FINAL REPORT

EFFICIENCY OF EROSION CONTROL PRACTICES OF THE VIRGINIA DEPARTMENT OF HIGHWAYS AND TRANSPORTATION

by

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ABSTRACT

Twelve streams affected by highway construction were monitored to ascertain the effectiveness of the Virginia Department of Highways and Transportation's erosion and sediment control practices. The streams were located throughout Virginia in areas having different types of soil; viz., silts, sands, and clays. The results of the study indicate that the proper installation of erosion and sediment control measures prior to undertaking earthwork is very important. Also, proper maintenance of these measures until permanent vegetation is well established is critical in controlling silt. On a seasonal basis the need for control measures is more critical in the early spring and fall than at other times. Where stream work is unavoidable and the stream ecology will not be affected, in-stream structures such as rock check dams were determined to retain silt generated by construction activities. However, further work to determine the effects of these structures on the stream ecology is recommended before their use is made a standard practice.

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INTRODUCTION

Prior to the widespread use of erosion and sediment controls in the early 1970's, a number of studies had documented the sediment levels generated by construction activities (Wolman 1964; Wolman and Shick 1967; Vice et al. 1969; Anderson and McCall 1968; Davis and Brooks 1967; Dawdy 1967; Swerdon and Kountz 1973; Guy 1963; Guy and Ferguson 1962; Yorke and Herb 1976; Keller 1962; Eskelin 1976; and NACRF 1970). The reports on these studies provide excellent data on sediment levels resulting from unprotected construction sites, but provide little insight into the effectiveness of programs subsequently developed to control erosion and sedimentation.

The Virginia Department of Highways and Transportation has supported activities leading to improvements in erosion and sedimentation control since the early 1960s. The earliest research activities included investigations into the design of sediment basins; stabilization of slopes; temporary downdrains; monitoring procedures; and the filtering efficiency of straw barriers, silt fences, gabions, and log check dams (Wyant, Sherwood, and Walker 1972; Sherwood and Wyant 1974 and 1976; Wyant 1975, 1976a, 1976b, and 1980; Poche 1975; Poche and Sherwood 1975).

Despite the Department's extensive efforts of the 1970s to control sediment resulting from highway construction, only sparse quantitative data were developed for judging the success or failure of the overall erosion and sediment control program. For instance, on construction projects where erosion and sediment control measures were considered to be performing well, it was still unclear in most cases if the level of control was adequate to avoid adversely affecting the aquatic communities and water quality in the receiving streams or if excessive, unnecessary expenses were being incurred.

While several studies in the 1970s documented that excessive amounts of sediment have a detrimental effect on biotic communities (Cairns 1968; Gammon 1970; Sorensen et al. 1977), to the author's knowledge none differentiated between the effects of construction-induced sediment and background sediment on the biotic communities of a stream. It is very difficult to delineate effects of the former on the biotic communities, because many environmental factors, such as the type and amount of sediment, the hydraulic characteristics of the stream, and the intensity and duration of storm events, affect the response of biota. In fact, a search of the literature has shown no study in which there was continuous monitoring of the sediment levels and the biota up- and downstream of a highway construction project. In only two studies was there continuous monitoring of the sediment up- and downstream of highway construction (Eckhardt 1976; Hainly 1980).

Planning for the present study, which was to ascertain the effectiveness of the Virginia Department of Highways and Transportation erosion and sediment control practices on a total project basis, was initiated in early 1978. A task group composed of persons from the Location and Design, Construction, and Environmental Quality divisions and the Research Council was formed to assist with the formulation of the study and to provide guidance during its execution. Work was initiated in August 1978 with state funds (Wyant 1978). However, in May 1979, because of the nationwide application of the information being developed, the study was converted to an HPR project (Wyant 1979).

In February 1981, an interim report was prepared to summarize the work accomplished to that time (Wyant 1981). The report described in detail the sampling schedule for the different parameters, the procedure used to process the data, the stream monitoring completed on four construction projects, and the suspended sediment discharge results from these four projects.

PURPOSE

The study was undertaken at the request of the Construction, Environmental Quality, and Location and Design divisions to evaluate the erosion and sediment control practices employed by the Department on construction projects. At the beginning, however, it was emphasized that the findings might not be conclusive nor lend themselves to unqualified generalizations because of the myriad factors that must be considered in determining the effectiveness of the practices in use on any given project. Nevertheless, it was decided that the study would provide very useful data on the continuous monitoring of sediment levels and biota up- and downstream of construction projects in various physiographic areas of the state. In addition, the data to be collected on the effectiveness of the Department's erosion and sediment control practices on a total project basis would allow a comparison with the effectiveness of each control measure as determined in previous laboratory work.

Among the factors to be considered were the nature of the construction; soil type; degree of slope; extent of the drainage area affected; the amount and intensity of rainfall; the type, spacing, and number of erosion and sediment control structures placed; the number of storm events; the amount of runoff; magnitude and velocity of the stream flow; and the effort expended in maintaining the control structures.

The basic purpose of the research was twofold: (1) to evaluate, on a total project basis, the effectiveness of the erosion and sediment control practices in use by the Department, and (2) to determine what level of erosion and sediment control can be obtained using present methods designed, installed, and maintained at the highest practical level.

SCOPE

The research was planned to be conducted in two phases that would proceed simultaneously and independently. In phase I, a number of the Department's construction sites on which standard erosion and sediment control measures were in use were to be monitored over several storm events. While it was planned that three to five projects in each of the three major physiographic areas of the state (Coastal Plain, Piedmont, and Valley and Ridge) would be studied, this distribution was not obtained. Twelve projects, described later, were selected. Sampling stations were located up- and downstream from the construction site but as near as possible to the site to avoid interference from intervening areas. Automatic samplers were used to obtain samples of total nonfilterable solids (suspended solids) and depth-integrated hand samples were obtained periodically (ASTM 1981; APHA, AWWA, WPCF 1975). Stream flow and rainfall were determined continuously at each site (Howell et al. 1972). Concurrently, periodic sampling and processing of in-stream biota were carried out by the Environmental Quality Division.

For phase II, a single stream affected by a specially selected construction project was to be monitored continuously for sediment. The project was to receive the best (design, installation, and maintenance) in erosion and sedimentation control consistent with the state of the art. The erosion and sediment control measures were to be designed to the highest practical level by the Research Council and the Location and Design Division, and be installed and maintained by the Research Council. This project was to be located close to the Research Council laboratories in Charlottesville and in very erosive Piedmont soils. It was expected that this phase of the study would provide a determination of the best results that could be expected when taking special care in the design, installation, and maintenance of the presently used erosion and sediment control measures. As in phase I, data on fish and benthic organisms in the receiving stream were to be generated by the Environmental Quality Division.

Seven or eight projects were screened as a possible site for phase II, but after several delays, the latest one lasting until the spring of 1982, it was decided to forego this part of the study. Through consultation with Federal Highway Administration officials, it was decided to terminate the study and submit a final report covering phase I. Also, it was decided that if a suitable site for the planned phase II research were to be found in the future, another working plan covering this phase would be submitted to the Federal Highway Administration to obtain HPR funding.

SUMMARY OF PROJECTS

As noted above, stream monitoring was completed on twelve construction projects under phase I of the study. As noted in Figure 1, seven of these were in the Piedmont Province, three in the Valley and Ridge, and two in the Coastal Plain. More Piedmont streams were monitored than originally proposed since several of these had been selected as possibilities for use in the aborted phase II research, and monitoring had been commenced before they were dropped from consideration. In addition, the micaceous silt of the Piedmont is the most erosive soil in the state, and it was decided that the data from two additional projects would enhance the evaluation of the erosion and sediment control practices.

P = Project in the Piedmont.

V = Project in the Valley and Ridge.

C = Project in the Coastal Plains.

P1 BUCK MOUNTAIN CREEK
P2 BUCK CREEK
P3 ROCKFISH RIVER
P4 MECHUMS RIVER
P5 WRECK ISLAND CREEK
P6 COUCHES CREEK
P7 TOMMEHETON CREEK
V1 BIG WALKER CREEK
V2 SINKING CREEK
V3 NORTH FORK SHENANDOAH RIVER
C1 SOUTH ANNA RIVER
C2 SOUTH RIVER

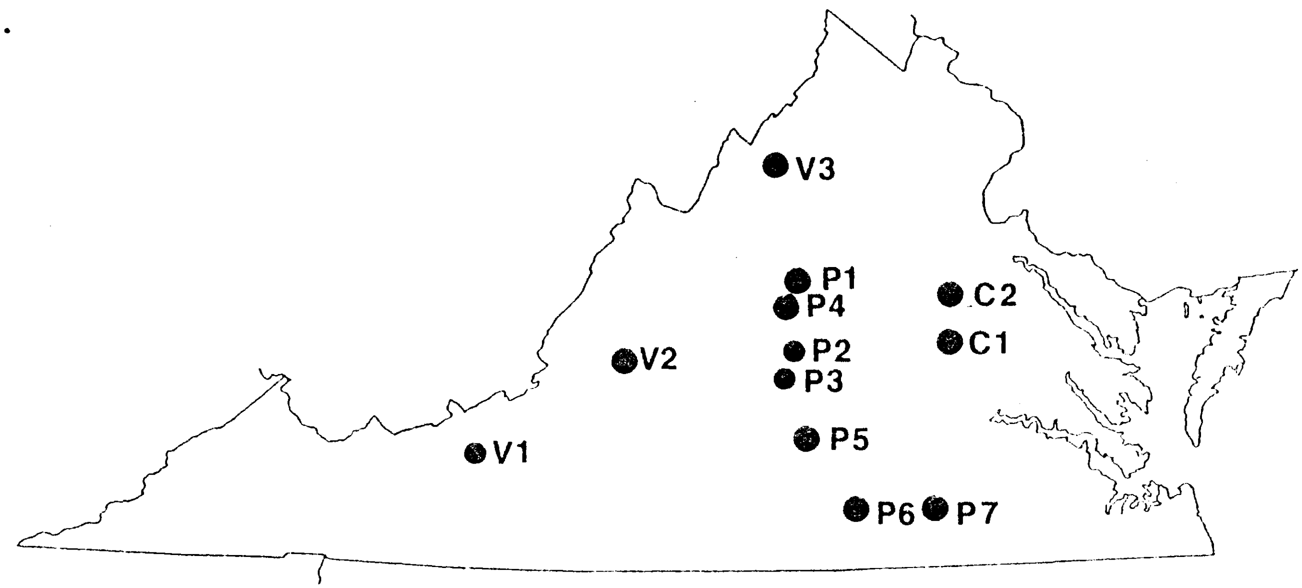

Figure 1. Locations of stream monitoring.

Because of the difficulty encountered in locating suitable projects, mainly because of the Department's economic situation, only two Coastal Plain projects were monitored. Four additional projects in that area were either monitored for background data or had been equipped for monitoring in anticipation of the start of construction when the study was terminated. Because of the economic situation, construction on these projects was delayed several times.

In the project descriptions that follow, little information, other than the results, is given on the four projects (P1, P2, P3, and V1 in Figure 1) described in detail in the interim report (Wyant 1981). For descriptive data on these, the reader should see that report.

The descriptions of the other eight streams include information on the watersheds and construction projects along with the data on water quality obtained by the Research Council. These data were essentially the same for the upstream and downstream sampling stations, but where differences or trends were noted they are pointed out here. The data on stream biota collected by the Environmental Quality Division are given in Appendix A along with comments on any noteworthy results.

Buck Mountain Creek, P1*

The data on suspended solids indicated that for ambient flow conditions and significant storm events, large amounts of soil were transported by Buck Mountain Creek and deposited within the construction limits during the winter months. This deposition was evident in the area of the new bridge where the velocity of the stream decreased.

It was noted that the erosion control measures were in place for approximately 5 months, and that, from the results obtained, they appeared to have performed their intended function of retaining silt. The results indicate that during the early spring storm events it was critical to have properly installed and maintained erosion control measures to prevent the movement of large amounts of eroded soil from the construction project into the stream.

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*Notation used on Figure 1.

Buck Creek, P2

Like Buck Mountain Creek, Buck Creek is a Piedmont stream, but smaller. No erosion and sediment control measures were installed on the project, except large riprap placed where the channel was changed. High sediment discharges were determined during several of the storm events. Since most of the eroded soil was deposited on the streambed, the automatic equipment monitoring the suspended sediment did not obtain data reflecting the condition of the stream as compared to Buck Mountain Creek.

Rockfish River, P3

Rockfish River is a large Piedmont stream that had a causeway built into it to accommodate construction on the project. Only riprap was used for erosion control. There were no monitored storm events during the early spring breakup, but data were obtained for two events in the early fall. These data indicated that large loads of waterborne sediment were generated but during only one event were these carried downstream. During the other event the sediment was deposited between the monitoring stations and the construction limits of the project.

Big Walker Creek, V1

Big Walker Creek is a large stream located in the Valley and Ridge physiographic area, where the soil is predominantly clayey. No erosion and sediment controls were installed on the project. Large amounts of soil were carried from the project into the stream during periods of high erosion and flow. The results indicate how a small construction project not protected against erosion and sedimentation can adversely affect a large stream.

Mechums River, P4

On this project, Rte. 601 in Albemarle County was relocated and improved for approximately 0.96 mi. (1.54 km). A two-lane 182 ft. (55 m) long concrete bridge was to replace a single-lane, steel-truss bridge. Approximately 2,400 ft. (732 m) of the new roadway on the southern end of the project drained into Mechums River. The grade of the roadway on this end was 6.8%. The northern end of the project was essentially flat with very little drainage into the river.

The drainage basin of Mechums River above the project encompasses 98.8 $mi.^2$ (255.9 km^2). For the most part, the basin is rolling farmland, but there are some heavily developed areas.

The plans called for straw silt barriers at the outlet ends of all pipes, in the two wet-weather ditches (one on each end of the project), and near the banks of the river. Two straw check dams and a total of 1,811 lin. ft. (552 m) of straw silt barriers were specified on the plans. In addition, 421 $yd.^3$ (322 m^3) of riprap protection was specified in the lower 400 ft. (122 m) of the large wet-weather ditch on the southern end of the project. An additional 71 $yd.^2$ (59 m^2) of riprap were specified at two locations in this section of the ditch for added bank protection. A plan view of the project and locations of the erosion and sediment control measures are shown in Figure B-1 of Appendix B.

Most of the earthwork, which presents a great potential for erosion problems, was done on the southern end of the project and above the wet-weather ditch. A total of 4.90 acres (2 ha) of disturbed area was specified on the plans for seeding.

Long straw and brush silt barriers were placed at the toe of the 8 to 10-ft. (2.4 to 3.0-m) fills on the northern end of the project. Barriers in addition to the ones specified on the plans were installed throughout the project. The number of erosion control measures and their locations were more than adequate. However, in most cases the measures were not properly installed. Several times during storm events muddy water entered Mechums River from the wet-weather ditch on the southern end of the project. Several of the brush and straw bale barriers placed in the ditch to trap silt appeared to be ineffective because of improper placement.

A stage-discharge curve for Mechums River was developed and is included in Figure B-2 of Appendix B.

Using the suspended solids and discharge data generated during ambient flow and storm events, the instantaneous sediment discharges were determined. Tables 1 and 2 give the suspended sediment discharges for ambient flow conditions and storm events, respectively. Plots of the suspended solids levels, stream flow, and rainfall for the storm events are shown in Figures C-1 through C-12 of Appendix C.

Table 1

Suspended Sediment Discharge for Mechums River
During Ambient Flow Conditions
(Construction commenced June 1980)

Month	Mean Discharge, ft.^{3}/s	Suspended Sediment Discharge, lb./hr. Downstream	Upstream	Difference
June	47	84	123	- 39
July	42	297	303	- 6
August	38	129	367	- 238
September	39	163	310	- 147

Conversion: 1 ft.^{3}/s = 0.028 m^3/s

1 lb./hr. = 0.454 kg./hr.

Table 2

Suspended Sediment Discharge for Mechums River
During Storm Events
(Construction commenced June 1980)

Date	Total Rainfall, in.	Monitoring Time, hr.	Suspended Sediment Discharge, lb. Downstream	Upstream	Difference
July 9	0.24	9	9,800	14,200	- 4,400
July 10	0.11	6	50,000	51,800	- 1,800
July 22	1.03	15	962,200	2,077,200	-1,115,000
July 28	0.54	16	67,800	98,400	- 30,600
Aug. 5	0.64	23	536,200	2,056,800	-1,520,600
Aug. 18	0.56	22	9,400	18,200	- 8,800

Conversion: 1 in. = 2.54 cm

1 lb. = 0.454 kg

Table 1 indicates that the stream flow in Mechums River, as was the case for most streams in Virginia in the summer of 1980, reduced because of the lack of significant rainfall. Also, Table 1 shows that the suspended sediment discharge was less downstream than upstream, which indicates sediment was deposited between the two sampling sites during ambient flow conditions. The lowest stream flow (38 $ft.^3/s$) occurred in August as did the highest suspended sediment discharge between the monitoring stations (238 lb./hr.).

Table 2 indicates that deposition between the sampling sites also occurred during the monitored storm events, there being two probable reasons. First, errors in the data could possibly yield these results (see section on SAMPLING ERROR). However, the largest source of error would be the location of the sampler suction hoses. As was done on all streams, the sections of the stream (up- and downstream) chosen for monitoring were similar in width, depth, and stream velocity. The suction points were placed at a depth to allow proper sampling during low flow periods as well as storm events when the bedload material would increase. In addition, the suction points were located as far as possible into the stream to avoid interference from the stream bank and any obstructions, such as fallen trees in the stream.

The second probable reason for the indication that deposition occurred between the two monitoring stations during the storm events relates to the widening of the stream in this area. This would cause a reduction in stream velocity that, in turn, would cause sediment to drop from suspension. With this occurring and most soil in the construction-generated runoff being retained by the erosion and sediment controls, it is understandable that the downstream sampler would measure less sediment in the stream. It should be noted that the muddy water recorded to be entering Mechums River during several storm events was not necessarily loaded with silt. At this location, the muddy color may be caused by filtrable residue or material that cannot be retained by erosion control materials and thus give the water an appearance of being sediment-laden.

In summary, this project is a good example of the results possible when erosion and sediment control measures are used in the proper locations. As mentioned earlier, it is believed that more than enough measures were installed, but that most of them were not installed properly. The remaining question is, Could similar results have been obtained if fewer measures had been used but had been installed properly? It is the opinion of the researcher, based on his experience in installing erosion control measures, that the answer is yes, and that some monetary savings could thus have been achieved.

Wreck Island Creek, P5

On project P5, Rte. 605 in Appomattox County was relocated and improved for 3,050 ft. (930 m). A 126-ft. (38-m), two-lane concrete bridge replaced a 62-ft. (19-m) single-lane wooden bridge over Wreck Island Creek. A 512-ft. (156-m) portion of roadway on the southern end of the project drained into Wreck Island Creek on a 5.9% grade. The northern end of the project was longer (2,412 ft. [735 m]) and steeper (11.5% grade) than the southern end.

The project required a 23,949 yd.^{3} (1.8×10^4-m^3) excavation and a 17,382 yd.^{3} (1.3×10^4-m^3) fill. A 4-acre (1.62 ha) area was to be distributed and revegetated according to the Department's specifications. In addition to the revegetation, the plans specified that 11 baled straw check dams and 1,044 ft. (318 m) of straw silt barriers be used as temporary control measures. To filter and contain the sediment pumped from the bridge footings and pier areas, a sediment trap with a heavy mil polyethylene sheet overflow to a filter-fabric silt fence was used. After the sediment-laden water passed through the silt fence, it returned to Wreck Island Creek. A plan view of the project and the locations of the various control measures are shown in Figure B-3 of Appendix B.

Construction on the project commenced in mid-April 1980 and was terminated in mid-September 1980. Seeding was done in stages as specified. In late May, sediment was evident in the pasture field east of the northern end of the project, and the sediment was heavy enough to make the stream muddy during several storm events in late May. Afterwards, straw bale and silt fence barriers were installed to correct the sediment problems on the northern side of Wreck Island Creek. However, in the opinion of the writer, not enough barriers were installed, nor were the straw bale barriers entrenched to prevent undermining. At the same time, riprap was installed near both ends of the bridge over Wreck Island Creek and the entire project was seeded.

In late July, it was noticed that large amounts of erosion had occurred on the project and the control of sediment was inadequate. Approximately two weeks later, the contractor placed straw bale barriers on the project and reseeded. Approximately one month after completion of the project (early October), grass was established on the slopes and the straw bale barriers seemed to be performing adequately.

A stage discharge curve for Wreck Island Creek was developed and is included in Figure B-4 of Appendix B. Tables 3 and 4 give the suspended sediment discharges for ambient flow conditions and storm events, respectively. Plots of the suspended solids, stream flow, and rainfall for the storm events are shown in Figures C-13 through C-24 of Appendix C.

Table 3

Suspended Sediment Discharge for Wreck Island Creek During Ambient Flow Conditions (Construction commenced April 14, 1980)

		Suspended Sediment Discharge, lb./hr.		
Month	Mean Discharge, $ft.^3/s$	Downstream	Upstream	Difference
April	61	61	70	- 9
June	25	54	48	6
July	20	75	72	3
August	18	5	55	-50
September	13	14	15	- 1

Conversion: 1 $ft.^3/s = 0.028\ m^3/s$

1 lb./hr. = 0.454 kg./hr.

As noted in the discussion of the Mechums River project, the summer of 1980 was dry and lacked significant rainfall, as evidenced by the discharge for the different months (Table 3). The upstream and downstream suspended sediment discharge values were almost equal for all months except August, when there apparently was a deposition of sediment between the two monitoring stations.

Table 4

Suspended Sediment Discharge
For Wreck Island Creek During Storm Events
(Construction commenced April 14, 1980)

Date	Total Rainfall, in.	Monitoring Time, hr.	Suspended Sediment Discharge, lb.		
			Downstream	Upstream	Difference
April 25	0.09	15	7,600	8,000	- 400
April 29	0.75	13	3,400	3,600	- 200
April 30	0.40	17	2,200	3,400	-1,200
June 24	0.03	14	6,200	1,400	4,800
July 23	0.35	10	400	200	200
July 23-24	0.13	9	400	400	0
Sept. 24-25	0.33	16	4,000	7,200	-3,200
Sept. 30	0.32	22	2,800	1,400	1,400

Conversion: 1 in. = 2.54 cm.

1 lb. = 0.454 kg.

Table 4 lists the eight storm events monitored. Several of these were small, but have been included in Table 4 because the summer was dry and significant rain events were scarce. Table 4 indicates that the larger storm events (0.32 in. [0.8 cm] and larger) contributed little if any sediment to the stream. In most cases deposition was indicated for these storm events. The smallest storm event (0.03 in. [0.08 cm]) contributed 4,800 lb. (2,179 kg.) of sediment to the stream from the project over the 14 hours of monitoring. This storm was included in the results to show that even with carefully planned and supervised studies of this type involving many variables, various problems and situations can arise to create errors. As mentioned earlier, with the equipment available on the market today, sampling errors are a big problem. The equipment does not collect integrated samples and the depth and size of the samples vary with stream flow.

However, the main problem with this small storm event creating the largest sediment discharge is the unmeasured effect of a localized storm. The storm occurred on one end of the project, while the rain gage was located across Wreck Island Creek on the other end where little rain fell. Therefore, sediment was generated from the project by more rainfall than is indicated in Table 4.

Several large rain events were mentioned earlier as occurring in late May and making Wreck Island Creek muddy. Attempts to monitor these events were unsuccessful because of various problems; e.g., once the sampling hose was pulled loose from the sampler by debris, on another occasion the hose was pinched by the water flow, and on a third there was a mechanical failure of a sampler.

In summary, for various reasons no large amounts of sediment were generated on this project: the erosion control measures were effective, an adjacent pasture retained large amounts of sediment, a seeding program was employed, and there was a lack of large rain events.

Couches Creek, P6

This project was in Lunenburg County where Rte. 40 was straightened across Couches Creek for 2,580 ft. (786 m). A 188-ft. (57-m) long, two-lane concrete bridge was to replace a narrower concrete bridge. The roadway on the northern end of the project was designed to drain into Couches Creek at a 4.5% grade, while the southern end was to be graded at a 6.7% slope. The drainage basin above the project is 8.5 $mi.^2$ (22.0 km^2).

The construction was to denude 4.0 acres (1.62 ha) that would require seeding. The plans specified that 1 rock check dam, 300 ft. (91 m) of fabric silt fence, and 1,081 ft. (330 m) of straw silt barriers be used as temporary erosion control measures until permanent vegetation was established. A plan view of the project and the locations of the various erosion and sediment control measures are shown in Figure B-5 of Appendix B.

Construction on this project commenced in mid-April 1980. Initially, most of the work was done on the bridge footings and the southern end of the project. Within the first week of work, approximately 800 ft. (244 m) of straw silt barriers were installed and the rock check dam was constructed as specified. As the work progressed over the next week to 10 days, the silt fences were installed. During the middle of May some of the straw bale barriers were washed out during several storm events. Approximately a week later, new barriers were installed where needed. During June it was noted that a large amount of sediment had been carried from the construction work upstream and deposited under the old bridge. As small storm events occurred and work progressed the straw bale barriers were maintained very well. In early July, riprap was placed in the pier areas. In mid-July, as the stream became very low, the contractor dug a large hole in the middle of the stream to remove the sediment and to store water for allaying dust on the project. This cleanout caused the stream to become very muddy.

A stage-discharge curve for Couches Creek is shown in Figure B-6 of Appendix B. Tables 5 and 6 give the suspended sediment discharges for ambient flow conditions and storm events, respectively, and plots of the suspended solids, stream flow, and rainfall for the storm events are shown in Figures C-25 through C-34 of Appendix C.

Table 5

Suspended Sediment Discharge for
Couches Creek During Ambient Flow Conditions
(Construction commenced April 1980)

Month	Mean Discharge, ft.^{3}/s	Suspended Sediment Discharge, lb./hr.		
		Downstream	Upstream	Difference
March	0.6	1.9	3.1	- 1.2
April	15.9	54.2	66.3	- 12.1
May	5.4	27.9	30.0	- 2.1
June	3.6	17.9	12.0	5.9
July	1.2	8.2	1.3	6.9

Conversion: 1 ft.^{3}/s = 0.028 m/^{3}s
1 lb./hr. = 0.454 kg./hr.

Table 6

Suspended Sediment Discharge for
Couches Creek During Storm Events
(Construction commenced April 1980)

Date	Total Rainfall, in.	Monitoring Time, hr.	Suspended Sediment Discharge, lb.		
			Downstream	Upstream	Difference
April 14	0.60	12	7,960,000	10,364,000	-2,404,000
May 19-20	1.22	16	372,000	548,000	- 176,000
May 20-21	1.81	17	482,000	490,000	- 8,000
May 23	0.28	6	5,200	7,800	- 2,600
July 10-11	0.92*	8	2,000	1,200	800

*Total rainfall only. Wires came loose on continuous recording gage, so used data from standing rain gage.

Conversion: 1 in. = 2.54 cm.

1 lb. = 0.454 kg.

Table 5 indicates that the mean discharge increased for the month of April but decreased through the summer months. For March through May, deposition occurred between the two monitoring stations. During June and July, however, sediment generated or deposited on the construction site was transported at an average rate of 5.9 lb./hr. or 142 lb./day, and for July this rate was even higher, 6.9 lb./hr. or 166 lb./day. As mentioned earlier, most of this sediment had been deposited under the old bridge during June. The amount of sediment transported from the project may have been greater had the rock check dam not been installed.

Table 6 shows the suspended sediment discharge during the five monitored storm events. The results are varied, but they indicate that sediment was deposited within the limits of construction during four of the storm events. The data indicate that the rock check dam retained sediment on the construction site. When the contractor cleaned out an area behind the dam in July to store water, sediment was resuspended and muddied the stream. From the limited amount of data collected, this activity did not appear to cause heavily sediment-laden water downstream. However, as do all in-stream structures, the rock check dam did affect the stream flow and may have affected the benthic population. Thus, although the use of in-stream structures is against the Department's policy, they may be of some benefit where the control of sediment for stream work cannot be achieved by any other method. Perhaps further research needs to be done in this area.

In summary, the erosion and sediment control measures on this project seemed to perform satisfactorily. The measures were installed in the proper locations and prior to work in the immediate area, and required repairs and replacements were usually made within one week. As on the other monitored projects, the straw bale barriers were not entrenched as specified on the plans.

Tommeheton Creek, P7

This project was also on Rte. 40, but in Dinwiddie County. The road was improved across Tommeheton Creek in the late summer of 1981. The existing two-lane concrete bridge was replaced with a wider one at a higher elevation to reduce the chances of flooding. The new bridge was designed to be 110 ft. (34 m) long, and the roadway was to be straightened and improved over a length of 4,511 ft. (1,375 m). The west end of the project was graded to drain into Tommeheton Creek at a 6% slope and the east end had a slope of 5.8%. The drainage basin of Tommeheton Creek above the project covers 11.4 $mi.^2$ (29.5 km^2).

The construction required 22 acres (8.9 ha) of land to be denuded and reseeded according to the Department's specifications. The plans for the project required that any wetlands destroyed be replaced on an equal acreage basis. The approximate acreage of wetland to be restored was 3 to 4 acres (1.2 to 1.6 ha) as noted on the plan view of the project in Figure B-7 of Appendix B.

The plans for the project specified that 6 baled straw check dams, 954 ft. (291 m) of straw silt barriers, 1,420 ft. (433 m) of temporary silt fence, and 2,868 yd.^{2} (2,398 m^2) of filter cloth for brush barriers and fabric check dams be used for protection against siltation until permanent vegetation was established. The locations of the erosion and siltation control measures are also shown in Figure B-7 of Appendix B.

Construction had commenced on Rte. 40 before the project was selected for study and the monitoring equipment installed in early August 1981. Reseeding of denuded areas upstream of the bridge construction in the area of the upstream sampler (Figure B-7 of Appendix B) was completed by the time the monitoring equipment was installed. The required baled straw check dams and silt barriers were installed around mid-August. Prior to the construction of the wetland area in late August, the temporary silt fences were installed. As noted on the plan view the restored wetland was further upstream than were the background or upstream sampling station. The location for the upstream station was dictated by the possibility of flooding in the lowland area upstream and the proximity of a military base. Only twice did flooding from the restored wetland result in erroneous data on stream sediment and these incidents are noted in the results.

Any needed maintenance on the erosion and sediment controls was usually performed within several days after a storm event. Several times, most noticeably during the October 27 storm event, the silt fences on the west side of Tommeheton Creek could not hold the runoff, which passed over the fence and eventually pulled it down.

The stage-discharge curve for Tommeheton Creek is given in Figure B-8 of Appendix B. Tables 7 and 8 give the suspended sediment discharges for ambient flow conditions and storm events, respectively, and plots of the suspended solids, stream flow, and rainfall for the storm events are shown in Figures C-35 through C-46 of Appendix C.

Table 7 indicates a small decrease in stream discharge from August to September, which is typical of most streams in Virginia during 1981 because of the drought. In September there was deposition in the stream, while sediment was transported from the construction limits during ambient flow conditions during August and October. It is estimated that less than 1 ton per day (907 kg/day) was transported downstream from the project.

Table 7

Suspended Sediment Discharge for Tommeheton Creek During Ambient Flow Conditions (Construction commenced prior to August 1981)

Month	Mean Discharge, $ft.^3/s$	Suspended Sediment Discharge, lb./hr.		
		Downstream	Upstream	Difference
August	33.5	120	80	40
September	32.8	114	124	-10
October	32.8	220	140	80

Conversion: 1 $ft.^3/s$ = 0.028 m^3/s

1 lb./hr. = 0.454 kg./hr.

Table 8

Suspended Sediment Discharge for Tommeheton Creek During Storm Events (Construction commenced prior to August 1981)

Date	Total Rainfall in.	Monitoring Time, hr.	Suspended Sediment Discharge, lb.		
			Downstream	Upstream	Difference
Aug. 21	0.49	27	4,800	2,800	2,000
Sept. 6	0.31	27	3,600	42,600	-39,000*
Sept. 15	1.00	10	4,200	23,800	-19,600*
Sept. 16	0.81	10	11,600	26,800	-15,200
Oct. 22	0.33	13	2,800	4,400	- 1,600
Oct. 27	0.69	9	8,200	11,400	- 3,200

Conversion: 1 in. = 2.54 cm

1 lb. = 0.454 kg.

*Flooding from restored wetland affected upstream samples.

Table 8 indicates that sediment was retained within the construction limits of the stream during five of the six storm events. However, as noted earlier, flooding of the silt fence around the restored wetland twice in September caused erroneous data from the upstream sampler. From a comparison of the results of these two storm events with those of the others it would seem that the silt fences being flooded did not significantly affect the data.

A notable occurrence on this project was the construction of a beaver dam just below the downstream sampler after it was installed in August. As would be expected, this dam reduced the stream flow and caused the deposition of sediment. As was noted for the previous construction project, in-stream structures increase the on-site deposition of sediment but create problems when they are removed or cleaned out.

In summary, this project indicates the benefit of in-stream structures, whether planned or not, prompt seeding of denuded areas, the installation of erosion and sediment control measures prior to earth-disturbing activities, and prompt maintenance. It shows that sediment in a stream can be retained within the limits of construction during a storm event and then be transported downstream during ambient flow conditions.

Sinking Creek, V2

Project V2 consisted of improving a 4,745-ft. (1,446 m) section of Rte. 220 through the community of Gala in Botetourt County. Included in the improvement was the replacement of a narrow two-lane, 132-ft. (40 m) long concrete bridge across Sinking Creek with a wider one. Although this area of Virginia is mountainous, Rte. 220 runs through lowland with a mountain on the west and railroad tracks on the east. A plan view of the project is shown in Figure B-9 of Appendix B.

Most of the drainage into Sinking Creek from the construction-affected area was from the 1,400 ft. (427 m) of roadway on the northern end of the project. Sinking Creek received very little drainage from the 300-ft. (91 m) section of roadway to its southeast. Southeast of this point, runoff from the project was carried to another stream. The average grade of the roadway draining into Sinking Creek was 0.4%.

The drainage basin of Sinking Creek above this construction site is 21.9 $mi.^2$ (57 km^2), most of it mountainous and lightly developed. As shown on the plan view, Sinking Creek is a tributary of the James River, and in certain incidents during this study, its backwaters flooded the surrounding lowland because of the high flow in the James.

The plans stated that 4.6 acres (1.9 ha) of land would be denuded during construction and would be reseeded by the contractor according to the Department's specifications. While permanent vegetation was being established, 1,454 ft. (443 m) of silt fence and 471 ft. (144 m) of straw silt barriers were to be in place as temporary erosion and sediment control measures. In addition, riprap and 1 silt trap were to be installed to control erosion and sediment in several critical locations. The various erosion and sediment control measures are shown on the plan view.

Construction equipment was moved onto the project in early March and the contractor commenced work soon afterwards. Initially, he relocated the drainage ditch on the east side of Rte. 220 south of Sinking Creek. After several floodings of the lowland during early May, water sampling of Sinking Creek proceeded satisfactorily. By mid-May the contractor had done extensive earthwork on the project. In conjunction with this work various erosion and sediment control measures were employed, but some measures were not installed until after a May 8 storm event that was monitored for this study. Cut slopes had been serrated to enhance the establishment of vegetation and the denuded areas were seeded in stages. Straw bale check dams and a rock check dam were installed in the drainage ditch on the southern end of the project. Filter fabric silt fences were installed as shown on the plan view, since work around Sinking Creek was proceeding rapidly. All of the silt fences were installed properly.

By mid-May work on the bridge over Sinking Creek was under way and erosion and sediment control was provided in this critical area. A causeway for pier construction was built approximately halfway across Sinking Creek. A cofferdam was installed around the pier area after the causeway was built. Riprap and straw bale barriers were placed between the stream and the toe of the bridge fills as shown on the plan view. The straw bale barriers were not entrenched as called for on the plans.

Additional erosion and sediment control measures were installed as needed throughout the course of construction, in addition to the seeding on the project.

All erosion and sediment control measures were maintained properly as specified by the Department except during the month of August, when construction on the southern end of the project was terminated. The measures were sited satisfactorily. Placement of the straw bale barriers presented the biggest problem. During the middle of May, water pumped from around a pier footing into the drainage ditch behind the straw bale and rock check dams returned to Sinking Creek, causing it to become muddy. The turbidity was not caused solely by extremely fine particles that are hard to remove with standard control measures; additional suspended solids could have been removed if the straw bale dam in the drainage ditch had been properly entrenched. Figure B-10 indicates that suspended solids levels of 25 to 40 ppm were reached downstream after sediment-laden water was pumped from the pier footings during the period from May 13 to May 15. On May 14 a hole came in the cofferdam and the level of suspended solids went as high as 75 ppm. The suspended solids level near the pier construction was probably higher than these measured values, since the sampling equipment was 150 to 200 ft. (46 to 61 m) downstream. In addition, Figure B-10 shows the effects of two storm events omitted from the results from the other monitored events because flow data were unavailable. However, the 0.23 in. (0.58 cm) storm event on May 12 created a peak suspended solids level nearly equivalent to the levels during the pumping operations.

A stage-discharge curve for Sinking Creek is included in Figure B-10 of Appendix B, and Tables 9 and 10 give the suspended sediment discharges for ambient flow conditions and storm events, respectively. Plots of the suspended solids, stream flow, and rainfall for the storm events are shown in Figures C-47 through C-54 of Appendix C.

Table 9 indicates that, as for previous streams monitored, the stream flow decreased during the summer months. The suspended sediment discharge during ambient flow conditions was low, but did indicate that more sediment was discharged from the project in May than in the other months. This increase probably resulted from the bridge pier work and the problems noted earlier; i.e., the hole in the cofferdam and the pumping of water from around the pier footings.

Although the total rainfall for the storm events in Table 10 was low, there was more rainfall on the project than at the rain gage, except for the May 23 storm. The other three events monitored were localized storms.

Attempts to monitor several widespread storm events were not successful, because of equipment malfunctions. For security reasons, the continuous recording rain gage was placed near the inspector's trailer approximately 1 mile (k,609 m) from the project and thus did not always give readings representative of the rainfall at the construction site.

Table 9

Suspended Sediment Discharge for Sinking Creek During Ambient Flow Conditions (Construction commenced in March 1980)

Month	Mean Discharge, $ft.^3/s$	Suspended Sediment Discharge, lb./hr.		
		Downstream	Upstream	Difference
May	80.0	3.00	0.70	2.3
June	94.0	4.00	5.00	-1.0
July	2.0	0.16	0.06	0.1
August	1.2	0.02	0.02	0.0

Conversion: 1 $ft.^3/s$ = 0.028 m^3/s

1 lb./hr. = 0.454 kg./hr.

Table 10

Suspended Sediment Discharge for Sinking Creek During Storm Events (Construction commenced in March 1980)

Date	Total Rainfall, in.	Monitoring Time, hr.	Suspended Sediment Discharg, lb.		
			Downstream	Upstream	Difference
May 8	0.06	11	4,962	641	4,321
May 23	0.17	8	118	7	111
Aug. 21	0.05	11	1,351	20	1,331
Aug. 22	0.01	6	2,357	2	2,355

Conversion: 1 in. = 2.54 cm

1 lb. = 0.454 kg.

Table 10 indicates that sediment was carried off the project during the localized storm event on May 8. As noted earlier, erosion and sediment control measures were being installed prior to this event but had not been completed, which probably contributed to the high suspended sediment discharge. In addition, this time of year is critical in erosion and sediment control since the soil is more susceptible to erosion after the spring breakup than during the winter or summer months. Table 10 also gives results from two storm events just prior to the other critical period – the early fall. Suspended sediment values reached nearly 1,200 ppm during August, even though the flow was low. These results indicate the absence of continual maintenance of the erosion and sediment control measures that is so important. Although permanent seeding is done, temporary erosion and sediment control measures need to be kept up until vegetation is well-established.

North Fork of Shenandoah River, V3

This project consisted of relocating Rte. 698, a secondary road in Shenandoah County, over a length of 3,153 ft. (961 m) near the city limits of Mount Jackson. An old steel-truss bridge over the North Fork of the Shenandoah River was replaced with a wider, 262 ft. (80 m) long concrete bridge. Approximately 927 ft. (283 m) of roadway was relocated on the west side of the North Fork of the Shenandoah River and 1,964 ft. (599 m) on the east side. The average grade on the west side is 8% from the intersection with Rte. 11 to a point approximately 300 ft. (91 m) from the river. From that point to the river the grade flattens out to 1%. On the east side of the river the grade also averages 1%. A plan view of the project is shown in Figure B-11 of Appendix B.

The terrain in the Mount Jackson area is from slightly rolling to flat. Most of the land is used for farming. The drainage basin above this bridge encompasses 506 $mi.^2$ (1,311 km^2).

Reseeding of 2 acres (0.8 ha) of land denuded by construction was specified on the plans. In addition, 753 $yd.^2$ (630 m^2) of riprap were specified for erosion and sediment control in critical areas near the river, and 177 lin. ft. (54 m) of straw bale barriers and 2,420 lin. ft. (738 m) of temporary silt fences were called for.

The contractor commenced clearing trees around the first of December 1980, and stream sampling equipment was installed about the same time. Immediately after the first of January, the contractor constructed a cofferdam around a pier in the western edge of the river. In addition, straw bale and silt fence barriers were installed as shown on the plan view.

Clearing and grubbing on the east end of the project were done in early January and earthwork commenced around January 15. The construction of additional cofferdams in early February created silt in the river, and as work progressed on the footings of the west pier muddy water was pumped from that area into a settling basin in the field northwest of the bridge. Near mid-March the cofferdam around the west pier was removed and work for the piers on the east bank was intensified. A crane with a clam shell was used to remove the east bank and some streambed material in the pier locations. This activity created enough silt to muddy the river for a considerable distance downstream. For additional pier work from the east bank, a rock causeway was constructed approximately halfway across the river in mid-April.

Additional straw bales were installed around mid-April but were not entrenched, and the fill slopes were seeded at the same time. Then, around the end of April, work on the project necessitated additional seeding and stream protection at the end of the fill on the east bank. By mid-May rills were present in the fills, and although the major portion of the fills were seeded in April the vegetation was very light.

The sampling equipment was removed from the project in early June, at which time there was noticeable vegetation but the temporary erosion and sediment control measures were still needed.

A stage-discharge curve for the North Fork of the Shenandoah River is included in Figure B-12 of Appendix B. Tables 11 and 12 give the suspended sediment discharges for ambient flow conditions and storm events, and plots of the suspended solids, stream flow, and rainfall for the storm events are shown in Figures C-55 through C-62 of Appendix C.

Table 11

Suspended Sediment Discharge for the Shenandoah River
During Ambient Flow Conditions
(Construction commenced in December 1980)

Month	Mean Discharge, $ft.^3/s$	Suspended Sediment Discharge, lb./hr.		
		Downstream	Upstream	Difference
March	65	91	74	17
April	140	427	609	-182
May	112	832	643	189

Conversion: 1 $ft.^3/s$ = 0.028 m^3/s

1 lb./hr. = 0.454 kg./hr.

Table 12

Suspended Sediment Discharge for the North Fork
of the Shenandoah River During Storm Events
(Construction commenced in December 1980)

Date	Total Rainfall, in.	Monitoring Time, hr.	Suspended Sediment Discharge, lb.		
			Downstream	Upstream	Difference
Mar. 4-5	0.13	17	7,600	7,400	200
May 11-12	0.42	17	8,400	4,000	4,400
May 19-21	1.03	42	2,776,000	1,325,800	1,450,200
May 28-29	0.47	25	29,492,000	16,008,000	13,484,000

Conversion: 1 in. = 2.54 cm

1 lb. = 0.454 kg.

Table 11 indicates that during April sediment was deposited between the monitoring stations under ambient flow conditions. The deposition may have resulted in part from the causeway being constructed halfway across the stream and a settling area being created behind the structure. In May, sediment was transported from the project as indicated in Table 11. This sediment probably resulted from a lack of protection at the toe of the fill on the east bank. In addition, it was evident by the rills on the fill slopes that soil was being removed. Thus, these results confirm the finding from previous projects that properly operating temporary erosion and sediment control measures are critical until permanent vegetation is well-established. The data in Table 12, especially the results for the last two storm events in May, emphasize the importance of this point. During the storm events large volumes of soil were transported downstream. As indicated by the May 28-29 storm event as compared with that of May 19-21, the total amount leaving the project limits is not indicative of the size of the storm or its duration. The main factor is the proper installation and maintenance of the temporary controls and the establishment of permanent vegetation.

South Anna River, C1

The large volume of traffic on Interstate 95 between Washington, D.C. and Richmond has necessitated the widening of this highway. For project C1, an additional lane was being added in each direction and the construction crossed the South Anna River near Ashland. This project called for approximately 108,000 yd.^{3} (82,577 m^3) of fill that denuded 32 acreas (13 ha). The grades of the roadway draining into the South Anna River are about 1.5%.

The plans specified that 700 lin. ft. (213 m) of straw bale barriers, 1 straw bale check dam, 2,188 yd.^{2} (1,829 m^2) of filter fabric cloth, 785 lin. ft. (239 m) of silt fence, and 1 rock check dam be used for erosion and sediment control until permanent vegetation was established. Although the denuded areas were seeded according to the Department's specifications, no seeding was done during this study. Temporary erosion and sediment controls were installed as noted on the plan view in Figure B-13 of Appendix B. Most of the controls satisfactorily retained the silt generated by the storm events monitored. However, maintenance of the controls was the biggest problem noticed. Usually, they were cleaned out when nearly full of silt rather than when half full as required by the Department's specifications. In addition, when the contractor cleaned the fine-grained silt from behind the control, the material was not transported to a waste area where damage to property, plants, animals, or streams could be avoided. Instead it was placed on the slope above and usually downstream of the control so it would not fill the control again. During the next rain or rains the silt would wash into the next lowest control or into the stream.

Most of the temporary control measures were in place when the sampling equipment was installed in early November 1980. In mid-November riprap was placed on the south bank of the river, at which time forming was being installed for a concrete apron under the bridges on the north bank.

The stage-discharge curve for the South Anna River is included in Figure B-14 of Appendix B, and Tables 13 and 14 give the suspended sediment discharges for ambient flow conditions and storm events. Plots of the suspended solids, stream flow, and rainfall for the storm events are shown in Figures C-63 through C-70 of Appendix C.

Table 13 indicates that in November and December ambient flow transported sediment from the project. In November, the sediment was probably generated by placing the riprap on the south bank and forming for the concrete on the north bank. Most of the generated sediment could be attributed to placement of the riprap, as some stones rolled down the slope into the river and had to be removed and replaced on the slope.

Table 14 indicates that the four storm events monitored carried sediment from the construction project to the stream. This sediment most likely was generated by work on the bank, the absence of seeding and permanent vegetation, and the lack of proper maintenance, especially proper disposal of the silt cleaned out from the erosion and sediment control measures.

South River, C2

Approximately 15 miles north of project C1 on I-95, monitoring was conducted on the South River near Ladysmith, where I-95 also was widened to 6 lanes. Construction involving the South River bridges covered by a section 3.76 mi. (6,051 m) long. The average grade of the roadway draining into the South River was 1.2%. It was estimated that 48.6 acres (19.7 ha) would be denuded and reseeded.

Table 13

Suspended Sediment Discharge for South Anna River During Ambient Flow Conditions (Work commenced prior to November 1980)

Month	Mean Discharge, ft.^{3}/s	Suspended Sediment Discharge, lb.		
		Downstream	Upstream	Difference
Nov.	85.3	196	123	73
Dec.	85.3	61	63	- 2

Conversion: 1 ft.^{3}/s = 0.028 m^3/s

1 lb./hr. = 0.454 kg./hr.

Table 14

Suspended Sediment Discharge for South Anna River During Storm Events (Work commenced prior to November 1980)

Date	Total Rainfall, in.	Monitoring Time, hr.	Suspended Sediment Discharge, lb.		
			Downstream	Upstream	Difference
Nov. 17	1.09	13	2,755	687	2,068
Nov. 24	0.51	10	7,358	751	6,607
Nov. 27	0.38	9	2,841	429	2,412
Dec. 9	0.17	9	12,054	4,163	7,891

Conversion: 1 in. = 2.54 cm

1 lb. = 0.454 kg

While the construction area was denuded and permanent vegetation was being established, 2,446 ft. (746 m) of baled straw silt barriers and 4,287 ft. (1,307 m) of temporary silt fences were specifed to be used.

Monitoring equipment was installed on the South River in late July, well after construction had commenced. Baled straw silt barriers and temporary silt fences, as noted on the plan view in Figure B-15 of Appendix B, were installed in early August. Installation of the silt fences was satisfactory, but the baled straw barriers were not entrenched. A rock check dam with an outlet pipe was placed upstream of the box culvert construction to divert the stream from the construction activities. In mid-August seeding was performed throughout the project as specified by the Department.

In early September, additional seeding was done. The sediment trap shown on the plan view had been installed and was performing satisfactorily. In mid-September a significant storm event occurred causing sections of the silt fence to collapse and allow silt to enter the stream. Within a day after this failure, the contractor was repairing the fence and cleaning it out. All controls performed satisfactorily until mid-October, when additional failures occurred. By this time the monitoring equipment had been removed.

The stage-discharge curve for South River is included in Figure B-16 of Appendix B. Tables 15 and 16 give the suspended sediment discharges for ambient flow conditions and storm events, respectively, and plots of the suspended solids, stream flow, and rainfall for the storm events are shown in Figures C-71 through C-80 of Appendix C.

Table 15 indicates that during ambient flow conditions a small amount of sediment left the project, with the discharge rate for both August and September being 2.3 lb./hr. (1.0 kg./hr.).

Table 16 indicates that during the five monitored storm events, sediment was transported from the project, with the amount of sediment increasing with the size of the storm event. The sediment discharge for the August 6 and 7 storm events was high because of the lack of entrenchment of the straw bales as described earlier.

Table 15

Suspended Sediment Discharge for the South River
During Ambient Flow Conditions
(Construction commenced prior to July 1981)

Month	Mean Discharge, ft.^{3}/s	Suspended Sediment Discharge, lb./hr. Downstream	Upstream	Difference
August	0.9	2.9	0.6	2.3
September	0.9	2.8	0.5	2.3

Conversion: 1 ft.^{3}/s = 0.028 m^3/s

1 lb./hr. = 0.454 kg./hr

Table 16

Suspended Sediment Discharge for the South River
During Storm Events
(Construction commenced prior to July 1981

Date	Total Rainfall, in.	Monitoring Time, hr.	Suspended Sediment Discharge, lb. Downstream	Upstream	Difference
Aug. 6-7	0.50	22	1,547.2	428.6	1,118.6
Aug. 11-12	0.37	18	281.8	7.8	274.0
Aug. 19-20	0.14	23	57.7	3.9	53.8
Sept. 5-7	0.16	44	77.4	18.2	59.2
Sept. 15-16	0.85	30	6,550.6	22.6	6,528.0

Conversion: 1 in. = 2.54 cm

1 lb. = 0.454 kg

The September 15 and 16 storm event contributed the most sediment downstream (6,528 lb. [2,964 kg]). This large amount was mainly due to the flooding of the silt fences.

This project illustrates the importance of properly installing controls, and the sedimentation and siltation of ensues when controls fail during a storm event.

SAMPLING ERROR

Though not planned at the working plan stage, it was decided, in consultation with the Federal Highway Administration, to do detailed sampling on one stream in the Piedmont physiographic area of the state during a high flow condition to gain an indication of the accuracy of the sampling procedures and equipment. While it was realized that many variables influence the results of sampling, it was felt that an idea of the accuracy was needed. Mechums River was chosen for the additional monitoring. To ascertain the spatial effects on the levels of suspended solids between the up- and downstream monitoring sites, eight evenly spaced traverse lines were established across the stream between the two sites. Five integrated water samples were taken at points evenly spaced across the traverse line and analyzed for suspended solids. It was determined that the suspended solids values did decrease between the up- and downstream monitoring sites, which indicated deposition between them. Also, the data indicated that some sediment was contributed from the wet-weather ditch on the southern end of the project, but this was only slightly noticeable 30 ft. (9 m) downstream and was undetectable at 60 ft. (18 m). Therefore, unless a detailed sampling program, which would be expensive, is used, sources of pollution that appear to affect the stream will not be detected. The monitoring program conducted in this study would not identify these pollution sources.

In addition to the spatial effects up- and downstream, integrated water samples were taken closely together across the stream. In most cases, the data indicated that differences between samples were slight and within the accuracy of the laboratory filtration test. However, differences are apparent where sediment from a point source is contributed to a stream. Samples taken near the point of pollution are higher in sediment than are samples taken further away.

A third possible source of error evaluated was the placement of the withdrawal tube for the automatic water sampler. A comparison of samples taken at a fixed depth with integrated samples from the same location showed differences no greater than 8 ppm, which is less than can be detected by the filtration test.

From the limited data collected in the detailed sampling program, one would conclude that the sampling method used in the main part of the study was fairly accurate. Also, a very detailed sampling procedure would be needed to determine the amount of suspended sediment entering a stream at various sources and the distance it travels.

Therefore, considering the many possible sources of error and varying field conditions (stream flow, different soil types, sampler location, sampler tube location, depth of sampler tube, etc.), one should make a judgement on project performance only when there are large differences (1,000 lb. or more) between the up- and downstream results.

CONCLUSIONS

From the experience gained in this study, it is evident that no durable, reliable sampling equipment suited for outside monitoring and capable of obtaining an integrated sample is commercially available. There are different types of equipment that can meet one or two of these requirements but none can meet all of them. Because of the problems with the equipment and the many variables involved, the conclusions from this study cannot be generalized as envisioned when it was planned. The results, however, provided extremely useful trends.

There seems to be no indication that one region of the state is more critical than another from the standpoint of erosion sedimentation, or that any one way of arranging erosion and sediment control measures is better than another.

The results from the twelve streams monitored do, however, indicate the following trends.

1. A lack of erosion and sediment control measures and bad construction techniques cannot be tolerated (Buck Creek and Big Walker Creek).

   No controls were employed on the Buck Creek and Big Walker Creek projects and the results for the two were similar, even though one was in the clayey soils of the Valley and Ridge region and involved a small construction project with a large stream and the other was in the silty soils of the Piedmont and involved a large project with a small stream. The large amounts of sediment transported from the Valley and Ridge project were detected by the sampling equipment; however, due to limitations of the equipment, the results for the Piedmont project did not reflect how badly the stream was silted. In addition, observations on both projects revealed the use of bad construction techniques (fills built to edge of box culverts and streams, slopes steep and loose, and no stage seeding but seeding only at completion of all work).

2. Erosion and sediment control measures need to be properly sited and installed and must be in place prior to earthwork activities (South River, Sinking Creek, and Mechums River).

   Construction was under way in an area on Sinking Creek where erosion and sediment control measures were being installed when a storm event occurred. Since the measures were not completed and soil was disturbed near the stream, high sediment discharges were noted.

The proper installation of control measures, especially the entrenchment of straw bales, is essential to good performance. The other step is maintenance. On the South River project, failure to entrench the straw bales led to high levels of silt in the stream. On the Mechums River project the lack of entrenchment seems to have been offset by the use of additional control measures properly sited. However, from a cost-benefit standpoint such use of additional measures is not desirable.

3. Temporary erosion and sediment control measures need to be maintained until permanent vegetation is well-established (North Fork of Shenandoah River).

