Sediment Deposition in Lake Clarke, Lake Aldred, and Conowingo Reservoir, Pennsylvania and Maryland, 1910-93

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 96-4048

Prepared in cooperation with the

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Lemoyne, Pennsylvania
1997

U.S. DEPARTMENT OF THE INTERIOR

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
square foot (ft^2)	0.0929	square meter
square mile (mi^2)	2.590	square kilometer
square foot per day (ft^2/d)	0.09290	square meter per day
	Volume	
acre-foot (acre-ft)	1,233	cubic meter
	Flow	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
	Mass	
pound (lb)	0.4536	kilogram
pound per cubic foot (lb/ft^3)	16.02	kilogram per cubic meter
ton, short (2,000 lb)	0.9072	megagram

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called "Sea Level of 1929."

SEDIMENT DEPOSITION IN LAKE CLARKE, LAKE ALDRED, AND CONOWINGO RESERVOIR, PENNSYLVANIA AND MARYLAND, 1910-93

By Lloyd A. Reed and Scott A. Hoffman

ABSTRACT

The Susquehanna River carries a significant amount of the sediment and the nutrient load transported to the Chesapeake Bay. Three large hydroelectric dams are located near the mouth of the Susquehanna River. The three dams and associated reservoirs are Safe Harbor (Lake Clarke) and Holtwood (Lake Aldred) in southern Pennsylvania and Conowingo (Conowingo Reservoir) in northern Maryland. Two of these reservoirs, Lakes Clarke and Aldred, have reached a state of equilibrium with sediment transport in the river. The third, Conowingo Reservoir, continues to accumulate sediment as well as particulate organic nitrogen and particulate phosphorus. Bottom-elevation surveys of Conowingo Reservoir made in 1959, 1990, and 1993 indicate that the reservoir will reach equilibrium with sediment transport of the river during the next 10 to 20 years. Data collected from 1985-89 indicate that the Susquehanna River transports about 1,780 million pounds of sediment, 147 million pounds of nitrogen, and 5.1 million pounds of phosphorus to the Chesapeake Bay during a year of normal streamflow. Once equilibrium is reached in the Conowingo Reservoir, these loads may increase to levels currently transported by the river to the reservoirs, about 6,600 million pounds of sediment, 153 million pounds of nitrogen, and 9.1 million pounds of phosphorus per year. These higher loads may effect progress made on reducing nutrient loads and should be considered when planning future programs.

INTRODUCTION

The District of Columbia, the State of Maryland, the Commonwealths of Pennsylvania and Virginia, the Chesapeake Bay Commission, and the U.S. Environmental Protection Agency (USEPA) have agreed to reduce nutrient loads to the Chesapeake Bay in an attempt to restore and protect the estuarine environment. The agreement calls for a 40 percent reduction in controllable nutrient loads to the Bay by the year 2000. The Susquehanna River, which drains 27,510 mi^2 in New York, Pennsylvania, and Maryland, is the largest tributary to the Bay and transports significant quantities of sediment, nitrogen, and phosphorus (Ott and others, 1991). The deposition of sediment and nutrients behind three large hydroelectric dams (fig. 1) on the Lower Susquehanna River influences actual loads transported to the Bay by the Susquehanna River. Two of the dams and the associated lakes—Safe Harbor (Lake Clarke) and Holtwood (Lake Aldred)—are in southern Pennsylvania and the third, Conowingo (Conowingo Reservoir), is in northern Maryland. Because significant amounts of suspended organic nitrogen and suspended phosphorus are transported with and deposited with suspended sediment, the Bureau of Land and Water Conservation of the Pennsylvania Department of Environmental Protection and the U.S. Geological Survey (USGS) cooperated in a study to quantify sediment deposition rates in the three reservoirs. Sediment deposition in the reservoirs occurs until the cross-sectional area is reduced to the point where the reservoir is in equilibrium with sediment transport of the river. When equilibrium is reached, deposition rates for sediment, nitrogen, and phosphorus in the reservoirs will be significantly reduced and most of the load transported by the Susquehanna River will pass through the reservoirs and enter the Chesapeake Bay.

