Effectiveness of Sediment-Control Techniques Used During Highway Construction in Central Pennsylvania

By LLOYD A. REED

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 2054

Prepared in cooperation with the Pennsylvania Department of Transportation, the State Conservation Commission, Pennsylvania Department of Environmental Resources, and the Federal Highway Administration

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1978

UNITED STATES DEPARTMENT OF THE INTERIOR

CECIL D. ANDRUS, *Secretary*

GEOLOGICAL SURVEY

H. William Menard, *Director*

Library of Congress Cataloging in Publication Data
Reed, Lloyd A.
Effectiveness of sediment-control techniques used during highway construction in central Pennsylvania.
(Geological Survey Water-Supply Paper 2054)
Bibliography: p. 57
Supt. of Docs. no.: I 19.13:2054
1. Road construction—Pennsylvania. 2. Sediment transport—Pennsylvania. 3. Erosion—Pennsylvania. I. Title. II. Series: United States Geological Survey Water-Supply Paper 2054.
TE24.P4R43 625.7'3 77-60181

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402
Stock Number 024-001-03114-1

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Multiply English units	*By*	*To obtain (SI) units*
Inch (in)	25.4	Millimeter (mm)
Foot (ft)	.3048	Meter (m)
Mile (mi)	1.609	Kilometer (km)
Acre	.4047	Hectares (ha)
Ton (short)	.9072	Tonne (t)
Acre-foot (acre-ft)	1,233	Cubic meter (m^3)
Cubic foot per second (ft^3/s)	.02832	Cubic meter per second (m^3/s)
Cubic foot per second-day (ft^3/s-day)	.02832	Cubic meter per second-day (m^3/s-day)
Degree Fahrenheit (°F)	-32x5/9	Degree Celsius (°C)

EFFECTIVENESS OF SEDIMENT-CONTROL TECHNIQUES USED DURING HIGHWAY CONSTRUCTION IN CENTRAL PENNSYLVANIA

By Lloyd A. Reed

ABSTRACT

A different method for controlling erosion and sediment transport during highway construction was used in each of four adjacent drainage basins in central Pennsylvania. The basins ranged in size from 240 to 490 acres (97 to 198 hectares), and the area disturbed by highway construction in each basin ranged from 20 to 48 acres (8 to 19 hectares). Sediment discharge was measured from each basin for 3 years before construction began and for 2 years during construction. In one of the basins affected by the construction, three offstream ponds were constructed to intercept runoff from the construction area before it reached the stream. In another basin, a large onstream pond was constructed to trap runoff from the construction area after it reached the stream. In a third area, seeding, mulching, and rock dams were used to limit erosion. In the fourth area, no sediment controls were used.

The effectiveness of the various sediment-control measures were determined by comparing the sediment loads transported from the basins with sediment controls to those without controls. For most storms the offstream ponds trapped about 60 percent of the sediment that reached them. The large onstream pond had a trap efficiency of about 80 percent, however, it remained turbid and kept the stream flow turbid for long periods following storm periods. Samples of runoff water from the construction area were collected above and below rock dams to determine the reduction in sediment as the flow passed through the device. Rock dams in streams had a trap efficiency of about 5 percent. Seeding and mulching may reduce sediment discharge by 20 percent during construction, and straw bales placed to trap runoff water may reduce sediment loads downstream by 5 percent.

INTRODUCTION

The Pennsylvania Departments of Transportation and Environmental Resources (State Conservation Commission), the Federal Highway Administration, and the U.S. Geological Survey have cooperated in a study to evaluate sediment control used during highway construction. Hydraulic data were collected for 5 years from tributaries to Conodoguinet Creek, which drain five adjacent basins, four of which were crossed by construction of Interstate 81 (3 years before construction and 2 years during construction). The data included measurements of precipitation, streamflow, suspended-sediment concentration, and turbidity.

A stream-gaging station was constructed in each basin adjacent to the stream. Equipment was installed in the stations to record streamflow continuously and to collect samples of streamflow during storm runoff. Continuously recording turbidity meters were installed in three stations, and three recording precipitation gages were installed in the study area.

This report is divided into three sections and covers data collected from October 1, 1969, through September 30, 1974. Construction of the highway began in November 1972 and was almost completed by September 30, 1974. The effects of construction on the streams are shown in the first section. Streamflow, suspended-sediment discharge, and turbidity are shown for the period of construction and are compared to those for the 3 years before construction. The sediment transport and turbidity caused by Hurricane Agnes (June 1972) are also shown and compared to that caused by the construction.

In the second section the effects of the different construction operations on sediment discharges are discussed. The sediment discharge measured from basins 2 and 3 are compared to the sediment discharge measured from basin 1 on a storm by storm basis. Clearing and grubbing, bridge construction, culvert construction, the spring slack period, early earthmoving, winter, final earthmoving, and automatic grading are examined and their relative influence on sediment discharge is discussed. Suspended sediment that entered the stream due to equipment operations in the clearing and grubbing phase of construction is compared to that transported during storms.

The effectiveness of the erosion-and-sediment-control techniques is discussed in the third section. Basins 1 and 2 were used as standards against which the effectiveness of the erosion-control measures used in the other three basins was evaluated. Basin 1 had no construction; whereas, basin 2 had construction, but no erosion-control measures were used.

In basin 2A, three offstream ponds were constructed to intercept the sediment from the construction area before it reached the stream. In basin 2B, a large onstream pond, similar to a farm pond, was constructed below the construction area to trap the sediment from the construction area as well as the normal sediment from the construction area as well as the normal sediment from the total drainage area. During construction in basin 3, the completed cut-and-fill slopes were seeded and mulched and small rock dams were used to trap the sediment that entered the streams. Seeding and mulching were also applied in basins 2A and 2B as frequently as possible to stabilize the cut-and-fill slopes. No seeding and mulching was done in basin 2 until after the paving was completed. The sediment control devices were designed by Mr. Jeffrey P. Weaver, Engineering District 8-0, Pennsylvania Department of Transportation.

THE STUDY AREA

The study area is about 10 mi (16 km) west of Harrisburg and is comprised of five adjacent drainage basins. Figure 1 shows the location of highway construction, major sediment-control facilities, and data-collection points. Drainage area 1 was the continuously monitored drainage area of no construction, and drainage areas 2, 2A, 2B, and 3 were crossed by construction of Interstate 81 (LR 1005).

The drainage areas extend from the crest of Blue Mountain to the stream-monitoring stations along Valley Street or State Route 944. The altitude of Blue Mountain is about 1,200 ft (370 m) and altitudes at the stream-monitoring sites range from 380 to 425 ft (120 to 130 m). Slopes on Blue Mountain average about 30 percent, but some are as high as 50 percent. Slopes average about 4 percent in most of the valley area.

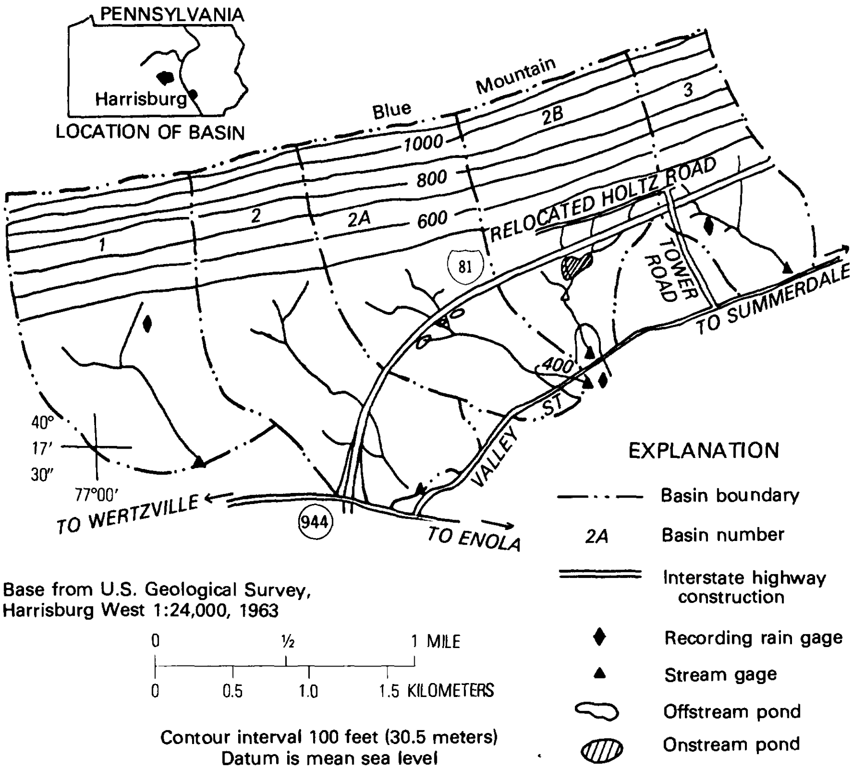

FIGURE 1.—Location of basins and data-collection sites.

Blue Mountain is underlain by shale and sandstone of the Clinton Formation (Pennsylvania Geological Survey, 1960) and the underlying quartzitic Tuscarora Sandstone, both of Silurian Age. The valley is underlain by shale of the Martinsburg Shale of Ordovician Age. Soils on Blue Mountain are classified as very stony to stony and gravelly loams. The valley soils, derived from the underlying Martinsburg Shale, are mostly shaly silt loams and range from 1 to 5 ft (0.3 to 1.5 m) thick, though most are 2-3 ft (0.6-0.9 m) thick. The topsoil is generally 44 percent sand, 41 percent silt, and 15 percent clay. The subsoil is generally 39 percent sand, 35 percent silt, and 26 percent clay. Permeability is moderate to low, and the available moisture capacity is about 3 in. (76 mm).

Forests occupy the mountainous area and the steeper parts of the valley. The flatter areas in the valley are open fields, a few of which are actively farmed; the rest is grassland. Residential development is sparse; the number of houses in the basins ranges from 6 in basin 2A to 28 in basin 3. Size and land use of each basin are given in table 1.

TABLE 1.—*Land use in basins drained by Conodoguinet Creek tributaries 1, 2, 2A, 2B, and 3, March 30, 1974*

Basin	Area (mi^2)	Elevation at gate (feet)	Percentage of basin					
			Forest	Grass	Active farmland	Secondary roadways	Buildings	Construction area
1	0.77	425	65	29	5.3	0.4	0.3	0
2	.76	405	51	32.8	9.2	.5	.3	6.2
2A	.70	380	76	9.8	9.2	.3	.2	4.5
2B	.65	385	75	4.0	8.5	.5	.5	11.5
3	.38	415	76	11.8	0	1.5	1.2	9.5

HYDROLOGIC CONDITIONS

The climate is typical of temperate zones at lat 40° N. Temperature ranges from an average of 32°F (0°C) in January to 76°F (24°C) in July. Average yearly temperature is 53°F (12°C). Normal, minimum, and maximum temperatures range from 0°F (-18°C) in January or February to 95°F (35°C) in July or August. Average precipitation, based on National Oceanographic and Atmospheric Administration (NOAA) records from Harrisburg, Carlisle, and Bloserville, is 40.6 in. (1,030 mm) per year. Harrisburg is 10 mi (16 km) southeast, Carlisle is 13 mi (21 km) southwest, and Bloserville is 20 mi (32 km) west of the study area. Precipitation is fairly uniformly distributed throughout the year.

PRECIPITATION

Precipitation was graphically recorded at three locations (fig. 1). Gages were located near the centers of drainage basins 1 and 3 and near the gaging station in basin 2A. Figure 2 shows the precipitation gage in basin 3, with the cover removed.

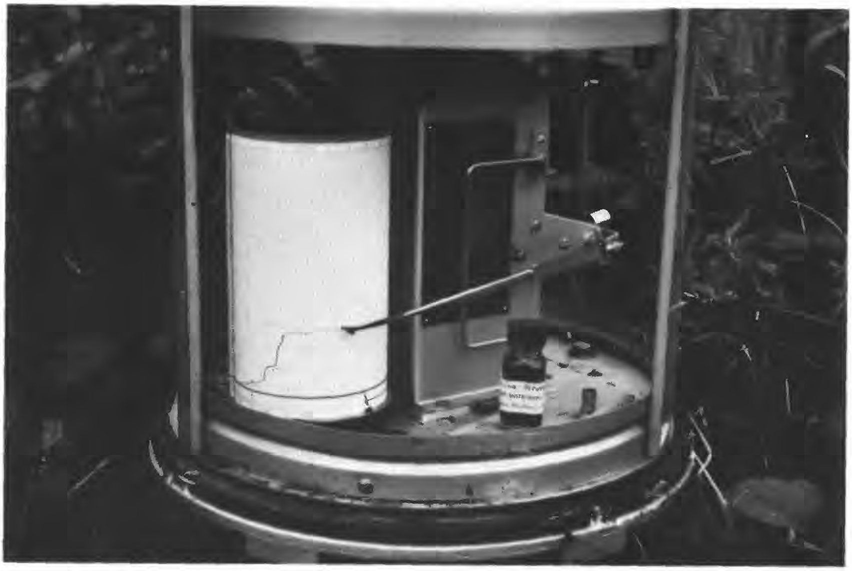

FIGURE 2.—Recording rain gage in basin 3, with cover removed, showing precipitation of August 1, 1973, when 1.49 in. (37 mm) fell from 8 a.m. to 3 p.m.

Precipitation recorded at each gage was tabulated monthly. A cumulative sum of the monthly values was plotted against time (fig. 3) for the 5 years of the study. The years are water years which extend from October 1 to September 30. For example, the 1972 water year is the period from October 1, 1971, to September 30, 1972. Precipitation average 43.4 in. (1,100 mm) per year for the 5 years. The yearly averages for the three gages were 41.5, 38.0, 49.1, 49.1, and 39.4 in. (1,050, 970, 1,250, 1,250, and 1,000 mm) from 1970 through 1974. During the 3 years of data collection before highway construction, precipitation averaged 42.9 in. (1,090 mm), and during the 2 years of construction it averaged 44.2 in. (1,120 mm). From figure 3 it can be seen that slightly more precipitation was recorded at the gage in basin 2A and slightly less at the gage in basin 1. The variation between gages, less than 6 percent, could be caused by local differences in climate or simply by recording errors. For most storms the difference between the three sites was small. Occasionally, as on August 10, 1973, variations were large. On this day, 1.87 in. (48 mm) was recorded in basin 3 and only 0.97 in. (25 mm) in basin 1. On June 28, 1973, 1.72 in. (44 mm) was recorded in basin 1 and only 0.70 in. (18 mm) in basin 3.

The maximum monthly precipitation, 16.7 in. (424 mm), was recorded in June 1972, of which 12.5 in. (317 mm) was associated with the passage of Hurricane Agnes. The minimum monthly precipitation, 0.6 in. (15 mm), occurred in January 1971. For most of the 5-year period, precipitation was uniformly distributed and was close to the long-term average, 40.6 in. (1,030 mm), for the area. The maximum precipitation for one storm during the construction of the roadway was 4.9 in. (124 mm) on September 14, 1973.

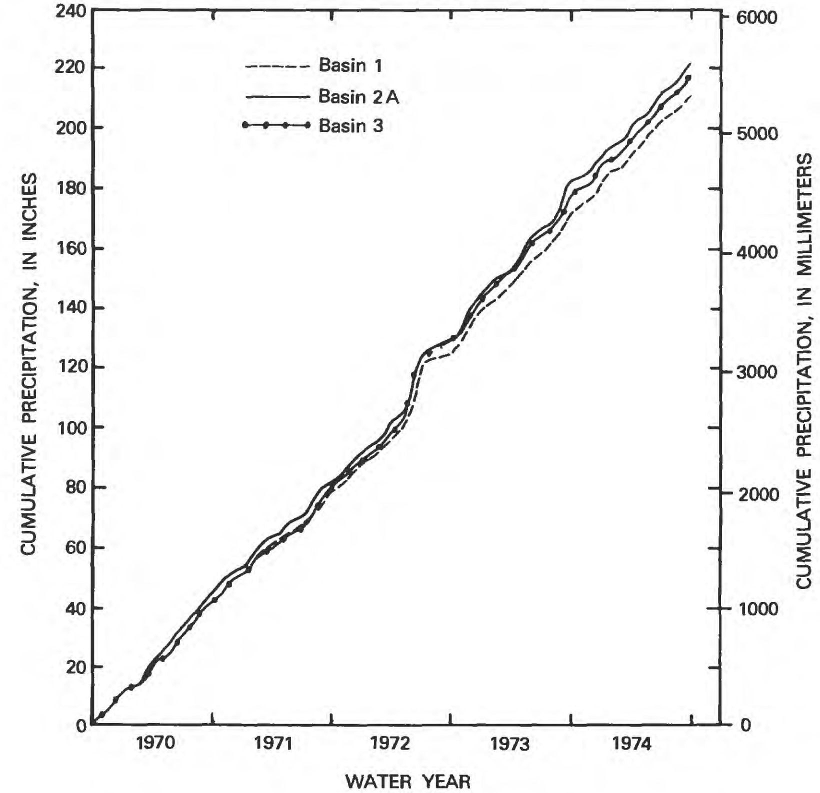

FIGURE 3.— Cumulative precipitation recorded in basins 1, 2A, and 3, from October 1, 1969, to September 30, 1974.