The results from the Shenandoah River project indicate the importance of maintaining temporary control measures until permanent vegetation is established on areas that have been denuded, even if needed after work has ceased. Because control measures were not maintained, sediment was transported from this project during ambient flow conditions as well as during storm events.

4. Temporary erosion and sediment control measures need to be maintained constantly and properly (South Anna River, Sinking Creek, and South River).

Erosion and sediment control measures need to be checked after and, when possible, during every storm event to ascertain if they are performing satisfactorily. If problems do arise, they should be corrected immediately, in case another storm occurs (Sinking Creek). All measures should be cleaned when half-full to avoid the loss of silt and possible overtopping (South River). The silt cleaned out should be disposed of in a waste area where it can do no harm. It should never be placed on the slope or below the control measure (South Anna River).

5. The proper use of erosion and sediment control measures is very critical during heavy rain events in early spring and fall (Sinking Creek, Rockfish River, and Buck Mountain Creek).

During these two critical times of the year large volumes of sediment are generated on construction projects.

6. Stage and temporary seedings are very important in controlling erosion (Wreck Island Creek, Mechum River, and Tommeheton Creek).

7. In-stream structures, such as rock check dams, retain silt generated by unavoidable stream activities (Couches and Tommeheton Creeks).

   Although these in-stream structures retain silt during the stream work, consideration must be given to the effects of this type structure on the stream ecology, the effects of clean-out operations, and the effects of removing the structure.

8. Due to different factors, deposition occurs within the limits of construction (Mechums River, Buck Mountain, Wreck Island, Couches, and Tommeheton Creeks).

   The results from these five projects indicate that deposition occurs in the stream between the monitoring stations. They also indicate that large volumes of sediment transported from areas above the construction projects were deposited within the construction limits when the stream velocity was decreased as the streams were widened.

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APPENDIX A

WATER QUALITY AND BENTHIC DATA PROVIDED BY ENVIRONMENTAL QUALITY DIVISION

APPENDIX A

STUDY DESCRIPTION

This study, an adjunct of the Efficiency of Erosion Control Practices of the Virginia Department of Highways and Transportation, quantifies the response of the macrobenthic community to sediment.

Sampling stations were selected upstream and downstream of the construction sites. Stations with similar habitats were selected insofar as possible. The stations were sampled using a D-frame dip net to obtain a twenty-minute kick sample with equal concentrations on each available substrate type. Each sample was collected, preserved, and taken to the lab, where the macrobenthic organisms were separated and identified. A computer program was used to obtain a diversity index based on Dr. John Carin's sequential comparison index.

The objective of the study was to qualify the macrobenthic population's response to highway siltation through changes in the numbers and diversity of organisms to supplement the Research Council's quantitative sediment data. Significant changes in the population (numbers or diversity) downstream as compared to the control station would indicate the adverse impacts of the highway construction. Many variables are imposed on a dynamic system such as a stream. Most of these variables were uncontrollable and not qualified in this limited study; therefore, extreme caution must be used in interpreting the data for either trends or specific predictions.

DATA SUMMARIES

The following streams were found unsuitable for benthic sampling due to the water being too deep for sampling, unsuitable macrobenthic habitats, or poor water quality.

Sinking Creek
Wreck Island Creek
South Anna River
North Fork Shenandoah Riber
Tommeheton Creek
South River
Big Walker Creek

Buck Creek at Route 29 was sampled on five occasions between June 23, 1978, and October 26, 1979. Construction commenced on August 15, 1977. It was noted that large quantities of silt entered the stream and should have produced a significant population decline at the downstream site. However, because of an irreconcilable sampling error and the fact that benthic sampling did not commence until 10 months after construction had begun, we have deleted the data from this study.

Rockfish River - Route 29

The Rockfish River was sampled on five occasions from June 23, 1978, through October 26, 1979. Construction commenced on September 1, 1978. The macrobenthic populations declined after construction of both the upstream and the downstream stations (Table A-1 and Figure A-1). However, both stations showed fluctuations during the sampling periods, indicating that factors other than highway construction were having a significant detrimental impact. Silt from upstream agricultural areas and variable flow conditions are the most probable explanations for the response registered by the macrobenthic population. Davis Creek was monitored as a control station on this project and showed a similar pattern of fluctuations. (Table A-1 and Figure A-2).

Buck Mountain Creek - Route 665

Five samples were collected from Buck Mountain Creek from August 4, 1978, to October 26, 1979. Construction commenced on July 26, 1978. Comparisons of the benthic populations show that for the first two samples the downstream station had a far greater number of insects than the upstream station (see Table A-2 and Figure A-3). On the final three sampling dates, the upstream station exceeded the downstream station. This fluctuation was caused by a deposition of silt over the downstream station that was related to the project. Interpretations of these data has only limited value in that collections were not made prior to commencement of construction.

Mechums River - Route 601

Mechums River was sampled on six dates from February 21, 1980, to June 9, 1981. Construction was started on June 24, 1980. A comparison of the benthic populations response between the upstream and downstream stations was not possible due to a constant shifting of silty and sandy bottom sediments (see Table A-3 and Figure A-4).

Couches Creek - Route 40

Couches Creek was sampled on eight occasions between August 22, 1979, and April 16, 1981. Construction was started on April 1, 1980. A comparison of benthic populations shows that through the first three sampling periods the sites corresponded in numbers (see Table A-4 and Figure A-5). On the fourth sample and at the start of construction, the downstream station showed a higher population peak than for the upstream site. This would indicate a higher productivity for this area than for the upstream station. Subsequently, both stations showed a decline in population numbers. However,

Table A-1. Summary Data – Rockfish River

BENTHIC DATA

Downstream

Date:	6-23-78	10-12-78	3-20-79	6-26-79	10-26-79
No. Organisms	4119	1184	343	7994	693
No. Taxa	19	23	14	25	23
Family Diversity	0.87	0.61	0.72	0.70	0.81
No. Families With Greatest Abundance	3	1	2	2	2

Upstream

No. Organisms	3741	967	787	3059	1121
No. Taxa	28	24	20	25	21
Family Diversity	0.87	0.71	0.67	0.80	0.85
No. Families With Greatest Abundance	4	2	2	3	2

Control (Davis Creek)

No. Organisms	1642	1717	899	1026	751
No. Taxa	14	21	16	18	21
Family Diversity	0.64	0.65	0.16*	0.76	0.71
No. Families With Greatest Abundance	1	2	1	2	2

*Order Ephemerellidae of the Family Ephemeroptera represents 91% of the sample.

WATER QUALITY

Rockfish River

Parameter					
D. O.	8	10	11	9	7
pH	7.1	7.4	7.5	7.2	6.4
Temp. deg C, Water	22	15	9	17	16
Temp. deg C, Air	30	21	15	21	18

Davis Creek

Parameter					
D. O.	8	9	10	10	11
pH	7.1	7.4	7.4	7.2	7.2
Temp. deg C, Water	27	17	12	12	8
Temp. deg C, Air	29	25	18	22	10

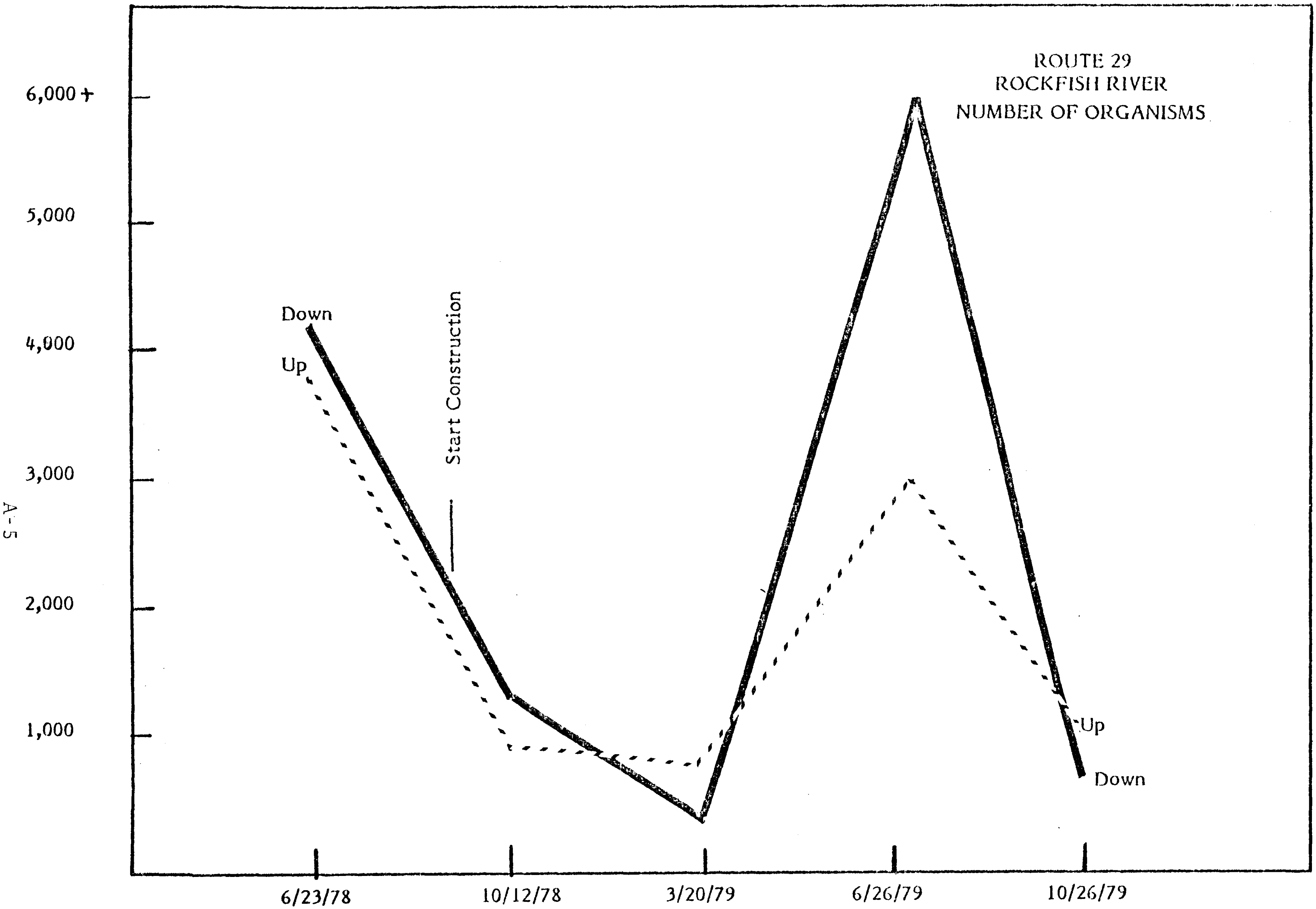

ROUTE 29
ROCKFISH RIVER
NUMBER OF ORGANISMS
6,000+
5,000
4,000
3,000
2,000
1,000
Down
Up
Start Construction
Up
Down
6/23/78
10/12/78
3/20/79
6/26/79
10/26/79

Figure A-1.

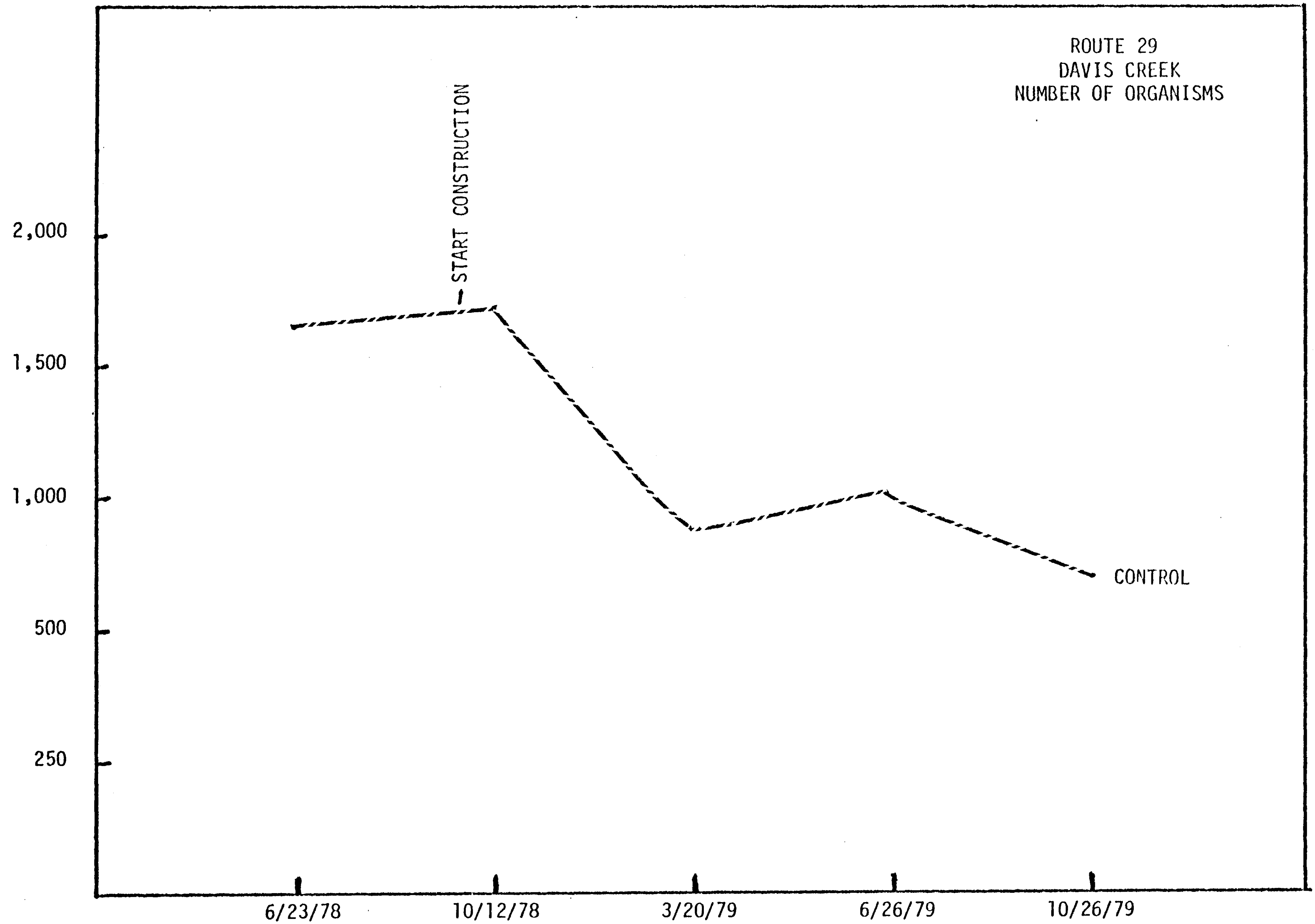

ROUTE 29
DAVIS CREEK
NUMBER OF ORGANISMS
START CONSTRUCTION
CONTROL
2,000
1,500
1,000
500
250
6/23/78
10/12/78
3/20/79
6/26/79
10/26/79

Figure A-2.

the downstream station showed a much slower recovery rate due to the silt deposition from the clean out of an upstream settling basin. This was further reinforced by the last sample, where both stations showed population increases. However, the upstream station's recovery far exceeded that of the downstream station. Therefore, the recovery from siltation of the stream's habitat was decidedly slower in the downstream station, an area more productive than the control stations by data comparison prior to commencement of construction.

Table A-2. Summary Data Buck Mt. Creek

BENTHIC DATA

Date:	8-4-78	10-12-78	3-20-79	6-26-79	10-26-79
Downstream					
No. Organisms	2617	4799	315	180	100
No. Taxa	28	27	20	12	15
Family Diversity	0.78	0.74	0.76	0.81	0.84
No. Families With Greatest Abundance	3	3	4	2	4
Upstream					
No. Organisms	1407	1588	849	986	408
No. Taxa	30	25	22	16	19
Family Diversity	0.82	0.75	0.83	0.83	0.87
No. Families With Greatest Abundance	3	2	3	2	4
Control (Piney Creek)					
No. Organisms	290	1669	206	612	395
No. Taxa	18	25	19	18	24
Family Diversity	0.82	0.70	0.76	0.73	0.85
No. Families With Greatest Abundance	3	2	2	2	3

WATER QUALITY

Buck Mt. Creek					
Parameter					
D.O.	8	11	10	10	9
pH	7.0	7.6	6.8	7.4	7.0
Temp. deg. C, Water	23	16	11	19	12
Temp. deg. C, Air	24	27	17	22	20

Piney Creek					
Parameter					
D.O.	No	9	10	9	9
pH	Samples	7.0	--	6.6	6.8
Temp. deg. C, Water	Taken	14	12	19	12
Temp. deg. C, Air		24	17	22	19

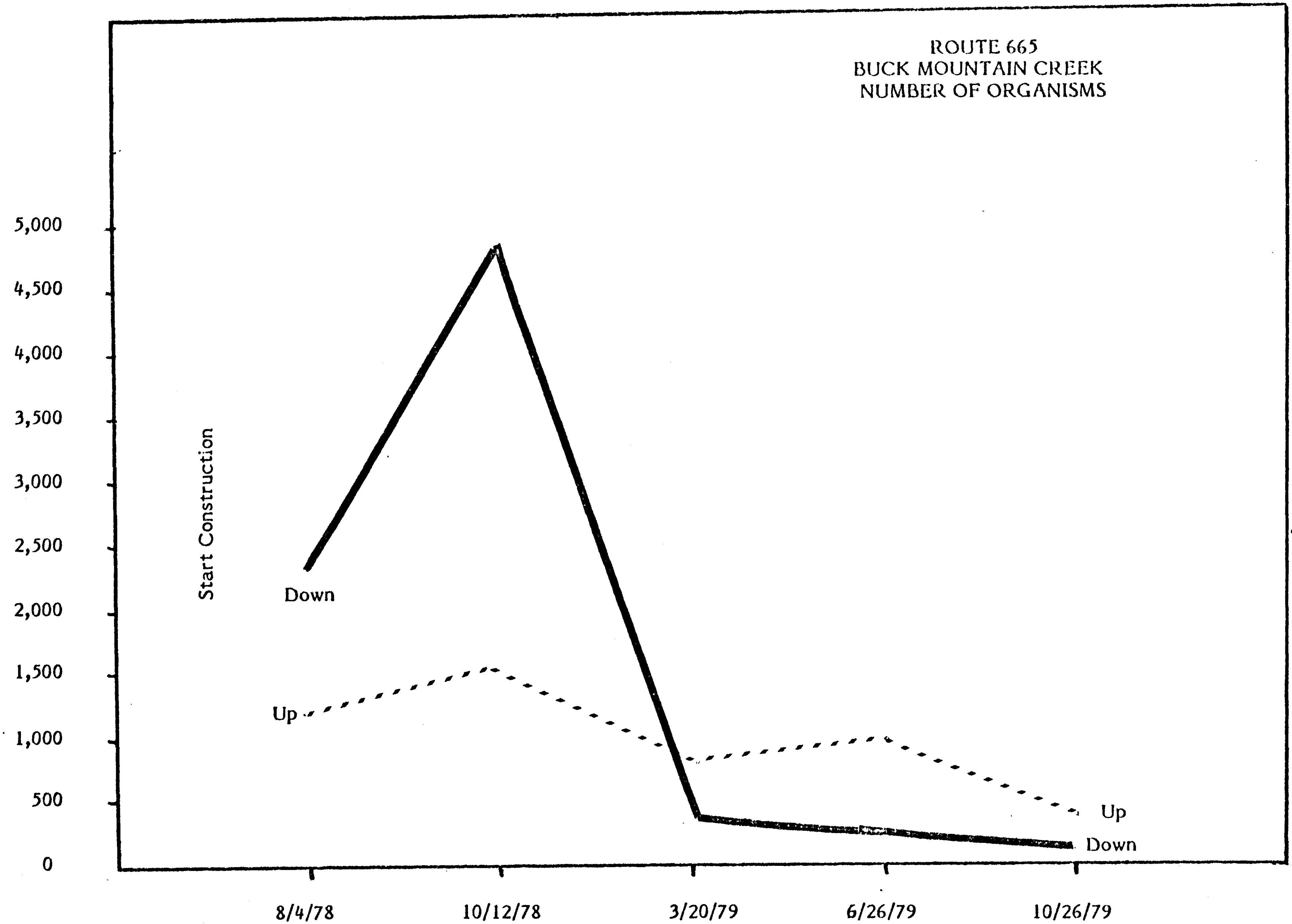

ROUTE 665
BUCK MOUNTAIN CREEK
NUMBER OF ORGANISMS
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
Start Construction
Down
Up
Up
Down
8/4/78
10/12/78
3/20/79
6/26/79
10/26/79

Figure A-3.

Table A-3. Summary Data - Mechums River

BENTHIC DATA

Downstream						
Date:	2-21-80	5-12-80	8-12-80	11-20-80	2-21-81	6-9-81
No. Organisms	1021	587	450	758	624	490
No. Taxa	24	20	25	21	28	23
Family Diversity	0.85	0.69	0.85	0.76	0.71	0.83
No. Families With Greatest Abundance	3	2	4	2	3	3
Upstream						
No. Organisms	864	494	3090	716	860	629
No. Taxa	22	17	27	19	16	19
Family Diversity	0.51	0.75	0.68	0.54	0.77	0.83
No. Families With Greatest Abundance	1	2	1	1	2	3

WATER QUALITY

Downstream	2-21-80	5-12-80	8-12-80	11-20-80	2-21-81	6-9-81
pH	7.2	7.6	7.1	6.8	7.8	7.6
D.O.	12	10	7	12	12	8
Temp. deg. C, Air	14	24	20	18	5	28
Temp. deg. C, Water	7	17	23	3	6	24
Upstream						
pH	7.2	7.4	7.1	6.8	7.6	7.6
D.O.	12	10	7	12	12	8
Temp. deg. C, Air	16	24	20	18	15	28
Temp. deg. C, Water	7	18	23	3	6	24

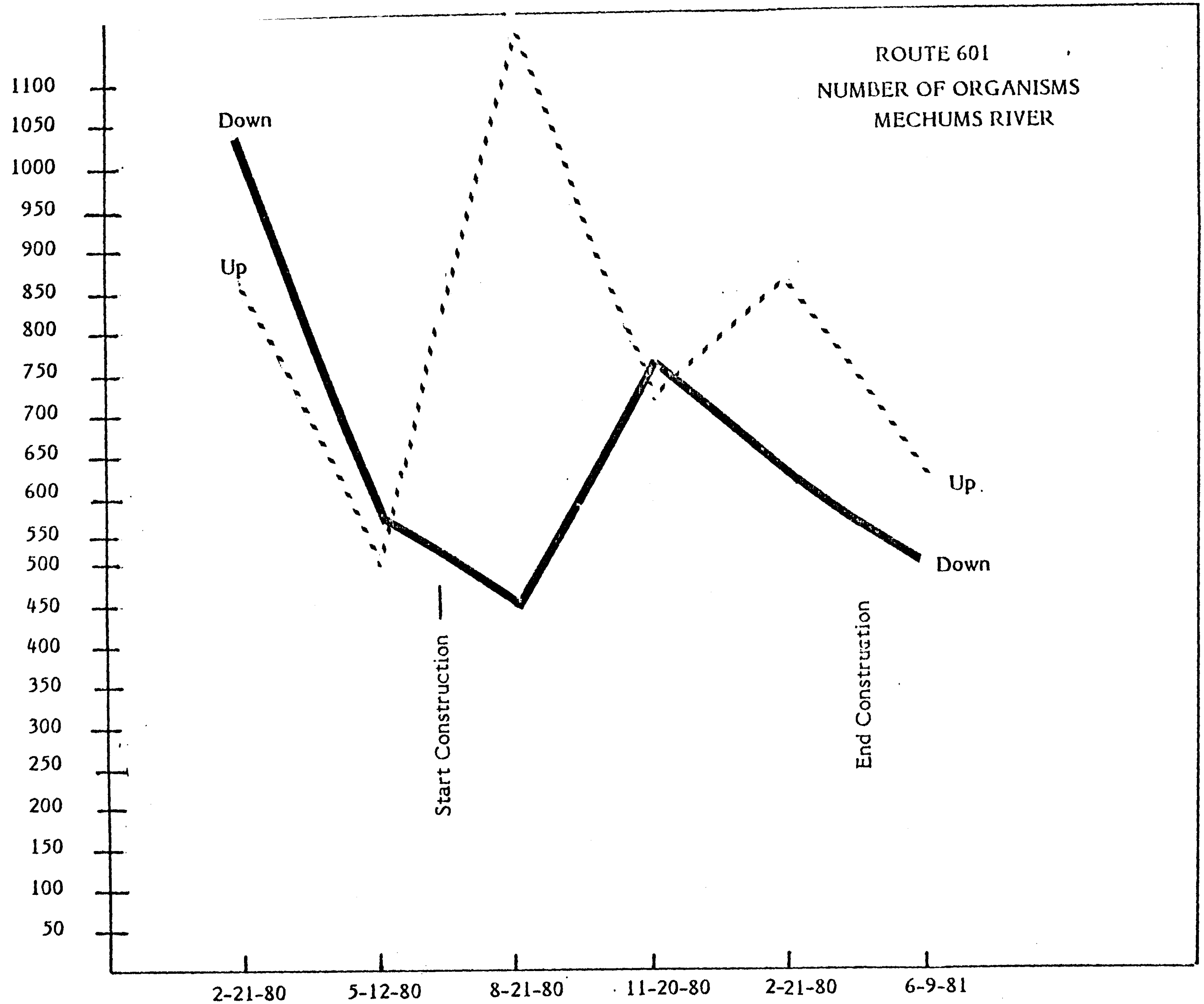

ROUTE 601
NUMBER OF ORGANISMS
MECHUMS RIVER
Down
Up
Up
Down
Start Construction
End Construction
1100
1050
1000
950
900
850
800
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
2-21-80
5-12-80
8-21-80
11-20-80
2-21-80
6-9-81

Figure A-4.

Table A-4. Summary Data – Couches Creek

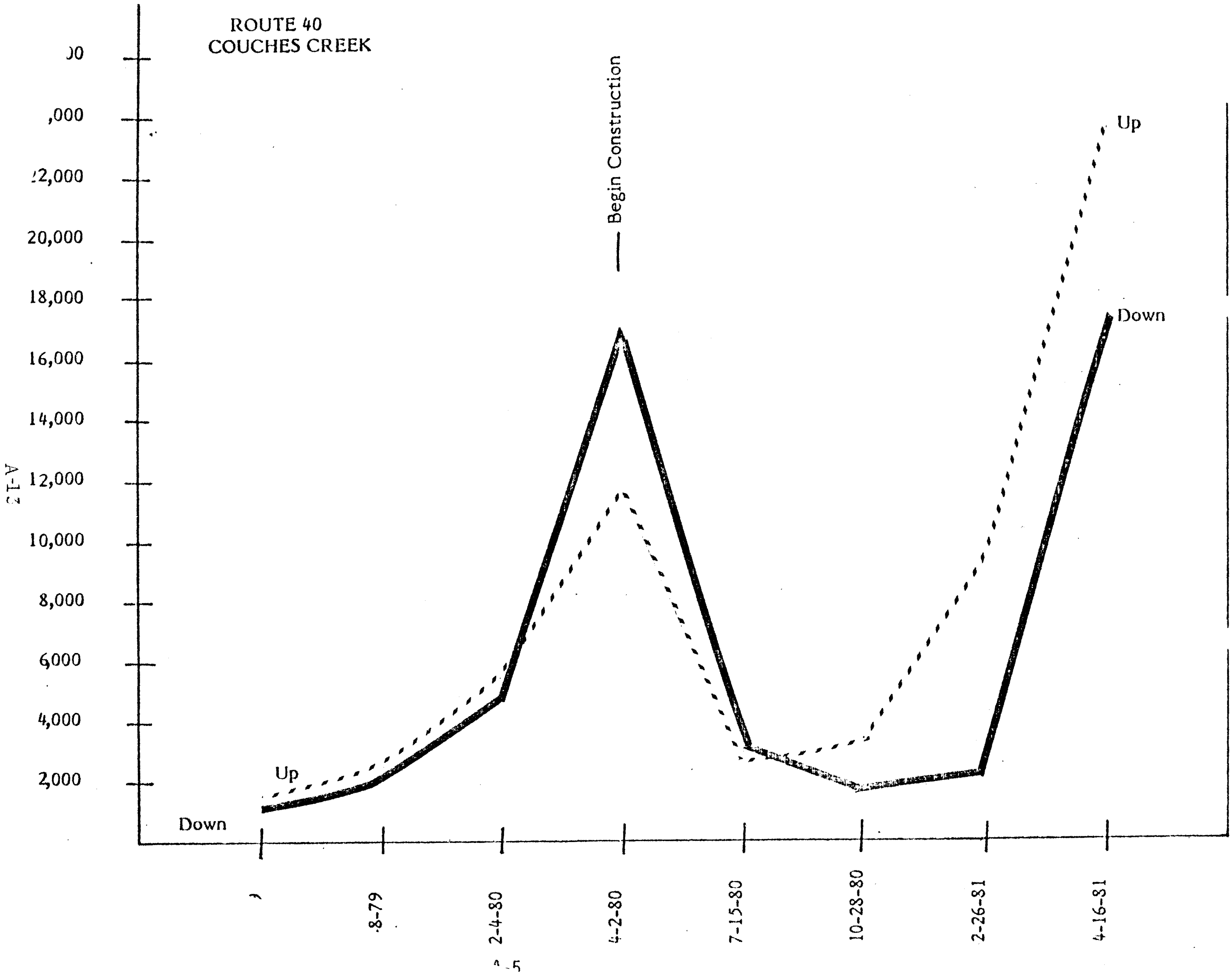
BENTHIC DATA

Date:	8-22-79	11-8-79	2-4-80	4-2-80	7-15-80	10-28-80	2-26-81	4-16-81
Downstream								
No. Organisms	1280	2137	4709	16938	2695	1630	2553	17309
No. Taxa	28	29	31	47	32	37	48	47
Family Diversity	0.84	0.82	0.84	0.57	0.74	0.86	0.82	0.66
No. Families With Greatest Abundance	3	2	3	1	2	3	3	2
Upstream								
No. Organisms	1434	2236	5314	11731	2446	3260	9182	23648
No. Taxa	27	32	31	39	23	35	40	42
Family Diversity	0.85	0.83	0.87	0.58	0.70	0.54	0.73	0.66
No. Families With Greatest Abundance	3	3	3	1	1	1	2	2

WATER QUALITY

	8-22-79	11-8-79	2-4-80	4-2-80	7-15-80	10-28-80	2-26-81	4-16-81
Downstream								
pH	7.4	7.4	7.2	6.4	7.8	7.6	8.6	8.8
D. O.	8	11	12	11	9	9	14	13
Temp. deg. C, Air	23	12	2	18	28	10	12	18
Temp. deg. C, Water	20	9	0	13	23	11	7	14
Upstream								
pH	7.4	7.6	7.4	6.4	7.8	7.6	8.6	9.0
D. O.	8	11	12	12	9	9	14	13
Temp. deg. C, Air	23	16	5	22	28	10	12	22
Temp. deg. C, Water	21	9	0	13	23	11	7	15

ROUTE 40
COUCHES CREEK



CONCLUSIONS

Many complications were encountered in sampling the macrobenthic communities for this study. Streams such as the Rockfish River, Mechums River, and Buck Mountain Creek were far too large to permit proper sampling. Such streams have many associated uncontrollable impacts related to their watersheds that have a greater influence on the macrobenthic populations than the highway-generated sediment. These impacts masked the problems that were caused by the highway construction siltation in most of the streams. The size of the streams further complicated analysis by overtaxing the equipment and the operator.

If impacts upon the macrobenthic populations are to be correlated with sediment loadings, the benthic samples will need to be taken as soon as possible after the storm event. In many cases, the samples were taken several weeks after the storm events, which would allow time for the benthic populations to reestablish themselves through drift, a common factor for diverse populations. Also, greater care must be taken in the selection of the sampling station so as to allow for the selection of a stream that is not greatly influenced by factors other than highway construction. Further, the stream size must be proportional to the potential for silt impacts. Many of the streams selected in this study would rate a limited, if any, impact from the projected total potential of the project. The Department will have a more definitive study available on the impact of construction upon macrobenthic populations from I-66, a major interstate construction project in Northern Virginia, approximately during the first quarter of 1983.

APPENDIX B

SELECTED SUSPENDED SOLIDS DATA, PLAN VIEWS, AND STAGE-DISCHARGE CURVES

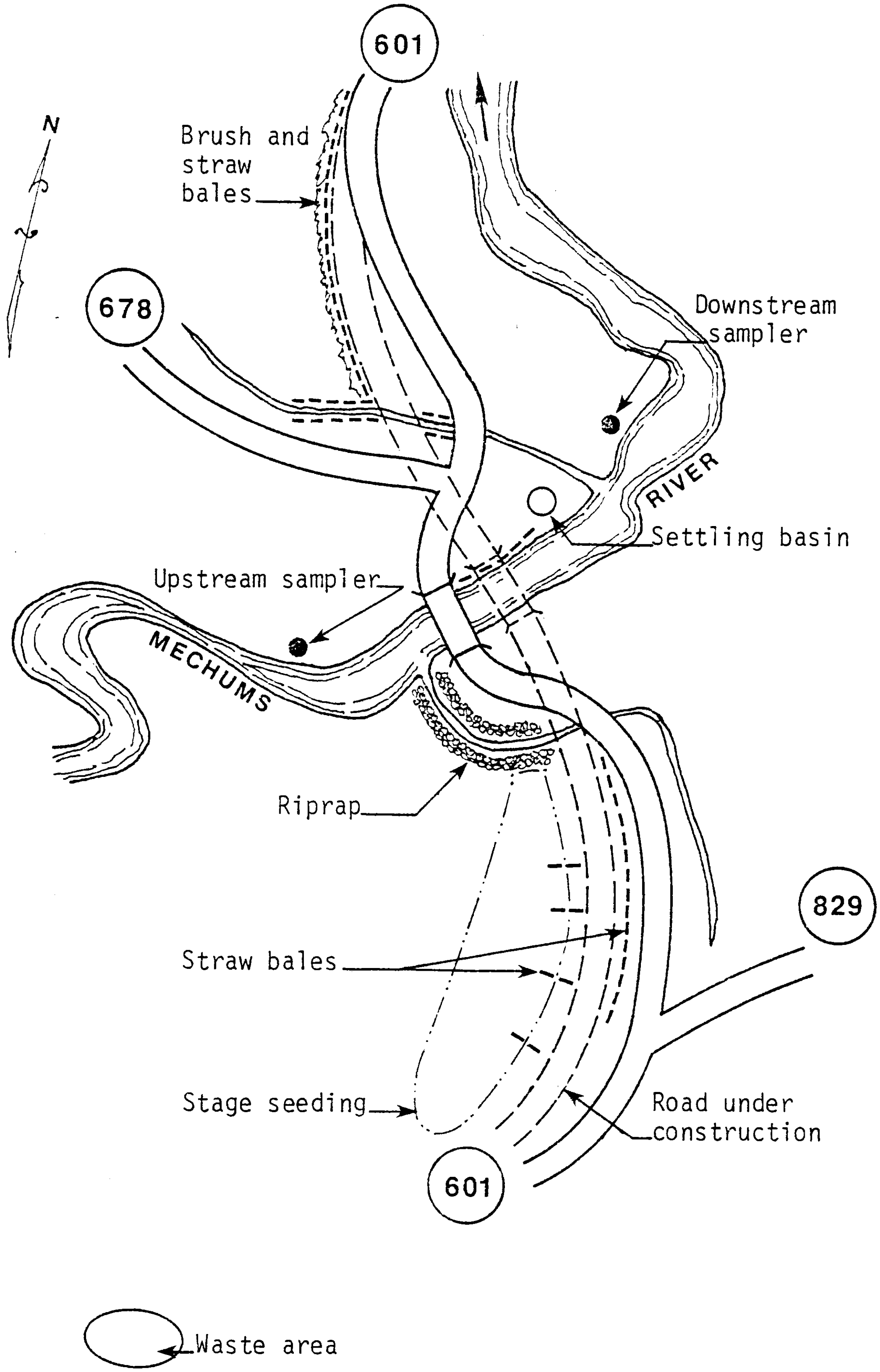


Figure B-1. Plan view of Mechums River erosion controls and sampler locations.

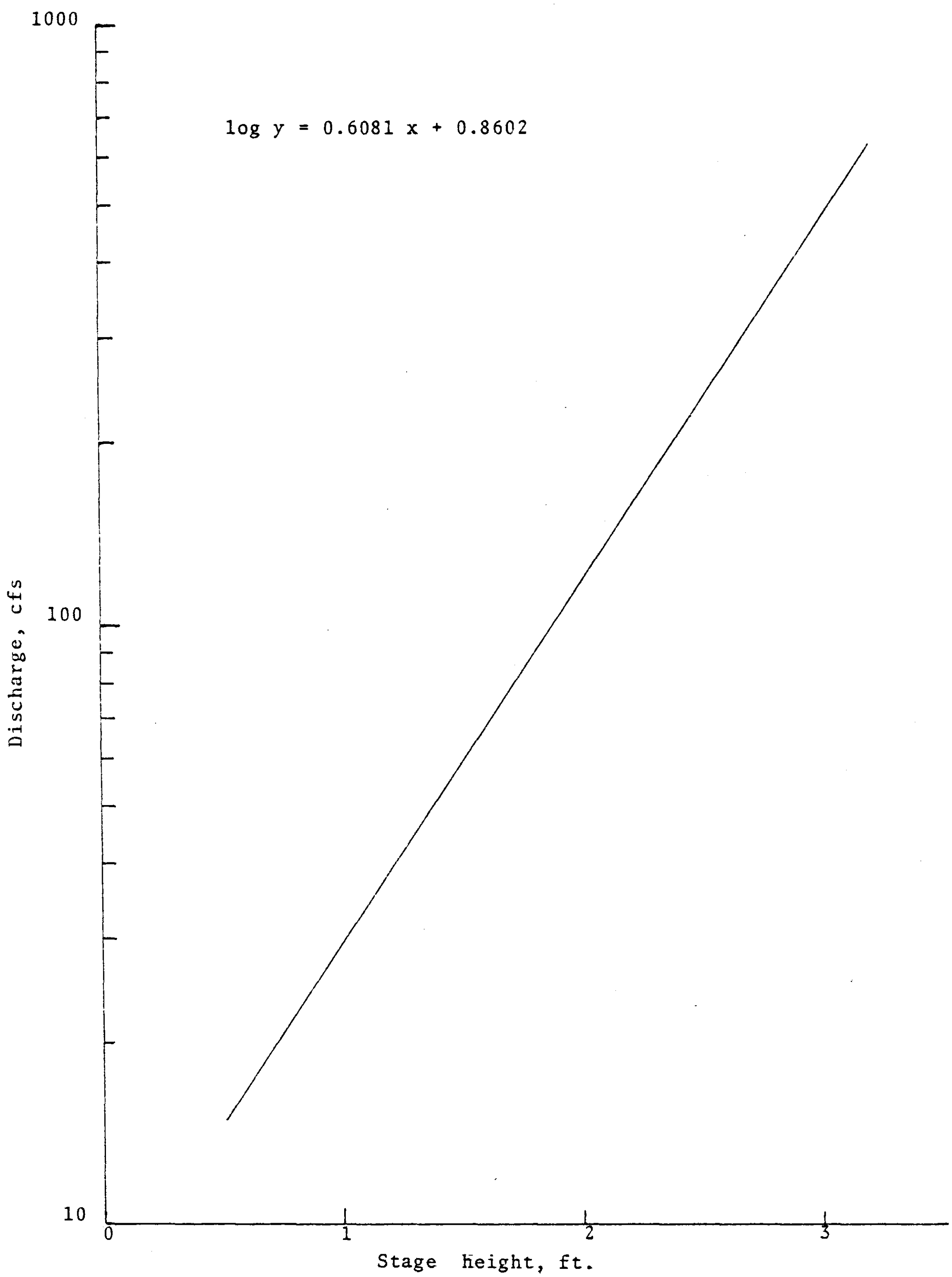


Figure B-2. Stage-discharge curve for Mechums River.

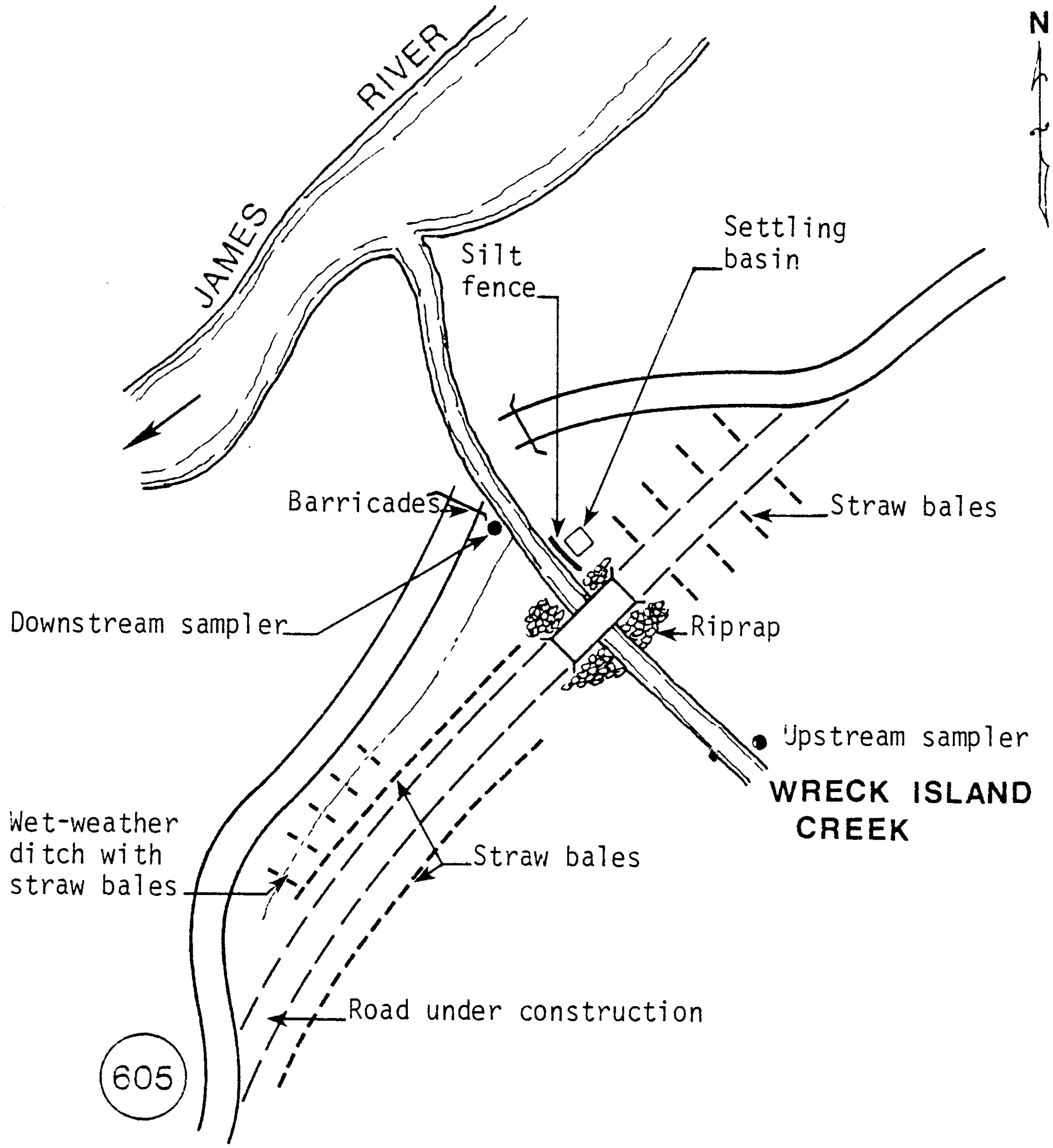


Figure B-3. Plan view of Wreck Island Creek erosion controls and sampler locations.

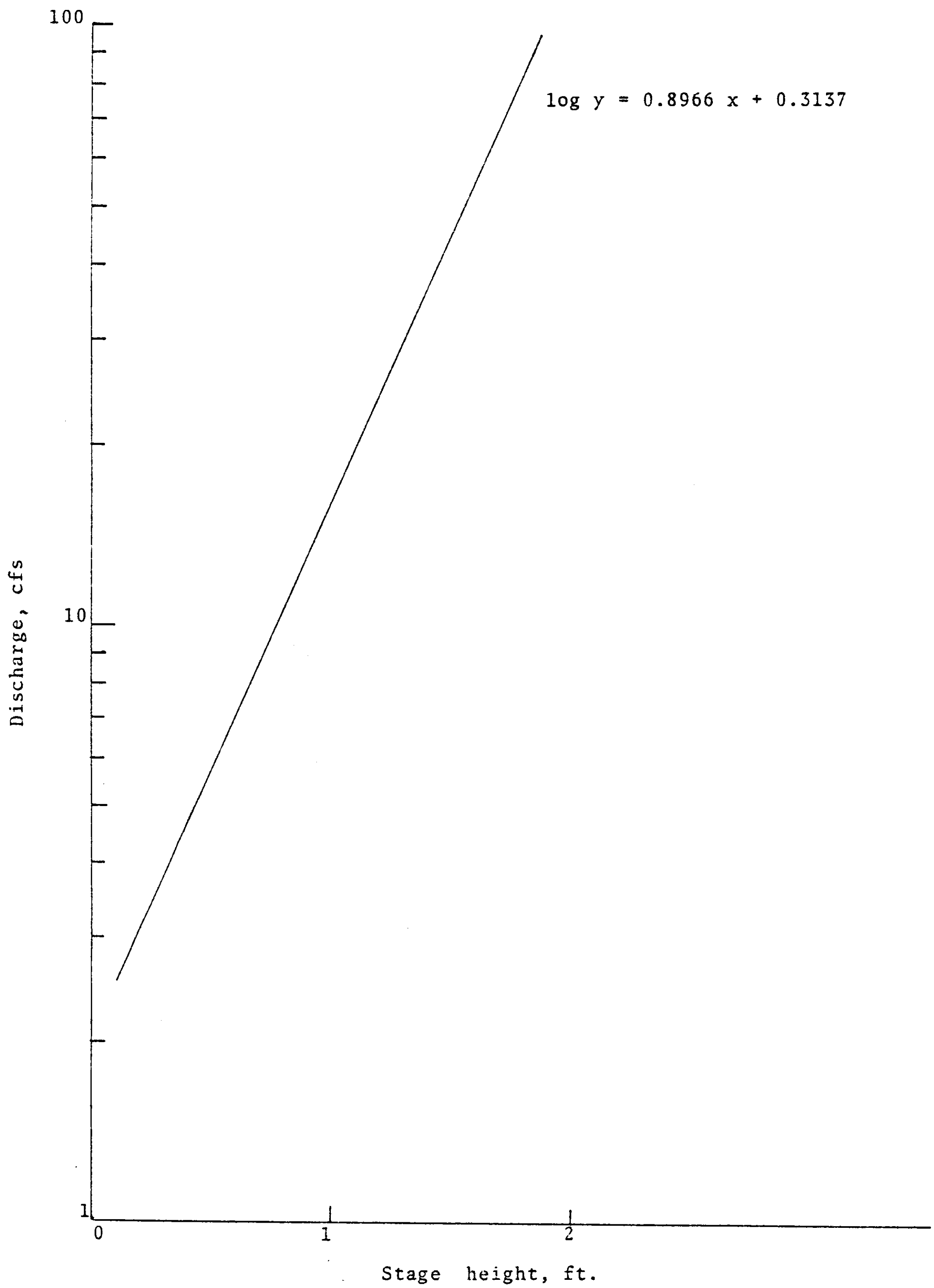


Figure B-4. Stage-discharge curve for Wreck Island Creek.

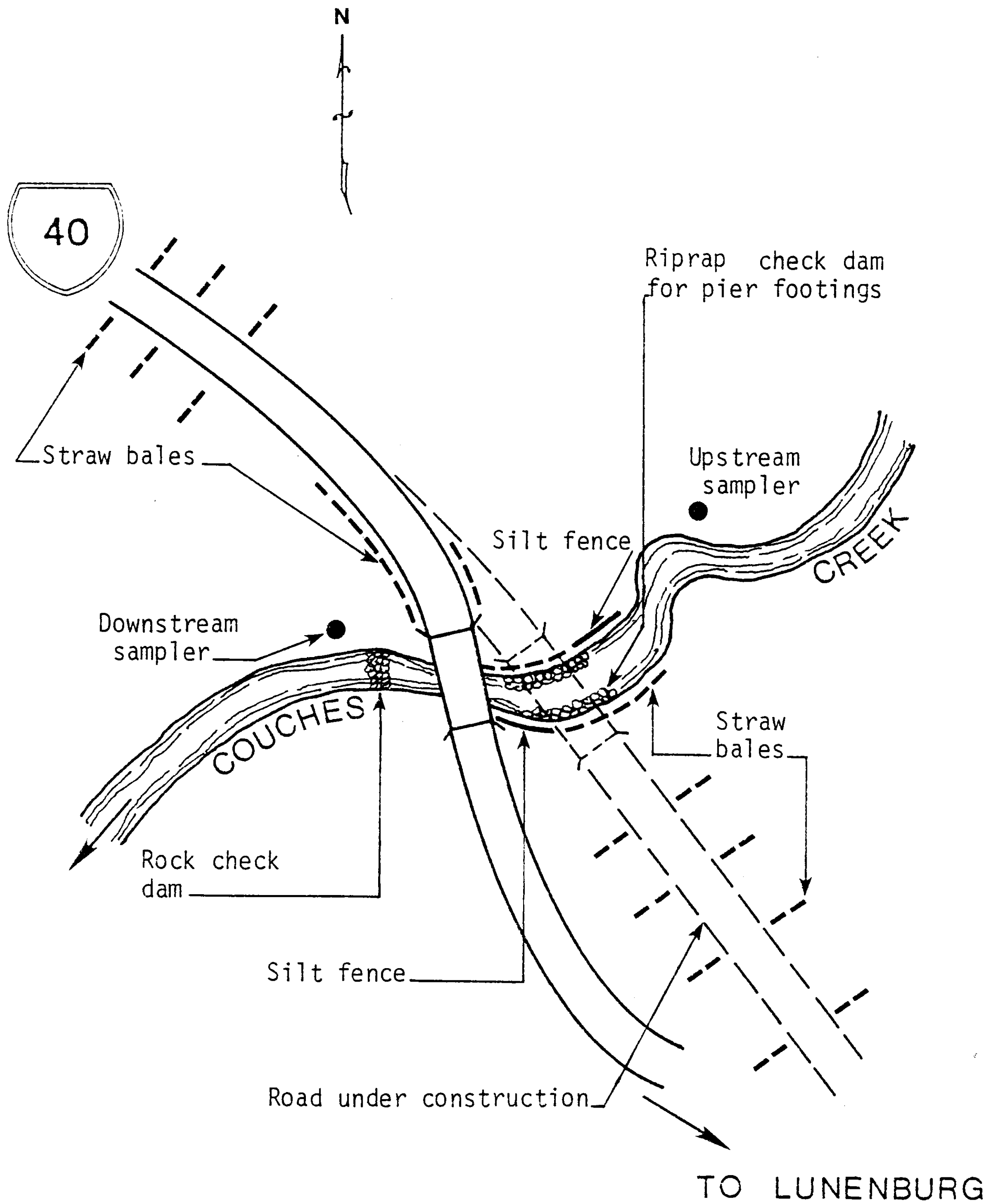


Figure B-5. Plan view of Couches Creek erosion controls and sampler locations.

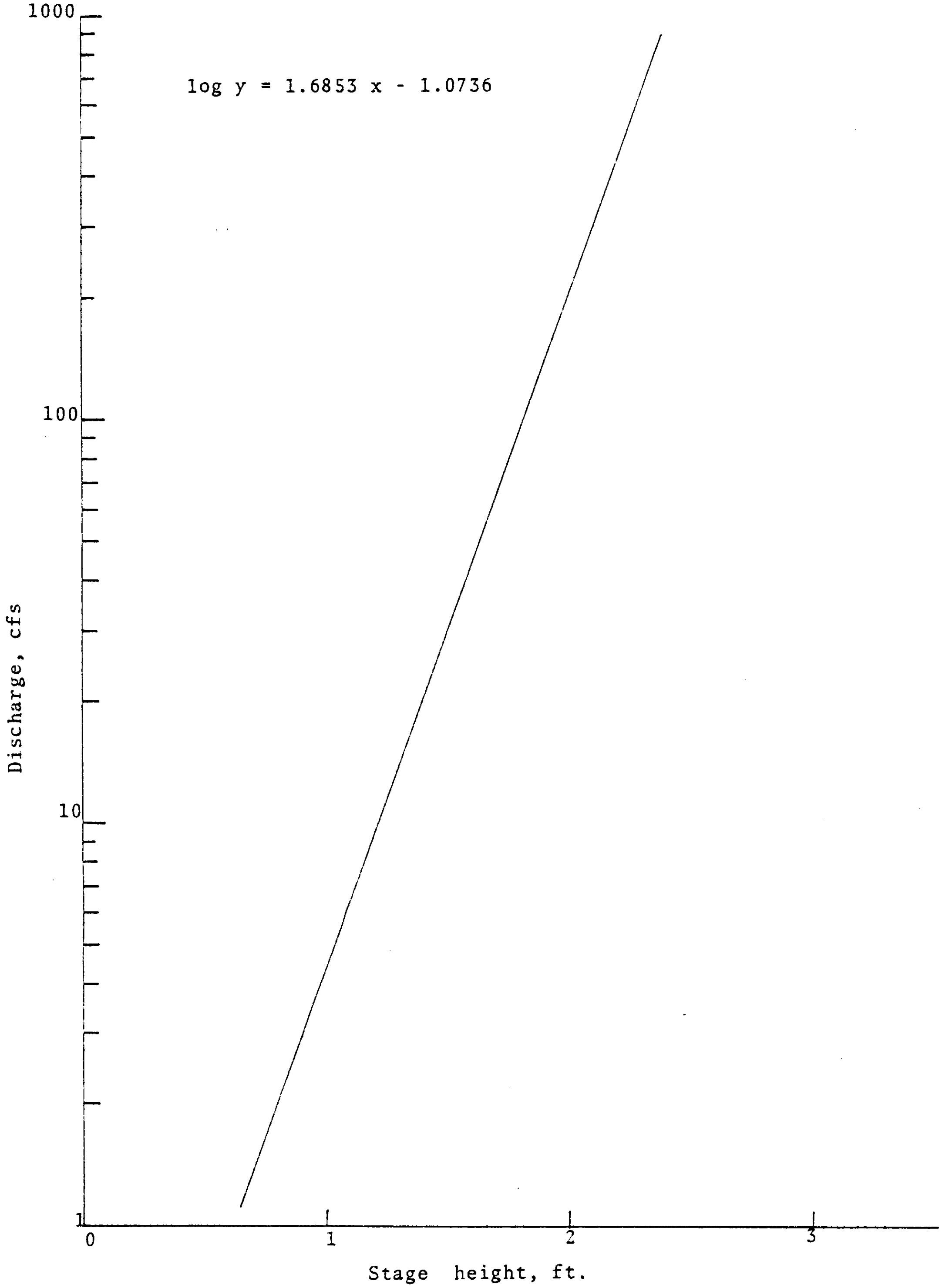


Figure B-6. Stage-discharge curve for Couches Creek.