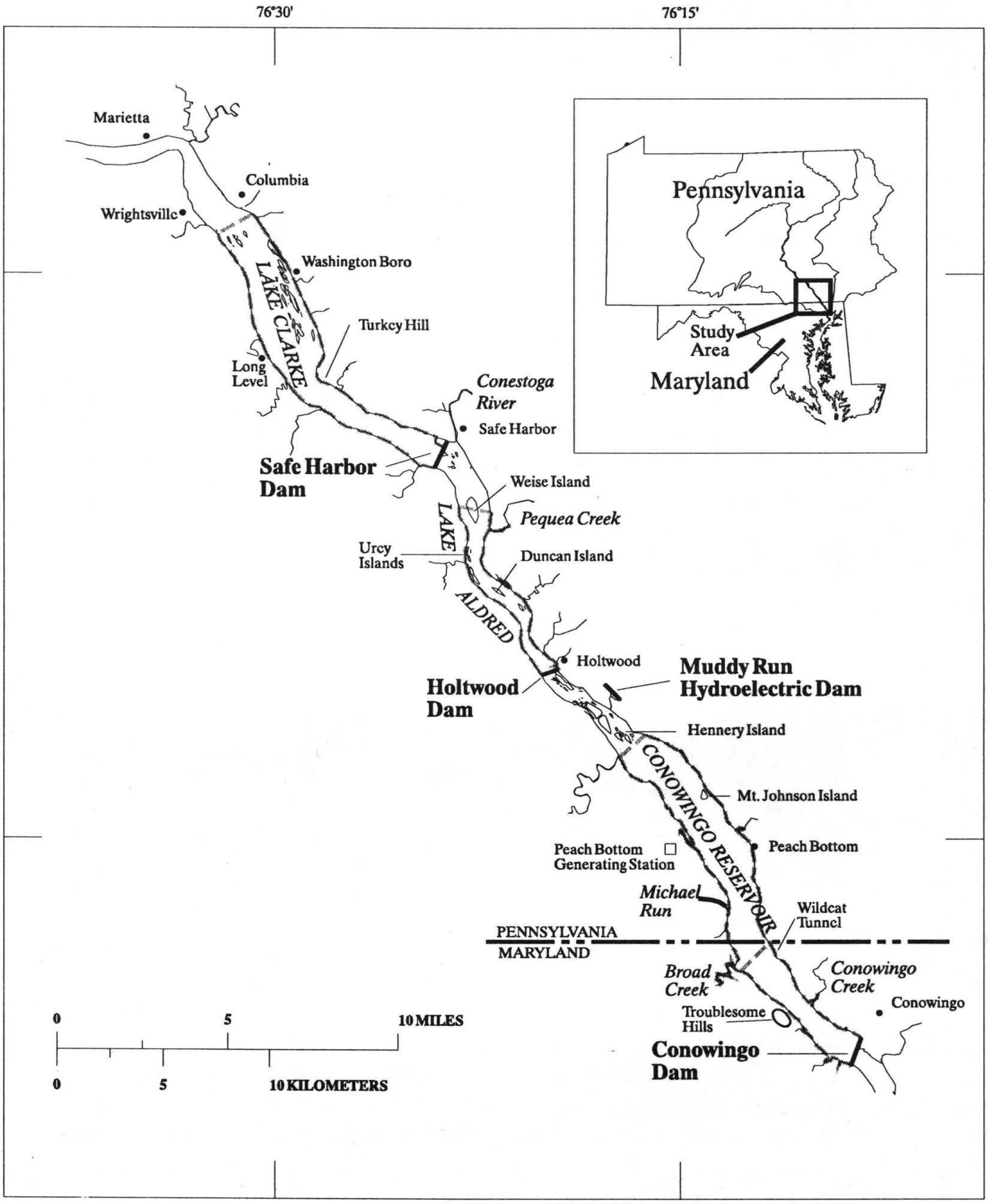

Figure 1. The location of the three hydroelectric dams on the Lower Susquehanna River.

Purpose and Scope

This report presents detailed bathymetric maps of the three major reservoirs on the lower Susquehanna River for 1993, evaluates historical net change in bottom sediment distribution of each reservoir, and discusses the effect of changes in sediment content of the reservoirs on future water quality of the Chesapeake Bay. Water depths were measured across 68 sections in the three reservoirs—26 in Lake Clarke, 19 in Lake Aldred, and 23 in Conowingo Reservoir. Net changes in the contents of Lakes Clarke and Aldred were determined by comparing lake volumes reported by Schuleen and Higgins (1953) and data collected by the USGS in 1990 (Hainly and others, 1995). Net changes in the elevation of bottom sediments were determined at selected cross sections in Conowingo Reservoir by comparing the 1993 data with the original capacity of Conowingo Reservoir and with data collected by the Johns Hopkins University in 1959 (Whaley, 1960) and data collected by the USGS in 1990 (Hainly and others, 1995). Water depth and conveyance were used to calculate the equilibrium of sediment storage in the reservoirs.

Approach

This report presents maps of water depths in the three reservoirs, using 5-ft contour intervals, prepared from data collected in 1993. The maps show normal water depth, which is the depth between the normal water-surface elevation of the lake and the elevation of the bottom sediment. The normal water-surface elevation is the water-surface elevation the dams were designed to maintain. The lake bottom is, in most cases, the surface elevation of the bottom sediment; however, the headwaters of each of the lakes contain areas where sediment deposition has not occurred, and the bottom is composed of bedrock ledges.

Historical data were evaluated and used to estimate sediment deposition rates. Cross-section data were collected in Lake Aldred during 1939, 1950, and 1961 by the Holtwood Steam Electric Station (Ledvina, 1962). Cross-section data were collected in Lake Clarke several times from 1932 to 1951 by the Pennsylvania Water and Power Company (Schuleen and Higgins, 1953). Cross-section profiles were surveyed at six sections in Conowingo Reservoir in 1959 as part of a limnology study of the reservoir conducted by the Johns Hopkins University (Whaley, 1960). Cross-section profiles were obtained at selected sections in all three reservoirs during 1990 (Hainly and others, 1995) and 1993. Cross-section profiles were surveyed in 1990 to determine the elevation of the sediment surface and the aerial extent and thickness of sediment deposition. Profiles were surveyed in 1993 to provide enough data to map the elevation of the bottom sediment and determine changes that occurred in the elevation of the bottom sediments since the earlier survey. The water-storage capacity of the reservoirs was computed and differences between the original capacity and the capacity at the time of the survey were used to compute sediment deposition. A dry weight of sediment of 67.8 lb/ft^3 was used.

During the 1990 survey, a fathometer recorded data on water depth and a Loran[1] positioning system collected position data. A recording fathometer also was used during the 1993 survey to determine water depth, but position data were collected with a global positioning system. Water-stage recorders set to sea level were used to record water-surface elevations while the transect data were being recorded. Data collected from the Conowingo Reservoir were supplemented with data published by the Philadelphia Electric Company (1989). The 1993 data were used to prepare maps of each reservoir showing depth to sediment using 5-ft contour intervals for most areas.

