Fluvial Sediment in Hocking River Subwatershed 1 (North Branch Hunters Run), Ohio

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1798-I

Prepared in cooperation with the
U.S. Department of Agriculture
Soil Conservation Service

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By RUSSELL F. FLINT

SEDIMENTATION IN SMALL DRAINAGE BASINS

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CONTENTS

ILLUSTRATIONS

TABLES

FLUVIAL SEDIMENT IN HOCKING RIVER SUBWATERSHED 1 (NORTH BRANCH HUNTERS RUN), OHIO

By RUSSELL F. FLINT

ABSTRACT

From May 1956 to May 1962, Hocking River subwatershed 1 of Upper Hocking River Pilot Watershed had an average annual sediment yield from its contributing area of 0.94 square mile of 1,195 tons per square mile. Annual suspended-sediment yield at the outlet, expressed in tons per acre-foot of outflow, decreased from 0.45 in the 1957 water year to 0.10 in the 1962 water year, reflecting a decrease in sediment yield from the 1.04-square-mile drainage area above detention structure 1.

The particle-size distribution of the sediment entering reservoir 1 averaged 4 percent sand, 38 percent silt, and 58 percent clay, whereas the particle-size distribution of sediment discharged from the reservoir averaged 1 percent sand, 12 percent silt, and 87 percent clay. The specific dry weight of the sediment deposited in the reservoir averaged 71.6 pounds per cubic foot. Trap efficiency of reservoir 1 was about 88 percent for the 6.08-year period of the study.

Average annual runoff from subwatershed 1 was 9.5 inches. Comparable runoff for the entire Hunters Run watershed, as measured at Hunters Run at Lancaster, was 11.84 inches during the study period. Average annual inflow to reservoir 1 was 9.2 inches. Outflow from reservoir 1 occurred during 41 percent of the period of investigation. About 91 percent of the annual water discharge and about 94 percent of the annual sediment discharge occurred during the 7-month period, January through July.

Chemical-quality analyses of the inflow showed a general range in concentration of calcium from 10 to 70 milligrams per liter and of sodium from 1 to 5 milligrams per liter, and a range in specific conductance from about 140 to 520 micromhos. The ratio of calcium to sodium was 11 to 1, suggesting that flocculation of primary clay particles may have been occurring in the reservoir. However, the available data were insufficient to predict the extent of such flocculation.

INTRODUCTION

In May 1956 the U.S. Geological Survey, in cooperation with the U.S. Soil Conservation Service, began an investigation of fluvial sediment in Hocking River subwatershed 1 (North Branch

Hunters Run) of Upper Hocking River Pilot Watershed near Hooker, Ohio (fig. 1). The investigation was part of a study to determine the trap efficiency of several flood-retarding structures throughout the nation for use in future design of detention structures. The U.S. Geological Survey was responsible for (1) measurement of the total sediment discharge at the outflow of reservoir 1, (2) periodic sampling of the reservoir inflow to determine particle-size distribution of the inflow sediment, and (3) determination of particle-size distribution of sediment discharged from reservoir 1 (C. R. Collier, written commun., 1956). In conjunction with particle-size analyses, partial chemical analyses were made on the inflow and outflow. Reservoir surveys, which included sampling of the deposited sediments and determination of their volume and densities, were made by the U.S. Soil Conservation Service. Both suspended- and deposited-sediment data were used in the computation of trap efficiency in this report.

This report summarizes and interprets the suspended-sediment data and includes hydrologic data pertaining to precipitation and runoff. The report also gives values of sediment yield for the sediment-contributing area of 0.94 square mile of subwatershed 1 and provides trap-efficiency values for reservoir 1.

ACKNOWLEDGMENTS

Records of stage and discharge of reservoir 1 were maintained by the U.S. Soil Conservation Service, Lancaster, Ohio, under the direction of area engineers, R. D. Otney, 1956-60, and John Garrett, 1960-62. The U.S. Geological Survey assisted in the computation and review of flow records. During the last 9 months of the study, by agreement with the U.S. Soil Conservation Service, the U.S. Geological Survey performed the field and office work necessary in the collection and computation of the flow records.

During the preparation of this report, R. E. Quilliam, state conservationist, U.S. Soil Conservation Service, made several members of his staff available for consultation with the author.

DESCRIPTION OF THE AREA

The Upper Hocking River Pilot Watershed, of which subwatershed 1 is a part, includes the Hocking River and all its tributaries at or above the city of Lancaster. The drainage area of the Hocking River basin immediately below Hunters Run is 47.7 square miles (30,528 acres); Hunters Run (fig. 1), which enters the Hocking River at Lancaster, has a drainage area of 11.1 square miles (7,104 acres); and subwatershed 1 (North Branch