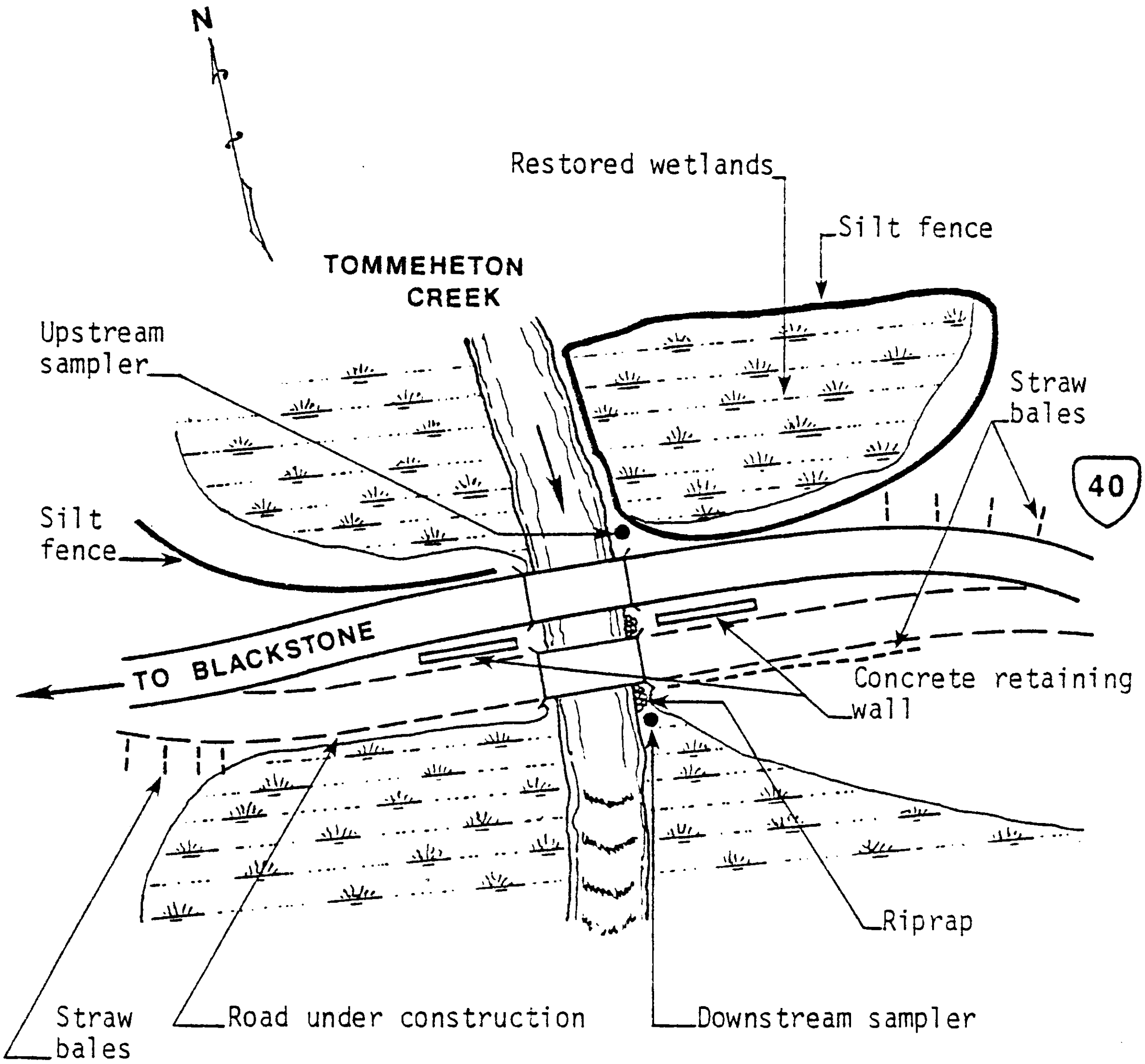


Figure B-7. Plan view of Tommeheton Creek erosion controls and sampler locations.

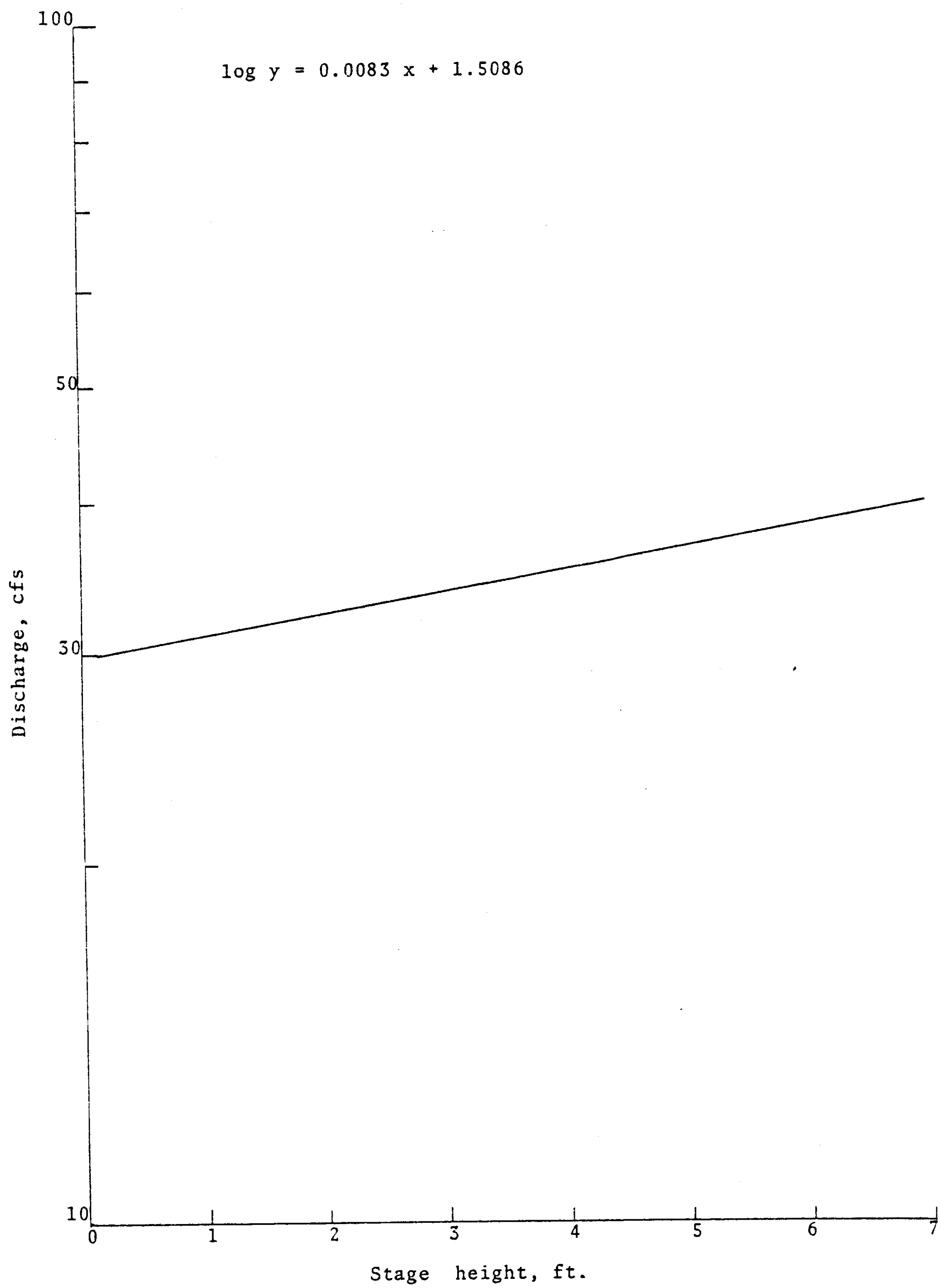


Figure B-8. Stage-discharge curve for Tommeheton Creek.

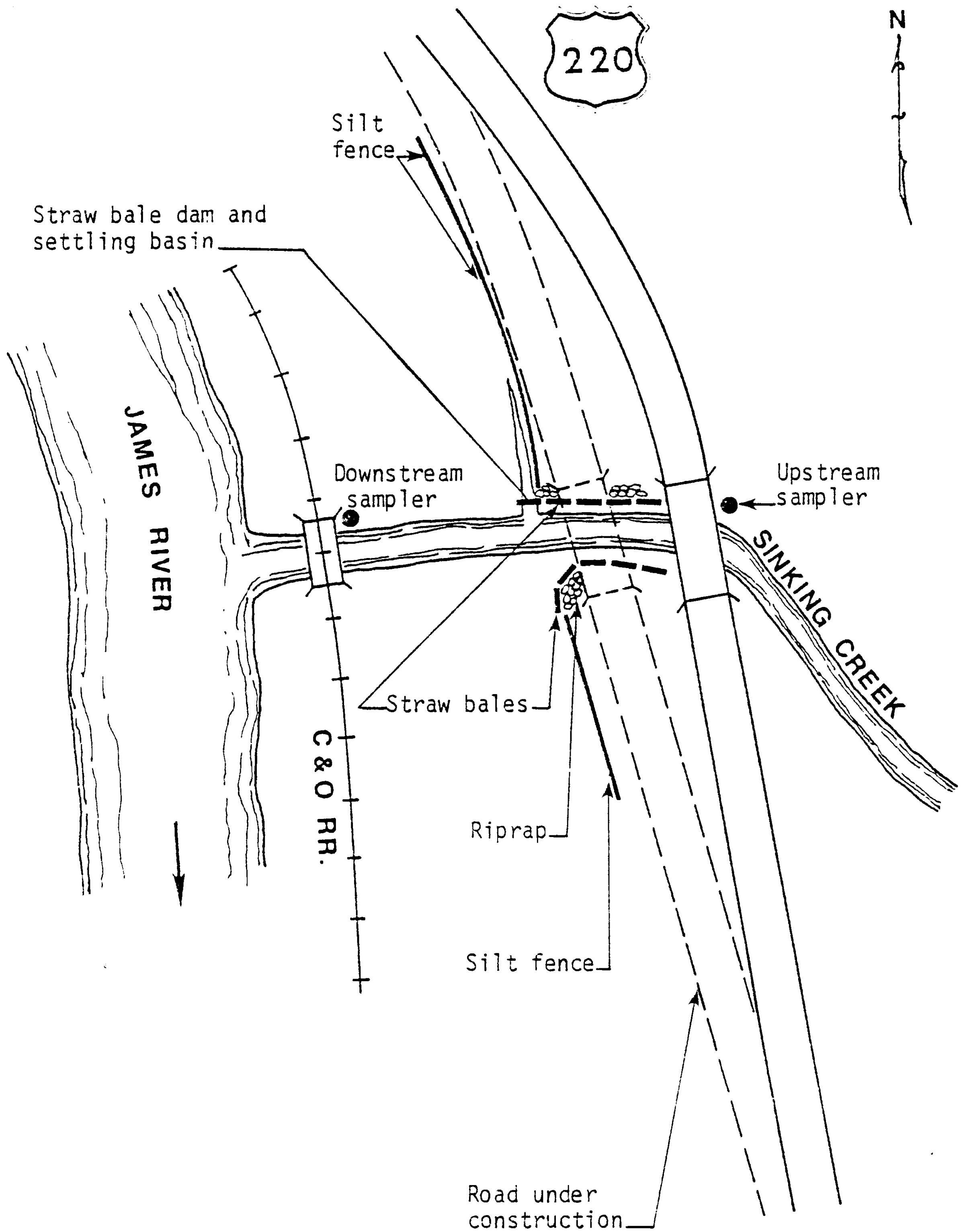


Figure B-9. Plan view of Sinking Creek erosion controls and sampler locations.

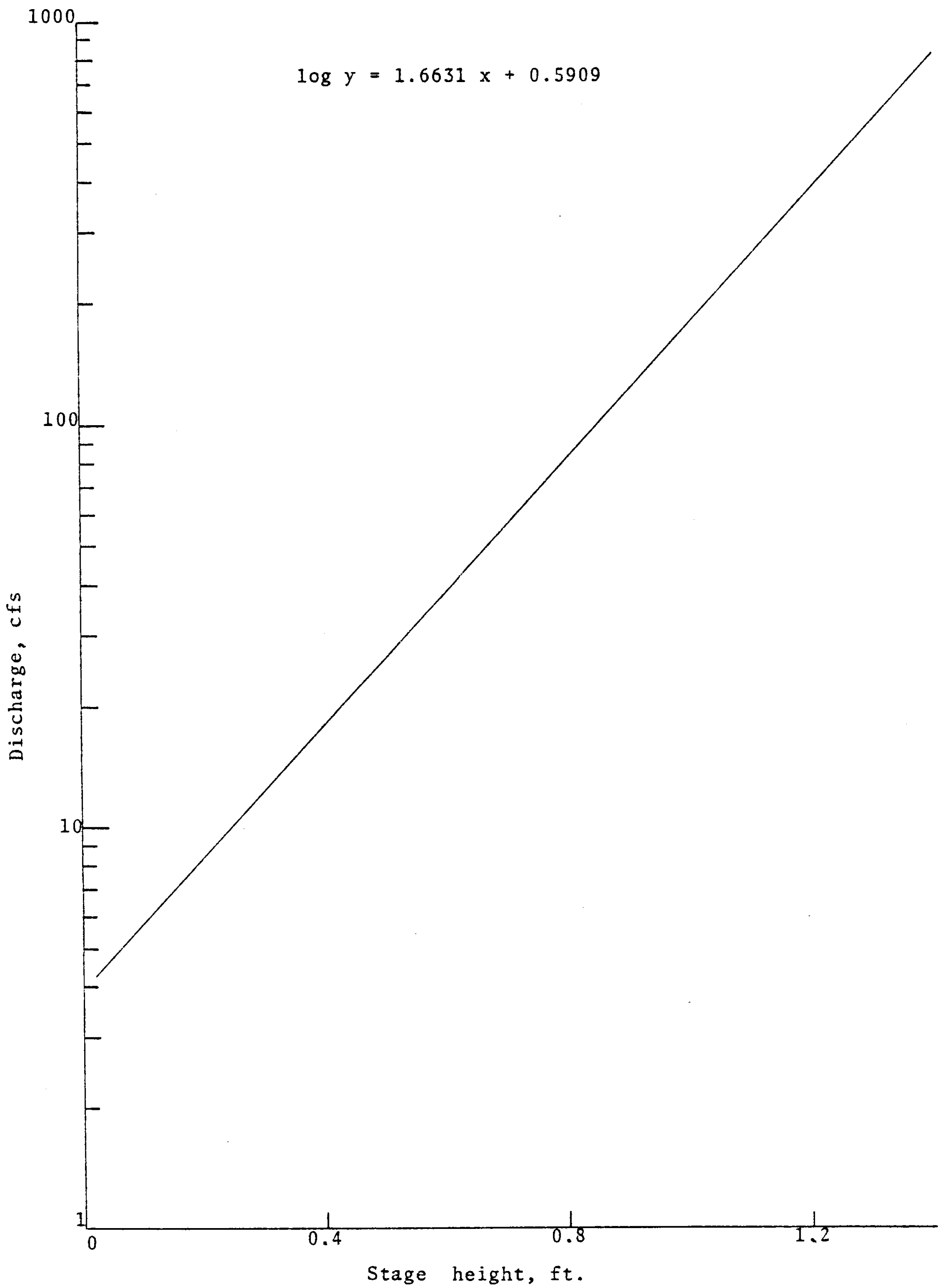


Figure B-10. Stage-discharge curve for Sinking Creek.

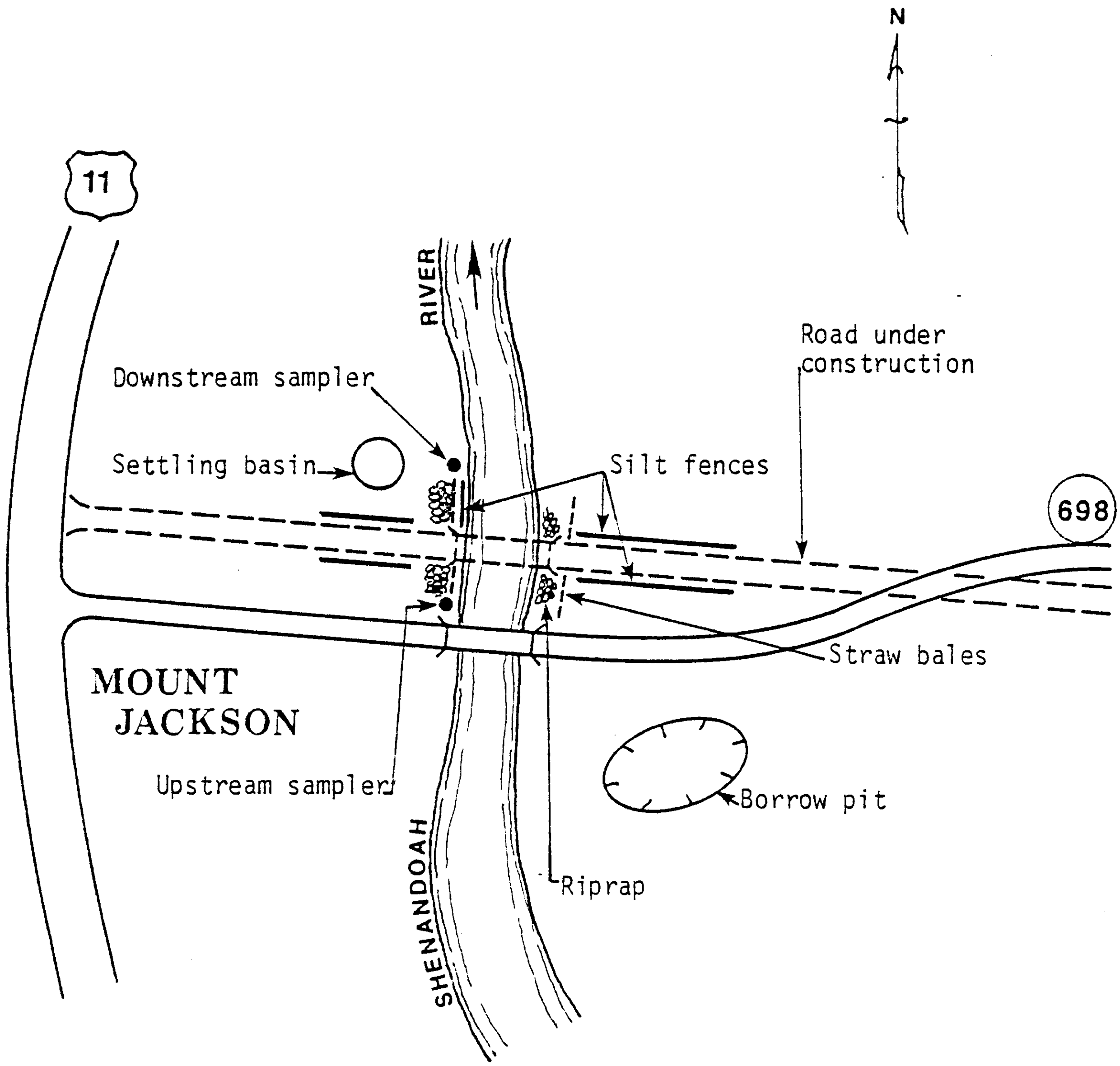


Figure B-11. Plan view of North Fork of Shenandoah River erosion controls and sampler locations.

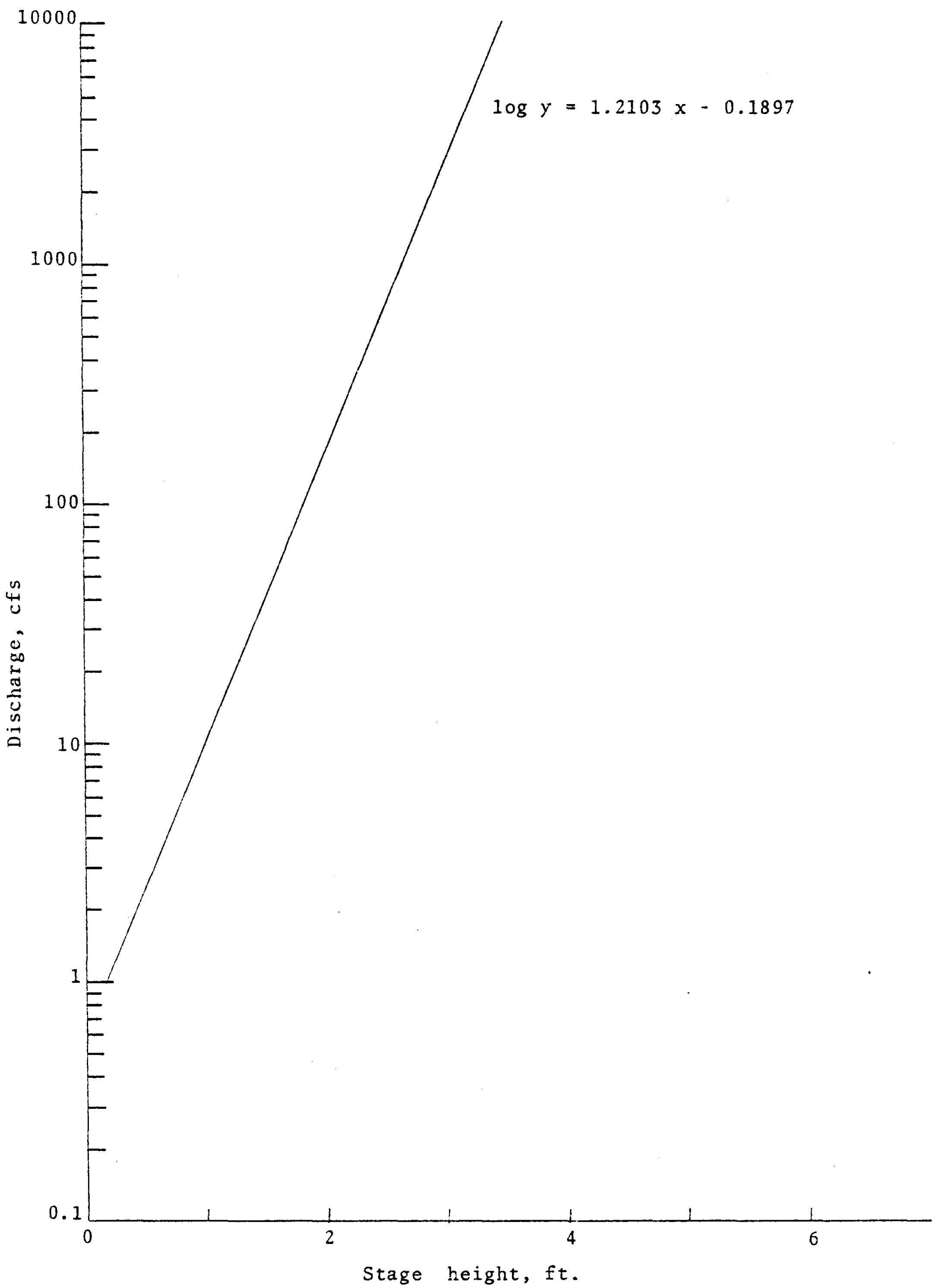


Figure B-12. Stage-discharge curve for the North Fork of the Shenandoah River.

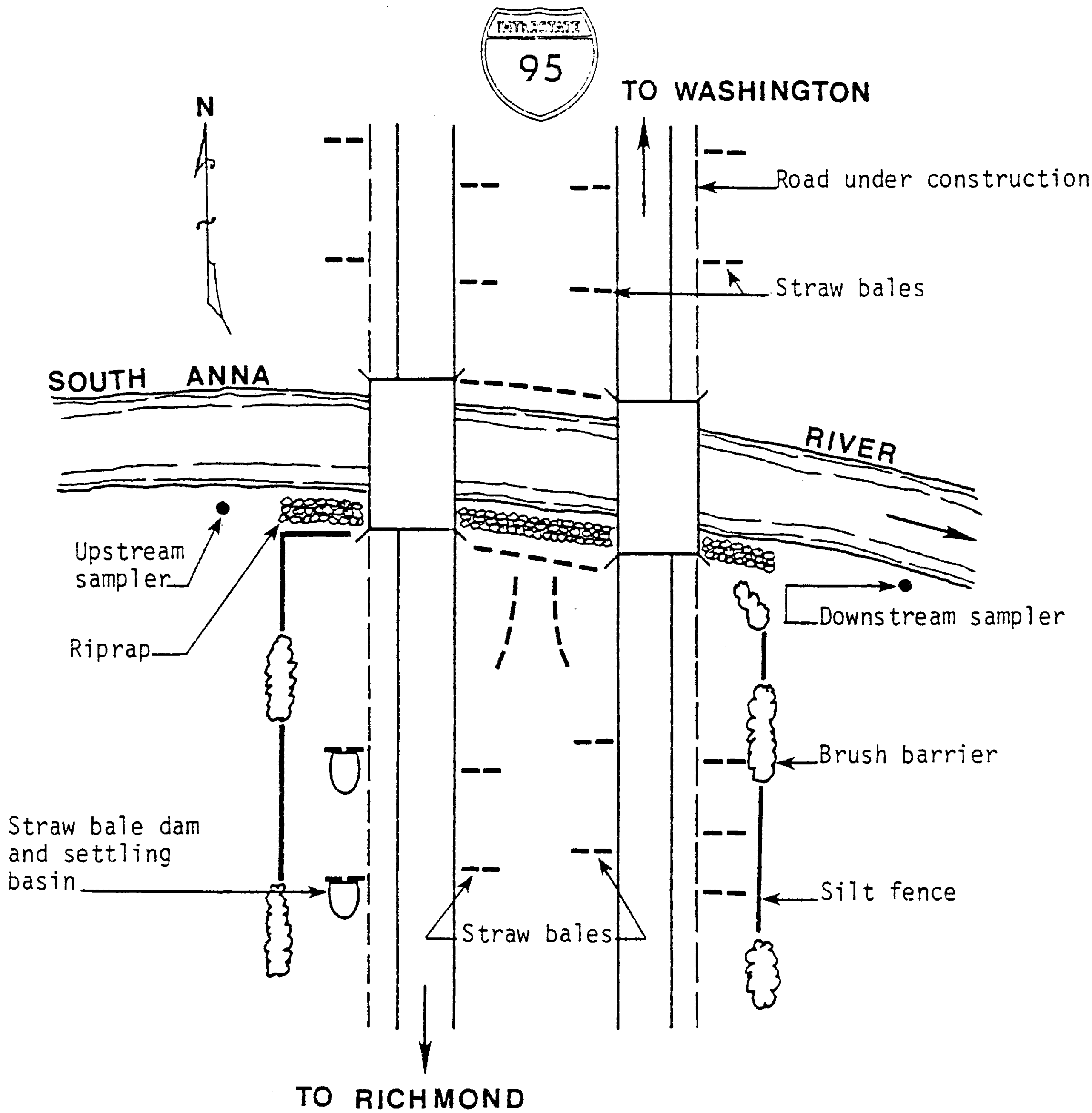


Figure B-13. Plan view of South Anna River erosion controls and sampler locations.

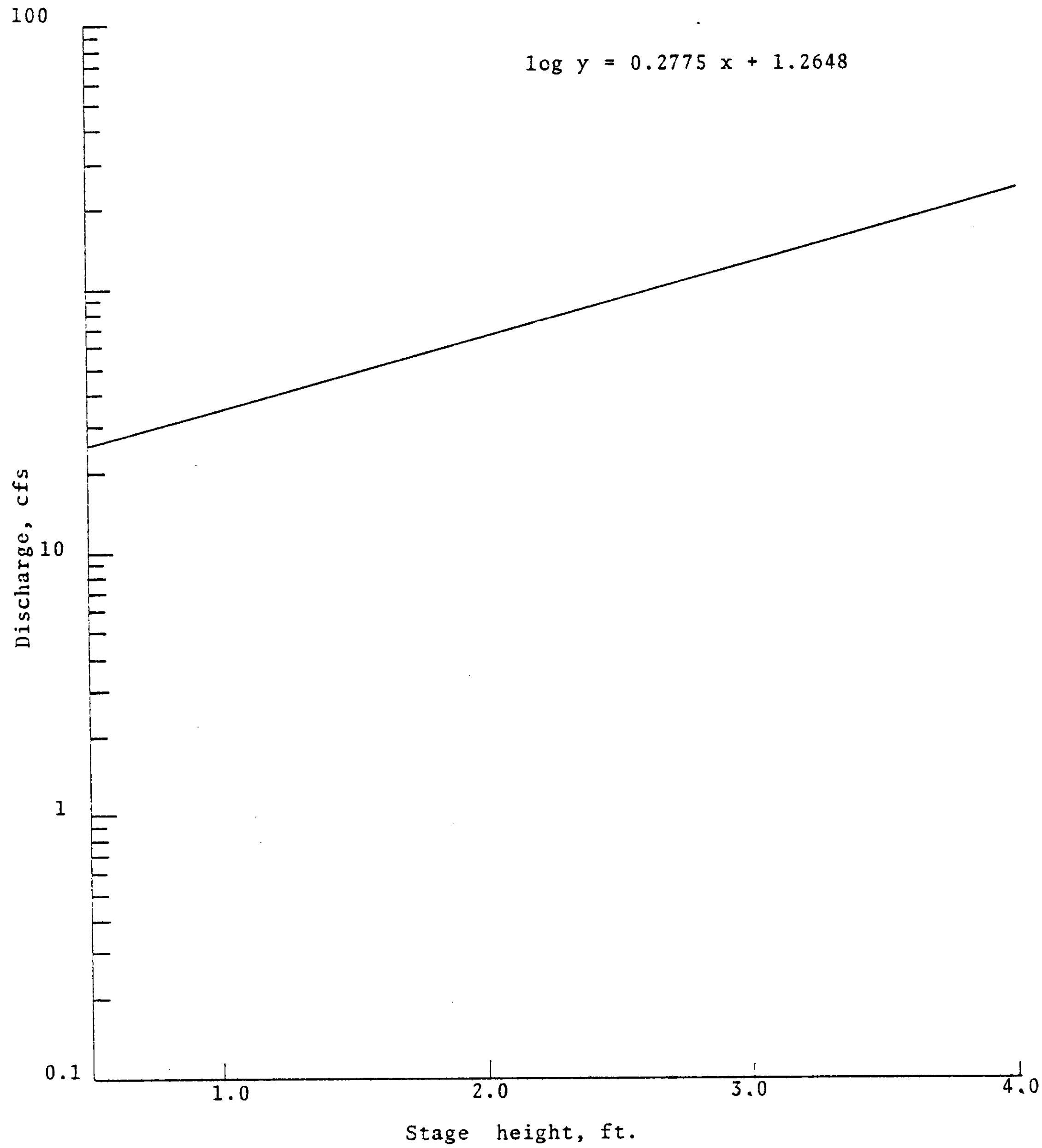


Figure B-14. Stage-discharge curve for the South Anna River.

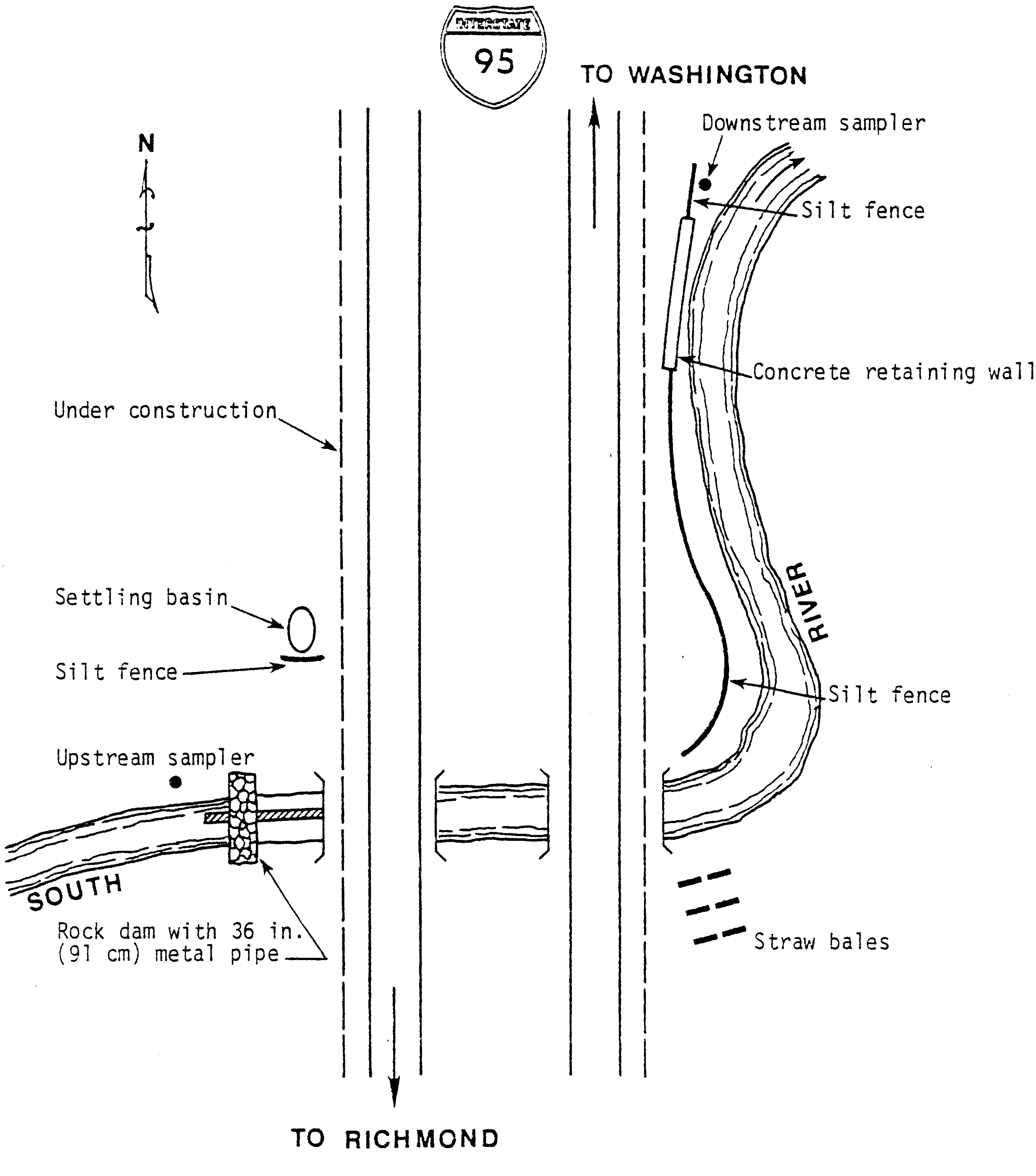


Figure B-15. Plan view of South River erosion controls and sampler locations.

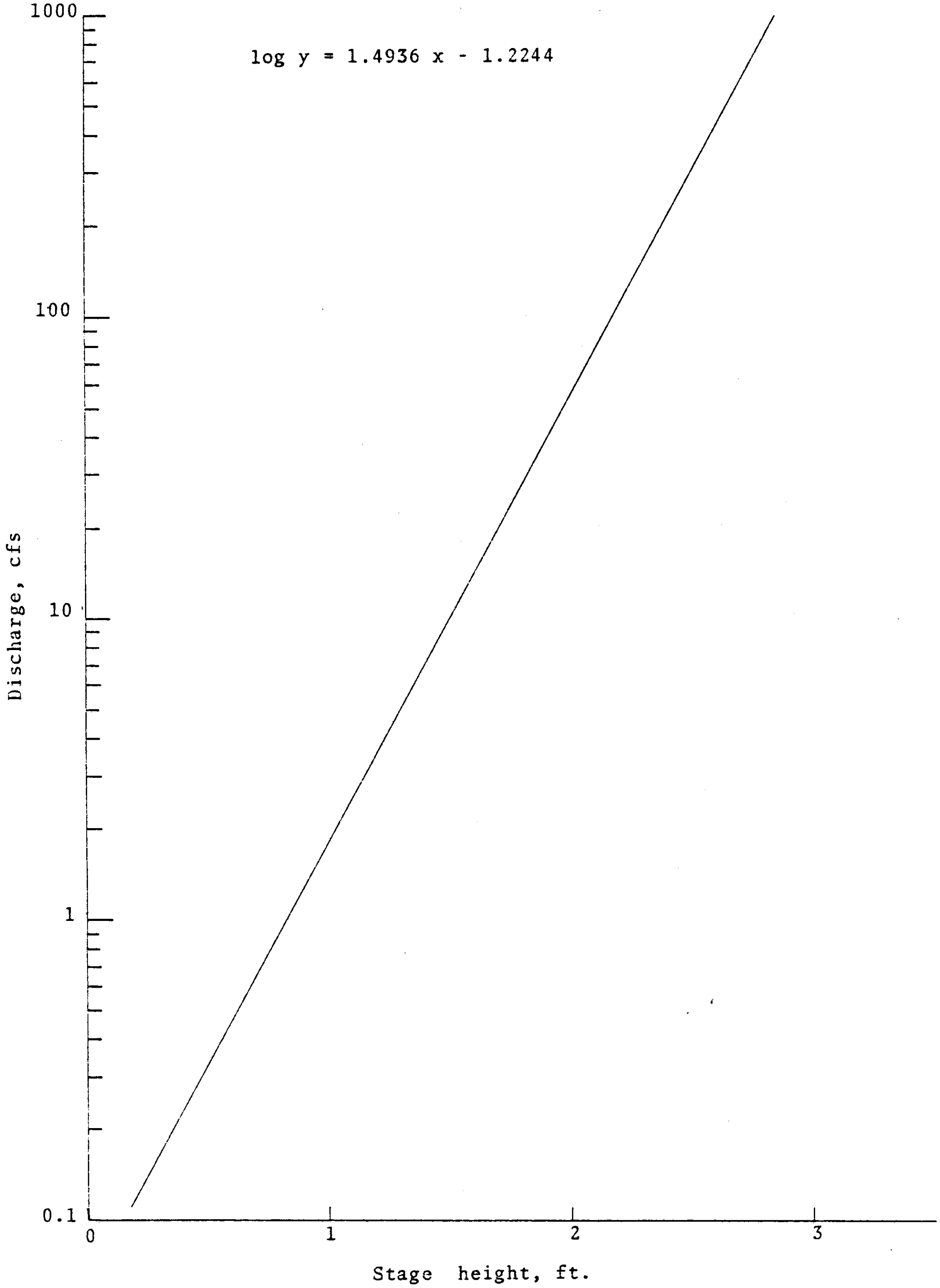


Figure B-16. Stage-discharge curve for the South River.

APPENDIX C

SUSPENDED SOLIDS, STREAM FLOW, AND RAINFALL DATA FOR EACH PROJECT

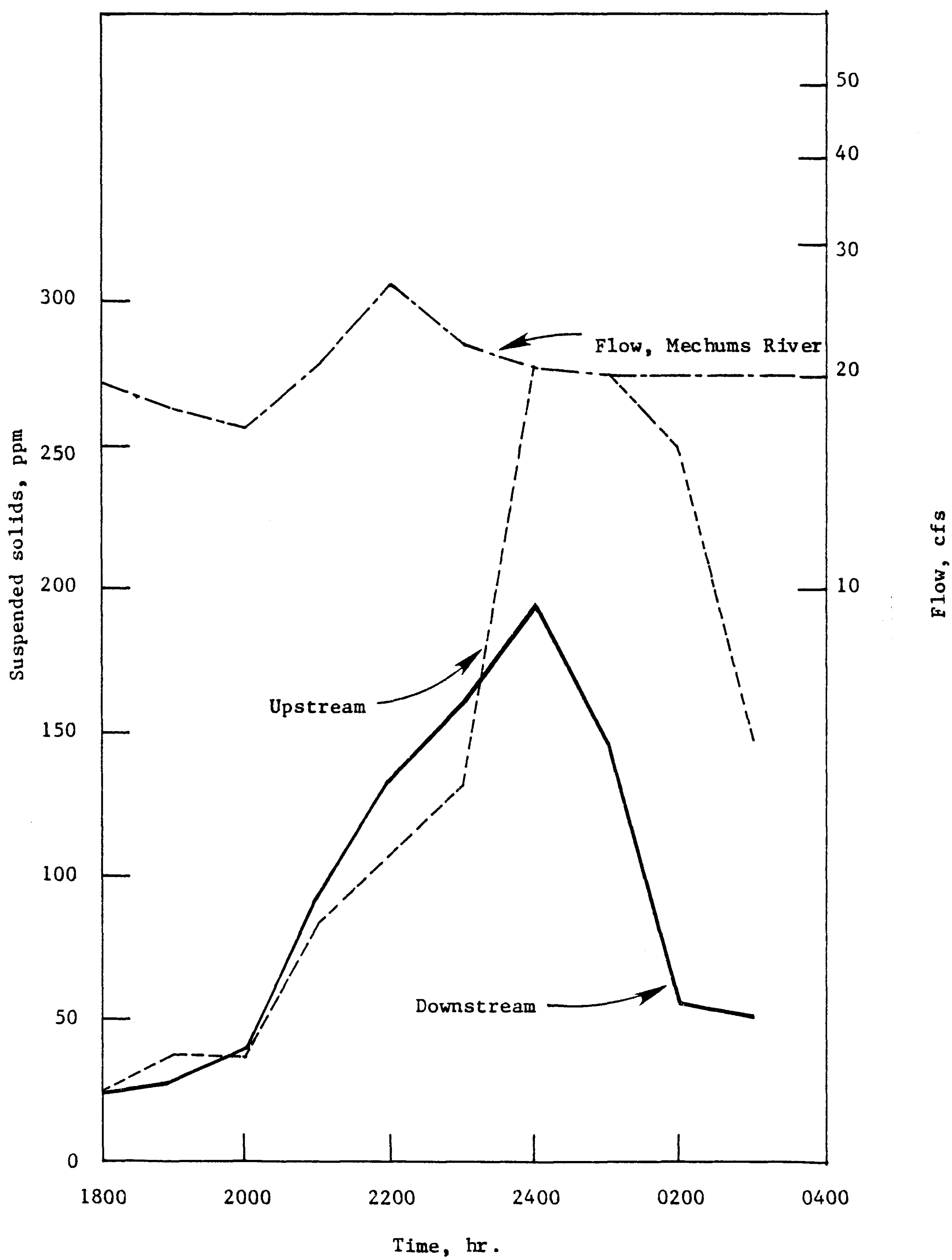


Figure C-1. Suspended solids and stream flow data for July 9, 1980, storm event.

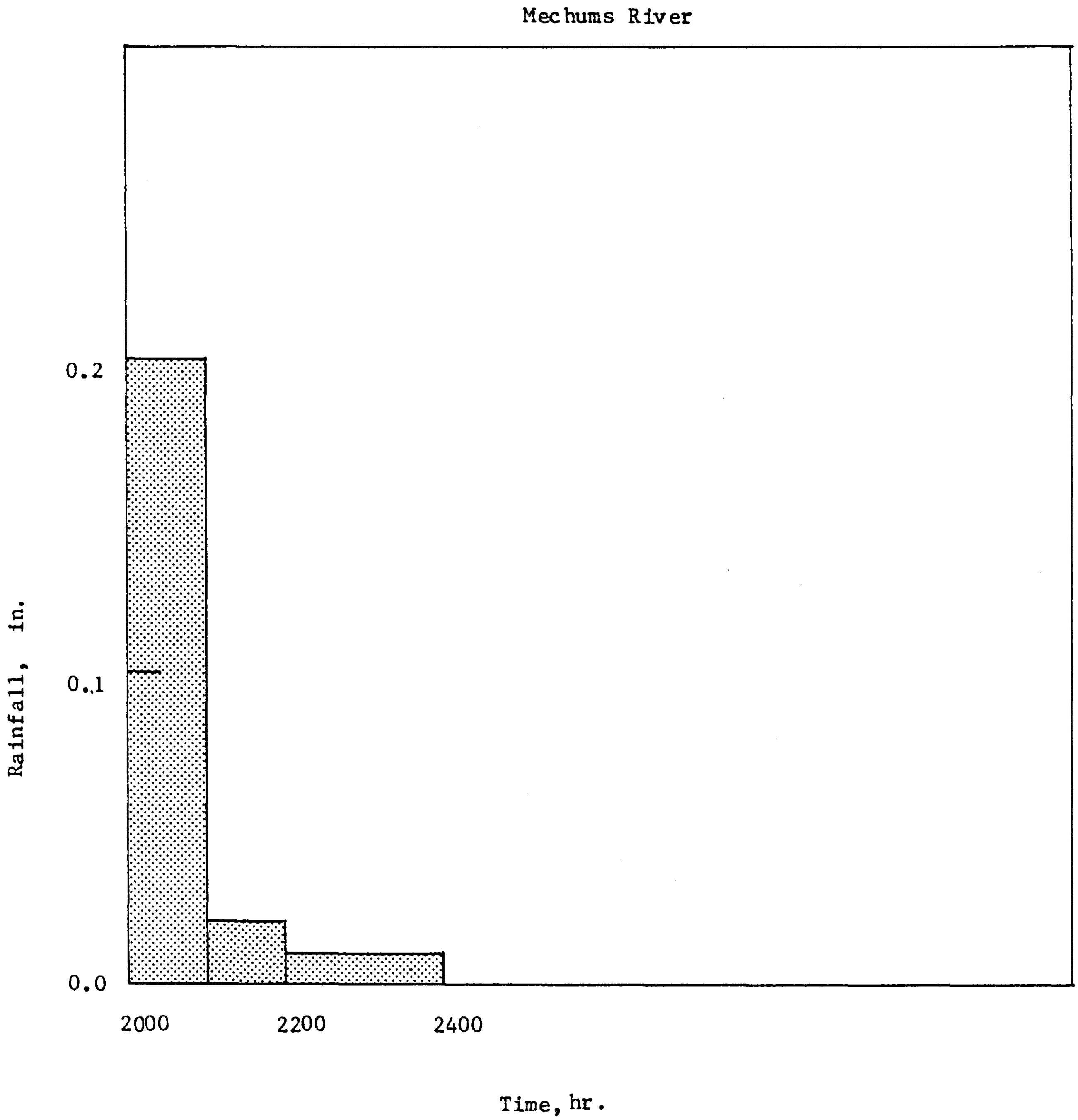


Figure C-2. Rainfall data for July 9, 1980 storm event (total rainfall = 0.24 in.)

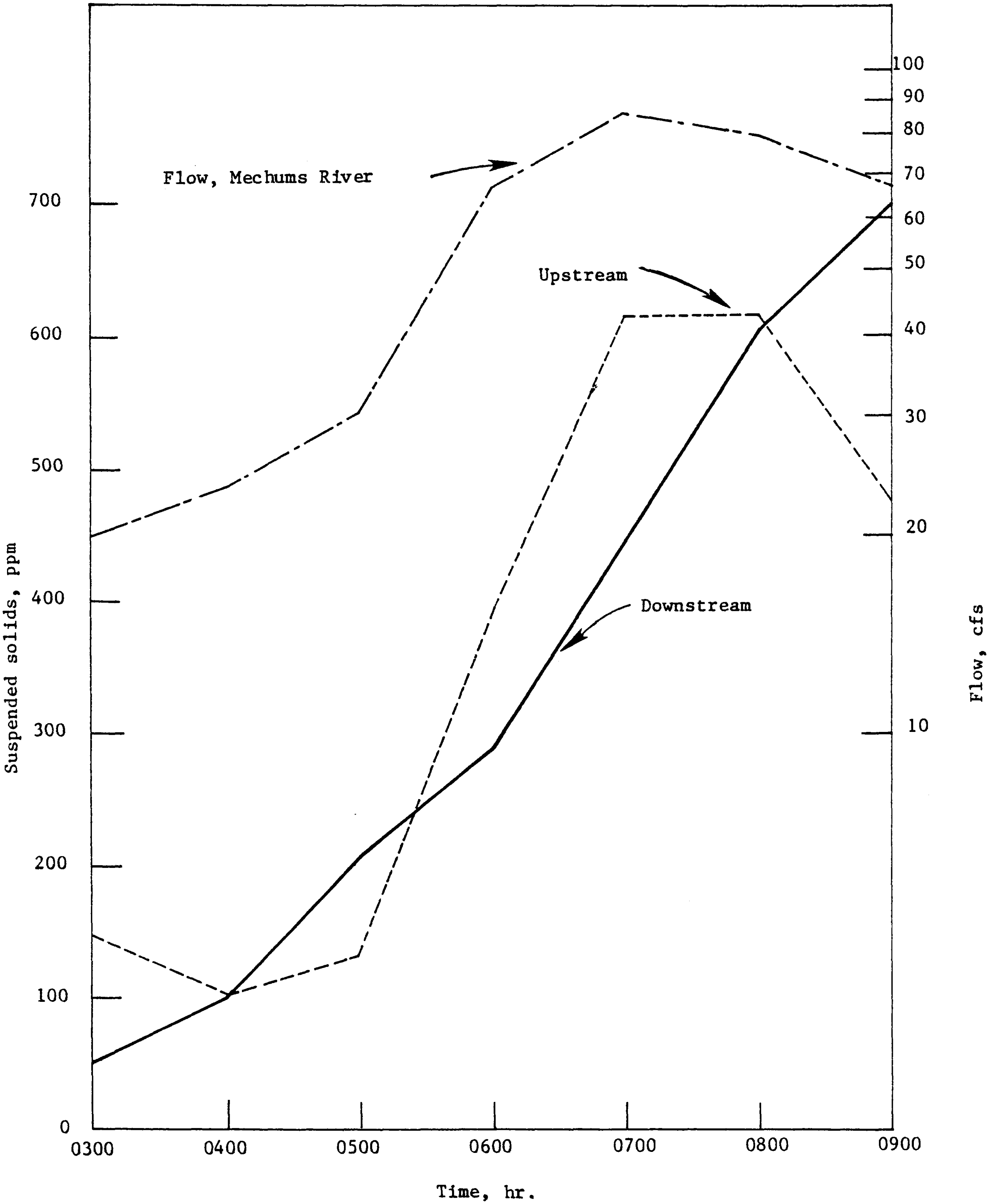


Figure C-3. Suspended solids and stream flow data for July 10, 1980 storm event.

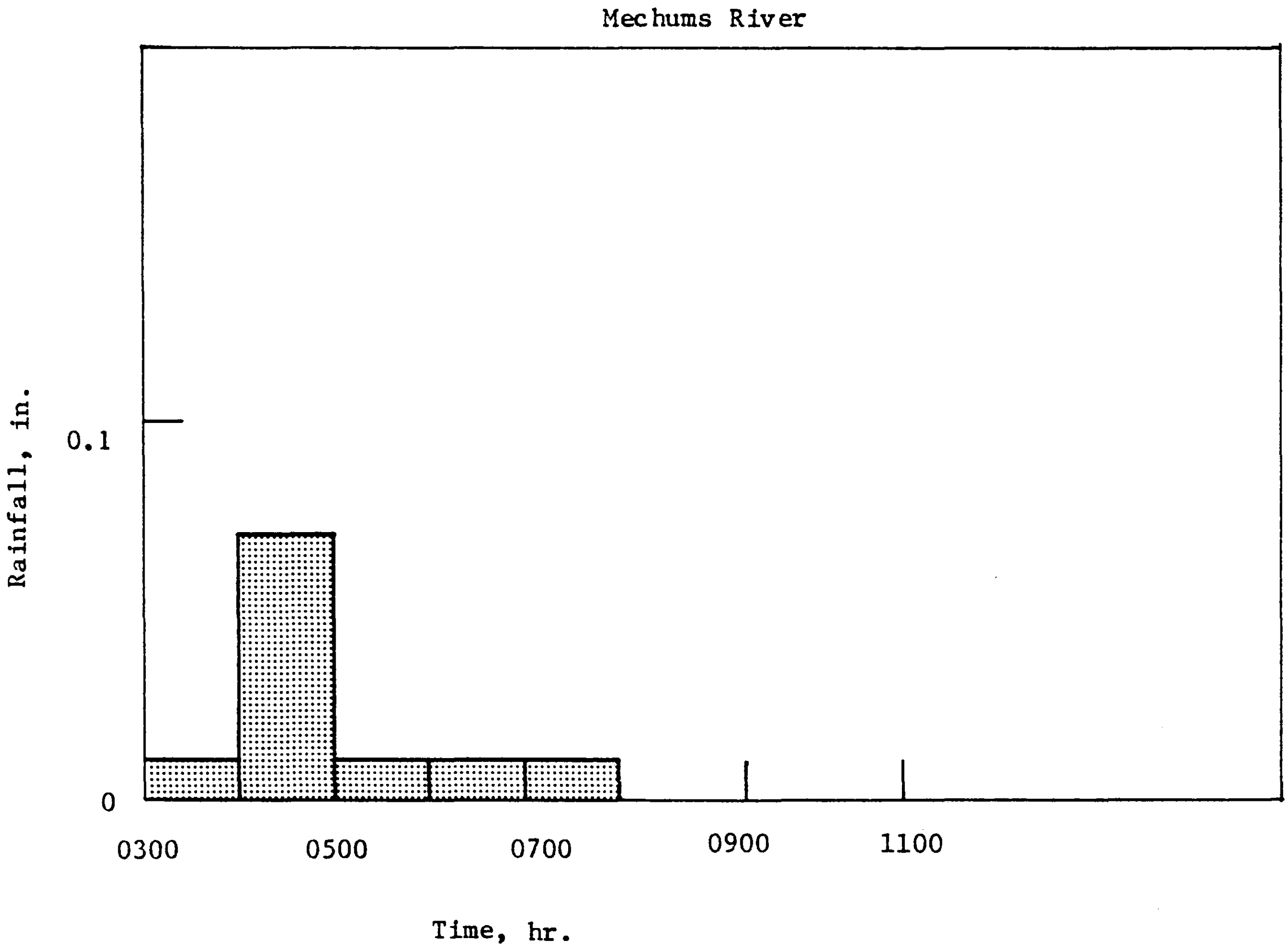


Figure C-4. Rainfall data for July 10, 1980 storm event. (Total rainfall = 0.11 inches).