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[1] Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

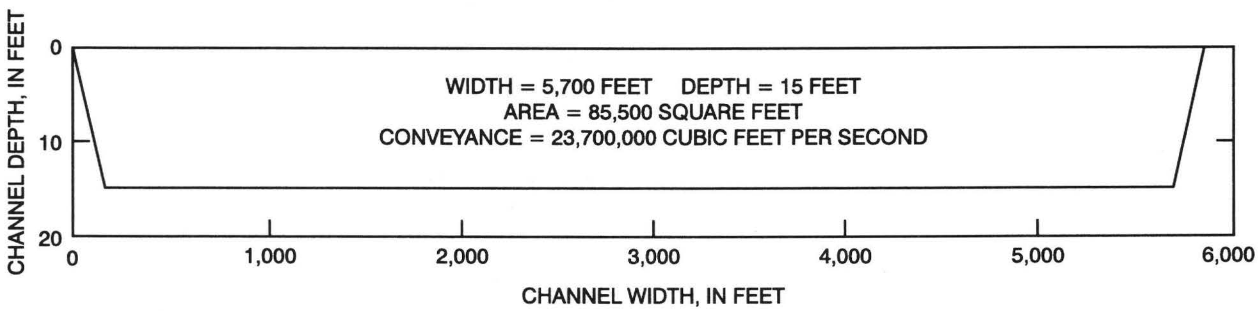
Conveyance is defined (Benson and Dalrymple, 1967, p. 28) as a "measure of the carrying capacity of the channel." Conveyance along with the greater number of cross sections surveyed in 1993 as compared to those surveyed in 1990 (Hainly and others, 1995) was used to more accurately define both the locations that have reached equilibrium between sediment deposition in the reservoirs and sediment transport by the river and more accurately estimate the sediment storage capacity of the reservoirs. The units of conveyance are cubic feet per second, and the roughness coefficient used in all calculations for both Lake Clarke and the Conowingo Reservoir was 0.032. An example of how the shape of a channel effects conveyance is shown on figure 2. Both channels have the same cross-sectional area, but the deeper-narrower channel can convey more water because less water is in frictional contact with the bottom and sides of the channel. Conveyances and cross-sectional areas were not calculated for Lake Aldred because the lake is small and lake levels are not controlled by flood gates.

DESCRIPTION OF THE SUSQUEHANNA RIVER BASIN

The Susquehanna River extends from south-central New York State through east-central Pennsylvania and enters the Chesapeake Bay in north-eastern Maryland (fig. 1). The river drains an area of 27,510 mi^2. Much of the land (63.1 percent) in the Susquehanna River Basin is forested; 26.1 percent is agriculture, 9.3 percent is urban, and 1.5 percent is water (Hannawald, 1989). Most of the woodland is in the northern and western parts of the basin. Much of the agricultural land is along the river valleys in the central and northern parts of the basin and in the southern part of the basin. About 75 percent of the agricultural land is tilled. Most urban land is in the southern part of the basin. Annual precipitation ranges from an average of about 34 in. in southern New York State to over 46 in. in parts of central Pennsylvania.

Sediment and Nutrient Transport in the Lower Susquehanna River

Using data collected from 1985 to 1989, Ott and others (1991) reported long-term average annual sediment and nutrient loads transported by the Susquehanna River. Their data indicate that the reservoirs on the Lower Susquehanna River trap about 4,800 million pounds of sediment, about 6.0 million pounds of nitrogen, and about 4.0 million pounds of phosphorus per year. They reported that the long-term average annual loads of sediment, nitrogen, and phosphorus transported to the Chesapeake Bay by the Susquehanna River at Conowingo, Md. (drainage area of 27,100 mi^2) were 1,780, 147, and 5.1 million pounds per year, respectively. They calculated long-term loads by adjusting for variations in annual streamflow relative to long-term mean streamflow. Conowingo Dam currently traps about 70 percent of the sediment, about 4 percent of the nitrogen, and about 45 percent of the phosphorus transported by the river. Once sediment deposition in the reservoirs reaches equilibrium with sediment transport in the river, the amount of sediment and nutrients that is transported to the Chesapeake Bay will increase. This increase in loads should be considered when planning future programs.



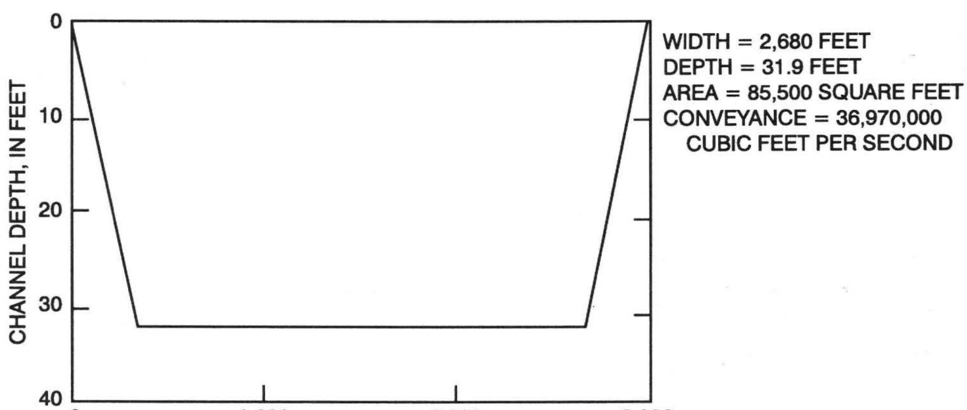


Figure 2. Conveyance of two channels with similar cross-sectional areas.