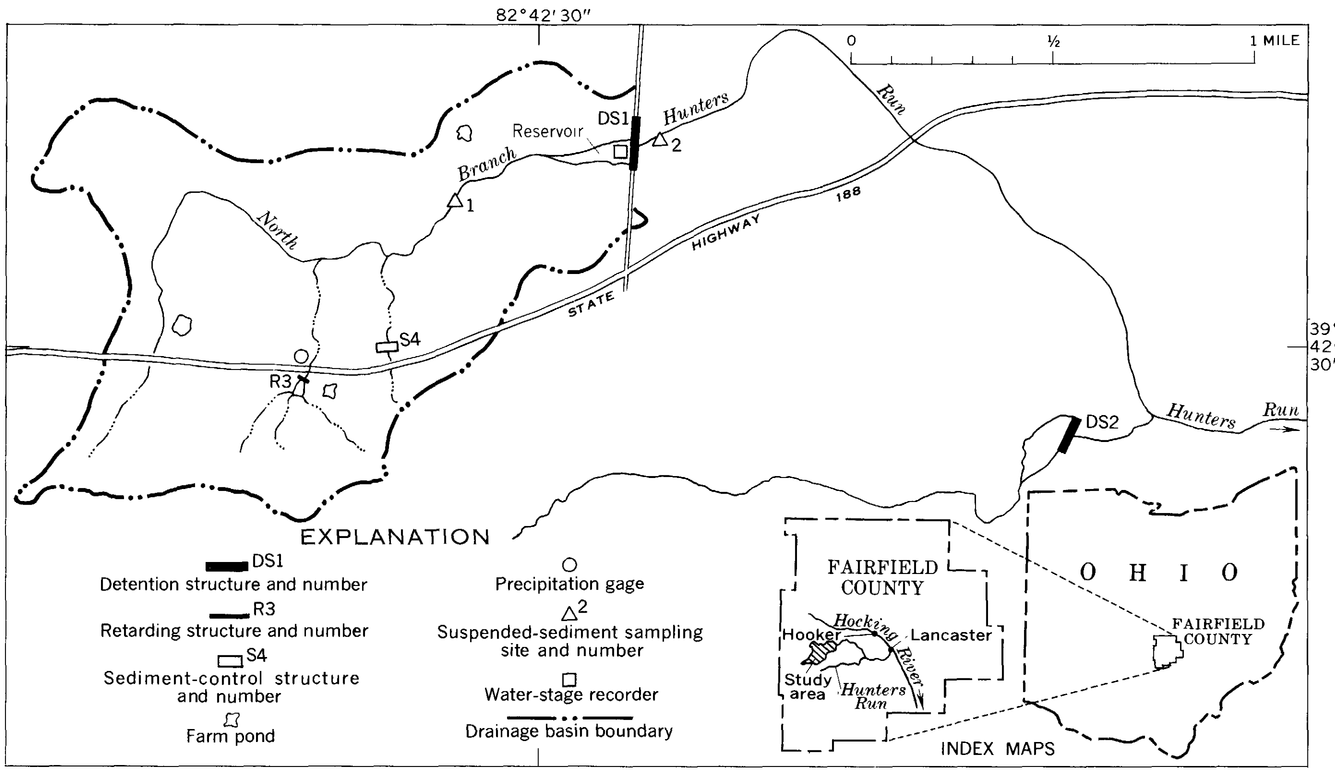

FIGURE 1.—Drainage area of Hocking River subwatershed 1 (North Branch Hunters Run) in west-central Fairfield County, Ohio, showing hydraulic structures and instrumentation for the study.

Hunters Run) is 9.4 percent (1.04 square miles or 666 acres) of the Hunters Run basin. (See Cross, 1967, p. 17.)

Reservoir 1, shown in figure 1, is in west-central Fairfield County, Ohio, 0.3 mile north of State Highway 188, 3.2 miles southwest of Hooker, and 4.6 miles west of Lancaster, and is included on the Amanda, Ohio, 7.5-minute topographic map. It is in the glaciated Allegheny Mountain section of the Appalachian Plateaus physiographic province (Meeker and others, 1960, p. 4).

ELEVATIONS AND SLOPES

North Branch Hunters Run, shown in figure 1, heads in the southwest part of subwatershed 1, about 2.2 channel miles upstream from reservoir 1. The highest elevation in subwatershed 1 is 1,180 feet above mean sea level near the extreme southwest corner. The lowest elevation is 972 feet above mean sea level near the upstream base of detention structure 1.

Slopes of the upland surfaces of the basin range from 6 to 25 percent, whereas those of the bottom lands range from 0 to 5 percent.

SOILS AND LAND USE

Thirteen soil types have been mapped by the U.S. Soil Conservation Service in subwatershed 1 (Meeker and others, 1960). Ninety percent of the soils were formed on calcareous glacial till, glacial outwash terraces, or in glacial depressions. The most important soil series is the Alexandria. Two soil types of this series, Alexandria silt loam and Alexandria silty-clay loam, cover about 61 percent of the drainage basin. Silt loams of other series, chiefly the Loudenville, Marengo, and Cardington, comprise most of the remaining soils of the area. Most of the soils are well drained.

In 1951 about 50 percent of subwatershed 1 was cropland and about 47 percent was in pasture or woods; the remaining 3 percent was used for farmsteads and roads. The percentage of cropland has decreased with time. Practically no cultivation in the subwatershed was observed by the author in 1970.

GEOLOGY

The bedrock of the subwatershed is a coarse sandstone and conglomerate of the Cuyahoga Group of Mississippian age. The area was covered by both the Illinoian and Wisconsin ice sheets. Surface deposits of subwatershed 1 are glacial drift of late Wisconsin age. They were derived from local sandstone and shale; from limestone, dolomite, and shale outcrops in central and northwestern Ohio; and from granite, quartzite, and other crystalline rock outcrops in the Canadian highlands (Meeker and others, 1960, p. 5).

CLIMATE

The climate of the area is classified as continental (Miller, 1968), which is characterized by large variations in temperature. Summers are moderately warm and humid, and winters are cold and cloudy with an average of 4 days of subzero temperatures.

Rainfall is abundant and well distributed throughout the year. Annual precipitation averages 38.42 inches.

No evaporation data are available for the immediate vicinity, but pan data collected during the season May to October at Senecaville, Ohio, indicated an average annual evaporation of about 37 inches for the period of investigation (Kohler and others, 1959). This figure was not converted to lake values as it is assumed that pan values of evaporation closely approximate small reservoir values (M. E. Miller, oral commun., 1970).

The growing season averages about 155 days per year. The frost-free season extends from early May to early October. From 1935 to 1967, temperatures of 32°F were recorded as early as September 17 and as late as May 25 (Miller, 1968).

HYDRAULIC STRUCTURES

During 1955-61, the U.S. Soil Conservation Service installed eight major floodwater-retarding structures and 22 minor stabilizing and sediment-control structures in the Upper Hocking River Pilot project area. Detention structure 1, which was completed in 1955, was one of the major structures. As pictured in figure 2, it is a sodded earthen dam with concrete drop outlet works and an earthern emergency spillway. In April 1956 reservoir 1, shown in figure 3, had a storage capacity of 450.0 acre-feet and a surface area of 36.9 acres at the crest of the emergency spillway (elevation 1,009 feet above mean sea level). Table 1 gives the "as constructed" area and capacity of reservoir 1 at 1-foot increments of elevation based upon the April 1956 survey.

