# Suspended-Sediment Discharge, in Five Streams near Harrisburg, Pennsylvania, Before, During, and After Highway Construction

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 2072

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

# Suspended-Sediment Discharge, in Five Streams near Harrisburg, Pennsylvania, Before, During, and After Highway Construction

*By* LLOYD A. REED

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 2072

*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 : 1980

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.
Suspended-sediment discharge in five streams near Harrisburg, Pennsylvania, before, during, and after highway construction.

(Geological Survey water-supply paper ; 2072)
Bibliography: p.
Supt. of Docs. no.: I 19.13:2072
1. Sediments (Geology) – Pennsylvania – Harrisburg region. 2. Sediment transport – Pennsylvania – Harrisburg region. 3. Roads – Pennsylvania – Harrisburg region. I. Pennsylvania. Dept. of Transportation. II. Pennsylvania. State Conservation Commission. III. United States. Federal Highway Administration. IV. Title. V. Series: United States, Geological Survey. Water-supply paper ; 2072.
GB1225.P4R423 551.3'54'0974818 80–607068

**For sale by Superintendent of Documents, U.S. Government Printing Office**
**Washington, D.C. 20402**

## CONTENTS


| | Page |
|---|---|
| Factors for converting inch-pound units to International System (SI) units | V |
| Abstract | 1 |
| Introduction | 1 |
| The study area | 4 |
| Climate | 5 |
| Precipitation | 5 |
| Streamflow | 7 |
| Suspended sediment | 8 |
| Suspended-sediment load | 9 |
| Daily-mean suspended-sediment concentrations | 15 |
| Particle-size distribution of suspended sediment | 17 |
| Effectiveness of the erosion and sediment-control measures | 20 |
| Offstream ponds | 20 |
| Onstream ponds | 23 |
| Rock dams | 26 |
| Seeding and mulching | 26 |
| Straw bales | 28 |
| Modified compaction equipment | 30 |
| Grassed fields | 30 |
| Energy dissipaters | 30 |
| Lined channel | 32 |
| Temporary channel crossings | 32 |
| Costs | 32 |
| Guidelines for selecting sediment-control methods | 33 |
| Summary and conclusions | 35 |
| Selected references | 37 |


## ILLUSTRATIONS


| | Page |
|---|---|
| FIGURE 1. Map showing location of basins and data-collection sites | 2 |
| 2–4. Graphs showing: | |
| 2. Cumulative precipitation recorded in basins 1, 2A, and 3, October 1, 1969, to September 30, 1976 | 6 |
| 3. Cumulative water discharge in basins 1, 2, 2A, 2B, and 3, October 1, 1969, to September 30, 1976 | 7 |
| 4. Cumulative sediment discharge in basins 1, 2, 2A, 2B, and 3, October 1, 1969, to September 30, 1976 | 9 |

## ILLUSTRATIONS


Page

FIGURE 5. Photograph showing runoff water sampled in basin 2A, May 12, 1974 ---- 18
6. Bar graph showing particle-size distribution in the soil and suspended sediment in samples collected on the construction site and from the streamflow in basins 2, 2A, 2B, and 3, December 6, 1972, to September 3, 1974 ---- 19
7. Map of basin 2A ---- 21
8. Photograph showing the three offstream ponds in basin 2A 22
9. Graph showing the relationship between precipitation and reduction in the storm-runoff suspended-sediment load from basin 2A due to the offstream ponds, October 3, 1973, to August 3, 1974 ---- 23
10. Graph showing the 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 ---- 24
11. Map of basin 2B ---- 25
12. Photograph showing the onstream pond in basin 2B April 1974 ---- 26
13–15. Graphs showing:
13. Relationship between precipitation and reduction in the storm-runoff suspended-sediment load caused by the onstream pond in basin 2B, October 29, 1973, to August 3, 1974 ---- 27
14. Relationship between precipitation and percent the onstream pond increased or decreased the mean 5-day turbidity of the streamflow during and after periods of precipitation, Conodoguinet Creek tributary 2B, October 29, 1973, to August 3, 1974 ---- 28
15. Turbidity, in nephelometric turbidity units (NTU), of samples of runoff water collected above and below small rock dams, Conodoguinet Creek tributaries 2B and 3, September and October 1973 ---- 29
16. Photograph showing a rockstilling basin ---- 31
17. Photograph showing a hydraulic jump energy dissipater ---- 31

# TABLES


| | | Page |
|---|---|---|
| TABLE 1. | Land use in the basins drained by the Conodoguinet Creek tributaries 1, 2, 2A, 2B, and 3, March 30, 1974 | 6 |
| 2. | Yearly water discharge recorded from Conodoguinet Creek tributaries 1, 2, 2A, 2B, and 3, 1970–76 water years | 8 |
| 3. | Ratios of yearly water discharges per square mile between basin 1 and basins 2, 2A, 2B, and 3, 1970–76 water years | 8 |
| 4. | Yearly suspended-sediment discharge, in tons, Conodoguinet Creek tributaries 1, 2, 2A, 2B, and 3 from October 1, 1969, to September 30, 1976 | 11 |
| 5. | Average annual sediment loads before, during, and after highway construction, without the effects of Hurricanes Agnes and Eloise, Conodoguinet Creek tributaries 1, 2, 2A, 2B, and 3, October 1, 1969, to September 30, 1976 | 15 |
| 6. | Average daily-mean base-level suspended-sediment concentrations, Conodoguinet Creek tributaries 1, 2, 2A, 2B, and 3, October 1, 1969, to September 30, 1976 | 16 |
| 7. | Average daily-mean storm-runoff/suspended-sediment concentrations, Conodoguinet Creek tributaries 1, 2, 2B, and 3, October 1, 1969, to September 30, 1976 | 17 |
| 8. | Summary of the effectiveness and the probable costs of the sediment controls used during construction of highway I-81, Conodoguinet Creek tributaries 2, 2A, 2B, and 3, November 10, 1972, to September 30, 1974 | 36 |


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

| *Multiply inch-pound units* | *By* | *To obtain SI units* |
|---|---|---|
| inch (in) | 25.4 | millimeter (mm) |
| foot (ft) | 0.3048 | meter (m) |
| mile (mi) | 1.609 | kilometer (km) |
| acre | 0.4047 | hectares (ha) |
| ton (short) | 0.9072 | metric ton (t) |
| acre-foot (acre-ft) | 1,233 | cubic meter ($m^3$) |
| cubic foot per second ($ft^3/s$) | 0.02832 | cubic meter per second ($m^3/s$) |
| cubic foot per second-day ($ft^3/s$-d) | 0.02832 | cubic meter per second-day ($m^3/s$-day) |
| degree Fahrenheit (°F) | $-32\times5/9$ | degree Celsius (°C) |

# SUSPENDED-SEDIMENT DISCHARGE, IN FIVE STREAMS NEAR HARRISBURG, PENNSYLVANIA, BEFORE, DURING, AND AFTER HIGHWAY CONSTRUCTION

By LLOYD A. REED

ABSTRACT

Rainfall, streamflow, sediment, and turbidity data were collected as part of a study to evaluate the effects of highway construction on suspended-sediment discharges in streams. The study was also designed to evaluate the effectiveness of different erosion-control measures in reducing sediment discharge. Although highway construction increased suspended-sediment discharges from two to four-fold, the rate of sediment discharge quickly returned to pre-construction levels when construction ended.

The most effective sediment control evaluated was offstream ponds, which were designed to trap and store sediment laden water from the construction area. The offstream ponds trapped about 70 percent of the sediment that reached them during most storms. Seeding and mulching generally reduced sediment loads about 20 percent. Rock dams and bales reduced loads about 5 percent. An onstream pond, constructed on a large stream below the construction area, reduced sediment loads about 80 percent. However, unlike the offstream ponds, which stopped discharging runoff water soon after precipitation ended, the onstream pond kept discharging runoff water, and the stream below the pond remained turbid for extended periods.

## INTRODUCTION

The Pennsylvania Departments of Transportation and Environmental Resources (State Conservation Commission), the Federal Highway Administration, and the U.S. Geological Survey cooperated in a study to determine the effects of highway construction on both suspended-sediment discharges and concentrations in streams. The study was also designed to determine the effectiveness of different types of erosion-control measures in reducing sediment during construction.