A few periods of high flow resulting from storms transport most of the sediment. The average yearly peak flow of the Susquehanna River above the reservoirs is about 274,000 ft^3/s. Peak flows exceeded once in 5, 10, and 25 years are equal to or greater than 382,000 ft^3/s, 464,000 ft^3/s, and 583,000 ft^3/s, respectively. Sediment data collected from sites upstream and downstream from the reservoirs indicate that some sediment scour from the reservoirs begins to occur when river flow exceeds about 400,000 ft^3/s (Lang, 1981). Flows of this magnitude occur about once every 6 or 7 years. Flows that have caused significant scour in the past have a small chance of occurrence. For example, the peak flow to the reservoirs from the storm of June 1972 was about 1,080,000 ft^3/s (a chance of recurrence of about once in 150 to 200 years). Net scour of sediment from the reservoirs during the 1972 storm (using data from Gross and others, 1978) was about 20,200,000 ton. Also, the peak flow to the reservoirs from the storm in September 1975 was about 560,000 ft^3/s (a chance of recurrence of about once in 20 to 25 years). Net scour of sediment from the reservoirs during the September 1975 storm was about 2,400,000 ton. In addition to sediment that has been transported from forested, agricultural, and urban areas in the Susquehanna River Basin, anthracite was mined in several areas of eastern Pennsylvania, and fine coal from processing plants in the mining region was a large component of the sediment transported by the Susquehanna River from the late 19th century through the early 20th century.

SAFE HARBOR DAM AND LAKE CLARKE

Safe Harbor Dam, 32 mi upstream from the Chesapeake Bay, was constructed in 1931. The reservoir behind Safe Harbor Dam, Lake Clarke, extends upstream about 9.5 mi to near Columbia, Pa. The lake surface occupies about 9.5 mi^2, and the normal water-surface elevation is 227.2 ft above sea level. Flood gates along the top of the dam to the west of the hydroelectric plant regulate streamflow in excess of plant capacity. Lake Clarke was surveyed in 1931, 1939, several times from 1940 to 1964, and during 1990 and 1993. Reservoir capacity (fig. 3) decreased from about 145,000 acre-ft in 1931 to about 81,000 acre-ft in 1950 (Schuleen and Higgins, 1953), and only small changes in capacity were measured after 1950. The average decrease in capacity was about 3,400 acre-ft per year for the first 19 years and sediment deposition averaged about 4,770,000 ton per year during the 19-year period. Much of the deposited sediment was sand and coal. As part of a coal-recovery operation, about 1,000,000 ton of sand and coal were dredged from Lake Clarke each year from 1954 to 1972. A survey in 1964 by the Safe Harbor Water Power Corporation indicated that incoming sediments replaced the dredged material (K.F. Williams, U.S. Geological Survey, written commun., 1965).

Along with the surveys of Lake Clarke, the Pennsylvania Water and Power Company collected suspended-sediment data from the Susquehanna River at Columbia (upstream of Lake Clarke) and at Safe Harbor (downstream of Lake Clarke) from 1948 to 1953. Schuleen and Higgins (1953) reported that particle size data obtained from the samples indicated that net scour of silt and clay occurred when river flow exceeded 250,000 ft^3/s and that net scour of sand would probably occur when river flow exceeded about 840,000 ft^3/s. Schuleen and Higgins (1953) also reported that the sediment deposition had resulted in a reduction in the cross-sectional area of the lake from the upstream end to a point about 7,000 ft above the dam. They reported that when the cross-sectional area was reduced, further deposition was not seen and that the area had reached a state of "sediment saturation." By 1950, this sediment saturation point had reached to within 7,000 ft of the dam, and the only area where sediment was still depositing was from the dam upstream for a distance of 7,000 ft.