Structures R3 (drainage area, 47 acres) and S4 (drainage area, 18 acres) located in the southern part of the subwatershed (fig. 1) were constructed in 1956 to control runoff and to serve as sediment traps. Both structures have sodded earthen spillways with 18-inch discharge tubes. Structures R3 (fig. 4) and S4 (fig. 5) have sediment-storage capacities of 1.27 acre-feet and 0.15 acre-foot, respectively, and maximum temporary floodwater-storage capacities of 5.8 acre-feet and 0.8 acre-foot, respectively. The effect of these structures as traps for sediment has not been

FIGURE 2.—View of upstream face of detention structure 1 showing high- and low-stage risers of outlet works. Emergency spillway at left end of dam is not shown. Photograph by C. R. Collier.

FIGURE 3.—View of reservoir 1 looking upstream from roadway on top of detention structure 1. Photograph by C. R. Collier.

FIGURE 4.—Minor floodwater-retarding structure R3 located in southern part of subwatershed 1.

FIGURE 5.—Minor sediment-control structure S4 located on tributary to North Branch Hunters Run in southern part of subwatershed 1.

TABLE 1.—*Area and capacity of reservoir 1 as constructed at indicated elevations*

Elevation (feet above mean sea level)	Surface area (acres)	Capacity (acre-ft)	Remarks
973	0.3	0.2	
974	.4	.5	
975	.6	1.2	
976	.7	1.5	
977	.8	2.5	
978	1.0	3.1	
979	1.1	4.0	
980	1.3	5.0	
981	1.5	6.1	
982	1.8	7.9	
983	2.1	10.0	
984	2.4	12.8	Gage datum.
985	3.0	15.8	
986	3.8	19.1	
987	4.5	23.1	
988	5.4	27.5	Crest of low-stage inlet.
989	6.3	33.5	
990	7.3	40.5	
991	8.3	48.5	
992	9.4	57.2	
993	10.9	67.5	
994	12.5	79.8	
995	14.1	93.2	
996	15.8	108.5	
997	17.3	125.5	
998	18.9	143.8	
999	20.5	163.5	
1,000	22.1	184.3	
1,001	23.8	207.0	
1,002	25.5	231.1	
1,003	27.2	258.5	
1,004	28.9	286.0	
1,005	30.4	316.2	Crest of high-stage inlet.
1,006	31.9	347.5	
1,007	33.4	379.5	
1,008	34.9	413.5	
1,009	36.9	450.0	Earth spillway.
1,010	39.0	487.5	
1,011	41.3	527.0	
1,012	43.6	----	

evaluated to date; however, an onsite inspection by the author in 1970 revealed a very thin buildup of sediment above structure S4. In addition to these structures, three farm ponds are also in the subwatershed. Two of these are in the southwestern part of the basin, and one is in the north-central part of the basin. (See fig. 1.) These ponds may serve to inhibit runoff into the main channel; however, their effect is considered negligible (J. W. Roehl, oral commun., 1970).

RUNOFF

Storage in reservoir 1 began in late April 1956. The first outflow was observed at 1900 hours on May 2, 1956, and daily records of outflow began on May 3. Records of stage from May 1956 to February 1957 consist of daily readings of an outside staff gage. On February 11, 1957, a servomanometer, coupled with a water-stage recorder, was installed at the dam for the collection of a continuous record of stage and for computing outflow discharge from the reservoir.

Precipitation in subwatershed 1 was measured by the U.S. Weather Bureau at one station. (See fig. 1.) Records at this station were incomplete for several periods of the investigation, and data from alternate stations in the area were used to compute precipitation (U.S. Department of Commerce, 1956–62).

A comprehensive analysis of runoff in subwatershed 1 is not attempted in this report, because complete data are not available on storage and discharge for structures S4 and R3. Whereas water-discharge data are available for the outflow from reservoir 1, no data were available on periodic changes in content of reservoir 1.

Table 2 summarizes the outflow from reservoir 1. During the entire period of record, outflow occurred 41 percent of the time, which consisted of 40 separate periods of flow. Ten tons or more of sediment was discharged during 12 of these flow periods. Considered together, these 12 periods accounted for 88 percent of the flow and 97 percent of the suspended-sediment discharge.

Although the project was terminated June 30, 1962, hydrologic records were collected only to the end of May 1962; thus, the term of investigation was 6.08 years.

Outflow from reservoir 1 was computed for the entire period, although no continuous record of stage was available until February 11, 1957. During the period of intermittent record, water discharges were computed from a gage-height graph based on staff-gage readings. Outflow by months and water years is given in table 3.

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Runoff from 65 acres (0.1 sq mi) of subwatershed 1 was controlled by one retarding structure, R3 (fig. 4), and by one sediment-stabilizing structure, S4 (fig. 5). No records are available for the amount and duration of flows into or out of these structures.

Total runoff from subwatershed 1 (table 4) includes water discharged from reservoir 1, seepage, evaporation from the reservoir surface, and net change in reservoir storage. Based on average annual evaporation of about 37 inches (Kohler and others, 1959) and an average surface area of 4.9 acres, evaporation from reservoir 1 totaled 91 acre-feet. Seepage was computed using an estimated value for the coefficient of permeability for Wisconsin glacial till (Norris, 1962, p. 150). The average annual runoff for the 6.08-year study period was 9.5 inches. This figure was somewhat lower than that for the Hunters Run at Lancaster

