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16. Abstract

Grab samples collected during the construction of a freeway in southwestern Travis County, Texas, indicate that suspended solids are the most important constituent present in stormwater runoff from the construction corridor. Despite the presence of an extensive system of temporary controls (primarily silt fences), the concentration of suspended solids in Danz Creek increased at least fivefold during and immediately after storm events. Other solids-related parameters, such as turbidity and iron, also increased. Despite the high concentrations of suspended solids, no permanent change in the channel resulting from runoff during construction was obvious. The effects of construction on Danz Creek were temporary, and similar to that reported in the literature for other rivers and streams.

Monitoring of a small ephemeral stream allowed documentation of changes in water quality and quantity resulting from highway runoff that would not be apparent in larger watersheds. The paved surfaces and storm sewer system combined to increase both the total volume and maximum flow rate of the creek. Even small storm events were sufficient to generate runoff below the highway right-of-way. Stormwater runoff from the highway caused increases in suspended solids, oil and grease, and zinc in Danz Creek. These constituents are commonly found in highway runoff. Although the increases were substantial, the resulting water quality was well within levels appropriate for aquatic life or at concentrations commonly reported for streams during the elevated flows following storm events in undeveloped watersheds. Because of the nature of the surrounding land use, ambient concentrations of many constituents in the creek were higher than those in the runoff from the new highway.

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EFFECTS OF HIGHWAY CONSTRUCTION AND OPERATION ON WATER QUALITY AND QUANTITY IN AN EPHEMERAL STREAM IN THE AUSTIN, TEXAS, AREA

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Research Report Number 1943-3

Research Project 7-1943
Water Quantity and Quality Impacts Assessment of Highway Construction
in the Austin, Texas, Area

conducted for the

TEXAS DEPARTMENT OF TRANSPORTATION

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CENTER FOR TRANSPORTATION RESEARCH
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THE UNIVERSITY OF TEXAS AT AUSTIN

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IMPLEMENTATION STATEMENT

The information on the quality of highway stormwater runoff can be used to predict the impacts of existing and proposed highways on water quality in environmentally sensitive areas, and to select the appropriate mitigation technology where necessary. In addition, the data can be used to educate the public on the effects of highway runoff on the environment. The data also demonstrate the overall efficiency of silt fences and other erosion control techniques on the quality of runoff from a highway construction site.

Prepared in cooperation with the Texas Department of Transportation.

DISCLAIMERS

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SUMMARY

Grab samples collected during the construction of a freeway in southwestern Travis County, Texas, indicate that suspended solids are the most important constituent present in storm water runoff from the construction corridor. Despite the presence of an extensive system of temporary controls (primarily silt fences), the concentration of suspended solids in Danz Creek increased at least fivefold during and immediately after storm events. Other solids-related parameters, such as turbidity and iron, also increased. Despite the high concentrations of suspended solids, no permanent change in the channel resulting from runoff during construction was obvious. The effects of construction on Danz Creek were temporary, and similar to that reported in the literature for other rivers and streams.

Monitoring of a small ephemeral stream allowed documentation of changes in water quality and quantity resulting from highway runoff that would not be apparent in larger watersheds. The paved surfaces and storm sewer system combined to increase both the total volume and maximum flow rate of the creek. Even small storm events were sufficient to generate runoff below the highway right-of-way. Storm water runoff from the highway caused increases in suspended solids, oil and grease, and zinc in Danz Creek. These constituents are commonly found in highway runoff. Although the increases were substantial, the resulting water quality was well within levels appropriate for aquatic life or at concentrations commonly reported for streams during the elevated flows following storm events in undeveloped watersheds. Because of the nature of the surrounding land use, ambient concentrations of many constituents in the creek were higher than those in the runoff from the new highway.