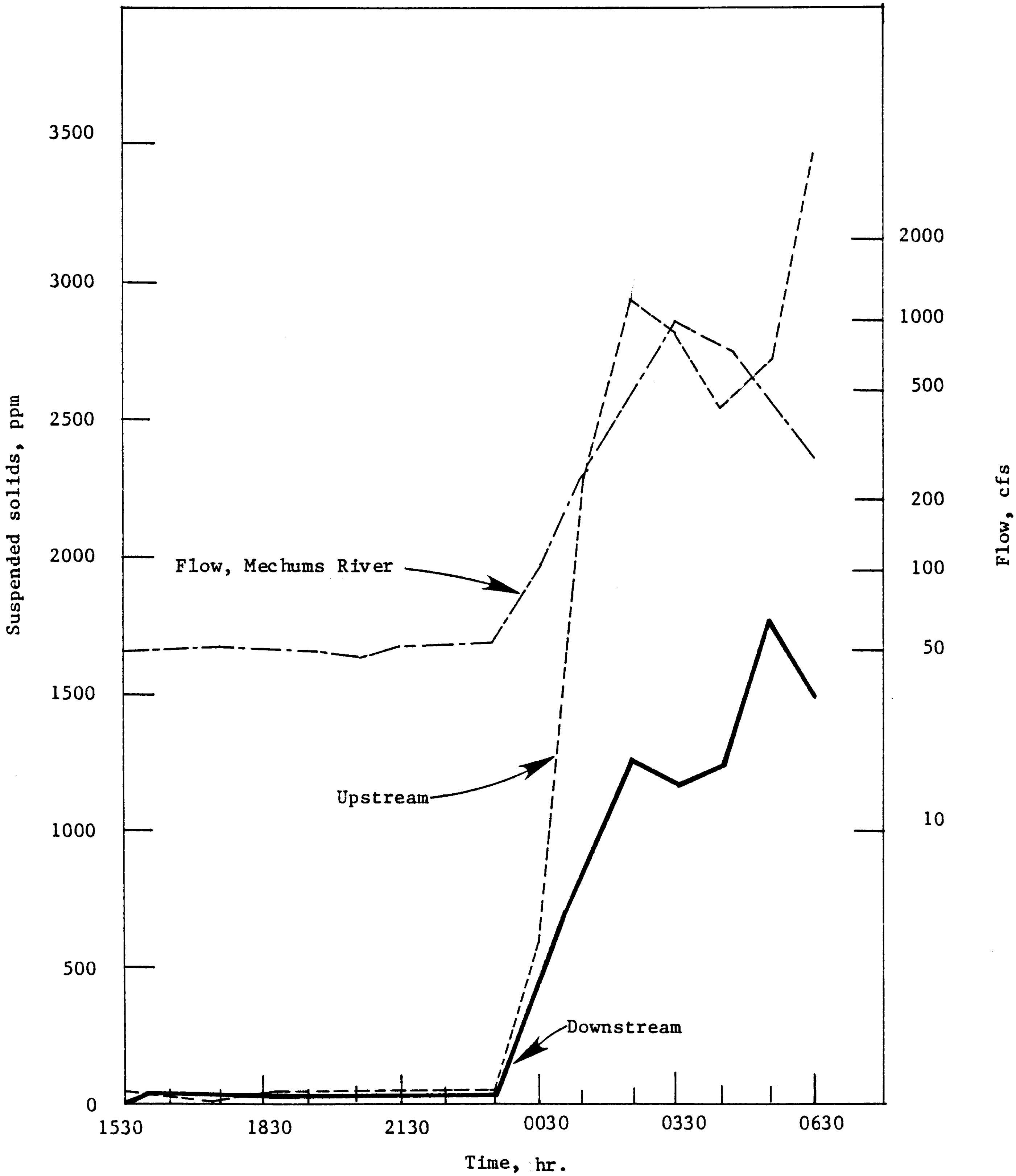


Figure C-5. Suspended solids and stream flow data for July, 1980 storm event.

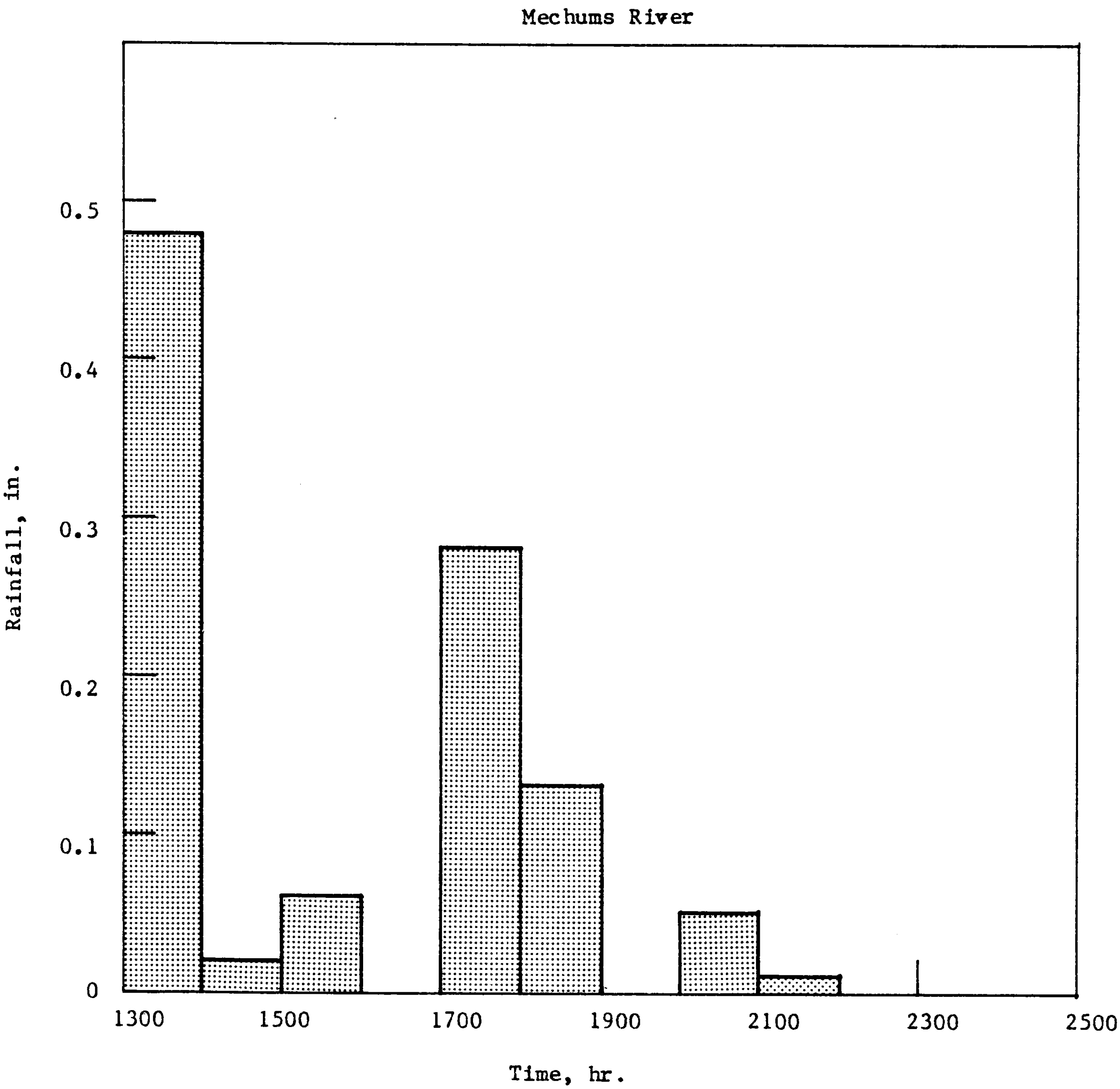


Figure C-6. Rainfall data for July 22, 1980 storm event (total rainfall = 1.03 in.)

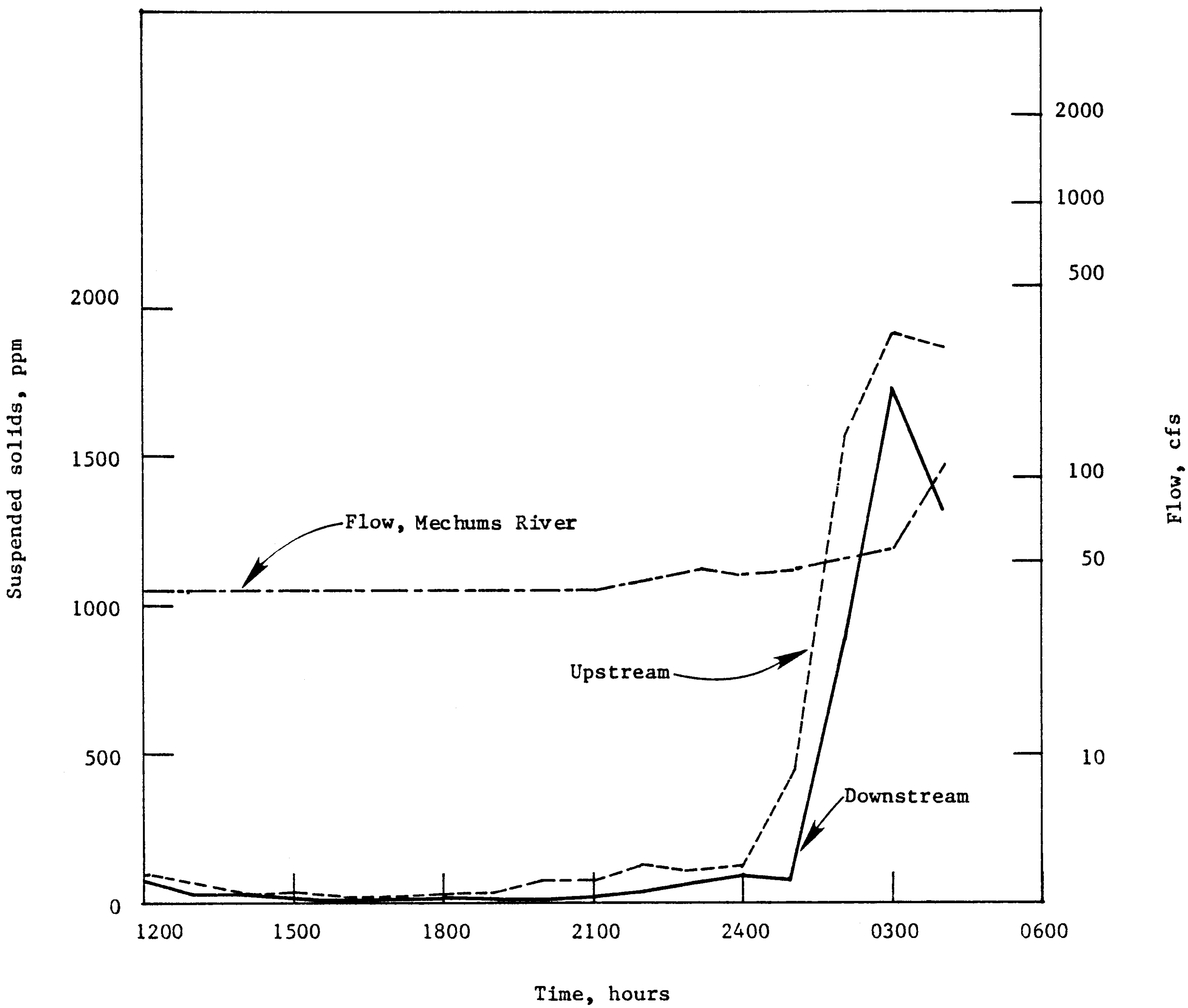


Figure C-7. Suspended solids and stream flow data for July 28, 1980 storm event.

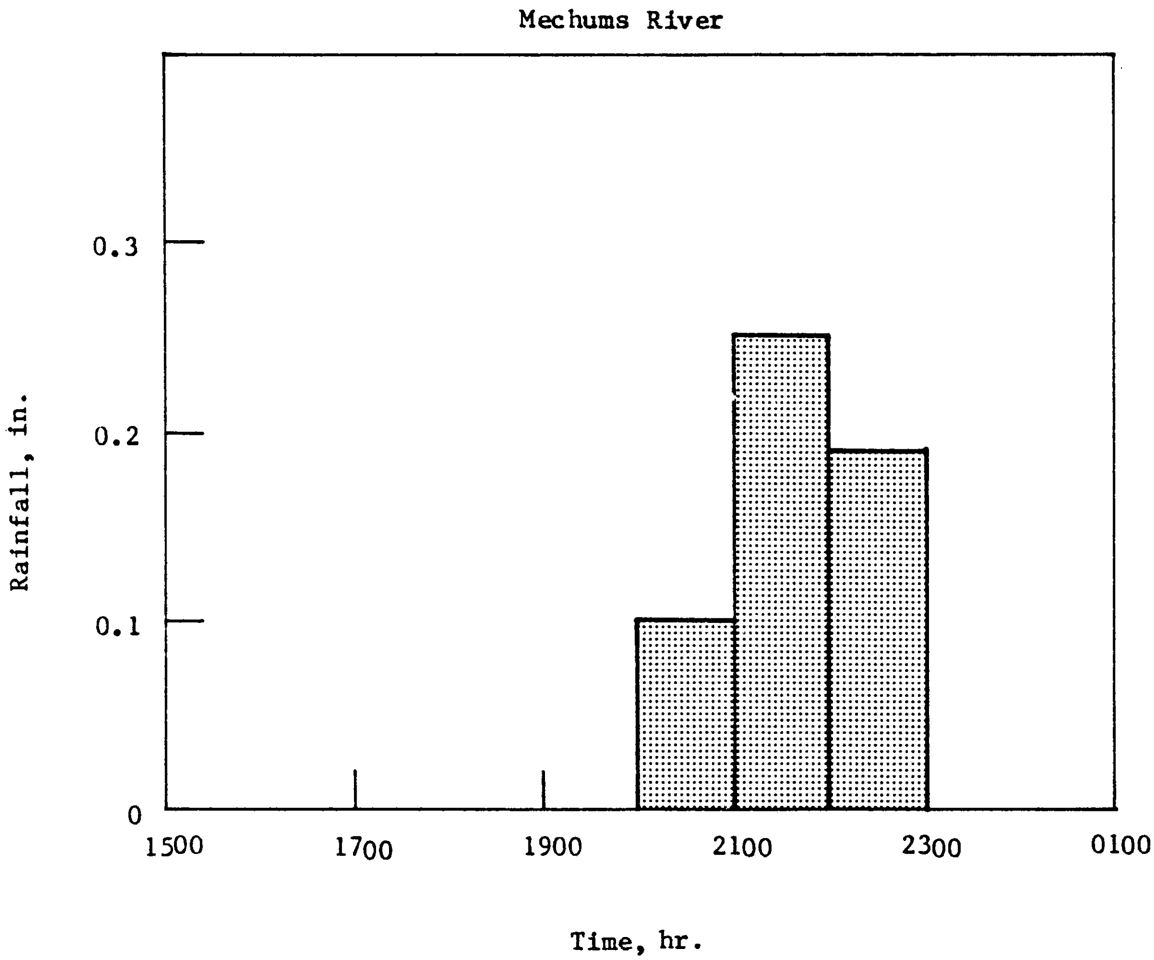


Figure C-8. Rainfall data for July 28, 1980 storm event (total rainfall = 0.54 in.).

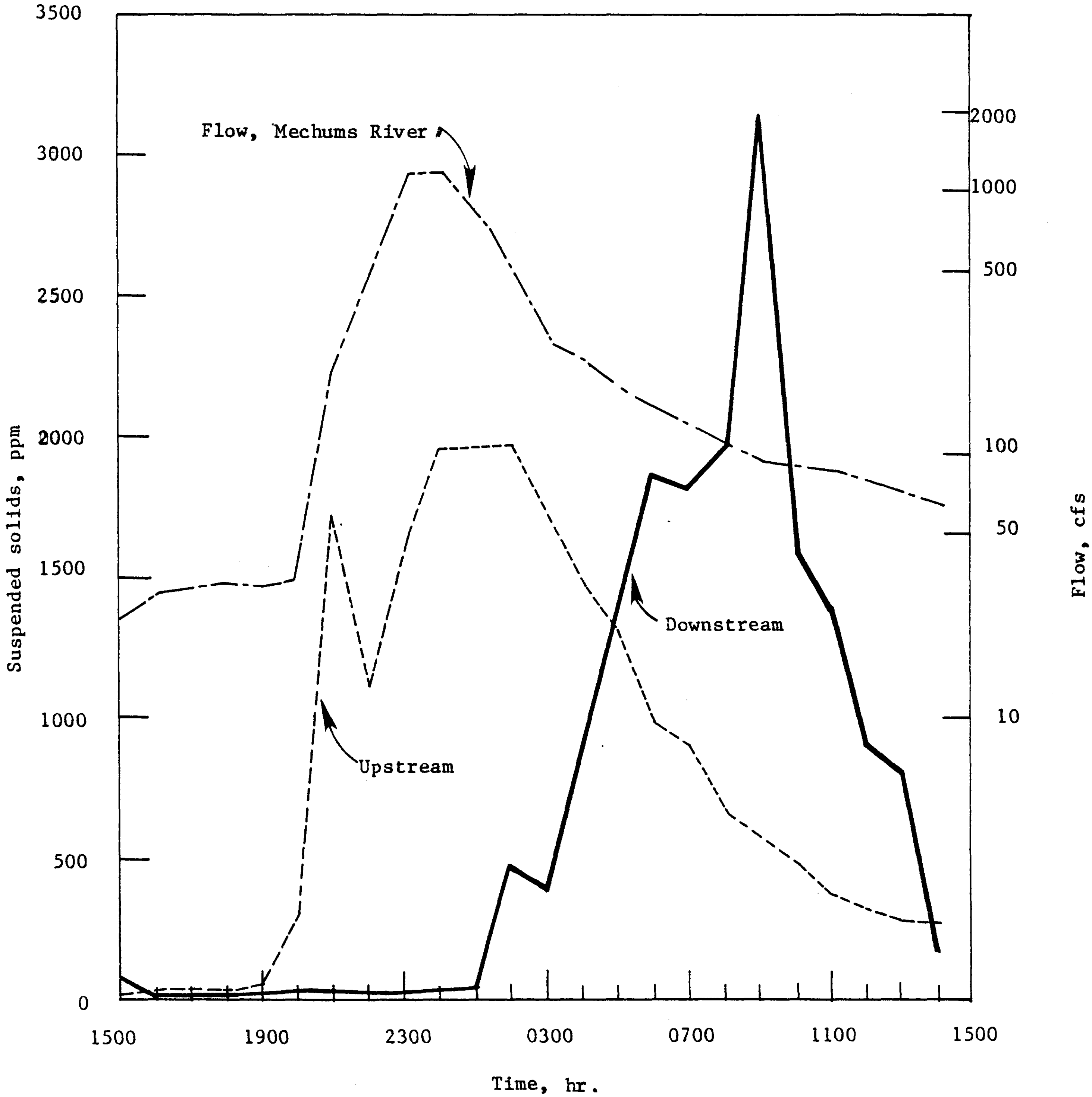


Figure C-9. Suspended solids and stream flow data for August 5, 1980 storm event.

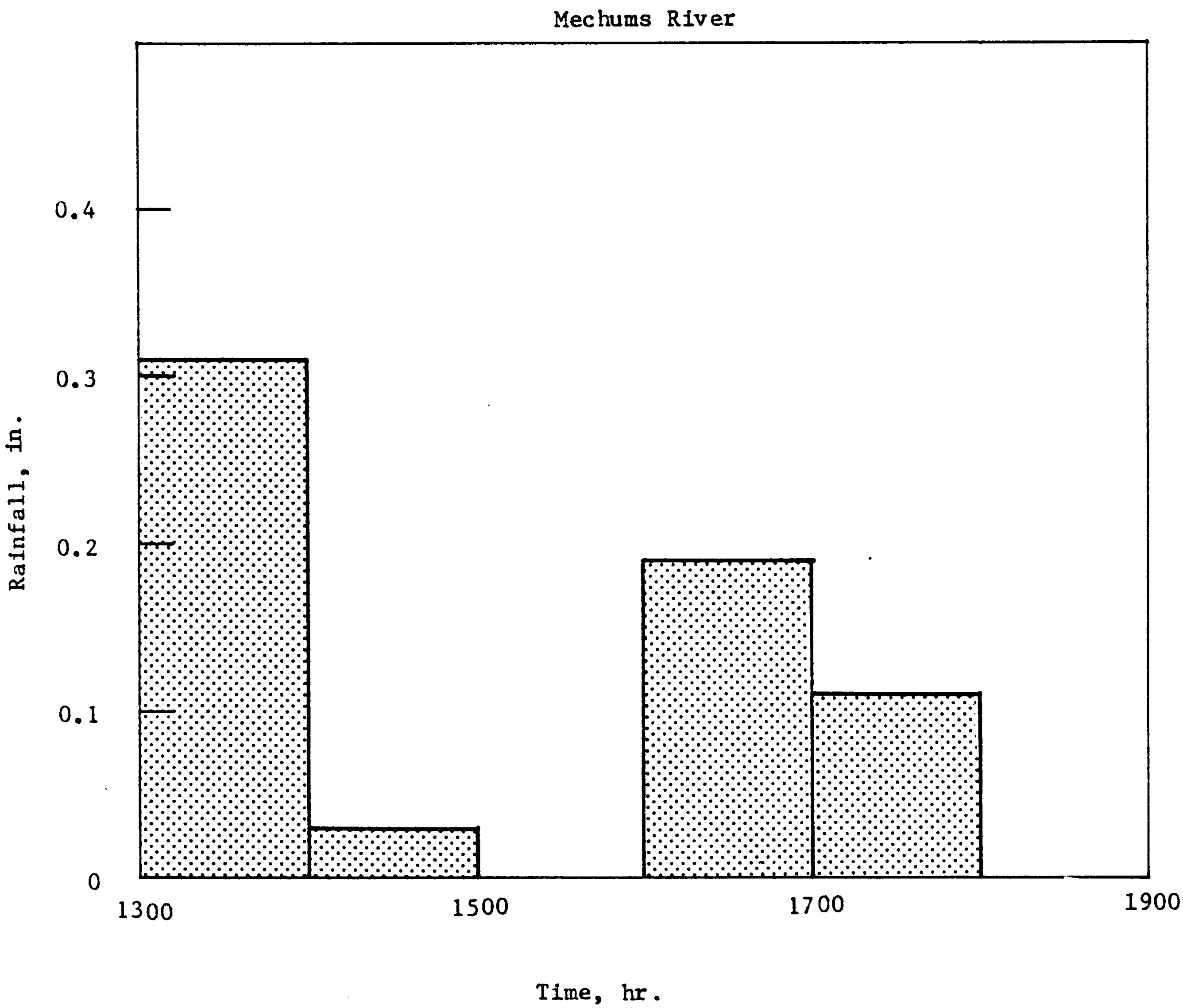


Figure C-10. Rainfall data for August 5, 1980 storm event (total rainfall = 0.64 in.).

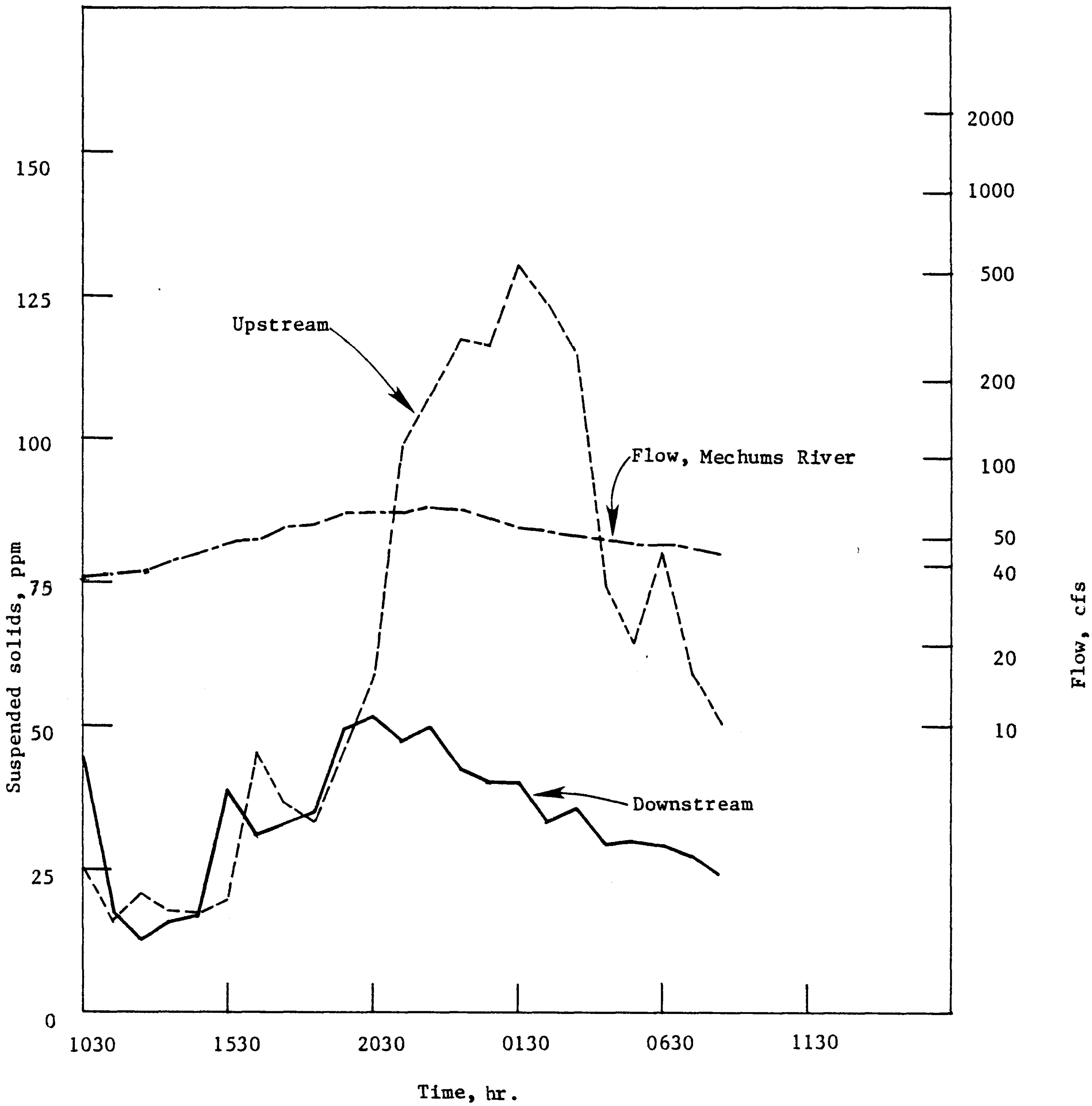


Figure C-11. Suspended solids and stream flow data for August 18, 1980 storm event.

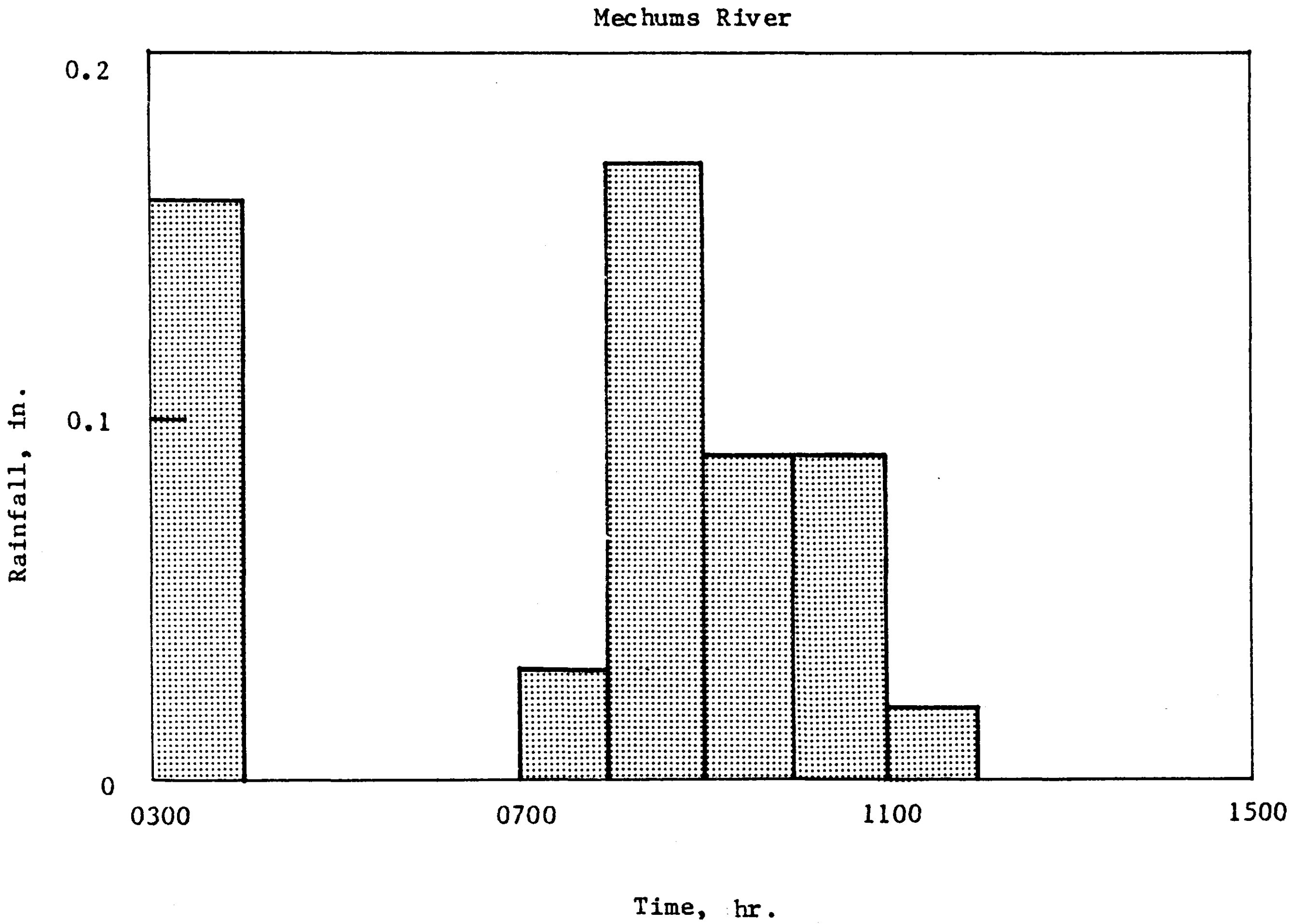


Figure C-12. Rainfall data for August 18, 1980 storm event (total rainfall = 0.56 in.).

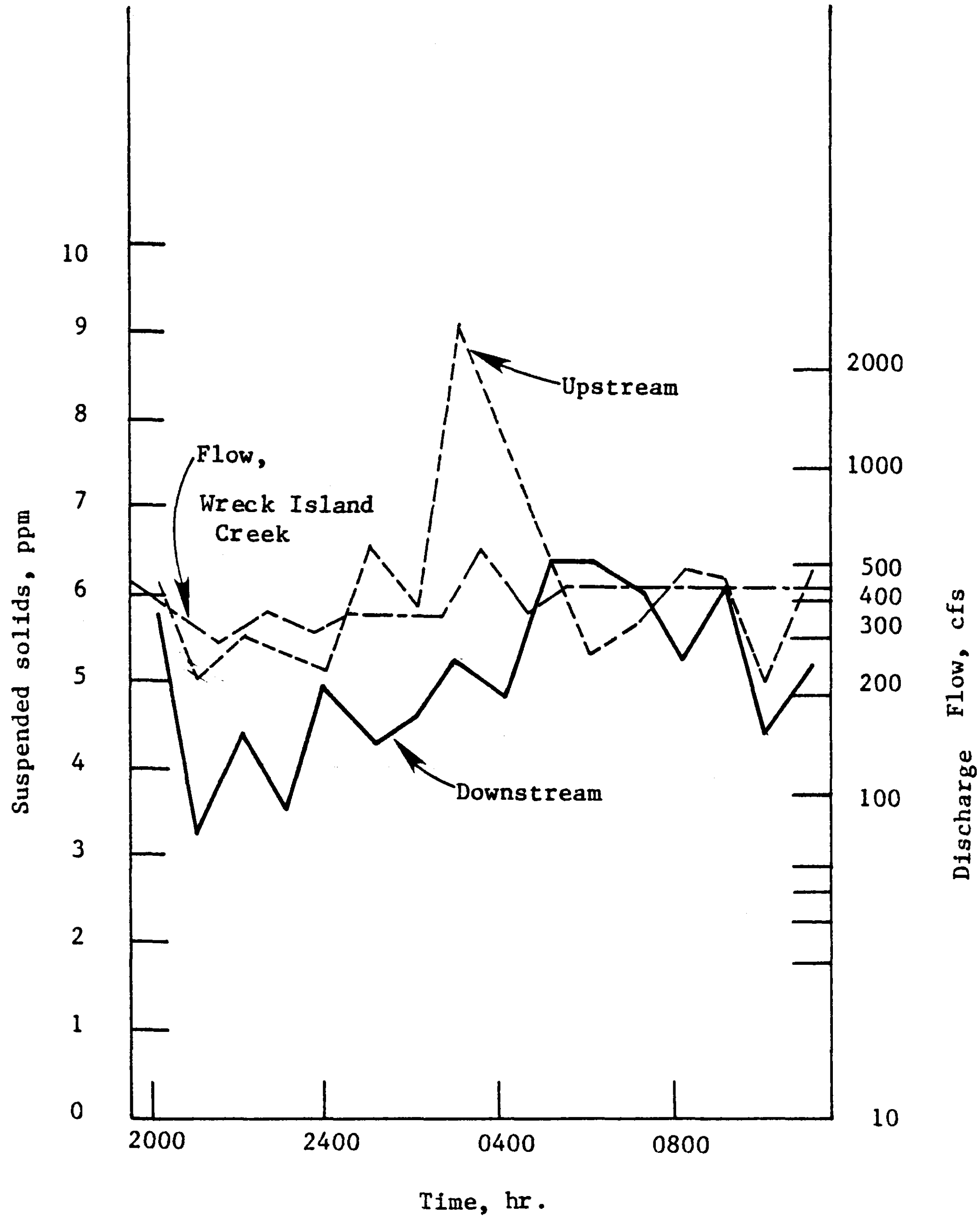


Figure C-13. Suspended solids and stream flow data for April 25, 1980 storm event. Total precipitation = 0.09 in. No rain intensity information available.

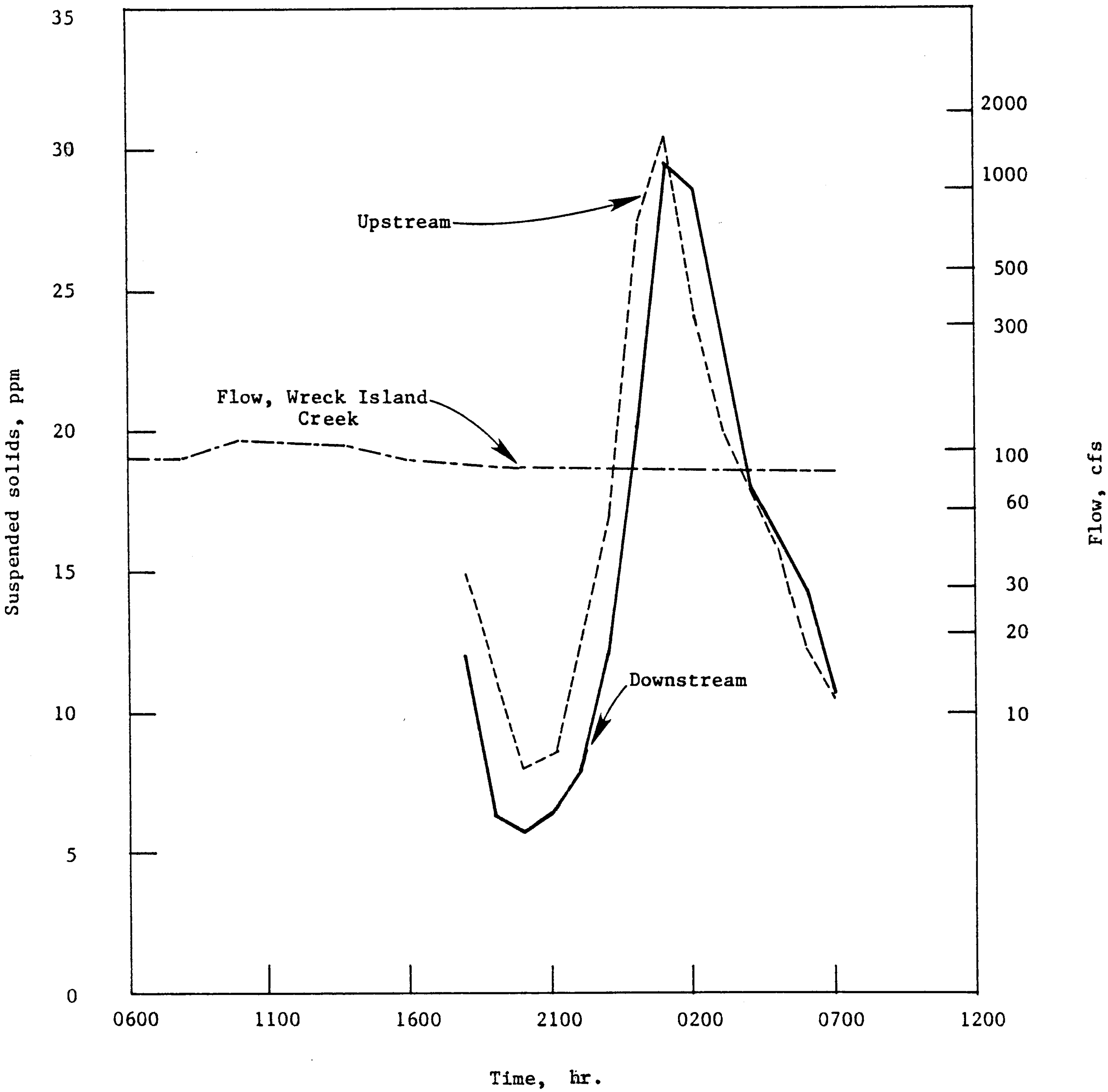


Figure C-14. Suspended solids and stream flow data for April 29, 1980 storm event. Total rainfall = 0.75 in.

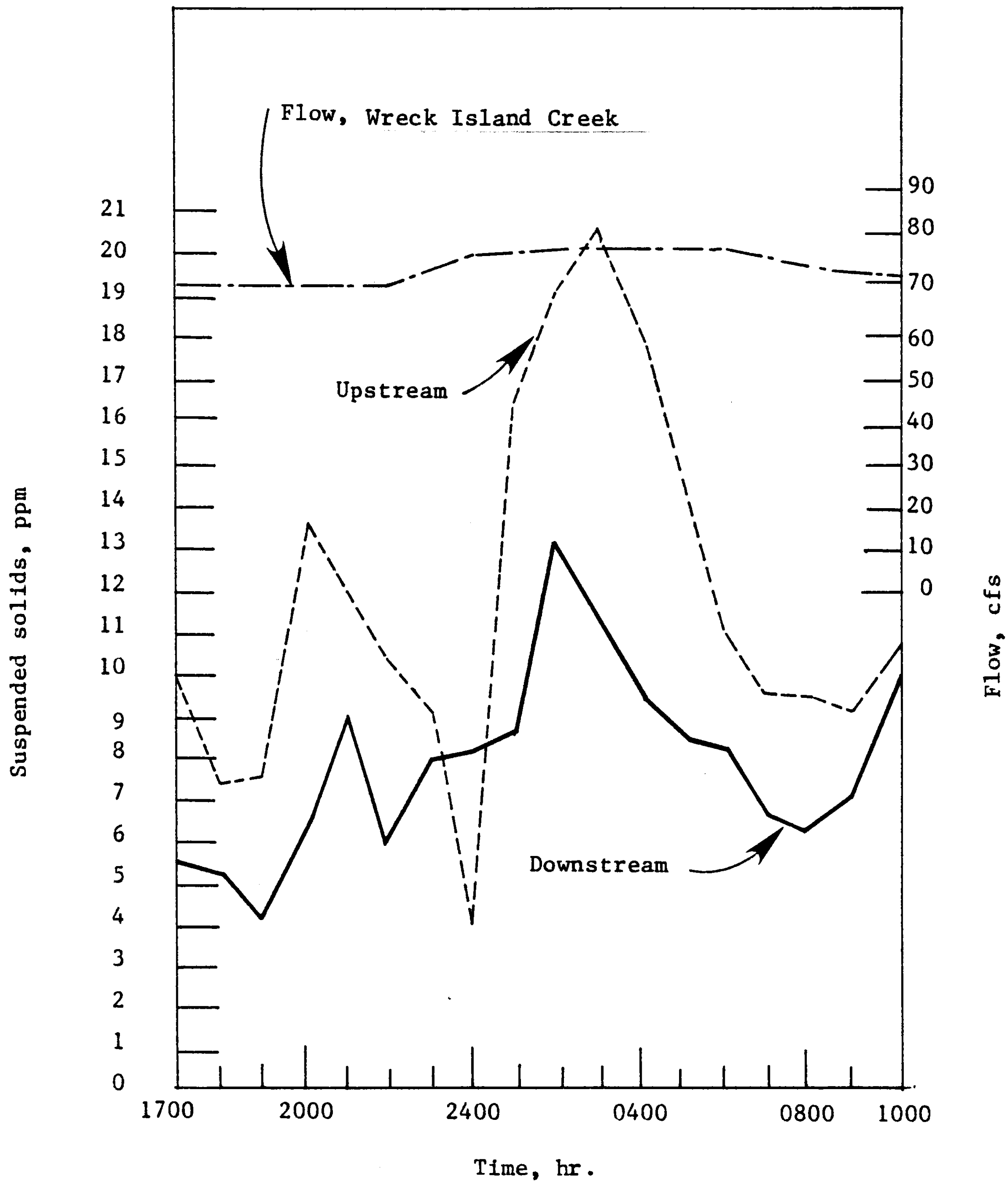


Figure C-15. Suspended solids and stream flow data for April 30, 1980 storm event.

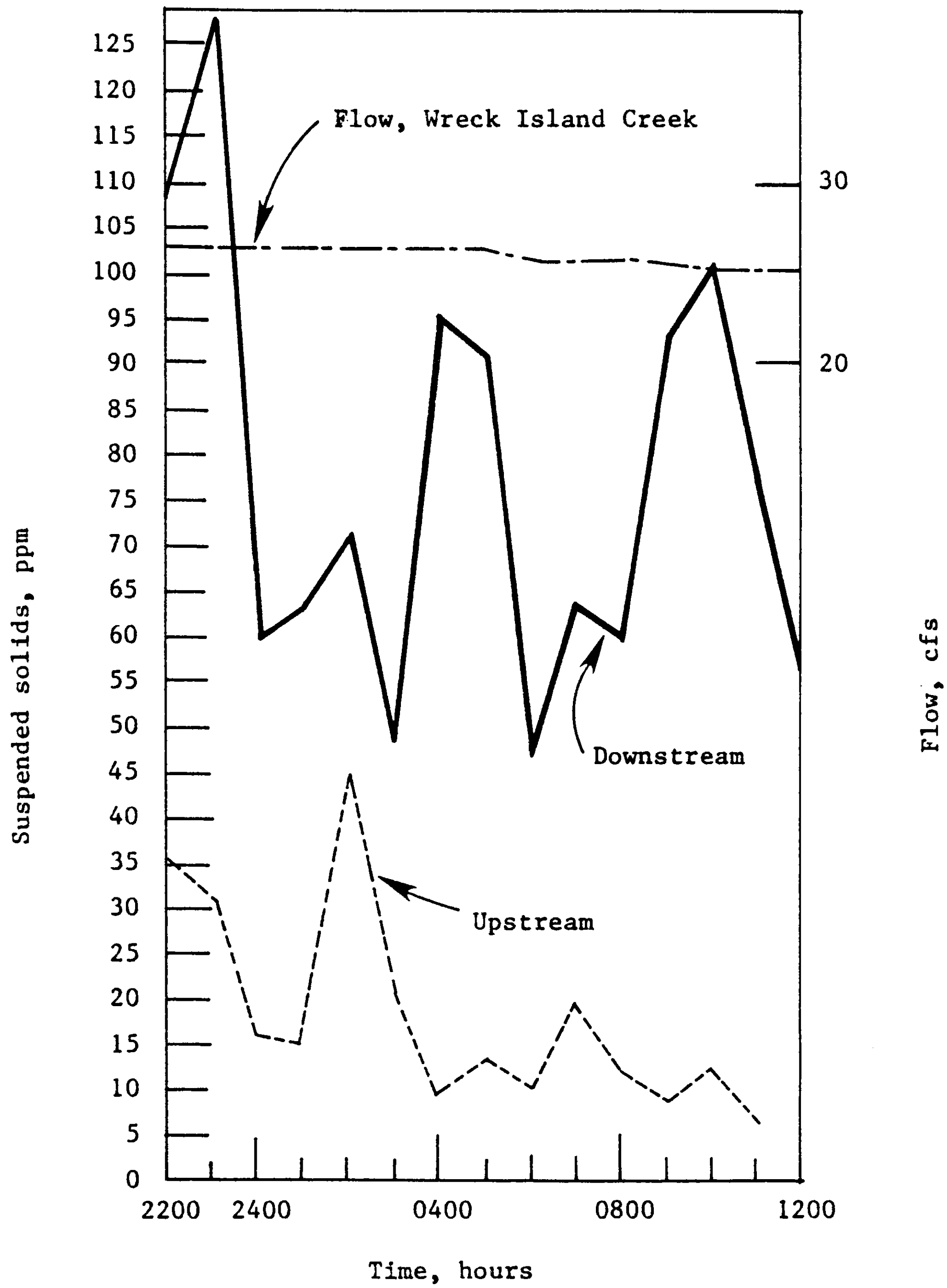


Figure C-16. Suspended solids and stream flow data for June 24, 1980 storm event.

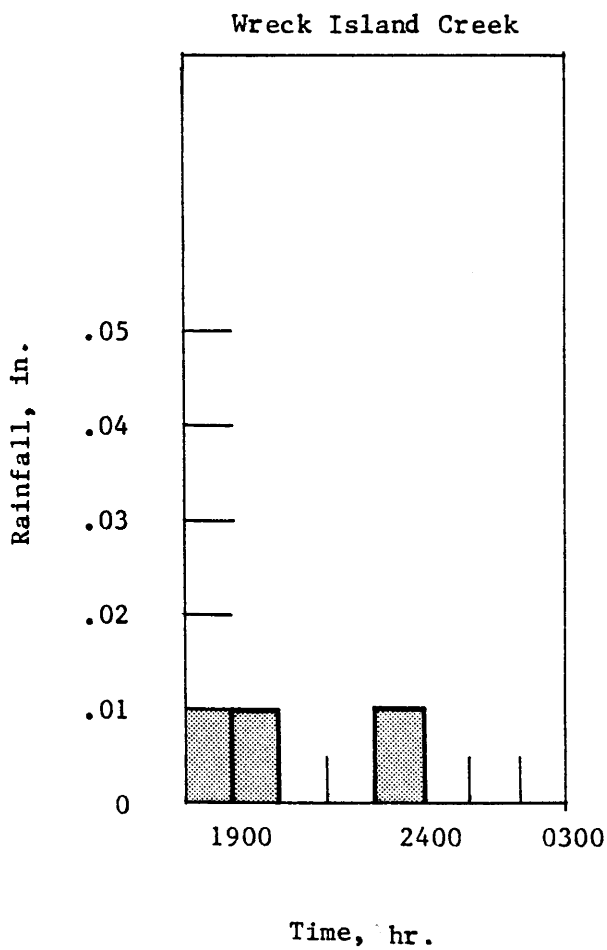


Figure C-17. Rainfall data for June 24, 1980 storm event (total rainfall = 0.03 in.).

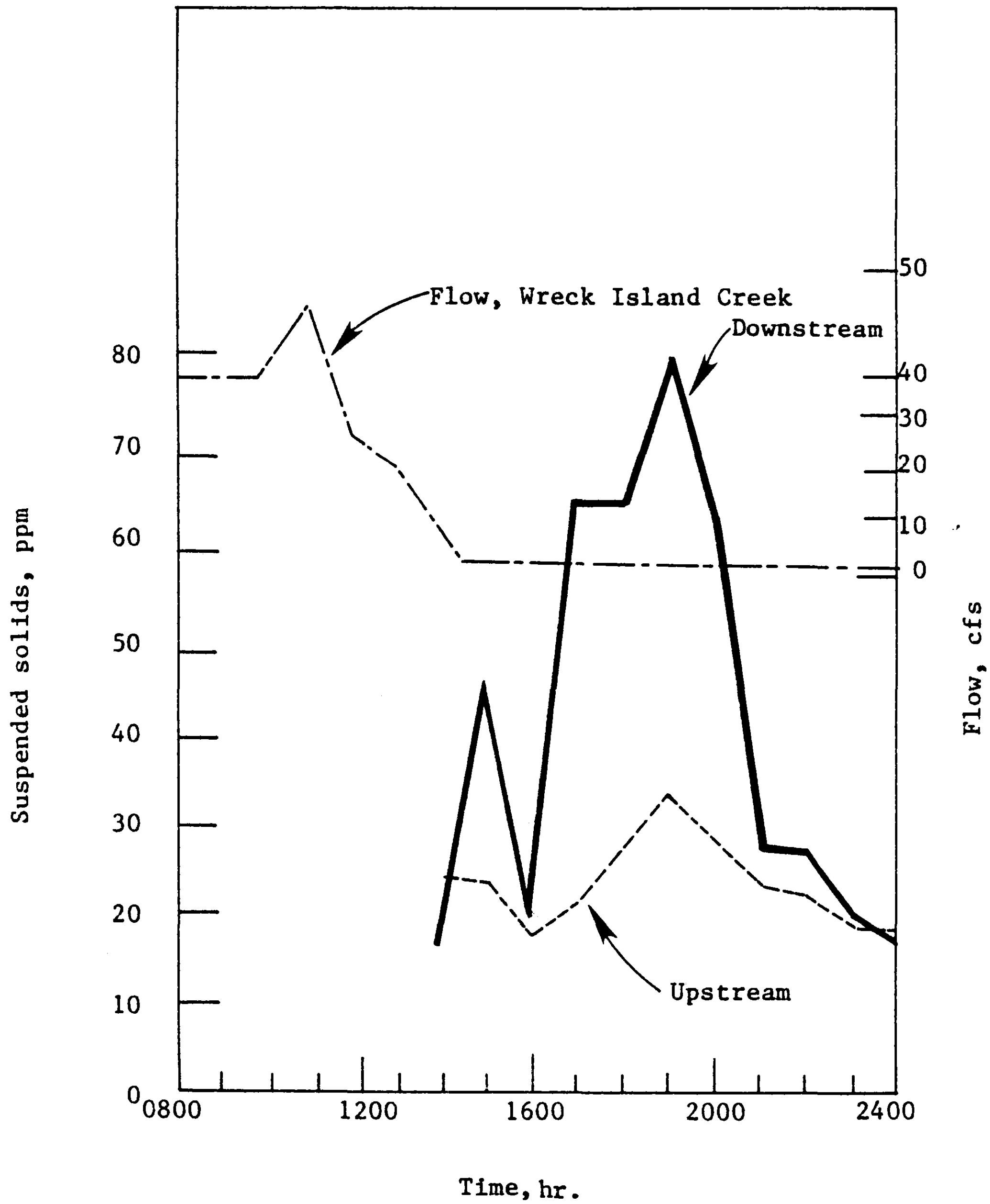


Figure C-18. Suspended solids and stream flow data for July 23, 1980 storm event. (Total rainfall = 0.35 in.).

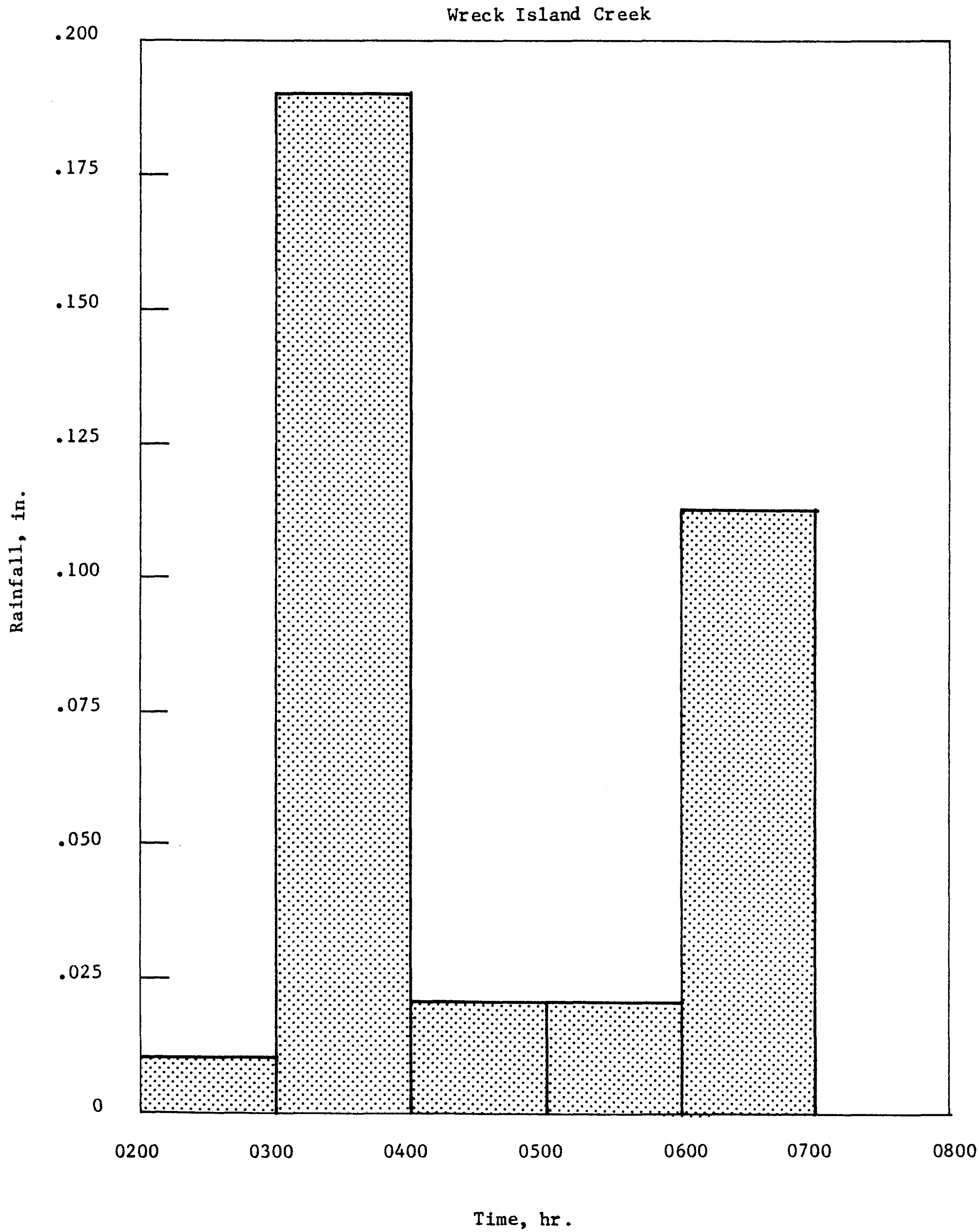


Figure C-19. Rainfall data for July 23,1980 storm event (total rainfall = 0.35 in.).