TABLE 2.—*Summary of outflow from reservoir 1, 1956–62*

Outflow period	Total days	Discharge		Sediment discharge		Discharge-weighted suspended-sediment concentration (mg/1)
		Cfs-days	Acre-ft	Pounds	Tons	
May 3–18, 1956	16	14.68	29.12	3,280	1.64	41
May 27–June 6, 1956	11	18.38	36.46	3,851	1.93	39
Feb. 1–22, 1957	22	87.24	173.04	216,588	108	461
Feb. 26–Apr. 30, 1957	64	80.87	160.41	87,756	43.9	201
May 20–30, 1957	11	10.79	21.40	4,649	2.32	80
June 1–2, 1957	2	.40	.79	65	.03	30
June 24–July 4, 1957	11	29.39	58.30	61,747	30.9	390
Dec. 7–23, 1957	17	34.65	68.73	26,939	13.5	144
Dec. 26, 1957–Jan. 2, 1958	8	6.66	13.21	1,579	.79	44
Jan. 22–Feb. 9, 1958	19	26.44	52.44	9,931	4.97	70
Feb. 23–Apr. 8, 1958	45	27.94	55.42	3,635	1.82	24
Apr. 10–16, 1958	7	4.96	9.84	2,780	1.39	104
Apr. 28–May 14, 1958	17	37.90	75.17	7,654	3.83	37
June 10–11, 1958	2	.23	.46	12	.01	10
June 13–July 1, 1958	19	30.29	60.08	42,426	21.2	260
July 6–Aug. 14, 1958	40	165.23	327.73	414,387	207	465
Aug. 21–27, 1958	7	2.97	5.89	608	.30	38
Sept. 7–9, 1958	3	7.46	14.80	5,834	2.92	145
Sept. 17–30, 1958	14	5.53	10.97	2,283	1.14	77
Dec. 5–15, 1958	11	1.21	2.40	167	.08	26
Dec. 20–21, 1958	2	.05	.10	6	----	22
Dec. 23, 1958–Apr. 14, 1959	113	190.54	377.94	257,251	129	250
Apr. 19–22, 1959	4	.19	.38	24	.01	23
Apr. 27–May 7, 1959	11	1.84	3.65	261	.13	26
May 10–14, 1959	5	.27	.54	30	.02	21
Dec. 12, 1959–Apr. 24, 1960	135	273.17	541.83	172,919	86.5	117
Apr. 30–May 1, 1960	2	.27	.54	48	.02	33
May 17, 1960	1	.02	.04	3	----	28
May 22-June 6, 1960	16	51.27	101.69	23,055	11.5	83
June 13–16, 1960	4	1.10	2.18	169	.08	29
June 22–23, 1960	2	.40	.79	104	.05	48
July 13–14, 1960	2	3.6	7.14	766	.38	39
July 23, 1960	1	.1	.20	14	.01	26
Jan. 17–June 27, 1961	162	259.95	515.61	164,677	82.3	118
Aug. 11–20, 1961	10	27.38	54.31	22,236	11.1	151
Dec. 19, 1961–Jan. 17, 1962	30	12.25	24.30	582	.29	9
Jan. 21–May 2, 1962	102	127.07	252.04	55,680	27.8	81
May 20–22, 1962	3	1.47	2.92	459	.23	58
May 26–June 2, 1962	8	3.41	6.76	252	.13	14
June 5–8, 1962	4	.54	1.07	14	.01	5
Totals	963	1548.11	3070.69	1,594,721	797.23	----

TABLE 3.—*Monthly water and sediment discharges, Hocking River subwatershed 1 (North Branch Hunters Run) near Hooker, Ohio*

Water year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Total	Percent of total
Water discharge, in cfs-days														
1956	--	--	--	--	--	--	--	27.13	5.93	0	0	0	33.06	2
1957	0	0	0	0	89.35	14.20	64.56	10.79	29.10	.69	0	0	208.69	13
1958	0	0	41.17	22.55	8.18	16.86	19.15	30.64	30.46	142.18	26.08	12.99	350.26	23
1959	0	0	1.98	102.97	48.61	32.59	6.62	1.33	0	0	0	0	194.10	13
1960	0	0	34.85	65.48	125.34	34.60	12.98	50.27	2.71	3.70	0	0	329.93	21
1961	0	0	0	3.04	42.80	58.24	82.97	55.99	16.91	0	27.38	0	287.33	19
1962	0	0	.95	35.50	56.04	35.12	11.51	4.86	.76	0	0	0	144.74	9
Total	0	0	78.95	229.54	370.32	191.61	197.79	181.01	85.87	146.57	53.46	12.99	1,548.11	--
Percent of total	0	0	5	15	24	12	13	12	6	9	3	1	--	100
Sediment discharge, in pounds														
1956	--	--	--	--	--	--	--	5,703	1,428	0	0	0	7,131	1
1957	0	0	0	0	216,824	998	86,522	4,649	61,693	119	0	0	370,805	23
1958	0	0	28,490	9,430	1,034	2,171	4,781	6,612	42,436	410,689	4,308	8,117	518,068	32
1959	0	0	263	157,576	63,495	34,800	1,415	190	0	0	0	0	257,739	16
1960	0	0	13,710	20,510	126,923	8,627	3,162	22,762	604	780	0	0	197,078	12
1961	0	0	0	183	6,525	15,100	32,059	109,122	1,688	0	22,236	0	186,913	12
1962	0	0	27	9,742	37,530	8,609	346	712	21	0	0	0	56,987	4
Total	0	0	42,490	197,441	452,331	70,305	128,285	149,750	107,870	411,588	26,544	8,117	1,594,721	--
Percent of total	0	0	3	12	28	4	8	9	7	26	2	1	--	100

TABLE 4.—*Reservoir discharge, precipitation, and miscellaneous hydrologic data, reservoir 1, 1956–62*

Period	Reservoir discharge (acre-ft)	Precipitation (inches)
May to September 1956	65.57	[1] 16.07
1957 water year	413.94	[2] 36.93
1958 water year	694.74	[3] 46.07
1959 water year	385.00	[3] 27.41
1960 water year	654.42	[3] 37.09
1961 water year	569.92	[4] 38.85
October 1961 to May 1962	285.58	[4] 22.46
Total	3,069.17	224.88

Drainage area	square miles	1.04
Drainage area	acres	666
Average reservoir surface area for period	do	4.9
Direct precipitation on reservoir surface	acre-feet	92
Estimated evaporation from reservoir surface	do	[5] 91
Change in storage during period	do	24
Estimated seepage loss	do	10
Total runoff	do	3,194
Total inflow	do	[6] 3,102
Average annual inflow	inches	9.2

[1] Lancaster 2NW U.S. Weather Bureau (U.S. Department of Commerce, 1956–62).
[2] Lancaster 7WNW U.S. Weather Bureau (U.S. Department of Commerce, 1956–62).
[3] Lancaster 5WSW U.S. Weather Bureau (U.S. Department of Commerce, 1956–62).
[4] Lancaster 5NW U.S. Weather Bureau (U.S. Department of Commerce, 1956–62).
[5] Based on pan-evaporation data at Senecaville, Ohio, and on information from Kohler, Nordenson, and Baker (1959).
[6] Total inflow equals outflow plus evaporation plus change in storage plus seepage minus precipitation on reservoir surface.