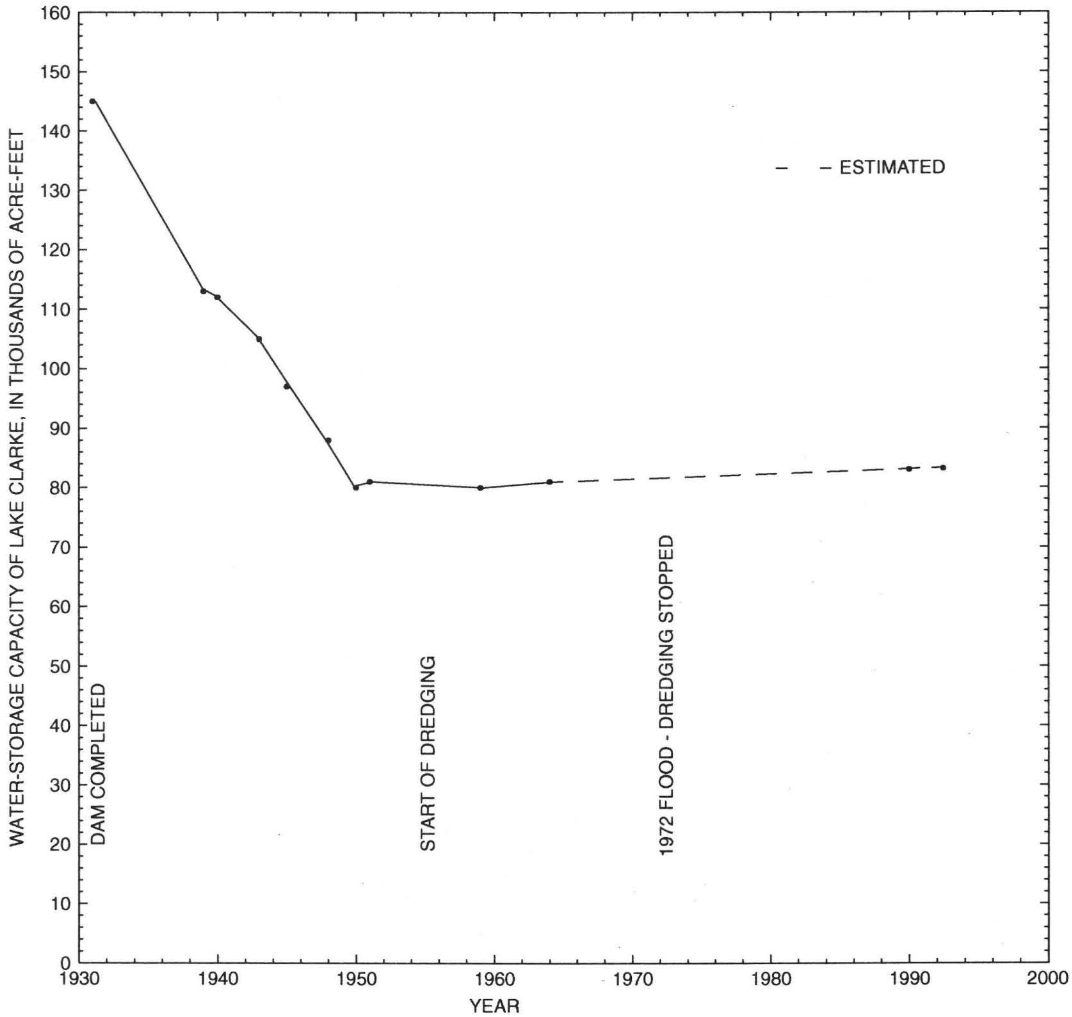


Figure 3. Water-storage capacity of Lake Clarke, Lower Susquehanna River Basin, from the time the Safe Harbor Dam was completed in 1931 through 1993. (Modified from Hainly and others, 1995.)

Cross-sectional areas and conveyances for that section of Lake Clarke from 685 to 24,000 ft above the dam are listed in table 1. Cross-sectional areas decreased from 127,000 ft^2 at a section located 685 ft above the dam to 78,900 ft^2 at a section located 7,400 ft above the dam. Cross-sectional areas from 7,400 to 19,800 ft upstream of the dam averaged 78,100 ft^2 and ranged from 74,300 to 80,300 ft^2. Conveyances decreased from 57,300,000 ft^3/s at the section 685 ft above the dam to 31,900,000 ft^3/s at the section 5,360 ft above the dam. The average conveyance from 7,400 to 19,780 ft upstream of the dam was 29,200,000 ft^3/s and ranged from 28,000,000 to 31,900,000 ft^3/s. The section from 7,400 to 19,780 ft was used to compute average cross-section areas and conveyances because the configuration is similar to that of Conowingo Dam.

Table 1. Cross-sectional areas and conveyances in Lake Clarke from 685 to 24,000 feet above the dam, computed from data collected in 1993

Distance upstream of dam (feet)	Width (feet)	Cross-sectional area (square feet)	Conveyance (Manning equation) (cubic feet per second)
685	4,210	127,000	57,300,000
2,330	4,930	115,000	44,000,000
3,510	4,570	104,000	39,300,000
5,360	4,000	87,400	31,900,000
7,400	3,070	78,900	31,900,000
10,000	3,260	74,300	28,000,000
12,860	3,000	75,300	30,300,000
15,000	3,840	79,500	28,100,000
17,540	3,860	80,300	28,500,000
19,780	3,900	80,300	28,300,000
21,930	4,000	73,200	23,800,000
24,000	4,710	83,400	26,600,000

Lake depths obtained during the 1993 survey and computed relative to the normal pool elevation of 227.2 ft above sea level are shown on plate 1. Most sediment deposited in the lake is in the area near Washington Boro and in the area from Turkey Hill to the Safe Harbor Dam. The channel opposite Long Level does not contain significant quantities of sediment. No notable changes were detected in the sediment distribution between the 1990 and 1993 surveys. As of 1993, the lake contained about 90,700,000 ton of sediment, about the same quantity of sediment as measured in 1950, indicating that sediment in the lake has been in equilibrium with sediment transport in the river for the past 43 years.

The water depths shown in plate 1 should not be used as a guide for boating because lake levels can decrease rapidly depending on release rates at the Safe Harbor Dam. Also, sediment bars can form in unexpected locations depending on sediment concentrations and local currents that can change from storm to storm. In addition, the lake contains many partially or fully submerged obstacles, such as rocks, trees, and stumps, that were not mapped.

HOLTWOOD DAM AND LAKE ALDRED

The Holtwood Dam, built in 1910, is 25 mi upstream of the Chesapeake Bay. The lake extends up river to near the base of Safe Harbor Dam. The surface area of the lake is about 4.0 mi^2, and the normal pool elevation is 169.75 ft above sea level. Holtwood Dam was built without flood gates and river flow in excess of plant capacity spills over the top of the dam to the west of the powerhouse. A coal fired power plant was built next to the hydroelectric plant in 1925. The coal plant had a capacity of 73,000 kilowatts and was designed to burn about 200,000 ton of river coal per year. From 1925 to 1972, the power plant burned coal dredged from the river.

The initial capacity of the reservoir, Lake Aldred, was about 60,000 acre-ft. Riverbed silt surveys conducted in Lake Aldred during 1939, 1950, and 1961 (Ledvina, 1962) show that the quantity of sediment stored in the reservoir decreased from 1939 to 1961. The decrease was probably caused by lower sediment transport rates to Lake Aldred after the completion of the Safe Harbor Dam in 1931 and the subsequent sediment deposition in Lake Clarke. Because Lake Aldred is about half the size of Lake Clarke and Lake Clarke reached equilibrium with sediment transport in 20 years, Lake Aldred probably filled with sediment in about 10 years or by about 1920. It has probably been in a state of equilibrium since then.

Lake depths, at normal pool elevation, are shown on plate 2. The lake contains about 8,580 acre-ft, or about 13,600,000 ton, of sediment. Most sediment is deposited near the islands in the middle and upper lake. No notable changes were detected in the sediment distribution between the 1990 and 1993 surveys. Lake depths, based on the 1993 survey (pl. 2), should not be used as a guide for boating because lake levels can decrease rapidly depending on release rates at the Holtwood Dam. Also, sediment bars can form in unexpected locations depending on sediment concentrations and local currents that can change from storm to storm. The lake contains many rocks, trees, and stumps at or just below the water surface; they have not been mapped. In addition, many bedrock ledges are at or just under the surface and they also have not been mapped.