The study area, composed of five adjacent drainage basins (fig. 1), is in Cumberland County, west of Harrisburg, Pa. Four of the basins were crossed by Interstate Highway 81, and the fifth basin served as a control. In each of the four basins where the highway was constructed, a different type of sediment control was used. In basin 3, rapid seeding, mulching and small rock dams were used; in basin 2B, a large onstream pond was constructed on the stream below the area of highway construction to trap both the natural sediment from the drainage area and the sediment from the construction area; in basin 2A, three offstream ponds were constructed to trap the sediment from the construction area before it reached the stream, and in basin 2 no sediment control measures were used. No construction occurred in basin 1, which was used as a control. The data from basin 1 were compared to the data collected from the other four basins to determine the sediment loads caused by construction. The data from basin 2 were compared to the data from

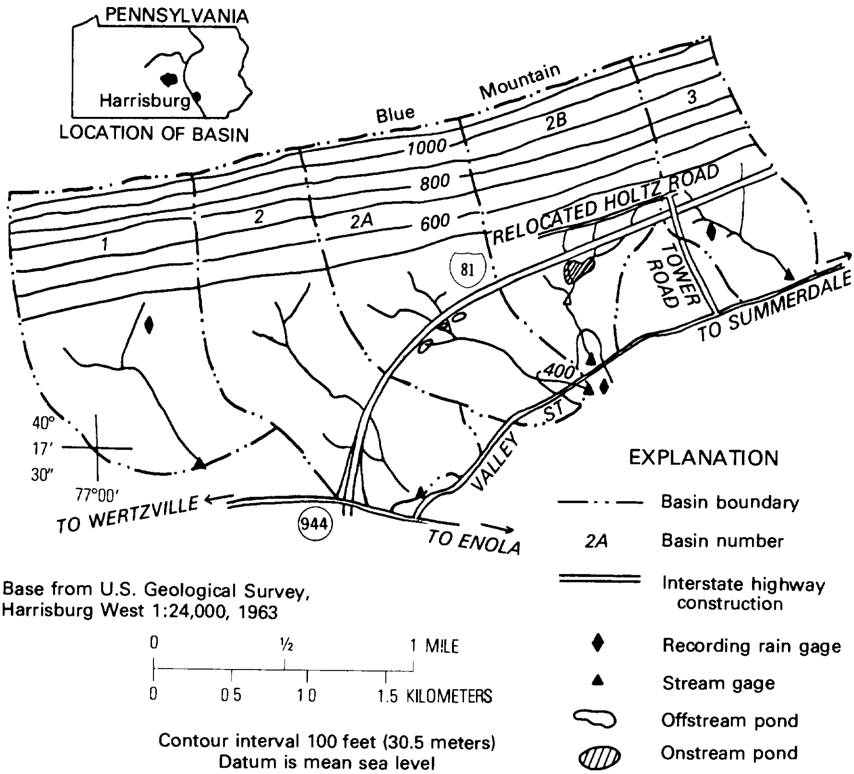


FIGURE 1.—Map showing location of basins and data-collection sites.

basins 2A, 2B, and 3 to determine the effectiveness of the control measures.

This report presents rainfall, streamflow, suspended-sediment concentration, and suspended-sediment discharge data collected from October 1969 to September 1976, and compares the data collected before, during, and after highway construction. Construction of the roadway began in the four basins in the fall of 1972 and was completed in three of the basins in the fall of 1974; construction was completed in the fourth basin in the late summer of 1975. Approximately 3 years of preconstruction, 2 years of construction, and 2 years of postconstruction data were collected. The years discussed in this report are water years and extend from October 1 to September 30. For example, the 1973 water year was from October 1, 1972, to September 30, 1973.

Earlier reports, "Sediment Characteristics of Five Streams Near Harrisburg, Pennsylvania, before Highway Construction" (Reed, 1976a) and "Effectiveness of Sediment-Control Techniques Used During Highway Construction in Central Pennsylvania" (Reed, 1978), discussed the preconstruction and construction data. In the preconstruction report, variations in sediment discharge between the five basins and reasons for the variations were discussed. Effects of highway construction on sediment discharge and the effectiveness of the several different sediment-control measures tried in the study were discussed in the construction report. Some of the discussion on effectiveness of sediment-control measures are repeated in this report.

Precipitation was recorded by using three 12-inch weighing capacity rain gages, having recording chart speeds of half an inch per hour. Their locations are shown in figure 1.

Streamflow from each of the five basins was measured indirectly by continuous recorders that record stages (water levels) behind weir flow-controls. The relationship between stage and flow for each stream was developed from current-meter measurements made on a regular schedule and during periods of unusual high or low flow. The streamflow was then computed by relating the recorded stages to the stage-discharge relationship.

Sediment concentrations were determined by collecting samples periodically during base-flow periods, when concentrations were normally low, and at more frequent intervals during storms, when concentrations were high and changing rapidly. Most of the samples were collected by hand during the base-flow periods.

During storms, most samples were collected by an automatic sampler installed in the stream-monitoring station. Hand samples were also collected during storms to supplement and check the automatic samples. Samples were analyzed in the U.S. Geological Survey sediment laboratory in Harrisburg. Daily-mean suspended-sediment concentrations and daily sediment loads were calculated by integrating the streamflow with the suspended-sediment concentrations.

The contents of this report reflect the findings of the author, who is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Pennsylvania Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

## THE STUDY AREA

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

The drainage areas extended 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, and altitudes at the stream-monitoring sites range from 380 to 425 ft. 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.

Blue Mountain is underlain by shale and sandstone of the Clinton Formation and quartzitic sandstone of the Tuscarora Formation, both of Silurian age. The valley is underlain by shale of the Martinsburg Formation of Ordovician age. Soils on Blue Mountain are classified as very stony and gravelly loams. The valley soils derived from the underlying Martinsburg Formation are mostly shaly silt loams and range from 1 to 5 ft thick, though most are 2 to 3 ft thick. The topsoil is generally 44 percent sand, 41 percent silt, and 15 percent clay. Permeability is moderate to low, and the available moisture capacity is about 3 in.

The mountainous area and the steeper parts of the valley are forested. The flatter areas in the valley are open fields, a few of which are actively farmed; the rest is grassland. Residential development is light; the number of houses in the basins range from 6 in basin 2A to 28 in basin 3. Size and land use of each basin, as of March 30, 1974, are given in table 1.

## CLIMATE

The climate is typical of temperate zones at 40° latitude. Temperature ranges from an average of 32°F in January to 76°F in July. Average yearly temperature is 53°F. Normally, the minimum temperature is 0°F and occurs in January or February; the maximum is normally 95°F and occurs in July or August. Average annual precipitation, based on NOAA (National Oceanographic and Atmospheric Administration) records for Carlisle, is 40.13 inches, and that for Bloserville is 40.96 inches. Carlisle is 13 mi southwest and Bloserville is 20 mi west of the study area. Precipitation is fairly uniformly distributed throughout the year.

## PRECIPITATION

Precipitation was recorded for this study at three locations (fig. 2) by graphic recording precipitation gages. Gages were placed near the centers of drainage basins 1 and 3 and near the gaging station in basin 2A.

Precipitation recorded at each of the three gages was tabulated monthly. A cumulative sum of the monthly values was plotted against time (fig. 2) for the 7 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 averaged 44.2 in. per year for the 7 years of the study. The yearly averages for the three gages were 41.5, 38.0, 49.1, 49.1, 39.4, 52.5, and 40.2 in. from 1970 through 1976. During the 3 years of data collection before highway construction, precipitation averaged 42.9 in.; during the 2 years of construction it averaged 44.2 in.; and during the 2 years after construction it averaged 46.4 in. From figure 2 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 differences between the three sites was small.

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

| Basin | 1 | 2 | 2A | 2B | 3 |
|---|---|---|---|---|---|
| Total area (mi²) | 0.77 | 0.76 | 0.70 | 0.65 | 0.38 |
| Construction area (mi²) | .0 | .047 | .032 | .075 | .036 |
| Elevation at gage (ft) | 425.0 | 405.0 | 380.0 | 385.0 | 415.0 |
| **Land Use** (Percent of basin) | | | | | |
| Forest | 65.0 | 51.0 | 76.0 | 75.0 | 76.0 |
| Grass | 29.0 | 32.8 | 9.8 | 4.0 | 11.8 |
| Active farmland | 5.3 | 9.2 | 9.2 | 8.5 | .0 |
| Secondary roadways | .4 | .5 | .3 | .5 | 1.5 |
| Buildings | .3 | .3 | .2 | .5 | 1.2 |
| Construction area | --- | 6.2 | 4.5 | 11.5 | 9.5 |
| Acres of construction area | --- | 30.0 | 20.0 | 48.0 | 23.0 |

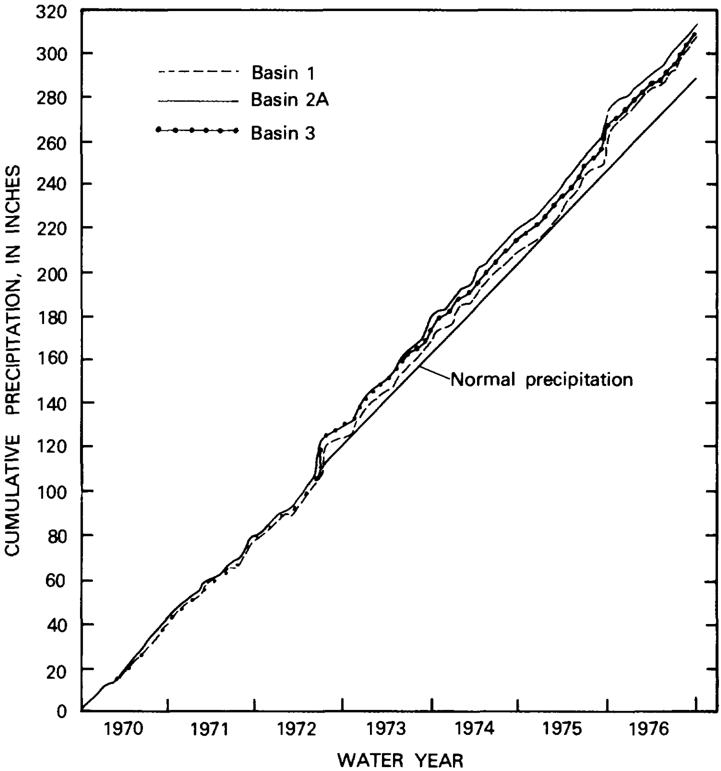


FIGURE 2.—Cumulative precipitation recorded in basins 1, 2A, and 3, October 1, 1969, to September 30, 1976.

