed-material sampler as recommended by Guy and Norman (1970). In the laboratory, the samples were sieved through 2-mm nylon mesh. The size fraction less than 2 mm was then analyzed for metals using the methods described by Skougstad and others (1979), for organic substances using the methods described by the U.S. Geological Survey (1973), and for particle-size distribution using the methods described by Guy (1969).

During a low-flow period in November and December of 1979, bed material in the Schuylkill River basin was again sampled. On the basis of analytical results of the bed-material samples collected in 1978, no samples were taken upstream of Schuylkill River at Berne (RM 95.5). The 1979 sampling involved 39 sites on the main stem of the river at intervals of about 2 river miles, and 30 sites on 23 tributaries. Figure 4 shows the bed-sediment sites in the study area, and table 3 lists the

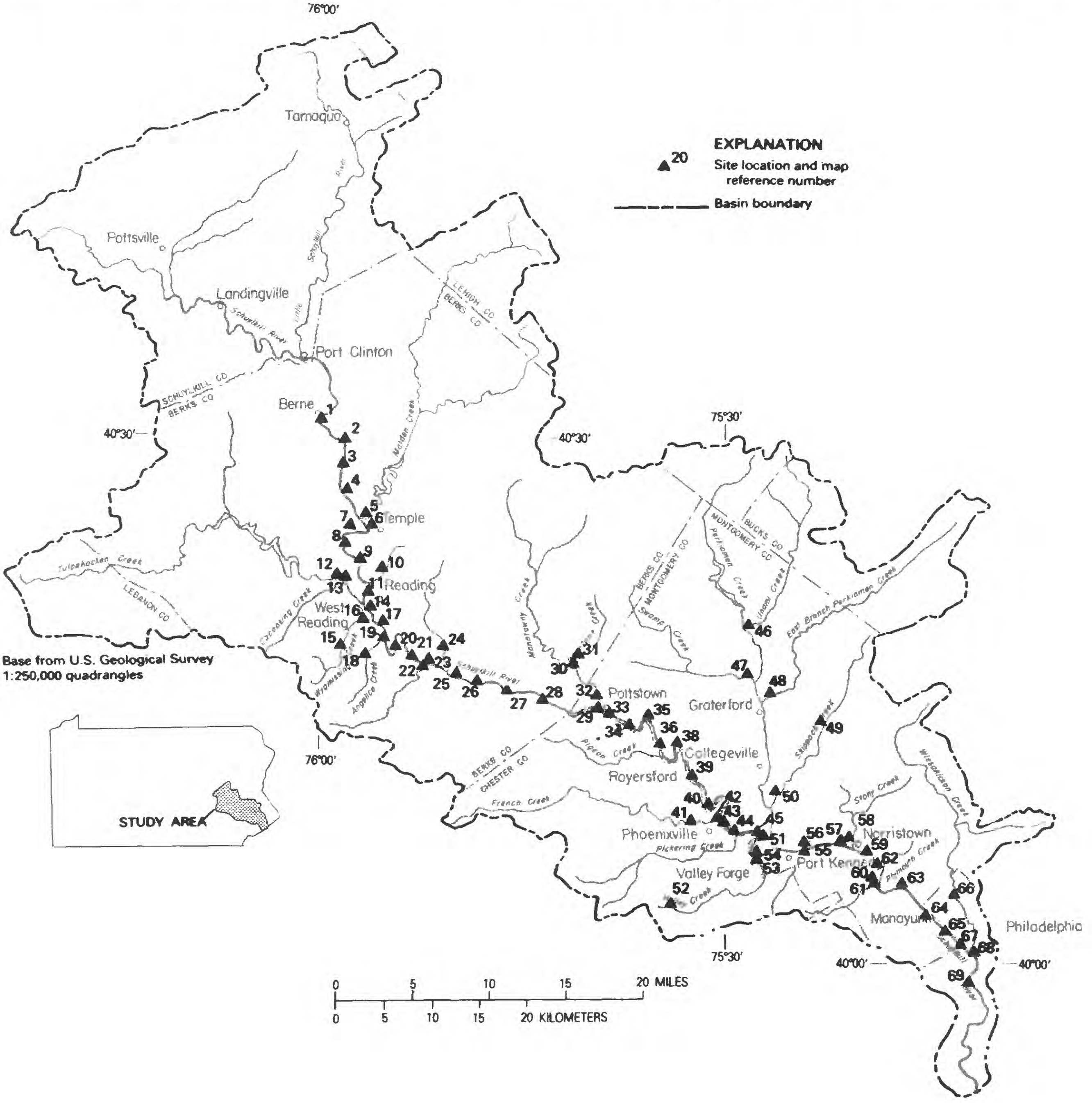

Figure 4. Bed-sediment sites.

Table 3. Map-reference number, station name, and river mile of bed-sediment sites in the Schuylkill River basin

Map-reference number (fig. 4)	Station name	River mile[1]
1	Schuylkill River at Berne	95.5
2	Schuylkill River at Shoemakersville	92.6
3	Schuylkill River at Mohrsville	90.8
4	Schuylkill River at Leesport	88.7
5	Maiden Creek near Leesport	86.7
6	Schuylkill River at Ontelaunee near Temple	85.9
7	Schuylkill River at Stoudts Ferry near Reading	83.9
8	Schuylkill River at Felix Dam near Reading	82.0
9	Schuylkill River at Muhlenberg	80.2
10	Bernhart Run at Reading Creek	78.3
11	Schuylkill River above Tulpehocken Creek at Reading	77.4
12	Cacoosing Creek near Reading	---
13	Tulpehocken Creek near Reading	76.8
14	Schuylkill River at Reading	75.7
15	Wyomissing Creek at Shillington	---
16	Wyomissing Creek at Museum Road, West Reading	75.3
17	Schuylkill River at South Street, Reading	74.4
18	Angelica Creek near Shillington	---
19	Angelica Creek at Reading	73.2
20	Schuylkill River at Ridgewood near Reading	71.4
21	Schuylkill River at Seyfert near Gibraltar	68.4
22	Allegheny Creek at Gibraltar	67.7
23	Schuylkill River near Lorane	67.3
24	Antietam Creek at Lorane	66.1
25	Schuylkill River at Heisters Creek near Birdsboro	65.1
26	Schuylkill River at Birdsboro	63.6
27	Schuylkill River at Monocacy Station near Birdsboro	61.0
28	Schuylkill River at Douglasville	58.2
29	Schuylkill River at Stowe near Pottstown	56.1
30	Manatawny Creek at Pine Forge	---
31	Ironstone Creek near Pine Forge	---
32	Manatawny Creek at Pottstown	54.2
33	Schuylkill River at Pottstown	53.7
34	Schuylkill River at East Coventry near Pottstown	51.4
35	Schuylkill River at Sanatoga Station near Pottstown	49.1
36	Schuylkill River at Linfield	46.8
37	Pigeon Creek at Parker Ford	46.5
38	Schuylkill River below Vincent Dam at Linfield	44.2
39	Schuylkill River at Royersford	41.4
40	Schuylkill River at Black Rock Pool near Phoenixville	39.2
41	French Creek at Nutt Road near Phoenixville	---
42	French Creek at Phoenixville	35.6
43	Schuylkill River at Phoenixville	35.6
44	Schuylkill River at Port Providence near Phoenixville	34.5
45	Schuylkill River at Oaks	32.6
46	Unami Creek at Perkiomenville	---
47	Swamp Creek near Zieglersville	---
48	East Branch Perkiomen Creek at Schwenksville	---
49	Skippack Creek at Skippack	---
50	Skippack Creek near Collegeville	---
51	Perkiomen Creek at Oaks	32.3
52	Valley Creek at Valley Forge	---
53	Valley Creek near Devault	30.6

See footnote at end of table.

Table 3. Map-reference number, station name, and river mile of bed-sediment sites in the Schuylkill River basin—Continued

Map-reference number (fig. 4)	Station name	River mile[1]
54	Schuylkill River at Valley Forge	30.6
55	Trout Creek near Valley Forge	27.5
56	Schuylkill River at Trout Creek near Valley Forge	27.4
57	Schuylkill River at Norristown	24.6
58	Stony Creek at Norristown	24.3
59	Schuylkill River at Swedesburg near Bridgeport	22.7
60	Schuylkill River above Plymouth Dam near Conshohocken	20.8
61	Gulph Creek at West Conshohocken	20.6
62	Plymouth Creek near Conshohocken	20.5
63	Schuylkill River at Spring Mill near Conshohocken	18.8
64	Schuylkill River above Flat Rock Dam, Philadelphia	15.7
65	Schuylkill River at Manayunk, Philadelphia	14.2
66	Wissahickon Creek at Bells Mill Road, Philadelphia	---
67	Wissahickon Creek at Mouth, Philadelphia	12.8
68	Schuylkill River at Falls Bridge, Philadelphia	12.1
69	Schuylkill River at Philadelphia	10.2

[1]RM indicated only for sites on the main stem of the Schuylkill River or for the mouth of its tributaries.

corresponding map-reference numbers, station names, and river miles. Samples were collected as they were in 1978 but were then sieved in the field through a 63-micrometer-mesh, stainless-steel sieve to reduce the site-to-site variation of constituent concentrations due to variations in particle-size distributions. Analyses were made on the fraction (silt- and clay-sized) that passed through the sieve. Determinations of trace metals, organochlorine insecticides, organic carbon, PCB's, and particle-size distribution were made on all samples collected. Concentrations of these constituents were plotted on normal-probability paper by the method described by Velz (1970) and were also plotted in relation to river mile to illustrate the distribution and to indicate sources of trace substances. The seven run-of-the-river dams downstream from Berne are not specifically shown in the constituent-concentration river-mile plots. The pools formed by the low dams were sampled; however, the data do not indicate that the dams had an effect on the distribution of constituent concentrations.

For naturally occurring constituents such as lead, probability analysis can be used to distinguish background concentrations from those due to anthropogenic sources. Fine bed sediments primarily are derived from the weathering of rock, and, given that no substantial geologic differences are present in a stream basin, concentrations of a particular constituent resulting from such weathering can be expected to be approximately normally distributed. Concentrations of the same constituent may also result from nongeologic sources within the basin and, however they are distributed statistically, would not be included in the population of data resulting from geologic contributions.

A simple means of distinguishing two sources (two populations of data) is to plot the cumulative relative frequencies (probabilities) of the aggregated data on normal-probability paper. Normally distributed data will plot as a straight line on probability paper. If the data do not plot as a straight line, the constituent concentrations may be the result of "natural" plus anthropogenic sources. The data plot would thus represent two or more populations and would be characterized by one or more changes in slope. The upper limit of the background concentrations can be interpreted as the concentration corresponding to the initial change in slope. For naturally occurring substances, constituent concentrations that exceed the maximum background concentration can represent enrichment.

For synthetic substances, which include PCB's and chlorinated insecticides, probability analysis also can be used to distinguish between concentrations that represent background and concentrations that represent enrichment. The concept of a background concentration of a synthetic substance differs from that of a natural substance. The natural background concentration of a synthetic substance is 0 μg/kg. The use of substances such as DDT, chlordane, dieldrin, and PCB's, however, has been so widespread for so many years that these substances have become ubiquitous in the environment. In addition, they are commonly present in concentrations sufficient to distinguish slightly enriched concentrations from moderately or grossly enriched concentrations.

From December 1978 to August 1980, samples of sediment-water mixtures were collected at 16 stream sites (fig. 5). Five of the sites were on the main stem of the Schuylkill River, and 11 sites were on tributaries. Sediment-water mixtures were collected from streams using depth-integrating techniques, as described by Guy and Norman (1970). The samples were collected from the streams during a wide range of flow conditions. Sampling frequency was mostly determined by the occurrence and duration of runoff. Water discharge at the time of sample collection was determined from stage observation and from the stage-discharge relation at each site. Field determinations included water temperature, specific conductance, and pH. Laboratory determinations included total and dissolved cadmium, chromium, copper, lead, nickel, zinc, and organic carbon, and total pesticides and PCB's. Suspended-constituent concentrations were determined from the difference between total and dissolved concentrations. Concentrations of suspended sediment that were sand-sized and silt-plus clay-sized also were determined for each sediment-water mixture. Inorganic determinations were made by the methods described by Skougstad and others (1979), organic determinations by the methods described by the U.S. Geological Survey (1973), and suspended-sediment concentrations by the methods described by Guy (1969). Data used in this study are available for examination at the Pennsylvania District office of the U.S. Geological Survey, 228 Walnut Street, Harrisburg, PA 17108.

Average annual transport of chemical constituents was computed by the transport flow-duration curve method described by Miller (1951) and by Colby (1956). For dissolved-constituent concentrations that did not relate to streamflow, average annual transport was computed on the basis of streamflow-weighted concentrations. For suspended-constituent concentrations that did not relate to streamflow, average annual transport was computed by multiplying (1) the ratio of the suspended-constituent concentration to the corresponding suspended-sediment concentration weighted by streamflow and (2) the average annual transport of suspended sediment.

The transport flow-duration method also was used to compute concentration-frequency curves for copper, lead, and zinc in the Schuylkill River at Manayunk, Philadelphia, in order to compare observed concentrations with Federal and State water-quality criteria. Concentration-frequency curves for other analyzed trace substances were not developed because the constituent concentrations were less than the level of detection, showed little variation, or did not relate to streamflow.

Water-quality criteria used in this report are from the U.S. Environmental Protection Agency (1976) and the Commonwealth of Pennsylvania (Public Law 1987, Chapter 39). These criteria are based on "total" constituent concentrations, which account for both dissolved and suspended materials. It should be noted that the concentration-frequency curves presented in this report were developed from concentration data for suspended materials only. This was done because these concentrations were more highly correlated with streamflow than were the dissolved or "total" concentrations. Values derived from the concentration-frequency curves will tend to be low and result in a more favorable comparison with water-quality criteria than would estimates based on "total" concentrations.

DISTRIBUTION OF TRACE SUBSTANCES IN STREAMBED SEDIMENTS

Streambed sediments can be used to determine the distribution of many of the trace substances. Many of the trace substances, particularly metals and chlorinated insecticides, become sorbed onto the sediments even though the substances may have been partially soluble during the initial discharge into the streams. During low flow, the streambed becomes a repository for incoming sediments. These sediments, in addition to the existing streambed sediments, act as a "sink" for trace substances. Summaries of selected trace-substance data for bed-sediment surveys made in 1978 and 1979 are shown in tables 4 and 5. An analysis of only the 1979 bed-sediment data is presented because (1) the 1978 bed-sediment

Figure 5. Transport stations.

Table 4. Summary of data from the 1978 bed-sediment survey in the Schuylkill River basin (analyses of size fraction less than 2 mm) [Concentrations of trace metals are in micrograms per gram, concentrations of trace organic substances are in micrograms per kilogram, concentrations of organic carbon are in grams per kilogram]

Constituent	Tributary sites	Main stem sites	Number of samples	Mean concentration	Minimum concentration	Maximum concentration	Range in concentration
Copper		X	16	98	10	330	320
	X		19	30	10	180	170
Lead		X	16	235	30	500	470
	X		26	134	20	1,600	1,580
Mercury		X	15	0.16	<.01	.87	.87
Zinc		X	16	423	80	1,000	920
	X		26	159	30	1,300	1,270
Organic carbon		X	11	55	11	123	112
	X		15	8.2	.1	29	28.9
Chlordane		X	10	26	<1	74	74
	X		14	10	<1	71	71
DDD		X	10	5.8	<.1	12	12
	X		14	1.8	<.1	13	13
DDE		X	10	.37	<.1	2	2
	X		14	4.0	<.1	43	43
DDT		X	10	6.6	<.1	14	14
	X		14	5.7	<.1	62	62
DDD, DDE, and DDT		X	10	13	<.1	25	25
	X		14	9.6	<.1	118	118
PCB's		X	10	442	<1	2,400	2,400
	X		14	99	<1	780	780

survey was intended only as a reconnaissance effort and (2) the 1979 bed-sediment data are more complete than the 1978 data.

Trace Metals

Trace metals are part of the minor elements in the Earth's crust. They generally are present in concentrations of less than 100 µg/g (Forstner and Wittmann, 1979). Most trace metals are essential to animal and plant nutrition in trace amounts but can become poisonous or toxic when beneficial concentrations are exceeded (Forstner and Wittmann, 1979). Table 6 summarizes the trace metals that were analyzed for and present in the bed sediments and sediment-water mixtures of the Schuylkill River basin.

Arsenic

Arsenic is a shiny, gray, brittle element having both metallic and nonmetallic characteristics. For purposes of organization, it is included with trace metals. The Earth's crust contains about 1.5 to 2 µg/g of arsenic (National Academy of Sciences, 1977). Arsenic and its compounds have long been known for their acute and chronic toxic effects on humans, although medicinal uses are reported (National Academy of Sciences, 1977a). Arsenic is used in glassmaking and in the manufacture of copper and lead alloys. Compounds of arsenic are used as herbicides and wood preservatives and in leather tanning and some paint pigments. Arsenic is released into the atmosphere as flue dust during the smelting of copper, lead, tin, and zinc ores and from the combustion of coal.