CONOWINGO DAM AND CONOWINGO RESERVOIR

Conowingo Dam, built in 1928, is 10 mi upstream of the Chesapeake Bay. The reservoir formed by the dam, Conowingo Reservoir, is the largest of the reservoirs. River flow in excess of plant capacity discharges through flood gates installed on the east side of the dam. At Conowingo Dam, the river-bed elevation is about 11 ft above sea level and the normal pool elevation is 108.5 ft above sea level. The reservoir extends upstream about 12 mi to Hennery Island, and the surface area of the reservoir is about 12.8 mi^2.

Whaley (1960) reported elevations at the top of the sediment layer at six cross sections in Conowingo Reservoir in 1959. The data show that the capacity of Conowingo Reservoir was reduced from the original capacity of 300,000 acre-ft in 1928 to about 235,000 acre-ft in 1959. Based on a dry weight of 67.8 lb/ft^3, the reservoir contained an estimated 96,000,000 ton of sediment in 1959.

Using the data collected in 1990 and data from a recreation guide for boating in the Conowingo Reservoir published by the Philadelphia Electric Company in 1989, the capacity of the Conowingo Reservoir was about 195,000 acre-ft (Hainly and others, 1995) constituting a reduction of 105,000 acre-ft from 1928 to 1990. Total sediment deposition in the Conowingo Reservoir from 1928 to 1990 was about 155,000,000 ton, and deposition averaged 2,500,000 ton per year over the 62-year period. Data collected in 1993 also were used to compute the reservoir capacity. The 1993 data indicate a remaining water-storage capacity of about 189,000 acre-ft and total sediment deposition to be about 164,000,000 ton. Sediment deposition averaged about 3,000,000 ton per year from 1990-93. The cross-sectional areas of Conowingo Reservoir for 1928, 1959, 1990, 1993, and at equilibrium are shown in figure 4. Considerable filling has occurred in the part of the reservoir from the dam upstream 29,000 ft. That part of the reservoir upstream from Michael Run (29,000 ft upstream of the dam) appears to have reached equilibrium with sediment transport in the river by or prior to 1959.

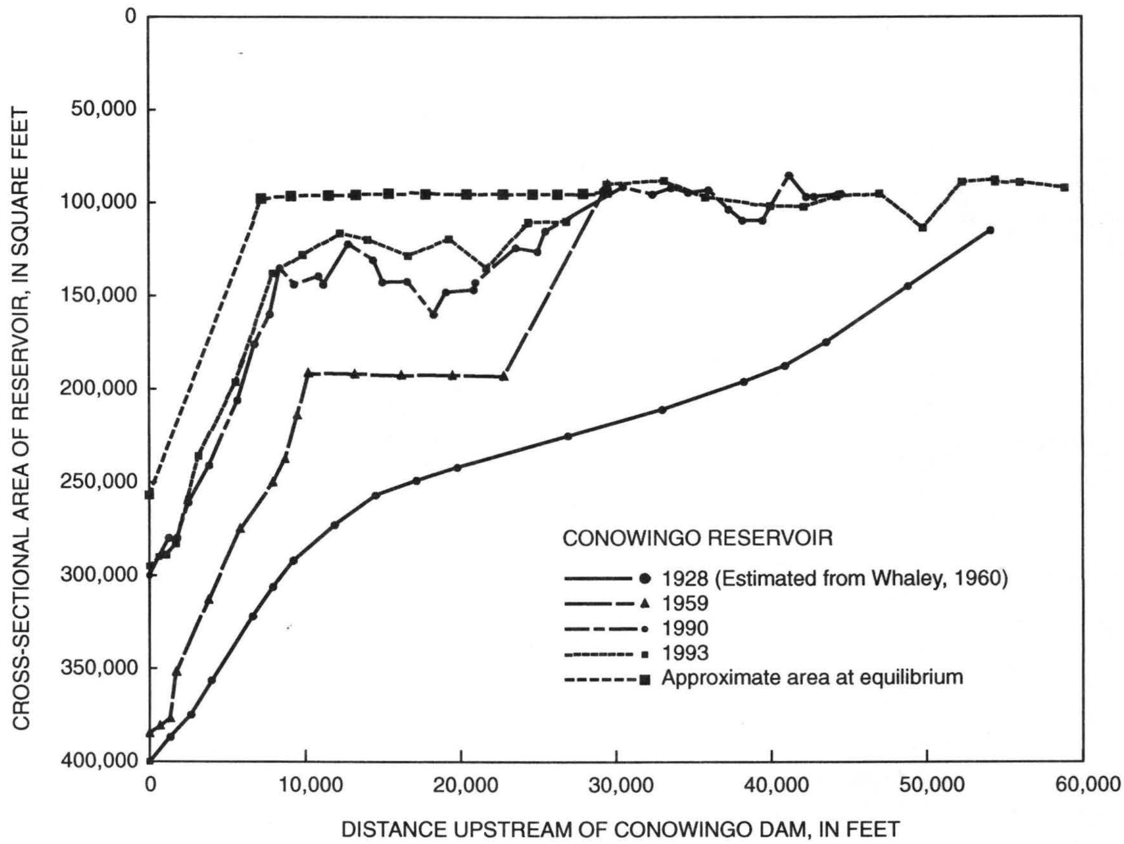


Figure 4. Cross-sectional area in Conowingo Reservoir, Maryland and Pennsylvania, 1959-93.