The September 1973 event is discussed in more detail, along with several others, in the "Phases of Construction" and "Sediment Control" sections of this report.

STREAMFLOW

Continuous streamflow records were obtained by graphic-stage recorders (fig. 4). Stream stage was related to flow on the basis of periodic current-meter measurements. Daily streamflows were calculated for the recorded stages. Those values, along with the daily maximum values for storm days, were tabulated.

Figure 5 shows the cumulative discharge in each of the five drainage areas plotted by months for the 5 years of data collection. Cumulative water discharge per unit drainage area is plotted because the basins are of slightly different size. When drainage area is considered, total streamflow from each of the basins differed by less than 8 percent from the mean for the five basins.

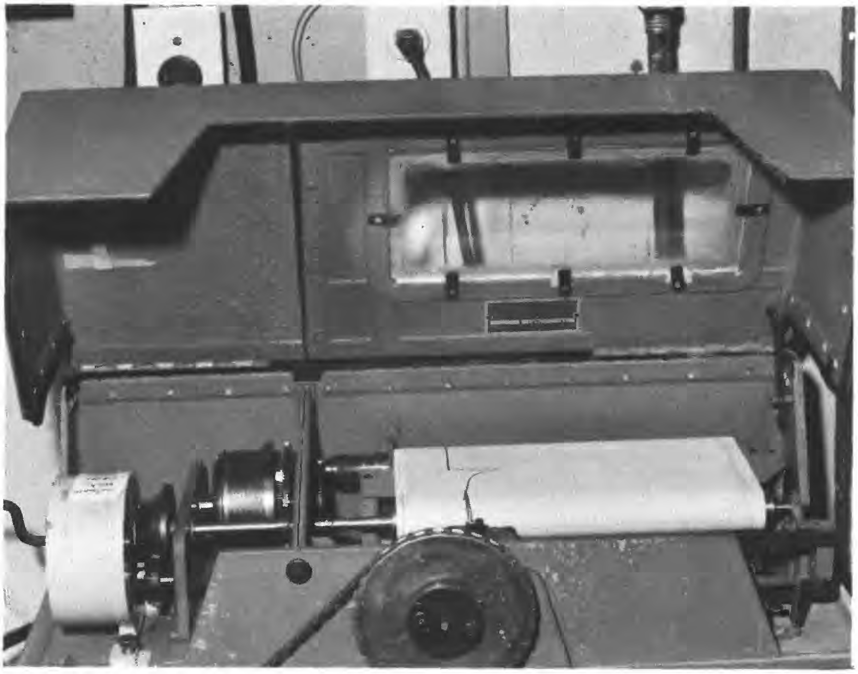

FIGURE 4.—Graphic-stage recorder in basin 2. (Photograph courtesy of Commonwealth Photographic Services.)

Maximum total monthly water discharge from the streams occurred in June 1972 as a result of rains associated with the passage of Hurricane Agnes. On a monthly basis, the average flow in each of the five basins before highway construction was very close to the average flow during the 2 years of construction.

Figure 6 is a plot of the cumulative-peak streamflow values for each of the five drainage areas, by months. All storm runoff that produced a peak water discharge of 10 ft^3/s (0.28 m^3/s) or more in any of the five basins was plotted. The values are not adjusted for differences in size of drainage area. The maximum values occurred in June 1972 and are the result of the passage of the hurricane. Peak streamflow does not seem to have been appreciably affected during highway construction.

SUSPENDED SEDIMENT

Samples of streamflow from each of the five basins were analyzed for suspended-sediment concentration. The samples were collected as frequently as every 15 minutes during storms, when concentrations were changing rapidly, and about twice weekly during base-flow periods, when the streams normally have low suspended-sediment concentrations. When construction began, samples were collected several times daily during the base-flow

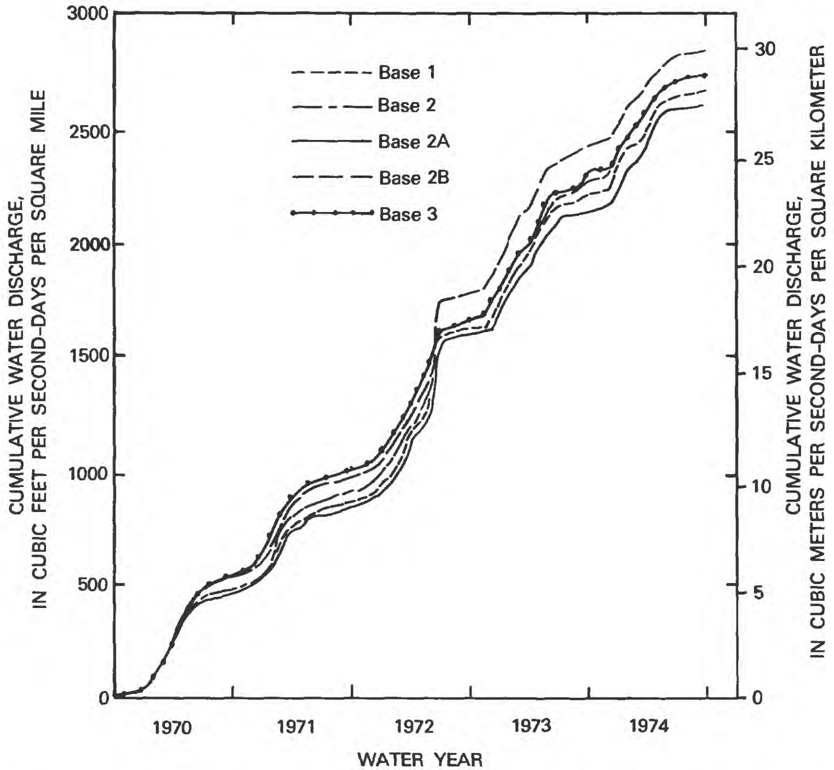

FIGURE 5.—Cumulative water discharge, Conodoguinet Creek tributaries 1, 2, 2A, 2B, and 3, October 1, 1969, to September 30, 1974.

periods to document any sediment flows that may have resulted from construction. The samples were collected by hand during visits to the sites and by automatic sampling equipment installed in the gages. A Spotts Pendulum Sampler,[1] (fig. 7) was installed at each gage site.

After the samples had been analyzed, the suspended-sediment concentrations were plotted against time on the stream-stage record. From the sediment concentration and stream-stage records, the time-weighted mean suspended-sediment concentrations and sediment loads (Guy, 1970; Porterfield, 1972) were calculated on a daily basis for each of the five basins.

Sediment-load and daily-mean sediment concentrations have different uses. Sediment load is the quantity of sediment transported past a given location during a period of time. It indicates the quantity of sediment that may be deposited in a downstream structure (lake or estuary) or, in some places, the stream channel itself. Daily-mean sediment concentrations tell

[1]The use of the brand name in this report is for identification purposes only and does not imply endorsement by the U.S. Geological Survey.

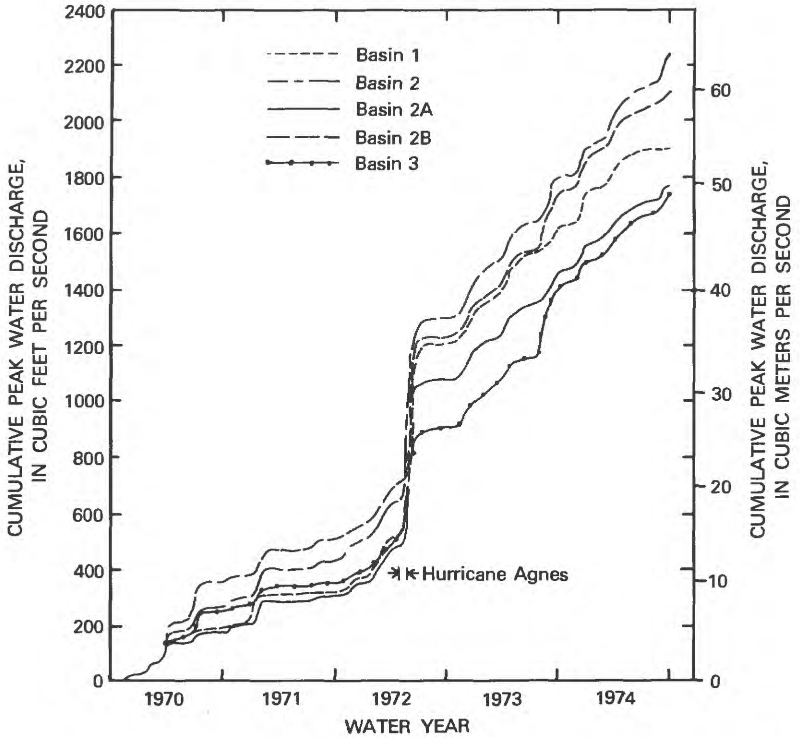

FIGURE 6.—Cumulative-peak water discharge, Conodoguinet Creek tributaries 1, 2, 2A, 2B, and 3, October 1, 1969, to September 30, 1974.

more about the appearance or clarity of the stream on a day-to-day basis. Most water users are much more conscious of the day-to-day appearance of the streamflow than the total sediment load. The relative importance of each parameter must be determined for each stream site.

SEDIMENT LOAD

The daily sediment discharge was cumulated for each of the five streams and is plotted by months in figure 8. The total sediment discharge from each of the five basins is also listed in table 2. The total discharge is broken down into the normal from each basin, that caused by highway construction, and that caused by Hurricane Agnes. The normal sediment load refers to the sediment load given no major changes in land use, and no unusual storms.

From Figure 8, it can be seen that the quantity of sediment during the 2 years of highway construction (1973-74) is equivalent to that normally discharged in 5 to 8 years. The quantity of sediment discharged during Hurricane Agnes was equivalent to that normally discharged in about 3 years. From table 2, the normal sediment discharge from basin 1 for the

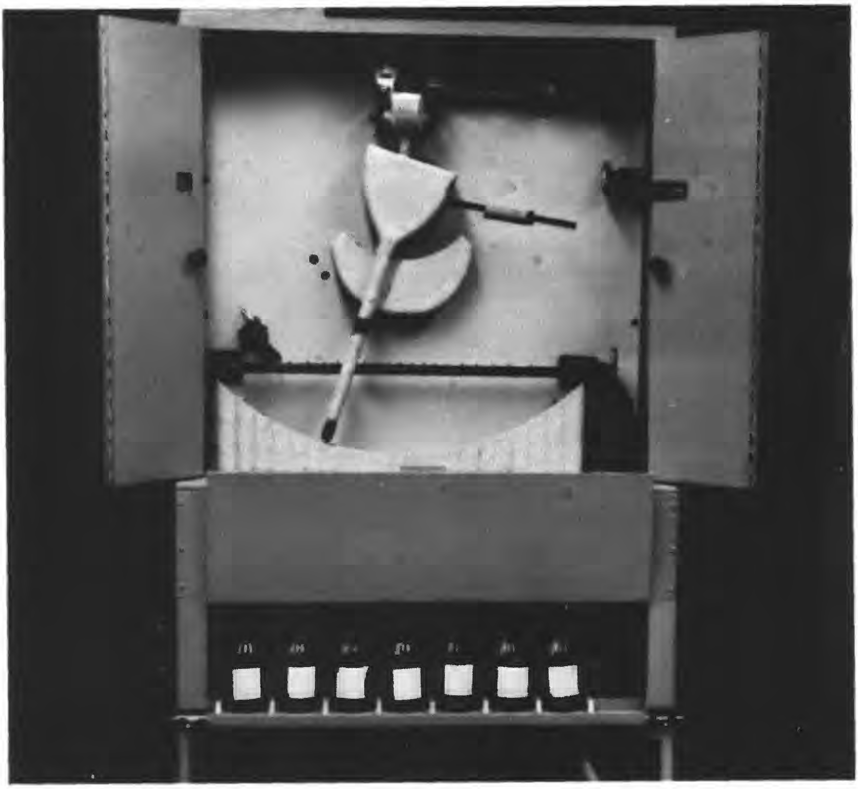

FIGURE 7.—Spotts Pendulum Sampler.

5-year period is the total load minus the load transported during Hurricane Agnes.

Normal sediment discharge rates from the basins affected by highway construction were determined by comparing the amount of sediment discharged from basin 1 with the amount discharged from the other basins during the preconstruction phase of data collection. Figure 9 shows the relation developed between basins 1 and 3. The relation was developed for individual storms and for yearly sediment-discharge values when land use and precipitation patterns were uniform. Similar relations were also developed between basin 1 and basins 2, 2A, and 2B.

PARTICLE-SIZE DISTRIBUTION OF SUSPENDED SEDIMENT

The suspended sediment was analyzed periodically to determine its particle-size distribution. Samples were usually collected by hand when the suspended-sediment concentration in the stream was more than 200 mg/L. Forty samples were collected for particle-size analysis from the five streams

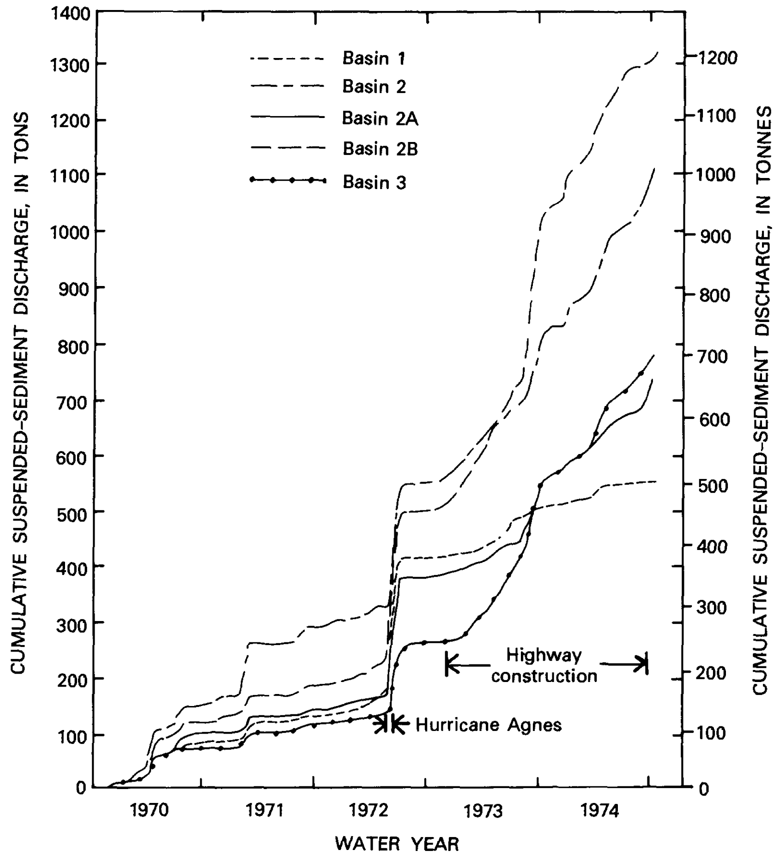

FIGURE 8.—Cumulative sediment discharge, Conodoguinet Creek tributaries 1, 2, 2A, 2B, and 3, October 1, 1969, to September 30, 1974.

during the 3-year period before construction; 111 samples were collected during the 2-year period of construction, 7 from the stream draining basin 1 and 104 from the streams draining the construction area.