## STREAMFLOW

Streamflow records were obtained by recording streamwater elevations continuously at the stream-gaging locations shown on figure 1. Water elevations in each stream were related to streamflow on the basis of periodic current-meter measurements of streamflow. Daily streamflows were calculated from the recorded elevations.

Figure 3 shows the cumulative water discharge from each of the five drainage areas plotted monthly for the 7 years of data collection. The cumulative water discharge per unit drainage

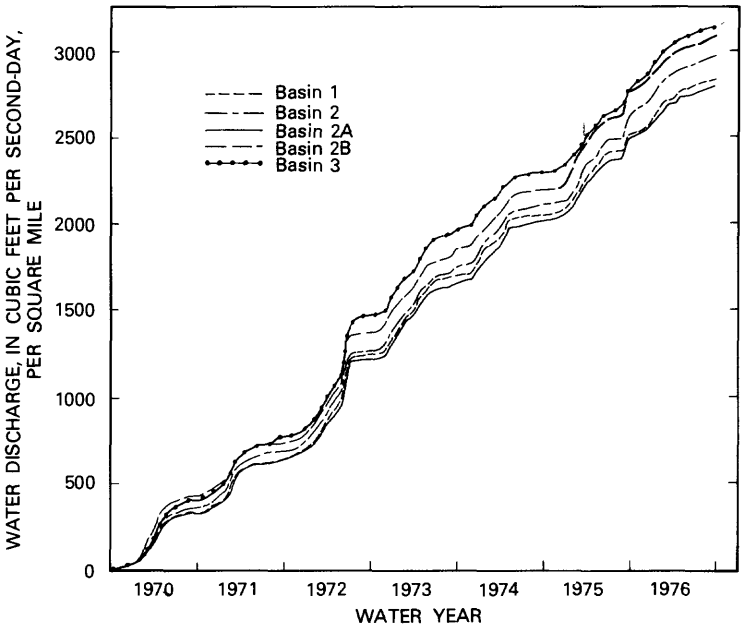


FIGURE 3.—Cumulative water discharge in basins 1, 2, 2A, 2B, and 3, October 1, 1969, to September 30, 1976.

area is plotted because the basins are of slightly different sizes. The variation in streamflow from each of the basins was less than 8 percent of the mean for the five basins. Table 2 lists the yearly water discharge by water years from each of the basins for the 7 years of data collection, and table 3 lists the ratio between the yearly water discharge from basin 1 and that from basins 2, 2A, 2B, and 3. When the yearly flows from basin 1

TABLE 2.—*Yearly water discharge in cubic feet per second-day per square mile recorded from Conodoguinet Creek tributaries 1, 2, 2A, 2B, and 3, 1970–76 water years*

| Basin | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 |
|---|---|---|---|---|---|---|---|
| 1 | 429 | 416 | 771 | 591 | 457 | 600 | 412 |
| 2 | 466 | 443 | 755 | 638 | 479 | 688 | 437 |
| 2A | 444 | 389 | 756 | 564 | 467 | 647 | 366 |
| 2B | 558 | 409 | 837 | 614 | 468 | 743 | 408 |
| 3 | 539 | 460 | 921 | 661 | 437 | 647 | 463 |

TABLE 3.—*Ratios of yearly water discharges per square mile between basin 1 and basins 2, 2A, 2B, and 3, 1970–76 water years*

| Basin | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 |
|---|---|---|---|---|---|---|---|
| 2 | 1.07 | 1.06 | 0.98 | 1.08 | 1.05 | 1.15 | 1.06 |
| 2A | 1.03 | .94 | .98 | .95 | 1.02 | 1.08 | .89 |
| 2B | 1.30 | .98 | 1.09 | 1.04 | 1.02 | 1.24 | .99 |
| 3 | 1.26 | 1.11 | 1.19 | 1.12 | .96 | 1.08 | 1.12 |

are compared to the yearly flows from the other four basins, no significant changes are apparent from before to during and after construction. Construction of the roadway disturbed 4.5 percent of basin 2A (table 1) and 11.5 percent of basin 2B; however, only about one third of the disturbed area was paved.

## SUSPENDED SEDIMENT

Suspended sediment 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 had low suspended-sediment concentrations. The samples were analyzed for suspended sediment concentration. When roadway construction began, samples were collected several times daily during the base-flow periods to document sediment loads that may have been caused by construction in or near the streams. The samples were collected by hand during visits to the sites and by automatic sampling equipment installed in the gages.

After the samples had been analyzed, the suspended-sediment concentrations were plotted against time. From the sediment concentration and streamflow records, the time-weighted mean suspended-sediment concentrations and sediment loads were calculated on a daily basis for each of the five basins.

Daily-mean sediment concentrations and sediment load have different uses. Sediment load, as used in this report, is a measure of the quantity of suspended sediment transported past a given location during a period of time. It indicates the amount of erosion in the basin and 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 more about the appearance or clarity of the stream on a day-to-day basis. Most downstream water users are more conscious of the appearance of the streamflow than the sediment load transported past their site. The relative importance of each parameter must be determined for each stream site.

## SUSPENDED-SEDIMENT LOAD

The suspended-sediment load as accumulated monthly for each of the five streams, is shown plotted on figure 4. The slope of the curves in figure 4 indicates the rate of sediment discharge with respect to time. Large sediment loads generally result in a nearly vertical slope, and small sediment loads result in a

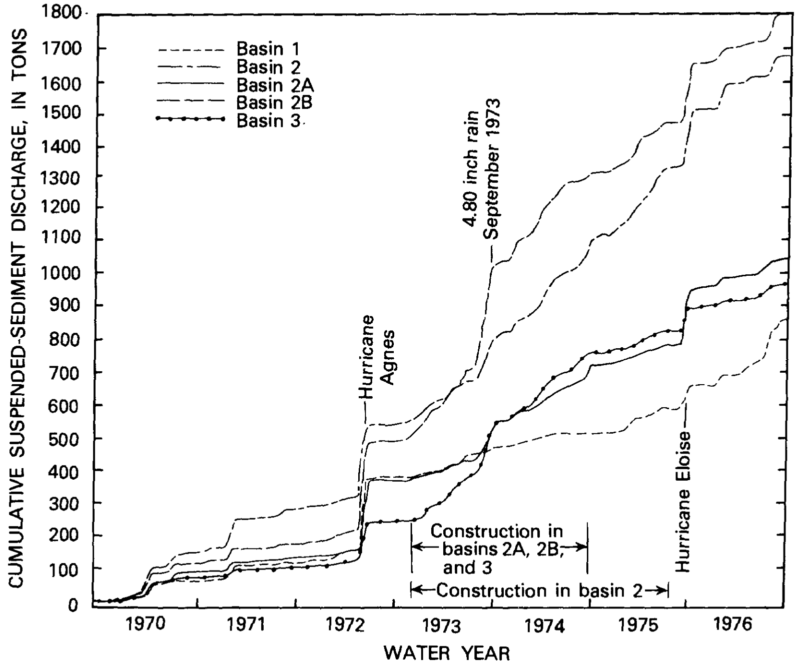


FIGURE 4.—Cumulative sediment discharge in basins 1, 2, 2A, 2B, and 3, October 1, 1969, to September 30, 1976.

nearly horizontal line. From figure 4, it can be seen that a significant amount of the sediment load discharged from the five basins was transported during three periods. The load transported during the first period (June 1972) was the result of rainfall associated with Hurricane Agnes (fig. 4). The load transported during the second period was the result of highway construction in basin 2, 2A, 2B, and 3. Highway construction began in December 1972 and was completed in October 1974, except for basin 2, which was not completed until August 1975. The load transported during the third period was the result of rainfall associated with Hurricane Eloise. Sediment discharges are listed on table 4, by water years.

From figure 4 and table 4, it can be seen that sediment discharge from basin 1, the basin where no construction occurred, totalled 867 tons for the 7-year period. Land use in basin 1 was fairly uniform throughout the 7-year period. The only changes in land use that affected sediment discharges were the pasturing in 1971 of a field through which the stream passed and the plowing of a grass field in 1976 and the planting of it to soybeans. The pasturing in 1971 affected suspended-sediment concentrations during low-flow periods, but did not appreciably affect the total sediment discharge for the year. The field planted to soybeans in 1976 contributed about 65 tons to the yearly sediment discharge. In the 1972 water year, 210 tons of sediment were discharged during Hurricane Agnes; and during the 1975 water year, 64 tons of sediment were discharged during Hurricane Eloise.

Sediment discharge from basin 1 for the 7-year period was about 870 tons. If the effects of the hurricane of 1972 and the change in land use in 1976 are subtracted, the annual sediment discharge was 592 tons. Since the drainage area of basin 1 is 0.77 square miles the average annual sediment discharge, assuming 592 tons represents the average, becomes 110 tons per square mile per year for the 7-year period.

Figure 4 and table 4 show that sediment discharges from basin 2 were more than the discharges from basin 1. During the 7-year period (1970 to 1976), a total of 1,665 tons of sediment were discharged from basin 2 compared with 870 tons from basin 1.