Arsenic can exist in valence states from negative trivalent to positive pentavalent; the two most common valence states are positive trivalent and positive pentavalent (National Academy of Sciences, 1977a). Both trivalent and pentavalent arsenic form stable compounds with carbon. Some of these organo-arsenical compounds are very toxic. Also, inorganic arsenic compounds can be

Table 5. Summary of data from the 1979 bed-sediment survey in the Schuylkill River basin (analyses of the size fraction less than 0.63 mm)

[Concentrations of trace metals are in micrograms per gram, concentrations of trace organic substances are in micrograms per kilogram, concentrations of organic carbon are in grams per kilogram]

Constituent	Tributary sites	Main stem sites	Number of samples	Mean concentration	Minimum concentration	Maximum concentration	Range in concentration
Arsenic		X	39	<1	<1	4	4
	X		30	<1	<1	1	1
Beryllium		X	39	8.2	<1	55	55
	X		30	3.1	1	6	5
Chromium		X	39	96	20	880	860
	X		30	28	10	80	70
Copper		X	39	252	40	3,000	2,960
	X		30	45	20	190	170
Lead		X	39	284	90	830	740
	X		30	760	30	19,000	18,970
Mercury		X	39	<.01	<.01	.08	.08
	X		30	<.01	<.01	.05	.05
Nickel		X	39	119	30	930	900
	X		30	27	10	90	80
Zinc		X	39	603	170	1,400	1,230
	X		30	169	70	780	710
Organic carbon		X	38	51	.8	98	97.2
	X		30	23	10	47	37
Chlordane		X	38	24	<1	57	57
	X		30	32	<1	140	140
DDD		X	38	4.3	<.1	11	11
	X		30	6.4	<.1	56	56
DDE		X	38	8.2	.6	24	23.4
	X		30	4.7	<.1	17	17
DDT		X	38	5.5	.4	32	31.6
	X		30	5.1	<.1	22	22
DDD, DDE, and DDT		X	38	18	2.6	59.6	57
	X		30	16.1	<.1	74	74
Dieldrin		X	38	1.8	<.1	7.9	7.9
	X		30	2.2	<.1	11	11
PCB's		X	38	152	22	320	298
	X		30	42	3	120	117

methylated through biological activity (National Academy of Sciences, 1977a).

Figure 6 shows a normal-probability plot of arsenic concentrations from the 1979 bed-material survey in the Schuylkill River basin. The data plot shows a two-stage curve with a change in slope at a concentration of 0.0 µg/g. Of the 11 sites that have detectable concentrations (greater than 0.1 µg/g), 10 are main-stem sites. Thus, the occurrence of arsenic in the main-stem bed sediments does not appear to be the result of natural tributary discharges of arsenic.

Beryllium

Beryllium is a relatively rare element and is not likely to occur in natural waters. Shacklette and others (1971) report a geometric mean concentration of 0.6 µg/g in surficial materials in the eastern part of the United States. Beryllium is not considered essential or beneficial to human or plant nutrition. The major hazard to humans posed by beryllium is inhalation of fumes and dusts containing beryllium that result from processing or fabrication operations (U.S. Environmental

Table 6. Summary of the trace metals analyzed for and present in the bed sediments and sediment-water mixtures of the Schuylkill River basin

[a—not detected or detected in very few samples at low concentrations; X—present]

Constituent	Sediment	Water
Antimony	a	a
Arsenic	X	a
Beryllium	X	a
Cadmium	X	a
Chromium	X	X
Copper	X	X
Lead	X	X
Mercury	X	a
Nickel	X	X
Selenium	a	a
Silver	a	a
Zinc	X	X

Protection Agency, 1976). Primary uses of beryllium include manufacture of special alloys, X-ray and neon tubes, and use as a catalyst in synthesis of organic compounds.

Beryllium salts vary in water solubility (Hem, 1970). At neutral pH, the oxide and hydroxide species are very slightly soluble. At low pH, beryllium ions in solution are strongly adsorbed by clay particles, and at higher pH, beryllium ions complex with hydroxide. Thus, beryllium should be present as a particulate in the Schuylkill River.

A normal-probability plot of beryllium concentrations from the 1979 bed-material survey shows a two-stage curve with a change in slope at 8 µg/g (fig. 7). About 88 percent of the beryllium concentrations are equal to or less than the maximum background concentration of 8 µg/g, which indicates that beryllium enrichment in the basin is not widespread. From figure 8, the

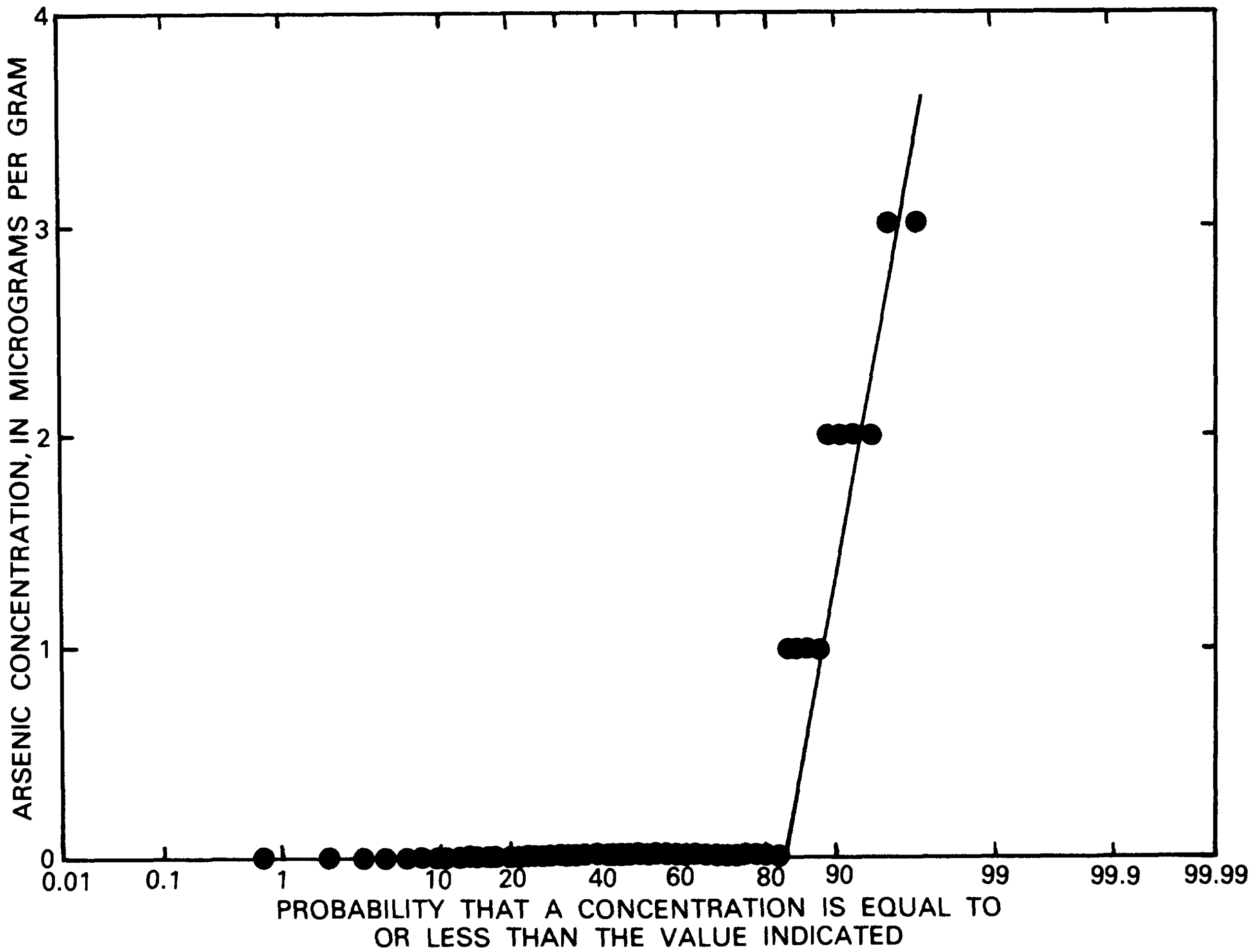

Figure 6. Normal-probability plot of arsenic concentrations from the 1979 bed-material survey in the Schuylkill River basin.

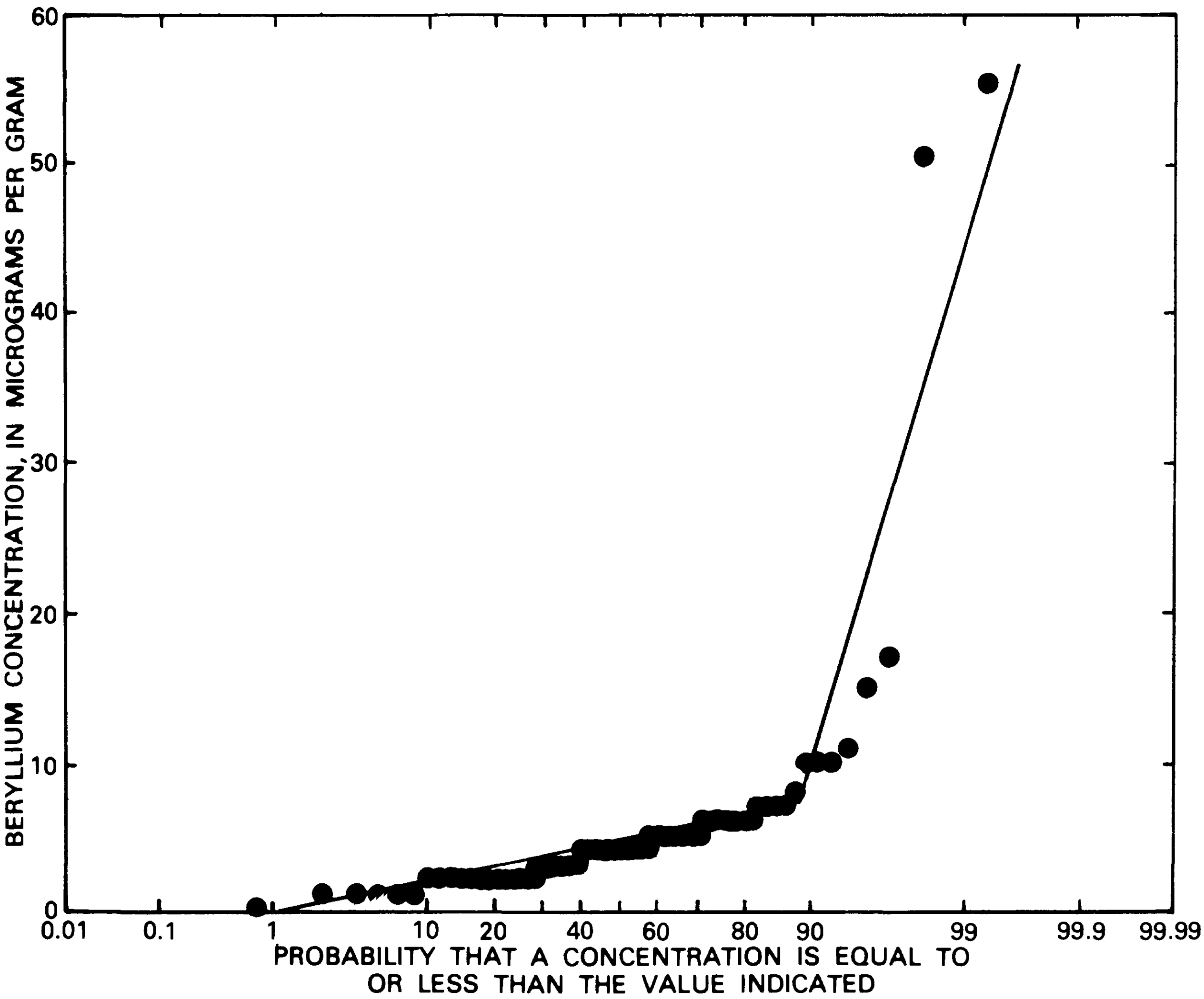

Figure 7. Normal-probability plot of beryllium concentrations from the 1979 bed-material survey in the Schuylkill River basin.

enrichment appears to be confined to the main stem of the river from Temple (RM 85.9) to Royersford (RM 41.4), with most large concentrations occurring in the Reading area. There are several industries in this reach whose business is metal manufacturing, including at least two industries that use beryllium.

Chromium

Chromium is a relatively abundant trace metal in the Earth's crust. Shacklette and others (1971) report a geometric mean concentration of 36 µg/g in the soils and surficial materials of the Eastern United States. Chromium is considered an essential trace element in human nutrition (National Academy of Sciences, 1974). It can exist in several oxidation states ranging from negative divalent to positive hexavalent. The positive trivalent form is the most prevalent in nature and potentially the least detrimental to humans. In contrast, hexavalent chromium is detrimental to humans by causing deterioration of protective mucous membranes (National Academy of Sciences, 1974).

Hexavalent chromium salts are used extensively in metal pickling and plating operations, for anodizing aluminum, for tanning leather, and in the manufacture of paints, dyes, and other substances. Trivalent chromium salts are less

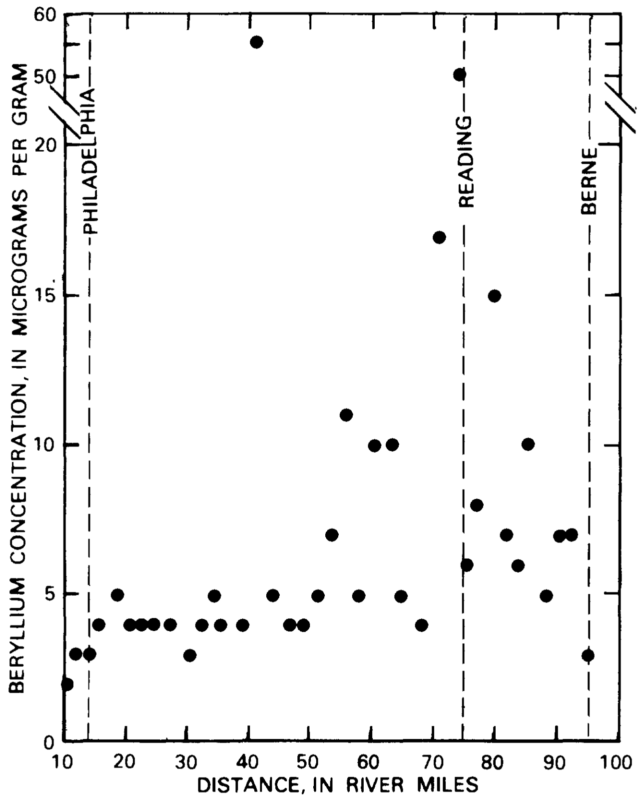

Figure 8. Relation of beryllium concentration to river mile of sampling point in bed sediments in the main stem of the Schuylkill River.

extensively used in industrial and manufacturing applications. Chromium compounds have been used as a corrosion inhibitor in condenser tubes at powerplants.

Trivalent chromium is formed in nature by either the oxidation of chromium compounds or the reduction of chromate compounds. Because trivalent chromium forms insoluble hydrated oxide in waters of pH 5 or above, it is likely that bed sediments become a sink for chromium compounds (National Academy of Sciences, 1974).

A normal-probability plot of chromium concentrations from the 1979 bed-material survey shows a two-stage curve with a change in slope at 30 µg/g (fig. 9). Rickert and others (1977) report a maximum background concentration of 60 µg/g in the less-than-20-micrometer size fraction of bed sediments in the Willamette River basin, Oregon. The higher background concentration in the Willamette River basin may reflect that chromium is more concentrated in soils that are derived from igneous rocks such as basalt. A plot of chromium concentrations in the main stem of the Schuylkill River in relation to river mile (fig. 10) shows that (1) concentrations of chromium downstream from Berne exceed the natural background of 30 µg/g, (2) concentrations of chromium increase from Berne to Reading, with peak concentrations occurring in Reading, and (3) concentrations decrease from Reading downstream to Philadelphia. From figure 10, the industrialized Reading area appears to be the primary source of chromium in the basin. Because the average concentration of chromium is 96 µg/g in the main stem and 28 µg/g in the tributaries, the enrichment of chromium appears to be confined primarily to the main stem of the river.

Copper

Copper is relatively abundant in the Earth's crust; the National Academy of Sciences (1977b) reports an average concentration of 50 µg/g. Shacklette and others (1971) report a geometric mean concentration of 14 µg/g in the soils and surficial materials in the Eastern United States. Trace amounts of copper are essential for the growth and well-being of plants and animals (National Academy of Sciences, 1977b). Concentrations of copper high enough to be dangerous to humans impart a disagreeable taste to water and thus render the water unpalatable. Copper salts are used extensively in textile processes, pigmentation, electroplating, insecticides, and other industrial processes. Perhaps the principal source of copper in the aqueous environment is copper sulfate used to control undesirable plankton growth in reservoirs, lakes, streams, water towers, and powerplant condensers.

Divalent copper ions discharged into natural waters having a pH of 7 or greater can form copper hydroxide or copper carbonate that precipitate from solution. Hem (1970) reports the solubility of these two compounds at a pH of 8 to be about 6.4 µg/L (micrograms per liter). The alkaline waters of the Schuylkill River downstream from its confluence with Maiden and Tulpehocken Creeks favor the precipitation and removal of copper ions from solution into the sediments.