A relation generally exists between streamflow and the particle-size distribution of the suspended sediment. As flow increases, velocity generally increases, and the stream can transport larger particles. Consequently, as flow increases, the percentage of the suspended sediment composed of sand (particles with diameters between 0.062 and 2.0 mm) would increase, and the percentage of the suspended sediment composed of silt (particles with diameters between 0.004 and 0.062 mm) and clay (particles with diameters < 0.004 mm) would decrease. Figure 10 shows the relation between streamflow and the percentage of the suspended sediment composed of clay-sized particles in samples collected from the stream draining basin 3.

The relation between streamflow and the percent clay in the suspended

TABLE 2.—*Suspended-sediment discharge, in tons, Conodoguinet Creek tributaries 1, 2, 2A, 2B, and 3, October 1, 1969, to September 30, 1974*

Tributary	5 normal years	Due to highway construction	Due to Hurricane Agnes	Total 5 years
1	320	...	210	530
2	350	433	207	[1]1,110
2A	320	217	202	739
2B	380	677	253	1,310
3	260	416	98	774

[1]Includes 120 tons that resulted from housing development in the basin in 1970.

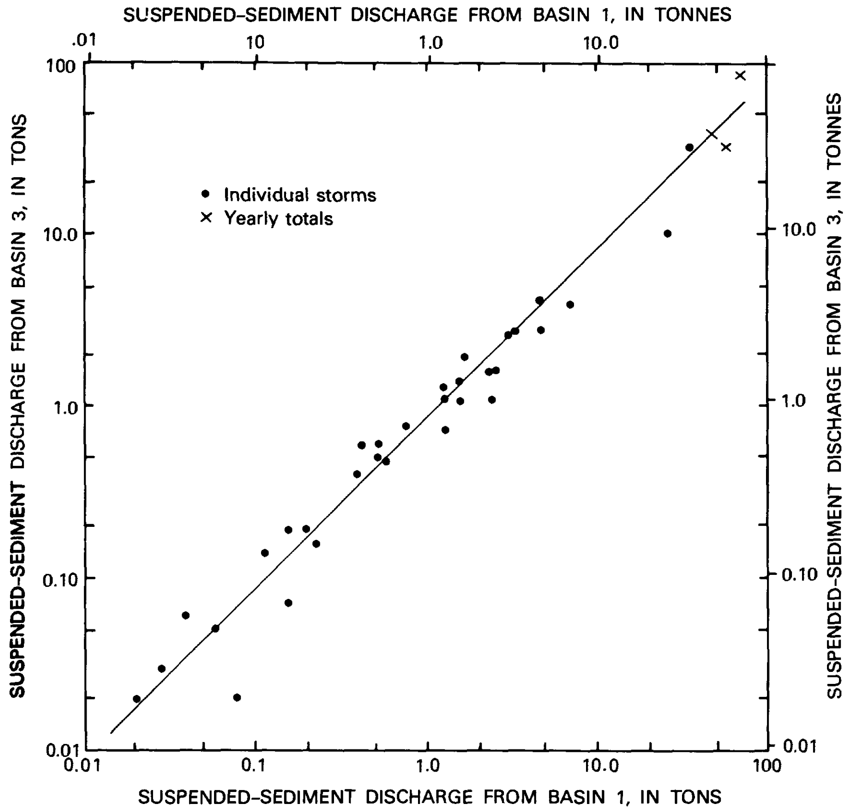

FIGURE 9.—Suspended-sediment discharge relation between basins 1 and 3 for individual storms and yearly totals, October 1, 1969, to November 30, 1972.

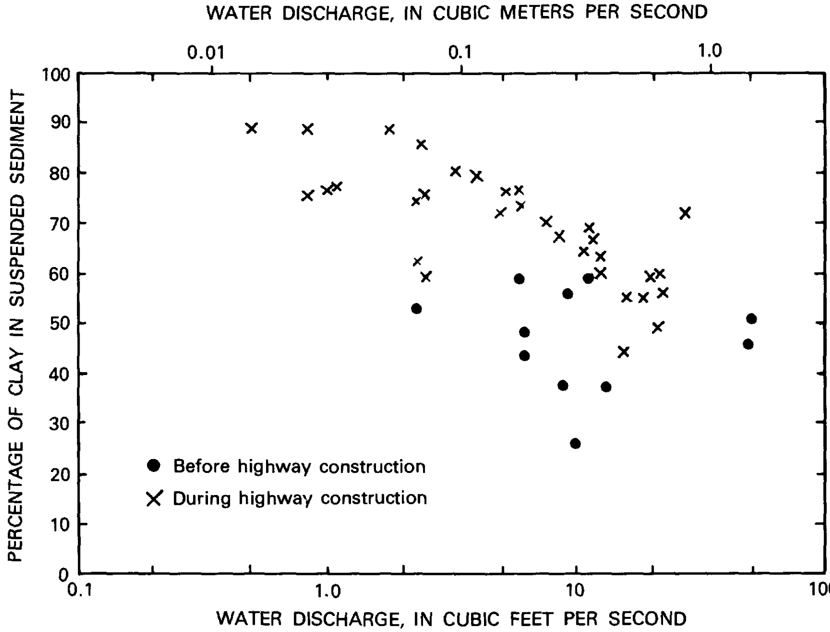

FIGURE 10.—Relation between streamflow and percentage of clay in suspended sediment, Conodoguinet Creek tributary 3, April 2, 1970, to September 12, 1974.

sediment is apparent. About 80 percent of the sediment was composed of clay at streamflows of 1 ft³/s (0.028 m³/s) compared to about 50 percent at flows of 10 ft³/s (0.28 m³/s).

A summary of the particle-size analyses is given in table 3. Before construction started, the particle-size distribution averaged about 7 percent sand, 50 percent silt, and 43 percent clay. During construction the particle-size distribution of the suspended sediment in the streams draining the areas affected by construction averaged 2 percent sand, 33 percent silt, and 65 percent clay. The size distribution of the suspended-sediment samples analyzed from basin 1 remained practically unchanged during construction.

The size distribution of the sediment in the analyzed samples was assumed to be representative of the size distribution of the total yearly sediment discharge. With this assumption, calculations were made to determine the quantities of sand, silt, and clay in both the normal sediment discharge and the sediment discharge caused by construction. The results of the calculations are given in table 4. The normal yearly sediment load is divided into yearly loads of sand, silt, and clay. The average yearly load measured during construction is also divided into loads of sand, silt, and clay. As the

TABLE 3.—*Summary of particle-size distribution of suspended-sediment samples, Conodoguinet Creek tributaries 1, 2, 2A, 2B, and 3, October 1, 1969, to September 30, 1974*

Basin	Number of analyses	Stream water discharge when samples were collected (ft^3/s): Range Low	Range High	Median	Mean	Particle-size distribution of suspended sediment (weight percent): Range Sand	Range Silt	Range Clay	Median Sand	Median Silt	Median Clay	Mean Sand	Mean Silt	Mean Clay
Preconstruction years 1970-72														
1	8	1.1	56	5.3	12.8	0-31	33-71	21-67	3	54	34	9	54	37
2	9	1.2	56	8.8	22.3	0-23	34-68	25-65	2	54	38	7	50	43
2A	7	1.5	56	7.7	13.0	1-20	48-54	28-50	2	52	42	8	52	40
2B	6	1.0	26	8.5	9.8	0-14	30-62	27-70	3	46	50	5	46	49
3	10	2.3	49	8.8	15.8	1-12	39-59	26-59	2	47	47	5	49	46
Construction years 1973-74														
1	7	5.7	27	17.0	15.9	2-22	38-58	26-60	4	51	38	8	51	41
2	31	1.5	36	11.2	12.5	0-17	10-55	32-90	0	32	66	1	33	66
2A	24	1.5	20	8.5	9.5	0-15	16-52	33-84	1	32	68	3	33	64
2B	16	0.9	30	13.8	15.5	0-10	15-55	40-85	2	35	63	3	36	61
3	33	0.5	22	7.8	13.7	0-5	11-55	44-88	0	30	70	1	30	69

TABLE 4.—*Particle-size distribution of suspended-sediment discharge, Conodoguinet Creek tributaries 1, 2, 2A, 2B, and 3, October 1, 1969, to September 30, 1974*

	Average annual sediment load (tons)								Sediment load due to highway construction					
	1970-72 (Excluding Agnes)				1973-74				Tons per year			Percent		
Basin	Sand	Silt	Clay	Total	Sand	Silt	Clay	Total	Sand	Silt	Clay	Sand	Silt	Clay
1	6	34	24	64	5	33	26	64	....	....	....	....	....	....
2	5	35	30	70	3	94	189	286	0	58	158	0	27	73
2A	5	33	26	64	5	57	110	172	0	24	84	0	22	78
2B	4	35	37	76	12	149	253	414	8	114	216	2	34	64
3	3	25	24	52	3	78	179	260	0	53	155	0	25	75

yearly load measured during construction includes the normal sediment from the basin, as well as that from the construction area, the normal sediment must be subtracted to determine the load from the construction area. The last six columns in table 4 show the sediment from the construction area that passed the gaging stations. The sediment is shown in tons as well as percentage of sand, silt, and clay. Of the 870 tons (789 t) of sediment resulting from the construction each year, 8 tons (7 t) was sand, 249 tons (226 t) was silt, and 613 tons (556 t) was clay. The sediment load from the construction area that was transported past the gaging stations contained 1 percent sand, 29 percent silt, and 70 percent clay.

Figure 11 shows the average annual suspended-sediment discharge from basin 3 as tons of sand, silt, and clay. The values for the 1970-72 water years represent the average yearly loads with the effects of the hurricane of 1972 removed. The average discharge for the 1973 and 1974 water years includes the normal sediment discharge and the sediment discharge from the highway construction. The calculated sediment discharge from the construction area is shown by the bars on the right side of figure 11 and in table 4 and was

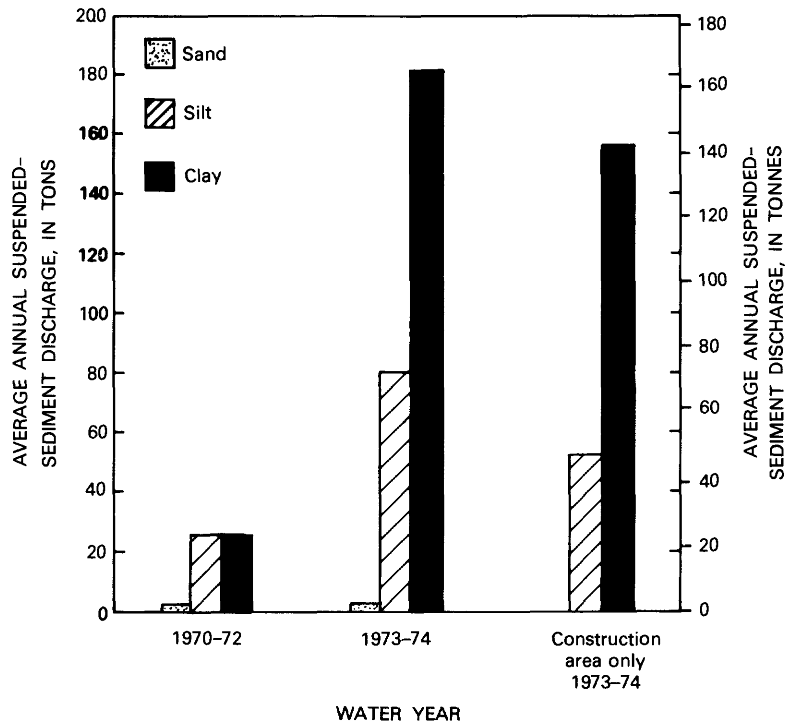

FIGURE 11.—Particle-size distribution of the suspended-sediment discharge, Conodoguinet Creek tributary 3, October 1, 1969, to September 30, 1974.

obtained by subtracting the average yearly loads in 1970-72 water years from the average loads in 1973-74 water years.

DAILY-MEAN SUSPENDED-SEDIMENT CONCENTRATIONS

Daily-mean suspended-sediment concentrations indicate the appearance of the streamflow on a day-to-day basis. The daily-mean concentrations were calculated on a time-weighted basis, and a daily mean of 200 mg/L indicates that the average suspended-sediment concentration for the 24-hour period was 200 mg/L. Analysis of the daily-mean suspended-sediment-concentration data is divided into two parts. One part concerns the periods when the streamflow is nearly free of sediment; these are called base-level periods. The streamflow is generally free of sediment about 80 percent of the time, or about 24 days each month. The second part concerns the time when the streams contains significant concentrations of suspended sediment. Normally, significant concentrations occur only during periods of storm runoff, generally about 20 percent of the time, or 6 days each month.

Average base-level suspended-sediment concentrations are summarized for each of the five streams in table 5 for periods before and during construction. The lowest 24 daily-mean sediment concentrations were averaged, on a monthly basis, to determine the values given in table 5.

Base-level suspended-sediment concentrations in the stream draining basin 1 (no construction) averaged 5 mg/L during the 5 years of data collection. The only detectable change occurred in the summer of 1971, when the concentrations averaged 10 mg/L, because the field just upstream from the gage was used as a pasture for cattle. During the period when construction was underway in the other four basins, the base-level concentrations in the stream draining basin 1 averaged 5 mg/L. The runoff

TABLE 5.—*Average base-level suspended-sediment concentrations, Conodoguinet Creek tributaries 1, 2, 2A, 2B, and 3, October 1, 1969, to September 30, 1974*

Basin	Type sediment controls	Average base-level suspended-sediment concentration, in milligrams per liter			
		Before construction	During construction: Clearing, grubbing and early earthwork	During construction: Late earthwork and final grading	During construction: Total construction period
1	No construction	5	5	5	5
2	Construction—no sediment controls	5	18	15	16
2A	Construction—offstream ponds	4	8	14	12
2B	Construction—onstream ponds	13	45	[1]28	60
3	Construction—seeding, mulching, and rock dams	8	37	16	25

[1]From data collected immediately below onstream pond.

associated with Hurricane Agnes, June 1972, had no effect on base-level sediment concentrations.

Base-level suspended-sediment concentrations showed significant increases in the four streams affected by highway construction. In the stream draining basin 2 (no sediment controls), base-level suspended-sediment concentrations averaged 5 mg/L from October 1, 1969, to July 31, 1970. They increased to 15 mg/L from August 1, 1970, to February 28, 1971, because of the construction of a 5-acre (2-ha) farm pond and a one-lane roadway. The effect of this pond construction is not shown in table 5; however, it was discussed in detail in earlier reports (Reed, 1971, 1976). The concentration decreased to 5 mg/L from March 1, 1971, to October 31, 1972, the start of highway construction.

During the first 11 months of highway construction in basin 2, base-level sediment concentrations averaged 18 mg/L. Construction in the basin was mostly clearing and grubbing. A box culvert to carry the main stream through the construction area was built during March and April 1973. From October 1, 1973, to September 30, 1974, the base-level sediment concentrations averaged 15 mg/L. During that period, earthmoving was active, and drainage structures for the roadway were installed. During the 23-month period of construction, the base-level sediment concentrations averaged 16 mg/L, or about 200 percent higher than those observed during the period before construction. The runoff from Hurricane Agnes, June 1972, had no effect on the base-level suspended-sediment concentrations.

Base-level suspended-sediment concentrations in basin 2A (offstream ponds) averaged 4 mg/L from October 1, 1969, to October 30, 1972, before highway construction. From November 1, 1972, through June 30, 1973, during which time the area was cleared and grubbed, base-level sediment concentrations averaged 8 mg/L. During the period of active construction—making cuts, fills, and drainage-structures—July 1, 1973, to July 31, 1974, base-level concentrations averaged 10 mg/L. During August and September 1974, the period during and immediately after which the sediment ponds were filled in, base-level concentrations averaged 40 mg/L, making the overall late-construction-period average 14 mg/L. The average for the entire construction period was 12 mg/L.

Base-level sediment concentrations in basin 2B (onstream pond) were affected by ducks, which occupied a small private pond. From October 1, 1969, through October 31, 1972, the concentrations averaged 13 mg/L. During the early earthwork period, concentrations averaged 45 mg/L, and, for the entire 23-month period of highway construction, they averaged 60 mg/L. One reason for the high values during construction was the resuspension of fine sediments caused by the ducks feeding in small private ponds; a second reason was discharge of water with high suspended-sediment concentrations for long periods after storms from the large onstream sediment-control pond just below the construction area. To determine the relative concentrations caused by the ducks and by the large onstream sediment-control pond, samples were also collected just below the large onstream sediment-control pond. For the 11-month period, November 1, 1973, to September 30, 1974, base-level suspended-sediment concentrations just below the large onstream sediment-control pond averaged 28 mg/L, while those below the duck pond averaged 74 mg/L. The difference between the concentrations below the large pond and those below the duck pond (46 mg/L) can be attributed to resuspension of sediment by the ducks.