Development work in 1970 in basin 2 affected sediment discharges during the period when prehighway construction data were being collected. The development work consisted of the

TABLE 4.—*Yearly suspended-sediment discharge, in tons, Conodoguinet Creek tributaries 1, 2, 2A, 2B, and 3 from October 1, 1969, to September 30, 1976*

| Basin | Drainage area (square miles) | Water Year 1970 | 1971 | 1972 Total | 1972 Hurricane Agnes | 1973 | 1974 | 1975 Total | 1975 Hurricane Eloise | 1976 | 1970-76 Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | .77 | 70 | 59 | 259 | 210 | 97 | 45 | 144 | 64 | [a] 128 | [a] 802 |
| 2 | .76 | 150 | 137 | 261 | 210 | [b] 257 | [b] 305 | [b] 387 | 170 | 168 | 1,665 |
| 2A | .70 | 93 | 45 | 238 | 205 | [b] 172 | [b] 191 | 225 | 165 | 91 | 1,055 |
| 2B | .65 | 116 | 62 | 316 | 270 | [b] 534 | [b] 282 | 337 | 176 | 154 | 1,801 |
| 3 | .38 | 78 | 33 | 142 | 105 | [b] 295 | [b] 226 | 134 | 67 | 71 | 979 |

[a] With no changes in land use.
[b] Period of highway construction.

construction of a 5-acre farm pond and a one-lane access road. Construction of the pond and roadway began in June 1970 and was completed in September 1970. Approximately 100 tons of the 287 tons of sediment that were discharged from basin 2 during 1970 and 1971 resulted from the development work (Reed, 1976a).

Hurricane Agnes in June 1972 produced a sediment discharge of 210 tons from basin 2. If the effects of the development work and Hurricane Agnes are subtracted from the 548 tons of sediment discharged from 1970 through 1972, the resulting load for the 3-year period was 238 tons. Annual yields for basin 2 were affected by changing land use patterns during 1972. Land acquisition for the planned highway resulted in less agricultural activity, and the 5-acre pond served as a sediment trap, reducing sediment yields from the headwaters of the basin. For the period of construction, the natural sediment discharge from basin 1 and basin 2 were assumed to be about equal.

Construction of highway I-81 from December 1972 to August 1975 affected sediment discharges during the 1973, 1974, and 1975 water years (table 4). During the 3-year period, 949 tons of sediment were discharged from basin 2; however, only about 660 tons were discharged as a result of the highway construction. Since highway construction covered a period of about 33 months, the annual sediment discharge from the construction area was about 240 tons per year. In all, about 30 acres were disturbed by construction, and the average sediment discharge from the construction area was about 8 tons per acre per year.

Sediment discharge from basin 2A totaled 1,055 tons for the 7-year period. During the 3 years before highway construction began, 1970 through 1972, 376 tons of sediment were discharged from basin 2A. The measured sediment discharge due to Hurricane Agnes was 205 tons, and development work in the basin during 1970 produced about 15 tons. If the sediment from these two events are subtracted, the total for the 3-year period becomes 156 tons, or an average annual sediment discharge of 75 tons per square mile per year. Sediment discharge from basin 1 for the same period, with the effects of Hurricane Agnes subtracted, was 178 tons, or about 77 tons per square mile per year. Basin 2A, which contains 0.70 square miles, discharged sediment at a rate of about 13 percent less than basin 1.

During highway construction, 1973-1974, 363 tons of sediment were discharged from basin 2A, while 142 tons were discharged from basin 1. About 125 of the 363 tons of sediment originated from natural sources. In addition, about 20 tons originated from the reconstruction of a farm pond upstream from the highway construction site. The remaining 220 tons came from the area of highway construction. Construction of the roadway was over a 22-month period, and about 20 acres were disturbed by construction. Sediment discharge from the construction area averaged about 6 tons per acre per year.

Three offstream ponds were constructed in basin 2A to trap sediment from the construction area before it reached the stream. Generally, the ponds trapped about 70 percent of the sediment that reached them. They were operational for about 12 months of the 22-month construction period, and their operation is discussed in more detail in an earlier report (Reed, 1978) and later in this report.

During the 2-year period after construction of highway I-81 was complete, 1975 and 1976, 316 tons of sediment were discharged from basin 2A. Hurricane Eloise, during September 1975, produced 165 tons of sediment and, if subtracted from the total, 151 tons or 75 tons per year were discharged from basin 2A. During the same 2-year period, with the effects of the Hurricane and the soybean field in basin 1 removed, 208 tons of sediment were discharged from basin 1, an average of 104 tons per year. After construction, basin 2A discharged sediment at a rate of about 27 percent less than basin 1, comparable to, but slightly less than, the rate observed before construction.

Sediment discharge from basin 2B totaled 1,801 tons for the 7-year period. During the 3 years before highway construction began, measured sediment discharge was 494 tons, 270 of which were discharged during Hurricane Agnes. If the effects of the Hurricane are subtracted, the average sediment discharge from basin 2B for the 3-year period was 75 tons per year. The sediment discharge from basin 2B was about 25 percent more than the discharge from basin 1.

During the 2-year period of highway construction, 816 tons of sediment were discharged from basin 2B, while 142 tons were discharged from basin 1. About 638 tons of sediment were discharged from basin 2B as a result of the roadway construction. Construction covered about a 22-month period, and about 48 acres were disturbed during construction. Sediment discharge from the construction area averaged about 7 tons per acre per year. A large (8 acre-feet) onstream pond was located on the main stream below the construction area to control excess sediment. Generally, the onstream pond trapped about 80 percent of the sediment that reached it. The onstream pond was operational for about 11 months of the 22-month construction period and is discussed later in this report and in an earlier report (Reed, 1978).

During the 2-year period after construction of highway I-81, 491 tons of sediment were discharged from basin 2B. Hurricane Eloise in September 1975 produced 176 tons of sediment. The remaining 315 tons, or an average of 158 tons per year, were discharged from basin 2B during the 2-year period after construction. This compares with 104 tons per year discharged from basin 1. After construction, the sediment load from basin 2B was about 20 percent more than the load before construction. However, increased agricultural activity in the basin may have produced the increased sediment loads after construction.

Sediment discharge from basin 3 totalled 979 tons for the 7-year period. During the 3 years before highway construction began, 1970 through 1972, 253 tons of sediment were discharged from basin 3. Hurricane Agnes produced a sediment discharge of 105 tons, and when the 105-ton load is subtracted from the 3-year total, the average sediment discharge is 49 tons per year. Basin 3 discharged an average of about 15 percent less sediment than basin 1. Since basin 3 contained 0.38 square miles, the average annual sediment discharge from basin 3 was 130 tons per square mile per year. Sediment discharge from basin 1 averaged 79 tons per square mile per year for the period. The reason more sediment was discharged from basin 3 on a per square mile basis was that there was more development in basin 3 (table 1).

During highway construction, 1973-74, the measured sediment discharge from basin 3 was 521 tons, while 142 tons were discharged from basin 1. Based on the relationship developed between basins 1 and 3, 400 tons of sediment were discharged as a result of the highway construction in basin 3. An average of 23 acres were disturbed by construction in basin 3, and, since the construction period lasted 22 months, sediment discharges averaged 9.5 tons per acre per year. Several small rock dams were constructed in basin 3, and the rock dams, rapid seeding, and mulching were primary sediment controls. The rock dams trapped about 5 percent of the sediment that reached them, and the seeding and mulching had an efficiency of about 20 percent. These devices are discussed later in this report and in an earlier report (Reed, 1978).

During the 2-year period after highway construction, 1975 and 1976, 205 tons of sediment were discharged from basin 3. Hurricane Eloise, during September 1975, produced 67 tons of sediment. If the 67 tons are subtracted, sediment discharge after construction averaged 69 tons per year. During the same period, sediment discharge from basin 1 averaged 104 tons per year. After construction, basin 3 discharged about 35 percent less sediment than basin 1, as compared to 15 percent less before construction.

Table 5 summarizes the average annual sediment loads measured from the five basins before, during, and after highway construction. The averages shown are with the effects of the hurricanes in 1972 and 1975 subtracted. Effects of land use changes in basin 1, during 1976, have also been subtracted.

TABLE 5.—*Average annual sediment loads before, during, and after highway construction, without the effects of Hurricanes Agnes and Eloise, Conodoguinet Creek tributaries 1, 2, 2A, 2B, and 3, October 1, 1969, to September 30, 1976*

| | Before construction | During construction—1973-74 | | | After construction |
|---|---|---|---|---|---|
| | | Measured load | Load from construction area | | |
| Basin | 1970-72 | Tons | Tons | Tons per acre | 1975-76 |
| 1 | 60 | 71 | -- | -- | 104 |
| 2 | 80 | 330 | 220 | 7 | 135 |
| 2A | 52 | 190 | 120 | 6 | 75 |
| 2B | 75 | 425 | 336 | 7 | 158 |
| 3 | 49 | 278 | 218 | 9.5 | 69 |

## DAILY-MEAN SUSPENDED-SEDIMENT CONCENTRATIONS

Daily-mean suspended-sediment concentrations indicate the concentration of sediment in 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 base-level periods when the streamflow is nearly free of sediment. Examination of the data indicates that the streamflow is free of sediment about 80 percent of the time, or about 24 days each month. The second part concerns the storm periods when the streams contain significant concentrations of suspended-sediment. Normally, significant concentrations only occur about 20 percent of the time, or 6 days each month.