A normal-probability plot of copper concentrations (fig. 11) in the bed sediments shows a two-stage curve with a change in slope at a concentration of 40 µg/g. This value is similar to the maximum background concentration of 43 µg/g reported by Rickert and others (1977) in the less-

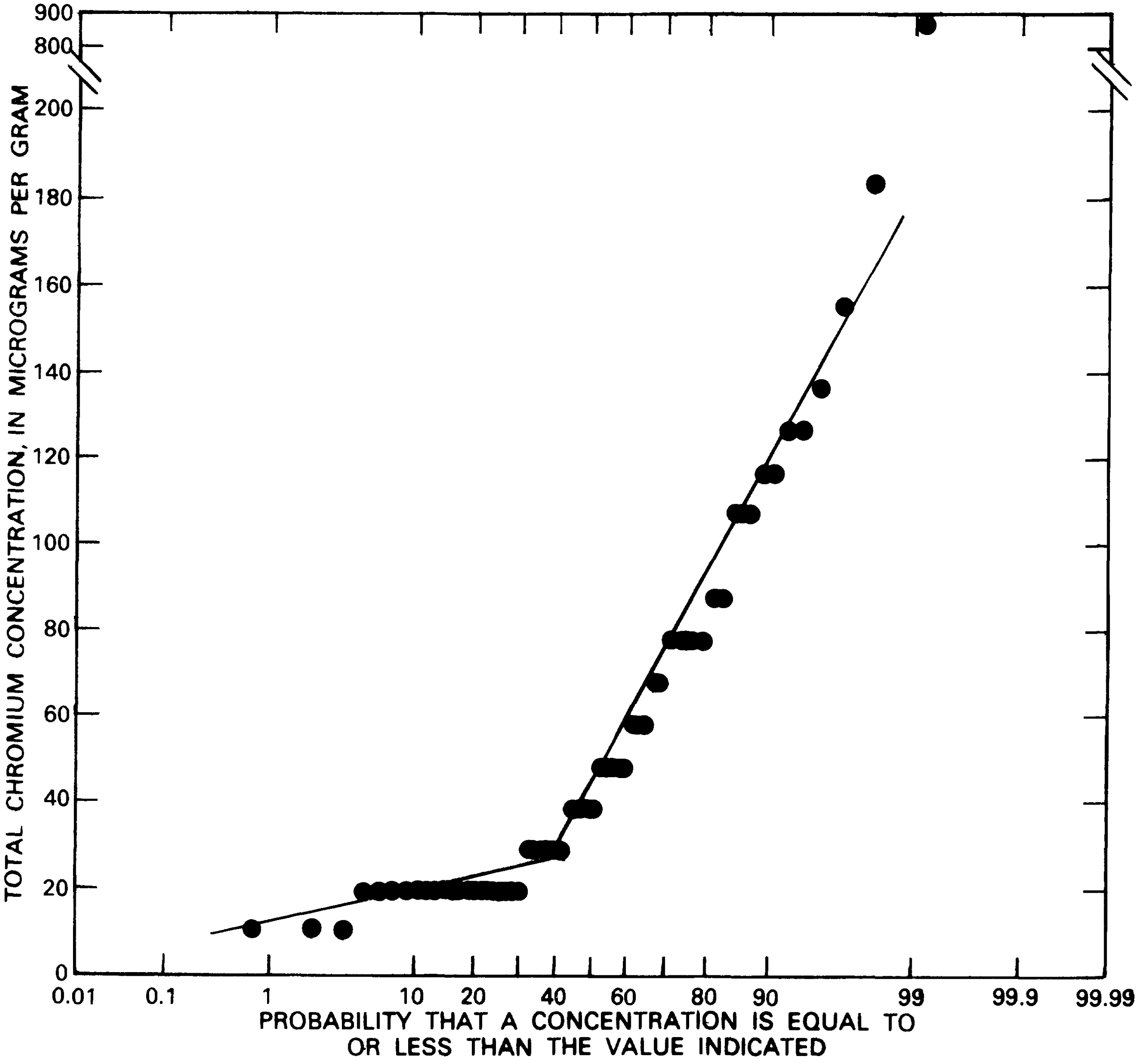

Figure 9. Normal-probability plot of chromium concentrations from the 1979 bed-material survey in the Schuylkill River basin.

than-20-micrometer size fraction in bed sediments in the Willamette River, Oregon. Analysis of the Schuylkill copper data indicates that tributary concentrations generally are low and main-stem concentrations are high, which indicates that the enrichment of the main stem is related to activities discharging directly into the main stem of the river.

A plot of copper concentrations in the main stem of the Schuylkill River in relation to river mile (fig. 12) shows that (1) concentrations of copper exceed the natural background level of 40 µg/g, (2) concentrations increase from Berne to Reading, (3) concentrations in the Reading area are an order of magnitude greater than concentrations elsewhere in the basin, and (4) concentrations gradually decrease from Reading downstream to Philadelphia. Figure 12 indicates that the industrialized Reading area is the primary source of copper in the basin.

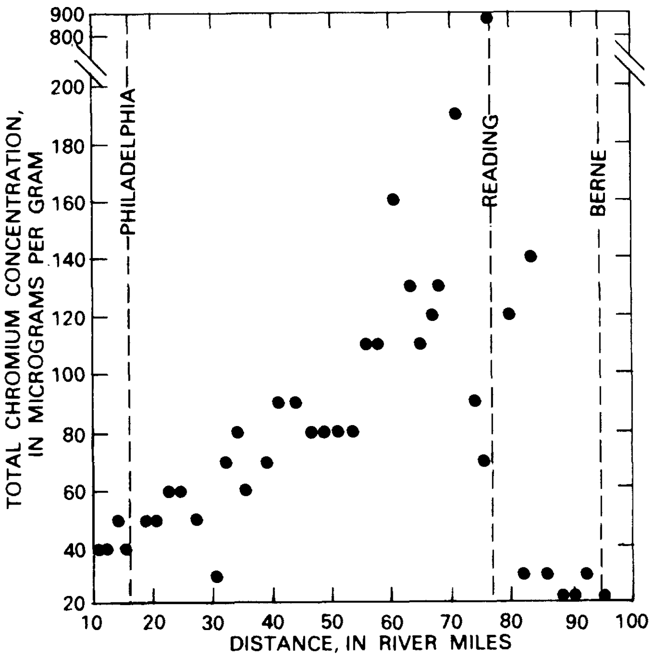

Figure 10. Relation of chromium concentrations to river mile of sampling point in bed sediments in the main stem of the Schuylkill River.

Lead

Lead is a cumulative poison in humans and is not considered essential to animal nutrition even in very low concentrations. Lead can be introduced into the aqueous environment from industrial processes such as plating, manufacture and reclamation of storage batteries, automobile emissions, and leaching from lead-containing materials. The carbonate and sulfate salts of lead are relatively insoluble (Hem, 1970). The formation of one or both of these salts is favored in the Schuylkill River basin--sulfate from acid mine drainage in the headwaters area and carbonate from the alkaline limestone waters of Maiden (RM 86.7) and Tulpehocken (RM 76.8) Creeks. Hem (1970) reports that the formation of these compounds could limit the solubility of lead to about 2 µg/L. V. C. Kennedy (U.S. Geological Survey, written commun., 1981) states that lead is strongly adsorbed by clays and organic matter and that sorption increases with pH. Thus, it is likely that the bed sediments become a sink for lead compounds.

A normal-probability plot (fig. 13) of lead concentrations in bed material in the Schuylkill River basin shows a three-stage curve with changes in slope at concentrations of 60 and 330 µg/g. The maximum background concentration of 60 µg/g is higher than the maximum background concentration of 43 µg/g in the less-than-20-micrometer size fraction of bed sediments in the Willamette River basin, Oregon (Rickert and others, 1977), and much higher than the geometric mean of 14 µg/g in the soils and other surficial materials in the Eastern United States (Shacklette and others, 1971). The higher background concentration of lead in the Schuylkill River basin than in the Willamette basin or eastern soils may reflect the degree of urbanization in the basin.

The three-stage curve in figure 13 represents concentrations from three distinctly different populations. The first stage of the curve represents concentrations of lead from tributary sites only. The second stage of the curve represents concentrations of lead at sites in tributaries that drain urban areas (for example, Stony and Wissahickon Creeks) or at sites in a generally lead-enriched main stem that receives lead from numerous and diverse sources. The third stage of the curve represents concentrations of lead at sites that are probably affected by discharges of lead directly into either the main stem of the river (see fig. 14) or into its tributaries--for example, French Creek.

A plot of concentrations of lead in the main stem of the Schuylkill River in relation to river mile (fig. 14) shows that (1) all the concentrations of lead exceed the maximum background concentration of 60 µg/g, (2) the largest concentrations of lead are in the Reading and Berne areas, and (3) concentrations of lead from about RM 70 downstream to Philadelphia are relatively similar.

Mercury

Mercury is a rare element compared with other trace metals and is a liquid in elemental form. Mercury and mercuric salts are considered to be highly toxic to humans and aquatic life. The element is not biologically essential or beneficial to life (National Academy of Sciences, 1978). Elemental mercury is used in the manufacture of solders, in dentistry, and in scientific and electrical instruments. In the elemental form, mercury is rather inert chemically and insoluble in water (National Academy of Sciences, 1977c). In contrast, many of the salts of mercury, both organic and

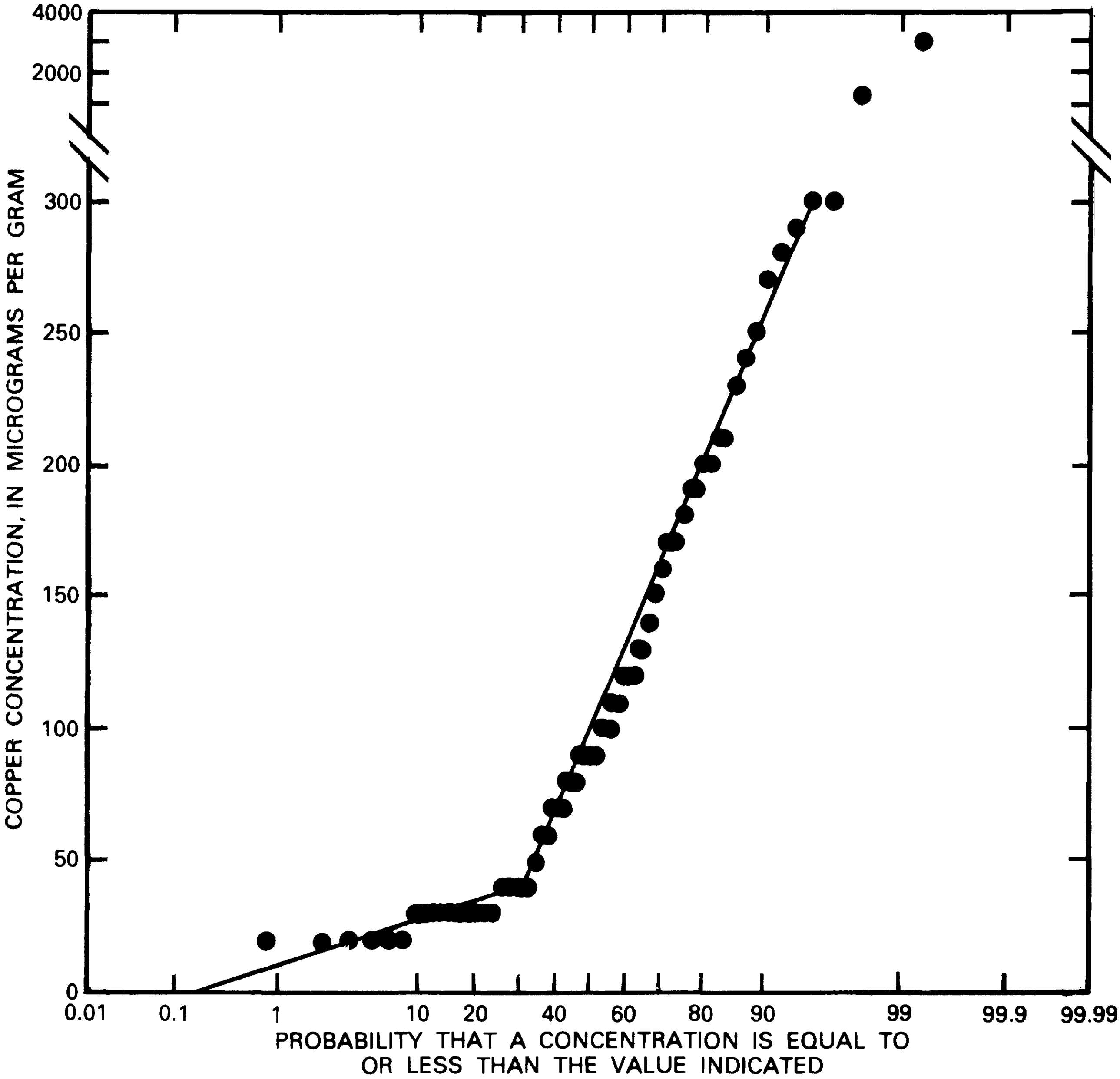

Figure 11. Normal-probability plot of copper concentrations from the 1979 bed-material survey in the Schuylkill River basin.

inorganic, are soluble in water. They are used in disinfecting, in preserving, and in the manufacturing of explosive caps, herbicides, and fungicides. Organic- mercury compounds have been used extensively in the paper industry to control slime. Certain micro-organisms can convert inorganic and organic forms of mercury to the highly toxic methyl or dimethyl mercury (National Academy of Sciences, 1977c). Conversion can occur readily in natural waters. Thus, the introduction of any form of mercury into the aqueous environment is potentially hazardous to the environment.

A normal-probability plot of mercury concentrations in the bed sediments of the

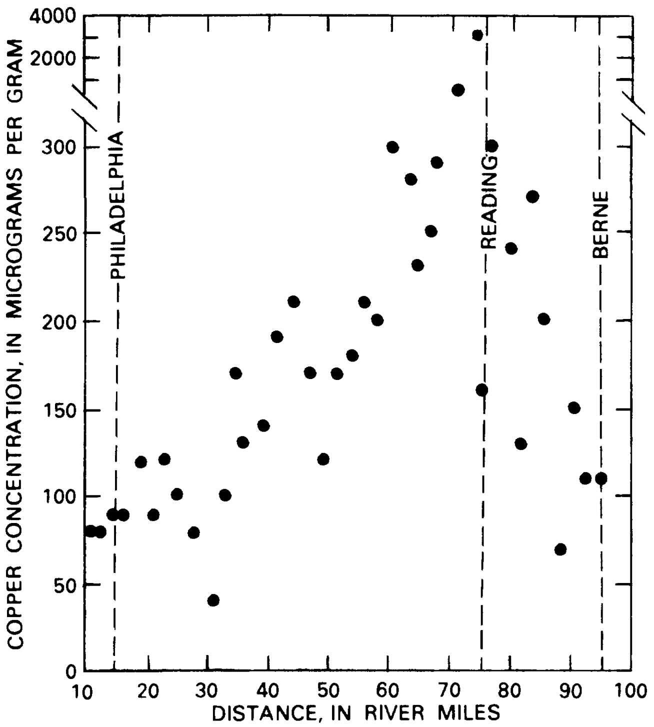

Figure 12. Relation of copper concentrations to river mile of sampling point in bed sediments in the main stem of the Schuylkill River.

Schuylkill River basin (fig. 15) shows a two-stage curve with a change in slope at a concentration of less than 0.01 µg/g. About 90 percent of the mercury concentrations are less than 0.01 µg/g; mercury enrichment appears to be a local problem in the basin. In contrast, Rickert and others (1977) report a maximum background concentration of 0.38 µg/g in the less-than-20-micrometer size fraction of bed sediments in the Willamette River basin, Oregon. A comparison of the mercury data from the bed-sediment surveys of 1978 and 1979 (tables 4 and 5) shows that higher concentrations of mercury were found in the 1978 samples. This could mean that the mercury may be associated more strongly with the sediment fraction equal to or greater than 63 µm than with the sediment fraction less than 63 µm; a similar observation was made by Rickert and others (1977).

Nickel

Nickel is a silver-white metallic element rarely found in nature in the elemental form. The National Academy of Sciences (1975) reports that the Earth's crust contains about 80 µg/g of nickel and that shale and carbonate rocks contain about 50 µg/g. Nickel appears to be relatively nontoxic to humans since no limits are included in the U.S. Environmental Protection Agency National Interim Drinking Water Regulations (40 FR 59566, December 24, 1975). Skin contact with nickel salts may result in dermatitis, and prolonged inhalation of nickel compounds can cause lung cancer (McNeely and others, 1979). Nickel is also considered less toxic to aquatic life than several of the other trace metals, although the degree of toxicity depends on pH, synergistic effects, and other factors.

In the elemental form, nickel is insoluble in water. However, many of the nickel salts, including chlorides, sulfates, and nitrates, are highly soluble in water. These salts primarily are used in metal-plating works, fabric dyeing, and the manufacture of ceramic colors. Nickel can enter the aqueous environment through discharges from the above industries and through aerosol fallout from the processing of nickel ores, waste incineration, and burning of fossil fuels. Hem (1970) reports that the nickel ion is probably strongly adsorbed by iron and manganese hydroxides.

A normal-probability plot of the nickel concentrations from the bed material in the 1979 survey in the Schuylkill River basin (fig. 16) shows a two-stage curve with a change in slope at a concentration of 30 µg/g. About 60 percent of the nickel concentrations exceed 30 µg/g, which suggests that nickel enrichment is significant in the basin. Of the 30 tributary sites sampled, 26 had concentrations of nickel of 30 µg/g or less; the highest tributary concentration measured was 90 µg/g.

Figure 17 shows a plot of nickel concentrations in the main-stem bed sediments in the Schuylkill River in relation to river mile. In general, concentrations of nickel increase from about 70 µg/g at Berne (RM 95.5) to a peak of 930 µg/g at Reading (RM 77.4). Concentrations of nickel decrease gradually downstream from Reading; the lowest concentrations occur near Philadelphia.