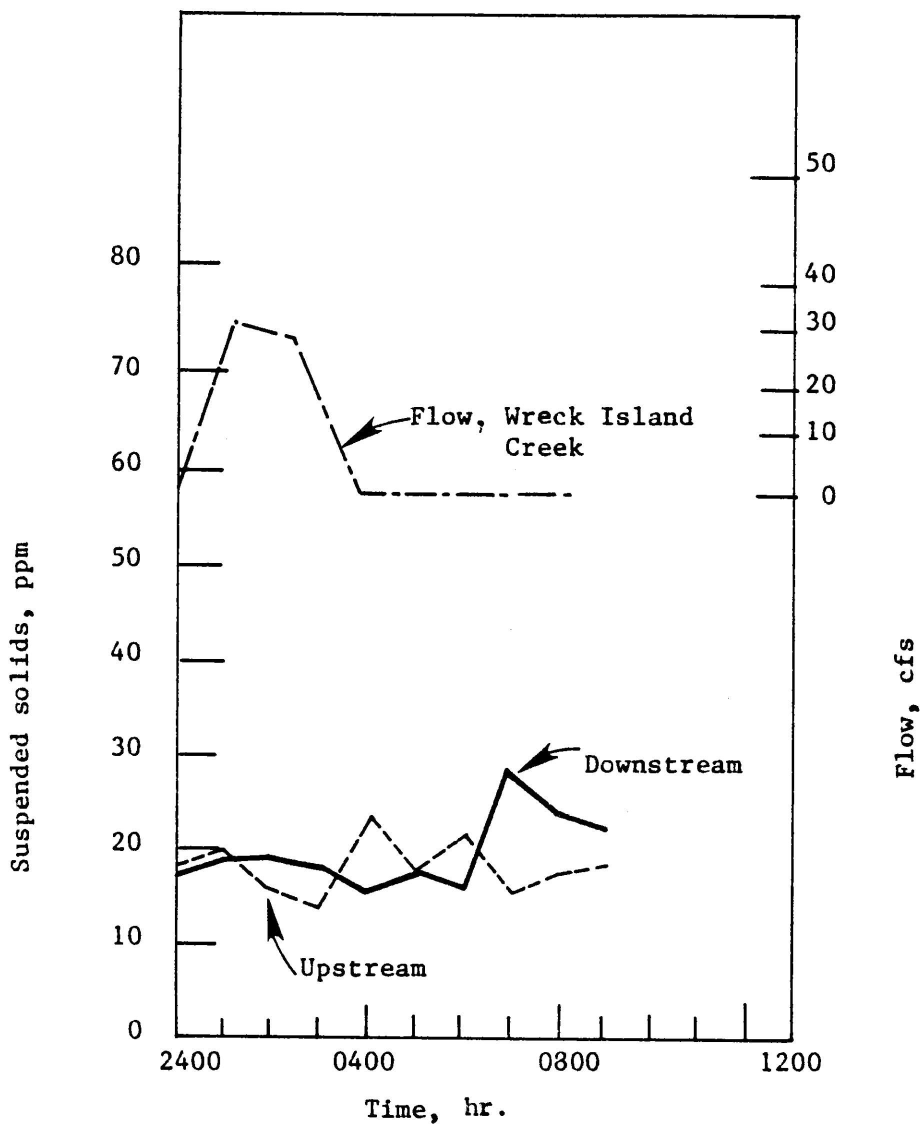


Figure C-20. Suspended solids and stream data for July 23-24, 1980 storm event. (Total rainfall = 0.13 in.).

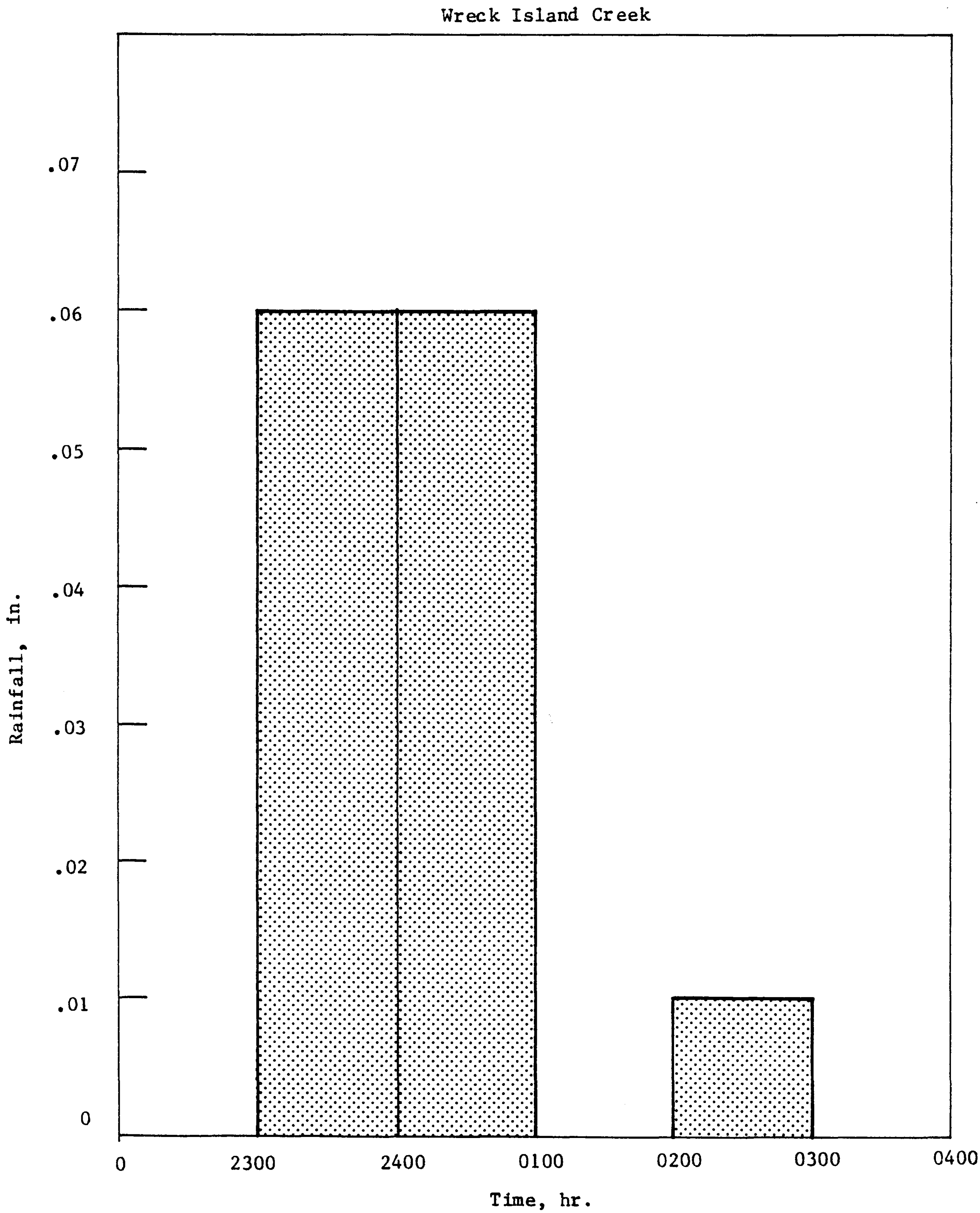


Figure C-21. Rainfall data for July 23-24, 1980 storm event (total rainfall = 0.13 in.).

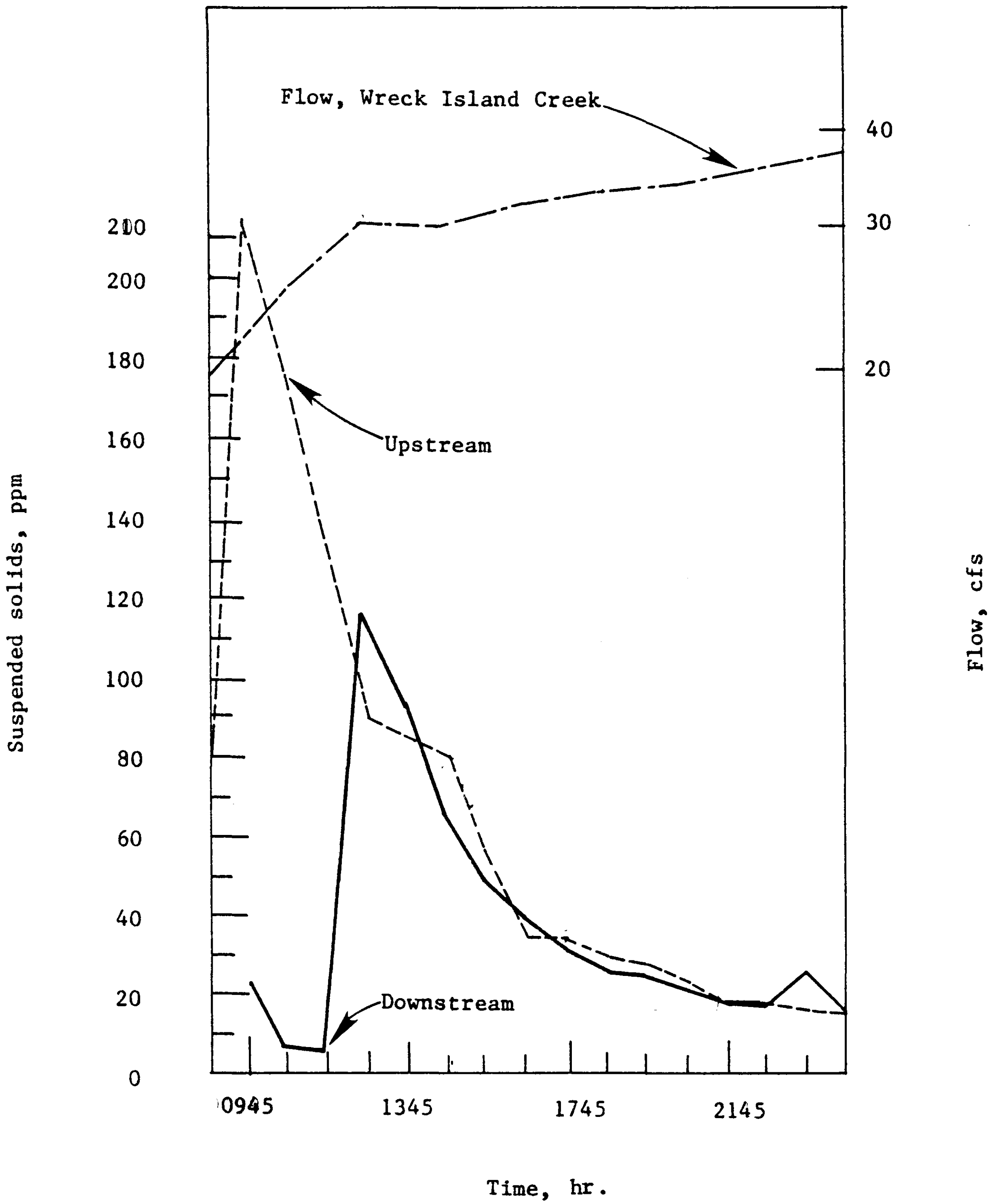


Figure C-22. Suspended solids and stream flow data for September 24 and 25, 1980 storm event.

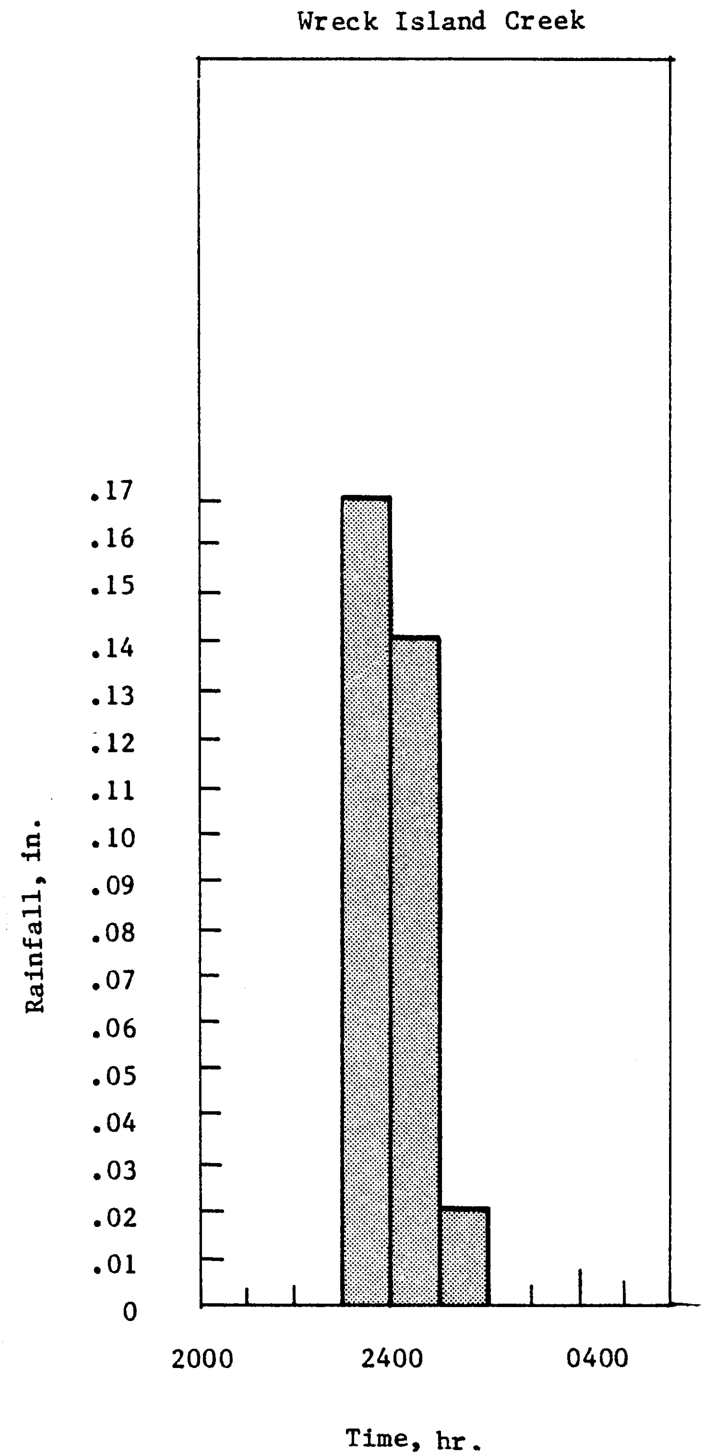


Figure C-23. Rainfall data for September 24 and 25, 1980 storm event (total rainfall = 0.33 in.).

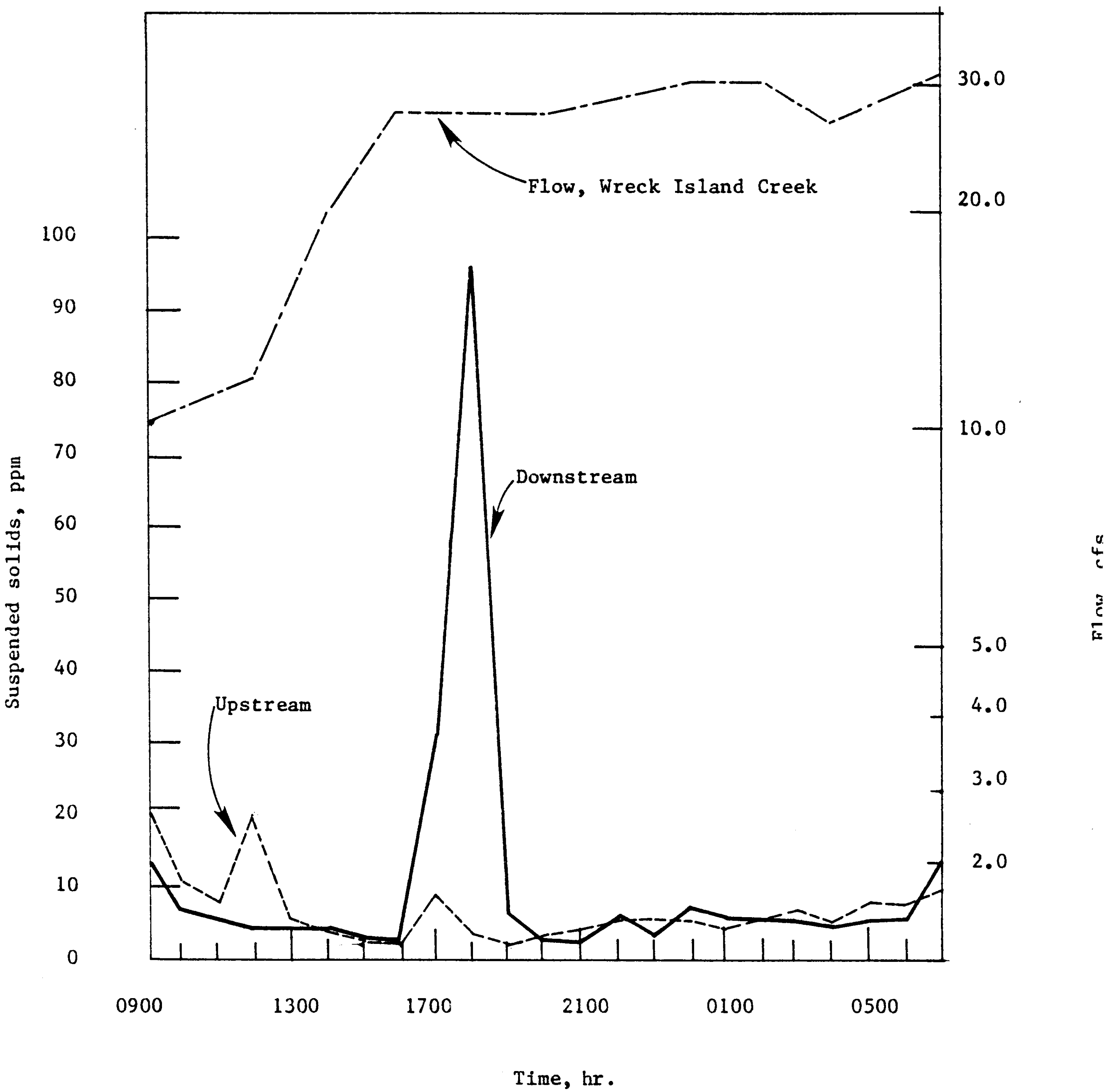


Figure C-24. Suspended solids and stream flow data for September 30, 1980 storm event.

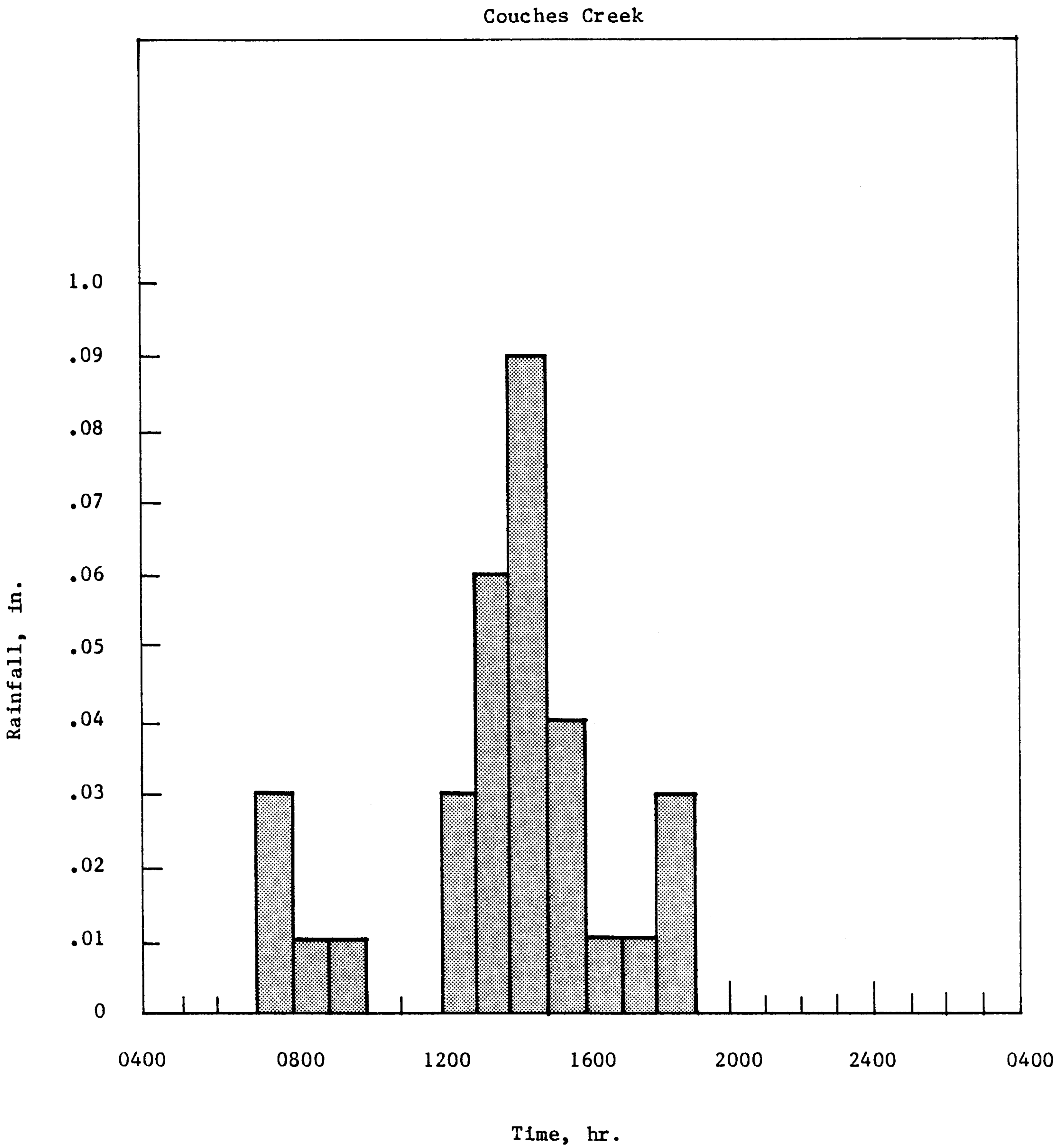


Figure C-25. Rainfall data for September 30, 1980 storm event (total rainfall = 0.32 in.).

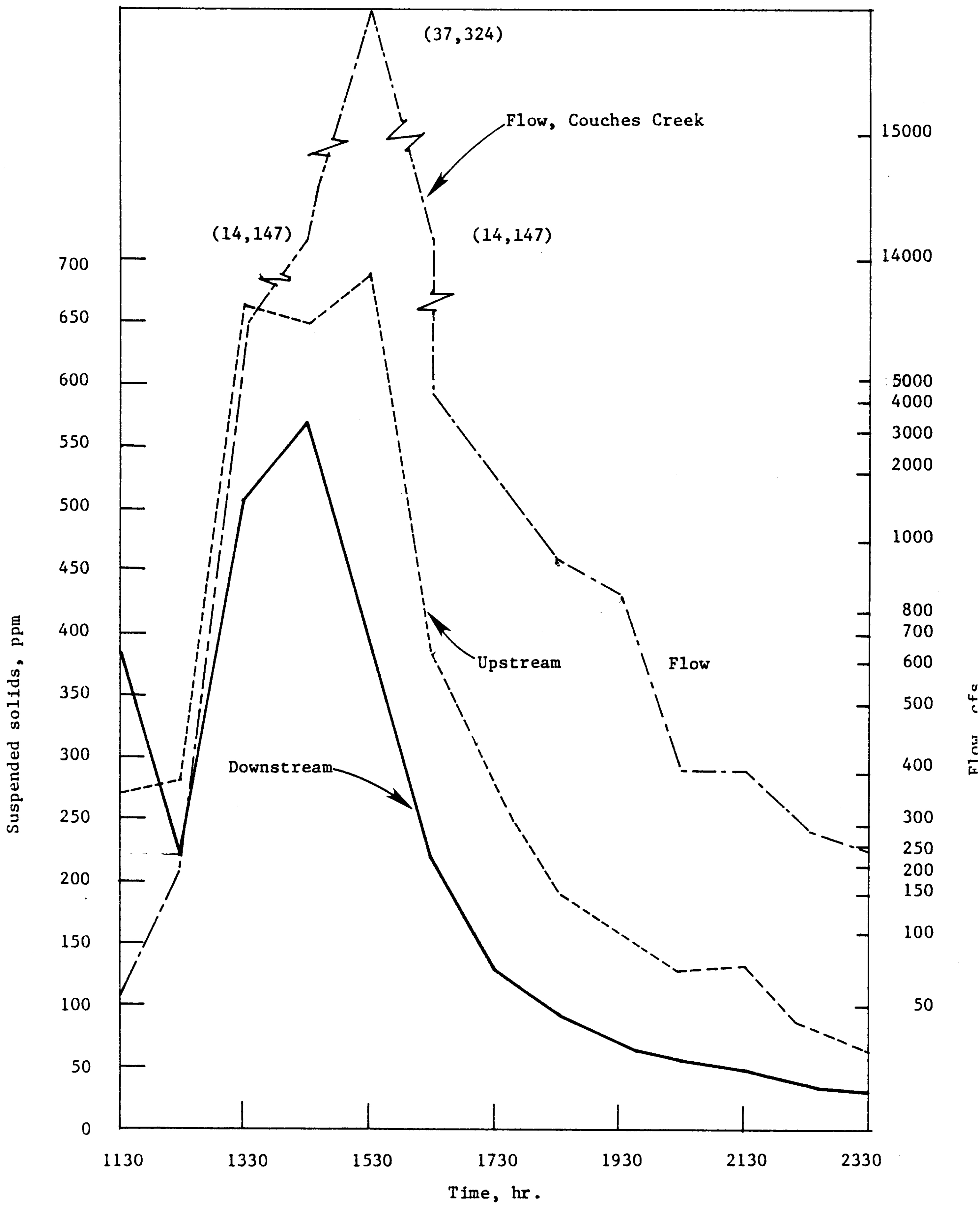


Figure C-26. Suspended solids and stream flow data for April 14, 1980 storm event.

Couches Creek

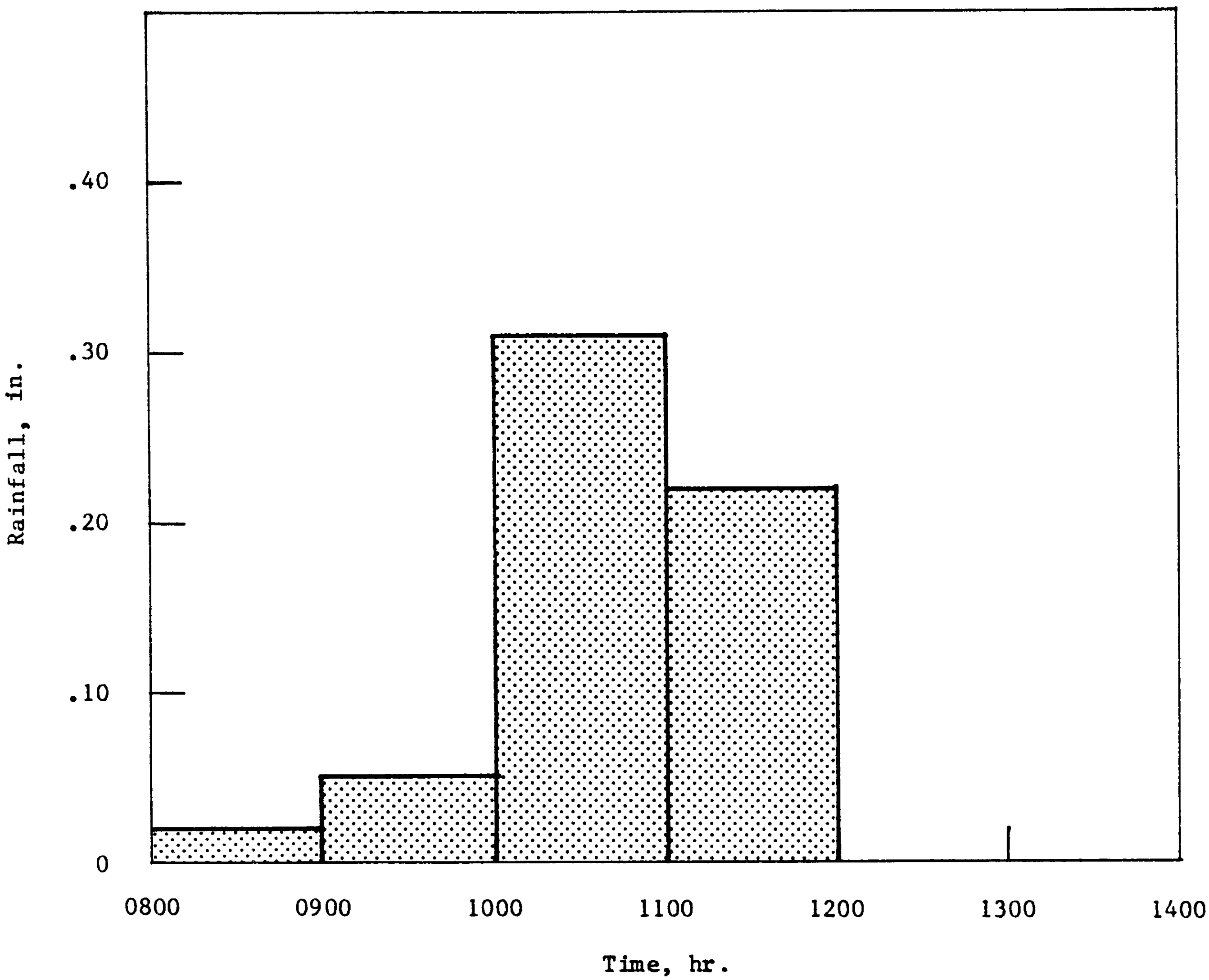


Figure C-27. Rainfall data for April 14, 1980 storm event (total rainfall = 0.60 in.).

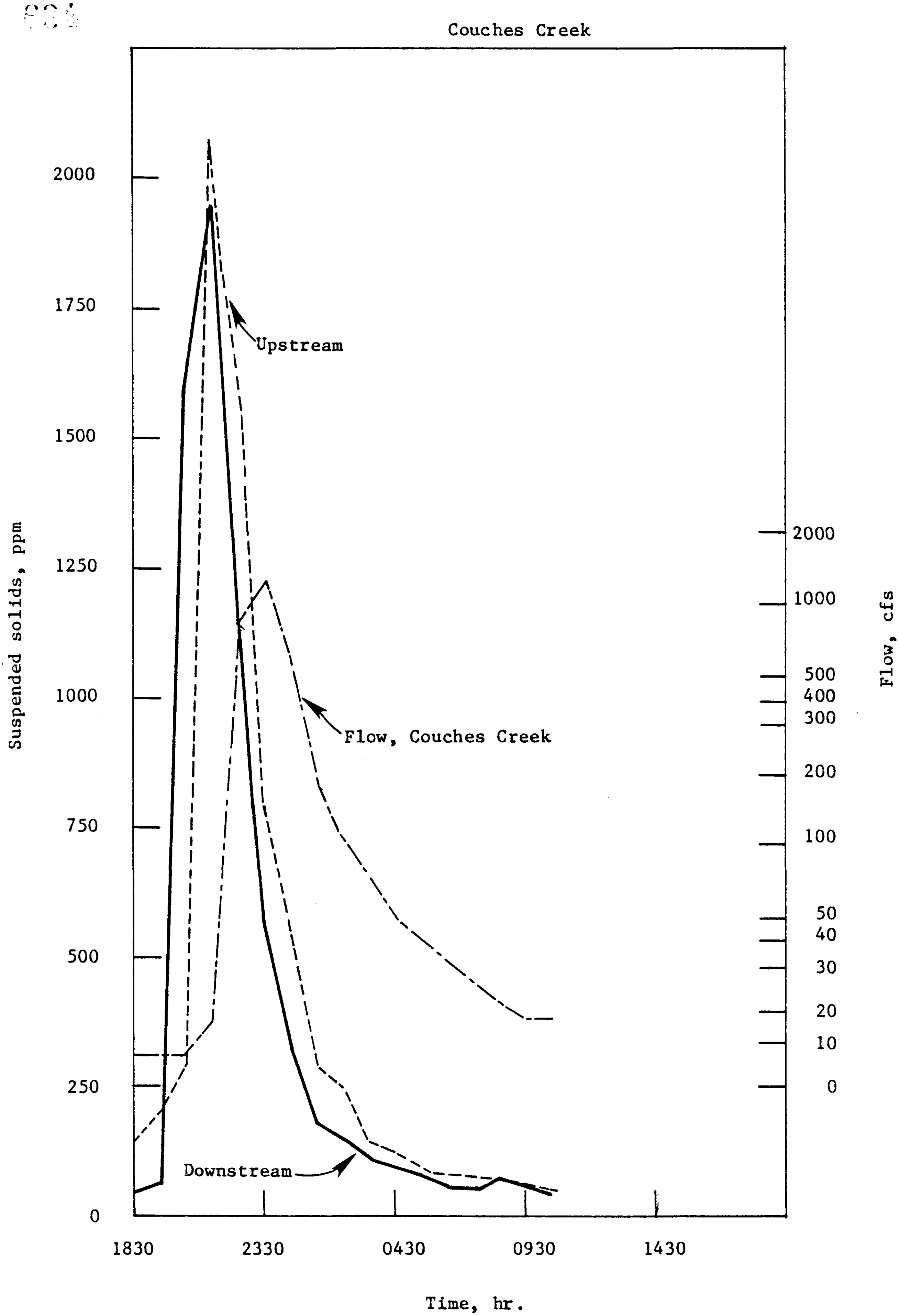


Figure C-28. Suspended solids and stream flow data for May 19 and 20, 1980 storm event.

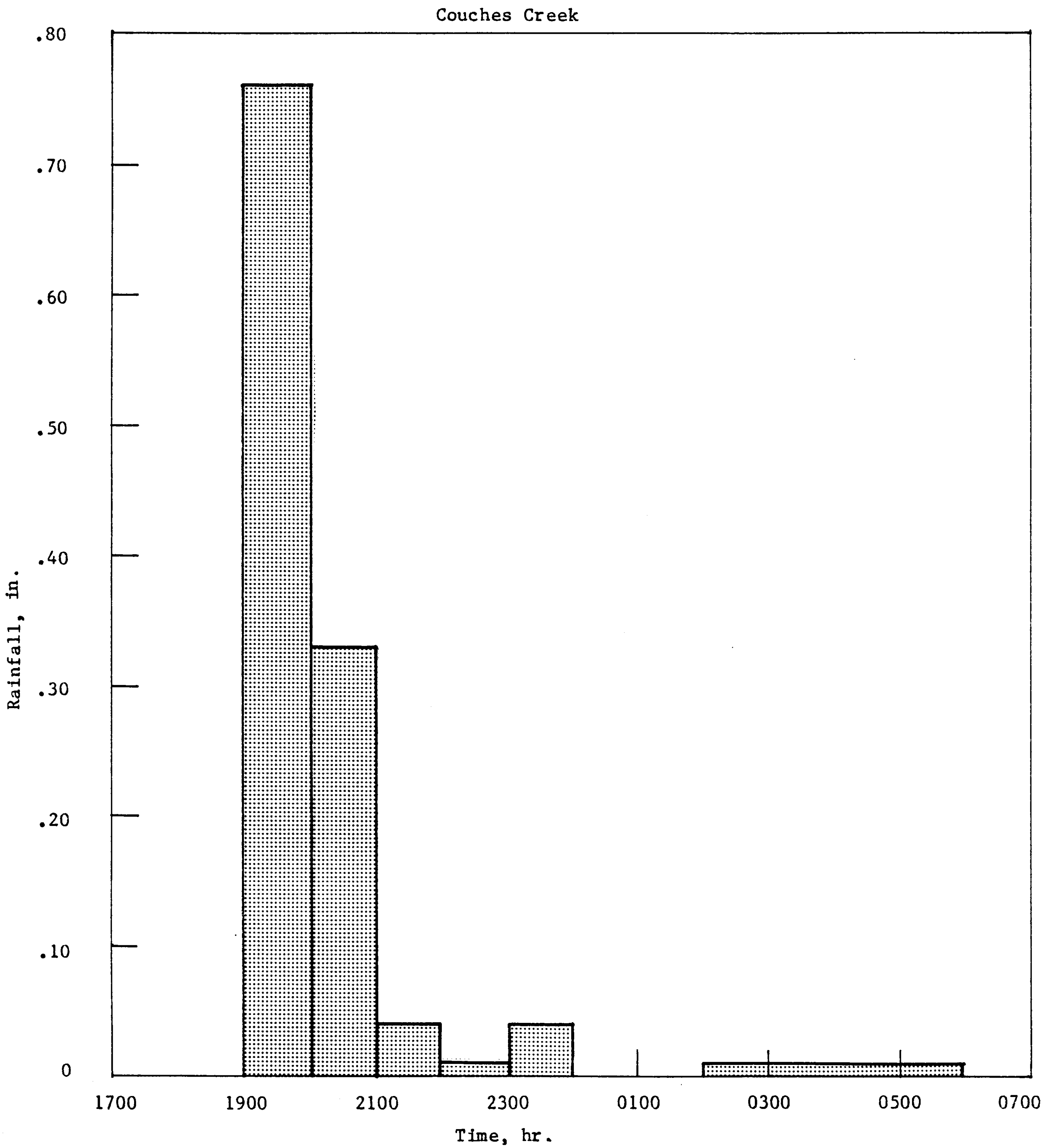


Figure C-29. Rainfall data for May 19-20, 1980 storm event (total rainfall = 1.22 in.).

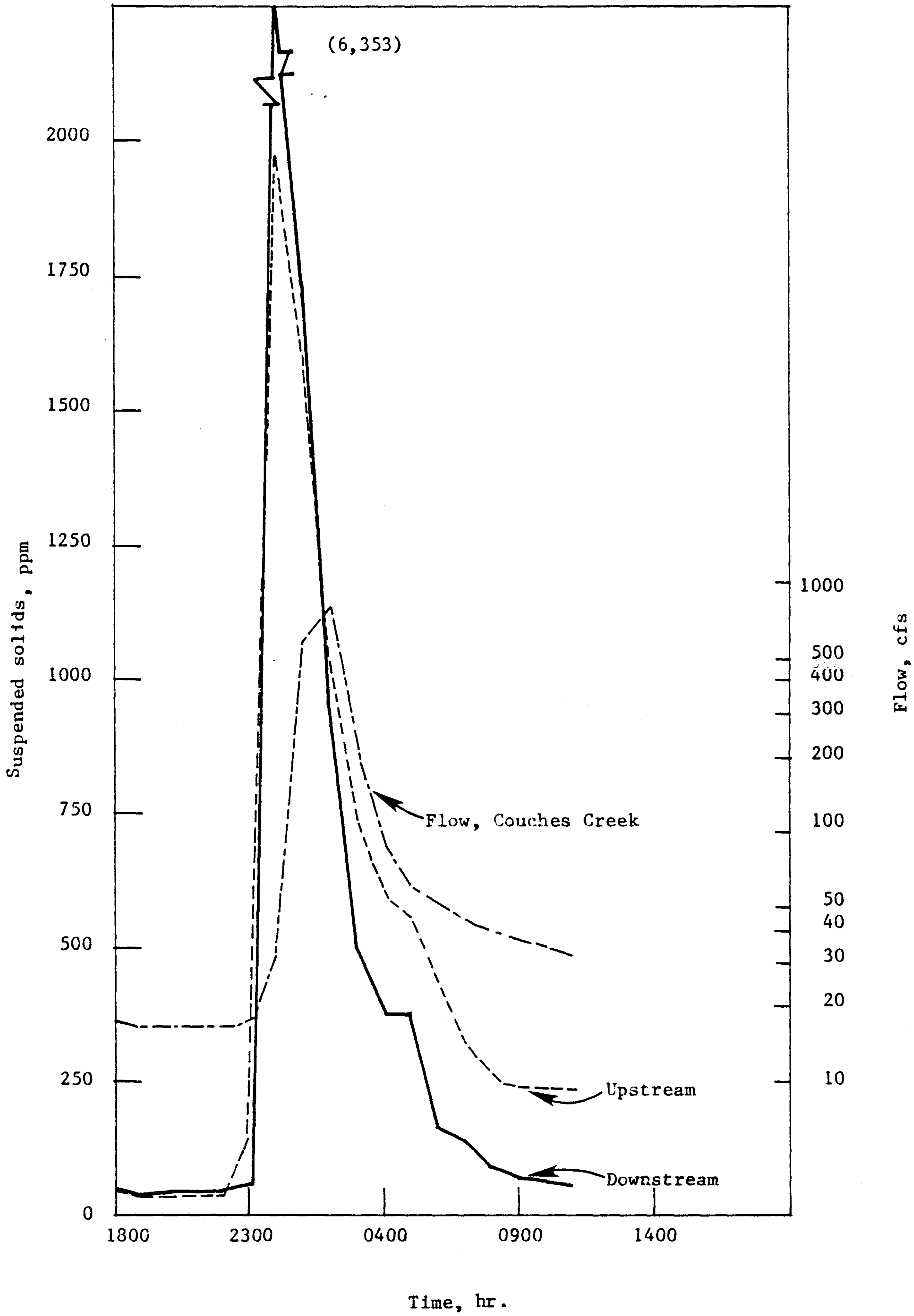


Figure C-30. Suspended solids and stream flow data for May 20 and 21, 1980 storm event.

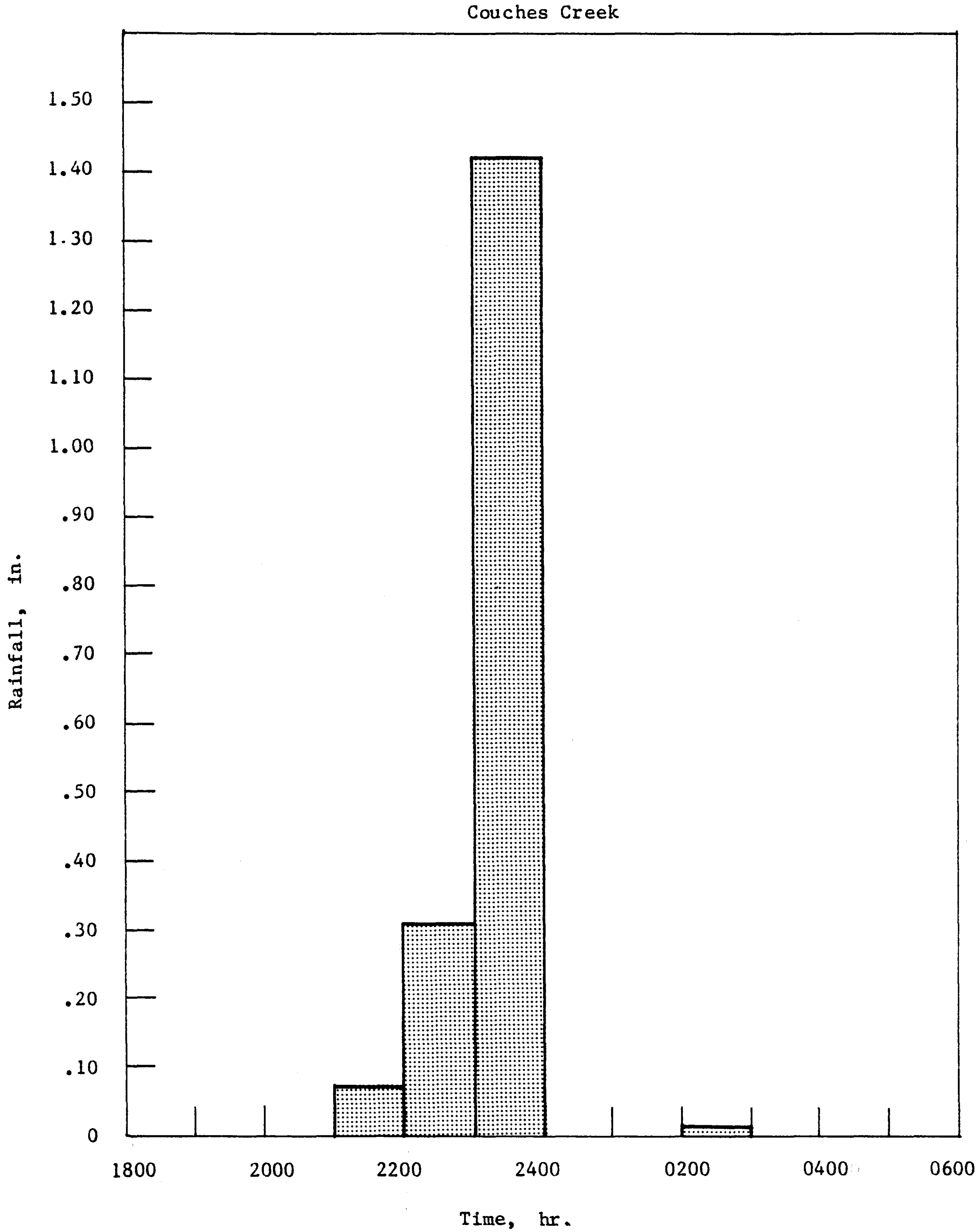


Figure C-31. Rainfall data for May 20 and 21, 1980 storm event (total rainfall = 1.81 in.).

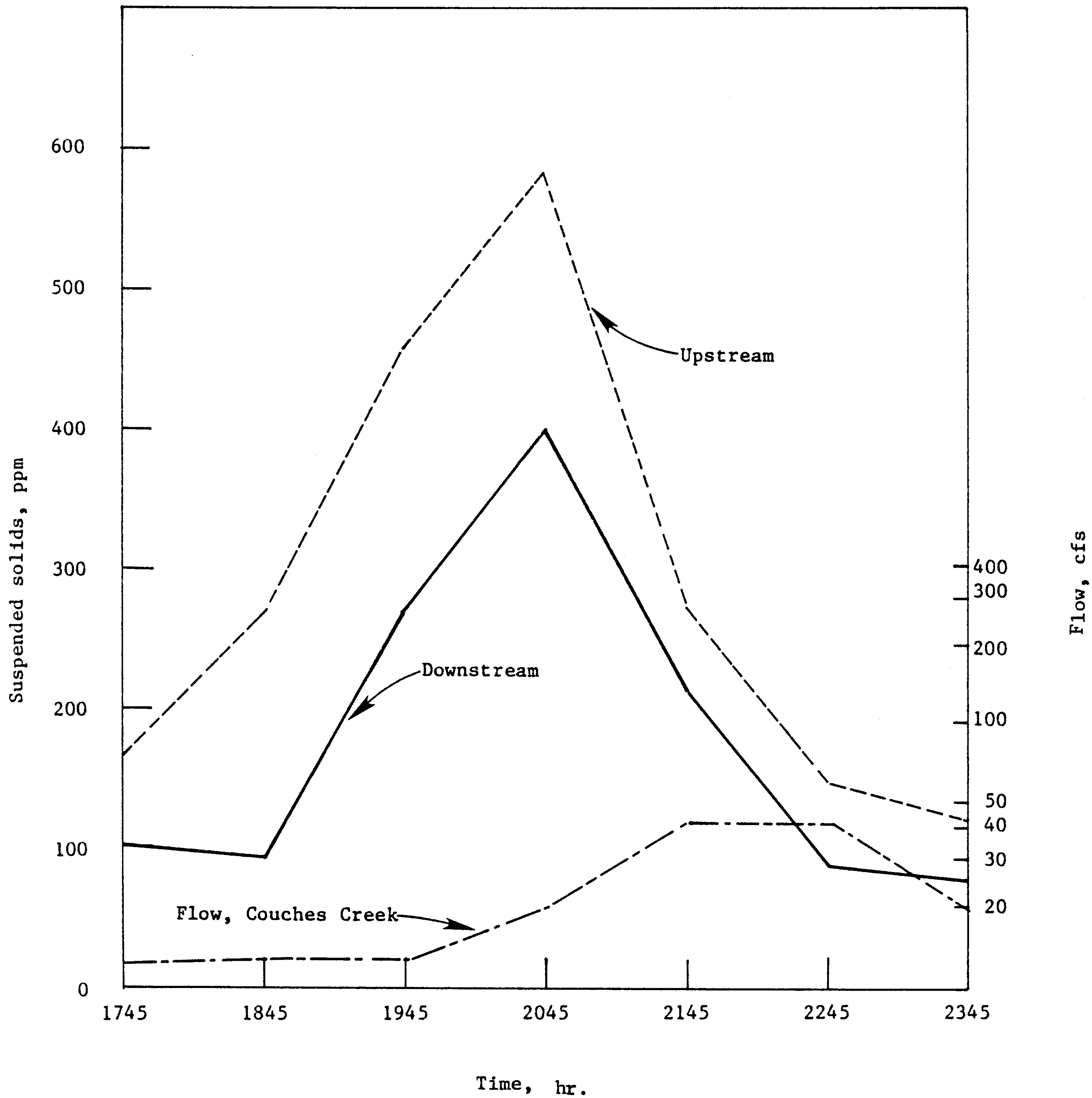


Figure C-32. Suspended solids and stream flow data for May 23, 1980 storm event.

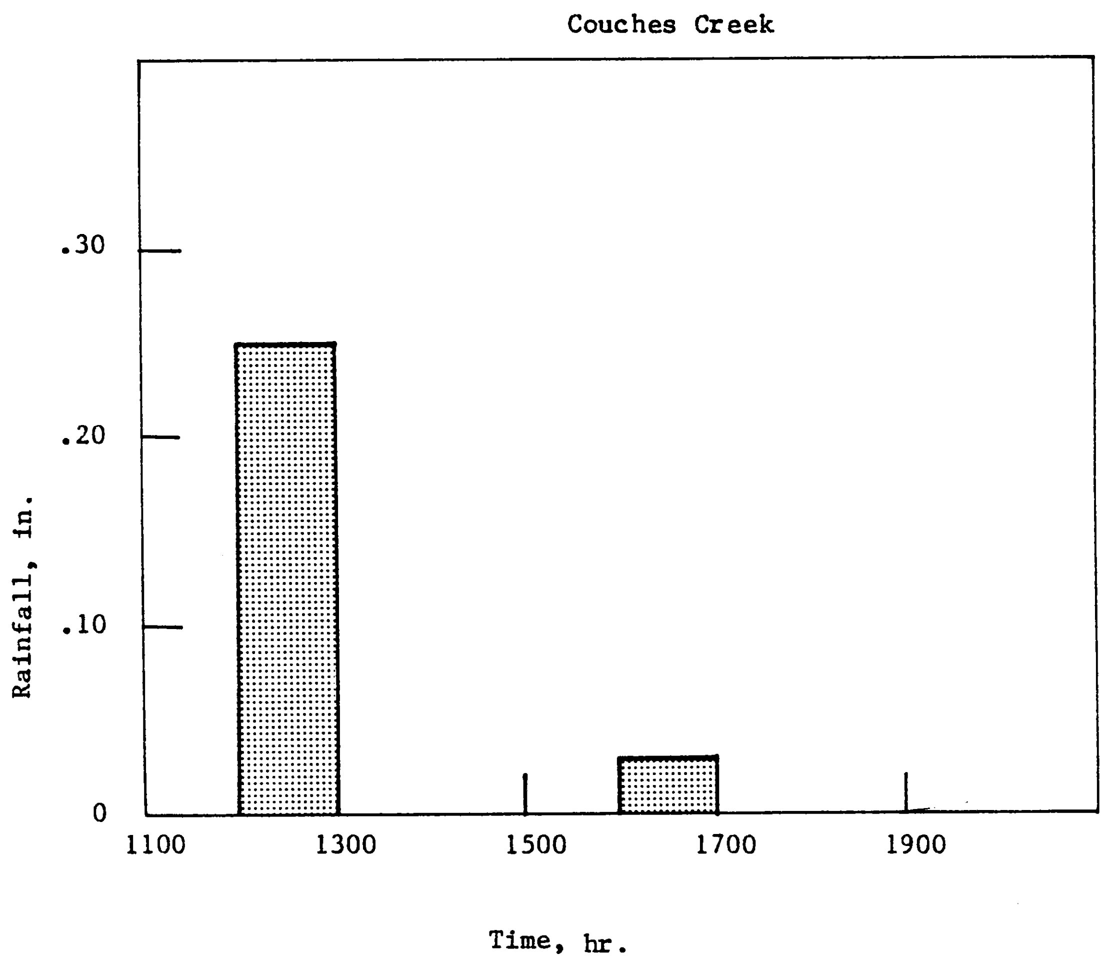


Figure C-33. Rainfall data for May 23, 1980 storm event (total rainfall = 0.28 in.).

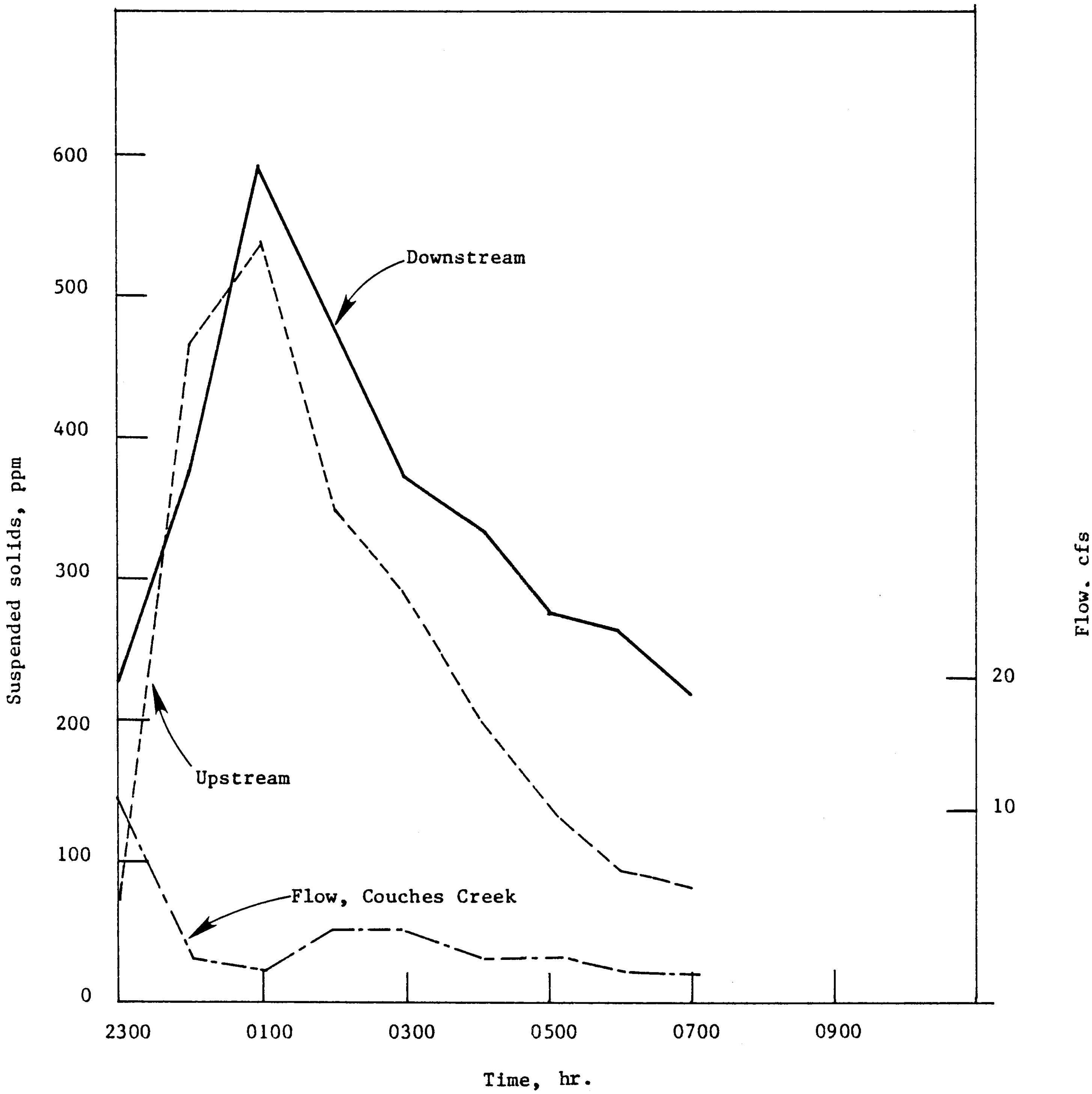


Figure C-34. Suspended solids and stream flow data for July 10, 1980 storm event.