The lowest 24 daily-mean suspended-sediment concentrations were tabulated for each month. The concentrations were averaged and are summarized in table 6, on a yearly basis for each of the five streams.

TABLE 6.—*Average daily-mean base-level suspended-sediment concentrations in milligrams per liter, Conodoguinet Creek tributaries 1, 2, 2A, 2B, and 3, October 1, 1969, to September 30, 1976*

| Basin | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 |
|---|---|---|---|---|---|---|---|
| 1 | 4 | 6 | 5 | 5 | 5 | 4 | 4 |
| 2 | 7 | 8 | 7 | [a]18 | [a]12 | [a]12 | 4 |
| 2A | 4 | 3 | 5 | [a]9 | [a]14 | 5 | 5 |
| 2B | 11 | 11 | 17 | [a]58 | [a]70 | 23 | 7 |
| 3 | 8 | 8 | 9 | [a]30 | [a]16 | 7 | 4 |

[a] Values affected by highway construction.

Base-level suspended-sediment concentrations in the stream draining basin 1 (no construction) averaged about 5 mg/L during the 7 years of data collection. They averaged 5 mg/L during the 3 years before highway construction and 5 mg/L during the 2 years of highway construction, 1973 and 1974. During 1975 and 1976, the base-level concentrations in basin 1 averaged 4 mg/L; this is the period following highway construction in the other four basins.

Base-level suspended-sediment concentrations in three of the streams affected by highway construction, 2, 2A, and 3, averaged 6 mg/L during the period before construction. During construction, the average concentrations of the three streams was 17 mg/L, and after construction, the base-level concentrations averaged 5 mg/L. Concentrations increased about twofold during construction of the roadway, but quickly returned to normal as construction was completed. Base-level concentrations in basin 2B were significantly affected by ducks and geese in the stream (Reed, 1976a, 1978). However, basin 2B returned to preconstruction levels once construction was completed.

The average storm-runoff suspended-sediment concentrations in the five streams are summarized in table 7 for periods before, during, and after construction. The highest six daily-mean suspended-sediment concentrations were tabulated for each month from October 1969 through September 1976 for each of the five streams. Those values are called storm-runoff suspended-sediment concentrations. Most of them represent periods when storms caused high suspended-sediment concentration; however,

## 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 the samples is shown on figure 15. The median reduction in turbidity for the samples shown on the figure is about 5 percent. Based on 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 similar trap efficiency.

## SEEDING AND MULCHING

During construction, seeding and mulching were limited to the completed cut-and-fill slopes. The width protected on the 300-ft wide right-of-way was about 100 ft. The median, which was about 80 ft 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


FIGURE 12.—Photograph showing the onstream pond in basin 2B, April 1974.

a storage capacity about equivalent to the runoff produced by a 1.0-in. rainfall.

Figure 14 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 of the storms, the mean turbidity of the stream below the onstream pond was increased more than 50 percent above the levels that would have occurred without the pond. The increase in turbidity was 100 percent or more for six storms, while the median increase was about 25 percent for all storms.

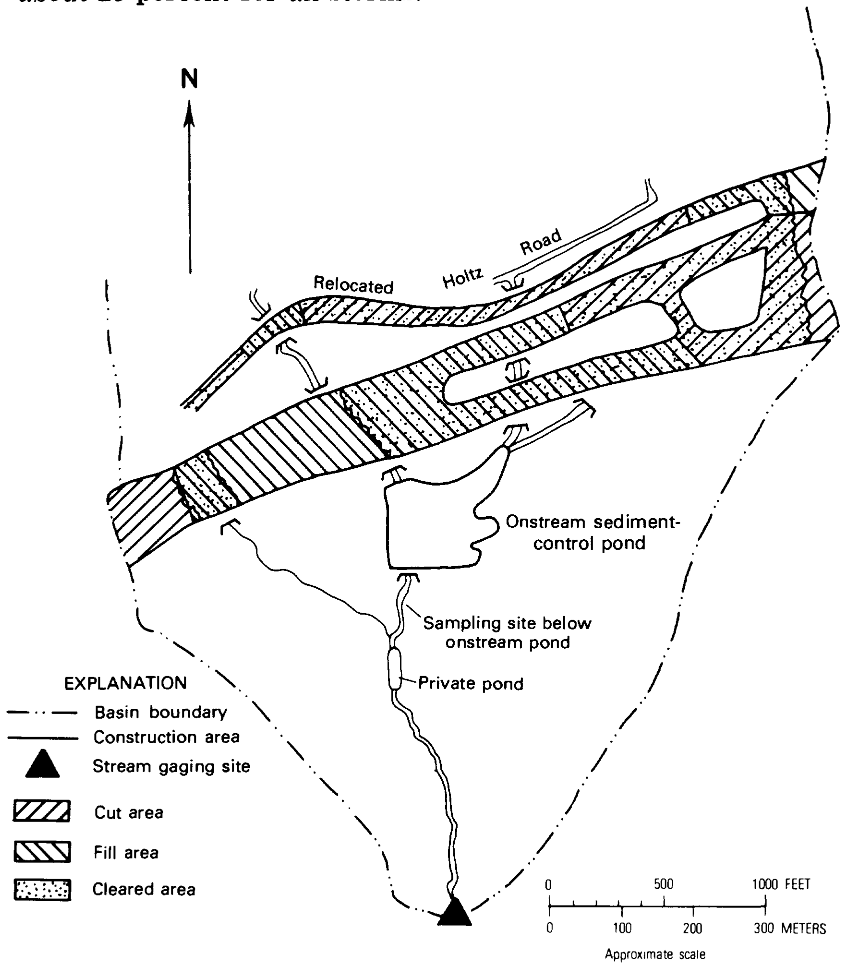


FIGURE 11.—Map of basin 2B.

pond had a relatively high suspended-sediment concentration and turbidity that persisted.

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 13 shows the percent the suspended-sediment load was reduced by the onstream pond. The median reduction was about 85 percent for storms that produced 1.25 in. of precipitation or less and about 60 percent for storms that produced more than 1.25 in. 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, about equivalent to the runoff produced by a 2.0-in. rainfall. The offstream ponds had

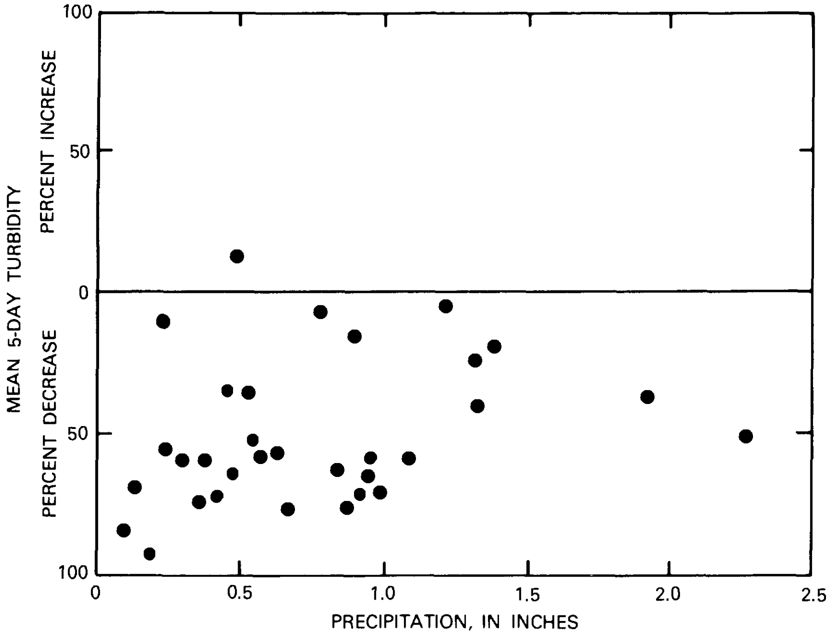


FIGURE 10.—Graph showing the percent the offstream ponds increased or decreased the mean 5-day turbidity of the streamflow during and after periods of precipitation, Conodoguinet Creek tributary 2A, October 2, 1973, to August 3, 1974.

## ONSTREAM PONDS

The onstream pond in basin 2B collected runoff from about 41 acres disturbed by construction and from about 300 acres of undisturbed watershed. Figure 11 is a map of basin 2B showing the main features, including the onstream pond. When the onstream pond filled, it had a permanent storage capacity of 8 acre-ft or 1.5 in. of storm runoff. Figure 12 shows the pond filled to capacity in April 1974.