Zinc

Zinc is a moderately abundant metal that generally is present as a sulfide in rocks and ores; it commonly is associated with the sulfides of other metals, especially lead, copper, cadmium, and iron. Zinc is used extensively in galvanizing iron and

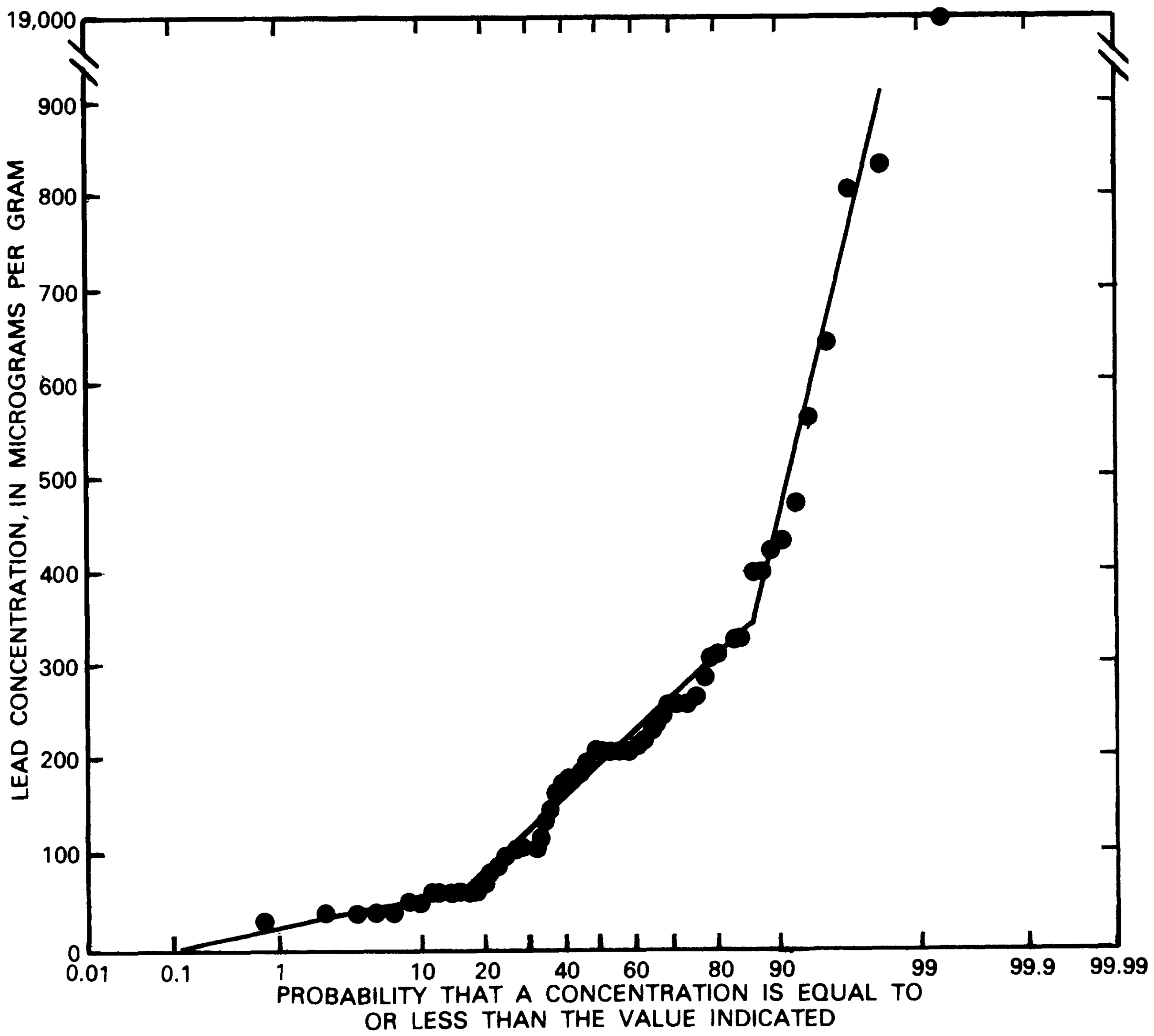

Figure 13. Normal-probability plot of lead concentrations from the 1979 bed-material survey in the Schuylkill River basin.

steel to prevent corrosion. The second most important use of the metal is in the production of alloys for die casting. Zinc is also used in dyes, insecticides, and paint pigments.

Unlike lead, arsenic, and mercury, zinc is an essential and beneficial element in human and plant nutrition (National Academy of Sciences, 1977c). However, zinc does adversely affect aquatic organisms, especially fish, by forming insoluble compounds with the mucous that covers the gills. Water hardness reduces the toxicity of zinc, whereas copper increases the toxicity of zinc.

Zinc salts differ in solubility depending on the pH of the water. Hem (1970) reports that the concentration of zinc at a pH of 8 in the presence of zinc hydroxide (at 25° C) would be about 650 µg/L. Hem (1970) also reports that concentrations of zinc in excess of 1 mg/L (milligram per liter) can be

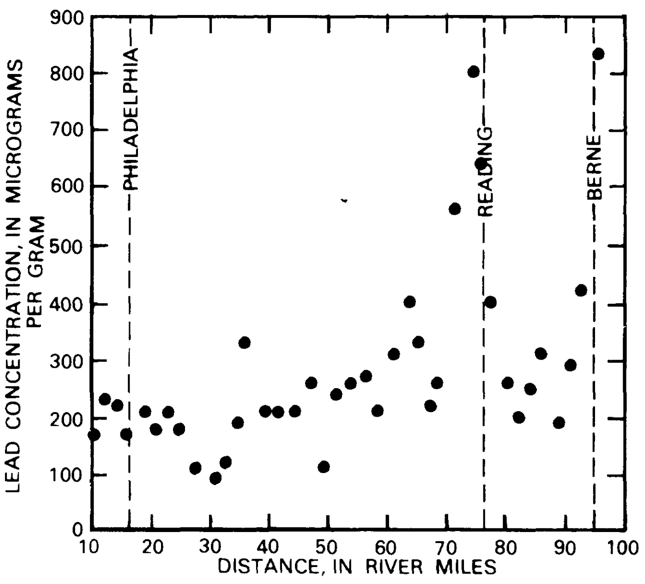

Figure 14. Relation of lead concentrations to river mile of sampling point in bed sediments in the main stem of the Schuylkill River.

chemically stable at neutral pH. Thus, zinc solubility in natural water is considerably greater than several of the other trace metals analyzed.

A normal-probability plot of zinc concentrations in the bed sediments of the Schuylkill River (fig. 18) indicates a multistage curve with an initial change in slope at a concentration of 140 µg/g. The maximum background concentration of 140 µg/g in the Schuylkill River basin is at the upper end of the 60- to 120-µg/g range that V. C. Kennedy (U.S. Geological Survey, written commun., 1981) found in less-than-8-µm soil fines and is similar to the maximum background concentration of 145 µg/g that Rickert and others (1977) report in the sediment fraction of less than 20 µm in the Willamette River basin, Oregon. The first stage of the curve in figure 18 includes only tributary concentrations. Concentrations from 160 to 240 µg/g include tributaries that mostly drain urban areas. The third and fourth stages of the multistage curve represent mostly main-stem concentrations, and the fifth stage represents potential sources in the Reading and Conshohocken areas.

A plot of zinc concentrations in the main-stem bed sediments of the Schuylkill River in relation to river mile (fig. 19) shows that (1) concentrations of zinc exceed the assumed background level of 140 µg/g and (2) concentrations of zinc plotted in relation to river mile form a sinusoidal curve with peaks occurring at about RM 70 and 22 and troughs occurring at RM 95, 50, and 11. The concentration peaks are probably the result of discharges from metal fabricating or plating industries.

Trace Organic Substances

Trace organic substances are defined in this report as synthetic or manmade chlorinated organic substances. Most of the trace organic substances that were analyzed in the sediments are chlorinated insecticides. The characteristics that have made these substances so effective in controlling insects are the same characteristics that have led to a ban on the manufacture and use of some of them in this country. The characteristics include water insolubility, persistence in nature, and toxicity. A summary of trace organic substances found through analyses of bed sediments and water is listed in table 7.

As indicated earlier, 69 sites in the Schuylkill River basin were sampled for bed sediments in 1979. A portion of one main-stem sample was not analyzed for chlorinated insecticides or PCB's. Therefore, the sample population for trace organic substances is 68.

Chlordane

Chlordane is a chlorinated cyclodiene insecticide. It is a viscous amber liquid and has been on the market since 1944. Chlordane was used principally as a preemergence soil insecticide for the control of pests, including corn rootworms, wireworms, and cutworms, in the treatment of seeds, as a soil poison for termites and ants, and for the control of boll weevil and bollworms on cotton. On April 1, 1976, the U.S. Environmental Protection Agency suspended the registration of chlordane for agricultural crop use because of its persistence in the environment and its carcinogenic property (National Academy of Sciences, 1977c).

A normal-probability plot of chlordane concentrations from the 1979 bed-material survey in the Schuylkill River basin (fig. 20) indicates a three-stage curve with changes in slope at concentrations of 8 and 36 µg/kg. Chlordane concentrations between 0.0 and 8 µg/kg represent

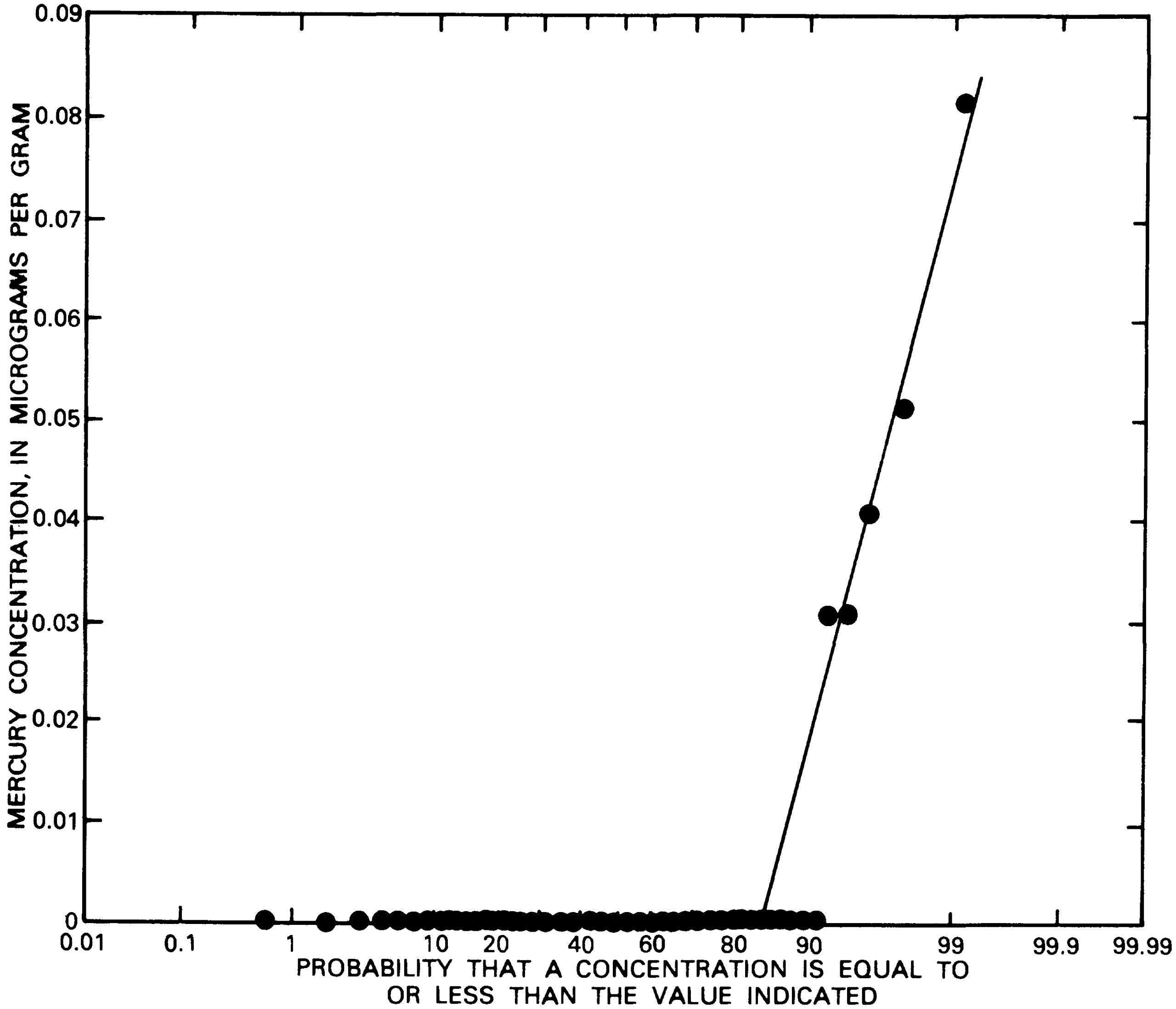

Figure 15. Normal-probability plot of mercury concentrations from the 1979 bed-material survey in the Schuylkill River basin.

slight enrichment over natural conditions of zero concentration. Concentrations between 8 and 36 µg/kg probably represent moderate enrichment, and concentrations greater than 36 µg/kg probably represent gross enrichment. Of the 68 samples analyzed, 14 comprise the third stage on the probability plot; of those 14 sites, 8 are tributary sites. The eight tributary sites have one characteristic in common--a public park, a golf course, or a cemetery is located just upstream of each site. The six main-stem sites on the third stage of the curve are immediately downstream from tributary sites where chlordane concentrations are anomalously high or immediately downstream from an activity similar to those noted for the tributary sites.

A plot of chlordane concentrations in the main-stem bed sediments of the Schuylkill River in relation to river mile (fig. 21) shows that concentrations of chlordane generally increase downstream from Berne to Philadelphia. The percentage of urban land also increases from Berne to Philadelphia (table 2). Thus, the data suggest that higher concentrations of chlordane may be related to the increasing percentage of urban land from Berne to Philadelphia.

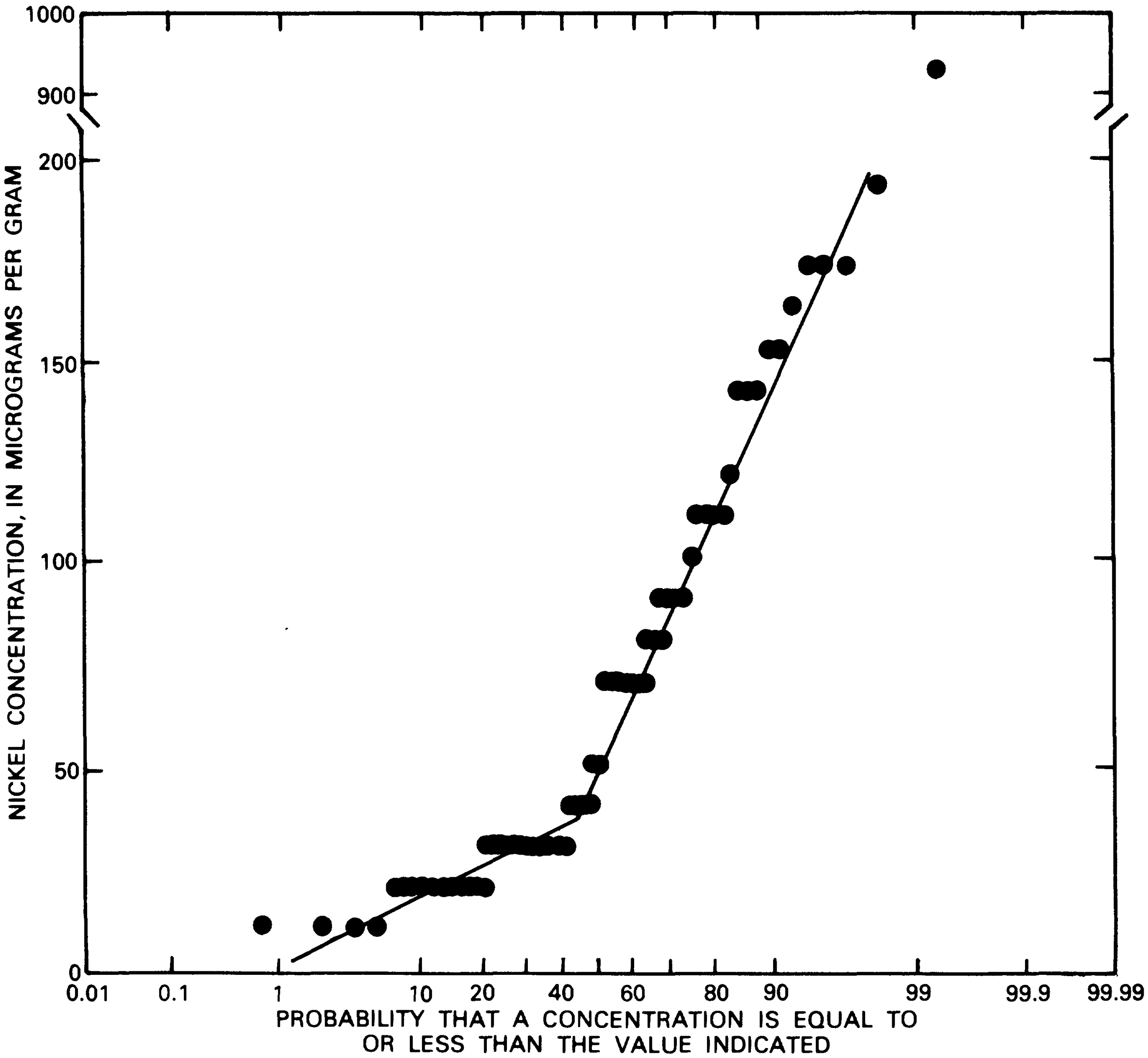

Figure 16. Normal-probability plot of nickel concentrations from the 1979 bed-material survey in the Schuylkill River basin.