Lake depths at normal pool elevation, as determined from the 1993 survey, are shown on plate 3. Two cross sections in Conowingo Reservoir are shown in figure 5; one was surveyed in 1959, in 1990, and again in 1993 and one was surveyed in 1959 and in 1993. Both show considerable deposition during the 34-year period. Sediment deposition from 1959 to 1993 in the section of the reservoir from Conowingo Creek to Troublesome Hills ranged from about 12 to 33 ft and averaged about 20 ft. Deposition in the section of the reservoir from Wildcat Tunnel to just above Broad Creek ranged from 4 to 28 ft and averaged about 20 ft. Net sediment deposition in Conowingo Reservoir (all net deposition was in the reach from Michael Run to the dam) totaled about 68,000,000 ton from 1959 to 1993. Total deposition for the period, including the 20,200,000 ton scoured in 1972 and the 2,400,000 ton scoured in 1975 (Gross and others, 1978), was about 91,000,000 ton or an average of 2,700,000 ton per year.

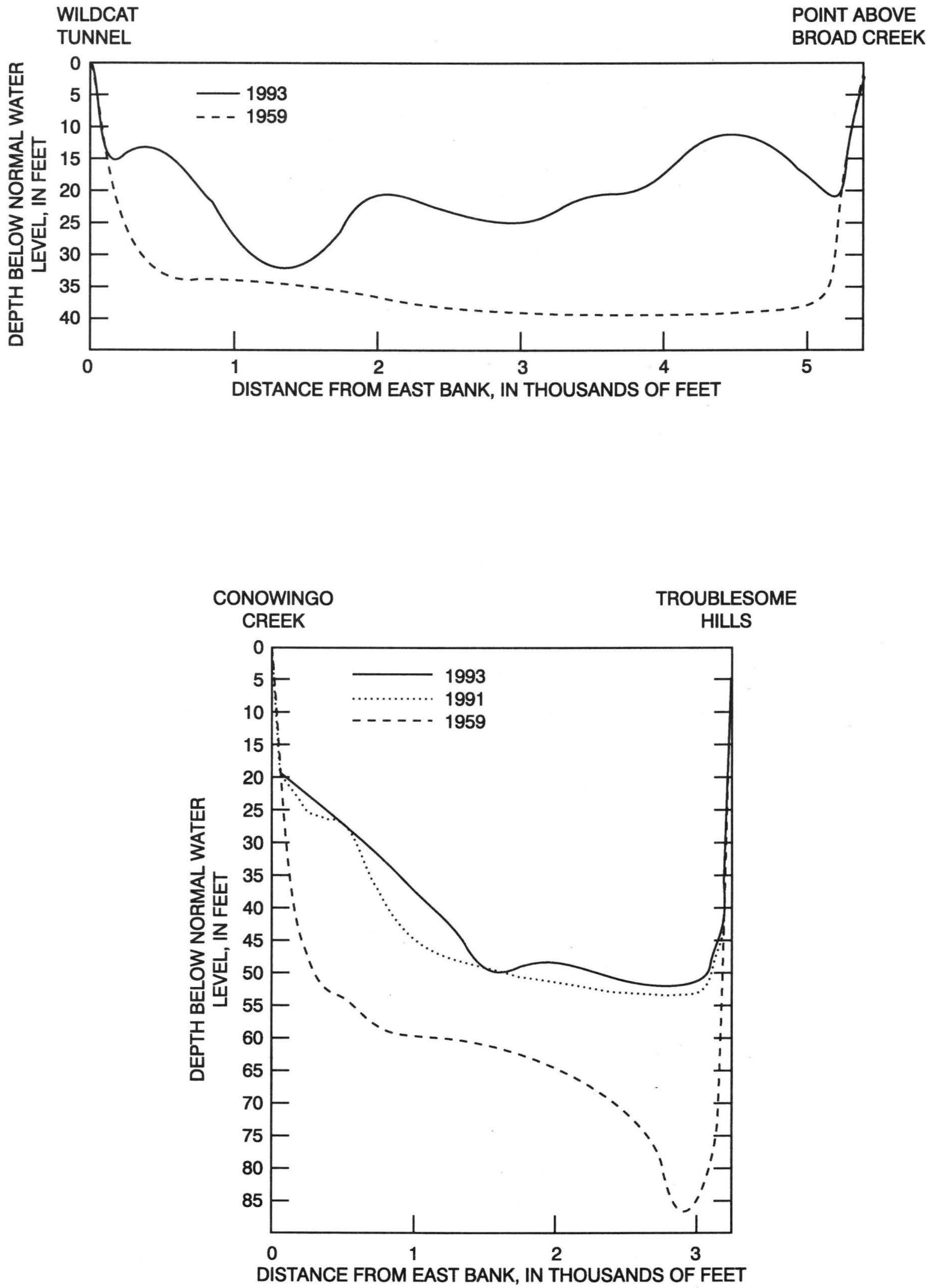


Figure 5. Changes in the elevation of bottom sediments at two cross sections in Conowingo Reservoir, Maryland and Pennsylvania, 1959-93.