1. INTRODUCTION

Regulatory agencies recently have focused attention on nonpoint sources of pollution such as urban runoff. The U.S. Environmental Protection Agency (EPA) National Pollutant Discharge Elimination System (NPDES) regulations regarding stormwater runoff are evidence of this effort to protect the water quality of receiving waters. In Texas, the Barton Springs/Edwards Aquifer Conservation District (District) and several environmentally oriented organizations became concerned about the potential for aquifer contamination as a result of proposed highway construction activities over the Edwards aquifer. The proposed construction corridor crosses and parallels three creeks and overlies a portion of the recharge zone of the Barton Springs segment of the Edwards aquifer. The Edwards is a karstic (cavernous) aquifer with numerous recharge features and thin soil cover and is particularly susceptible to degradation from nonpoint sources of pollution.

In January 1990, a Consent Decree and Judgment was issued requiring the Texas Department of Transportation (TxDOT) to fund a study to assess water quantity and quality impacts of highway construction in the Edwards aquifer recharge zone. One part of the study involved a field monitoring program of the quantity and quality of the surface water in the creeks and drainage ways affected by the construction and operation of highways in the target study areas. Surface water quality has a direct impact on water quality in the aquifer, because 85% of recharge to the aquifer occurs through beds of the major creeks (Slade et al., 1986).

The monitoring program was used to assess the impact of new highway construction on water quantity and quality in creeks flowing across the recharge zone. A suitable representative drainage area was selected since it was not economically feasible to monitor highway runoff at every location. The results can be extrapolated to assess the impact of the entire project. Results of this study also will add to the general body of knowledge regarding stormwater runoff, an issue of increasing importance throughout the United States.

Danz Creek, an intermittent stream that flows in a natural channel beneath both lanes of State Highway 45 (also known as the Outer Loop) was selected as a representative receiving water for a number of reasons: (1) Danz Creek is crossed three times by the TxDOT construction corridor, (2) The creek was easily accessible to project personnel for the collection of flow measurements and water samples, and (3) Portions of the creek were amenable to flow monitoring using established techniques. The impact of highway runoff on Danz Creek was assessed by determining the difference in water quality between sections of the creek upstream and downstream of the highway right-of-way.

2. LITERATURE REVIEW

Surface water quality may be affected adversely by highway construction and operation. During the construction phase, large areas of soil are exposed to the erosive forces of wind and rain. This erosion may result in a significant increase in sediment loads to receiving waters. Once construction has been completed and the roadway is open to traffic, constituents derived from vehicles and other sources can accumulate on the road surface. Rainfall washes these materials from the highway pavement, and runoff transports the substances into surface waters.

2.1 Effects of Highway Construction on Stream Water Quality

Highway construction and associated grading activities typically are initiated with a clearing and grubbing phase in which vegetation and other naturally occurring soil-stabilizing materials are removed from the construction site. The surface areas and slopes created by excavation or embankments are exposed to the erosive forces of wind and rain until the earthwork is completed and the grassy vegetation is restored or the surface is artificially stabilized.

Soil losses from erosion may be inconsequential when compared to the damage resulting from sediment transport and deposition into surface waterways. Fish spawning areas and benthic habitats may be destroyed or damaged when sediment deposition covers stream and river bottoms. Suspended solids also reduce light transmission, which limits in-stream photosynthesis and diminishes aquatic food supply and habitat. Suspended solids may also coat and abrade aquatic organisms, reduce surface water quality and suitability for various usages, and lead to diminished capacities of reservoirs or other conveyance systems via deposition (Goldman et al., 1986). The eroded solids also may act as a transport medium for phosphorus, nitrogen, and toxic compounds. Miller et al. (1982) compare several methods for the prediction of erosion from highway construction sites.

The effects of highway construction can be substantial even though the area involved may cover only a small portion of a watershed. Vice et al. (1969) studied the movement of sediment during a period of intensive highway construction in a 11.5-square-kilometer drainage basin in Virginia. The sediments were allocated to source areas. The data showed that highway construction areas, varying from less than 1 to more than 10 percent of the basin at any one time, contributed 85 percent of the sediment load.