Dieldrin

Dieldrin is a chlorinated cyclodiene insecticide. It was introduced in 1950 and gained wide acceptance because of its extreme persistence and efficacy against a wide range of insects. A primary agricultural use of dieldrin was the control of corn rootworms. In 1974, the U.S. Environmental Protection Agency suspended the registration of aldrin and dieldrin (National Academy of Sciences, 1977c). The decision to prohibit the use of dieldrin was based on its persistence in nature and its bioaccumulative and potentially carcinogenic properties (U.S. Environmental Protection Agency, 1976). Dieldrin is chemically similar to the chlorinated insecticide aldrin, which can be metabolically converted into dieldrin by aquatic organisms.

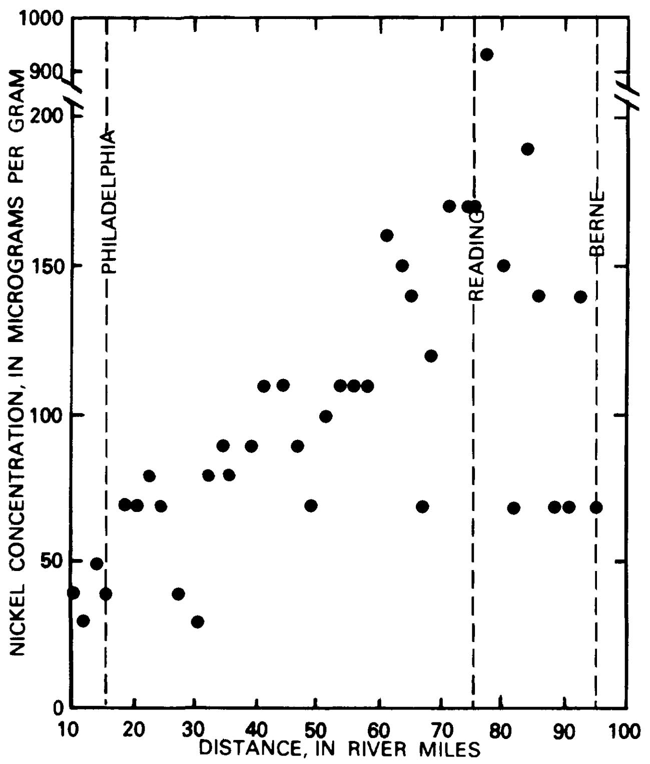

Figure 17. Relation of nickel concentrations to river mile of sampling point in bed sediments in the main stem of the Schuylkill River.

Results from the 1979 bed-sediment survey indicate the presence of low concentrations of dieldrin, but no aldrin. Figure 22 is a normal-probability plot of concentrations of dieldrin in the bed sediments in the Schuylkill River basin. The data plot indicates a three-stage curve with the first change in slope at a concentration of 1.5 µg/kg and the second at 3.5 µg/kg. Dieldrin concentrations between 0.0 and 1.5 µg/kg represent slight enrichment over natural conditions of zero concentration. Concentrations between 1.5 and 3.5 µg/kg probably represent moderate enrichment, and concentrations greater than 3.5 µg/kg probably represent gross enrichment. Each stage of the multistage curve represents concentrations from main-stem and tributary sites; however, the first stage of the plot generally represents sites in the upstream part of the basin, and the third stage represents sites in the downstream part of the basin.

Figure 23 shows a plot of dieldrin concentrations in the main-stem bed sediments in the Schuylkill River in relation to river mile. Concentrations appear to increase gradually downstream, from about 1 µg/kg at Berne to about 5 µg/kg at Philadelphia. The plot of dieldrin concentrations in relation to river mile is similar to that of chlordane (fig. 21). Concentrations of dieldrin might be expected to decrease with an increase in the percentage of urban land because of the use of dieldrin in agriculture, but that is not the case.

DDT and Its Metabolites

DDT is an organochlorine insecticide. It is a white amorphous powder that has a water solubility of about 1.2 µg/L (National Academy of Sciences, 1977c). DDT was banned in 1973 in the United States for all but essential public health use. The ban resulted from strong evidence of its persistence in nature, its bioaccumulative properties, and its potential carcinogenicity (National Academy of Sciences, 1977c). Over the years, DDT was the most widely used insecticide in the world. By 1970, the rate of annual production of DDT was about 400 million pounds, of which 80 percent was used in agriculture and the remaining 20 percent was used in public health programs (National Academy of Sciences, 1972). It is estimated that since 1944 about 4 billion pounds of DDT have been released into the environment, worldwide, and that about 25 percent of that amount remains either as DDT or as its even more stable decomposition product, DDE (National Academy of Sciences, 1972). Depending on environmental conditions, DDT will degrade into DDD or DDE; under anaerobic conditions, DDT will undergo reductive dechlorination to form DDD, and under aerobic conditions, the dominant environmental and biological reaction is the dehydrochlorination of DDT to form DDE.

A normal-probability plot of concentrations of DDT and its metabolites in the bed sediments of the Schuylkill River basin is presented in figure 24. The plot shows a three-stage curve with an initial change in slope at a concentration of about 4 µg/kg and a second change at 23 µg/kg. DDT concentrations between 0.0 and 4.0 µg/kg represent slight enrichment over natural conditions of zero concentration. Concentrations between 4.0 and 23 µg/kg probably represent moderate enrichment, and concentrations greater than 23 µg/kg probably represent gross enrichment. About 80 percent of the plotted concentrations exceed 4 µg/kg,

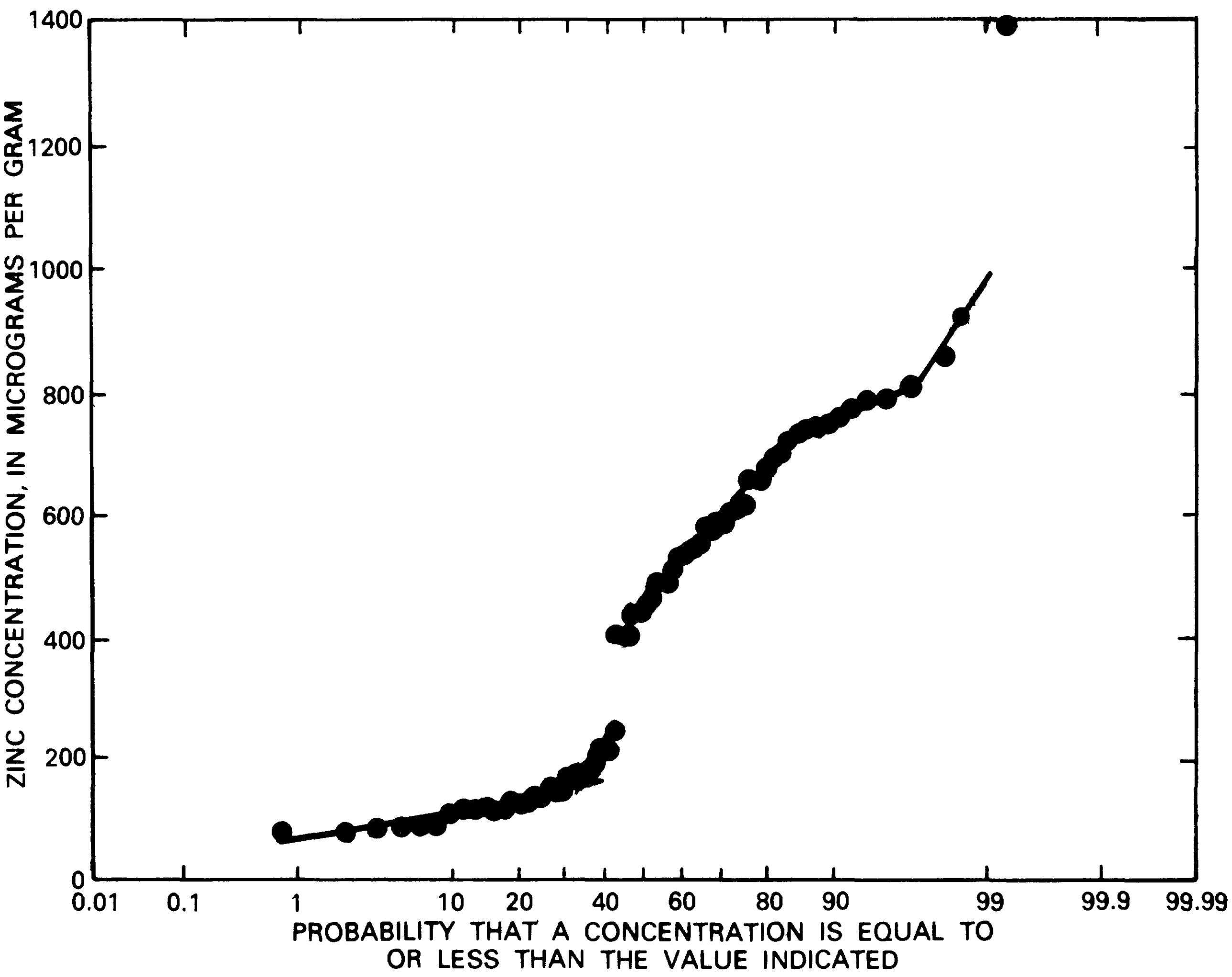

Figure 18. Normal-probability plot of zinc concentrations from the 1979 bed-material survey in the Schuylkill River basin.

indicating that enrichment of bed sediments in the Schuylkill River basin is widespread.

Figure 25 shows a plot of concentrations of DDT and its metabolites in the main-stem bed sediments in the Schuylkill River in relation to river mile. Concentrations are low at Berne, increase gradually downstream to Reading, and remain elevated into the Philadelphia area. Because the predominant use of DDT was in agriculture and because tributary drainage areas represent most of the agricultural drainage area of the Schuylkill River basin, concentrations of DDT in the main stem might be expected to reflect tributary sources. This, however, does not seem to be the case. Concentrations of DDT that exceed 30 µg/kg generally are not found immediately downstream from tributaries having high concentrations of DDT.

PCB's

PCB's are a group of synthetic chlorinated organic compounds. They are composed of a two-phenyl ring structure with variable chlorine substitution. Variation in the percentage of chlorine substitution produces PCB's with different chemical properties. PCB's were used as lubricants,

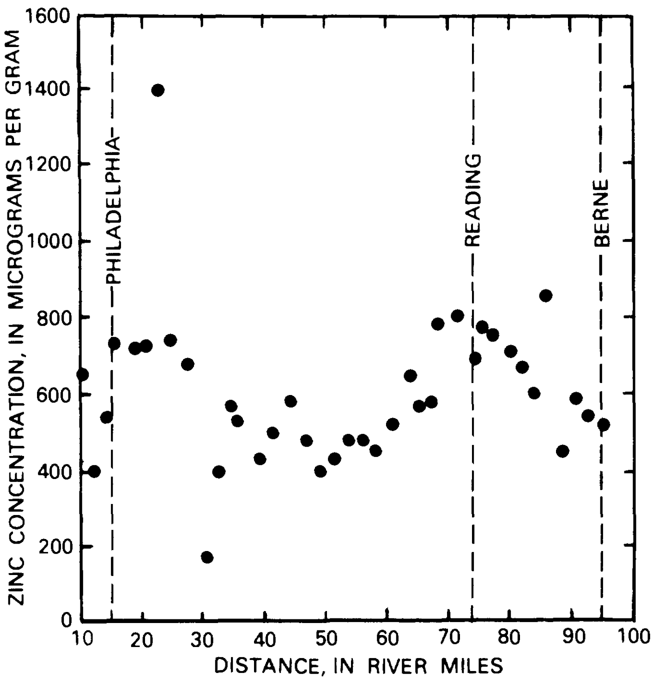

Figure 19. Relation of zinc concentrations to river mile of sampling point in bed sediments in the main stem of the Schuylkill River.

Table 7. Summary of trace organic substances analyzed for and present in the bed sediments and water in the Schuylkill River basin

[a—not detected or detected in very few samples at low concentrations; X—present]

Substance	Sediment	Water
Aldrin	a	a
Chlordane	X	a
DDD	X	a
DDE	X	a
DDT	X	X
Dieldrin	X	a
Endosulfan	a	a
Endrin	a	a
Heptachlor epoxide	a	a
Heptachlor	a	a
Lindane	a	a
Mirex	a	a
Methoxychlor	a	a
PCB's	X	X
Polychlorinated naphtalene	a	a
Perthane	a	a
Toxaphene	a	a

in hydraulic fluids, for insulation in transformers, and as plasticizers. Products containing PCB's included plastics, printing inks, paints, carbon paper, and tires. In 1976, the U.S. Government banned the further manufacture of PCB's in this country because of the toxicity of PCB's to humans and aquatic life. PCB's are highly resistant to chemical, biological, and thermal degradation and are soluble in water to a maximum concentration of about 200 µg/L (National Academy of Sciences, 1977c). Therefore, when PCB's are introduced into the aquatic system, they can accumulate in the bed sediments.

A normal-probability plot of PCB concentrations in the bed sediments of the Schuylkill River basin (fig. 26) shows a two-stage curve with a change in slope at a concentration of 12 µg/kg. PCB concentrations between 0.0 and 12.0 µg/kg represent slight enrichment over natural conditions of zero concentration. About 80 percent of the concentrations exceed 12 µg/kg, which probably indicates moderate PCB enrichment in the basin. The maximum background concentration of PCB's is also higher than the maximum background concentrations of chlordane, DDT and its metabolites, and dieldrin, which may indicate the extensive use of PCB's in the basin.

A plot of PCB concentrations in the main stem of the Schuylkill River in relation to river mile (fig. 27) shows that concentrations increase from Berne (RM 95.5) downstream to Reading; peak concentrations occur at RM 77.4 and 74.4. Concentrations generally decrease downstream from about RM 40. Concentrations of PCB's in the main stem, however, exceed 12 µg/kg, which probably indicates moderate enrichment.

Organic Carbon and Clay as Factors Affecting the Distribution of Trace Substances

Organic Carbon

Organic-carbon compounds in the aqueous environment generally are composed of humic substances and degraded plant and animal materials that fall into or are washed into the streams; additional sources can include municipal and industrial wastewater discharges. The significance of organic carbon lies in its ability to form complexes with metals and other organic compounds. Concentrations of various constituents

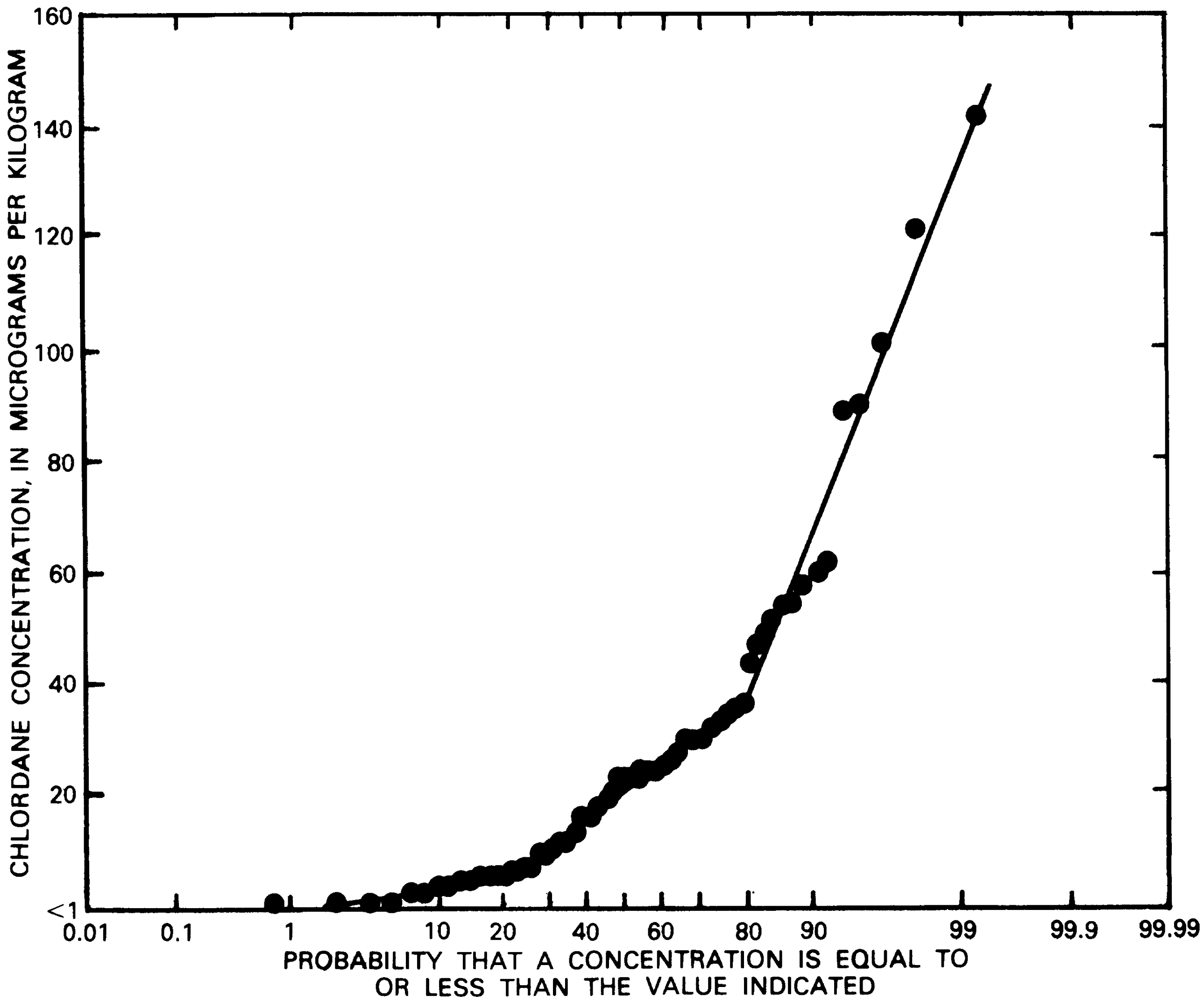

Figure 20. Normal-probability plot of chlordane concentrations from the 1979 bed-material survey in the Schuylkill River basin.

are often reported to be positively correlated with the organic-carbon content of sediments (Feltz, 1980). The correlation between concentrations of organic carbon and concentrations of trace substances in Schuylkill River sediments is significant at the 99-percent or greater level of confidence for chromium, copper, lead, nickel, zinc, and PCB's. However, the variation in these constituents that can be explained by organic carbon is less than 35 percent.