(U.S. Geological Survey, 1961, 1962, 1964). For the latter station, during the same period, the average annual runoff was 11.84 inches.

Inflow to reservoir 1 during May 1956 to May 1962 equaled total runoff minus precipitation on the reservoir surface, or 3,102 acre-feet, an average annual value of 9.2 inches.

FLUVIAL SEDIMENT

Fluvial sediment as defined by Colby (1963, p. VI) is that sediment which "is transported by, or suspended in, water or that has been deposited in beds by water." The fluvial sediment under discussion in this report is primarily suspended sediment in the inflow and outflow of reservoir 1. To quantify the sediment yield of the contributing area of subwatershed 1, a brief discussion of the sediment deposited in reservoir 1 is included. The sum of the sediment deposited in reservoir 1 and discharged from the reservoir was used to calculate both the reservoir trap efficiency and the subwatershed sediment yield.

SUSPENDED SEDIMENT

A DH–48 sediment sampler was used to collect depth-integrated sediment samples at the outflow of reservoir 1. (See fig. 6.) The established frequency of collection was sufficient to define the daily concentration. During periods of increased inflow to the reservoir, additional samples were collected at sampling site 1 on the inflow channel. (See fig. 1.) Both inflow and outflow locations were analyzed to determine the sediment concentration in milligrams per liter, and selected samples were analyzed to determine the particle-size distribution of the suspended sediment. Table 2 shows sediment discharge, in pounds, for the periods of flow from reservoir 1. Table 3 gives a summary of monthly discharges for water and sediment. Table 3 indicates that 91 percent of the total water discharge and 94 percent of the total sediment discharge from reservoir 1 occurred during the 7-month periods, January through July. Ninety-one percent of the total sediment discharged from reservoir 1 occurred during only 5 percent of the period of investigation. Because this included only 107 days, the importance of increased frequency of sampling during major runoff events is demonstrated.

Because sampling of the outflow includes the entire depth of flow, the computed sediment discharge represents the total sedi-

FIGURE 6.—Outflow conduit of reservoir 1 showing walkway from which sediment samples were taken. Photograph by C. R. Collier.

ment discharge from the reservoir. Samples that were collected at the inflow to the reservoir are also thought to be representative for the channel flow. The turbulence at this point probably suspends most of the sediment particles that were available for transport. Sediment discharge of the inflow was not a part of this study; however, one measurement taken during flood runoff on January 21, 1959, indicated an instantaneous sediment discharge of 20,400 pounds per day into the reservoir. The measured inflow at this time was 10.8 cubic feet per second, and the sediment concentration was 351 mg/l.

The maximum daily load of the outflow for the period of record was 170,000 pounds (85 tons) on July 7, 1958. This represented more than 10 percent of the sediment discharged during the entire period of investigation. The maximum daily mean concentration was 569 mg/1 on February 9, 1957. The highest observed instantaneous concentration at the outflow was 892 mg/l on May 8, 1961. For this sample, the instantaneous sediment discharge amounted to 315,000 pounds per day, of which 76 percent was clay and 24 percent was silt.

Particle-size analyses of both inflow and outflow samples of reservoir 1 were made by sieve and sedimentation methods. The sedimentation device used for analysis of the silt and clay fractions was the bottom-withdrawal tube. The results of 65 analyses of the inflow are given in table 5. Of these 65 particle-size analyses, 33 were analyzed in a distilled-water settling medium. The remaining 32 were analyzed in a native-water settling medium. The distilled water, with a chemical dispersing agent added, was used to determine the particle-size distribution of the discrete particles of sediment. The dispersing agent served to promote deflocculation of the silt and clay particles. Analysis of samples in the native-water medium was intended to partially preserve the particle-size characteristics of the sediment as they might occur in the natural setting. Results of distilled-water particle-size analyses of the inflow samples indicated an average particle-size distribution of 4 percent sand, 38 percent silt, and 58 percent clay. The percentages of sand, silt, and clay in the inflow analyses are shown in figure 7, along with definitions of the size ranges included for sand, silt, and clay.

Flocculation occurred in the native-water settling medium in the laboratory. Analyses in native water indicated an average reduction of 15 percent clay, and an equal increase in percentage of silt when compared with their distilled-water counterparts. A clue to the cause of this flocculation is offered by the chemical-quality analyses of the native water, the results of which are

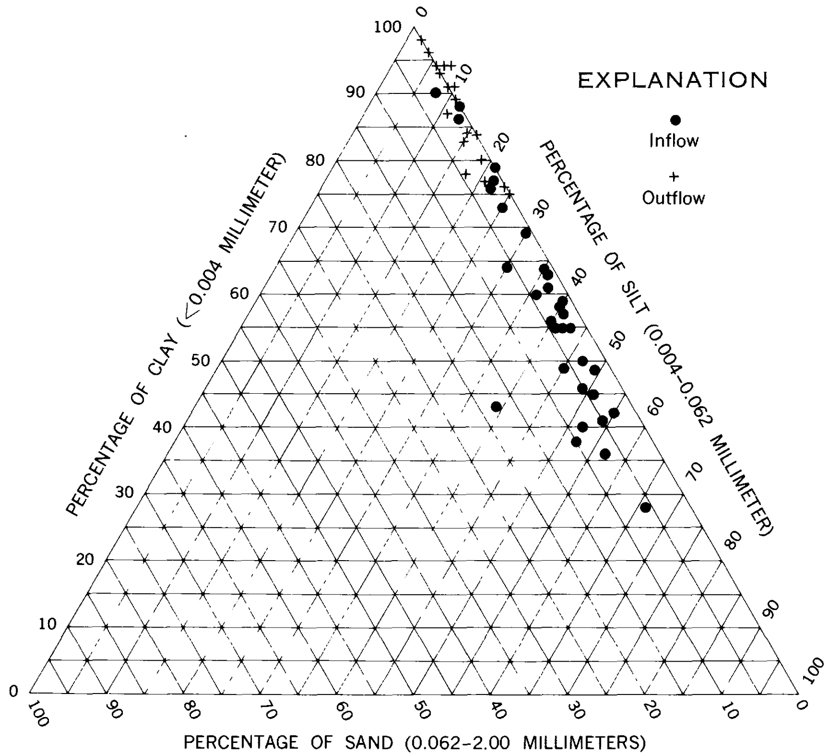

FIGURE 7.—Percentage of sand, silt, and clay in suspended sediment of inflow and outflow, reservoir 1.