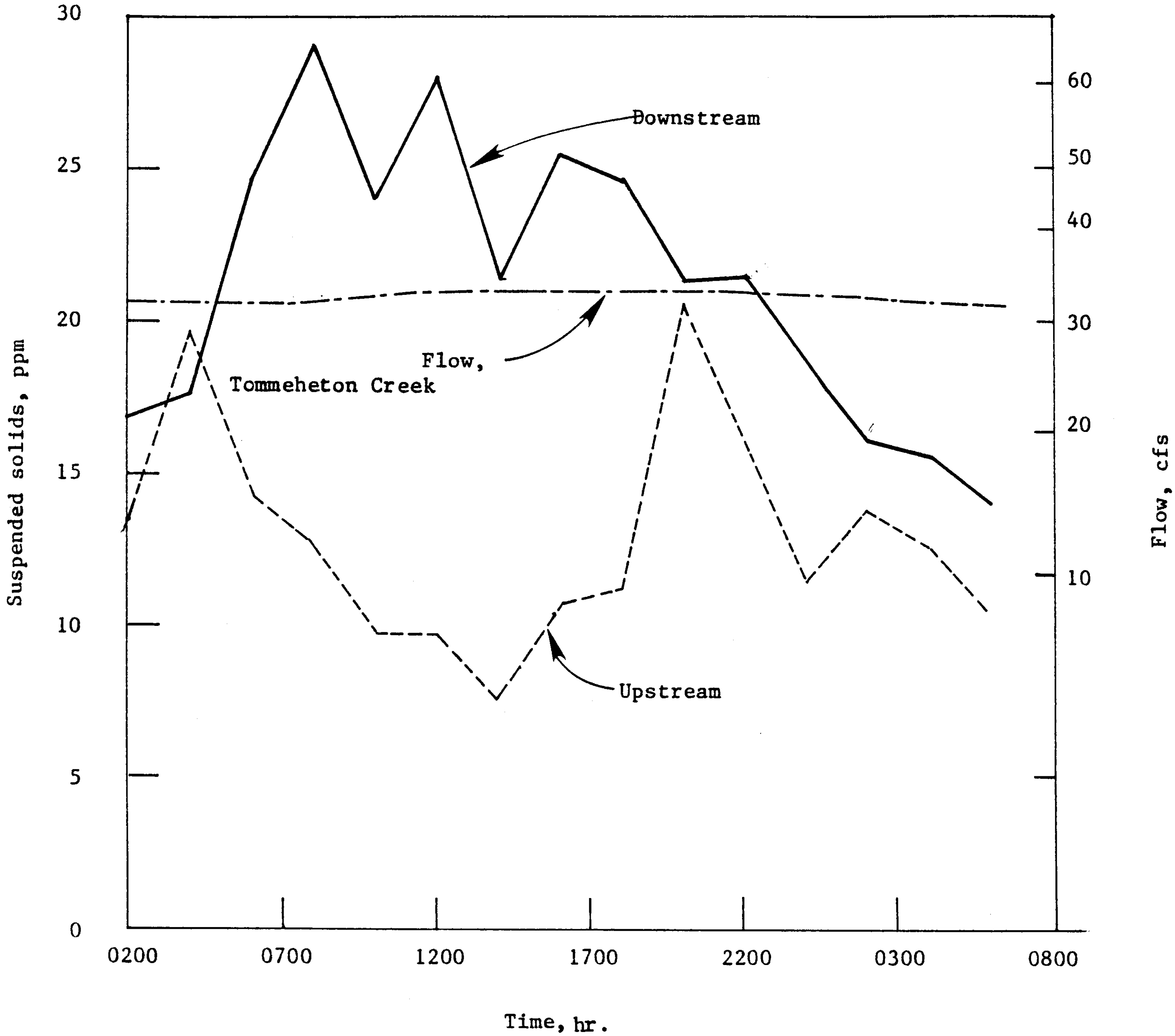


Figure C-35. Suspended solids and stream flow data for August 21, 1981 storm event.

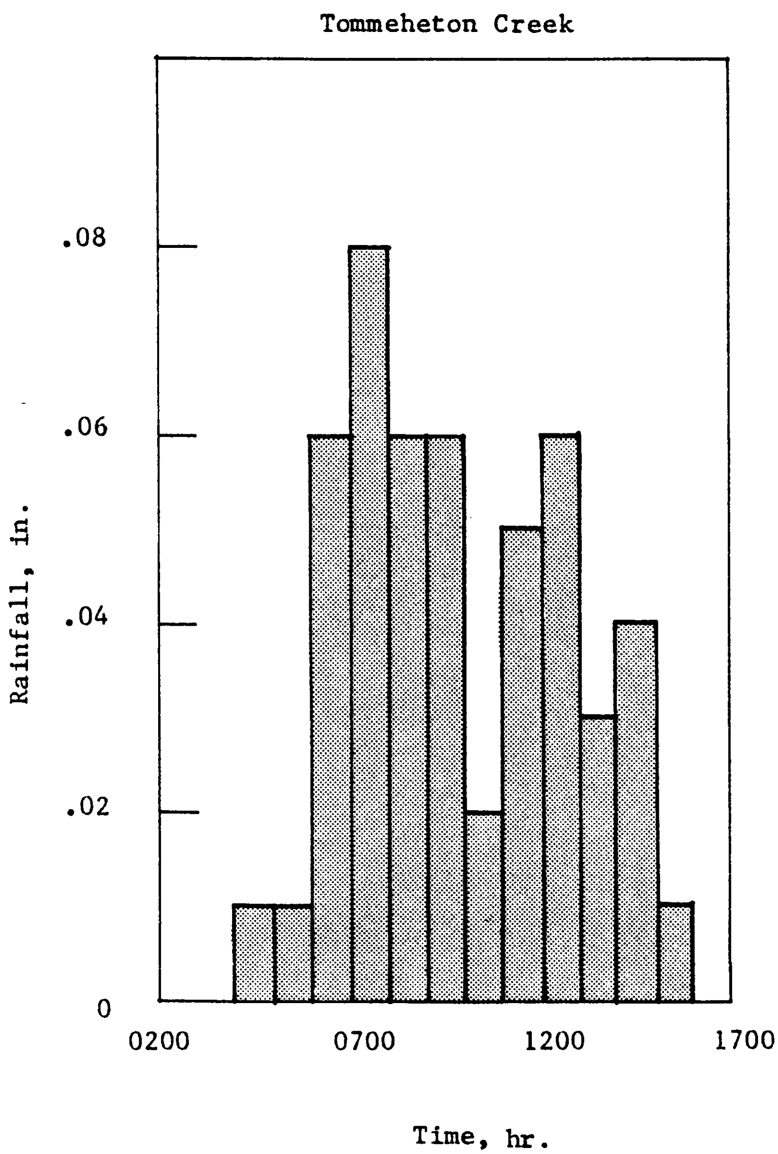


Figure C-36. Rainfall data for August 21, 1981 storm event.

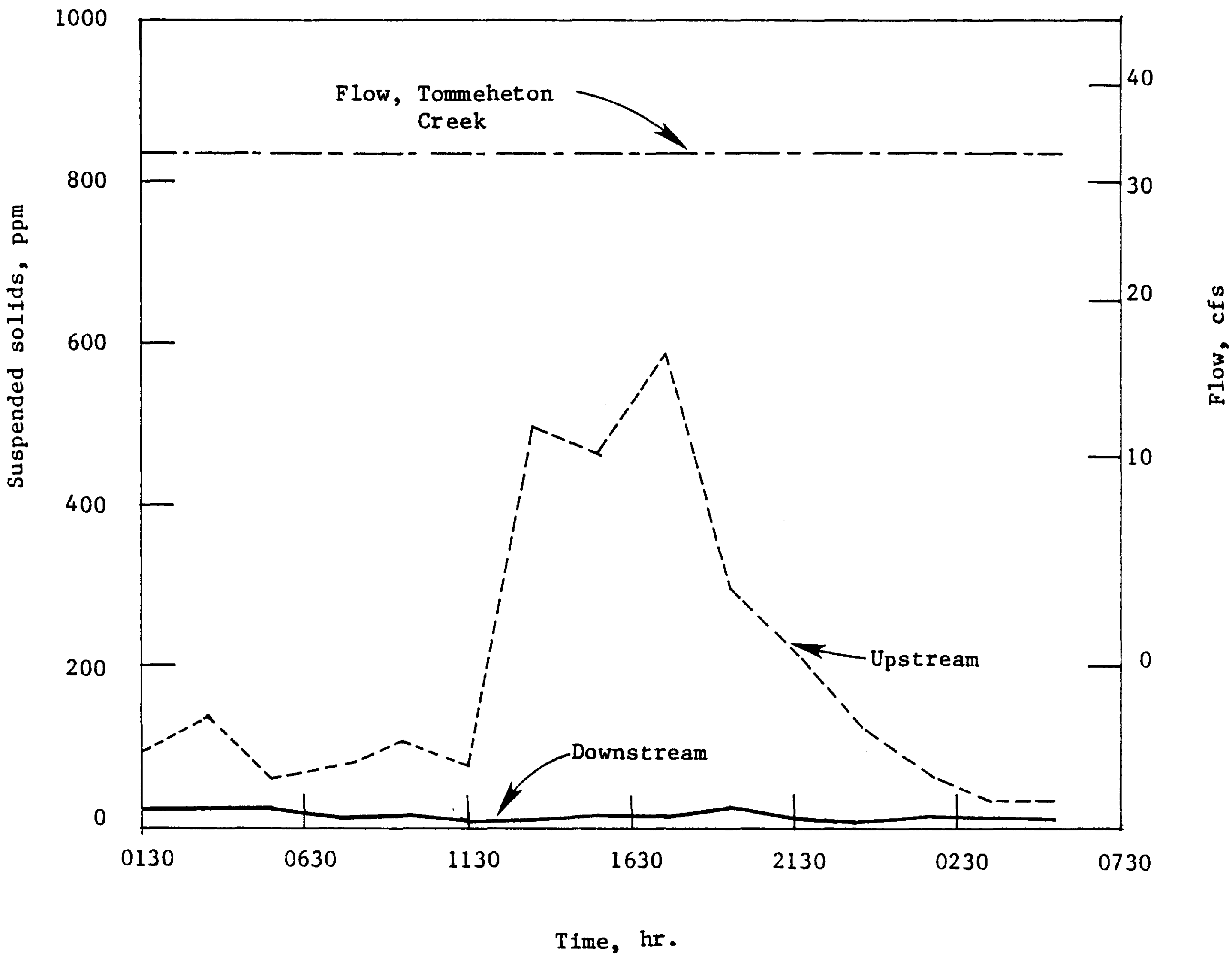


Figure C-37. Suspended solids and stream flow data for September 6, 1981 storm event.

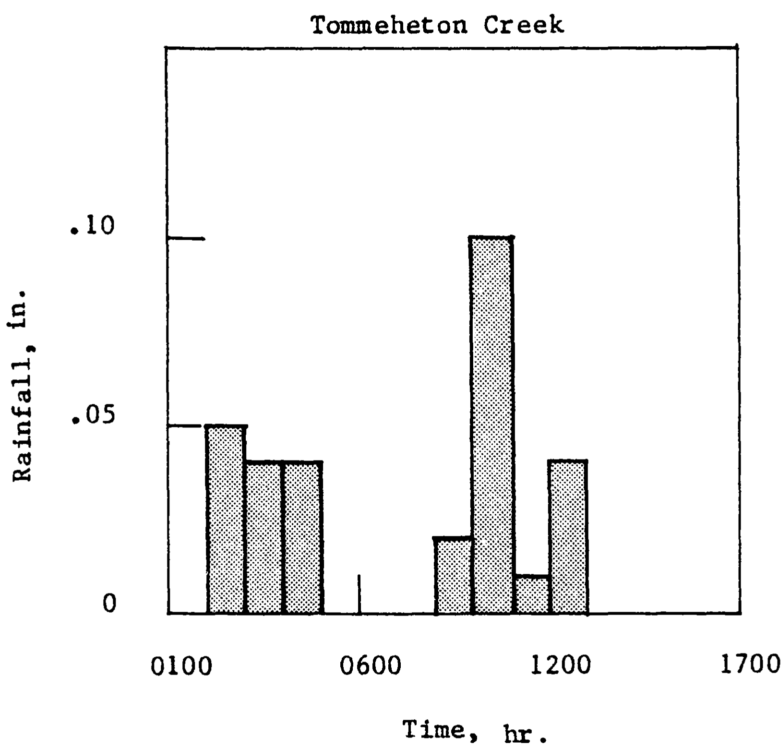


Figure C-38. Rainfall data for September 6, 1981.

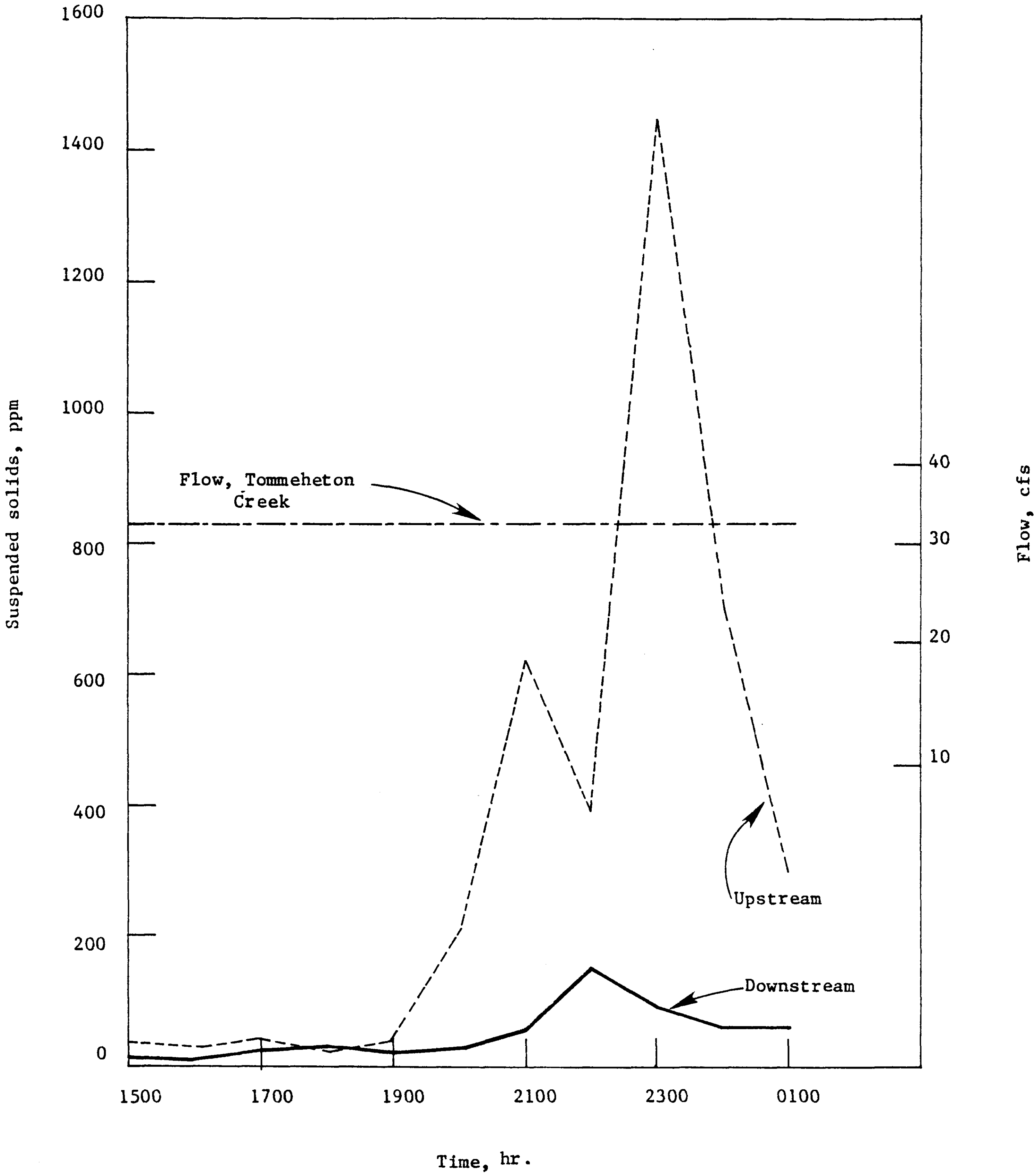


Figure C-39. Suspended solids and stream flow data for September 15, 1981 storm event.

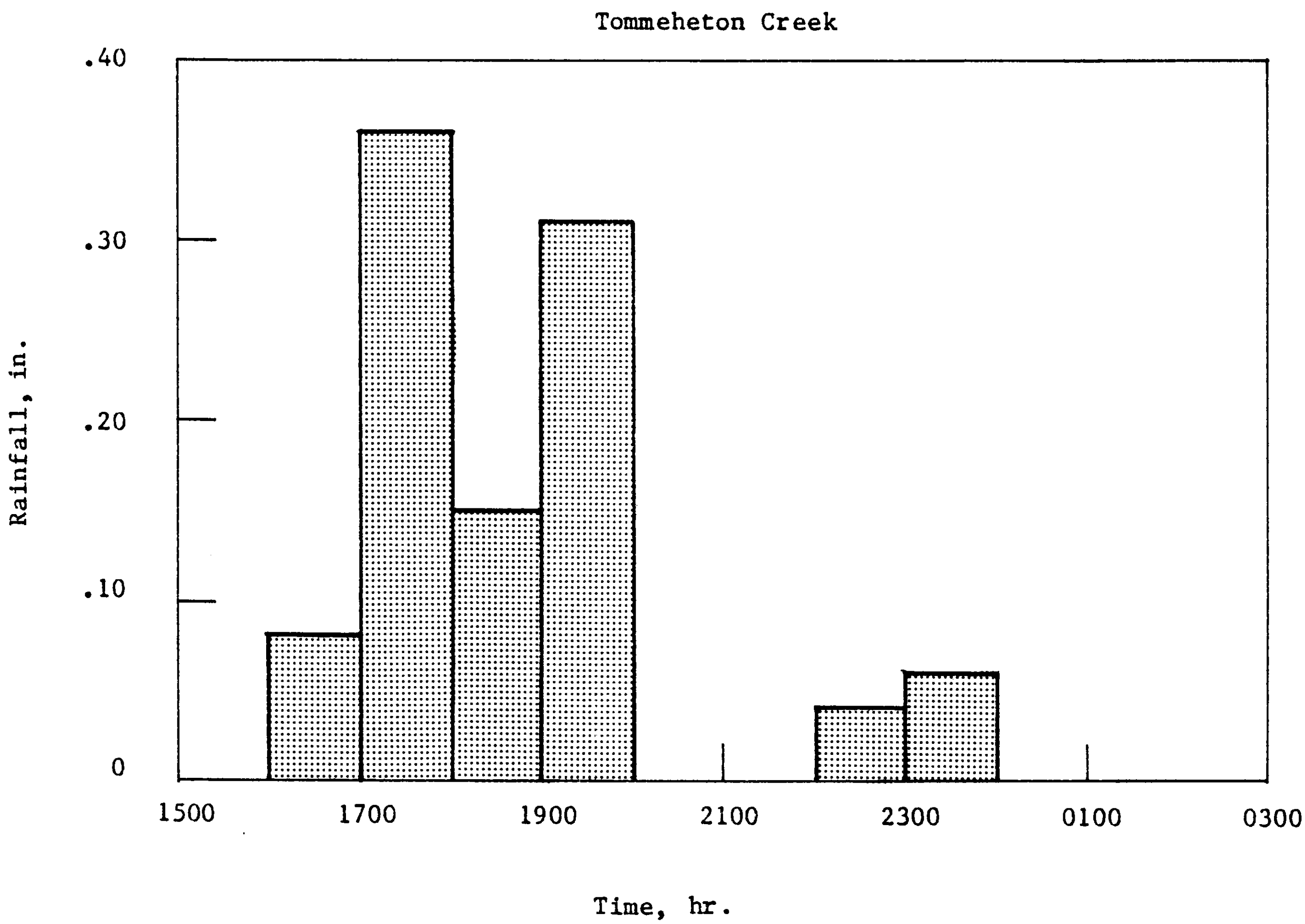


Figure C-40. Rainfall data for September 15, 1981.

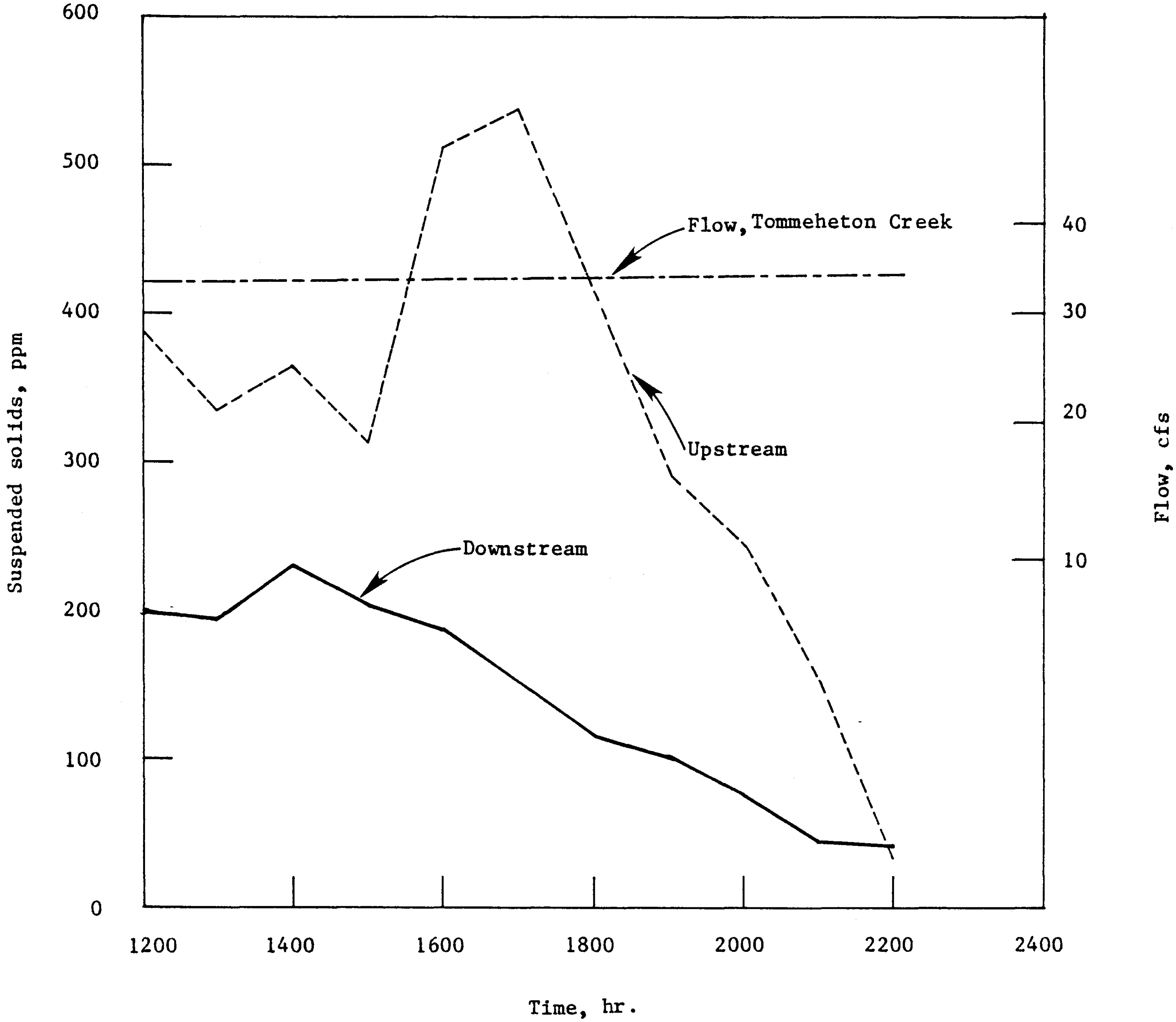


Figure C-41. Suspended solids and stream flow data for September 16, 1981 storm event.

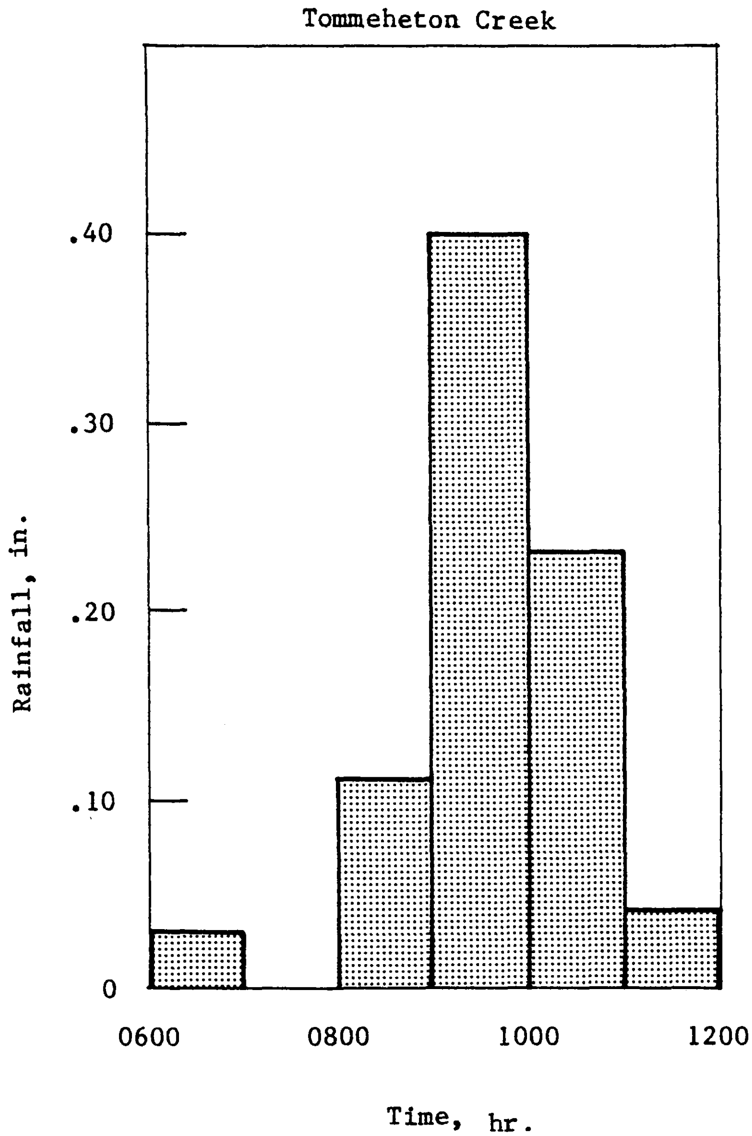


Figure C-42. Rainfall data for September 16, 1981 storm event.

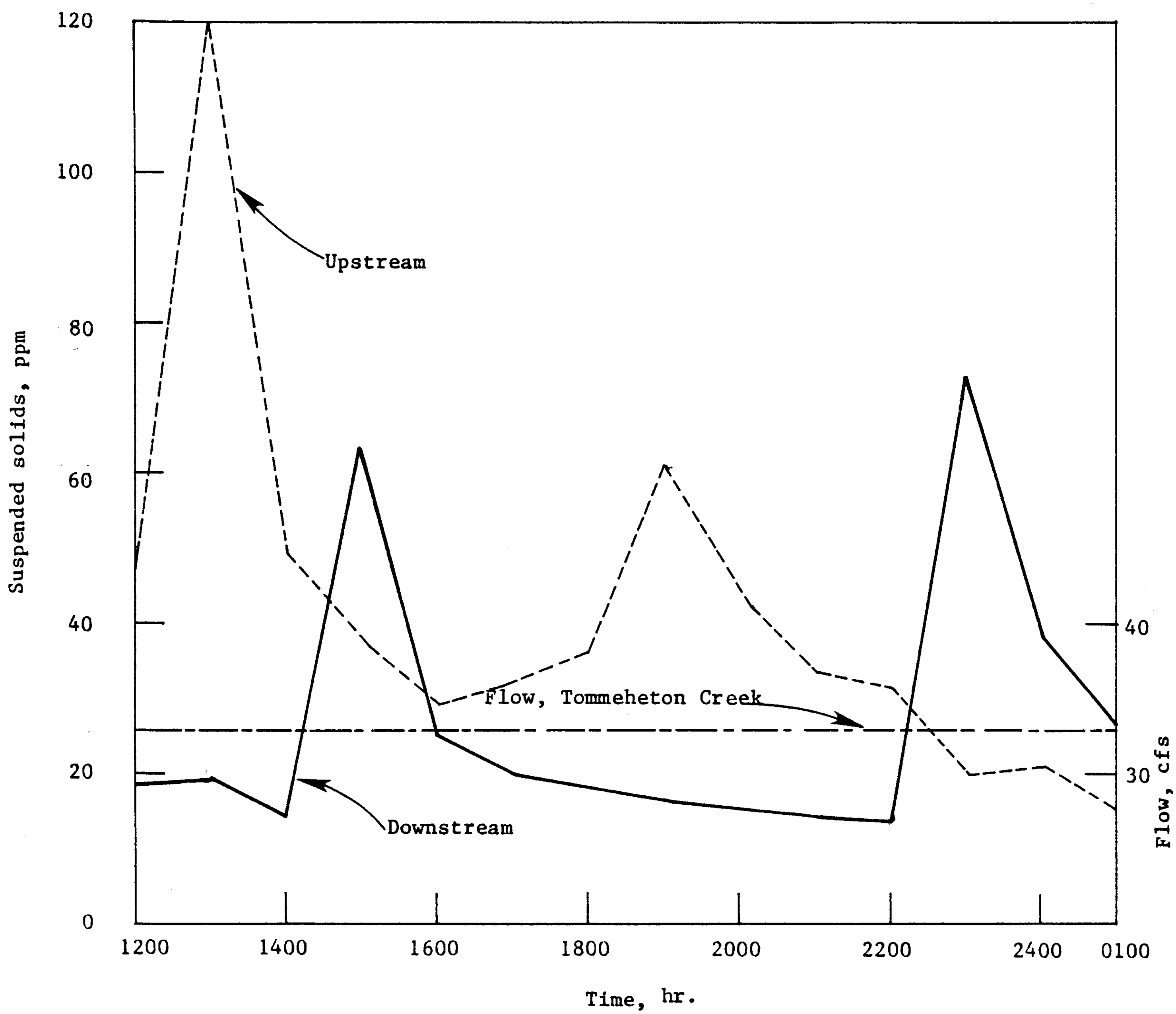


Figure C-43. Suspended solids and stream flow data for October 22, 1981 storm event.

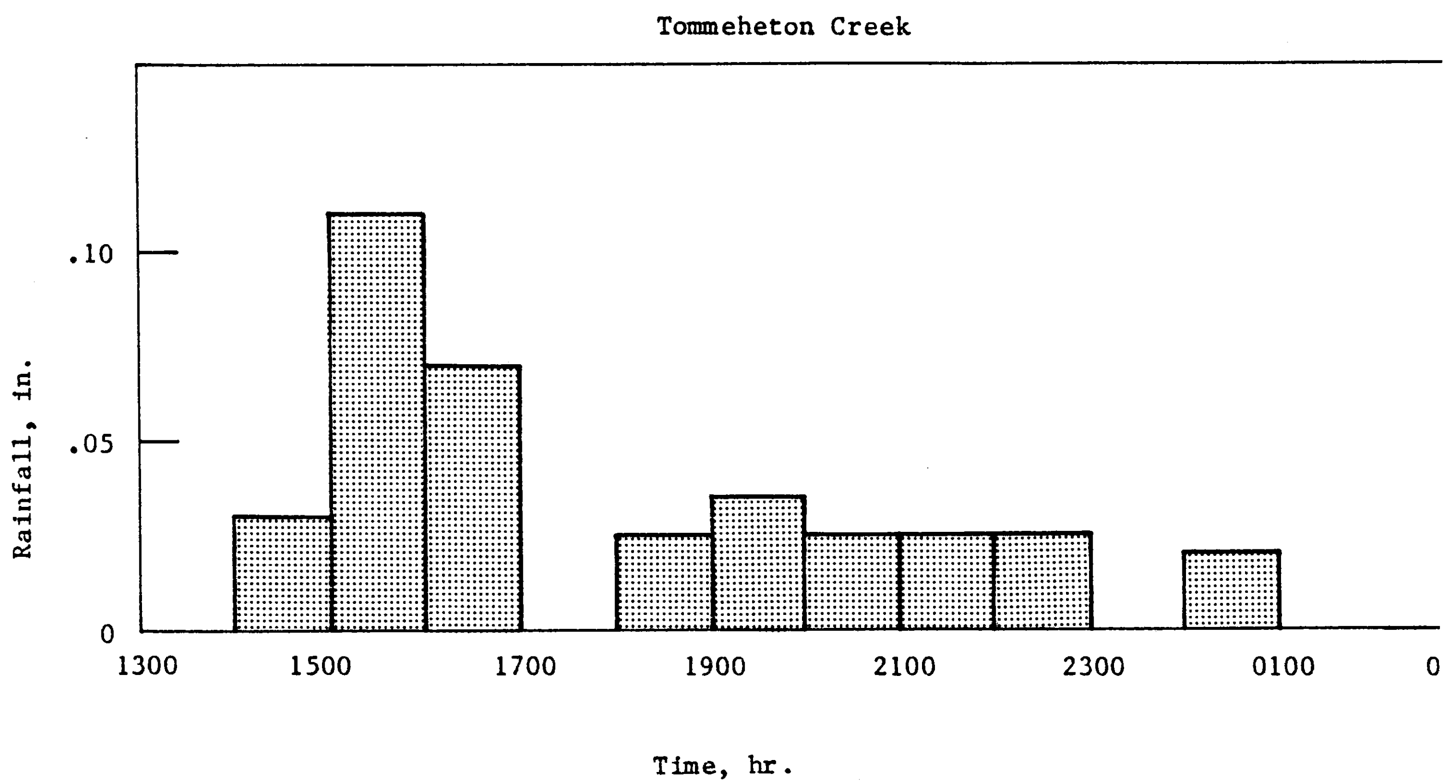


Figure C-44. Rainfall data for October 22, 1981 storm event.

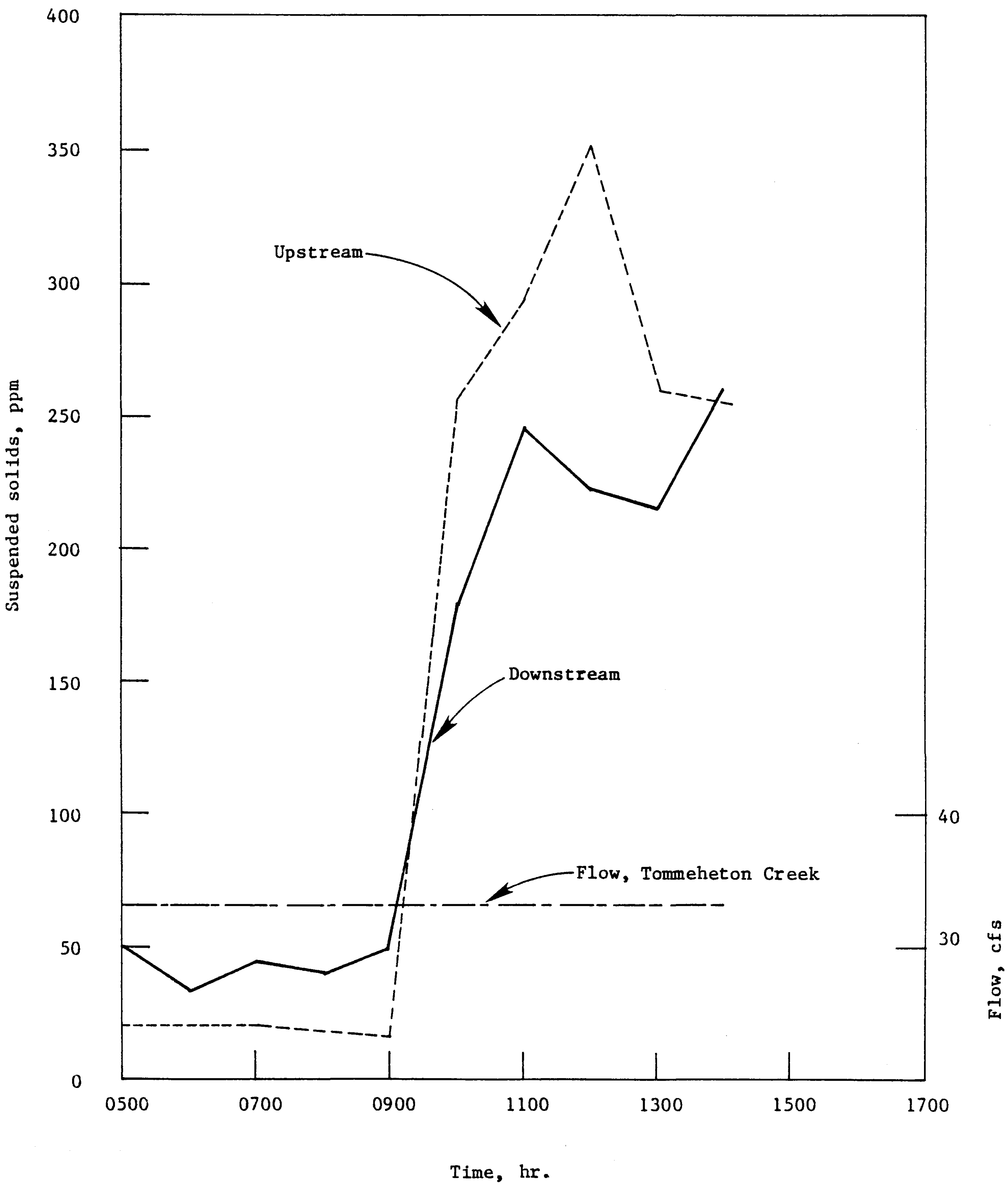


Figure C-45. Suspended solids and stream flow data for October 27, 1981 storm event.

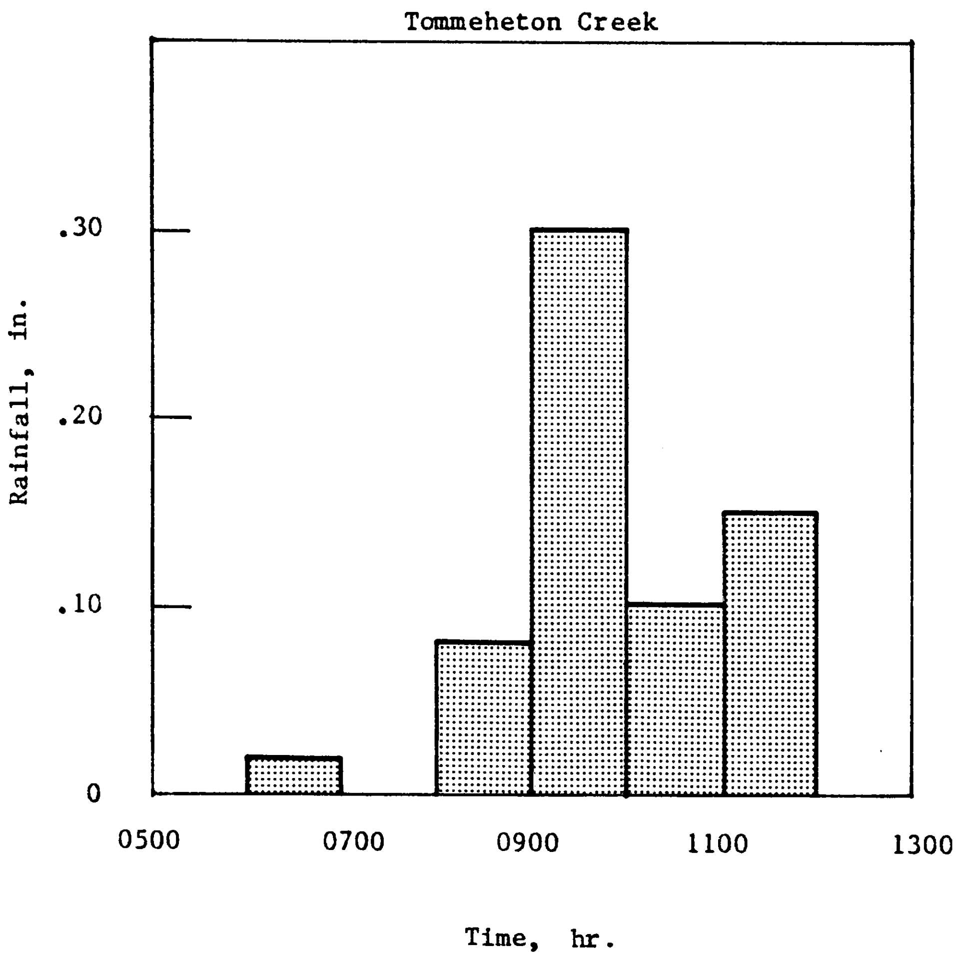


Figure C-46. Rainfall data for October 27, 1981 storm event.

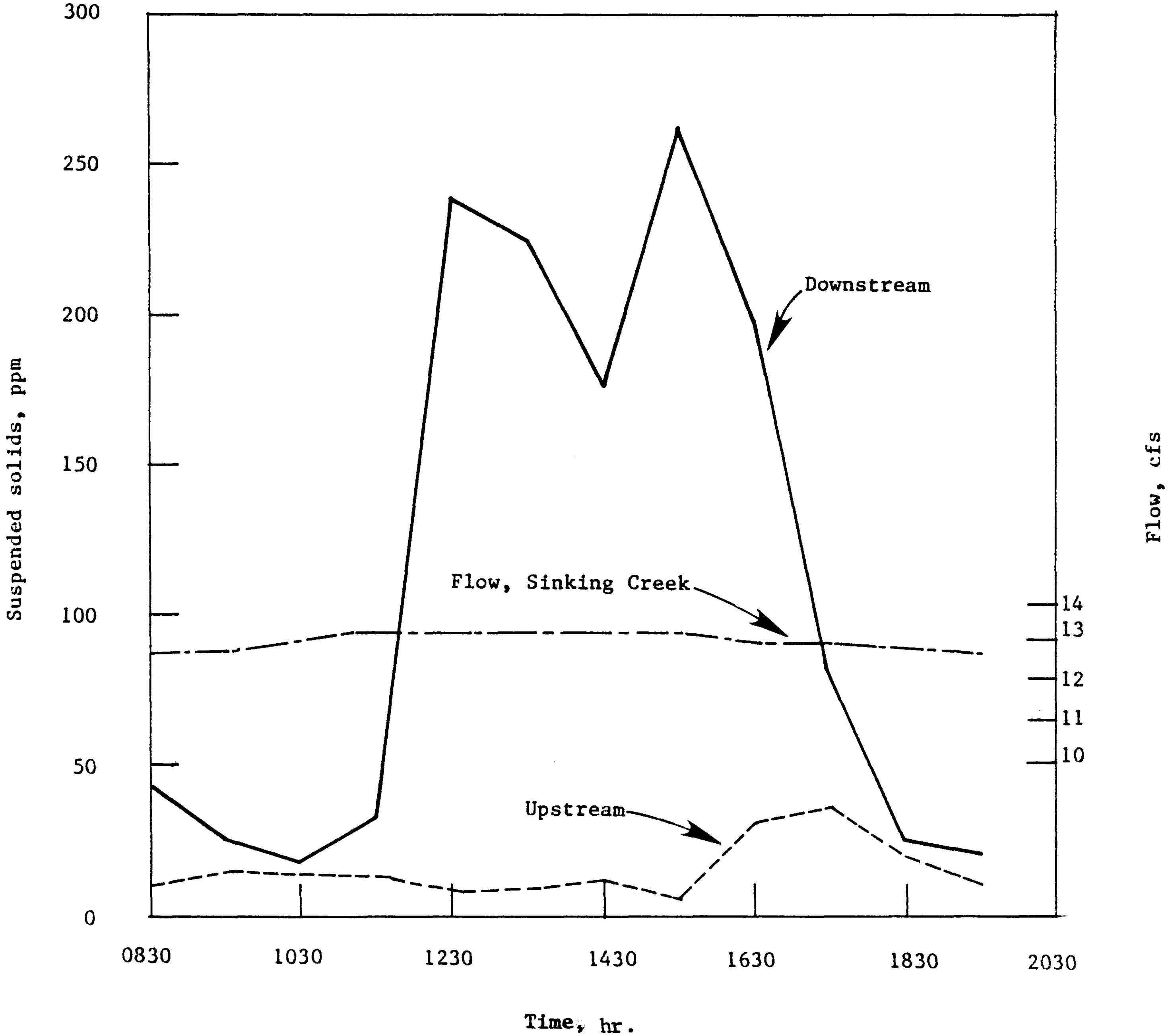


Figure C-47. Suspended solids and stream flow data for May 8, 1980 storm event.

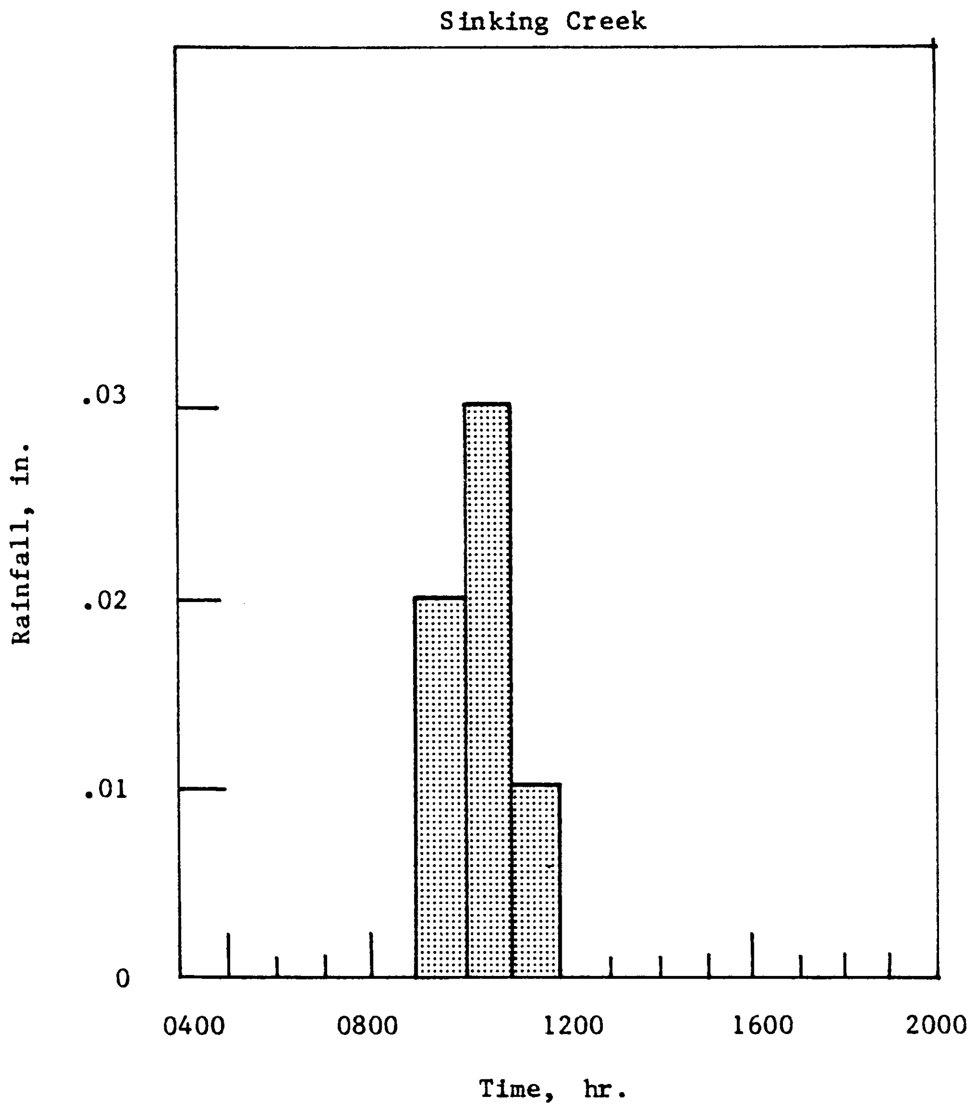


Figure C-48. Rainfall data for May 8, 1980 storm event.

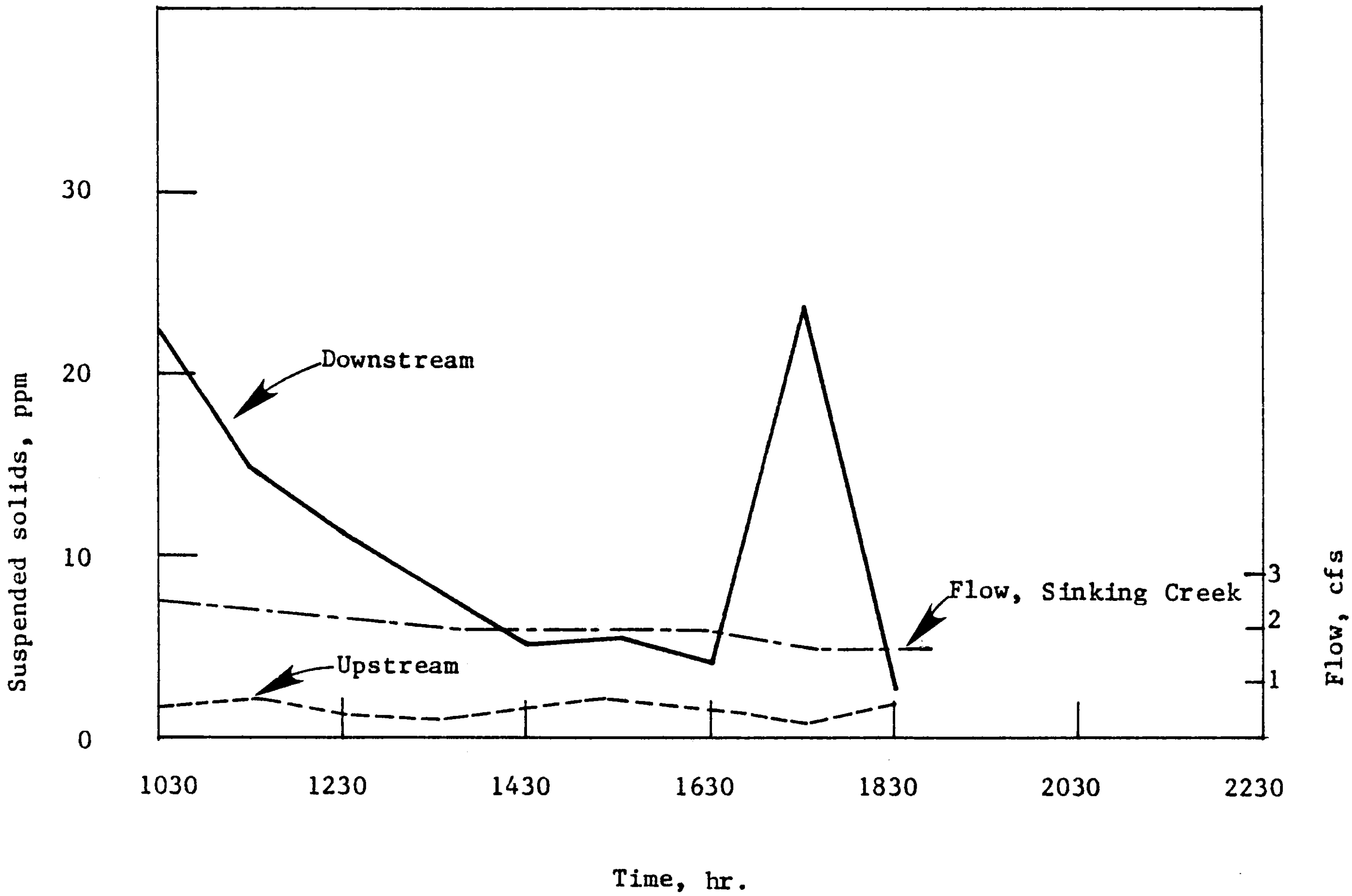


Figure C-49. Suspended solids and stream flow data for May 23, 1980 storm event.

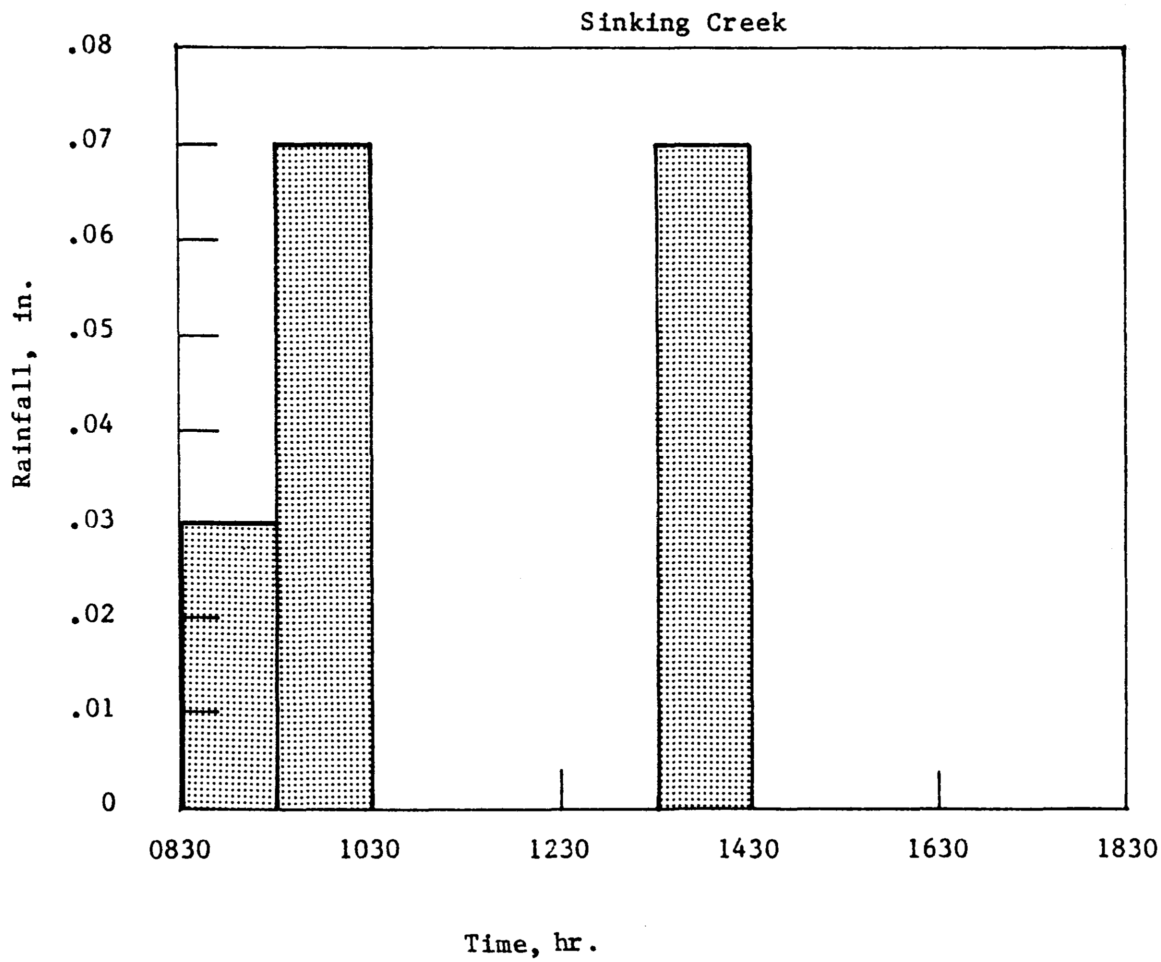


Figure C-50. Rainfall data for May 23, 1980 storm event.