Normal-probability plots of tributary and main-stem organic-carbon concentrations from the 1979 bed-material survey in the Schuylkill River basin are shown in figures 28 and 29. The median values of the tributary and main-stem concentrations are 20 and 50 g/kg. The two populations of data are significantly different at the 99-percent confidence level based on the Mann-Whitney U test (Klugh, 1970). The higher concentrations at the main-stem sites could be the result of two factors: (1) transport of coal fines from the upstream coal regions and (2) discharge from sewage-treatment plants.

A plot of organic-carbon concentrations in the main-stem bed sediments in the Schuylkill River in relation to river mile is shown in figure 30.

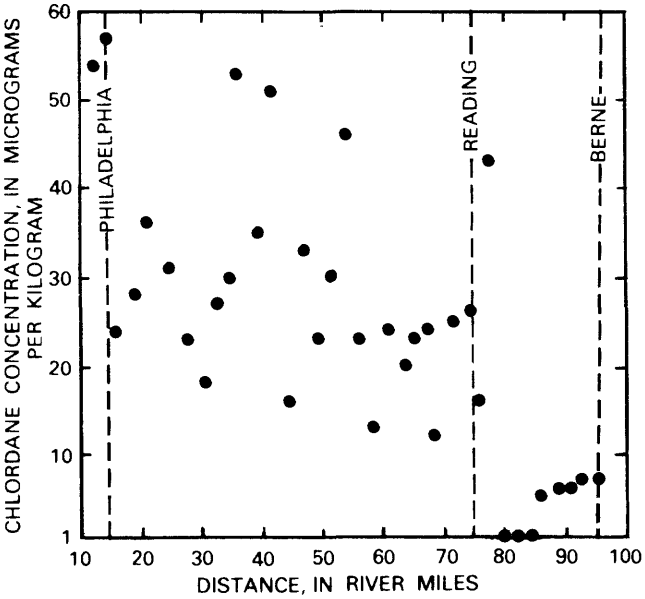

Figure 21. Relation of chlordane concentrations to river mile of sampling point in bed sediments in the main stem of the Schuylkill River.

Concentrations are high in the Berne and Reading areas and generally decrease downstream toward the Philadelphia area. If discharges from the sewage-treatment plants were a predominant source of the organic carbon in the river, concentrations of organic carbon would increase downstream because most of the municipal discharges, from a volume standpoint, are toward the downstream end of the study area. Therefore, the general shape of the concentration plot of organic carbon probably results from two major sources of organic carbon in the headwaters--coal from the Southern Anthracite coal field and detrital material from the extensive forests upstream of the study area.

Clay

Clay is a fine-grained material that consists primarily of hydrated silicates of aluminum. In this report, clay is defined as particles of sediment that have a median-fall diameter of less than 4 µm.

The literature is replete with references to relationships between concentrations of trace substances and particle size of sediments (Demayo and others, 1978). Generally, the concentration of sorbed substances is inversely proportional to the size of sediment particles--that is, for a given weight of sediment, the smaller the particle, the larger the surface area available for sorption; clay-sized particles generally are associated with higher concentrations of trace substances than are coarser grained sediments. Correlations between clay as a percentage of the silt- and clay-sized fraction and concentrations of trace substances are significant at the 99-percent or greater level of confidence for copper, lead, nickel, and zinc and are significant at the 98-percent level for PCB's. The variation in percentage of these constituents that can be explained by the percentage of clay, however, is less than 26 percent.

Analysis of clay as a percentage of the silt- and clay-sized fraction in the bed sediments in the Schuylkill River basin indicates that the clay percentage is higher in the main-stem sediments than in the tributary sediments; the difference is significant at the 99-percent level of confidence, based on the two-tailed t-test (Klugh, 1970). The higher percentage of clay in the main-stem sediments may account, in part, for the higher concentrations of copper, lead, zinc, and PCB's in those sediments compared with concentrations in the tributary sediments.

Figure 31 shows a plot of clay as a percentage of the silt- and clay-sized fraction in the main-stem bed sediments in the Schuylkill River in relation to river mile. Although the data show much scatter, the percentage of clay generally is higher in the Berne area and lower in the Philadelphia area.

TRANSPORT OF TRACE SUBSTANCES

A summary of the computed average annual transport of total and suspended trace metals and organic carbon by stream station is shown in table 8. The data show that, in general, the average annual transport of trace metals (1) increases or remains about the same in the river reach from Berne to Reading, (2) increases substantially in the urban-industrial reach from Reading to Pottstown, and (3) decreases or remains about the same from Pottstown to Manayunk in Philadelphia.

Table 8 also shows that most of the metal is transported by stream in suspension. The average ratio of suspended to total metal transport is 0.71

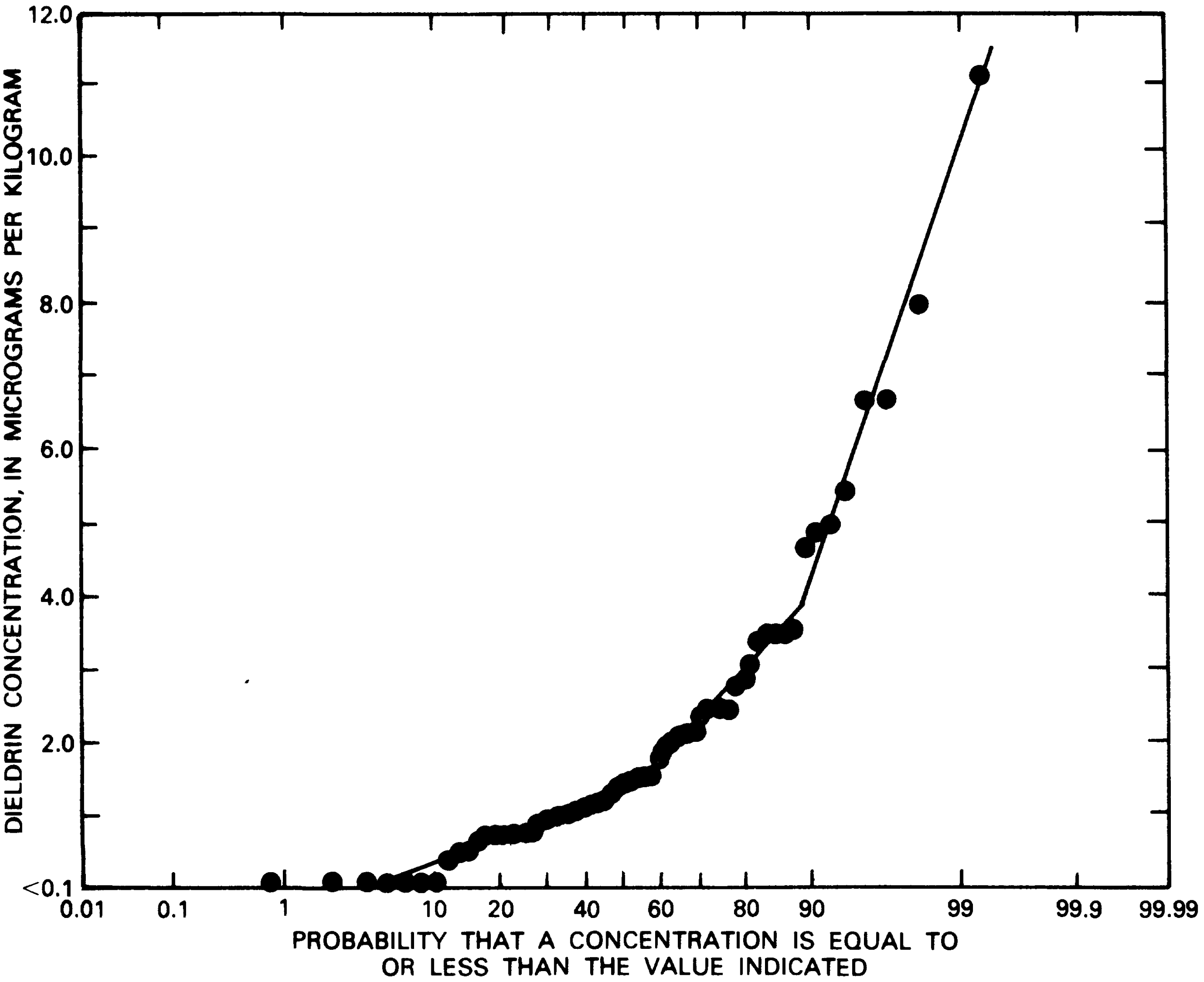

Figure 22. Normal-probability plot of dieldrin concentrations from the 1979 bed-material survey in the Schuylkill River basin.

for the five metals and 16 stream stations in table 8. Ratios ranged from 0.93 for lead to 0.52 for copper. Faye and others (1980) report that about 60 percent or more of the average annual trace-metal transport in the Upper Chattahoochee River (Georgia) was contributed by suspended sediment.

The average annual transport of 230 tons per year of zinc at Manayunk in Philadelphia was the largest of the five metals for which transport could be computed; the transport of nickel was least, being 28 tons per year at Manayunk in Philadelphia.

Average annual constituent yields and land use for comparable drainage areas for two Piedmont streams are shown in table 9. Constituent yields for the two rivers are of the same order of magnitude, although the yield of lead in the Chattahoochee River basin is about five times greater than in the Schuylkill River basin. Although several water-quality problems in the Chattahoochee River basin have been documented (Stamer and others, 1979; Cherry and others, 1980; and Faye and others, 1980), the transport of trace metals was not considered a problem in that basin.

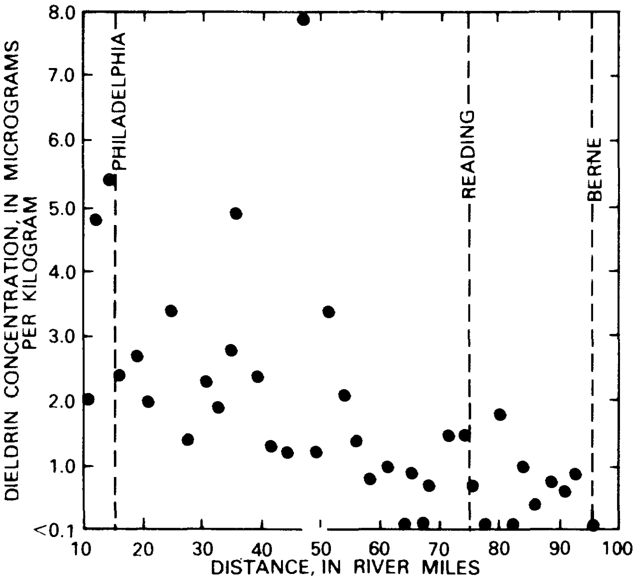

Figure 23. Relation of dieldrin concentrations to river mile of sampling point in bed sediments in the main stem of the Schuylkill River.

The average annual transport of trace organic substances by the Schuylkill River is small. Samples of sediment-water mixtures from the 16 stream sites in table 8 were analyzed for concentrations of trace organic substances (chlorinated insecticides, PCB's, and polychlorinated naphthalenes) for a period of several months. Sampling for trace organic substances was later discontinued at all but two sites because a large number of zero values were obtained and observed concentrations generally were at the minimum detection limit. Table 10 summarizes the concentrations of trace organic substances at Schuylkill River at Pottstown (RM 53.7) and at Manayunk, Philadelphia (RM 14.2). The highest observed concentration of trace organic substances at each site was for PCB's. However, no transport computations were made for PCB's because the most numerous concentration measured was less than the detection level of 0.1 µg/L.

Table 8. Summary of average annual transport of total and suspended trace metals and organic carbon by stream station in the Schuylkill River basin

[Values of total and suspended loads are in tons per year]

Station name	Chromium			Copper		
	Total	Suspended	Ratio of suspended to total	Total	Suspended	Ratio of suspended to total
Schuylkill River at Berne	6.7	6.3	0.94	14	11	0.79
Maiden Creek at Wiley's Bridge near Temple	1.9	1.6	.84	1.6	<.01	.00
Tulpehocken Creek near Reading	2.4	([1])	([1])	13	11	.85
Schuylkill River at Reading	18	14	.78	15	5.1	.34
Wyomissing Creek at Museum Road, West Reading	.02	.02	[2]<1.0	.01	<.01	<.01
Angelica Creek at Reading	.01	---	---	.05	.01	.20
Manatawny Creek near Pottstown	1.7	1.7	[2]<1.0	1.8	1.4	.78
Schuylkill River at Pottstown	62	53	.85	55	42	.78
French Creek at Phoenixville	1.1	.29	.26	.67	.25	.37
Perkiomen Creek near Graterford	3.2	3.2	[2]<1.0	4.5	2.2	.49
Skippack Creek near Collegeville	.02	.01	.50	.89	.52	.58
Valley Creek at Wilson Bridge near Valley Forge	.50	.50	[2]<1.0	.67	.58	.87
Schuylkill River at Port Kennedy	61	55	.90	37	22	.59
Stony Creek at Norristown	.14	.14	<1.0	.24	.16	.67
Schuylkill River at Manayunk, Philadelphia	43	37	.86	52	28	.54
Wissahickon Creek at mouth, Philadelphia	.91	.65	.71	1.4	.68	.49

See footnotes at end of table.

Table 8. Summary of average annual transport of total and suspended trace metals and organic carbon by stream station in the Schuylkill River basin—Continued

Station name	Lead			Nickel		
	Total	Suspended	Ratio of suspended to total	Total	Suspended	Ratio of suspended to total
Schuylkill River at Berne	13	12	0.92	17	6	0.35
Maiden Creek at Wiley's Bridge near Temple	.68	.52	.76	.91	.65	.71
Tulpehocken Creek near Reading	6.4	6.3	.98	2.7	2.4	.89
Schuylkill River at Reading	15	14	.93	19	10	.53
Wyomissing Creek at Museum Road, West Reading	.09	.09	[2]<1.0	.02	.02	[2]<1.0
Angelica Creek at Reading	.03	([1])	([1])	.00	.00	
Manatawny Creek near Pottstown	2.3	2.3	[2]<1.0	.82	.77	.94
Schuylkill River at Pottstown	39	37	.95	20	13	.65
French Creek at Phoenixville	.26	.18	.69	.15	.09	.60
Perkiomen Creek near Graterford	3.6	3.2	.89	2.0	1.4	.70
Skippack Creek near Collegeville	.88	.82	.93	.44	.32	.73
Valley Creek at Wilson Bridge near Valley Forge	1.4	1.4	[2]<1.0	.48	.48	[2]<1.0
Schuylkill River at Port Kennedy	37	35	.95	27	17	.63
Stony Creek at Norristown	.75	.74	.99	.22	.21	.95
Schuylkill River at Manayunk, Philadelphia	36	34	.94	28	13	.46
Wissahickon Creek at mouth, Philadelphia	2.9	2.9	[2]<1.0	.40	.31	.78

Station name	Zinc			Organic Carbon		
	Total	Suspended	Ratio of suspended to total	Total	Suspended	Ratio of suspended to total
Schuylkill River at Berne	43	23	0.53	---	---	---
Maiden Creek at Wiley's Bridge near Temple	11	5.8	.53	---	---	---
Tulpehocken Creek near Reading	18	13	.72	---	---	---
Schuylkill River at Reading	59	35	.59	---	---	---
Wyomissing Creek at Museum Road, West Reading	.26	<.01	<.01	---	---	---
Angelica Creek at Reading	.04	<.01	<.01	---	---	---
Manatawny Creek near Pottstown	7.6	5.9	.78	---	---	---
Schuylkill River at Pottstown	390	310	.82	11,000	5,100	0.46
French Creek at Phoenixville	1.2	.26	.22	---	---	---
Perkiomen Creek near Graterford	14	8.8	.63	---	---	---
Skippack Creek near Collegeville	3.0	2.3	.77	---	---	---
Valley Creek at Wilson Bridge near Valley Forge	2.7	<.01	<.01	---	---	---
Schuylkill River at Port Kennedy	140	94	.67	17,000	2,400	.14
Stony Creek at Norristown	17	17	[2]<1.0	---	---	---
Schuylkill River at Manayunk, Philadelphia	230	110	.48	25,000	15,000	.60
Wissahickon Creek at mouth, Philadelphia	3.4	3.4	[2]<1.0	---	---	---

[1]Indicates that the total constituent load was computed based on total constituent concentration, therefore, no values for suspended constituent concentration or ratio of suspended to total is available.

[2]Indicates that the dissolved constituent load is small.