shown in table 6. A high calcium-sodium ratio in water will cause flocculation of soil colloids, and water with a low calcium-sodium ratio will tend to disperse soil colloids (Rainwater and Thatcher, 1960, p. 127, 265). The average calcium-sodium ratio in the 34 chemical analyses shown in table 6 is 11 to 1. Calcium concentrations generally ranged from about 10 to 70 mg/l, sodium ranged from about 1 to 5 mg/l, and specific conductance ranged from about 140 to 520 micromhos. Under these conditions and with a calcium-sodium ratio in the native water of 11 to 1, the discrete clay particles tend to flocculate and acquire sedimentation characteristics of larger particles.

The precise amount of flocculation in the inflow water of reservoir 1 could not be determined because natural factors such as turbulence and temperature conditions, both important in sedimentation processes in the reservoir, were not duplicated in the laboratory. However, it can be stated that flocculation occurred in the inflow samples. The deposited sediments would likely contain some of these floccules.

TABLE 5.—*Particle-size analyses of suspended sediment, inflow to reservoir 1*

[Methods of analysis: B, bottom-withdrawal tube; C, chemically dispersed; N, in native water; S, sieve; W, in distilled water. Sampling site 1, fig. 1]

Date of collection	Time	Suspended sediment										Method of analysis
		Concentration (mg/1)	Percent finer than indicated size, in millimeters									
			0.002	0.004	0.008	0.016	0.031	0.062	0.125	0.250	0.500	
1956												
May 27	1400	288	52	64	77	88	92	94	96	98	100	SBWC
May 27	1400	288	46	58	80	91	94	96	97	100	....	SBN
May 29	1900	1,550	58	79	95	99	99	100	....	....	....	SBWC
May 29	1900	1,550	43	58	80	99	100	....	....	....	....	BN
May 31	2200	1,500	33	42	52	72	81	97	99	100	....	SBWC
May 31	2200	1,500	25	36	54	74	90	97	99	100	....	SBN
1957												
Feb. 9	1800	658	84	90	95	97	97	98	98	99	100	SBWC
Feb. 9	1800	658	64	93	97	97	98	98	98	99	100	SBN
Feb. 26	0900	938	21	28	37	54	76	94	98	99	100	SBWC
Feb. 26	0900	938	3	7	16	36	74	91	97	99	100	SBN
Apr. 1	1800	464	68	76	82	90	96	98	99	100	....	SBWC
Apr. 1	1800	464	41	58	78	89	95	98	99	100	....	SBN
Apr. 3	1800	598	65	73	81	88	94	98	100	....	....	SBWC
Apr. 3	1800	598	36	60	72	82	90	97	98	98	100	SBN
Apr. 8	0600	736	78	86	91	96	98	99	100	....	....	SBWC
Apr. 8	0600	736	75	86	92	96	98	99	100	....	....	SBN
May 22	0600	2,120	35	49	61	77	93	98	100	....	....	SBWC
May 22	0600	2,120	11	20	30	51	87	98	100	....	....	SBN
June 24	0800	818	72	88	96	98	99	100	....	....	....	SBWC
June 24	0800	818	50	96	96	99	99	99	100	....	....	SBN
Dec. 7	1500	760	44	55	68	80	89	97	99	100	....	SBWC
Dec. 7	1500	760	21	33	53	80	91	97	99	100	....	SBN
1958												
Jan. 21	1700	....	46	56	69	82	91	96	98	100	....	SBWC
Apr. 10	1700	1,500	36	46	59	75	91	95	98	99	100	SBWC
Apr. 10	1700	1,500	27	38	53	74	90	95	98	99	100	SBN
Apr. 29	0845	352	43	58	71	86	95	98	100	....	....	SBWC
Apr. 29	0845	352	34	47	68	90	97	99	100	....	....	SBN
May 6	1630	733	37	50	63	82	95	97	99	100	....	SBWC
May 6	1630	733	25	37	56	81	96	98	100	....	....	SBN
May 15	1730	1,290	57	69	86	95	97	99	100	....	....	SBWC
May 15	1730	1,290	22	37	65	96	99	99	100	....	....	SBN
May 16	1730	1,660	42	55	64	82	95	98	100	....	....	SBWC