The onstream pond received continuous inflow and had a continuous discharge. When a storm occurred, sediment-laden inflow mixed with water in the pond that was free of sediment. Discharge from the pond was relatively sediment free at the beginning of the storm; however, the sediment concentrations increased as sediment-laden inflow mixed with water in the pond. When the storm was over, water in the pond and in the streams below the

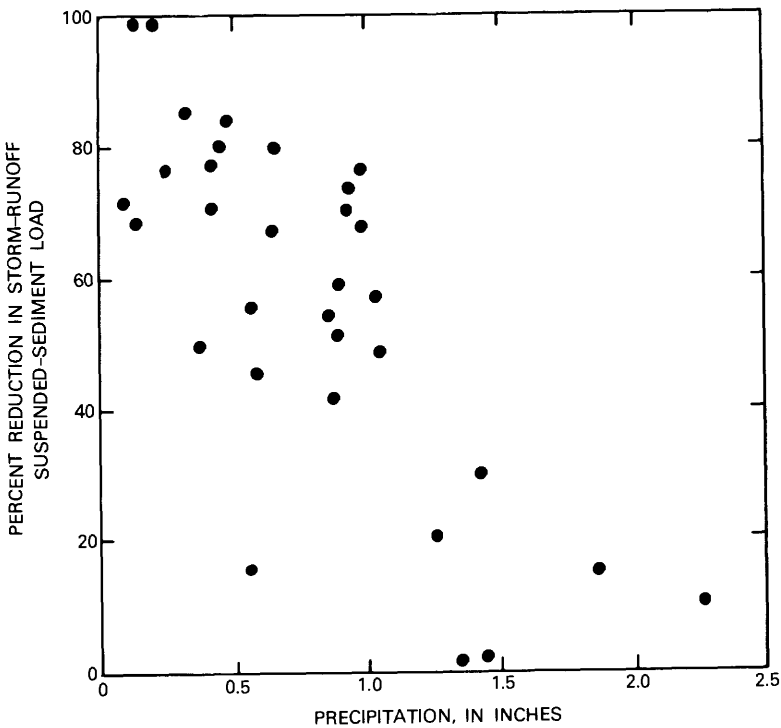


FIGURE 9.—Graph showing the relationship between precipitation and reduction in the storm-runoff suspended-sediment load from basin 2A due to the offstream ponds, October 3, 1973, to August 3, 1974.

The effectiveness of the offstream ponds was computed on the basis of their trap efficiency and their ability to reduce turbidity. The ponds were operational during 39 storms, which produced from 0.05 to 2.35 in. of precipitation. 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.

Although the offstream ponds were effective in reducing sediment loads, the effectiveness could be increased in several ways. The water in the ponds could be treated with a coagulating agent, so that the fine sediment particles would settle rapidly. The ponds could be located so that they would intercept runoff from as much of the construction area as possible. Greater effectiveness would also be realized if the ponds could be installed at the time of clearing and grubbing and maintained until the construction area stabilized. The capacity of the ponds could also be increased.

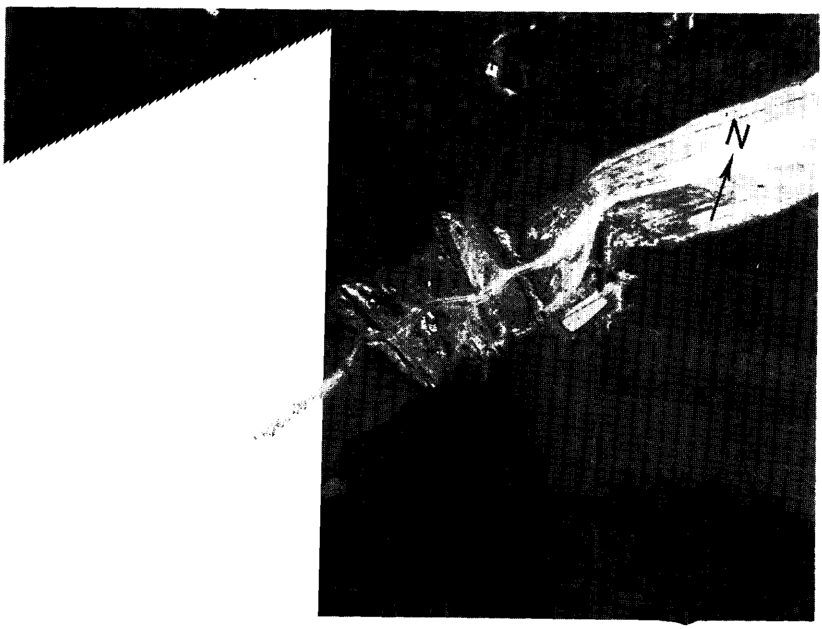


FIGURE 8.—Photograph showing the three offstream ponds in basin 2A.

ponds were operational are not included. For storms that produced 1.25 in. of precipitation or less, the median reduction in the sediment load was about 70 percent, and, for storms that produced over 1.25 in. of precipitation, the median reduction was about 15 percent. The median reduction for all storms shown in figure 9 was about 60 percent.

Mean turbidity of streamflow was calculated over a 5-day period, including the day of the storm and the following 4 days. Figure 10 shows the percent increase or percent decrease in the mean 5-day turbidity of the stream draining basin 2A. Figure 10 shows that the median decrease in mean turbidity was about 60 percent.

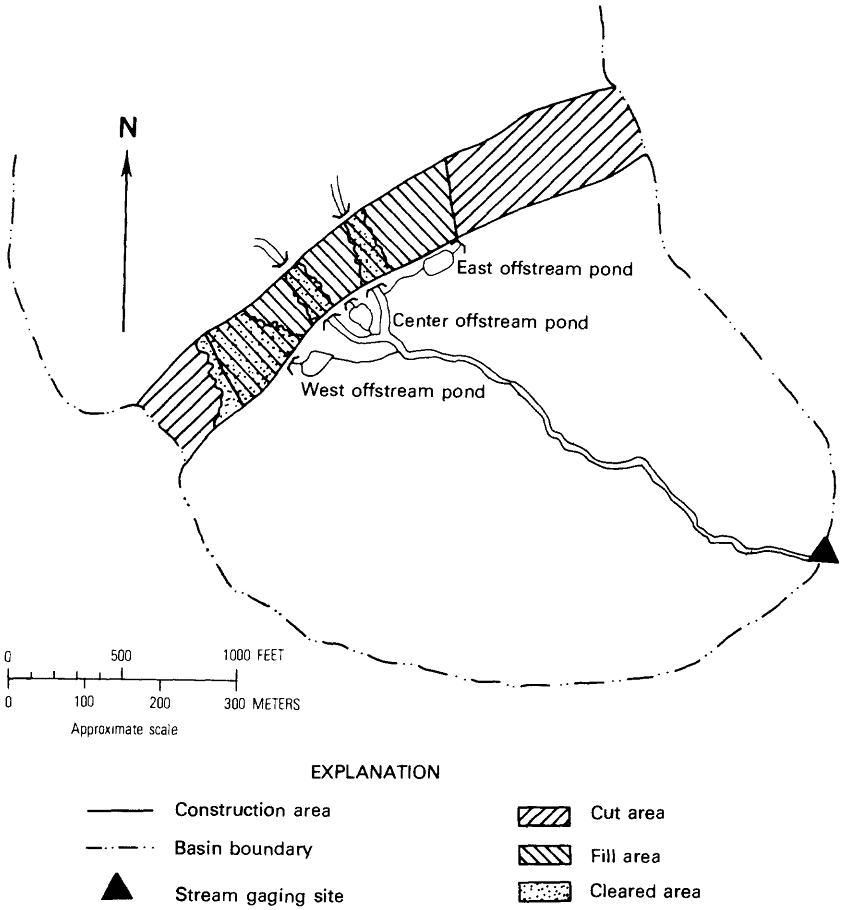


FIGURE 7.—Map of basin 2A.

ample opportunity to settle out because of their rapid settling velocities and the short distance they have to settle. As a result, the material that reaches deep flowing water at the edge of the construction area (fig. 5) is composed of a higher percentage of fine particles than actually exists on the construction area.

## 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 used seeding, mulching, and jute matting to reduce the exposed area. A second used check devices, such as small dams made of rock or straw-bales, to trap sediment. The third system used detention ponds to trap the runoff water and sediment. The detention ponds were of two types: one type was an onstream pond constructed directly 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.

### OFFSTREAM PONDS

Three offstream ponds were constructed in basin 2A. Each pond was designed to trap about half an inch of runoff. Generally, a 1-inch storm would produce half an inch of runoff. Figure 7 is a sketch map of basin 2A, showing the main features of the basin. A separate culvert system was used in connection with each pond. Each culvert system collected drainage from the construction area and discharged it directly to the sediment ponds. An additional culvert system was used to carry the normal streamflow from the upstream drainage area through the construction site.

The three offstream ponds constructed in basin 2A can be seen on figure 8. The west pond received runoff from 4 acres of construction and from a 6-acre field. Runoff from an area of about 5 acres drained into the center pond. The east pond received drainage from an area of about 8 acres. Inflow to the center and east ponds was entirely from the construction area.

Figure 9 shows the percent the offstream ponds in basin 2A reduced the suspended-sediment load during 32 individual storms. Data for seven storms that produced only small runoff while the percent silt, 13 percent coarse clay, and 57 percent fine clay. Those values are shown by the bar graph on figure 6. The figure also shows the particle-size distribution of the topsoil, the subsoil, and the suspended 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 6 it can be seen that there is only a slight relationship between the size distribution of the soil on the construction site and the size distribution of the material transported from the area as sediment.