Although the large pond constructed to control sediment from the highway contributed to base-level suspended-sediment concentrations, the overall effectiveness of the pond must be looked at to determine its relative merits. The third section of this report discusses the effectiveness of the large pond as well as other sediment-control measures in detail.

Base-level suspended-sediment concentrations for the stream draining basin 3 (seeding and mulching and small rock dams), averaged 8 mg/L from October 1, 1969, through December 31, 1972. From January 1, 1973, to May 31, 1973, during the clearing and grubbing period, base-level concentrations averaged 23 mg/L. During the first 4 months of active earthmoving and culvert construction in basin 3, June 1, 1973, to September 30, 1973, the concentrations averaged 53 mg/L. The average concentration for the first 9 months of construction was 37 mg/L. From October 1, 1973, to September 30, 1974, the late earthwork and final grading period, the concentrations averaged 16 mg/L. During this last 12-month period, work on earthmoving and drainage structures was completed, and most of the paving was placed by September 30, 1974.

The average storm-runoff suspended-sediment concentrations are summarized for each of the five streams in table 6 for periods before and during construction. The highest six daily-mean suspended-sediment concentrations were averaged for each month from October 1969 through September 1974 for each of the five streams. Most of them represent periods when storms caused high suspended-sediment concentrations. However, some values are included when operations in or near the streams caused increased concentrations.

TABLE 6.—*Average storm-runoff suspended-sediment concentrations Conodoguinet Creek tributaries 1, 2, 2A, 2B, and 3, October 1, 1969, to September 30, 1974*

Basin	Average storm-runoff suspended-sediment concentration, in milligrams per liter				
	Prior to construction	During construction			
		Clearing, grubbing	Early earthwork	Late earthwork and final grading	Total construction period
1	45	45	45	45	45
2	45	200	200	200	200
2A	44	55	210	110	170
2B	68	225	820	[1]120	370
3	50	370	370	230	280

[1]From data collected immediately below the onstream pond.

Storm-runoff suspended-sediment concentrations in the stream draining basin 1 (no construction), averaged 45 mg/L, from October 1, 1969, to September 30, 1974. There were no significant changes in the concentrations during the 5-year period. Hurricane Agnes, June 1972, had only a slight effect. The average for June 1972 was 140 mg/L, a value equaled three other times, once in 1971 and twice in 1973.

Storm-runoff suspended-sediment concentrations in the stream draining basin 2 (no controls) were affected during the 1970-71 period by the construction of a 5-acre (2-ha) farm pond and related access road for a development. From July 1, 1970, to February 28, 1971, the concentrations averaged 142 mg/L. During the remainder of the period, from October 1, 1969, to October 31, 1972, the concentrations averaged 45 mg/L, which probably represents the average storm-runoff suspended-sediment concentration before construction. During highway construction, from November 1, 1972, to September 30, 1974, storm-runoff suspended-sediment concentrations averaged 200 mg/L. The highest values occurred in August and September 1974, when the concentrations averaged 510 and 710 mg/L, respectively.

In the stream draining basin 2A (offstream ponds), storm-runoff suspended-sediment concentrations averaged 44 mg/L from October 1, 1969, to October 31, 1972. During clearing and grubbing, from November 1, 1972, to May 31, 1973, concentrations averaged 55 mg/L. During the period from June 1, 1973, to July 31, 1974, concentrations averaged 160 mg/L. In August and September 1974 the concentrations averaged 640 mg/L. The filling of the sediment ponds in August 1974 and the related channel work contributed to the unusually high values observed in August and September 1974. For the entire period of construction, the concentrations averaged 170 mg/L.

In the stream draining basin 2B (onstream pond) storm-runoff suspended-sediment concentrations averaged 68 mg/L during the period from October 1, 1969, to October 31, 1972. During the clearing and grubbing phase, November 1, 1972, to May 31, 1973, the concentrations averaged 225 mg/L. During the early stages of earthmoving and culvert work, when the large pond was being constructed, June 1, 1973, to September 30, 1973, the concentrations averaged 820 mg/L. From the time the large pond was filled, November 1, 1973, to the end of September 1974, storm-runoff suspended-sediment concentrations just below the pond, averaged 120 mg/L. At the gaging station, concentrations averaged 308 mg/L; however, they were influenced by both sediment that passed through the large pond and by sediment that was transported down a small tributary that did not enter the large pond.

In the stream draining basin 3 (seeding and mulching and small rock dams), storm-runoff suspended-sediment concentrations averaged 50 mg/L from October 1, 1969, to December 31, 1972. During clearing and grubbing, as well as the early construction period, concentrations averaged 370 mg/L. In the last 12 months of construction, October 1, 1973, to September 30, 1974, the concentrations averaged 230 mg/L. For the entire construction period in basin 3, the concentrations averaged 280 mg/L.

TURBIDITY

Turbidity is often used as an indicator of the amount of suspended material in water. It reflects the size, shape, refractive index, and number of particles in suspension. Turbidity of the streamflow from basins 2, 2A, and 2B was measured continuously by means of surface-scatter turbidimeters installed in the gaging stations. In addition, the turbidity of all suspended-sediment samples collected after January 1, 1971, from each of the five streams, was measured in the laboratory using a nephelometric turbidity meter. For periods before January 1971, the turbidity of the streamflow was computed from a relation developed between suspended-sediment concentration and turbidity. When turbidity of the streamflow was less than 5 nephelometric turbidity units (NTU), the streamflow looked clear; when turbidity was 10 NTU, the streamflow looked slightly milky; when turbidity was 30 NTU, visibility in the water was about 5 in. (130 mm); and when turbidity was 100 NTU visibility was about 1 in. (25 mm). Streamflow generally looked similar at turbidity levels above 100 NTU, and differences could only be detected by measurements.

TURBIDITY LOAD

Turbidity load is computed by relating the turbidity of the streamflow to the quantity of flow. The water-weighted mean-daily turbidity is multiplied by the mean-daily streamflow, the product is then divided by an average-annual streamflow.

$$\text{Daily turbidity load} = \frac{\text{Mean-daily water-weighted turbidity} \times \text{Mean-daily streamflow}}{\text{Average annual streamflow}}$$

The cumulative sum of the monthly values was plotted against time (fig. 12), and the loads are summarized in table 7. Any large monthly increases in the cumulative turbidity load would indicate that increased turbidity could exist in a downstream reservoir.

One large and three minor increases occurred in the turbidity load discharged by the stream draining basin 1. The largest monthly increase occurred in June 1972 when runoff associated with Hurricane Agnes produced a turbidity load of 120 NTU. Storm events in April 1970, February 1971, and June 1973 produced turbidity loads of 18, 17, and 13 NTU, respectively. If the effects of the hurricane runoff in June 1972 are removed, the average-annual turbidity load is 34 NTU, or a load of 3 NTU per month for the 5-year period.

The cumulative turbidity load discharged by the stream draining basin 2 was 680 NTU for the 5-year period. The largest monthly turbidity load

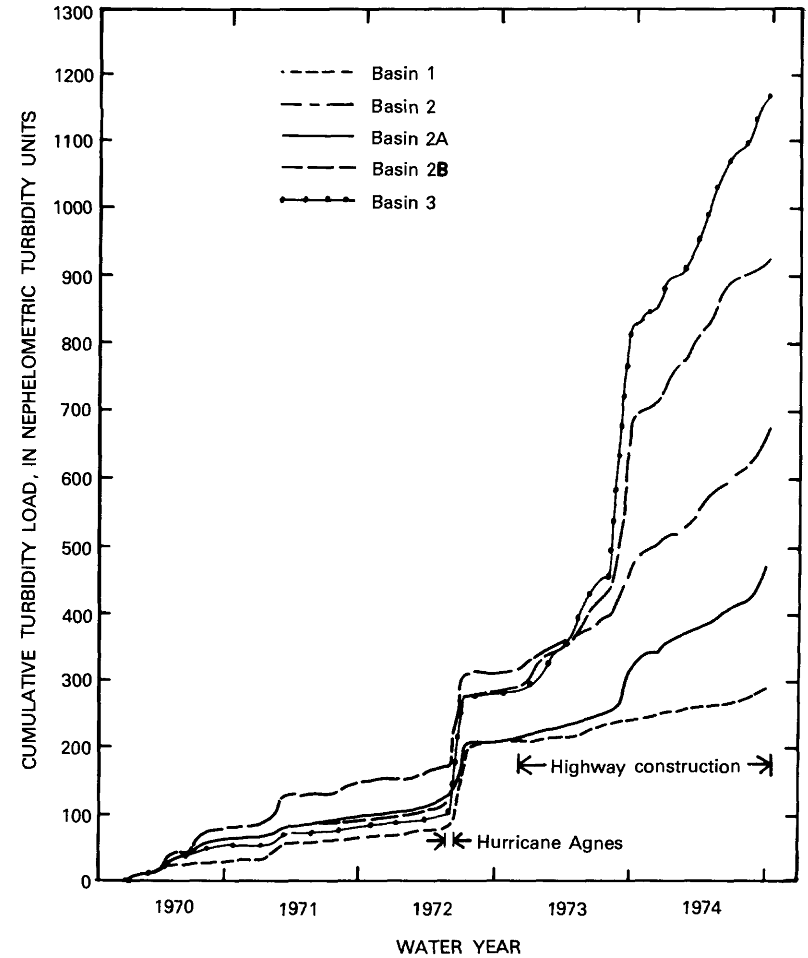

FIGURE 12.—Cumulative turbidity load, Conodoguinet Creek tributaries 1, 2, 2A, 2B, and 3, October 1, 1969, to September 30, 1974.

occurred in June 1972 when a load of 140 NTU was discharged. Significant turbidity loads were discharged from basin 2 three additional times before the start of construction of Interstate 81. They occurred during April and July 1970 and February 1971 and were 29, 23, and 40 NTU, respectively. The high values for July 1970 and February 1971 were partially the result of the construction of a 5-acre (2 ha) farm pond and a single lane roadway discussed in earlier reports (Reed, 1971, 1976). If the effects of the hurricane and the pond-roadway construction are removed, the turbidity load from basin 2 averaged 40 NTU per year, or 3 NTU per month during the period before construction of Interstate 81 began.

During the 23-month period (November 1, 1972, to September 30, 1974) of construction of Interstate 81 the turbidity load discharged by the stream draining basin 2 averaged 190 NTU per year, 16 NTU per month. The largest monthly increases occurred in September 1973 and September 1974 when a load of 40 NTU was discharged each month.

Turbidity loads in the stream draining basin 2A also show the effects of the hurricane in June 1972. During that month the turbidity load was 110 NTU. Significant turbidity loads were also discharged in April 1970 and February 1971 from basin 2A. The loads during these two months were 25 and 17 NTU, respectively. If the effects of the hurricane in June 1972 are removed, the average annual turbidity load from basin 2A was 38 NTU, or a load of 3 NTU per month.

During construction of Interstate 81, in basin 2A the turbidity load averaged 140 NTU per year, or a load of 12 NTU per month. The largest turbidity loads were discharged during September 1973 and September 1974 and were 47 and 43 NTU, respectively.

The turbidity load discharged by the stream draining basin 2B during June 1972 was 150 NTU. During April and July 1970 and February 1971 turbidity loads of 24, 11, and 18 NTU were discharged. If the turbidity load resulting from the hurricane in June 1972 is not included, the average annual turbidity load from basin 2B was 48 NTU, or 4 NTU per month, from October 1, 1969, to October 31, 1972.

During the period of highway construction in basin 2B (November 1, 1972, to September 30, 1974) the turbidity load discharged was 640 NTU. Nearly 30 percent of the 640 NTU total was discharged during August and September 1973 when 100 NTU was discharged in August and 110 NTU was discharged in September. During the final 11 months of construction, when the large sediment-control pond was operational, the turbidity-load discharge through the sediment-control pond was 120 NTU, and the load measured at the gaging station was 220 NTU. Most of the additional load was from the construction area that drained into the stream below the large pond.

The stream draining basin 3 discharged a turbidity load of 150 NTU during June 1972, most of it associated with the runoff from Hurricane Agnes. The next largest turbidity load transported from basin 3 prior to the start of construction was 25 NTU, and it occurred in April 1970. During July 1970 a load of 11 NTU was transported, and during February 1971 a load of 15 NTU was transported. Excluding the turbidity load transported from basin 3 during the runoff from the hurricane in June 1972, the load transported during the 3-year period before highway construction was 150 NTU. The average annual turbidity load was 50 NTU, or 4 NTU per month.

During the 21-month period when construction of Interstate 81 was in progress a turbidity load of 870 NTU was transported from basin 3. Nearly half of the load during construction was transported during August and September 1973, the result of two large storm events. The August load was 220 NTU and the September load was 150 NTU. The next largest loads were transported during March and April 1974 and were 50 and 60 NTU, respectively. If the August and September 1973 loads are eliminated, the average monthly turbidity load during the period of construction was 26 NTU.

The turbidity load discharged by the five streams for the 5-year period is summarized in table 7. The total load is broken down into the normal 5-year load, that which resulted from the hurricane in June 1972, and the load which resulted from construction of the roadway.

TABLE 7.—*Summary of turbidity load transported by Conodoguinet Creek tributaries 1, 2, 2A, 2B, and 3, October 1, 1969, to September 30, 1974*

Tributary	Turbidity Load, in nephelometric turbidity units (NTU)				
	5 normal years		Due to highway construction	Due to Hurricane Agnes	Total 5 years
	Total	Average annual			
1	170	34	0	120	290
2	200	40	290	140	[1]680
2A	190	38	180	110	480
2B	240	48	520	150	910
3	250	50	750	150	1,150

[1]Includes 50 NTU that resulted from development in the basin in 1970.

INCREASE IN SEDIMENT YIELD DURING CONSTRUCTION

How each of the different phases of construction affected the amount of sediment in the streams is described on the following pages. Two factors are considered: first, the sediment that gets into the streams from equipment operation and, second, the sediment that gets into the streams due to precipitation on the construction area. In order to determine which part of the construction contributed most to sediment in the streams, the construction activities were divided into seven phases. They are clearing and grubbing, culvert construction, bridge construction, early earthmoving, winter, final earthmoving and drainage operations, and automatic grading. The seven phases are discussed separately.

CLEARING AND GRUBBING

Generally, clearing and grubbing are limited to the area of the planned roadway that contains trees or low brush. Table 8 lists the dates when clearing and grubbing was begun in each of the four basins, as well as the area cleared. In basin 2 the clearing and grubbing operation was begun on November 10, 1972. A total area of 14.3 acres (5.8 ha) was cleared. From basin 2, the clearing and grubbing operation progressed to basin 2A and 2B. Basin 3 was the last area to be cleared and grubbed.

The sediment load that was discharged from each of the four basins during clearing and grubbing is summarized in table 9. The number of days significant sediment concentrations occurred in the streams because of clearing and grubbing operations are also shown as well as the stream lengths that were cleared. An average of about 15 percent of the total

TABLE 8.—*Summary of the clearing and grubbing operations in basins 2, 2A, 2B, and 3, November 10, 1972, to March 18, 1973*

Basin	Starting date	Area cleared	
		Percent of basin	Acres
2	11-10-72	3.0	14.3
2A	12-7-72	1.5	6.5
2B	12-11-72	9.8	40.7
3	1-12-73	10.4	25.2

sediment resulting from the clearing operation in each basin was a direct result of construction operations. Generally, this sediment was transported during periods when the streams would normally have been free of suspended sediment. The remaining 85 percent was produced by erosion of the disturbed areas during storms, periods when the streams are normally transporting some suspended sediment.

The average increase in sediment from basin 2 due to the clearing and grubbing was about 170 percent for the period from November 10, 1972, to March 18, 1973. The largest increase, about 450 percent, occurred February 8, 1973, immediately after the grubbing operation. Once the operations ended the increase in sediment yields quickly declined.