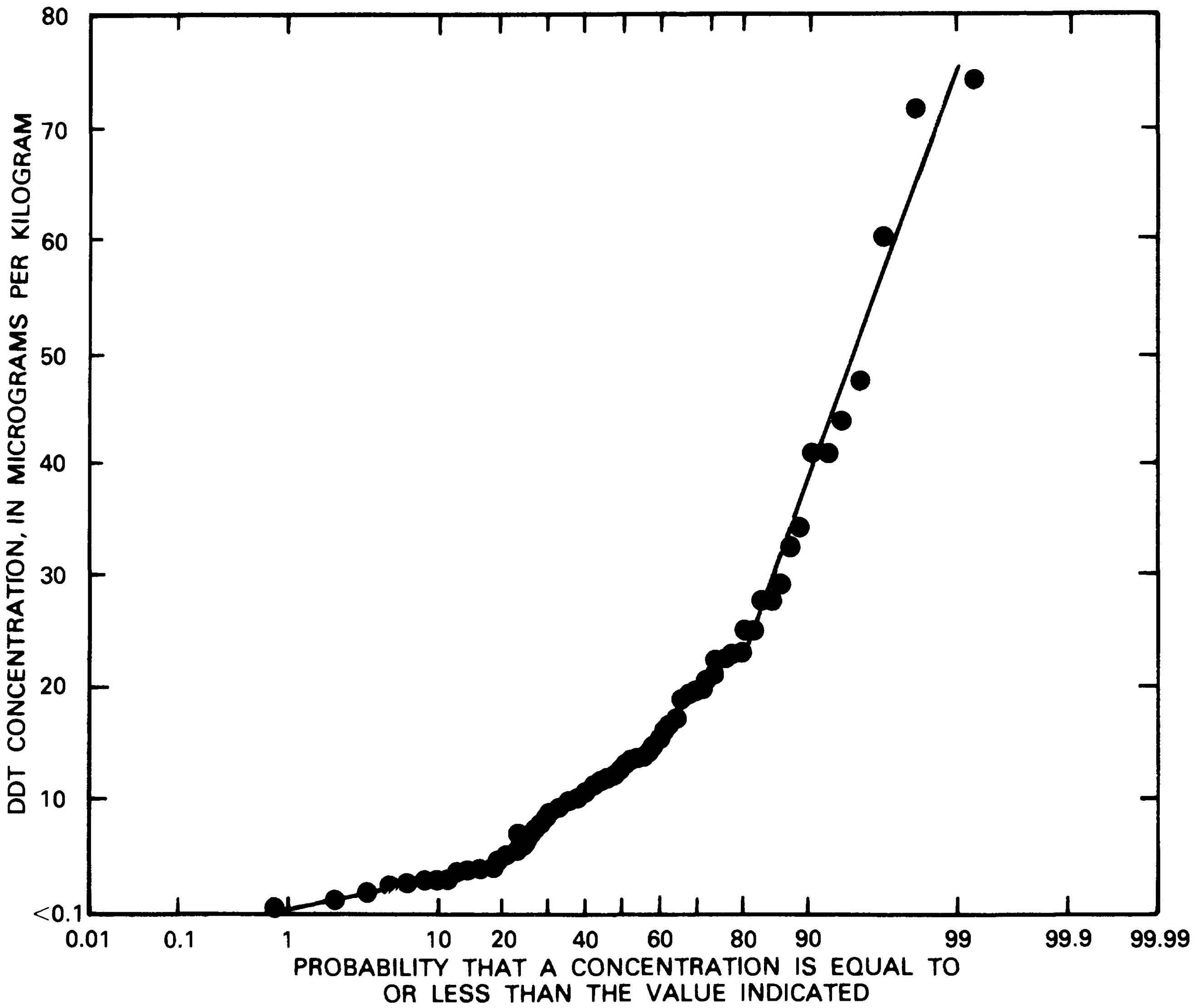

Figure 24. Normal-probability plot of concentrations of DDT and its metabolites as DDT from the 1979 bed-material survey in the Schuylkill River basin.

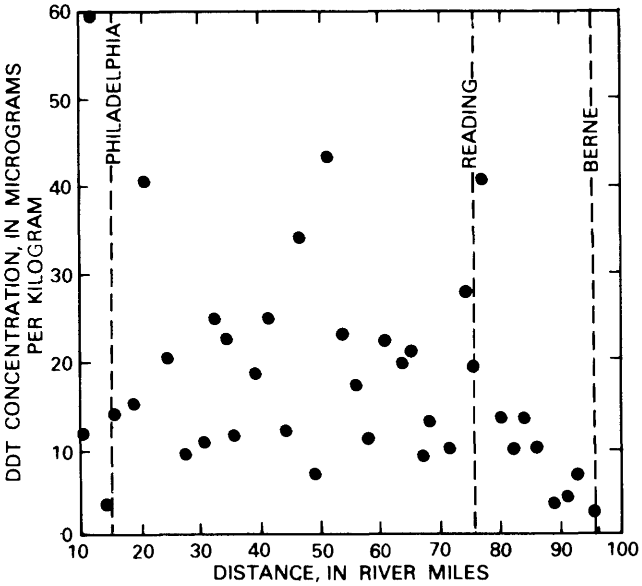

Figure 25. Relation of concentrations of DDT and its metabolites as DDT to river mile of sampling point in bed sediments in the main stem of the Schuylkill River.

COMPARISON OF CONCENTRATIONS OF TRACE SUBSTANCES WITH WATER-QUALITY CRITERIA

An objective of the project was to compute the frequency at which water-quality criteria are exceeded in the Schuylkill River. General criteria for domestic water supply and freshwater aquatic life, as specified by the U.S. Environmental Protection Agency (1976), and specific criteria for the Schuylkill River from the Little Schuylkill River confluence to Fairmount Dam, as specified by the Commonwealth of Pennsylvania (Public Law 1987, Chapter 39), are given in table 11. The criteria apply to the total concentration of a constituent in the water column; that is, the total is the sum of the suspended and dissolved constituent fractions.

Concentration-frequency curves were constructed for copper, lead, and zinc for the Schuylkill River at Manayunk in Philadelphia, using the method of Miller (1951) and Colby (1956) previously described. Concentrations of copper, lead, or zinc are estimated to exceed the corresponding water-supply criteria less than 1 percent at the time, or less than 4 days per year on the average.

The Philadelphia Water Department monitors the chemical quality of water at its two water-supply intakes (RM 10.2) in the Schuylkill River. Samples of raw river water generally are collected on Monday morning of each week. The average, minimum, and maximum monthly concentrations of total trace metals at the Belmont and Queen Lane intakes for July 1978 to June 1979 are shown in table 12. The concentrations of trace metals in the raw river water at the two intakes are generally lower than the water-quality criteria shown in table 11.

SUMMARY

In general, concentrations of trace substances in the bed sediments of the main stem of the Schuylkill River were greater than those in the tributaries and exceeded the background concentrations in the basin. Concentrations of most trace metals in the main-stem bed sediments generally were highest in Reading and lowest in Berne; however, concentrations of chlordane, DDT and its metabolites, and dieldrin increased gradually from Berne to Philadelphia.

Table 9. Comparison of constituent yields and land use for the Schuylkill River and the Chattahoochee River (Georgia)
[Constituent yields are in tons per square mile per year]

	Drainage area (square miles)	Land use (percent)[1 2]			Constituent yield[3]			
		Urban	Rural	Forest	Total copper	Total lead	Total zinc	Total organic carbon
Schuylkill River at Manayunk, Philadelphia	1,811	15.5	52.4	32.1	0.029	0.020	0.13	14
Chattahoochee River from Atlanta to Whitesburg, Georgia	1,390	19.2	9.6	71.2	.043	.099	.12	12

[1]Urban includes mining and other; forest includes water; and rural can be considered to be agricultural.
[2]Data source for land use in the Chattahoochee River basin is Cherry and others (1980).
[3]Data source for constituent yields in the Chattahoochee River basin is Stamer and others (1979).

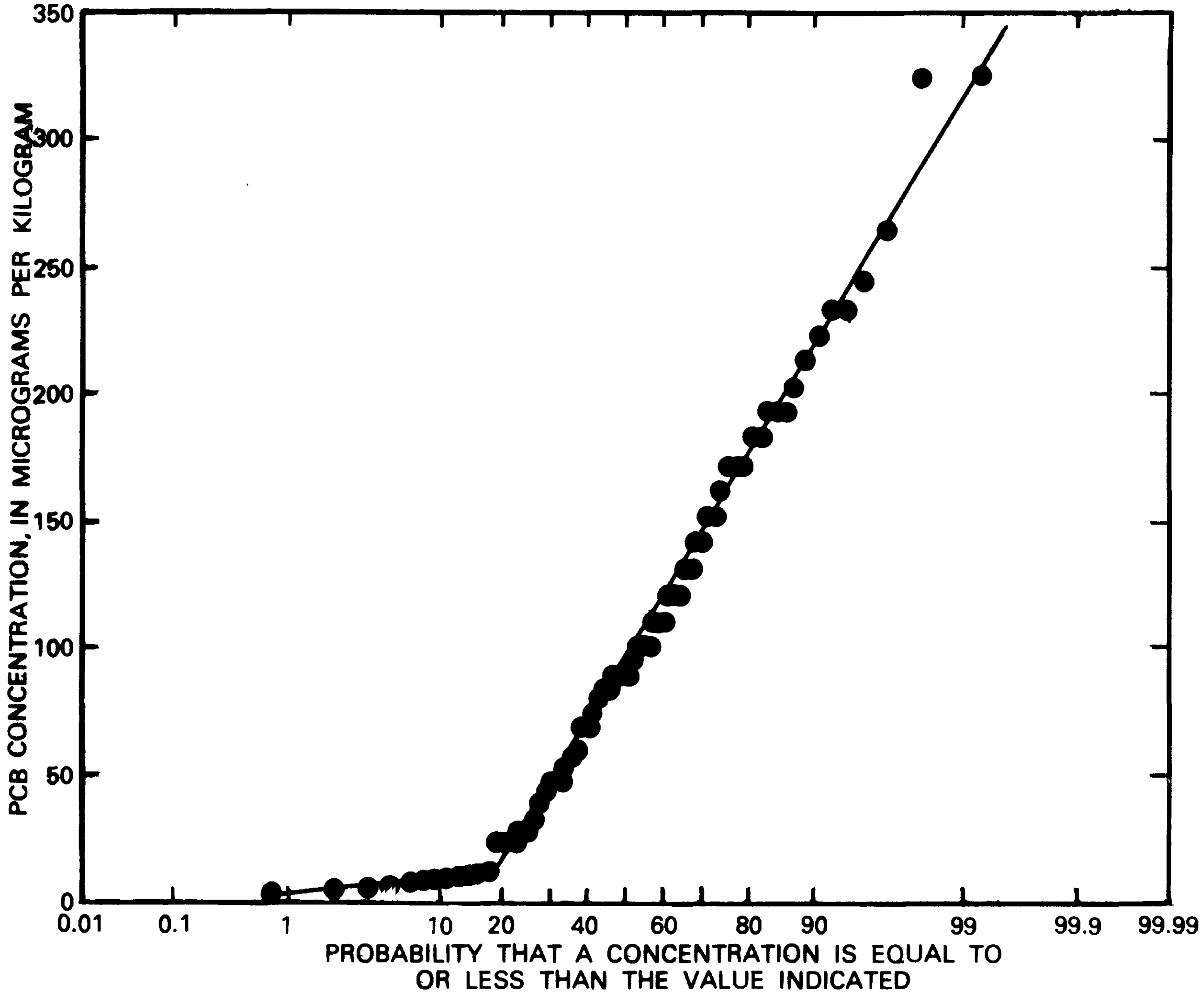

Figure 26. Normal-probability plot of PCB concentrations from the 1979 bed-material survey in the Schuylkill River basin.

Table 10. Summary of concentrations of trace organic substances in the Schuylkill River at Pottstown and Manayunk, Philadelphia
[Concentrations are in micrograms per liter]

Trace organic substance	Pottstown			Manayunk		
	Number of samples	Mean	Range	Number of samples	Mean	Range
Aldrin	12	<0.01	---	14	<0.01	---
Chlordane	12	<.1	---	14	<.1	---
DDD	12	<.01	---	14	<.01	---
DDE	12	<.01	---	14	<.01	---
DDT	12	.001	0.00–0.01	14	<.01	---
Dieldrin	12	<.01	---	14	<.01	---
Endosulfan	12	<.01	---	14	<.01	---
Endrin	12	<.01	---	14	<.01	---
Heptachlor epoxide	12	<.01	---	14	<.01	---
Heptachlor	12	<.01	---	14	<.01	---
Lindane	12	<.01	---	14	<.01	---
Mirex	12	<.01	---	12	<.01	---
PCB's	12	.01	0–.2	14	.11	<0.01–0.3
Polychlorinated naphthalene	12	<.01	---	14	.01	<.01– .1
Perthane	12	<.01	---	14	<.01	---
Toxaphene	12	<1.0	---	14	<1.0	---

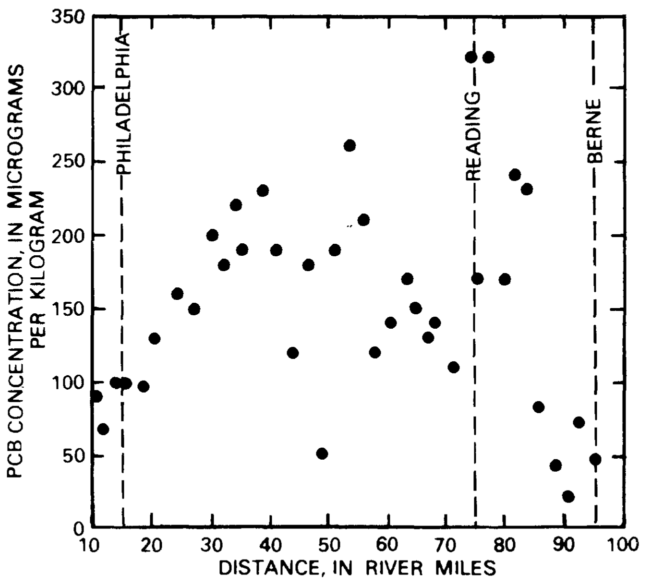

Figure 27. Relation of PCB concentrations to river mile of sampling point in bed sediments in the main stem of the Schuylkill River.

The average concentrations of trace metals in the finer than 63-μm-sized bed sediments of the main stem of the Schuylkill River were 603 μg/g for zinc, 284 μg/g for lead, 252 μg/g for copper, 119 μg/g for nickel, 96 μg/g for chromium, 8.2 μg/g for beryllium, 0.64 μg/g for arsenic, and 0.002 μg/g for mercury. The average concentrations of trace organic substances in the finer than 63-μm-sized bed sediments of the main stem of the Schuylkill River were 152 μg/kg for PCB's, 24 μg/kg for chlordane, 18 μg/kg for DDT and its metabolites, and 1.8 μg/kg for dieldrin. Concentrations of trace substances in the bed sediments correlated with clay as a percentage of the silt- and clay-sized fraction and with concentrations of organic carbon at the 98-percent or greater level of confidence.

The average annual transport of trace substances was computed for chromium, copper, lead, nickel, and zinc. The transport of other metals and trace organic substances was not computed because concentrations generally were at or below detection limits. Average annual transport in the study area was greatest for zinc and lowest for nickel. An average of about 71 percent of the total transport of trace metals occurs as suspended material; percentages transported as suspended material ranged from 52 for copper to 93 for lead.

A comparison of yields of copper, lead, zinc, and total organic carbon in tons per square mile per year in the Schuylkill River basin with yields of the constituents in the Chattahoochee River (Georgia) indicates yields of the same order of magnitude; the yield of lead in the Chattahoochee River basin was, however, about five times that in the Schuylkill. Both river basins have about the same percentage of urban land, and both are Piedmont streams.

The frequency of occurrence of concentrations of selected trace metals (copper, lead, and zinc) in the Schuylkill River at Manayunk in Philadelphia were compared with Federal and State water-quality criteria for domestic water supply and freshwater aquatic life. Analysis of the data indicates that the criteria are exceeded, on the average, less than 1 percent of the time, or about 4 days per year. If the criteria applied to concentrations of dissolved metals rather than total

Table 11. Water-quality criteria for selected metals
[Units are in micrograms per liter]

Trace metals	Domestic water supply[1]	Freshwater aquatic life[1]	Schuylkill River at Manayunk[2]
Arsenic	50	No criterion	50
Cadmium	10	4.0	No criterion
Chromium	50	No criterion	50 as hexavalent
Copper	1,000	([3])	([3])
Lead	50	([4])	50 or ([4]), whichever is lesser
Mercury	2.0	.05	No criterion
Nickel	No criterion	([4])	([4])
Selenium	10	([4])	No criterion
Silver	50	([4])	Do.
Zinc	5,000	([4])	([4])

[1]Criteria from U.S. Environmental Protection Agency (1976).
[2]Criteria from commonwealth of Pennsylvania, Public Law 1987, Chapter 39.
[3]Criterion is 0.1 times the concentration that is lethal to 50 percent of the fish or sensitive resident species in a 96-hour bioassay.
[4]Criterion is 0.01 times the concentration that is lethal to 50 percent of the fish or sensitive resident species in a 96-hour bioassay.