Cross-sectional areas and conveyances (table 2) were computed for Conowingo Reservoir for reaches from just above the dam to just above Mt. Johnson Island, about 49,800 ft upstream of the dam. Cross-sectional areas and conveyances in Conowingo Reservoir where sediment deposition is no longer occurring, from 29,450 to 49,800 ft above the dam, indicate that the equilibrium cross-sectional area ranges from 88,100 to 113,420 ft^2 and averages 98,000 ft^2, and the equilibrium conveyance ranges from 26,300,000 ft^3/s to 42,200,000 ft^3/s and averages 30,400,000 ft^3/s. That part of Conowingo Reservoir from about 7,000 to 29,000 ft above the Conowingo Dam has a configuration similar to that part of Lake Clarke from 7,000 ft above the Safe Harbor Dam to just downstream of Turkey Hill. Because the configurations are about the same, the cross-sectional areas and conveyances in these sections of Conowingo Reservoir and Lake Clarke should be about the same once equilibrium is reached in Conowingo Reservoir. The cross-sectional area and conveyance in this section of Lake Clarke averaged 78,100 ft^2 and 29,200,000 ft^3/s, respectively. A conveyance of 30,400,000 ft^3/s was used to compute the volume of Conowingo Reservoir that remains for sediment storage in the reach from 7,000 to 29,000 ft upstream of the Conowingo Dam. Equilibrium in the reservoir reach from the Conowingo Dam upstream 7,000 ft was estimated from the Lake Clarke data and based on the different configuration of the Conowingo Dam. Using the 1993 survey as a base, from 21,000 to 25,000 acre-ft remained for sediment storage in 1993. If Conowingo Dam continues to fill at a constant rate, as Lake Clarke did from 1932 to about 1950, it is estimated the reservoir will reach equilibrium in the next 10 to 20 years. Once equilibrium is reached, average annual sediment, nitrogen, and phosphorus loads to the Bay, currently 1,780, 147, and 5.1 million pounds per year, respectively, may increase to levels close to the loads currently transported by the river, 6,600, 153, and 9.1 million pounds per year, respectively.

Table 2. Cross-sectional areas and conveyances in Conowingo Reservoir from the dam to just above Mt. Johnson Island

[Note: Equilibrium cross-sectional areas are based on (1) a cross-sectional area of 98,000 square feet and (2) a conveyance of 30,400,000 cubic feet per second except for the first three sections, which were estimated because of the effects of the turbine intakes and the flood gates. Equilibrium cross-sectional areas are not included for sections more than 29,000 ft upstream of the Conowingo Dam because that area has been in equilibrium for some time.]

Distance upstream of dam (feet)	Width (feet)	Cross-sectional area (square feet)	Conveyance (Manning equation) (cubic feet per second)	Conveyance based cross-sectional area at equilibrium (square feet)	Volume remaining to fill based on equilibrium, in acre-feet	
					Cross-sectional area of 98,000 square feet	Conveyance of 30,400,000 cubic feet per second
1,700	5,050	283,000	195,000,000	220,000	3,510	3,510
3,150	4,610	236,000	153,000,000	188,000	2,110	2,110
5,530	4,450	196,000	115,000,000	136,000	3,660	3,660
7,950	3,520	138,000	74,800,000	83,200	1,760	2,410
9,880	3,380	128,000	67,900,000	81,800	1,490	2,300
12,280	3,350	116,000	58,100,000	81,500	860	1,650
14,050	3,560	120,000	58,500,000	83,400	1,100	1,840
16,650	5,240	128,000	50,800,000	97,500	1,810	1,840
19,300	5,000	120,000	58,500,000	95,800	1,280	1,400
21,700	6,180	135,000	49,300,000	104,000	2,170	1,820
24,400	5,300	110,000	39,100,000	98,000	710	710
26,850	5,050	110,000	40,300,000	96,100	930	1,080
29,450	4,710	90,000	40,200,000	94,100	--	--
33,150	4,700	88,100	29,300,000	94,000	--	--
35,800	6,510	97,100	27,500,000	--	--	--
39,990	7,600	102,000	28,400,000	--	--	--
42,150	6,540	102,000	29,800,000	--	--	--
44,250	6,900	96,600	26,300,000	--	--	--
47,010	6,350	95,200	27,100,000	--	--	--
49,800	6,810	113,000	34,600,000	--	--	--

Lake depths for Conowingo Reservoir, as determined from the 1993 survey, are shown on figure 4. These depths should not be used as a guide for boating because lake levels can increase or decrease rapidly depending on discharges from Holtwood, withdrawals or discharges from the Muddy Run Pump Storage facility, and release rates from Conowingo Dam. Also, sediment bars can form in unexpected locations depending on sediment concentrations and local currents that can change from storm to storm. In addition, the lake contains many partially or fully submerged obstacles, such as trees, stumps, and rocks, that were not mapped. The area above Mt. Johnson Island contains many bedrock ledges that are just under the surface.

SUMMARY AND CONCLUSIONS

The Susquehanna River drains 27,510 mi^2 in New York, Pennsylvania, and Maryland and is the largest tributary to the Chesapeake Bay. Three large hydroelectric dams span the Susquehanna River. Safe Harbor (Lake Clarke) and Holtwood (Lake Aldred) are in southern Pennsylvania, and Conowingo (Conowingo Reservoir) is in northern Maryland, about 10 mi upstream of the Chesapeake Bay. By 1993, about 269,300,000 ton of sediment had been deposited in the three reservoirs; Lake Clarke contained about 90,700,000 ton, Lake Aldred contained about 13,600,000 ton, and the Conowingo Reservoir contained about 164,000,000 ton. Two of these reservoirs, Lakes Clarke and Aldred, have reached a state of equilibrium with sediment transport in the river. Lake Aldred reached equilibrium with sediment transport of the river about 1920 and Lake Clarke reached equilibrium about 1950. The third, Conowingo Reservoir, continues to accumulate sediment, but surveys in 1959, 1990, and 1993 indicate that the original water-storage capacity of Conowingo Reservoir, 300,000 acre-ft in 1928, was reduced to 235,000 acre-ft in 1959, to 195,000 acre-ft in 1990, and to 189,000 acre-ft in 1993. A comparison of cross-sectional areas and conveyances computed for Lake Clarke with those computed for Conowingo Reservoir indicates that Conowingo Reservoir will reach equilibrium with sediment transport of the river during the next 10 to 20 years. Once equilibrium is reached, average annual sediment, nitrogen, and phosphorus loads to the Bay, currently 1,780, 147, and 5.1 million pounds per year, respectively, may increase to loads currently transported by the river, 6,600 million pounds of sediment per year, 153 million pounds of nitrogen per year, and 9.1 million pounds of phosphorus per year, respectively.

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