TABLE 9.—*Summary of the sediment load that was transported by Conodoguinet Creek tributaries 2, 2A, 2B, and 3, November 10, 1972, to March 18, 1973*

Basin	Sediment load (tons)				Days stream affected by construction operations	Stream length cleared (ft)
	Undisturbed area of basin	Construction area	Construction operations	Total		
2	29	44	6	79	14	2,450
2A	22	4	1	27	5	1,320
2B	24	56	8	88	27	7,100
3	14	28	4	46	14	2,490

CULVERT CONSTRUCTION

In basin 2 a box culvert was constructed to carry the main stream under the roadway. Work on the culvert started on March 18, 1973, and was concluded by the end of June 1973. Figure 13 is a photograph showing the culvert construction. The culvert was constructed in the original channel after the stream was temporarily diverted.

The culvert construction in basin 2 was the only culvert construction in any of the basins that did not take place simultaneously with major earthmoving operations. From March 18 to June 27, 1973, the sediment discharged from basin 2 came from three sources: (1) the undisturbed drainage area, (2) the area disturbed by the clearing operation, and (3) the area under construction for the culvert. Between March 18 and June 27,

FIGURE 13.—Culvert construction in basin 2, May 14, 1973.

1973, a total of 44 tons (40 t) of sediment were discharged by basin 2. During the same period 22 tons (20 t) of sediment were discharged by the adjacent basin 1 which was not disturbed by highway construction.

Sediment resulting from the clearing operation was probably contributing an increase of about 50 percent to the normal sediment load discharged from basin 2. About 75 percent of the 44-ton (40-t) load probably resulted from the natural sediment load and sediment from the clearing operation. Construction of the culvert which disturbed an area of about 3 acres (1.2 ha) contributed the remaining 11 tons (10 t) of sediment during the 3-month period. Sediment concentrations in the stream were affected a total of 6 days directly by the construction operations, including construction of the temporary channel; however, only 1.0 ton (0.9 t) of sediment was discharged during these six days. The remainder, 10 tons (9 t), was discharged as the result of runoff events.

Culverts are generally constructed at the location of the original stream channel after the flow has been bypassed. In some cases, it may be possible to locate the culvert adjacent to the original channel, instead of in it, so that it would not be necessary to temporarily bypass the streamflow. A small work area must also be established to unload supplies and park construction equipment. If this area was graded to drain into a holding pond, a reduction in sediment in the stream could be realized. The holding pond could also serve as a sediment-control basin that could be used when pumping sediment-laden water from the footers, or other low areas around the foundation.

BRIDGE CONSTRUCTION

A structure to carry Tower Road over Interstate 81 in basin 3 (fig. 14) was started in March 1973 and was completed in May 1973. In all, subsoil was exposed on about 3 acres (1.2 ha) by the construction. During the 10-week period when the bridge was being constructed, 52 tons (47 t) of sediment were discharged from basin 3; during the same period 20 tons (18 t) of sediment were discharged from basin 1. The sediment discharge resulting from bridge construction was estimated as 20 tons (18 t).

The bridge structure was located about 100 ft (30 m) from the stream, and the stream was only slightly disturbed during the construction. Therefore, most of the sediment that entered the stream from the bridge construction site was the direct result of storm runoff. Some sediment, about 0.3 ton (0.3 t), entered the stream as the result of pumping water from footers. Sediment yields from such bridge construction areas could be reduced if small ponds could be located to intercept the runoff from the immediate area and to collect water pumpted from the footers.

FIGURE 14.—Construction work in progress for Tower Road crossing in basin 3, March 31, 1973.

EARLY EARTHMOVING

Early earthwork began in basin 2 about August 7, 1973, the topsoil was removed from the east end of the basin and was stockpiled just off the right-of-way. The area of exposed subsoil in basin 2 was about 10 acres (4 ha) on August 27. From September 17 to September 28 the topsoil was removed from the west end of the basin, and the area of exposed subsoil was increased to about 20 acres (8 ha). On October 22 material was excavated from the east end of the basin and was placed in the area of the box culvert. With this earthmoving the area of exposed subsoil expanded to 25 acres (10 ha).

From November 23 to December 13, 1973, the crossing for Wertzville Road (fig. 15) was excavated, and some of the material was placed as fill toward the east center of the basin. The area of exposed subsoil reached 30 acres (12 ha). Figure 15 shows the area when the cut was made at the Wertzville Road crossing; and figure 16 shows the stream crossing where part of the material was placed as fill.

Nineteen storms occurred during the period of early earthmoving in basin 2. For the storms rainfall ranged from 0.25 in. (6 mm) to 4.90 in. (120 mm). Total sediment discharge during the period from basin 1 was 24 tons (22 t), and from basin 2 it was 168 tons (152 t). Based on the preconstruction sediment discharge relations, the overall increase in sediment discharge from basin 2 for the period was 530 percent. However, the increase in sediment yield varied considerably from storm to storm.

FIGURE 15.—Cut area at Wertzville Road crossing in basin 2, May 17, 1974.

FIGURE 16.—Area where fill was placed in basin 2, May 17, 1974.

The largest increase in sediment discharge occurred during a storm on October 29, 1973. About 1.85 in. (47 mm) of precipitation fell in each basin, and 0.8 ton (0.7 t) of sediment was discharged from basin 1, while 23 tons (21 t) were discharged from basin 2. At the time of this storm 25 acres (10 ha) of subsoil were exposed in basin 2.

In basin 3 work on the Tower Road structure was started in March 1973. By the end of May, 3 acres (1.2 ha) of subsoil were exposed. Earthmoving began on June 11 when topsoil was removed from an area west of the Tower Road structure. The west area was then excavated, and the material was used for an embankment for the Tower Road crossing. The area of exposed subsoil in basin 3 was expanded from 3 acres (1.2 ha) on May 30 to 12 acres (4.8 ha) on July 2. Construction work on the culverts just east of the Tower Road crossing was started about July 1 and was completed about July 30. During August and September, earthmoving operations were active, and by September 20 (fig. 17) most of the cuts and fills west of Tower Road had been completed. On October 15 part of the area west of Tower Road was seeded and mulched. From October 25 through December 7 fill was placed east of Tower Road. The area of exposed subsoil reached a maximum in basin 3 about October 30 when 36 acres (15 ha) were exposed. By December 14 the exposed area had been reduced to 22 acres (8.9 ha).

During the 7-month period of early earthmoving in basin 3, June 11 to December 15, 1973, sediment discharge from basin 3 totalled 310 tons (281

FIGURE 17.—Most of the construction area in basin 3, September 20, 1973.

t), an increase of about 700 percent over what would have normally been expected. The maximum increase in sediment yield from basin 3 during this period was 3,000 percent. The increase in sediment yield during storm events generally varied from 500 to 2,000 percent.

WINTER CONSTRUCTION DELAY

The first significant snow fell on December 16 and 17, 1973. The snow was followed by about 2 in. (50 mm) of rain on December 20 and 21, and earthmoving work that had stopped December 13 did not resume until about April 14, 1974. Storm runoff suspended-sediment yields from basin 2 averaged about 140 percent above normal, and those from basin 3 averaged about 230 percent above normal during the 4-month winter period when construction was inactive.

FINAL EARTHMOVING AND DRAINAGE OPERATIONS

Final earthmoving covers the time between April 14, 1974, when construction resumed, and June 30, 1974, when earthmoving was completed. About the last foot (0.3 m) of material placed on the fills was composed of soil free of stones that could be shaped by automatic grading equipment. This type of material was also placed in excavation areas so they could be shaped and graded to close tolerances. During the final earthmoving operation the last of the drainage structures were also completed. Parallel and cross drains were placed, and the drop inlet structures were completed.

Twelve runoff events occurred in basins 2 and 3 from April 14 to June 30, when final earthmoving and drainage operations were underway. The average increase in sediment transport from basin 2 during the 2 1/2-month period was 780 percent, a figure comparable to the increased values observed during early earthmoving in the fall of 1973. The average increase from basin 3 for the 2 1/2-month period was about 800 percent.

AUTOMATIC GRADING

During the final earthmoving and drainage operations fine material was placed on the cut-and-fill sections so that the area could be graded close to desired elevations. After the area was close to the desired elevations a precision automatic grader was used to prepare the surface for placement of subbase material.

In basin 2 most of the cuts and fills were at the desired elevation for the automatic grading operation by June 30, 1974; however, the automatic grading operation was not started until August 15, 1974. Automatic grading continued in basin 2 on an intermittent basis through September 30, 1974. The paving subbase was not placed until October 1974, and that period of several weeks is not covered in this report. Increases in the suspended-sediment load discharged by the stream draining basin 2 ranged from about 2,000 to 8,000 percent during the July to September period over what it would have been if highway construction had not occurred. The average increase during the period was about 4,000 percent, significantly higher than the increases during any of the other phases of construction. During the 3-month period, July, August, and September 1974, the measured sediment discharge from basin 2 was 114 tons (103 t) while the measured discharge from basin 1 was 1.4 tons (1.3 t).

Automatic grading started in basin 3 about July 15 and progressed eastward in the northbound line. The southbound line in basin 3 was graded August 8. The first subbase was placed about July 31 in the northbound line of basin 3. Subbase was placed in the southbound line of basin 3 about August 19.

During the 3-month period, July, August, and September 1974, sediment discharge from basin 3 was 58 tons (53 t); the measured sediment discharge from basin 1 was 1.4 tons (1.3 t).

The fine-grading phase of construction produced the greatest increases in sediment of the different phases of construction. Part of the reason for the large increases is because the construction surface is a flat, impermeable, compacted subsoil. Large quantities of fine material pulverized by construction operations are suspended by the energy of rainfall and as there are few depressions much of the material makes its way to the streams. A second reason for the relatively large increases is the time of year. During the summer small precipitation events on undisturbed drainage basins do not produce significant increases in streamflow because much of the precipitation is trapped by vegetation. As a result, only small amounts of water are available to dilute and transport the sediment from the construction area.

SUMMARY OF CONSTRUCTION PHASES

Only data from basins 2 and 3 were used in the analysis of sediment yield because the extensive sediment-control measures installed in basins 2A and 2B affected sediment yields after their installation. Moderate increases in sediment discharge, about twofold, were observed in the clearing and grubbing phase and during periods when construction was relatively inactive in the winter and early spring. During the phases that involved active earthmoving, sediment discharge increased about sevenfold. The greatest increases were observed in the period when the area was being fine graded and was being prepared for paving; these increases were about fortyfold. Table 10 lists the phases of construction and the relative increases in sediment discharge observed during each.

TABLE 10.—*Average percent increase in sediment load transported from basins 2 and 3 during various phases of construction, November 10, 1972, to September 30, 1974*

Basin	Clearing and grubbing	Culvert construction	Bridge construction	Early earthmoving	Winter	Final earthmoving and drainage	Automatic grading
2	170	50	....	530	140	780	4,000
3	220	....	100	700	230	800	4,000

PARTICLE-SIZE STUDY

Particle-size data collected at the gaging stations indicated that most of the sediment from the construction area was composed of silt and clay. In order to determine whether large amounts of sediment were being eroded from the construction area and were not being transported by the stream system, many samples of the topsoil and subsoil used on the construction area and many samples of runoff from the construction area were analyzed for particle size distribution.

Samples of the topsoil collected in the area had an average particle-size distribution of about 42 percent sand, 42 percent silt, 6 percent course clay (particles with diameters between 0.004 and 0.002 mm), and 10 percent fine clay (particles with diameters smaller than 0.002 mm). Subsoil exposed on the construction area contained about 39 percent sand, 35 percent silt, 6 percent coarse clay, and 20 percent fine clay.

Storm-water runoff from the construction area was sampled 25 times, and the suspended sediment was analyzed for particle-size distribution. Figure 18 shows a sample of runoff water collected in basin 3 on March 21, 1974. The sediment in the samples had an average particle-size distribution of 3 percent sand, 27 percent silt, 13 percent coarse clay, and 57 percent fine clay. Those values are shown by the bar graph in figure 19. The figure also shows the particle-size distribution of the topsoil, the subsoil, and the sediment in the flow at the gaging stations, which was 1 percent sand, 29 percent silt, 13 percent coarse clay, and 57 percent fine clay. From figure 19 it can be seen that there is only a slight relation between the size distribution of the soil on the construction site and the size distribution of the material transported from the area as sediment.

FIGURE 18.—Samples of sediment-laden runoff water collected from the construction area in basin 3, March 21, 1974.

Much of the material on a construction area that becomes suspended probably is redeposited in a relatively short time. If the soil material on a construction area is uniformly distributed before a storm, the size distribution of the material initially placed in suspension is probably close to the size distribution of the soil on the construction surface. However, as the suspended sediment makes its way across the construction area, in sheet flow, the sands and many of the silt particles have more than ample opportunity to settle out because of their rapid settling velocities and because of the short distance they have to settle. As a result, the material that

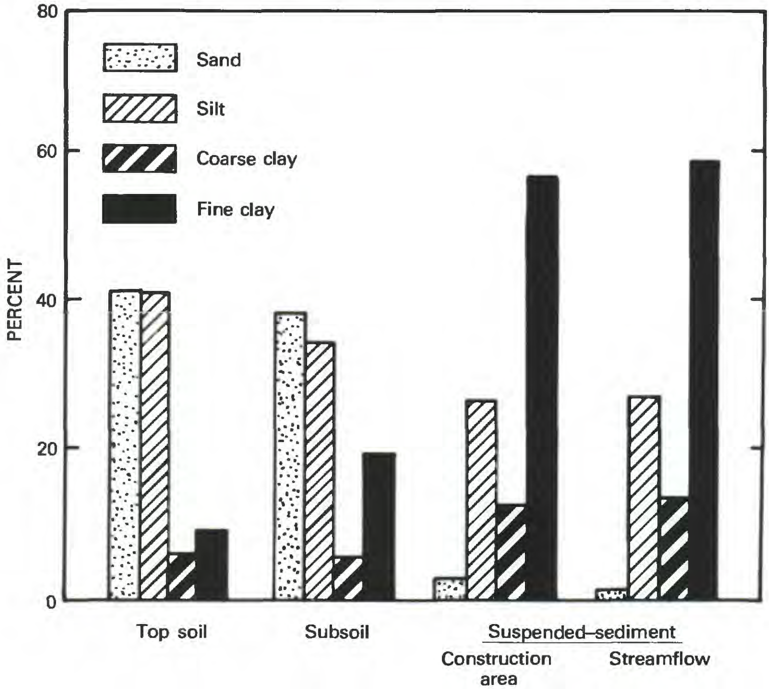

FIGURE 19.—Particle-size distribution of the soil and suspended sediment in samples collected on the construction site and from the streamflow, Conodoguinet Creek tributaries 2, 2A, 2B and 3, December 6, 1972, to September 3, 1974.

reaches deep-flowing water at the edge of the construction area (fig. 20) is composed of a higher percentage of fine particles than actually exists on the construction area.

Once the water from the construction flat reaches the side of fill slopes it has a capacity to erode large rills or gullies in the fills. The size distribution of the material eroded from the fill slope will be the same as the soil in the fill. The largest of the eroded particles will be deposited near the bottom of the slope, while much of the silt-and clay-sized material may move into the stream.

Areas where fills are placed are essentially impermeable because of constant compaction. As a result, most of the precipitation runs off, and only small amounts are trapped as surface storage. Because the area is being actively worked, a fresh supply of soil material is generally available for suspension at the beginning of each storm. A soil layer with a thickness of 0.04 in. (1.0 mm) on an area of 1.0 acre (0.4 ha) amounts to more than an ample supply for most of the storms that occurred during this study. When the soil in a construction area is partially composed of fine-grained clays, most of the sediment that is transported from the construction area is probably clay.

FIGURE 20.—Channel flow from basin 2A, May 12, 1974.

EFFECTIVENESS OF THE EROSION AND SEDIMENT-CONTROL MEASURES

Three methods were considered to control the quantity of sediment transported by streams from the active construction areas. One of the control systems included seeding, mulching, and jute matting to reduce the exposed area. A second was the use of check devices, such as small dams made of rock or straw bales, to trap sediment. The third system included detention ponds constructed to trap the runoff water and sediment from the construction area. The detention ponds were of two types: one was an onstream pond, constructed directly on the stream below the construction area, designed to trap the sediment and streamflow from the entire watershed; the second type was a smaller, offstream pond designed to intercept the runoff water and sediment from the construction area before it reached the stream.