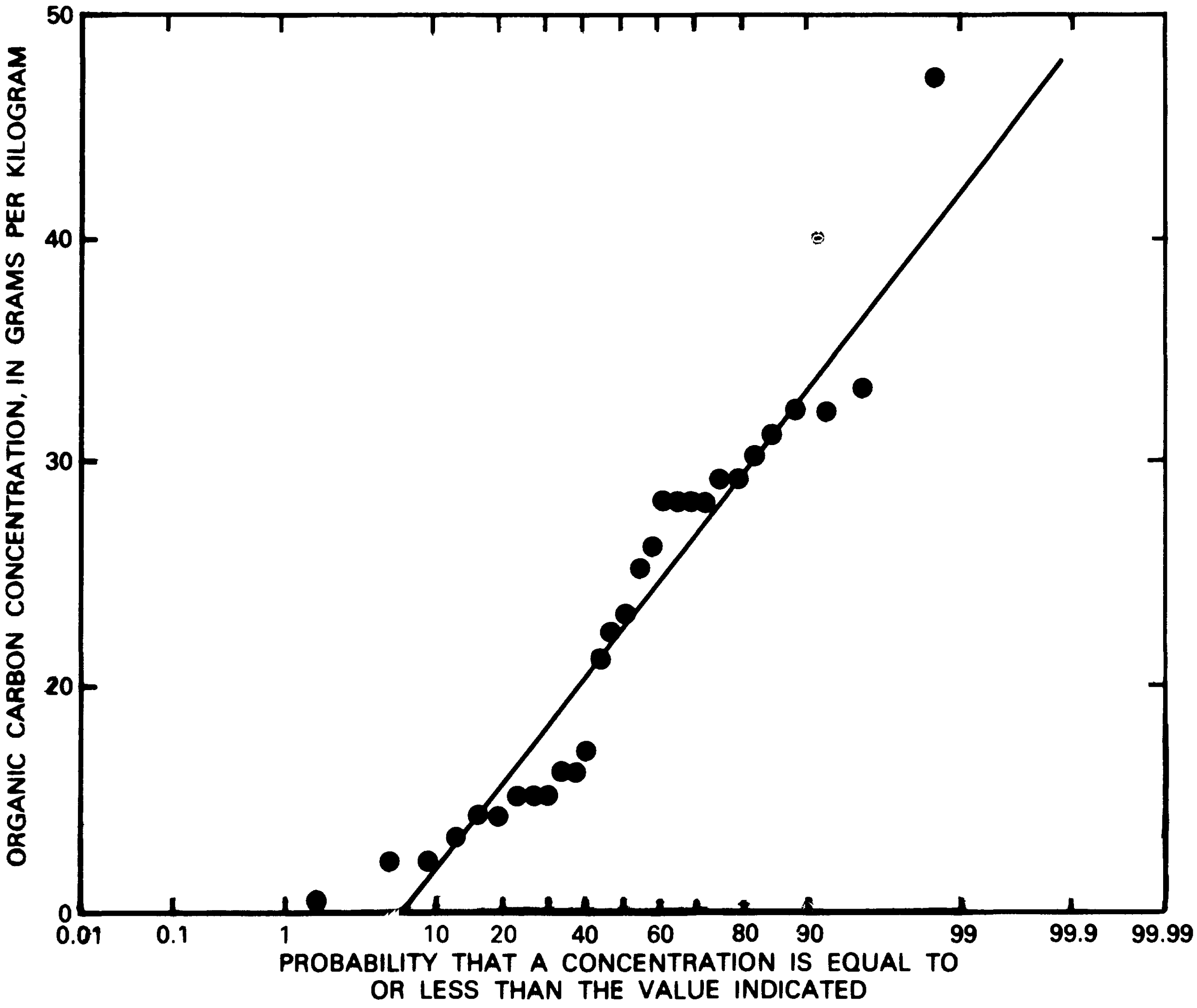

Figure 28. Normal-probability plot of organic-carbon concentrations in the tributary bed sediments from the 1979 survey in the Schuylkill River basin.

metals, the criteria would be exceeded much less than 1 percent of the time because the largest part of the concentration of trace metal in the waters of the Schuylkill River is associated with suspended sediment.

Table 12. Summary of monthly concentrations of total trace metals in the Schuylkill River at Philadelphia from July 1978 to June 1979
[Concentrations are in micrograms per liter. ND means not detected; — means no data]

Year	Month	Arsenic Average	Arsenic Maximum	Arsenic Minimum	Cadmium Average	Cadmium Maximum	Cadmium Minimum	Chromium Average	Chromium Maximum	Chromium Minimum
		City of Philadelphia — Belmont Intake — Belmont Laboratory								
1978	July	3	3	3	0	0	0	2	2	2
	August	11	20	2	0	0	0	2	2	2
	September	3	3	3	0	0	0	3	3	3
	October	2	2	2	0	0	0	4	4	3
	November	2	2	1	1	1	0	5	6	4
	December	ND	ND	ND	ND	ND	ND	ND	ND	ND
1979	January	ND	ND	ND	ND	ND	ND	ND	ND	ND
	February	ND	ND	ND	ND	ND	ND	ND	ND	ND
	March	ND	ND	ND	ND	ND	ND	ND	ND	ND
	April	5	10	0	0	0	0	3	3	3
	May	3	3	3	0	0	0	3	3	2
	June	5	7	2	0	0	0	3	3	2
		City of Philadelphia — Queen Lane Intake — Queen Lane Laboratory								
1978	July	0	0	0	0	0	0	2	2	2
	August	2	2	2	0	0	0	4	4	4
	September	4	5	2	0	0	0	3	3	2
	October	2	2	1	0	0	0	4	5	3
	November	3	3	2	1	1	0	24	43	5
	December	3	3	3	0	0	0	4	4	4
1979	January	—	—	—	—	—	—	—	—	—
	February	3	3	3	—	—	—	—	—	—
	March	—	—	—	—	—	—	—	—	—
	April	2	2	2	0	0	0	4	6	2
	May	26	50	3	0	0	0	2	2	2
	June	3	3	3	1	1	0	4	4	3

Year	Month	Nickel Average	Nickel Maximum	Nickel Minimum	Selenium Average	Selenium Maximum	Selenium Minimum	Silver Average	Silver Maximum	Silver Minimum
		City of Philadelphia — Belmont Intake — Belmont Laboratory								
1978	July	ND	ND	ND	ND	ND	ND	0	0	0
	August	ND	ND	ND	0	0	0	0	0	0
	September	ND	ND	ND	0	0	0	ND	ND	ND
	October	ND	ND	ND	0	1	0	0	0	0
	November	ND	ND	ND	0	0	0	0	0	0
	December	ND	ND	ND	ND	ND	ND	0	0	0
1979	January	ND	ND	ND	ND	ND	ND	ND	ND	ND
	February	ND	ND	ND	ND	ND	ND	ND	ND	ND
	March	ND	ND	ND	ND	ND	ND	ND	ND	ND
	April	ND	ND	ND	0	0	0	0	0	0
	May	0	0	0	1	1	0	0	0	0
	June	0	10	0	0	0	0	0	0	0
		City of Philadelphia — Queen Lane Intake — Queen Lane Laboratory								
1978	July	—	—	—	0	0	0	0	0	0
	August	—	—	—	0	0	0	0	0	0
	September	—	—	—	0	0	0	—	—	—
	October	—	—	—	0	1	0	0	0	0
	November	—	—	—	0	0	0	0	0	0
	December	—	—	—	—	—	—	0	0	0
1979	January	—	—	—	—	—	—	—	—	—
	February	—	—	—	—	—	—	—	—	—
	March	—	—	—	—	—	—	—	—	—
	April	—	—	—	0	0	0	0	0	0
	May	0	0	0	0	0	0	0	0	0
	June	0	0	0	0	0	0	0	0	0

Table 12. Summary of monthly concentrations of total trace metals in the Schuylkill River at Philadelphia from July 1978 to June 1979—Continued

Year	Month	Copper			Lead			Mercury		
		Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum
City of Philadelphia — Belmont Intake — Belmont Laboratory										
1978	July	ND	ND	ND	4	4	4	0.0	0.0	0.0
	August	ND	ND	ND	6	6	6	ND	ND	ND
	September	ND	ND	ND	4	4	3	0.0	0.0	0.0
	October	ND	ND	ND	7	9	2	.3	.5	.1
	November	ND	ND	ND	4	4	4	.2	.4	0.0
	December	ND	ND	ND	ND	ND	ND	.2	.2	.2
1979	January	ND	ND	ND	ND	ND	ND	0.0	0.0	0.0
	February	ND	ND	ND	ND	ND	ND	ND	ND	ND
	March	ND	ND	ND	ND	ND	ND	ND	ND	ND
	April	6	7	6	9	11	7	ND	ND	ND
	May	4	4	3	7	10	3	0.0	0.0	0.0
	June	7	10	4	7	11	3	0.0	0.0	0.0
City of Philadelphia — Queen Lane Intake — Queen Lane Laboratory										
1978	July	—	—	—	5	5	5	0.0	0.0	0.0
	August	—	—	—	10	10	10	—	—	—
	September	—	—	—	10	14	5	0.0	0.0	0.0
	October	—	—	—	7	11	4	2.1	5.3	0.5
	November	—	—	—	4	6	2	1.4	2.7	0.1
	December	—	—	—	8	8	8	0.0	0.0	0.0
1979	January	—	—	—	—	—	—	0.3	0.3	0.3
	February	—	—	—	—	—	—	—	—	—
	March	—	—	—	—	—	—	—	—	—
	April	7	8	6	8	10	6	—	—	—
	May	5	6	4	4	5	3	0.0	0.0	0.0
	June	8	10	5	6	9	3	0.0	0.0	0.0

Year	Month	Zinc		
		Average	Maximum	Minimum
City of Philadelphia — Belmont Intake — Belmont Laboratory				
1978	July	50	50	50
	August	30	30	30
	September	80	110	50
	October	150	200	100
	November	170	180	150
	December	70	70	70
1979	January	ND	ND	ND
	February	ND	ND	ND
	March	ND	ND	ND
	April	50	70	20
	May	60	90	20
	June	190	270	100
City of Philadelphia — Queen Lane Intake — Queen Lane Laboratory				
1978	July	70	70	70
	August	50	50	50
	September	90	120	60
	October	130	150	100
	November	170	200	130
	December	50	50	50
1979	January	—	—	—
	February	—	—	—
	March	—	—	—
	April	50	70	30
	May	50	70	20
	June	100	140	60

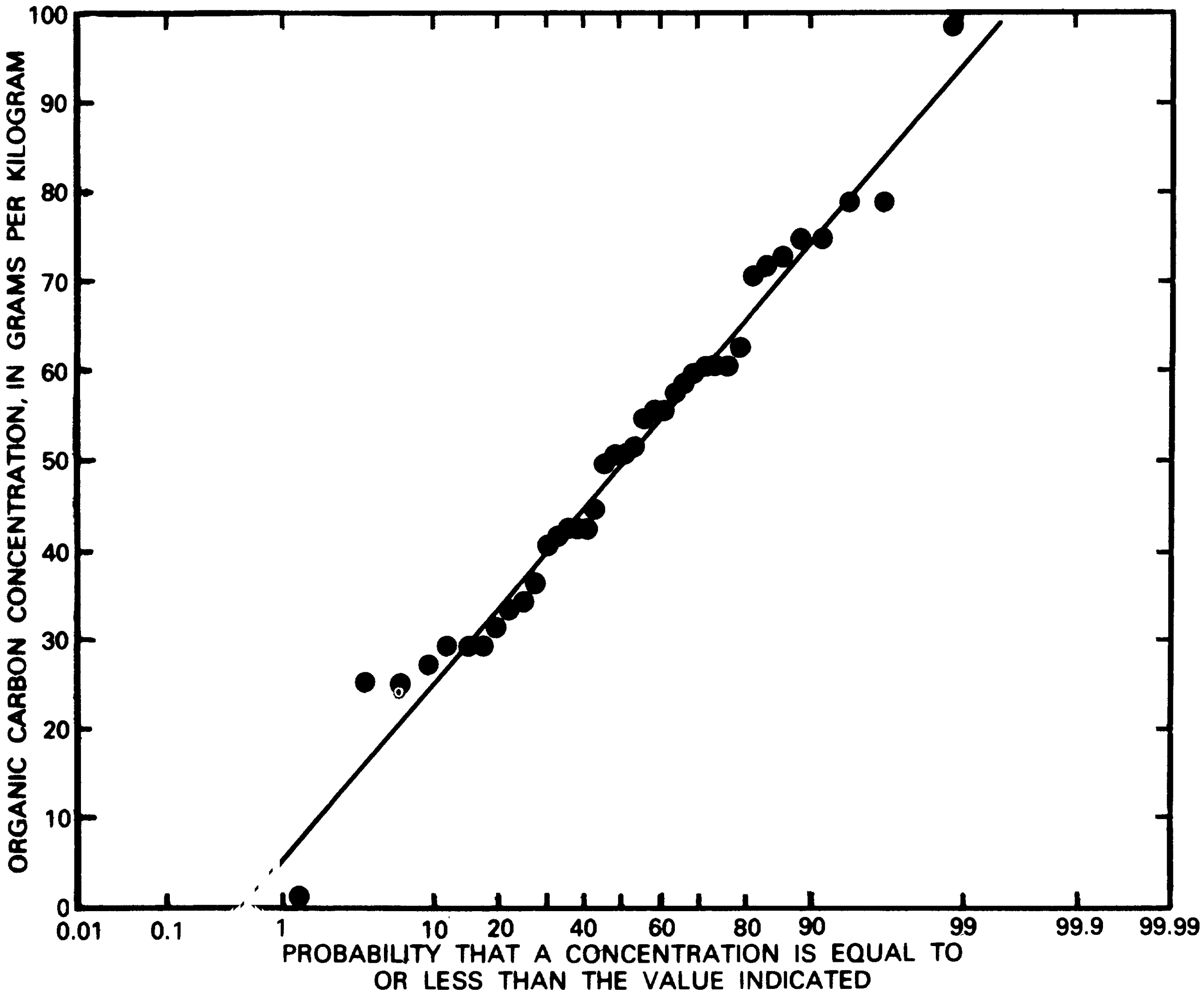

Figure 29. Normal-probability plot of organic-carbon concentrations in the main-stem bed sediments from the 1979 survey in the Schuylkill River basin.

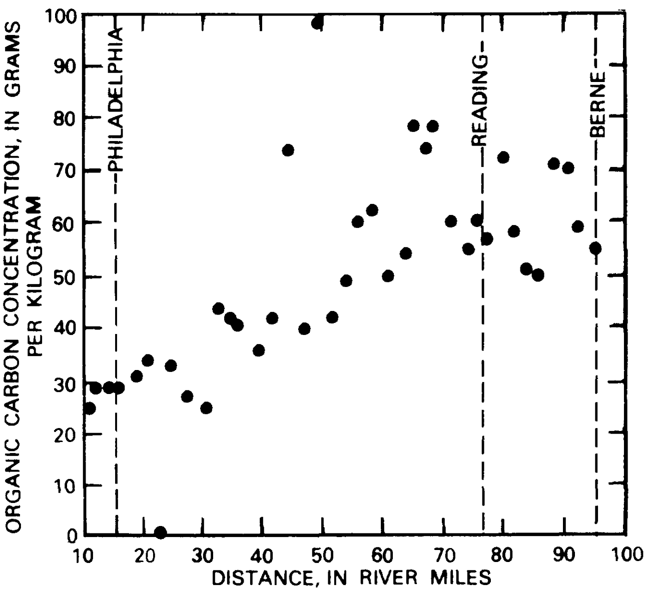

Figure 30. Relation of organic-carbon concentration to river mile of sampling point in bed sediments in the main stem of the Schuylkill River.

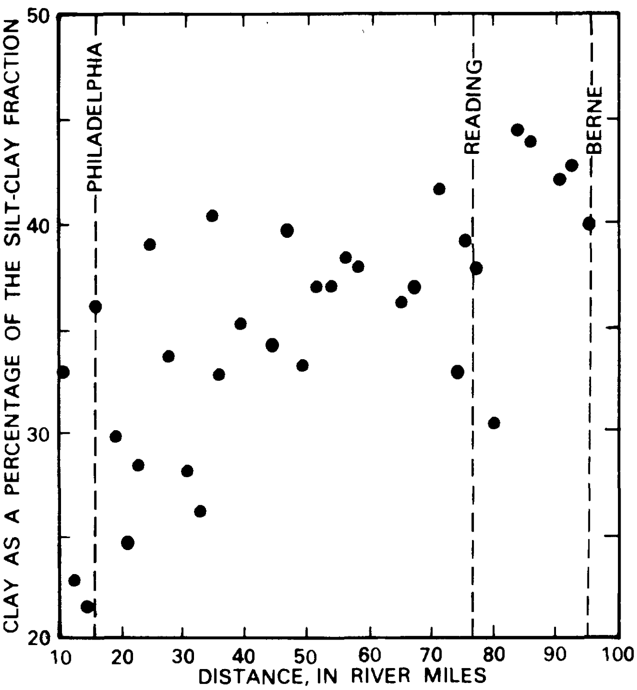

Figure 31. Relation of clay as a percentage of the silt- and clay- sized fraction to river mile of sampling point in the bed sediments in the main stem of the Schuylkill River.

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METRIC CONVERSION FACTORS

Factors for converting inch-pound units to International System of Units (SI)

Multiply inch-pound unit	By	To obtain SI unit
ft (foot)	3.048×10^{-1}	m (meter)
ft^3/s (cubic foot per second)	2.832×10^{-2}	m^3/s (cubic meter per second)
in. (inch)	25.40	mm (millimeter)
mi (mile)	1.609	km (kilometer)
mi^2 (square mile)	2.590	km^2 (square kilometer)
ton (short, 2,000 pounds)	9.072×10^{-1}	t (metric ton)
ton/mi^2/yr (ton per square mile per year)	3.503×10^{-1}	t/km^2/yr (metric ton per square kilometer per year)
°F (degree Fahrenheit)	5/9 (°F − 32)	°C (degree Celsius)