Reed (1977) investigated the response of aquatic macrobenthic and fish communities to the effects of siltation from highway construction. Community response was evaluated on the basis of community diversity and changes in the numbers of organisms and/or species. The primary response observed among the macrobenthic and fish communities was a reduction in numbers of species and in organisms downstream from the construction. The diversity index also demonstrated a statistically significant long-term change in aquatic community structure, but was less meaningful for indicating initial effects or making single comparisons. Reed (1977) suggested that drift is a major physical response of macrobenthos to increased siltation and that it may be a primary mechanism for repopulating stressed habitats. These observation are contrary to the commonly held hypothesis that smothering is a major effect and should be tested in further investigations. Fishes apparently vacated areas of increased siltation, but were able to repopulate such areas within 12 months after construction activity ceased. In general, Reed (1977) found that erosion-control measures commonly applied in highway construction were of limited value in preventing damages to stream communities, especially in the early construction stages.

Three highway construction projects in California were studied by Howell et al. (1979) to determine the influence on the water-quality environment. Most impacts were not foreseen in the preconstruction environmental assessment. Almost all of the short-term effects involved erosion and subsequent sediment transport into a stream. Mitigation measures were effective at reducing these effects. Howell et al. (1979) recommended that only projects with a direct bearing on a stream, lake, wetland, or other aquatic feature need to have a comprehensive water quality study performed.

Horner and Welch (1982) investigated the effects of channel reconstruction of the Pilchuck River on benthic macroinvertebrates and fish. A substrate comparable to the original was redeveloped within 1 year. The fauna was subject to temporal variation unrelated to the construction, but no indications of deterioration in diversity, quantity, or size in the reconstructed channel were observed.

A limnological investigation was carried out by Barton (1977) to document the effects of highway construction on a small stream in southern Ontario. The suspended solids concentrations increased to as high as 1390 mg/L during construction but later returned to pre-construction levels of <5 mg/L. Similarly, sediment deposition increased ten-fold below the construction site during stream rechannelization. No change in water chemistry was detected; however, the standing crop of fish was reduced from 24 to 10 kg/ha immediately below the site. The decrease did not occur further downstream, and the populations at the affected site returned to original levels after construction.

Embler and Fletcher (1983) monitored the turbidity and suspended sediment of a stream above and below a construction site in Columbia, South Carolina, before, during, and after construction. The quality of rainfall also was monitored. Peaks of turbidity and suspended solids concentrations were much greater after construction began. Turbidity never exceeded 25 NTUs (nephelometric turbidity units) during the preconstruction period, but after construction began, turbidity peaks ranged from 50 to 80 NTUs. Suspended solids concentrations remained below 30 mg/L prior to construction. The peak suspended solids concentration varied between 60 and 130 mg/L after construction began.

A 5-year study of the effects of highway construction in the 97-square-kilometer Blockhouse Creek basin was conducted by Hainly (1980). Water discharge, suspended-sediment discharge, and stream temperature were monitored at four stations in the basin. The samples were collected for 1 year before construction, 2 years during construction, and 2 years after construction. The effects of stream relocation and sediment-control methods used in the highway construction also were investigated. During the period of data collection, about 32,300 metric tons of suspended sediment were transported by Blockhouse Creek and Steam Valley Run. The data indicated that 8,300 metric tons were introduced to the stream from construction areas. The normal sediment yield for the two basins was determined to be 28 metric tons per square kilometer per year. Most of the sediment was transported by the streams during high flows and probably passed through

Blockhouse Creek, as little deposition was observed below the construction area. Stream temperature seemed to be relatively unaffected by the stream relocations and diversions.

Helm (1978) studied the effects of highway construction on suspended-sediment loads in the upper reaches of the Schuylkill River basin, Schuylkill County, Pennsylvania, from April 1975 to March 1977. From March 1975 to October 1976, a 6.9-kilometers section of State Route 209 was relocated through the upper reaches of the basin, a mountainous watershed with a drainage area of 69.4 square kilometers. About 14,550 metric tons of suspended-sediment were discharged from the basin during the construction. The highway construction produced about 7,300 tons, or 50 percent of the total sediment discharged. Steep slopes, the availability of fine coal wastes, coal-washing operations, and other land uses in the basin were responsible for most of the remaining sediment discharge.