In addition to the samples of streamflow collected at the gaging stations, many samples of the runoff water from the construction site were collected during storms. These samples were analyzed for turbidity, suspended-sediment concentrations, and particle-size distribution. Samples of runoff water were also collected above and below several of the sediment control devices to measure the differences in suspended-sediment concentration. Samples of the soils used in the construction were also collected to determine the particle-size distribution.

In this section the efficiency of the sediment control measures are discussed. The efficiency is discussed in terms of the particle-size distribution of the soil used in the construction, the concentration of sediment in the runoff water, and the particle-size distribution of the sediment in the runoff water. The efficiency of devices for which data are not available is also discussed.

OFFSTREAM PONDS

Three offstream ponds were constructed in basin 2A. Each pond was designed to trap about 0.50 in. (13 mm) of runoff from the contributing construction area. Generally a 1.00 in. (25.4 mm) storm would produce 0.5 in. (13 mm) of runoff. Figure 21 is a sketch map of basin 2A showing the main features. A separate culvert system was used in connection with each of the offstream ponds. Each culvert system collected drainage from the construc-

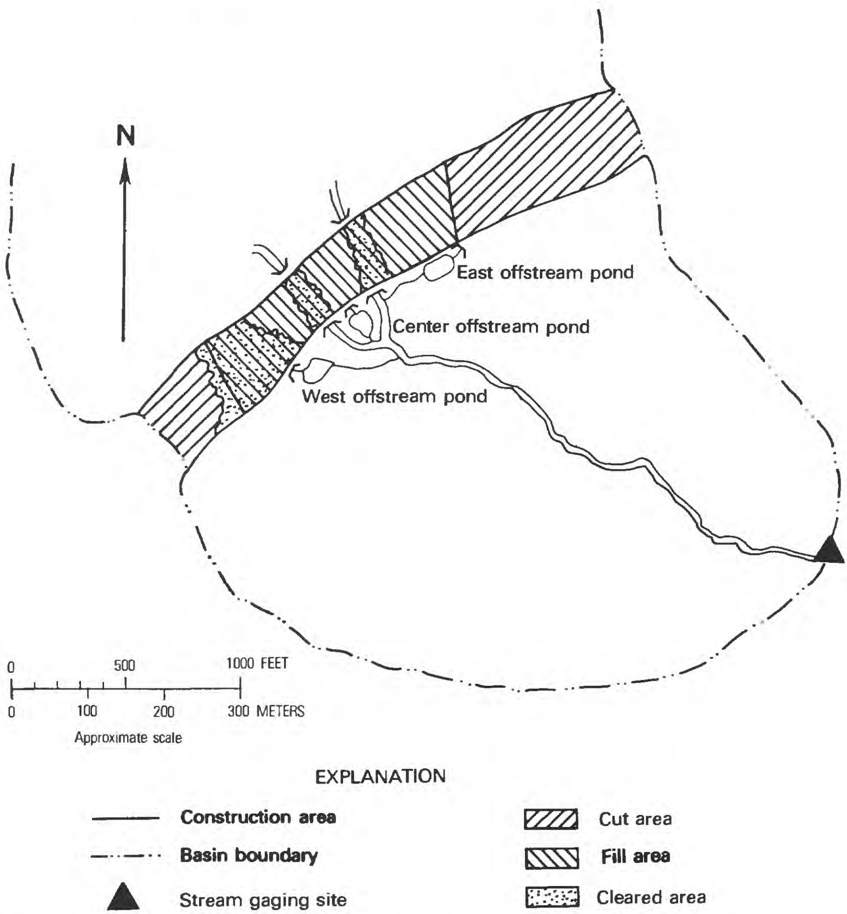

FIGURE 21.—Location of the construction area, the offstream sediment-control ponds, and the stream-gaging site in basin 2A.

tion area and discharged it directly to the sediment ponds. An additional system was used to carry the normal streamflow from the upstream drainage area through the construction site. Construction of the ponds began in June 1973 and was completed in October 1973.

The three offstream ponds, constructed in basin 2A, can be seen in figure 22. The west pond received runoff from 4 acres (1.6 ha) of the construction area and a 6 acre (2.4 ha) field. Runoff from an area of about 5 acres (2.0 ha) drained into the center pond. The east pond received drainage from an area of about 8 acres (3.2 ha). Inflow to the center and east ponds was entirely from the construction area. Figure 23 shows the center and east offstream ponds as viewed from the west side of the construction area.

Because the west pond was located in a low area, it was operational from the time it was completed in October 1973. The center and east ponds were located to receive drainage from culvert outlets (figs. 21, 23), and they were not fully operational until 1974 when the culvert systems were completed. Diversion ditches directed runoff water into the center and east ponds from the time they were constructed until the drainage structures were completed.

The offstream ponds intercepted the sediment-laden runoff from the construction area. Water remaining in the pond since the last storm would, in theory, be displaced by the incoming sediment-laden water. If the water displaced from the pond was sediment free, the pond would have a trap efficiency of 100 percent. As sediment-laden water continued to be discharged into the ponds from the construction area an efficiency of less

FIGURE 22.—The west, center, and east offstream ponds in basin 2A, July 11, 1974.

FIGURE 23.—The center and east offstream ponds as viewed from the west side of the construction area, basin 2A, July 11, 1974.

than 100 percent would occur. The efficiency for each storm was determined by the amount of mixing, by the detention time of the runoff water in the pond, by the amount of runoff water, and by particle settling velocities. Detention time varied from storm to storm depending on the amount of runoff and the period between storms.

During storms the first runoff from the construction area normally carried the highest sediment concentrations. As the storm continued, the runoff water usually carried lower concentrations of suspended sediment. Late in a storm, the pond could contain water with high sediment concentrations that had been intercepted earlier. This water could then be displaced by runoff with lower sediment concentrations. During a storm event, the instantaneous trap efficiency of the offstream ponds could change significantly and could be either positive or negative.

Figures 24 and 25 show the center pond during a storm that occurred May 12, 1974. Figure 24, taken at the start of the storm, shows sediment-laden water being discharged into the pond. The inflow is displacing relatively sediment-free water already in the pond, the discharge point is at the far end of the pond, right of center. At this time the trap efficiency of the pond is about 100 percent. Figure 25 shows the pond near the end of the storm. The culvert is discharging a substantial amount of sediment-laden runoff that is displacing sediment-laden water through the outlet. At this time the trap efficiency of the pond is near zero.

FIGURE 24.—Clear water in the center offstream pond in basin 2A being displaced by sediment-laden inflow at the start of the storm on May 12, 1974. Note the distinct difference in color of water in this figure and that in figure 25. A nylon blanket filled with concrete protects the culvert-outlet channel.

FIGURE 25.—Sediment-laden water in the center offstream pond in basin 2A being displaced by sediment-laden inflow near the end of the storm on May 12, 1974.

Figure 26 is a graph showing the suspended-sediment concentration of the water in the east pond versus the number of days since the last storm that affected the pond. The graph is for the period from September 19 to October 18, 1973. In this particular case, the sediment concentration just after the storm was 1,800 mg/L and 10 days after the storm it was 800 mg/L. Because storms seem to run in cycles—several during one 2-week period, then none for 2 weeks or so—it may be desirable to increase the efficiency of offstream ponds, possibly by adding a coagulant to increase the settling velocity of the suspended matter.

The effectiveness of the offstream ponds was computed on the basis of their trap efficiency and the ability to reduce turbidity. The ponds were operational for 39 precipitation events which ranged from 0.05 to 2.35 in. (1 to 60 mm) of water. In figures 27 and 28, the percent reduction in sediment load and mean turbidity is based on what the sediment load and mean turbidity would have been in the stream if the sediment-control ponds had not been installed. The reductions were calculated on the basis of the sediment load and turbidity measured from basin 3, where no offstream ponds were used.

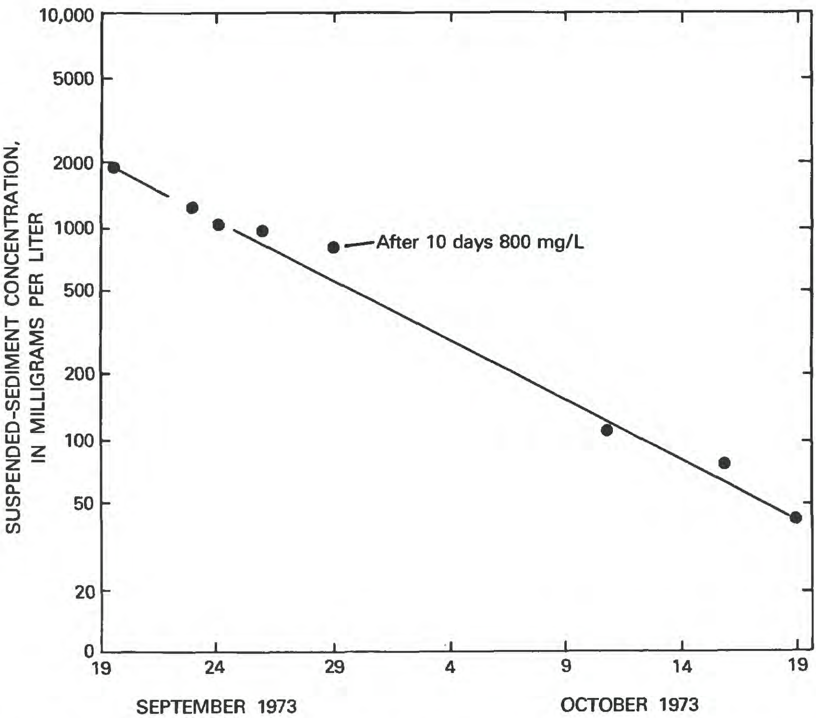

FIGURE 26.—Suspended-sediment concentration of water stored in the east offstream pond, basin 2A, September 19 to October 18, 1973.

Figure 27 shows the percent the offstream ponds in basin 2A reduced the sediment load versus the amount of precipitation for 32 storms. Data for seven storms that only produced small runoff events while the ponds were operational are not included. For storms that produced 1.25 in. (32 mm) of precipitation or less, the median reduction in the sediment load was about 70 percent, and for storms that produced over 1.25 in. (32 mm) of precipitation, the median reduction was about 15 percent. The efficiency of the ponds decreases as storm size increases because detention time is decreased by the increased runoff. The median reduction for all storms shown in figure 27 was about 60 percent.

Mean turbidity of streamflow was calculated over a 5-day period including the day of the storm and the following four days. Figure 28 shows the percent increase or decrease in the mean 5-day turbidity of the stream draining basin 2A. From figure 28 it can be seen that the median decrease in mean turbidity was about 60 percent.

Although the offstream ponds were relatively effective, the effectiveness could be increased in several ways. The water in the ponds could be treated

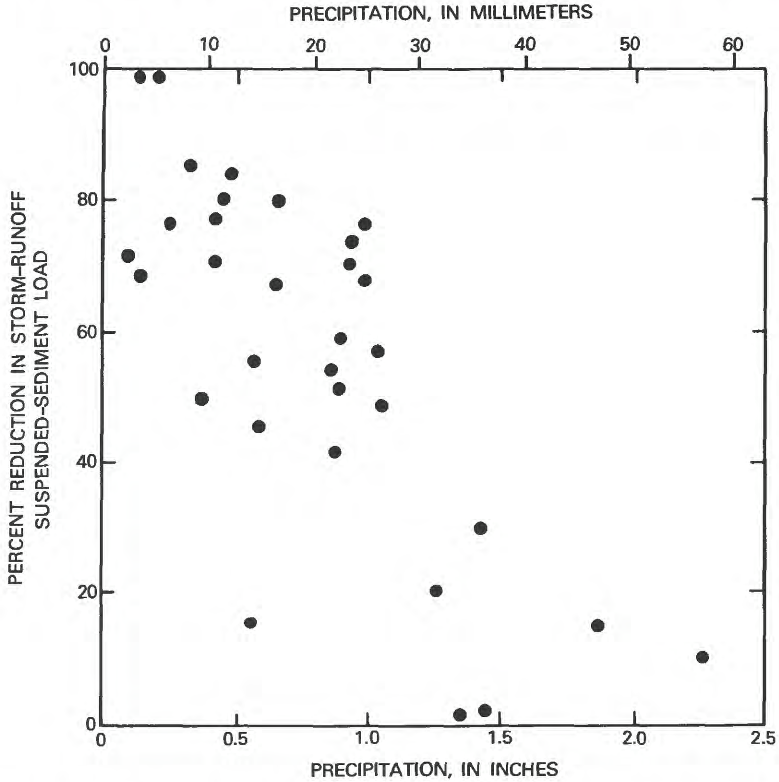

FIGURE 27.—Reduction in the storm-runoff suspended-sediment load from basin 2A due to the offstream ponds, October 2, 1973, to August 3, 1974.

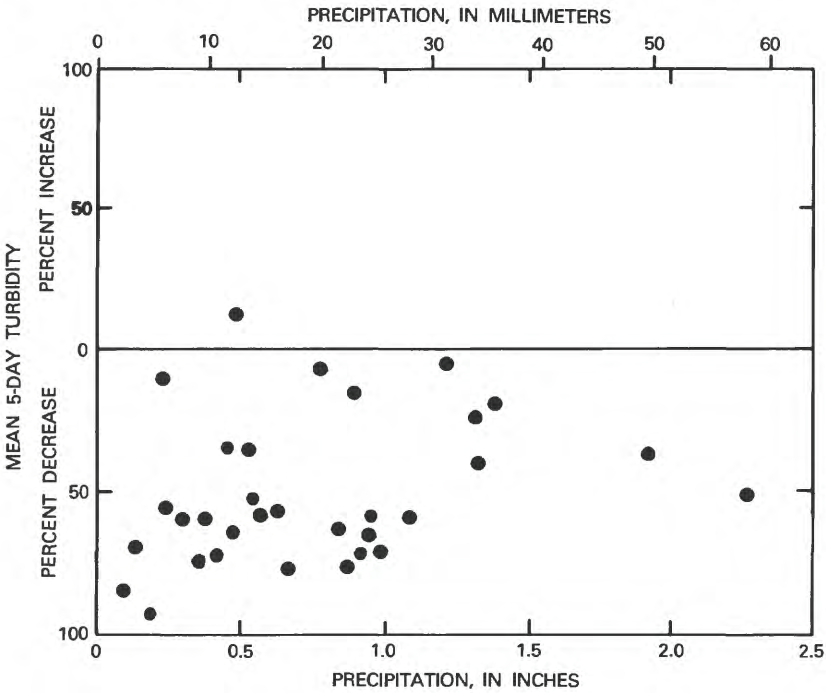

FIGURE 28.—Percent the offstream ponds increased or decreased the mean 5-day turbidity of the streamflow during and after periods of precipitation, Conodoguinet Creek tributary 2A, October 2, 1973, to August 3, 1974.

with a coagulating agent so that the fine-sediment particles would settle rapidly. The ponds should be located so that they would intercept runoff from as much of the construction area as possible (Swerdon and Kountz, 1973). Greater effectiveness would also be realized if the ponds could be installed at the time of clearing and grubbing and could be maintained until the construction area stabilized. The capacity of the pond could also be increased.

ONSTREAM PONDS

The onstream pond in basin 2B collected runoff from about 41 acres (17 ha) disturbed by construction and from about 300 acres (121 ha) of undisturbed watershed. Figure 29 is a sketch of basin 2B showing the main features including the sediment-control pond. Construction work on the dam began with the clearing operation since the dam was to be located in a forested area. The embankment for the dam was completed in August 1973. During September 1973, the pond drained through a 12 in. (305 mm) pipe located 2 ft (0.6 m) above the bottom. The normal water depth during

September was 2 ft (0.6 m) instead of the planned 12 ft (3.7 m) because a drain value had not been installed. When the onstream pond filled in October 1973, it had a permanent storage capacity of 8 acre-ft (10,000 m^3) or 1.5 in. (38 mm) of storm runoff. Figure 30 shows the pond filled to capacity in April 1974.