May 16	1730	1,660	13	21	39	73	97	98	99	100	....	SBN
May 20	1030	2,260	51	64	80	93	98	99	100	....	....	SBWC
May 20	1030	2,260	34	47	67	88	97	99	100	....	....	SBN
May 20	2130	3,460	33	43	54	65	77	82	88	96	100	SBWC
May 20	2130	3,460	25	35	50	67	81	82	88	96	100	SBN
July 15	2000	4,120	42	57	68	84	95	98	100	....	....	SBWC
July 22	1645	2,040	36	45	60	72	91	96	99	100	....	SBWC
July 22	1645	2,040	19	32	51	72	90	96	99	100	....	SBN
July 28	1715	6,260	31	41	55	72	88	95	99	100	....	SBWC
July 28	1715	6,260	17	26	42	63	88	95	99	100	....	SBN
Aug. 21	1730	773	49	61	77	90	96	98	99	100	....	SBWC
Aug. 21	1730	773	20	33	60	93	96	98	99	100	....	SBN
1959												
Jan. 21	*1345	351	47	55	67	79	93	96	99	100	....	SBWC
Jan. 21	*1345	351	39	54	65	81	93	97	99	100	....	SBN
Jan. 21	1800	10,600	30	36	53	71	84	93	98	100	....	SBWC
Jan. 21	1800	10,600	11	23	35	53	80	92	98	100	....	SBN
Oct. 8	1630	154	86	87	95	97	99	99	100	....	....	SBN
Dec. 12	0900	502	54	60	72	86	92	96	99	100	....	SBWC
Dec. 12	0900	502	41	57	71	90	96	98	99	100	....	SBN
1960												
Jan. 14	2115	413	46	59	70	85	97	99	100	....	....	SBWC
Jan. 14	2115	413	21	38	57	81	97	100	....	....	....	SBN
Feb. 10	1500	2,490	31	40	51	66	82	92	98	100	....	SBWC
Feb. 10	1500	2,490	18	27	43	59	81	89	96	100	....	SBN
May 26	2100	2,780	61	77	89	95	98	99	100	....	....	SBWC
May 26	2100	2,780	55	70	88	94	98	99	100	....	....	SBN
1961												
Feb. 25	1510	1,120	51	63	76	90	97	99	100	....	....	SBWC
Feb. 25	1510	1,120	26	32	52	79	94	95	100	....	....	SBN
Mar. 21	0910	1,040	58	69	79	90	95	99	100	....	....	SBWC
Mar. 21	0910	1,040	25	41	67	87	91	92	100	....	....	SBN
Apr. 25	1310	1,620	40	49	60	73	94	94	100	....	....	SBWC
Apr. 25	1310	1,620	15	25	42	56	81	86	96	100	....	SBN
May 8	0735	5,120	30	38	49	64	81	90	96	99	100	SBWC
May 8	0735	5,120	13	20	32	46	66	80	92	98	100	SBN

*Water discharge equal to 10.8 cubic feet per second.

TABLE 6.—*Chemical-quality analyses of inflow and outflow, reservoir 1, May 1956 to February 1962*

Date of collection	Instantaneous water discharge (cfs)	Calcium (mg/l)	Sodium (mg/l)	Specific conductance (micromhos at 25°C)	pH
Inflow (sampling site 1, fig. 1)					
1956					
May 27	----	33	2.8	263	7.8
May 29	----	33	3.2	262	7.7
May 31	----	25	1.5	197	7.5
1957					
Feb. 9	----	35	3.2	263	7.5
Feb. 26	----	76	3.3	505	8.2
Apr. 1	----	40	3.8	346	8.0
Apr. 3	----	43	3.3	321	8.1
Apr. 8	----	20	.8	142	7.8
May 22	----	40	5.2	344	7.7
June 24	----	19	1.6	165	7.6
Dec. 7	----	18	3.1	156	7.4
1958					
Jan. 21	----	19	2.2	167	7.7
Apr. 10	----	30	3.2	235	8.0
Apr. 29	----	31	2.4	246	7.4
May 6	----	32	2.3	260	7.3
May 15	----	46	3.1	355	7.6
May 16	----	49	1.8	358	8.2
May 20 (1030)	----	12	1.7	199	8.0
(2130)	----	11	1.0	170	7.8
July 15	----	29	1.7	215	7.0
July 22	----	23	1.3	175	7.3
July 28	----	25	1.2	185	7.2
Aug. 21	----	53	2.8	371	7.1
1959					
Jan. 21 (1345)	[1] 10.8	25	2.6	208	7.5
(1800)	----	32	3.2	222	7.3
Oct. 8	----	67	6.4	520	7.6
Dec. 12	----	31	3.6	261	7.5
1960					
Jan. 14	----	46	4.6	374	7.6
Feb. 10	----	40	4.0	325	7.5
May 26	----	22	2.1	209	6.8
1961					
Feb. 25	----	29	4.7	256	7.7
Mar. 21	----	27	4.2	238	7.4
Apr. 25	----	21	2.0	165	7.2
May 8	----	23	2.1	177	7.4
Outflow (sampling site 2, fig. 1)					
1957					
Apr. 4	62.1	26	2.0	216	7.9
June 24	36.1	30	3.2	236	7.9
1958					
July 7	40.1	21	1.6	170	7.3
1959					
Jan. 21	20.1	29	2.9	229	7.6
1960					
Feb. 11	18.4	35	3.8	282	7.8
1961					
Apr. 26	6.26	22	2.2	193	7.2
1962					
Feb. 26	9.87	29	4.8	239	7.9

[1] Based on main channel water discharge measurement at 1345.

Particle-size distribution of sediment in the outflow (table 7) was determined for 24 analyses. Nineteen of these were analyzed in a distilled-water medium, and results indicated a particle-size distribution of 1 percent sand, 12 percent silt, and 87 percent clay. Fewer native-water analyses were made for the outflow, but flocculation occurred with the sediments here as with the inflow, and to about the same extent. The percentages of sand, silt, and clay in the distilled-water analyses of the outflow are shown graphically in figure 7.

DEPOSITED SEDIMENT

In April 1956, reservoir 1 had a sediment pool capacity of 27.50 acre-feet. A survey in June 1962 revealed an accumulation of 3.87 acre-feet (168,577 cu ft) of sediment, or a resultant capacity of the sediment pool after 6.08 years of 23.63 acre-feet. The specific dry weight of the deposited sediment averaged 71.6 pounds per cubic foot (U.S. Department of Agriculture, 1970) ; thus, the total weight of the deposited sediment was 6,035 tons.

SEDIMENT YIELD

Sediment yield is defined as the quantity of sediment contributed from a drainage area, generally expressed in tons per square mile. For subwatershed 1, the sum of the deposited sediment (6,035 tons) and the total suspended sediment discharged from the reservoir (797 tons) would equal the total sediment discharge (6,832 tons) from the subwatershed. The net sediment-contributing area of 0.94 square mile excludes the drainage areas of the two upstream structures. The average annual sediment yield for the contributing area of subwatershed 1 was 1,195 tons per square mile, or 1.87 tons per acre.

Average annual sediment yield for the entire watershed does not reflect changes in yield, which probably occurred throughout the period of investigation. The year-by-year changes are suggested, however, by annual sediment discharged from the reservoir. During the period of investigation, the suspended sediment discharged from reservoir 1 exceeded 1.5 million pounds (797 tons). Table 8 shows the annual suspended-sediment discharges in tons per acre-foot of outflow from subwatershed 1 below detention structure 1. Of notable significance is the period May to September 1956; the suspended-sediment discharge is especially low because flow occurred only twice during the period. (See tables 2 and 3.)