The impacts of the construction of the four-lane Appalachian Corridor G highway were documented by Downs and Appel (1986). The areas disturbed were about 5 square kilometers in the Coal River basin and 0.9 square kilometers of the 12.2-square-kilometer Trace Fork basin in southern West Virginia. Construction had a negligible effect on runoff and suspended sediment load in the Coal River and its major tributaries, the Little Coal and Big Coal Rivers. Drainage areas of the mainstem sites in the Coal River basin ranged from 689 to 2,207 square kilometers, and average annual suspended-sediment yields ranged from 190 to 218 metric tons per square kilometer for the 1975-81 water years. Suspended-sediment load in the smaller Trace Fork basin was significantly affected by the highway construction. The normal background load at Trace Fork downstream from construction during the period July 1980 to September 1981 was estimated to be 755 metric tons; the measured load was 2168 metric tons. Runoff from the 0.90-square-kilometer area disturbed by highway construction transported approximately 1,410 metric tons of additional sediment. Downs and Appel (1986) also found that suspended sediment loads from the construction zone were higher than normal background loads during storms as well.

Chisholm and Downs (1978) recorded the effects of construction of the Appalachian Corridor G highway on the benthic population of a stream receiving construction runoff. Severe depletion or destruction of the benthic community was observed. However, within 1 year, rapid repopulation and stabilization of the community occurred. Channel relocation, bank recontouring, and reseeding accelerated the recovery of the community.

Eckhardt (1976) studied the effects of highway construction on stream sediment loads in Applemans Run basin, Columbia County, and Pennsylvania from October 1971 to May 1974. About 4,700 metric tons of suspended-sediment were discharged from the basin. Of this amount, about 2,500 metric tons, or about half the total sediment discharge, were derived from the highway construction area. Annual suspended-sediment yields from 44.6 hectares under construction ranged from 14,200 to 23,400 metric tons per square kilometer in the 1972 and 1973 water years, respectively. In the 1972 and 1973 years of active construction, 83 percent of the sediment transported from the construction site was eroded each year by storms from January to June. Seasonal trends in sediment discharge for 1972 show that 69 percent of that year's suspended-load was transported in April, May, and June, whereas less than 1 percent was transported in July, August, and September. Eckhardt (1976) reported that high sediment yields from the construction area continued after the completion of the highway in August 1973, even though seeding and mulching had reduced the erodibility of the steep embankment slopes. Those operations did not fully take effect until the spring of 1974, when a protective cover of crown vetch matured and measured sediment yields from the basin returned to normal.

Reed (1980) collected rainfall, stream flow, sediment, and turbidity data at an area of highway construction near Harrisburg, Pennsylvania. Construction increased suspended-sediment discharges from two to four-fold; however, the rate of sediment discharge quickly returned to preconstruction levels.

The influence of highway construction on a high mountain stream was investigated by Cline et al. (1982). The proportion of fine sediment in the substrate increased at impacted sites, but rapidly returned to levels similar to reference sites following cessation of construction. Algal species diversity and the organic content of the epilithon were reduced at the impacted sites. The macroinvertebrate community was altered by construction activities at some locations but not others, and was generally less severely affected than anticipated. Where alteration occurred, reduction in density, abundance, and diversity were apparent. The potentially adverse impacts were apparently ameliorated by the hydrologic regime and high gradient of the study stream.