During September, when the normal water depth was 2 ft (0.6 m), two storms occurred. The first storm on September 14, 1973, produced 4.8 in. (122 mm) of precipitation. Even though the onstream pond completely filled with water and did not empty until 24 hours after the storm a sediment discharge of 136 tons (123 t) was measured. On the basis of the sediment

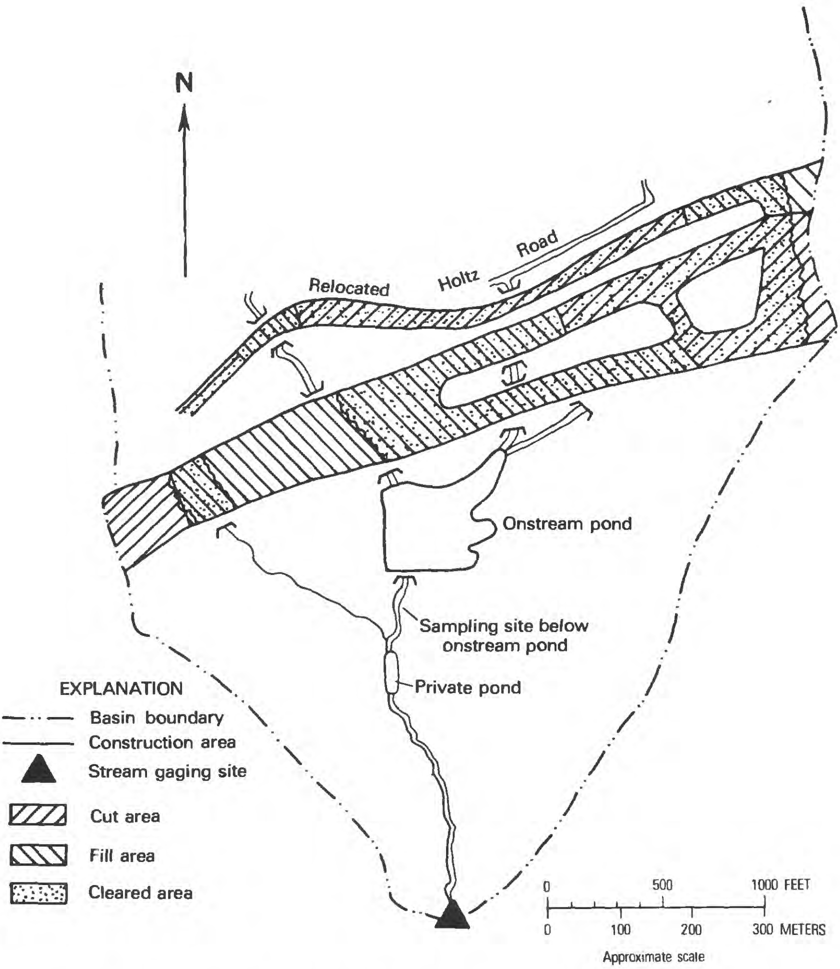

FIGURE 29.— Location of the construction area, the onstream sediment-control pond, and the stream-gaging site in basin 2B.

FIGURE 30.—Onstream pond in basin 2B, April 17, 1974.

discharged from basin 3, where highway construction was in the same stage, the trap efficiency of the onstream pond for the September 14 storm was about 10 percent.

The second storm occurred on September 18 when a total of 0.80 in. (20 mm) of precipitation fell. On the basis of the sediment discharge from basin 3, the onstream pond trapped about 4 tons (3.6 t) of sediment, about 25 percent of the load.

The mean turbidity over September 14 and 15 for basin 2B was 1,340 NTU while the mean turbidity for basin 3 for the same period was 600 NTU. The mean turbidity of the streamflow from basin 2B for September 18 and 19 was 520 NTU while the mean turbidity from basin 3 was 160 NTU. The onstream pond in basin 2B prolonged the period that the streamflow below the pond was turbid.

The onstream pond received continuous inflow from the upstream area that displaced water in the pond. As a result, the pond had a continuous discharge. When a storm occurred, sediment-laden inflow mixed with water in the pond. Discharge from the pond was relatively sediment free at the beginning of the storm event; however, the sediment concentrations increased as sediment-laden inflow mixed with water in the pond. When the storm was over, water in the pond had a relatively high suspended-sediment concentration and a turbidity that persisted for an extended period. As a result, water in the stream below the pond also had a high suspended-sediment concentration and a high turbidity for an extended period.

The effectiveness of the onstream pond was determined by sampling the outflow just downstream from the pond to determine suspended-sediment concentrations and turbidity and by using the streamflow hydrographs from the gage on tributary 2B to calculate water discharge. The sediment discharge through the onstream pond and the mean turbidity of the flow were then compared to that measured from basin 3.

Figure 31 shows the percent the sediment load was reduced by the onstream pond for the period from October 2, 1973, to August 3, 1974, the same period used for the evaluation of the offstream ponds. The median reduction was about 85 percent for storms that produced 1.25 in. (32 mm) of precipitation or less, and about 60 percent for storms that produced over 1.25 in. (32 mm) of precipitation. The median reduction for all storms was about 80 percent. The reason the onstream pond was slightly more efficient than the offstream ponds in reducing the sediment load was because it had a storage capacity of 8 acre-ft (10,000 m³), about equivalent to the runoff produced by a 2 in. (51 mm) rainfall. The offstream ponds had a storage capacity about equivalent to the runoff produced by a 1 in. (25 mm) rainfall.

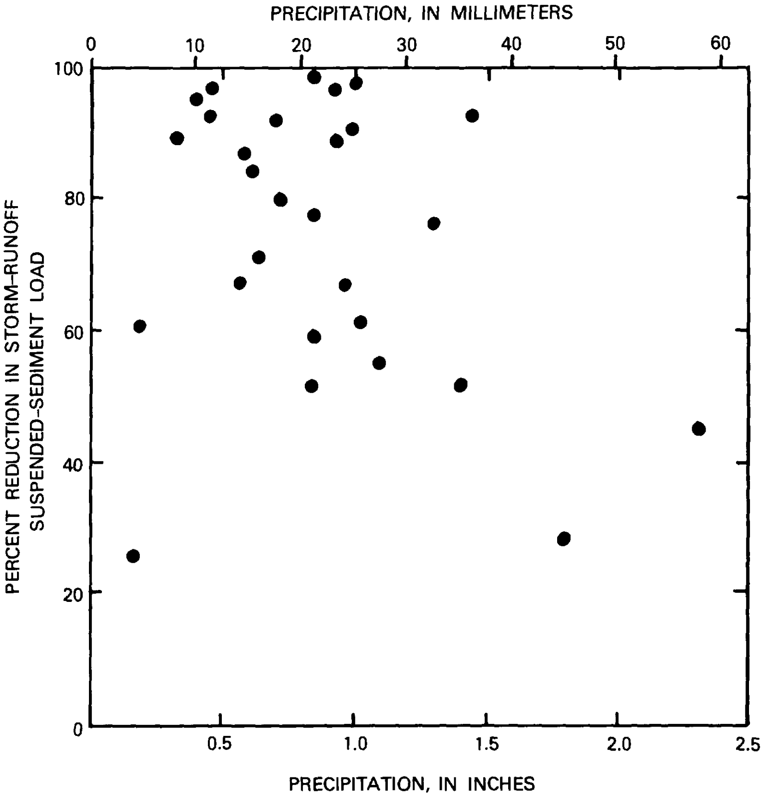

FIGURE 31.—Reduction in the storm-runoff suspended-sediment load caused by the onstream pond in basin 2B, October 29, 1973, to August 3, 1974.

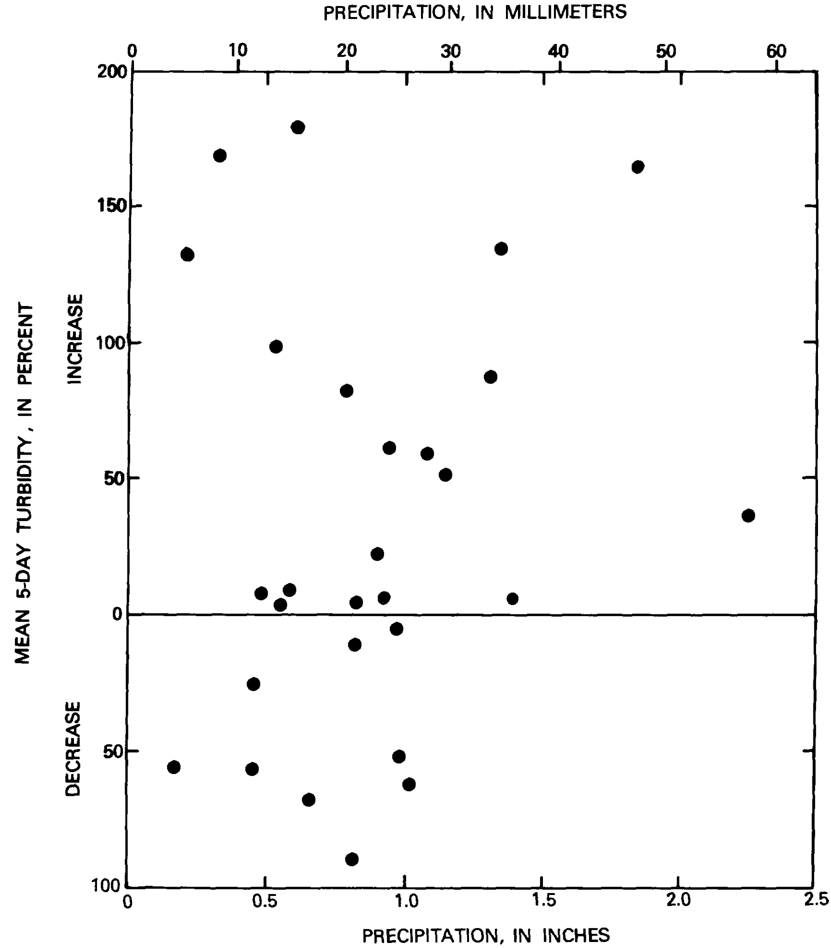

FIGURE 32.—Percent the onstream pond increased or decreased the mean 5-day turbidity of the streamflow during and after periods of precipiation, Conodoguinet Creek, tributary 2B, October 29, 1973, to August 3, 1974.

Figure 32 shows the percent change in mean turbidity of the streamflow below the onstream pond over a 5-day period beginning the day of the storm. The percent increase or decrease is based on what the turbidity of the streamflow would have been without the onstream pond. For about one-half the storm events, the mean turbidity of the stream below the onstream pond was increased more than 50 percent above the levels that would have occurred. The increase in turbidity was 100 percent or more for six events, while the median increase was about 25 percent for all events.

On May 12, 1974, a storm produced 1.45 in. (37 mm) of precipitation. Figure 33 shows the turbidity observed below the onstream pond in basin 2B

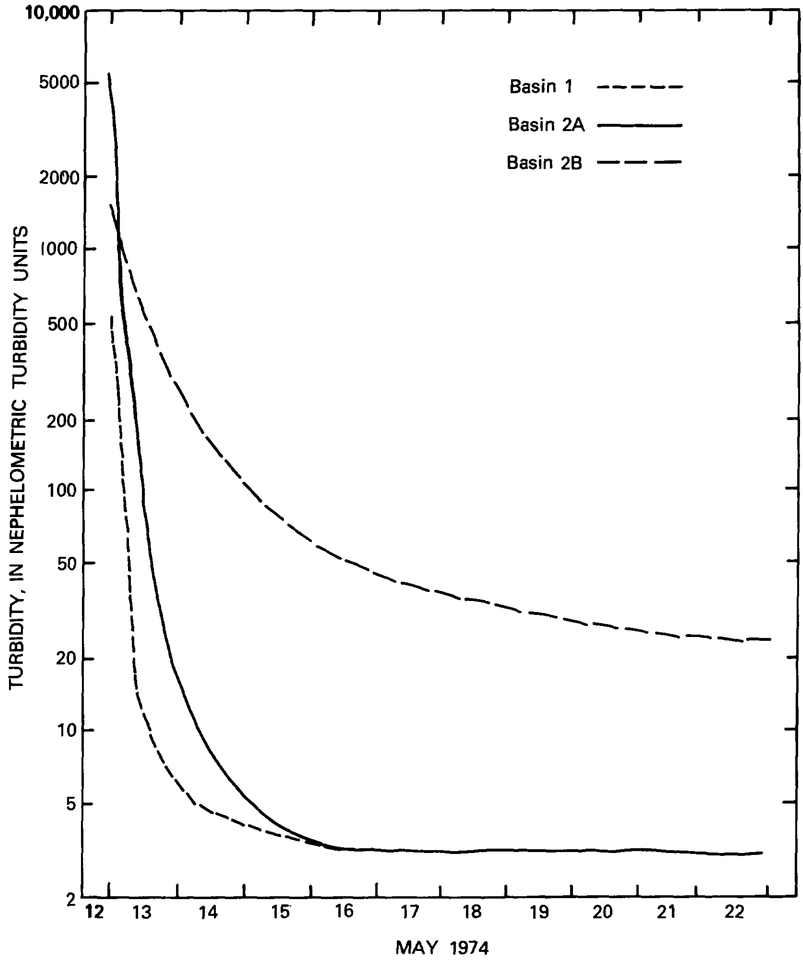

FIGURE 33.—Turbidity of the streamflow, Conodoguinet Creek tributaries 1, 2A, and 2B, May 12, 1974, to May 22, 1974.

and the turbidity below the three offstream ponds in basin 2A during the period from May 12 to May 22. Within 48 hours of the storm, the turbidity in the stream below the offstream ponds (basin 2A) had declined to 5 NTU or less, while the turbidity below the onstream pond was still about 100 NTU. After 10 days the turbidity below the onstream pond was still over 20 NTU. The turbidity of the stream draining the control (basin 1) is also shown in figure 33 for the same period.

The effectiveness of the onstream pond could probably be increased if some coagulating agent could be added to increase the settling velocity of the suspended sediment. However, the volume that would require treatment is substantial when compared to the volume of the offstream ponds. The effectiveness could also be increased if the clear streamflow could be routed around the pond so it did not displace turbid water. Construction of both types of ponds may require the purchase of additional area, or temporary easements, and may require temporary safety fencing.

ROCK DAMS

Samples were collected above and below several rock dams which were located in drainage channels to act as sediment traps. During periods of storm runoff, a sample of the flow was collected before it entered the pool formed by the rock dam. A few moments later, a sample of the outflow was collected. The turbidity of those samples is shown in figure 34. The median reduction in turbidity for the samples shown in the figure is about 5 percent. On the basis of the sediment yield from the construction area and the amount of material trapped behind the rock dam, a trap efficiency of 5 percent was calculated. W. Weber (written commun., 1975) reported that rock dams in other areas of the State also had a trap efficiency of about 5 percent.

SEEDING AND MULCHING

During construction, seeding and mulching were limited to the completed cut-and-fill slopes. The width protected, on the 300 ft (90 m) wide right-of-way, was about 100 ft (30 m), 50 ft (15 m) on each side. The median, which was about 80 ft (24 m) wide, was not seeded until the drainage structures and topsoil were in place. Parts of the sideslopes were reseeded after drains had been placed in the swale at the bottom of the cut slopes.

The net effect of seeding and mulching is to reduce the area disturbed by construction, and the effectiveness is proportional to the average area protected during the construction period. If a construction section contained 30 acres (12 ha), the maximum area protected during construction would be about 10 acres (4 ha). During construction the time-weighted average area protected by seeding and mulching would be about 6 acres. The maximum result would be a reduction in sediment of about 20 percent. Unlike the ponding devices, the reduction would be the same regardless of the size of a storm. The effectiveness of seeding and mulching could be increased if additional areas could be seeded on a temporary basis. These additional areas may include the medians, interchange areas, and side slopes.

After the median is seeded and mulched and the roadway areas are protected by subbase and paving, sediment loads are substantially reduced. Of the total construction area of 30 acres (12 ha), 20 acres (8 ha) are seeded and mulched, and the remaining 10 acres (4 ha) are protected by paving.

Generally, seeding and mulching should be completed so that a good stand of grass is established by the time the pavement is placed. In addition to the effectiveness of seeding and mulching in reducing sediment, green vegetation on a construction site has a more pleasing appearance.