Much of the material on a construction area that becomes suspended is probably redeposited in a relatively short time. If the soil 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 sand particles and many of the silt particles have more than

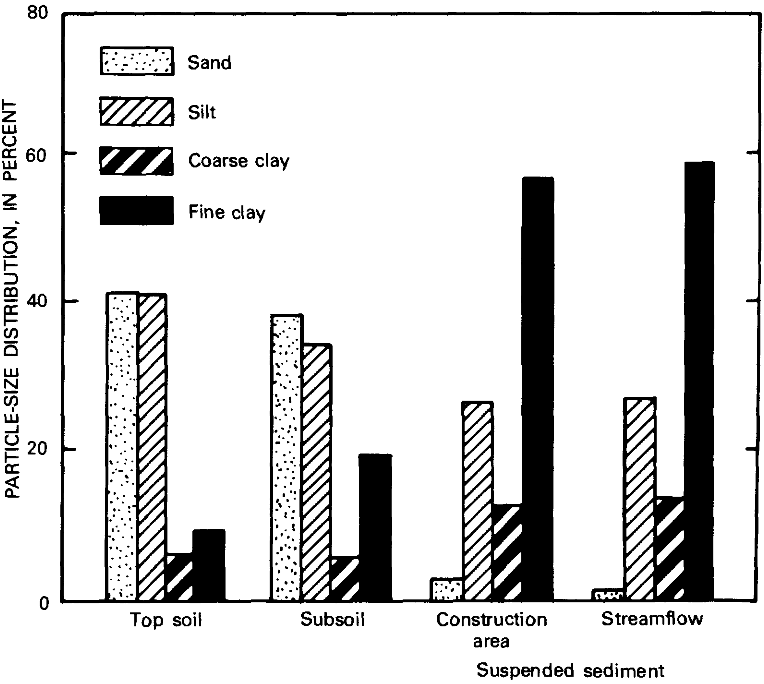


FIGURE 6.—Bar graph showing particle-size distribution in the soil and suspended sediment in samples collected on the construction site and from the streamflow in basins 2, 2A, 2B, and 3, December 6, 1972, to September 3, 1974.

Before construction started, the particle-size distribution of the suspended sediment transported from basins 2, 2A, 2B, and 3 averaged about 7 percent sand, 50 percent silt, and 43 percent clay. During construction, the particle-size distribution of the suspended sediment averaged 2 percent sand, 33 percent silt, and 65 percent clay. During the 2 years of postconstruction the particle-size distribution averaged about 20 percent sand, 45 percent silt, and 35 percent clay.

Samples of topsoil collected near the area disturbed by highway construction had an average particle-size distribution of 42 percent sand, 42 percent silt, 6 percent coarse 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 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 5 shows runoff water that was sampled in basin 2A on May 12, 1974. The sediment in the samples had an average particle-size distribution of 3 percent sand, 27

FIGURE 5.—Photograph showing runoff water sampled in basin 2A, May 12, 1974.

some values from the four basins affected by construction are from periods when operations near the streams increased mean suspended-sediment concentrations.

In basin 1, storm-runoff/suspended-sediment concentrations averaged about 45 mg/L during the 3-year period before highway construction began. Concentrations also averaged 45 mg/L during the 1973-74 period. During 1975, the concentrations averaged 42 mg/L; and during 1976, the concentrations averaged 69 mg/L. The high values in 1976 were caused by suspended sediment transported from a field that was converted from grass to soybeans. If the field had not been farmed, the concentrations for 1976 probably would have averaged about 45 mg/L.

Storm-runoff concentrations in the streams draining basins 2, 2A, and 3 averaged 49 mg/L before construction. During construction, the concentrations of the streamflow from the three basins averaged 195 mg/L, a threefold increase over the levels observed before construction. After construction, the concentrations averaged 49 mg/L from the three basins, the same values observed before construction. Storm-runoff suspended-sediment concentrations in the stream draining basin 2B were affected by farming operations during the postconstruction period. The farming operations in basin 2B probably contributed to the increases in suspended-sediment concentrations listed in table 7.

TABLE 7.—*Average daily-mean storm-runoff/suspended-sediment concentrations in milligrams per liter, Conodoguinet Creek tributaries 1, 2, 2A, 2B, and 3, October 1, 1969, to September 30, 1976*

| Basin | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 |
|---|---|---|---|---|---|---|---|
| 1 | 43 | 52 | 44 | 54 | 31 | 42 | 69 |
| 2 | 100 | 60 | 42 | [a]146 | [a]243 | [a]153 | 47 |
| 2A | 63 | 36 | 38 | [a]100 | [a]209 | 33 | 57 |
| 2B | 65 | 65 | 77 | [a]408 | [a]309 | 132 | 90 |
| 3 | 61 | 36 | 57 | [a]285 | [a]227 | 59 | 49 |

a Values affected by highway construction.

## 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. Samples were collected for particle-size analyses during the 3-year period before construction, during the 2-year period of construction, and during the 2-year postconstruction period.

disturbed by construction, and the effectiveness is proportional to the average area protected during the construction period. If a construction section contained 30 acres, the maximum area protected during construction is about 10 acres. During construction, the time-weighted average area protected by seeding and mulching is about 6 acres, about 20 percent of the area. Unlike the ponding devices, the reduction is proportional to the area protected, regardless of the size of 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 and side slopes are seeded and mulched and the roadway areas are protected by subbase and paving, sediment loads are substantially reduced.

Generally, seeding and mulching should be completed so that a good stand of grass is established by the time the pavement is

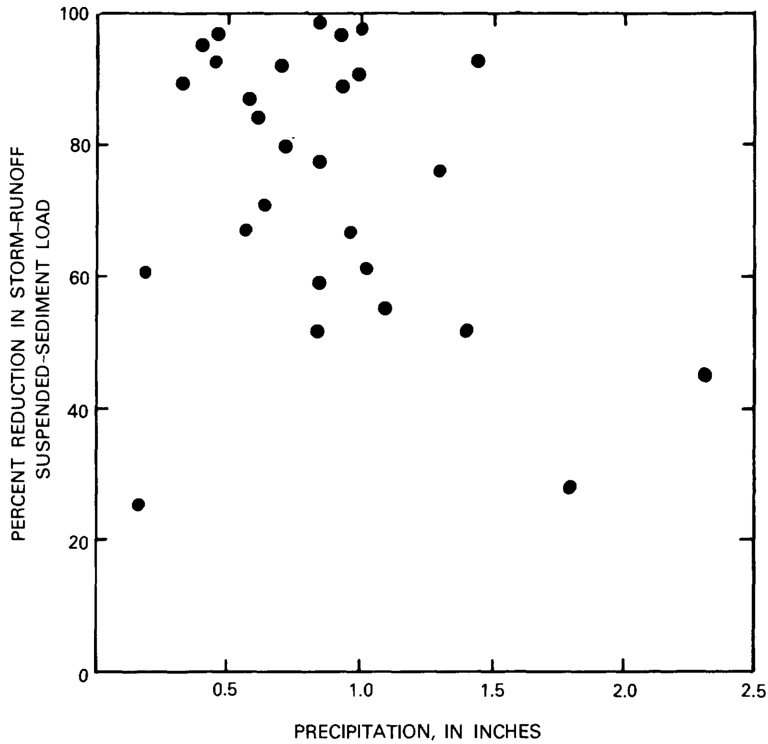


FIGURE 13.—Relationship between precipitation and reduction in the storm-runoff suspended-sediment load caused by the onstream pond in basin 2B, October 29, 1973, to August 3, 1974.

placed. In addition to the effectiveness of seeding and mulching in reducing sediment, green vegetation on a construction site has a more pleasing appearance.

### STRAW BALES

Bales may be used around small drop inlets, as dams or barriers and as erosion checks. They 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 deep, containing about 100 ft³ of water. Since drop inlets are normally

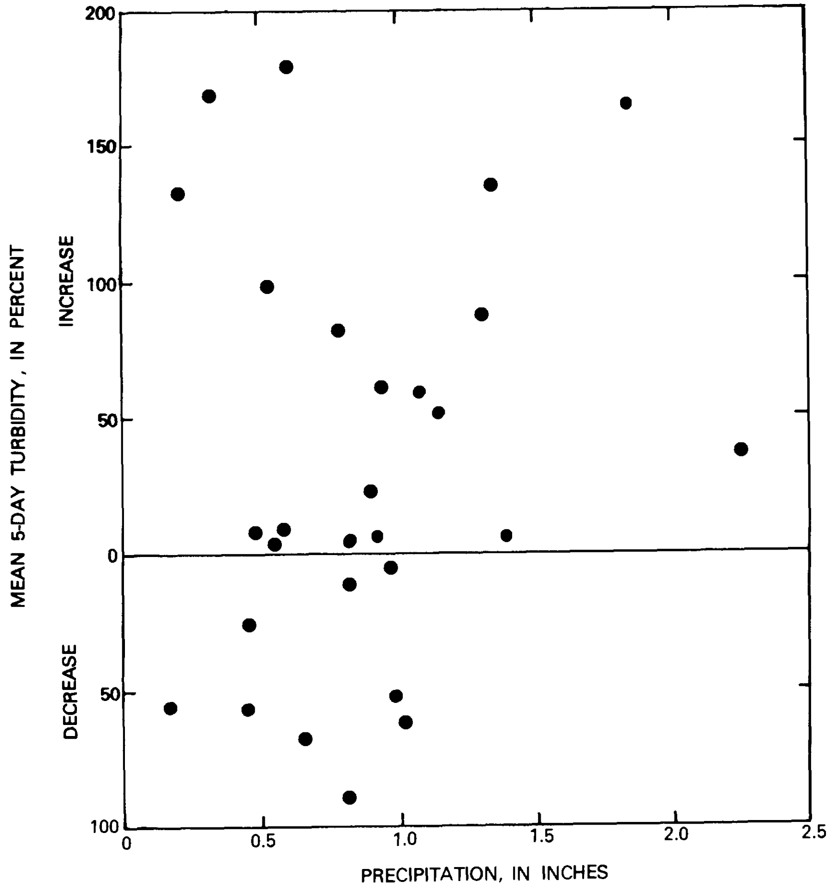


FIGURE 14.—Relationship between precipitation and percent the onstream pond increased or decreased the mean 5-day turbidity of the streamflow during and after periods of precipitation, Conodoguinet Creek tributary 2B, October 29, 1973, to August 3, 1974.