Ebert and Filipek (1988) documented the response of fish communities to habitat alteration caused by reconstruction and upgrading of a portion of a state highway in Arkansas. As a result of the construction, portions of Haw Creek, a third-order stream in the Boston Mountains, were straightened and channelized. In reconstructing reaches of the stream, banks were riprapped and vegetated, gabions constructed and positioned, and stream substrates and pool/riffle ratios altered. The channelized reaches became wide and shallow, lacking overstory cover and pools. Substrate particle size changed from boulder/rubble to rubble/gravel/sand, and velocity increased. *Campostoma anomalum*, *Notropis boops*, and *Etheostoma spectabile* accounted for more than 80 percent of all fish captures. This change represented a shift from piscivore- and insectivore/piscivore-dominated to herbivore- and insectivore-dominated feeding regimes. Natural reaches of the channel had more complex fish communities and greater abundance of sunfish and catfish (primarily deeper water groups). Larger biomass developed immediately after channelization (than in the natural reaches) (0.43-0.26 g/m^2). Channeled segments were nearly dry, and biomass decreased dramatically (0.06-0.11 g/m^2) during the following summer. One year after channelization, erosion and scouring had deepened the altered reaches at their headwaters. Fish community composition in altered reaches stabilized to a riffle-type assemblage dominated by the herbivore *Campostoma anomalum*.

The influence of highway construction on the Weber River in northern Utah was evaluated by Barton et al. (1972). Data on invertebrates, fishes, and hydrology were gathered to compare changes caused by highway construction. Eight study reaches were established, four in areas that were not to be changed and four in changed areas. Barton et al. (1972) reported that structures built into changed channels of the Weber River were effective in producing fish habitat that was comparable to, if not better than, the habitat of the unchanged sections. Structures made of large rip-rap material were economical and produced good fish habitat. Invertebrates colonized the new river bottom and produced equivalent numbers and species after 6 months. Fish populations were essentially equal in changed and unchanged areas 2 years after the construction.

Yew and Makowski (1989) discussed an area along the Tennessee-North Carolina border where highway construction contributed to toxic conditions for fish in several streams in the area. Highway excavation exposed a pyritic shale material, which allowed leaching of the sulfides in the form of sulfuric acid. Analysis of the water quality data indicated that a combination of low pH (pH 4.0 to pH 4.4) and alkalinity along with increased toxic metal concentrations, contributed to the toxic conditions at these impacted sites. Temporary control measures included the addition of sodium hydroxide to the acidic streams. More permanent mitigation involved sealing the exposed pyritic material in the road embankments from surface water infiltration with lime and topsoil.

A 20-month study of the effects of the construction of Interstate 10 near Tallahassee, Florida, was conducted by Burton et al. (1976). Construction activities resulted in increases in turbidity, suspended solids, total phosphorus, and dissolved silicon, despite the extensive use of erosion controls. No increased loadings of dissolved phosphorus or nitrogen were observed.

Extence (1978) also documented adverse effects of runoff from road construction on the chemistry, biology, and physical appearance of a receiving stream. Increased solids discharge was identified as the source of the problems. Deposition of sand and silt in the channel reduced the density and diversity of invertebrates in the affected area compared to an upstream monitoring site.

Streams near Richmondville, New York were monitored 2 years prior to construction, during construction, and 2 years after completion of the construction (Besha et al., 1983). Little evidence of construction-related declines in water quality was observed. Rather, peak concentrations were the consequence of high rainfall rather than construction activity. Turbidity reached high levels in one of the creeks, but only infrequently and temporarily. No detectable change in other variables was attributed to construction activity.

Duck (1985) investigated the effects of erosion during construction of a road near Loch Earn in the Scottish Highlands. In a two-month period, 20 times as much sediment passed a temporary gauging station than during an earlier 12-month monitoring period. The mean thickness of the resultant deposit measured in the lake should, under normal circumstances, have taken 20 to 25 years to accumulate.