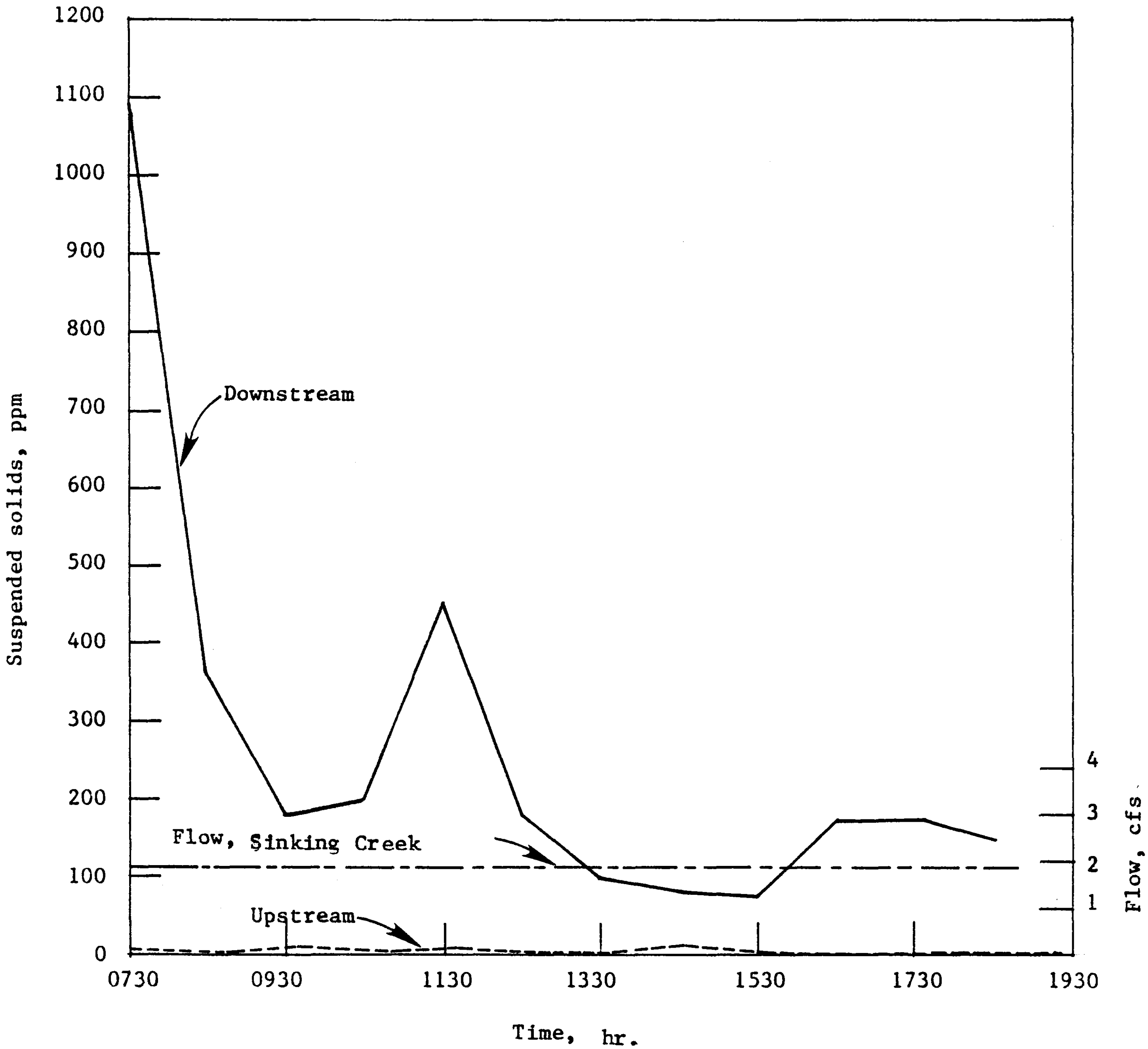


Figure C-51. Suspended solids and stream flow data for August 21, 1980 storm event.

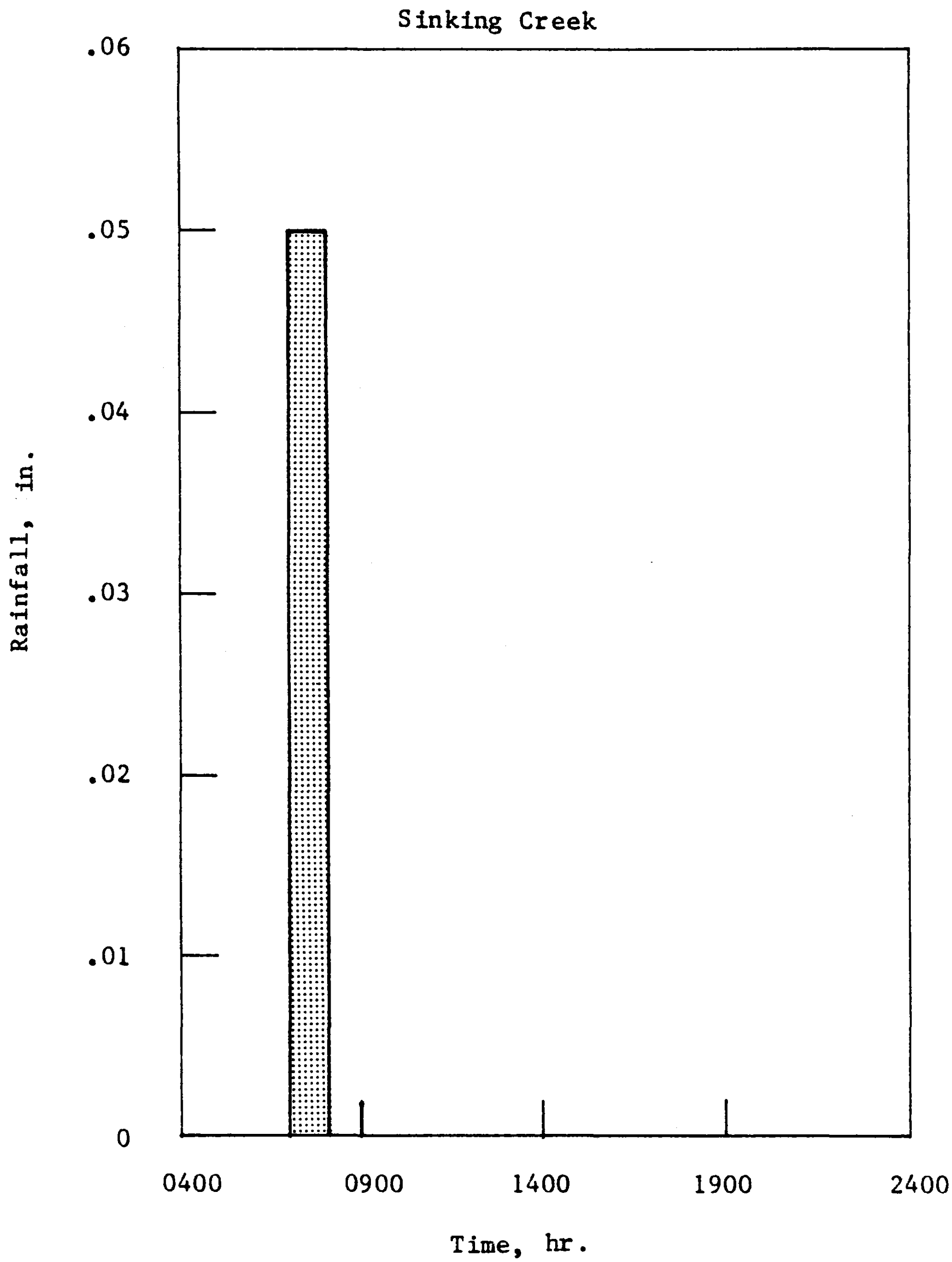


Figure C-52. Rainfall data for August 21, 1980 storm event.

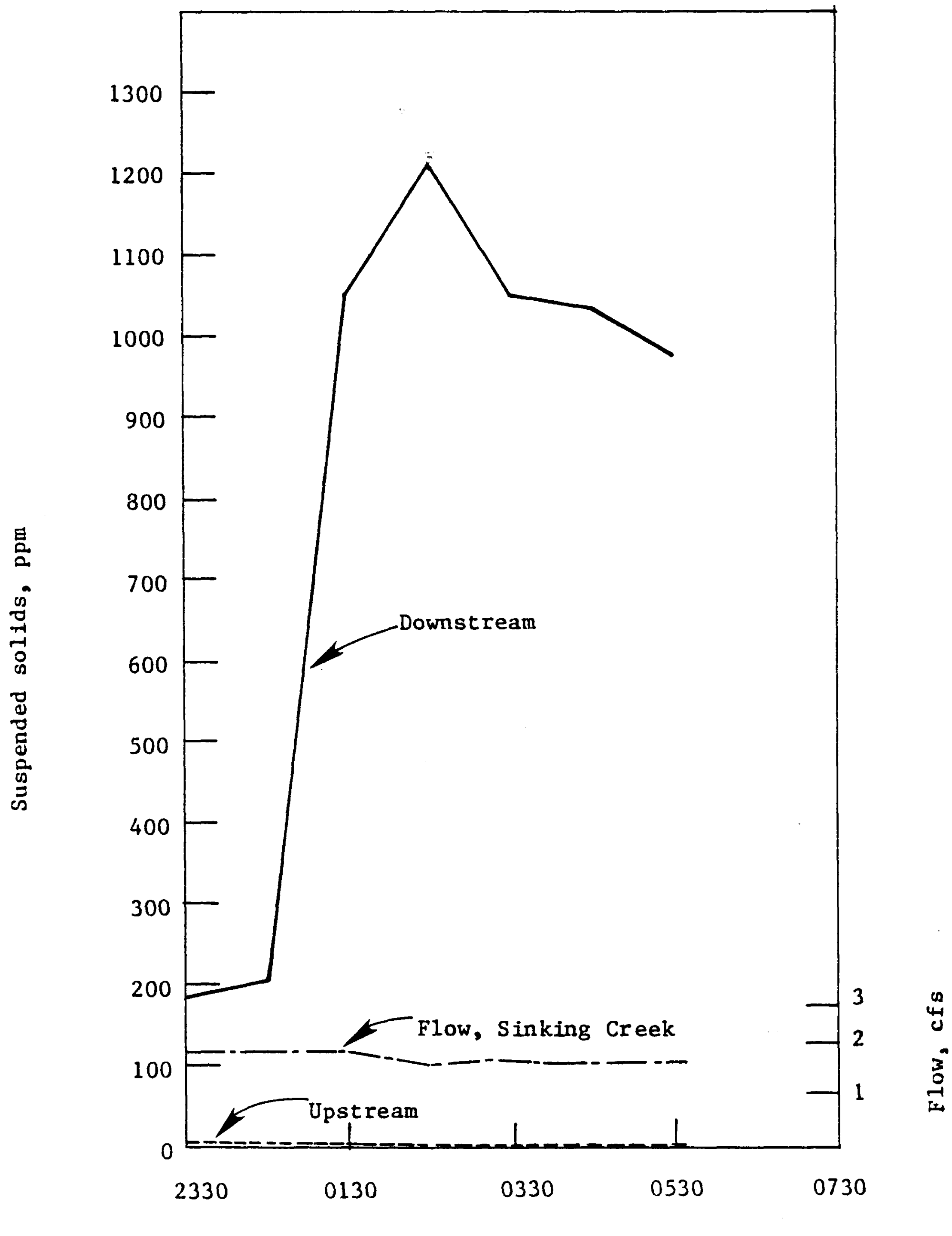


Figure C-53. Suspended solids and stream flow data for August 22, 1980 storm event.

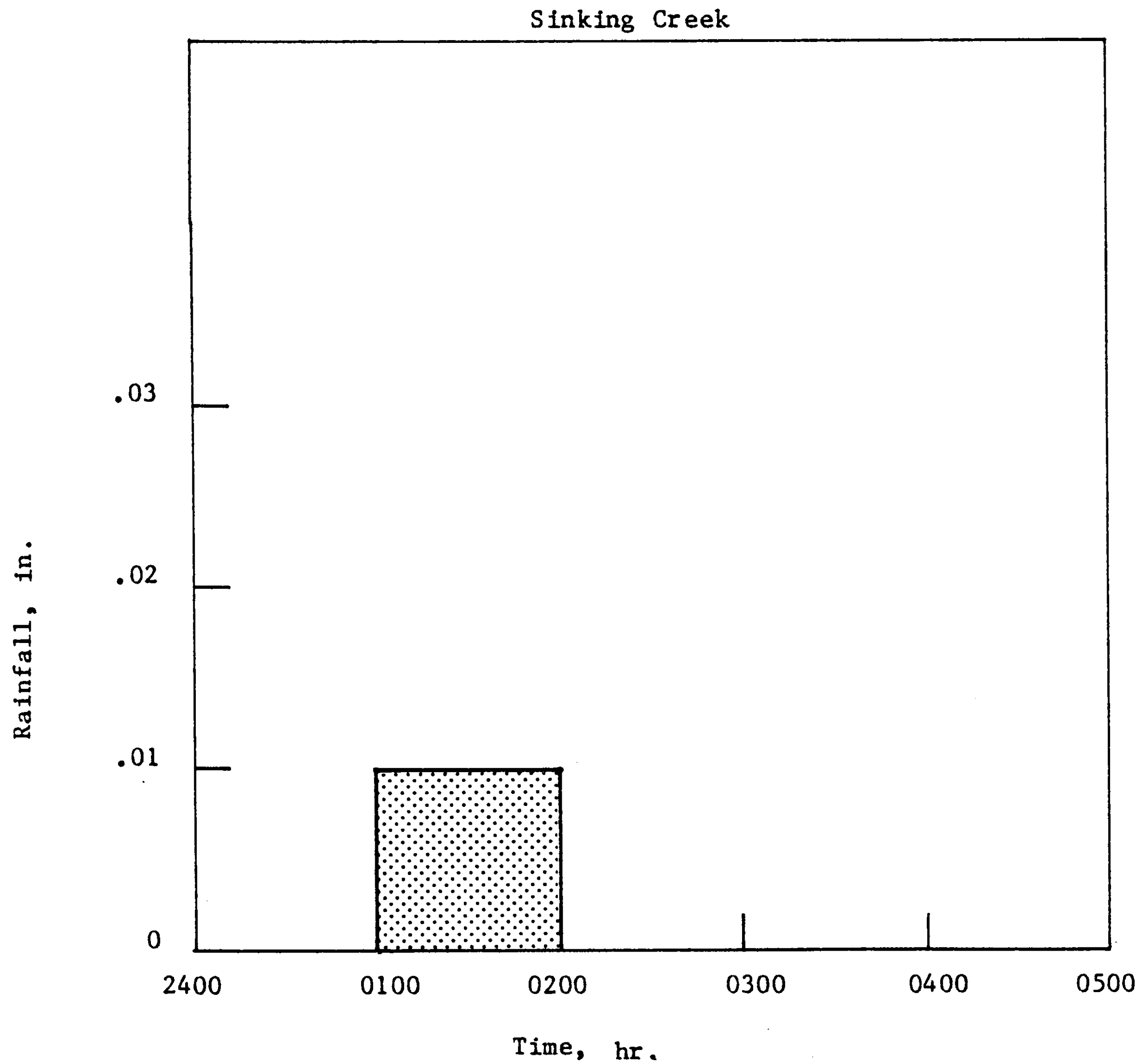


Figure C-54. Rainfall data for August 22, 1980 storm event.

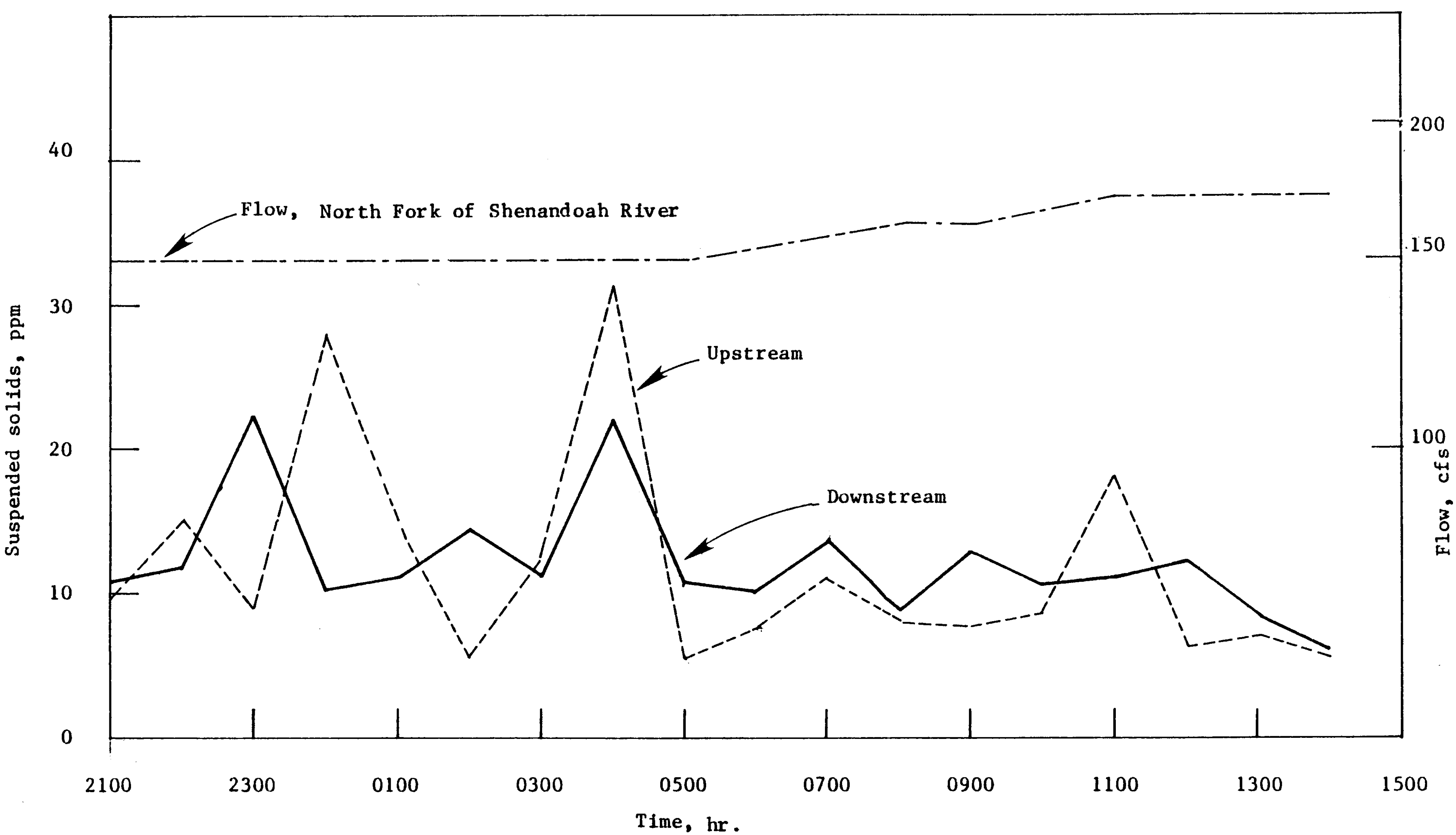


Figure C-55. Suspended solids and stream flow data for March 4-5, 1981 storm event.

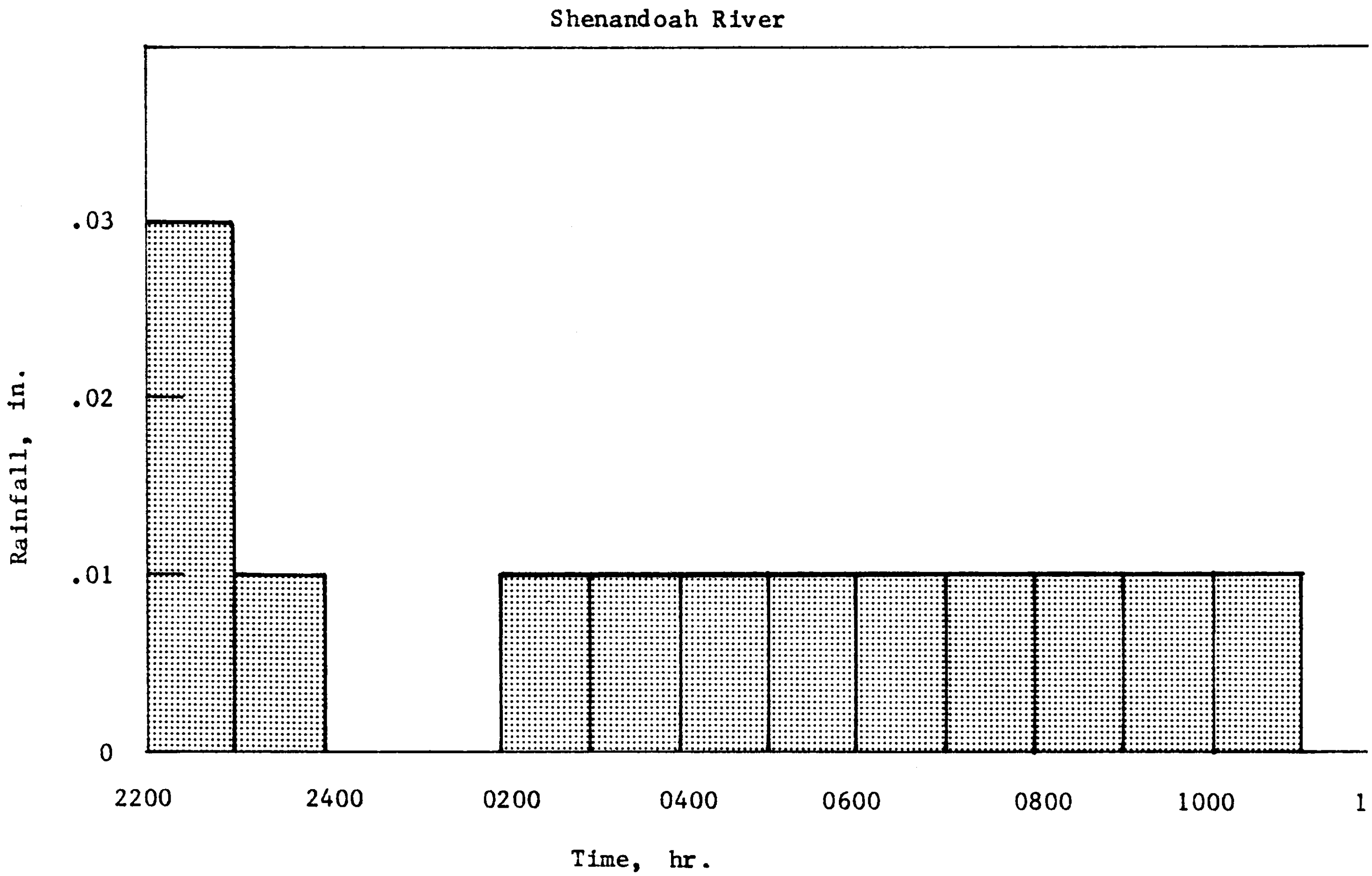


Figure C-56. Rainfall data for March 4-5, 1981 storm event.

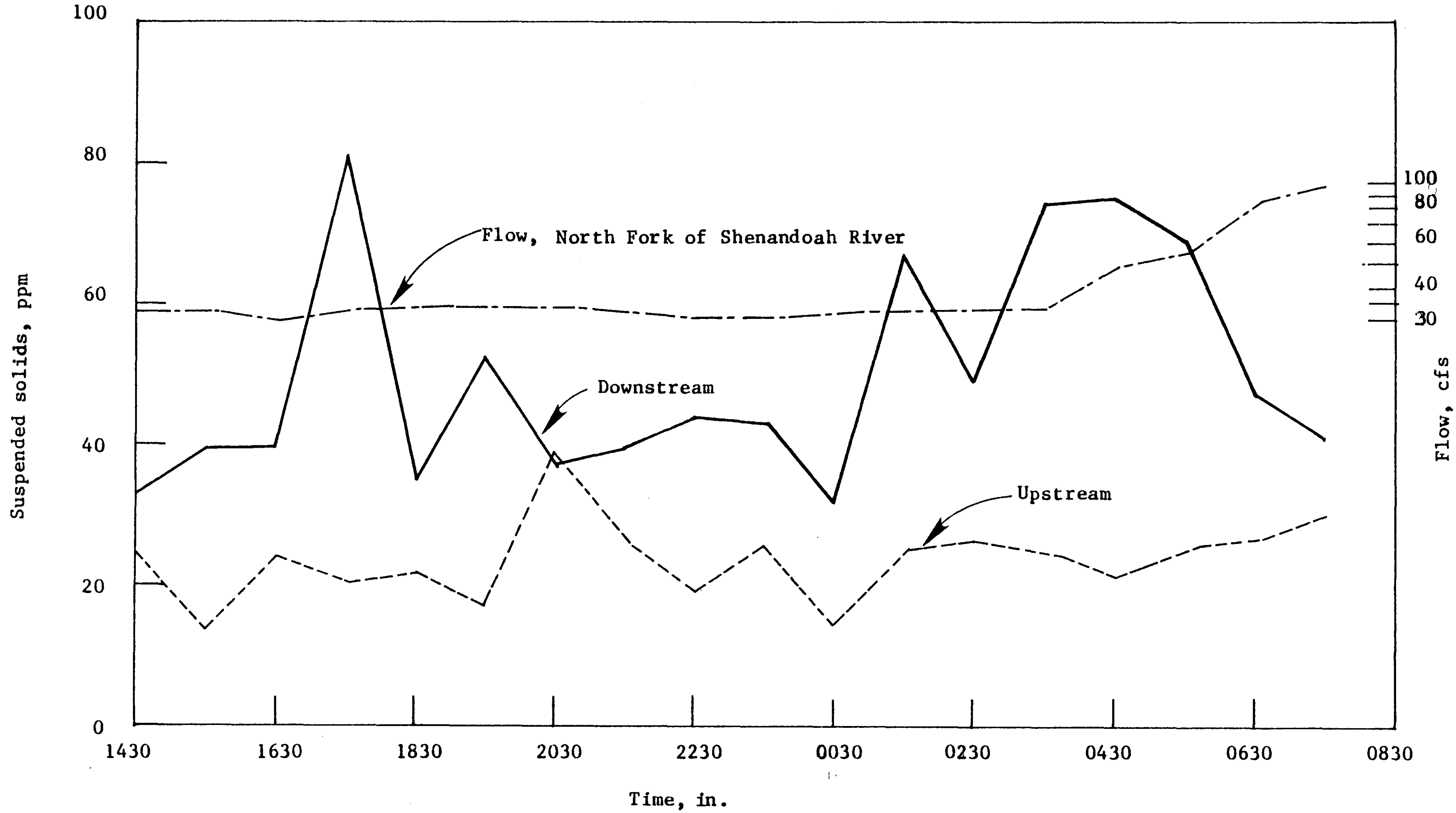


Figure C-57. Suspended solids and stream flow data for May 11 and 12, 1981 storm event.

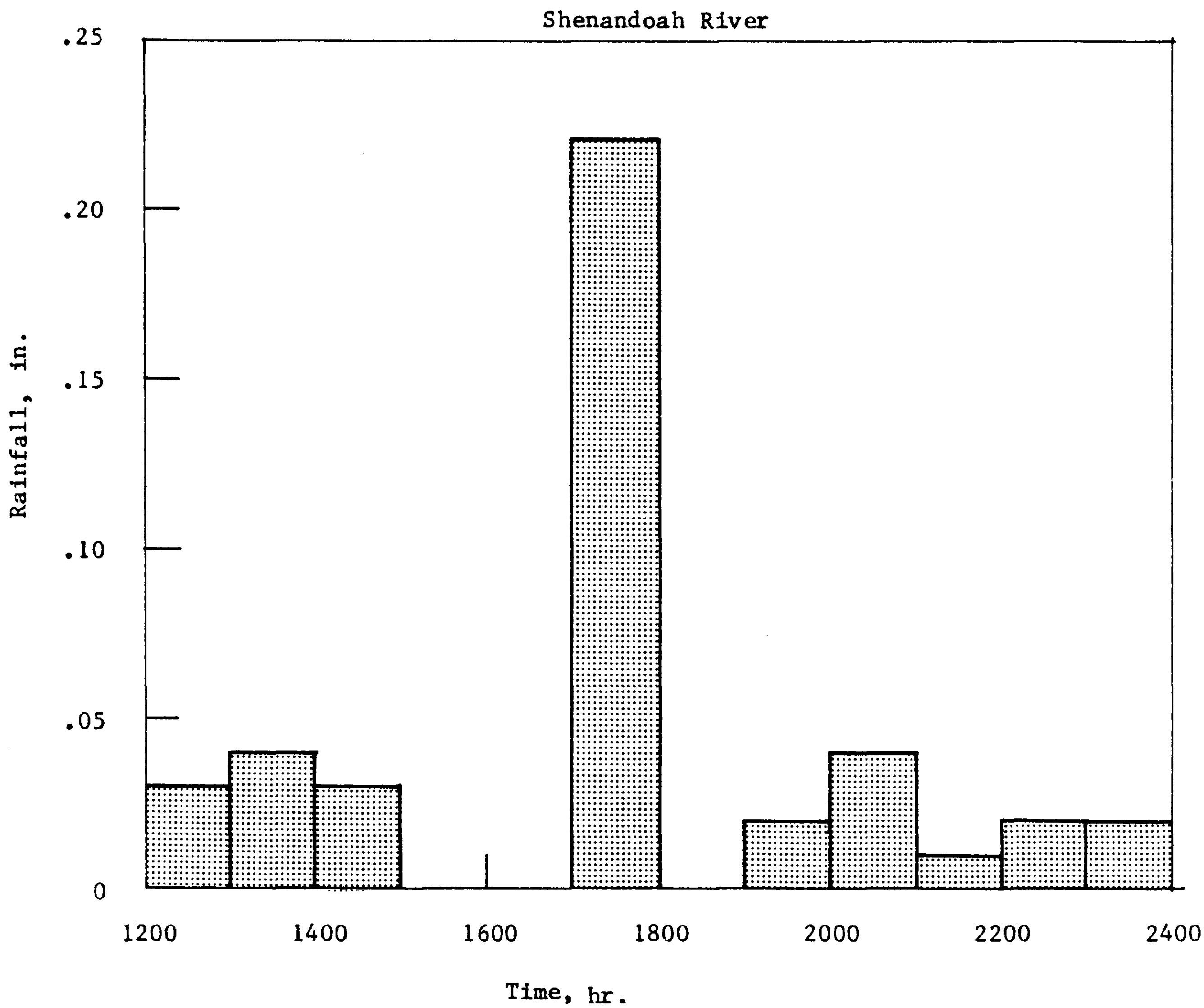


Figure C-58. Rainfall data for May 11, 1981 storm event.

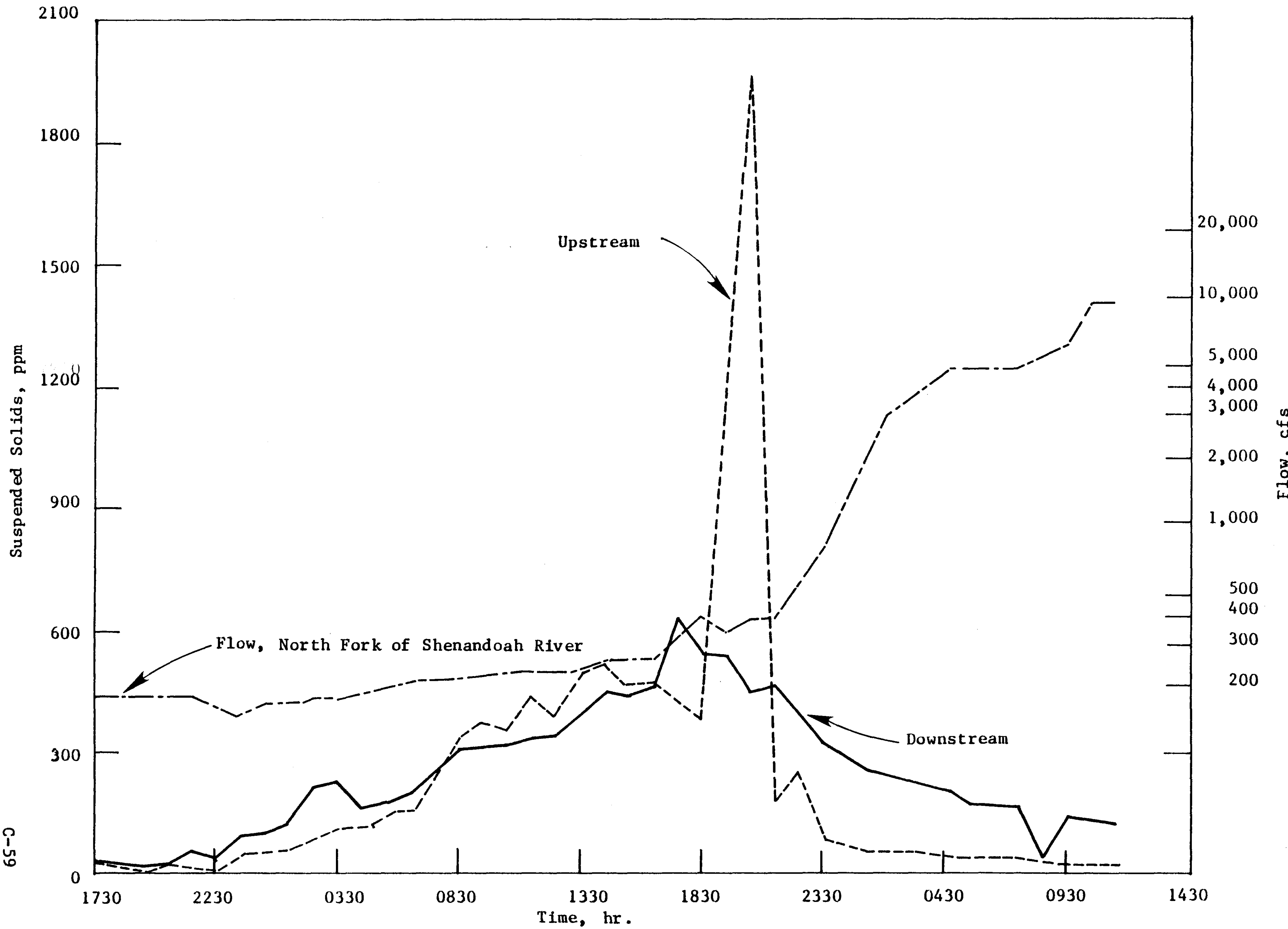


Figure C-59. Suspended solids and stream flow data for May 19 through 21, 1981 storm event.

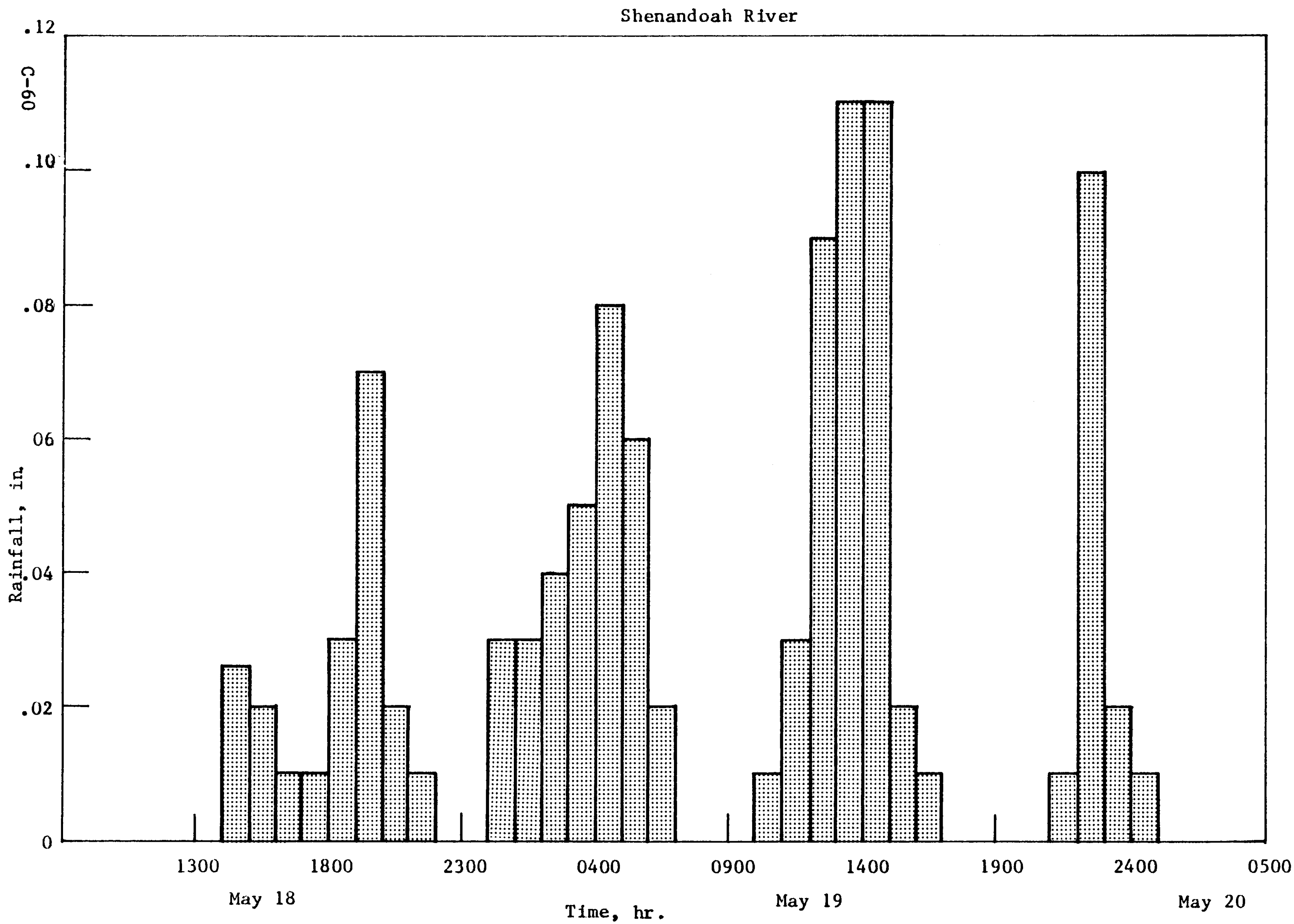


Figure C-60. Rainfall data for May 18 through 21, 1981 storm event.

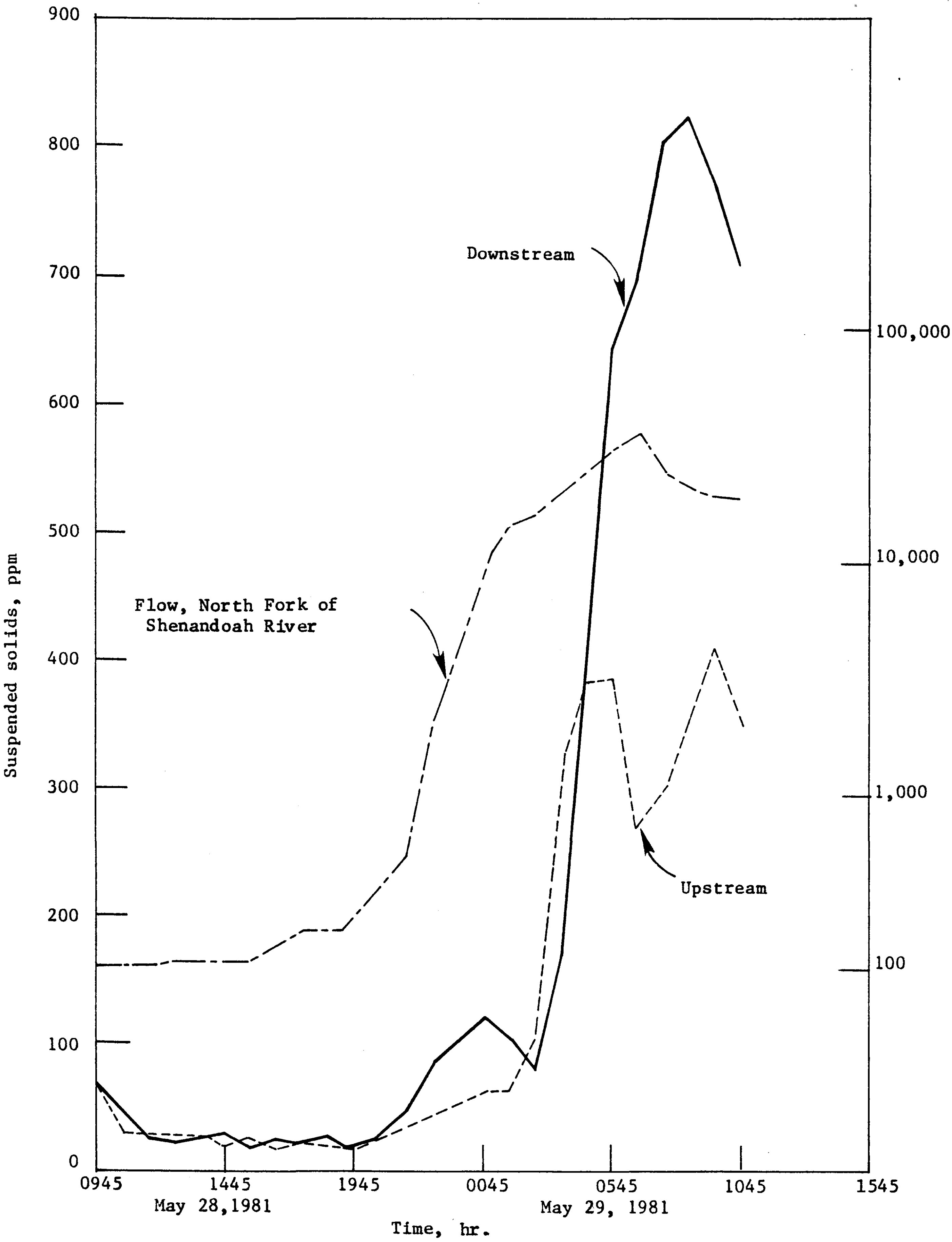


Figure C-61. Suspended solids and stream flow data for May 28 - 29, 1981 storm event.

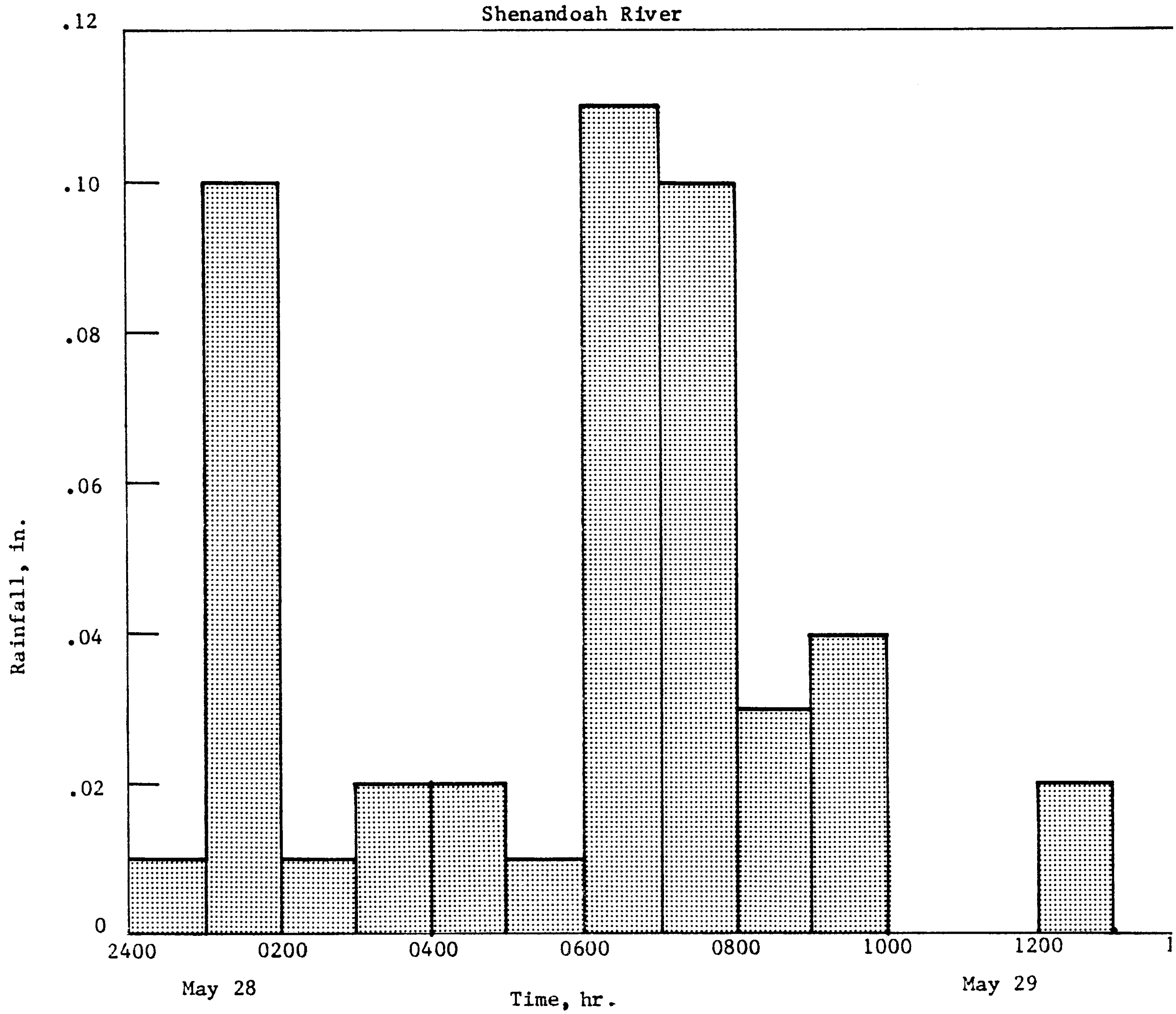


Figure C-62. Rainfall data for May 28-29, 1981 storm event (total rainfall = 0.47 in.).

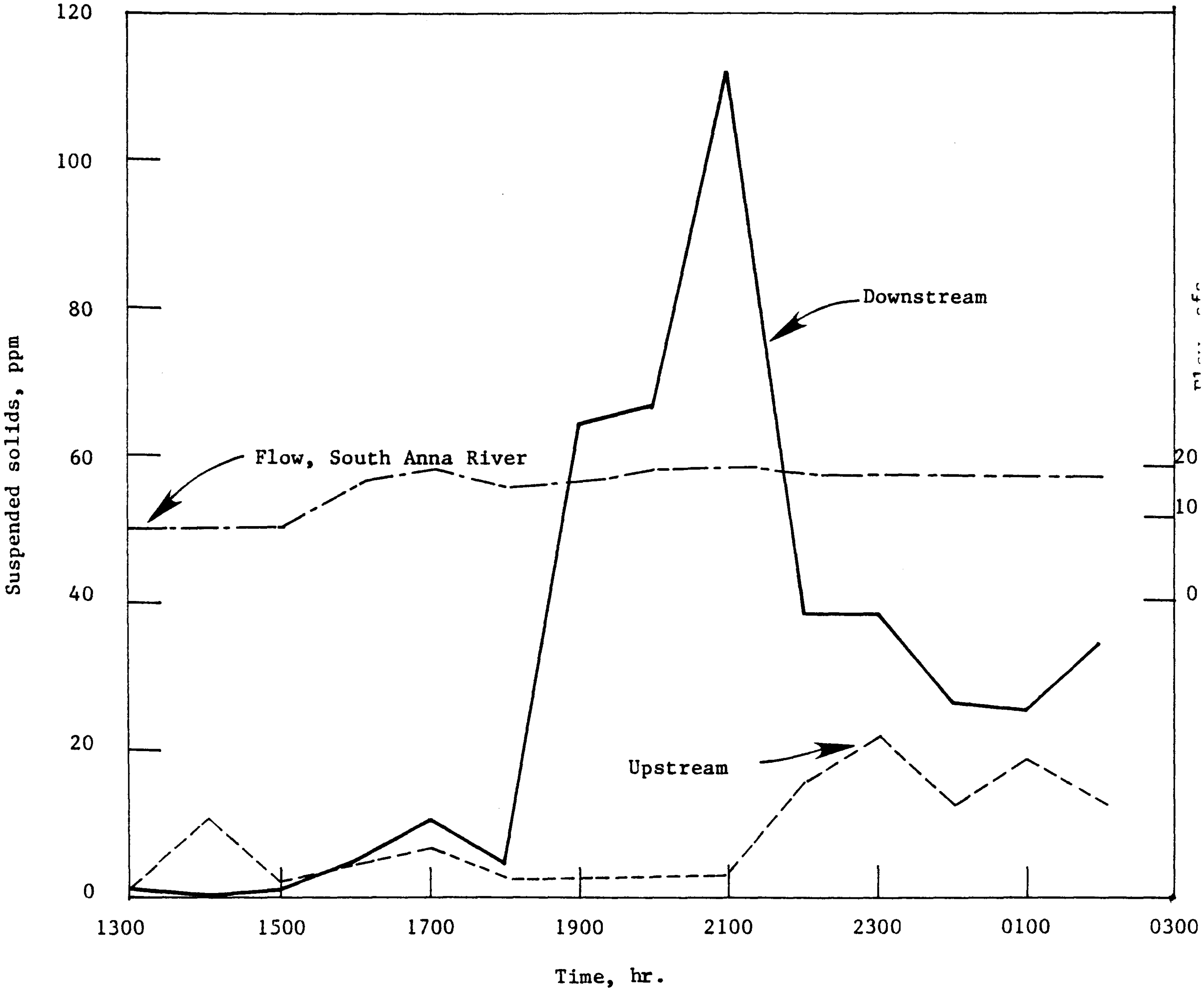


Figure C-63. Suspended solids and stream flow data for November 17, 1980 storm event.

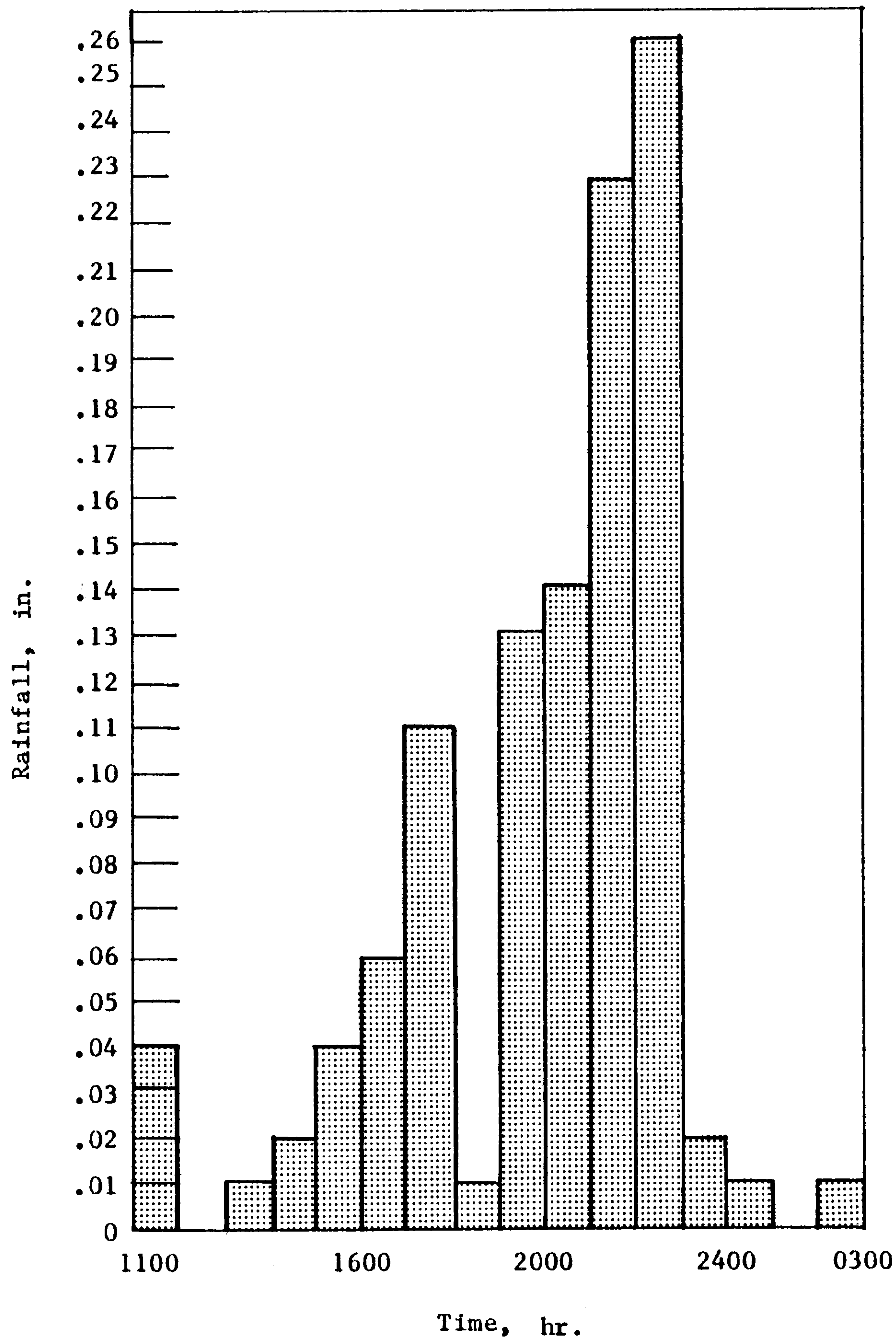


Figure C-64. Rainfall data for November 17, 1980 storm event.