spaced 300 ft apart, the drainage area into each may be about 1 acre. If half an inch of runoff occurs during the storm, then the runoff from 1 acre of construction is 1,800 $ft^3$ of water. The efficiency of the bales is about 10 percent for such a storm. The efficiency is determined by particle-size distribution of sediment, amount of runoff water, and 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 the bales are placed where the drainage area is 1 acre 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

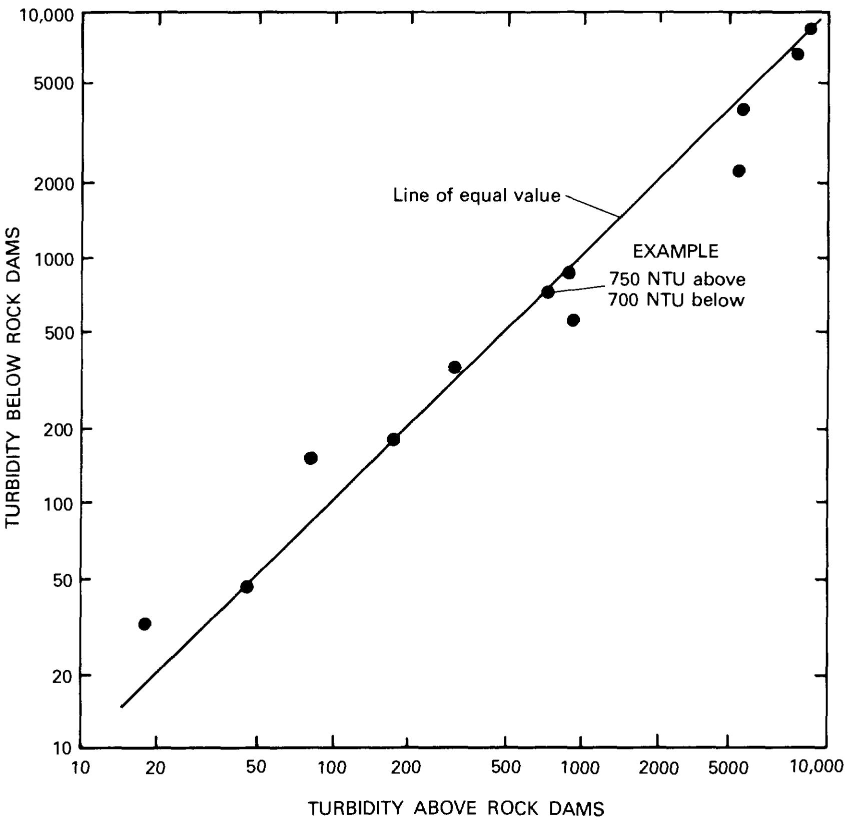


FIGURE 15.—Turbidity, in nephelometric turbidity units (NTU), of samples of runoff water collected above and below small rock dams, Conodoguinet Creek tributaries 2B and 3, September and October 1973.

drainage area is more than 3 acres, 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 from the toe of a slope. There, they can be installed at the start of earthmoving and left in place until construction is complete. The sand and gravel that washed down the side of the fill slope is trapped behind the bales; however, most of the silt and clay will pass over or between the bales.

### 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 they get smaller. Water is stored in the depressions during storms; 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.

### GRASSED FIELDS

Sediment may be substantially reduced when runoff water from construction areas drains into grassed fields. During small to moderate storms, the entire runoff from the construction section that drains across a grassed field may infiltrate before it reaches a stream. The effectiveness of grassed 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 grassed fields, are generally located off the right-of-way and are privately owned. 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 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 16 and 17 show two of the energy dissipaters that were installed. They have been successful at controlling or preventing scour at the outlets of the culverts.

FIGURE 16.—Photograph showing a rock stilling basin.

FIGURE 17.—Photograph showing a hydraulic jump energy dissipater.

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 the conveyance capacity may be reduced. The same can be caused by 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.

### LINED CHANNEL

Channel lining, like energy dissipaters, are designed to prevent local erosion. Much research has been done on channel linings (Normann 1975). New materials, such as fiber glass and plastic mats, are becoming available and 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, 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 onstream pond collected drainage from 41 acres of construction area, and cost about $15,000. The actual cost was more than $15,000, however, 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. Rock dams constructed in small drainage channels cost about $150 apiece, each controlling areas of 1 to 3 acres. Straw bales in place cost about $3.00 per linear foot and, when used around a drop inlet, cost about $50 per installation. Seeding and mulching on a temporary basis cost about $75 per acre.

## 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 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 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. 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 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.

If it is desirable to reduce sediment loads below the levels obtained with seeding and mulching, offstream ponds could be considered. When considering offstream ponds, the drainage patterns during the early stages of construction would be determined and compared with the final drainage patterns from the 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 half an inch of runoff is to determine the contributing drainage area, in acres, and to provide 75 cubic yards per acre 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, 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 also 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 is 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 to a populated area.

Rock dams can be used in small channels or in swales where the drainage area is about 1 acre. 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 located where they will be operational for as much time as possible.

Some form of lined channel—fiberglass, rock, rubble 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 dissipators 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 8. Their probable costs and the area which they can be expected to control is also listed.

## SUMMARY AND CONCLUSIONS

Seven years (1970–76) of precipitation, streamflow, and suspended-sediment data were collected from five small drainage basins west of Harrisburg. Four of the basins were crossed by construction of Interstate Highway 81. Data were collected for 3 years before construction began, for 2 years during construction, and for 2 years following construction.

Precipitation was generally uniformly distributed during the study period, averaging about 44.2 in. per year. Major storms occurred in 1972 (Hurricane Agnes) and in 1975 (Hurricane Eloise). Streamflow was also uniformly distributed during the 7-year period. Major streamflows occurred during the two major storms. The roadway construction did not produce any detectable changes in streamflow.

Sediment discharge was evaluated in three ways to determine the effects of construction and to determine if any detectable changes in sediment-discharge rates occurred after construction. Although the annual suspended-sediment discharge increased during construction from 100 to 300 percent, sediment discharge quickly returned to the preconstruction rate when construction was completed. Suspended-sediment concentrations in the streamflow during base-level and storm-runoff periods also returned to their preconstruction levels when construction ended.

TABLE 8.—*Summary of the effectiveness and the probable costs of the sediment controls used during construction of highway I-81, Conodoguinet Creek tributaries 2, 2A, 2B, and 3, November 10, 1972, to September 30, 1974*

| Type control | Effectiveness Sediment (percent) | Effectiveness Turbidity (percent) | Cost (dollars) | Construction area treated (acres) | Cost per acre (dollars) | 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. |

* Increase.

Offstream ponds with a storage capacity of half an inch of runoff trapped about 70 percent of the sediment from most storms. An onstream pond trapped about 80 percent of the sediment from most storms; however, it remained turbid and kept the streamflow turbid for extended periods. Seeding and mulching at frequent intervals reduced sediment loads about 20 percent; rock dams and straw bales reduced sediment loads about 5 percent.

## SELECTED REFERENCES

Guy, H. P., 1970, Fluvial sediment concepts: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 3, Chapter C1, 55 p.

——— 1976, Sediment-control methods in urban development; some examples and implications: Geological Society of America Special Spec. Paper 174, p. 1-35.

Norman, J. M., 1975, Design of stable channels with flexible linings: U.S. Department of Transportation Hydraulic Engineering Circular No. 15, 136 p.

Pennsylvania Department of Transportation, 1973, Erosion and sediment control: Roadway Construction-70, 4 p.

Pennsylvania Geological Survey, 1960, Geologic map of Pennsylvania: Pennsylvania Geological Survey, scale 1:250,000.

Porterfield, George, 1972, Computation of fluvial-sediment discharge: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 3, Chapter C3, 66 p.

Reed, L. A., 1976a, Sediment characteristics of five streams near Harrisburg, Pennsylvania, before highway construction: U.S. Geological Survey Water-Supply Paper 1798-M, 29 p.

——— 1976b, Hydrology and Sedimentation of Bixler Run Basin, central Pennsylvania: U.S. Geological Survey Water Supply Paper 1798-N, 20 p.

——— 1978, Effectiveness of sediment-control techniques used during highway construction in central Pennsylvania: U.S. Geological Survey Water-Supply Paper 2054, 57 p.

Swerdon, P. M., and Kountz, R. R., 1973, Sediment runoff control at highway construction sites: Pennsylvania State University Engineering Research Bulletin B-108, 120 p.

☆U.S. GOVERNMENT PRINTING OFFICE: 1980 O— 311-344/134