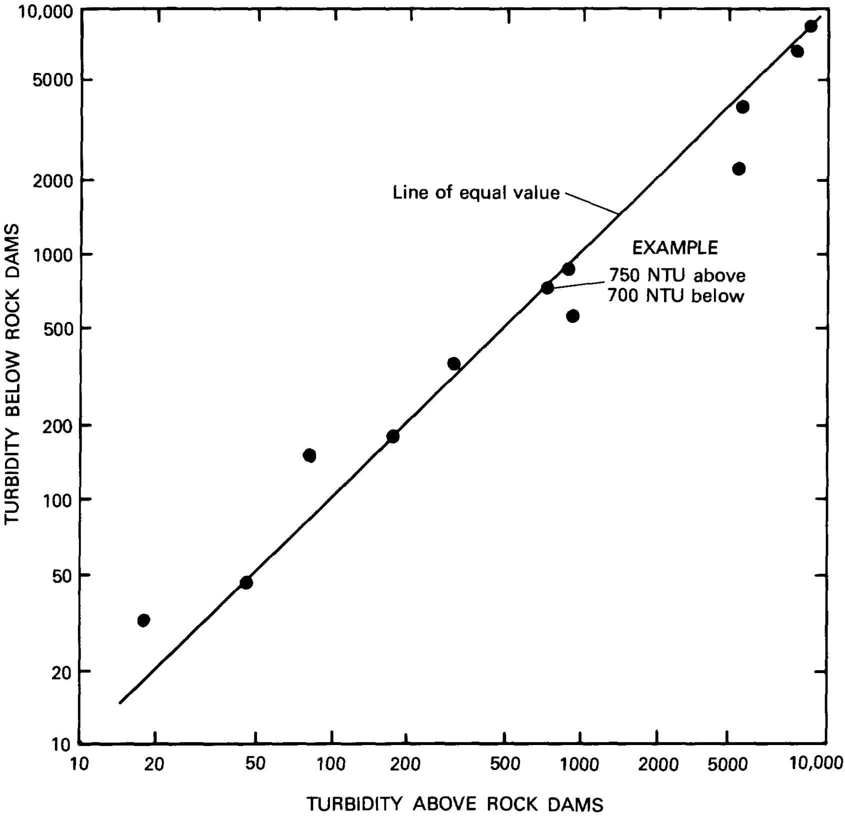

FIGURE 34.—Turbidity of samples of runoff water from the construction area collected above and below small rock dams, Conodoguinet Creek tributaries 2B and 3, September and October 1973.

STRAW BALES

Bales may be used around small drop inlets, as dams or barriers and as erosion checks. Bales decrease sediment loads principally by forming impoundments, allowing some of the sediment to settle out. Bales forming a barrier at a drop inlet could, under ideal conditions, form a pool of impounded water 1 ft (0.3 m) deep, containing about 100 ft^3 (2.8 m^3) of water. Since drop inlets are normally spaced 300 ft (90 m) apart, the drainage area into each may be about 1.0 acre (0.4 ha). If 0.5 in. (13 mm) of runoff occurs during a storm event, then the runoff from 1.0 acre (0.4 ha) of construction is 1,800 ft^3 (51 m^3) of water. The efficiency of the bales may be about 10 percent for such a storm event. The efficiency is determined by the particle-size distribution of sediment, the amount of runoff water, and the size of the pool behind the straw bales.

Bales can also be used as dams or barriers. An effectiveness similar to that observed for rock dams is possible provided they are placed where the drainage area was 1.0 acre (0.4 ha) or slightly less. If used on a larger drainage area, the amount of runoff into the pool behind the bales would be greater and their effectiveness would decrease. They probably should not be used where the drainage area is more than 3 acres (1.2 ha), and they generally should be used only where they can be staked to sod because they are very susceptible to washing out beneath.

The third area in which bales can be placed is about 2 to 3 ft (0.6 to 1 m) from the toe of a slope. There, they can be installed at the start of earthmoving and left in placer until construction is complete. They would have to be staked on sod so they do not wash out underneath. The sand and gravel that washes down the side of the fill slope is trapped behind the bales; however, this material would be deposited without the use of the bales if there were a flat grassy area at the bottom of the slope (Guy, 1976). Most of the silt and clay suspended in the runoff from the construction area passes over or between the bales with only small amounts being trapped.

MODIFIED COMPACTION EQUIPMENT

A modified sheepsfoot roller was used for compaction in order to leave indentations in the surface which would act as small settling ponds. When fill is first compacted the depressions are large but with further compactions the depressions get smaller. Water is stored in the depressions during storm events; however, this type storage conflicts with the construction requirement that the fill be relatively dry before construction resumes. As a result, after storms the wet uncompacted surface must be graded to the side. No data are available, but a reduction in sediment yield of 15 percent seems reasonable from compaction on fill areas. Counting the cut areas and other locations where the roller is not used, the overall efficiency may be about 5 percent.

GRASS FIELDS

Sediment may be substantially reduced when runoff water from construction areas drain into grass fields. During small to moderate storms the entire runoff from the construction section that drains across a grass field may infiltrate before it reaches a stream. The effectiveness of grass fields to control sediment at that time may be 100 percent, but at other times, when large storms occur or when the field is wet, only small amounts of sediment may be trapped.

Controls, such as grass fields, are generally located off the right-of-way and are privately owned. Generally, they are unsatisfactory because they may be covered with grass when the roadway is being planned and covered with some other crop when construction is in progress. They are also unsatisfactory because an uncontrolled discharge over an open field from the construction area may not be legally attainable.

ENERGY DISSIPATERS

Energy dissipaters are structures designed to reduce the velocity of flow at culvert outlets to a velocity close to the normal stream velocity. They are intended to prevent local erosion. Several types of energy dissipaters were installed as part of this study. Figures 35 and 36 show two of the energy dissipaters that were installed. They have been successful at controlling or preventing scour at the outlets of the culverts.

Information on the velocity of water being discharged into these devices from the culverts and the velocity of water in and leaving these devices is needed to determine their effectiveness. During storms streams transport a suspended load and a bedload. Relatively uniform water velocities in natural streams keep the bedload moving through the system and large bar deposits do not generally occur. If velocities in a culvert pipe are slower than those that normally occur in a stream, the bed material may be deposited in the culvert and reduce its conveyance capacity. The same is true of energy dissipaters that reduce stream velocity below the normal stream velocity. Dissipaters that become clogged with bed material could cause backwater and sediment deposition in the culvert system. The two energy dissipaters, figures 35 and 36, were built where stream slopes are relatively steep and clogging has not been a problem.

LINED CHANNEL

Much research has been done on channel linings (Normann, 1975). New materials, such as fiber glass and plastic mats, are becoming available and

FIGURE 35.—Rock stilling basin.

FIGURE 36.—A rock spillway and a section of lined channel below a culvert acts to reduce the velocity of water and to prevent scour.

should be evaluated. Generally, newly constructed channels and channels receiving runoff from drainage areas affected by construction should be evaluated in terms of the soil type, the slope, and the expected flow rates to determine if some form of lining is required. Some type of lining might also be considered in some swale areas that discharge only storm runoff. Channel lining (figs. 24, 25, 36), like energy dissipaters, are designed to prevent local erosion.

TEMPORARY CHANNEL CROSSINGS

Temporary crossings usually are required during the clearing and grubbing operation and during part of the early culvert construction and earthmoving operation. They are almost essential on perennial streams if the contractor intends to make frequent crossings without getting his equipment stuck. It is estimated that installation of temporary culverts generally would reduce the period that streams may be turbid by 10 to 15 days.

COSTS

Cost is a factor that must be considered when selecting sediment-control measures to use on a project. The onstream pond was the most expensive item used during this erosion-control study (J. P. Weaver, written commun., 1973). The stream pond collected drainage from about 41 acres (17 ha) of construction area and cost about $15,000. The actual cost was more than the $15,000 because the embankment was designed to carry a local service road.

The offstream ponds cost about $2,000 apiece, each controlling drainage from about 6 acres (2.4 ha). Rock dams constructed in small drainage channels cost about $150 apiece, each controlling areas of 1 to 3 acres (0.4 to 1.2 ha). Straw bales in place cost about $3.00 per linear foot ($10.00 per m), and, when used around a drop inlet, cost about $50 per installation. Seeding and mulching on a temporary basis cost about $75 per acre ($185 per ha).

GUIDELINES FOR SELECTING SEDIMENT-CONTROL METHODS

The selection of sediment-control methods or techniques for use during a construction project depends on factors such as the size of the construction and drainage areas, the quality and uses of the stream below the construction area, and the type of areas where runoff from construction will collect. A first step in selecting sediment controls might be to designate temporary crossings on all perennial streams. A second step might be to designate as much early seeding and mulching on the project as possible, especially on cut-and-fill slopes and possibly in the median and on interchange areas. Early seeding and mulching may be designated several ways: one would be to seed all cut-and-fill slopes and median areas at 2-week to 1 month intervals as they are completed; a second way would be to designate areas to be seeded and mulched on specific contract dates; and a third way would be to designate a total area to be seeded and mulched as the class I excavation[2] is moved. An example of the third method would be to require 25 percent of the total seeding and mulching be in place by the time 50 percent of the Class I has been moved. Seeding and mulching helps reduce sediment loads and lends a pleasing appearance. Areas temporarily seeded and mulched may have to be reseeded at a later time with permanent seed mixtures.

The location of the culvert system for carrying the flow of all perennial streams should be evaluated to see if it is possible to design the culvert to be placed at a location where the existing stream channel does not have to be relocated during construction. The stream could be diverted into the culvert when it is complete. Small offstream ponds could accommodate water pumped while dewatering the footers. Isolating drainage from the construction area would keep it from the normal stream culvert system until it can be treated for sediment removal.

If it is desirable to reduce sediment loads below the levels obtained with seeding and mulching, offstream ponds could be considered. In considering offstream ponds the drainage patterns during the early stages of construction would be determined and compared with the final drainage patterns from the

[2]Class I excavation generally includes all soils that can be excavated using pneumatic tired earth movers.

construction area. Drainage from the construction area during all phases of construction would be diverted into the offstream ponds before it enters the stream. One method to determine the volume of offstream pond required to store 0.5 in. (13 mm) of runoff is to determine the contributing drainage area, in acres, and to provide 75 cubic yards per acre (140 m^3 per ha) of storage capacity. A good design for offstream ponds is contained in the Pennsylvania Department of Transportation's erosion and sediment control drawings (1973). Further study of the local water quality and soil type would be needed to determine necessary coagulants, if any, needed to increase efficiency of offstream ponds.

In many places it may be possible to locate offstream ponds so that water from foundations or footers can be pumped into them. It may be possible to locate some offstream sediment-control ponds so they can be constructed before the topsoil is removed. When the topsoil is removed, diversion ditches may be needed to direct drainage from the construction area into the sediment ponds until earthmoving begins. It may not be possible to maintain diversions on the project area when earthmoving is in progress.

In construction areas where the toe of the fill runs parallel to the stream, it may be necessary to relocate and redesign the highway farther away from the stream so that a diversion can be located between the toe and the stream in order to direct runoff to an offstream sediment basin. When offstream basins are backfilled, soft material will rise to the surface; sod placed on the surface may prevent animals from being trapped, and the sod would prevent erosion of the surface.

Large onstream ponds would be necessary only when the construction area contains more than 30 percent of the total drainage area. The effectiveness of onstream ponds could be improved if base flow could be diverted around the pond, providing, in effect, an offstream pond.

Straw bales can be used as barriers around drop inlets. Bales could be used at drop inlets when the time between completion of the inlet and completion of the roadway is more than 2 months. They could also be used to some extent at the toe of slopes, mostly where the toe is close to a stream or close to a populated area.

Rock dams can be used in small channels or in swales where the drainage area is about 1 acre (0.4 ha). The drainage plan from the time of topsoil removal to the completion of the project could be evaluated to determine where runoff water will discharge, and the rock dams could be located where they will be operational for as much time as possible.

Some form of lined channel—fiberglass, rock, or ruble paving—can be used where channels are steeper than 3 percent, where new channels are located in soil, or where the drainage area to a channel is significantly increased. Energy dissipaters can be used at culvert outlets to reduce the exit velocities to normal channel velocities. Effective energy dissipaters are self-cleaning or remain effective despite being partly covered with bed material. A summary of the sediment controls used in this study and their effectiveness is presented in table 11. Their probable costs and the area which they can be expected to control is also listed.

TABLE 11. *Summary of the effectiveness and the probable costs of the sediment controls that were used during construction of Interstate 81, Conodoguinet Creek tributaries 2, 2A, 2B, and 3, November 10, 1972, to September 30, 1974*

Type of control	Effectiveness: Sediment (percent)	Effectiveness: Turbidity (percent)	Cost	Construction area treated (acres)	Cost per acre	Remarks	Location
Offstream pond	60	60	$2,000	6	$330	Temporary	Drainage ways
Onstream pond	80	-25*	15,000	41	375	Permanent	Main streams
Rock dam	5	5	150	2	75	Temporary	Small drainage channels
Seeding and mulching	20	20	375	5	75	Permanent	Cut-and-fill slopes and median
Straw bales	5	5	50	1	50	Temporary	Drop inlets

*Represents an increase in the turbidity.

SUMMARY

The Pennsylvania Departments of Transportation and Environmental Resources (State Conservation Commission) and the U.S. Geological Survey have cooperated in a study to evaluate sediment controls used during highway construction. Hydrologic data have been collected for 5 years from five adjacent drainage basins, four of which were crossed by construction of Interstate 81. About 30 acres (12 ha) were disturbed by highway construction in each of the four basins. Data covering a 3-year period were collected before construction began, and data covering the 2-year period of construction have been collected. The data collected included precipitation, streamflow, suspended-sediment concentration, and turbidity. A different method was used to control sediment or erosion in each of the drainage basins crossed by highway construction. In one area, no sediment control was used so that a base level could be established; in another area, three offstream sediment-control ponds were constructed; in a third area, a large onstream pond was constructed; and in a fourth area, techniques, such as frequent seeding and mulching to limit the exposed area and the construction of rock dams to trap the sediment, were used.

During the 5 years when data were collected precipitation averaged 43.4 in. (1,100 mm) per year. Runoff from each watershed averaged between 15.3 and 22 in. (390 and 560 mm) most years. Normal sediment discharge from the areas was about 65 tons (59 t) per year. The passage of Hurricane Agnes, June 1972, caused 200 tons (180 t) of sediment to be discharged, while construction of the highway over about a 2-year period produced a sediment discharge that ranged from 217 to 677 tons (197 to 614 t) in the four drainage basins.

Before highway construction began, the particle-size distribution of the suspended sediment averaged 7 percent sand, 51 percent silt, and 42 percent clay. Sediment discharged, coming from the highway construction area, averaged 1 percent sand, 29 percent silt, and 70 percent clay. There did not appear to be a very significant relation between the size distribution of the soil used in the construction and the size distribution of the soil transported from the construction area as suspended sediment.

During construction, base-flow suspended-sediment concentrations in the streams increased from about 5 mg/L to about 18 mg/L, and during storm runoff periods, suspended-sediment concentrations increased from about 45 mg/L to about 200 mg/L.

Construction of the roadway was broken into different phases to determine which phase contributed the largest increases in sediment discharge. Clearing and grubbing increased the sediment loads about 200 percent. Construction work on a bridge, that would carry a two-lane local roadway over the Interstate highway, resulted in an increased sediment load of about 100 percent. Early earthwork and culvert construction increased sediment loads about 700 percent.

The earthmoving was about 50 percent complete when construction was suspended in the winter. The average increase in sediment load during the winter and early spring period was about 200 percent. When construction resumed in the late spring the average increase in sediment load was about 800 percent.

During the period when areas were being fine graded and prepared for subbase placement, the highest increases in sediment discharge were observed. The increases averaged about 4,000 percent for the 3-month period.

The most effective sediment controls were the offstream ponds built to intercept the runoff from the construction area before it reached the stream. The offstream ponds reduced sediment loads about 60 percent and reduced stream turbidities about 60 percent.

The large onstream pond, located just below the construction area in basin 2B, reduced the sediment load about 80 percent, but it increased the turbidity of the streamflow below the pond 25 percent over what it would have been had the pond not been located there.

Rock dams had an efficiency of about 5 percent. For the most part, they trapped suspended sand and bedload. Actual data were not collected on the effectiveness of seeding and mulching; however, during the active construction operation, it was evident that the effectiveness was limited by the area that could be protected. An effectiveness of about 20 percent could be expected during the construction period. Data, also, were not collected on the efficiency of bales; however, those located around drop inlets, appear to have a net efficiency of about 10 percent. Seeding and mulching should be considered to stabilize fill slopes and drainage swales, and bales should be used only if no other means of sediment control is possible.

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☆U.S. GOVERNMENT PRINTING OFFICE: 1978—677-255