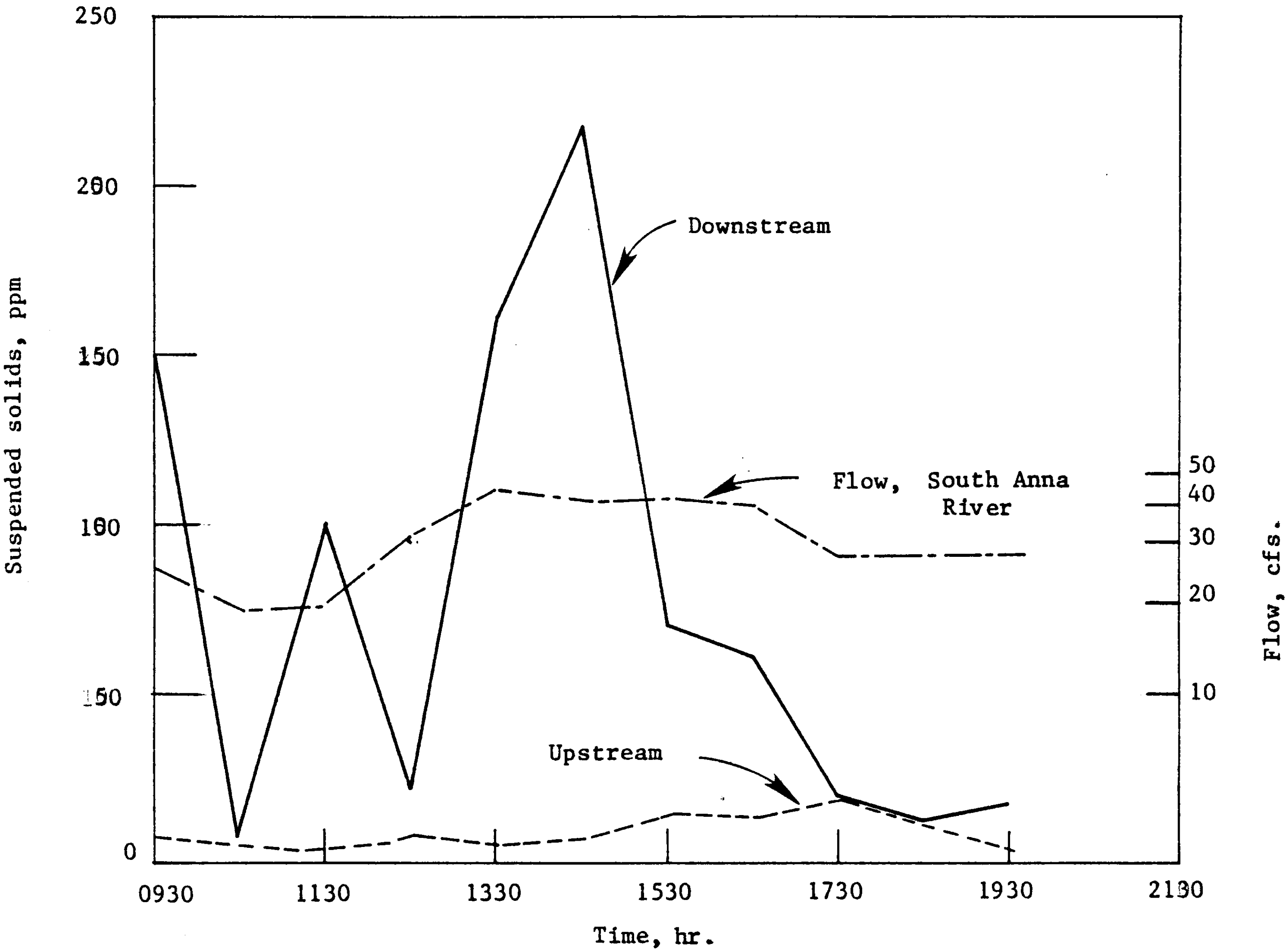


Figure C-65. Suspended solids and stream flow data for November 24, 1980 storm event.

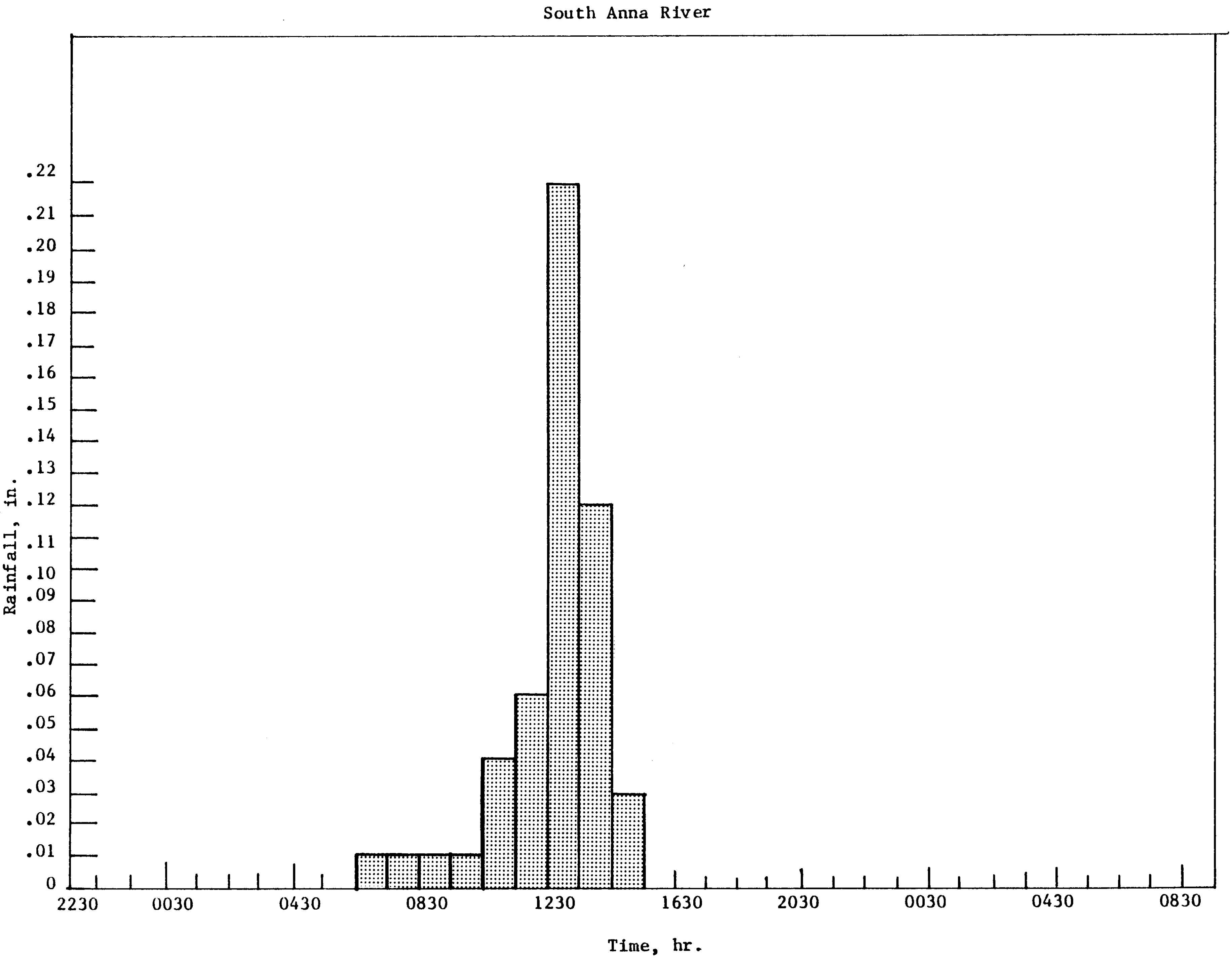


Figure C-66. Rainfall data for November 24, 1980 storm event (total rainfall = 0.51 in.).

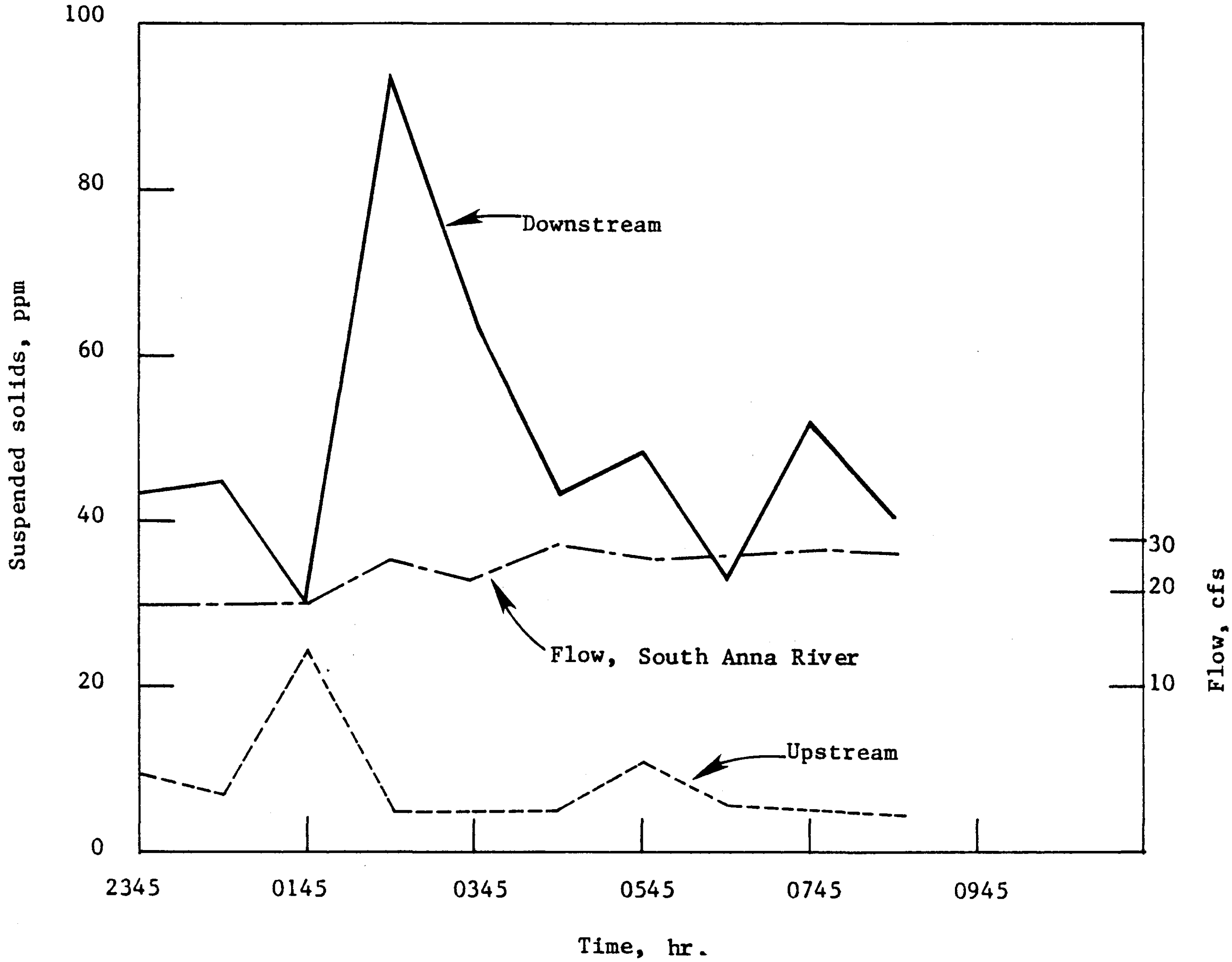


Figure C-67. Suspended solids and stream flow data for November 27, 1980 storm event.

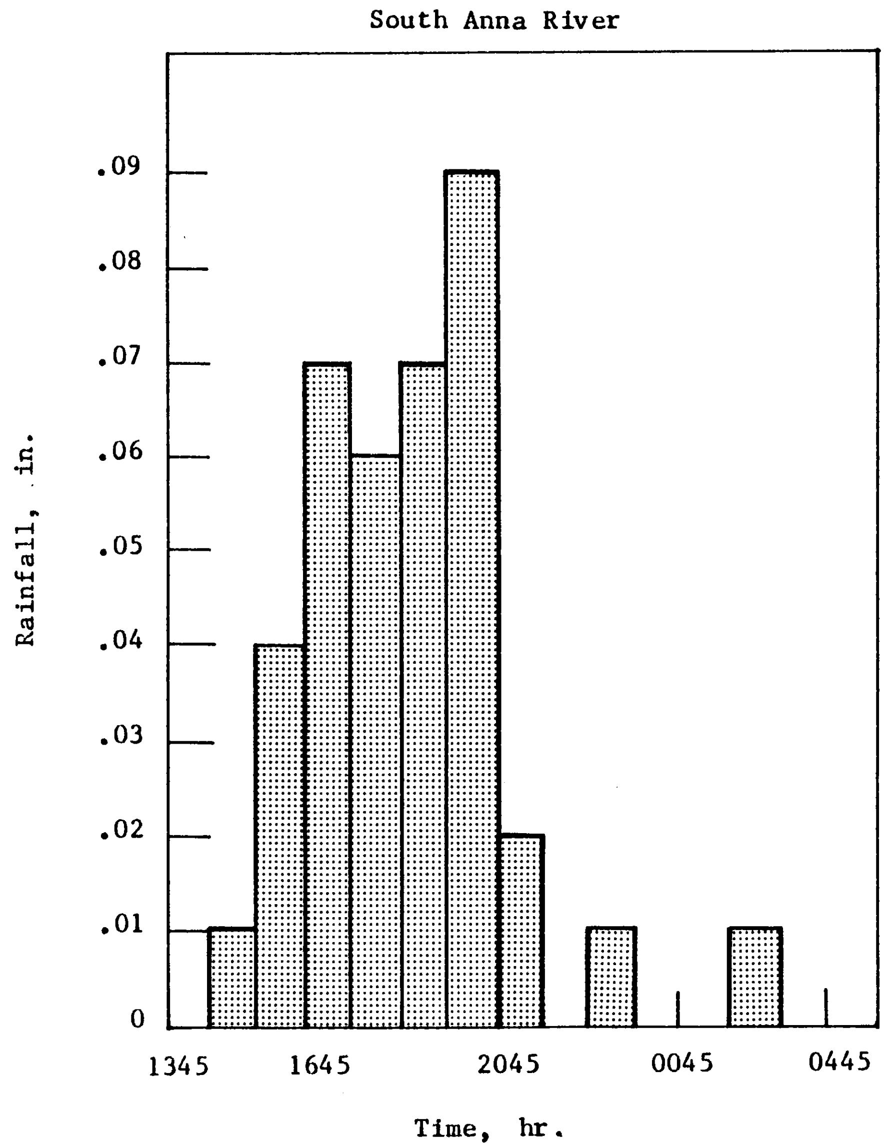


Figure C-68. Rainfall data for November 27, 1980 storm event

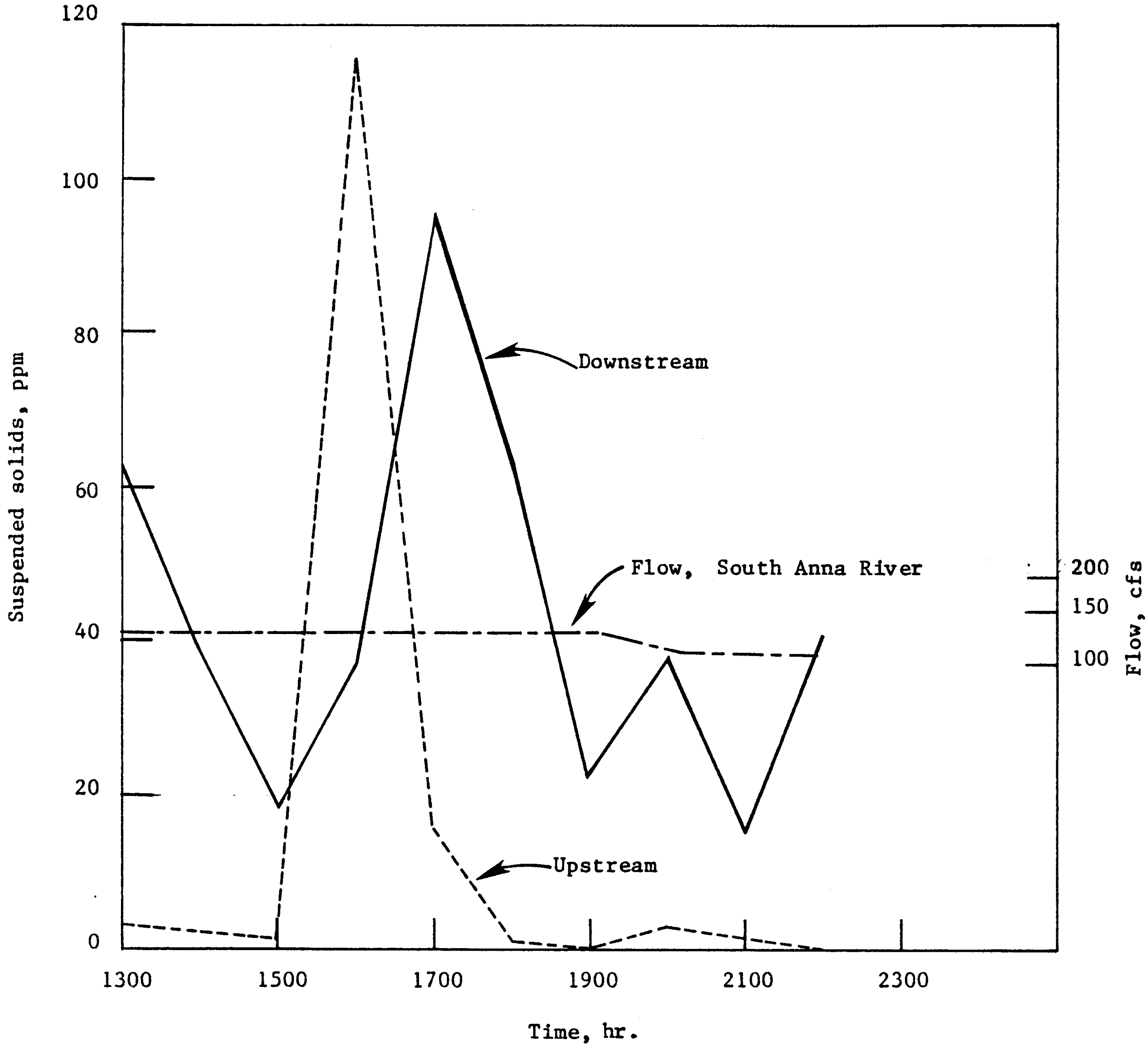


Figure C-69. Suspended solids and stream flow data for December 9, 1980 storm event.

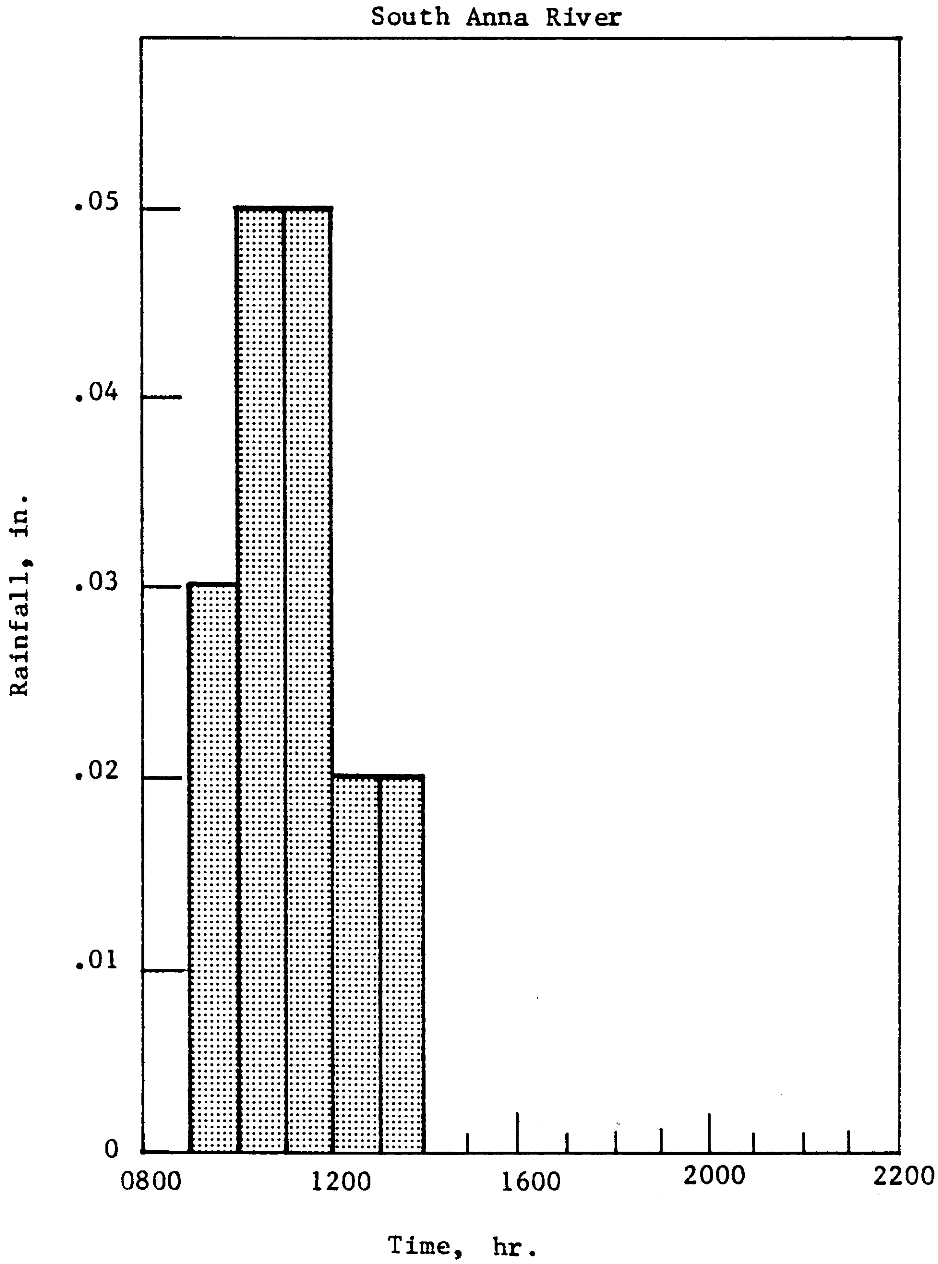


Figure C-70. Rainfall data for December 9, 1980 storm event (total rainfall = 0.17 in.).

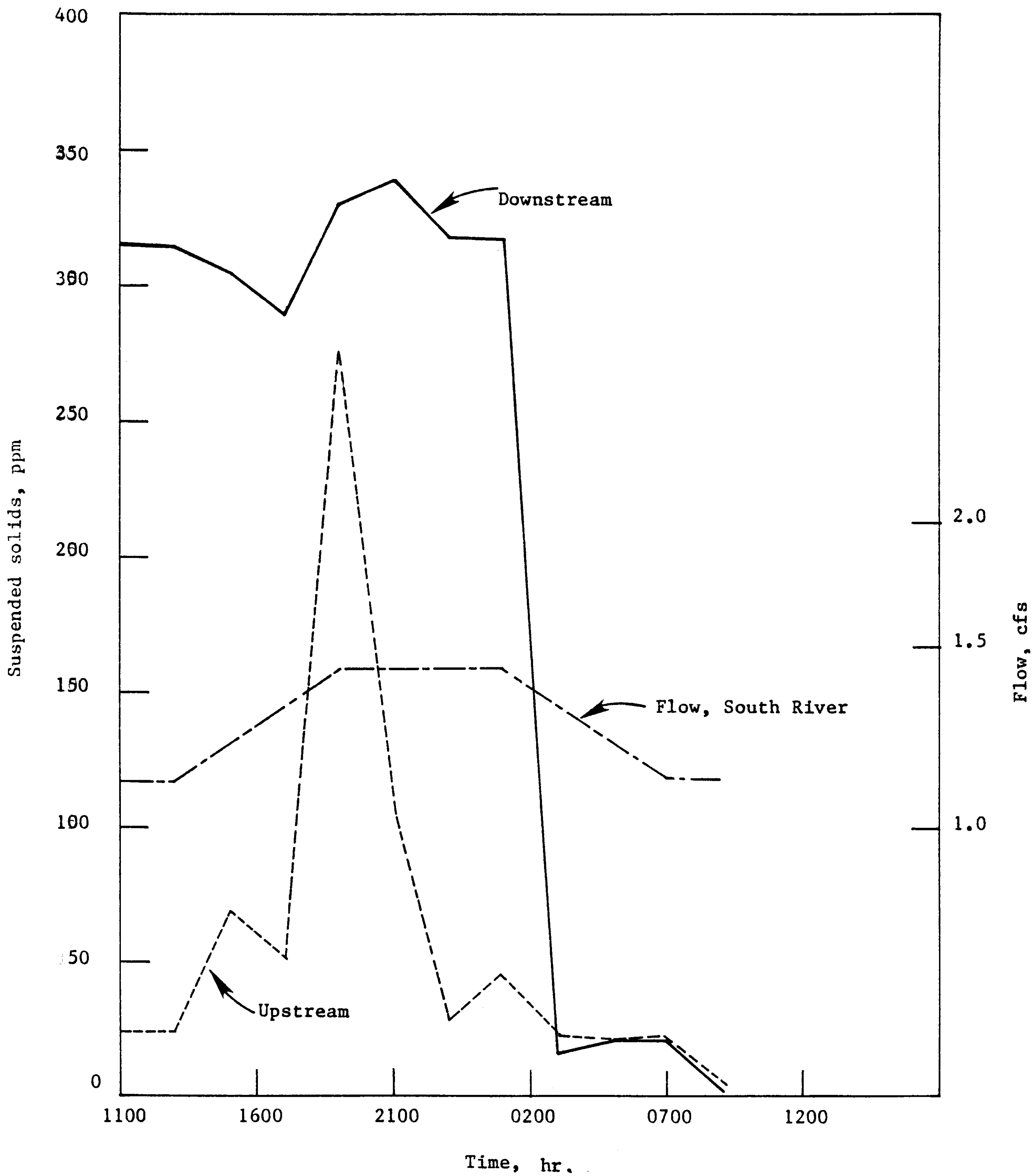


Figure C-71. Suspended solids and stream flow data for August 6-7, 1981 storm event.

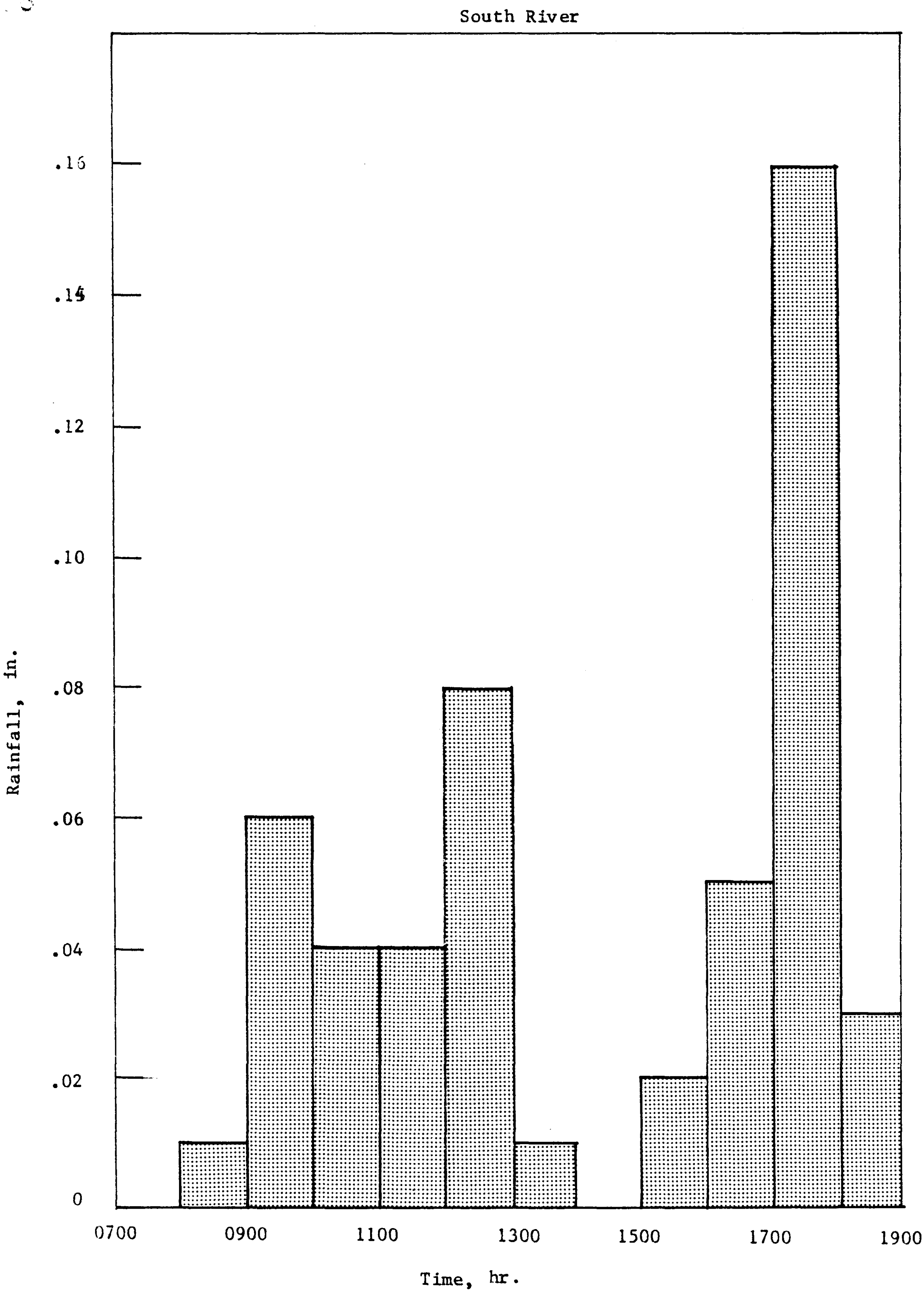


Figure C-72. Rainfall data for August 6 and 7, 1981 storm event.

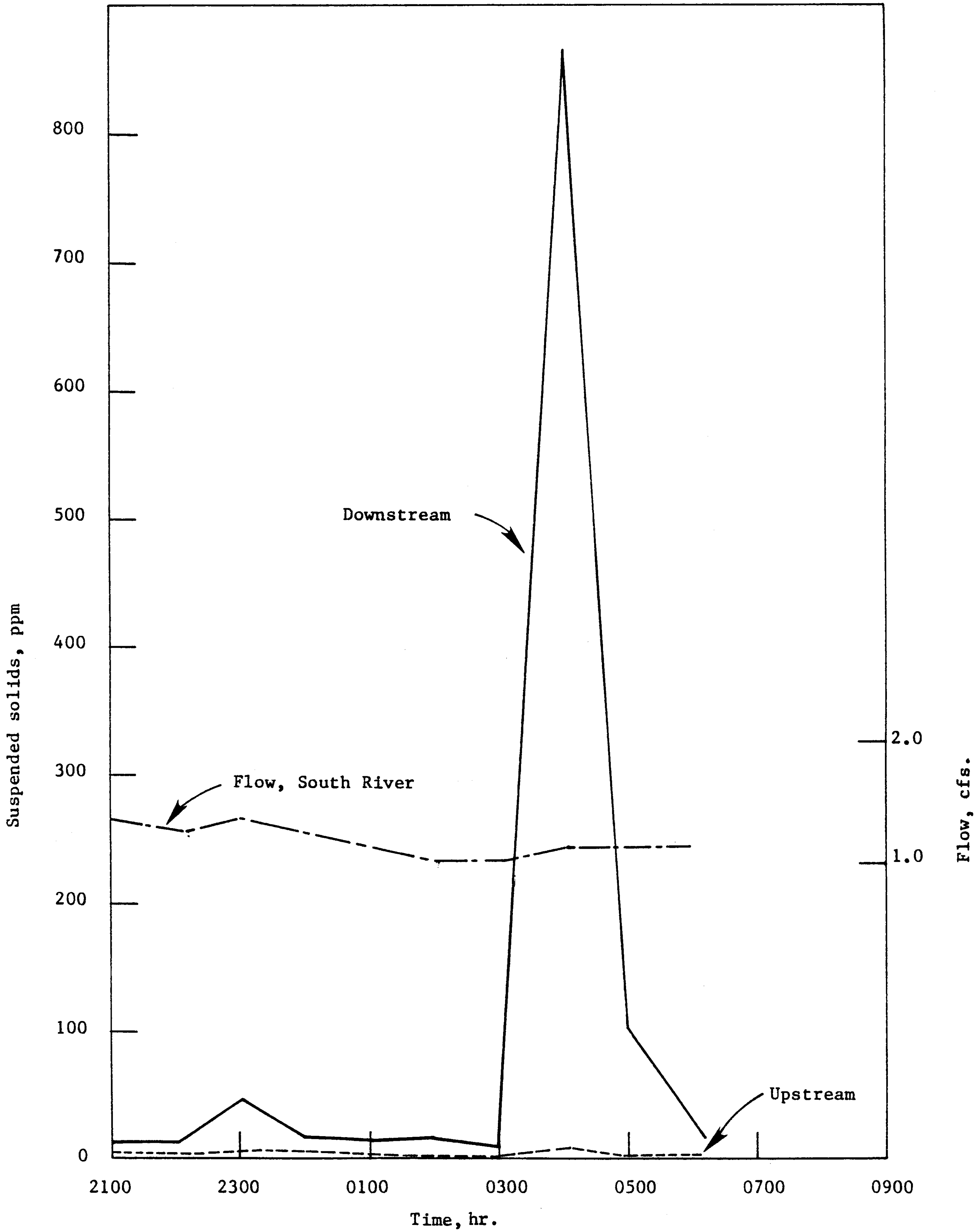


Figure C-73. Suspended solids and stream flow data for August 11 and 12, 1981 storm event.

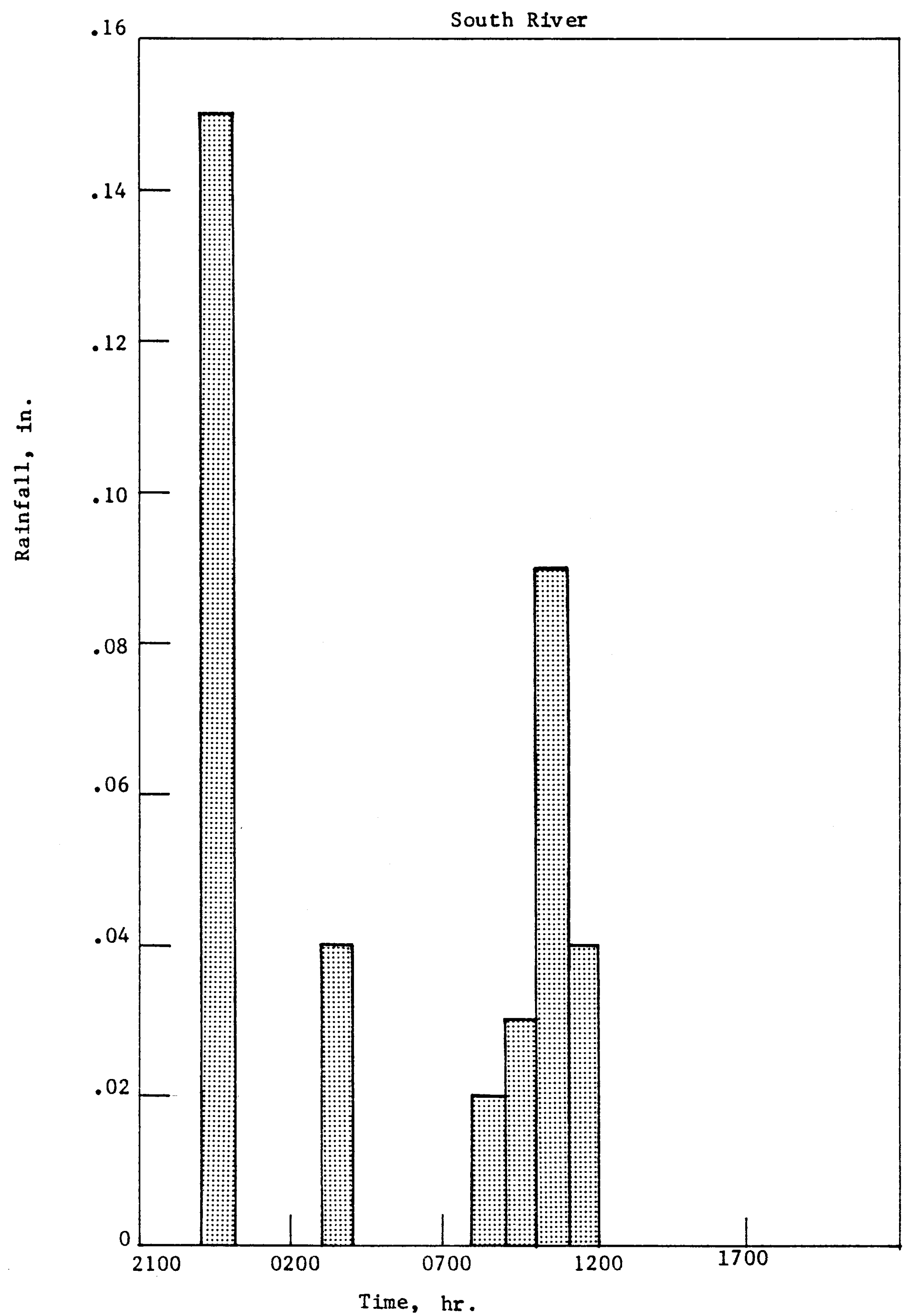


Figure C-74. Rainfall data for August 11 and 12, 1981 storm event (total rainfall = 0.37 in.).

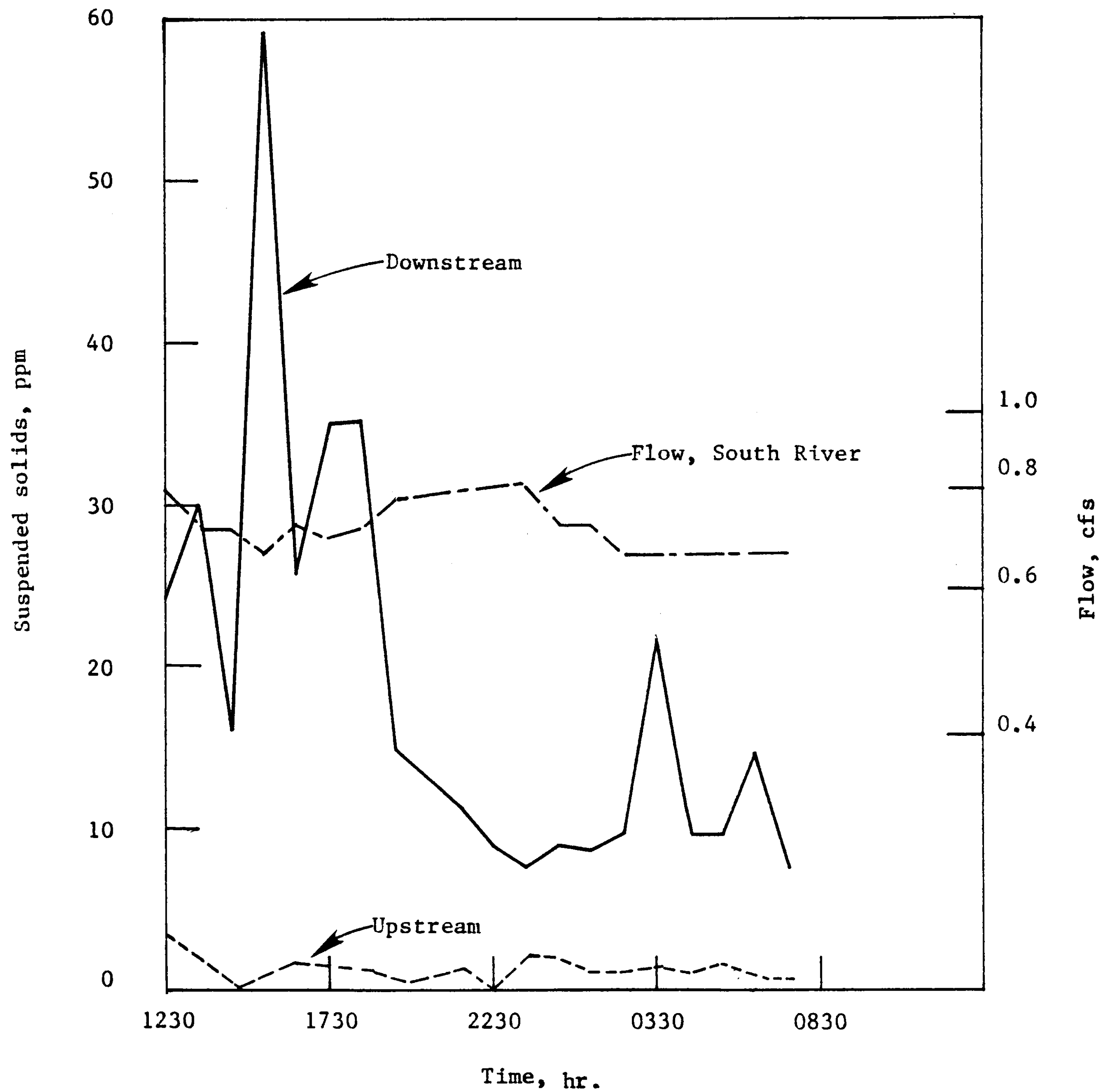


Figure C-75. Suspended solids and stream flow data for August 19 and 20, 1981 storm event.

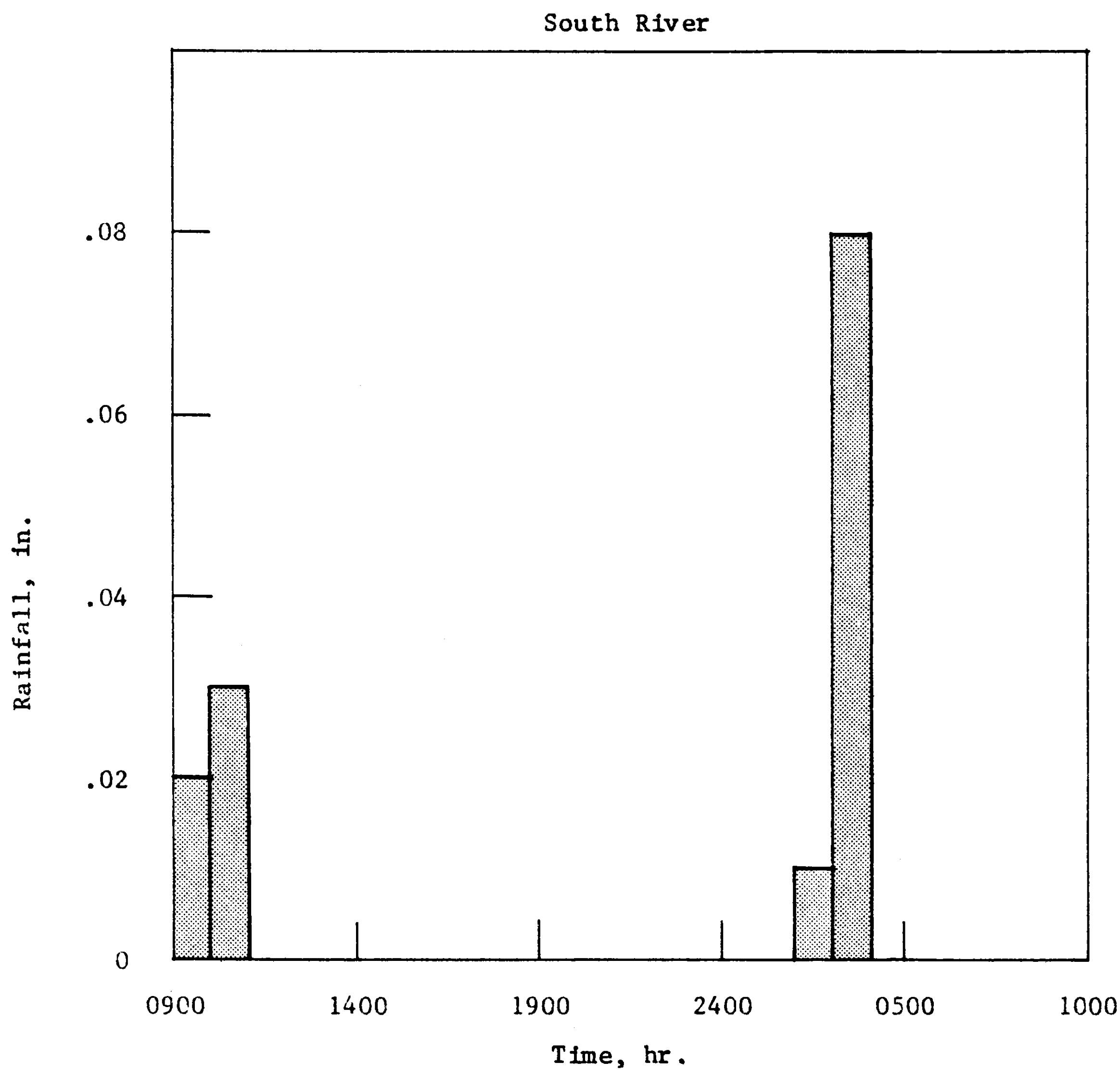


Figure C-76. Rainfall data for August 19 and 20, 1981 storm event.

Figure C-77. Suspended solids and stream flow data for September 5-7, 1981 storm event.

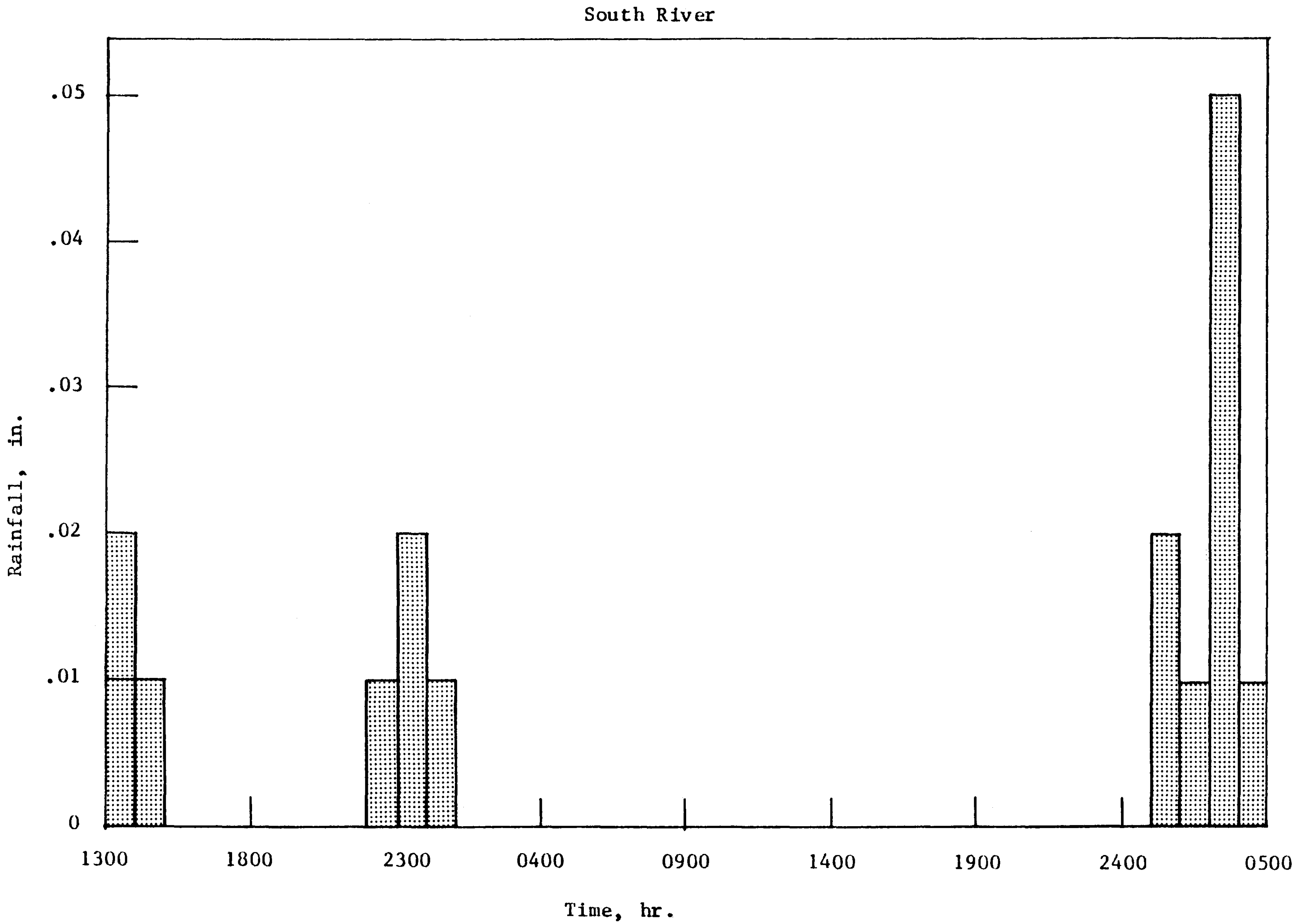


Figure C-78. Rainfall data for September 5-7, 1981 storm event.

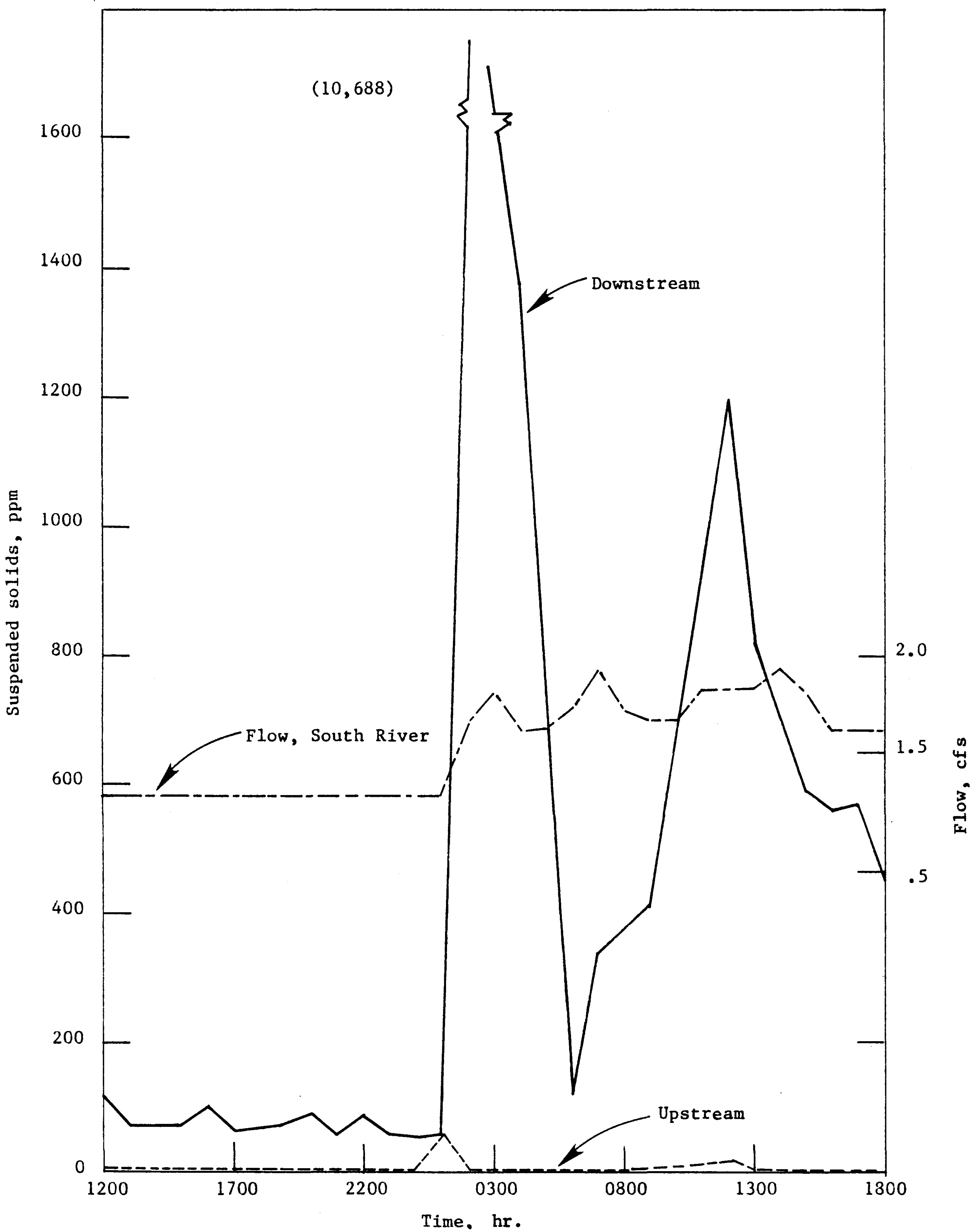


Figure C-79. Suspended solids and stream flow data for September 15 and 16 storm event.

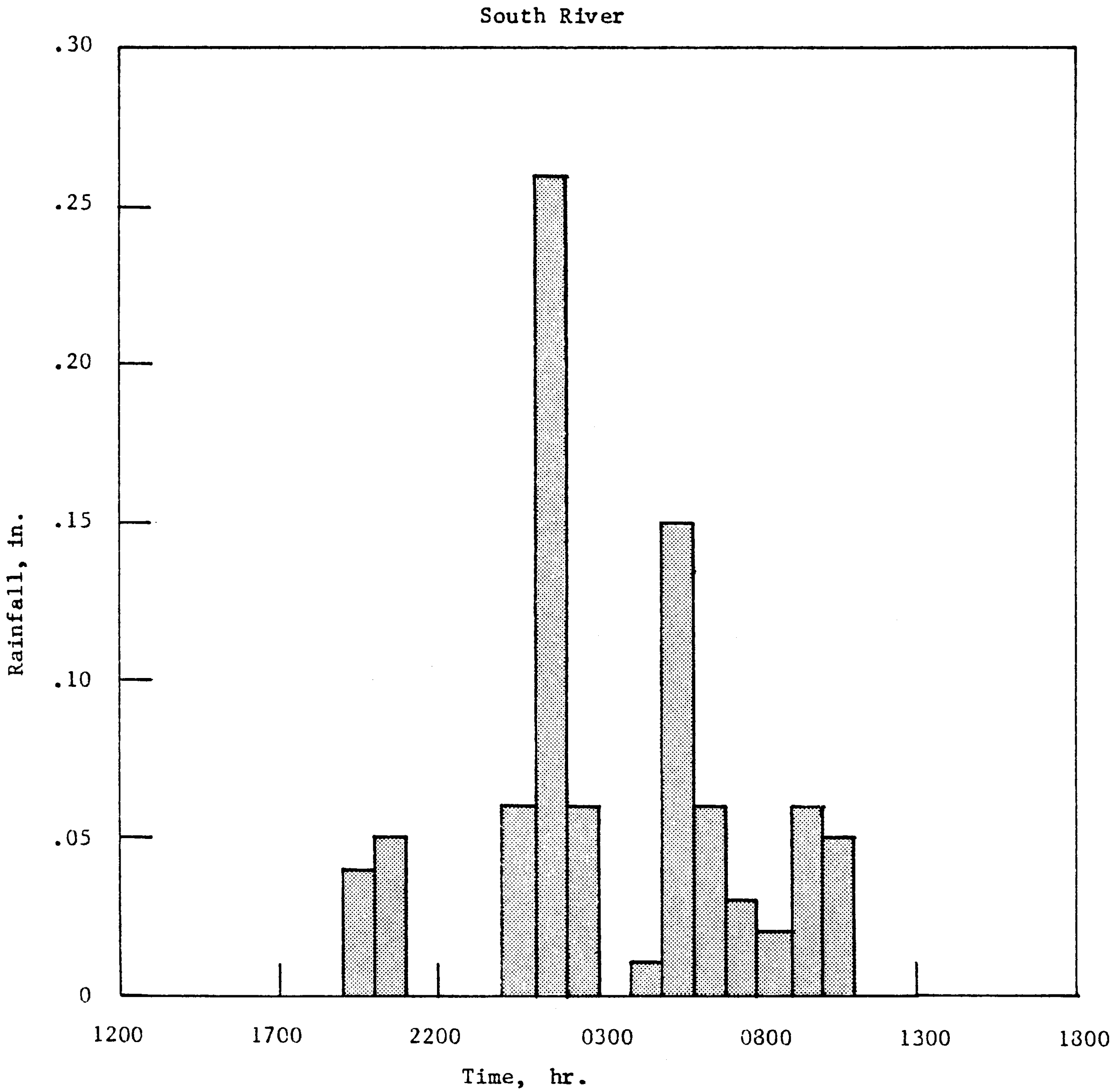


Figure C-80. Rainfall data for September 15 and 16, 1981 storm event (total rainfall = 0.85 in.).