A general decrease after the 1957 water year is evident from table 8. Although these figures do not include that part of the

TABLE 7.—*Particle-size analyses of suspended sediment, outflow from reservoir 1*

[Methods of analysis: B, bottom-withdrawal tube; C, chemically dispersed; N, in native water; S, sieve; W, in distilled water. Sampling site 2, figure 1]

Date of collection	Time	Discharge (cfs)	Suspended sediment: Concentration (mg/l)	Percent finer than indicated size, in millimeters: 0.002	0.004	0.008	0.016	0.031	0.062	0.125	0.250	Methods of analysis
1957												
Apr. 1	1800	3.74	147	74	83	90	93	97	98	100	....	SBWC
Apr. 4	1200	43.0	422	71	84	94	97	98	99	99	100	SBWC
Apr. 4	1300	62.1	686	67	80	92	97	99	99	100	....	SBWC
Apr. 4	1800	61.2	534	73	86	94	98	99	99	100	....	SBWC
Apr. 8	0600	1.32	198	80	87	93	96	97	98	99	100	SBWC
Apr. 8	1400	9.51	246	68	78	84	90	93	96	97	100	SBWC
June 24	0800	41.9	968	62	77	89	95	97	98	98	*99	SBWC
June 24	1200	28.9	629	73	91	96	98	99	100	....	....	SBWC
Dec. 20	0855	9.51	207	88	94	95	99	100	....	....	....	BWC
1958												
June 14	1000	27.5	458	86	96	98	99	100	....	....	....	BWC
July 7	0700	40.1	467	75	91	97	97	98	100	....	....	BN
1959												
Jan. 21	1220	20.1	347	74	84	91	93	96	100	....	....	BWC
Jan. 21	1220	20.1	347	60	81	93	94	97	100	....	....	BN
Jan. 21	1725	20.8	346	60	75	83	87	91	100	....	....	BWC
1960												
Feb. 11	0500	18.5	329	82	91	95	97	99	100	....	....	BWC
Feb. 11	1615	18.4	292	70	88	98	99	99	100	....	....	BN
Feb. 13	2035	16.0	280	92	94	96	98	99	100	....	....	BWC
1961												
Apr. 26	0950	6.26	259	87	98	99	99	100	....	....	....	BWC
Apr. 26	0950	6.26	259	55	72	94	97	99	100	....	....	BN
May 8	0930	65.5	892	62	76	90	99	100	....	....	....	BWC
Aug. 14	1145	.98	54	87	93	97	98	99	100	....	....	BWC
1962												
Jan. 22	0925	30.0	107	76	89	99	100	....	....	....	....	BWC
Feb. 26	1345	9.87	175	81	94	99	100	....	....	....	....	BWC
Feb. 26	1345	9.87	175	31	54	85	99	99	100	....	....	BN

*Percentage of particles finer than 0.5 millimeters is 100.

TABLE 8.—*Suspended-sediment discharge in outflow from reservoir* 1

Period	Sediment in outflow (tons per acre-ft)
May to Sept. 1956	0.06
Oct. 1956 to Sept. 1957	.45
Oct. 1957 to Sept. 1958	.37
Oct. 1958 to Sept. 1959	.34
Oct. 1959 to Sept. 1960	.15
Oct. 1960 to Sept. 1961	.16
Oct. 1961 to May 1962	.10
Average	.26

sediment which was trapped in the reservoir, the values in the table indicate that the sediment yield from the subwatershed above detention structure 1 probably decreased. The decline in cultivation and the increasing effectiveness of conservation practices before and during the period of investigation no doubt caused a decrease in sediment yield.

TRAP EFFICIENCY OF RESERVOIR 1

The trap efficiency of a reservoir is the percentage of the sediment inflow that is retained by the reservoir. Trap efficiency can be computed by the equation:

$$TE = \frac{A}{B} \times 100$$

where TE = trap efficiency of the reservoir, in percent,
A = weight of sediment (tons) retained by the reservoir, and
B = weight of sediment (tons) inflow into the reservoir.

The trap efficiency of reservoir 1 is 88 percent. This is about 9 percent below the estimated figure based on the capacity-inflow ratio method given by Brune (1953, p. 414). The upstream structures in the subwatershed probably trap many of the coarser sediments from 10 percent of the drainage area. They probably affected the particle-size distribution of sediment entering reservoir 1 by decreasing the proportion of coarser particles. Had the structures not been present, a larger percentage of inflowing sediment might have been trapped by reservoir 1.

CONCLUSIONS

Based on the 6.08 years of study of fluvial sediments of subwatershed 1, the following conclusions are made:

1. Outflow from reservoir 1 during the study period occurred only 41 percent of the total time during 40 separate flow

periods. Water discharge during 12 of these periods comprised 88 percent of the total water discharged and 97 percent of the total sediment discharged from the reservoir.

2. Average annual inflow to reservoir 1 was 9.2 inches.
3. The average annual runoff from subwatershed 1 was 9.5 inches, compared to 11.84 inches for the entire Hunters Run watershed.
4. Ninety-one percent of the water discharge and 94 percent of the sediment discharge occurred, on the average, during the 7-month period, January through July.
5. Ninety-one percent of the total sediment discharge occurred during 5 percent of the period of investigation.
6. Particle-size distribution of sediment in the inflow to reservoir 1 averaged 4 percent sand, 38 percent silt, and 58 percent clay. Particle-size distribution of sediment in the outflow averaged 1 percent sand, 12 percent silt, and 87 percent clay.
7. Flocculation of clay occurred in the native-water settling medium during particle-size analysis. It can be assumed that flocculation occurred in the reservoir, but the degree to which it occurred is unknown.
8. Average annual sediment yield from reservoir 1 was 1,195 tons per square mile, or 1.87 tons per acre.
9. The sediment discharged from reservoir 1 per acre-foot of water discharge was 0.45 ton in 1957 and decreased to 0.10 ton in 1962.
10. The trap efficiency of reservoir 1 was 88 percent for the 6.08-year period.

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