Finally, it should be noted that many factors may make it impossible to isolate the effects of highway construction (German, 1983). These factors include land-use changes, socioeconomic changes, and natural changes in the plant community of the receiving water. The relative effects of surrounding land use were documented by Helsel (1984). A highway construction site near Columbus, Ohio, contributed between 3,400 and 5,600 metric tons of sediment per square kilometer per year. Surrounding suburban terrain yielded 152 to 268 metric tons per square kilometer per year. However, the area of the construction project was small in comparison to the surrounding suburbs; therefore, no more than 4% of the yearly downstream sediment load was produced by the highway construction.

2.2 Effects of Highway Operation on Stream Water Quality

The type and size of the receiving body, the potential for dispersion, the size of the catchment area, and the biological diversity of the receiving water ecosystem are some of the factors that determine the extent and importance of the effects of highway runoff.

Hydrological effects of highways are highly site specific. The extent of increased storm runoff volumes and peak discharges caused by increased impervious cover depends on the relative sizes of highway right-of-way and total watershed area. Most highway projects are not large enough to create significant downstream flooding. A more likely problem is increased stream bank erosion resulting from the increased peak flows (Dupuis and Kobriger, 1985). Hollis and Ovenden (1988) analyzed the variations in stormwater quantity from roads caused by seasonal effects as well as rainfall characteristics. Methods of predicting the hydrologic effects of highways bridges and encroachments on surface waters were reported by Richardson (1974).

Water quality effects of highway runoff, like hydrological effects, are site specific. Different types of water bodies react differently to the loading of pollutants. The processes controlling the transport and fate of pollutants in lakes and reservoirs differ from those in rivers, streams, and aquifers. Lakes respond to cumulative pollutant loads delivered over an extended period and are usually analyzed on an annual or seasonal basis. Nutrients (nitrogen and phosphorus) are the pollutant types of greatest significance since the most common environmental issue in lakes is over-stimulation of aquatic life. On the other hand, streams respond to individual events since runoff produces a pulse of pollutant that moves downstream and is well removed by the time the next storm occurs. In general, the most common concern in streams is the suppression of aquatic life by the toxic effects of heavy metals (Driscoll et al., 1990). The relative size of the receiving water body determines the amount of dilution of highway runoff and related pollutants. In addition, the type of water body and the designated beneficial use determine the pollutants that will have the most important effects.

Seasonal variations of both lentic and lotic systems can influence the impact of highway runoff (Dupuis and Kobriger, 1985). In lakes, nutrient concentrations vary throughout the year relative to overturn, flushing, and uptake by algae. Water quality in streams and rivers is strongly affected by the amount of rainfall and other climatic factors. The size of a receiving water is also a factor. Lange (1990) theorized that highway runoff is a problem for watercourses with catchment areas less than 5 km^2, but can be discounted for watercourses with catchment areas greater than 20 km^2. The effects of dilution of bridge runoff by the James River were estimated by Zellhoefer (1989).

The potential impacts of various pollutants have been discussed by Dupuis and Kobriger (1985), Dorman et al. (1988), and McKenzie and Irwin (1983). Particulates and sediment in runoff can also cause problems by decreasing flow capacity in drainage ways, reducing storage volume in ponds and lakes, smothering benthic organisms, decreasing water clarity, and interfering with the respiration of small fish. Furthermore, toxic materials often are sorbed to and are transported by suspended solids. These toxics include metals, hydrocarbons, chlorinated pesticides, and PCB's, and they present acute and chronic threats to receiving water organisms.

Ellis et al. (1987) reported that the majority of toxic materials entering surface runoff are inert, occurring in association with inorganic particles or rubber, bitumen, and other organics found on road surfaces. Once this material is entrained during a storm event and removed from the surface, considerable phase transformations can occur that affect pollutant form and strength. Morrison et al. (1988, 1990) reported that bacterial activity and acid dissolution produce increases in dissolved metal in the storm sewer system. The resulting stormwater contains dissolved ionic forms of cadmium (Cd) and Zinc (Zn), which are toxic.

Researchers generally agree that nutrients (various forms of nitrogen and phosphorus) are a concern because of the long-term potential for eutrophication and the short term problem of "shock-loading." Oxygen-demanding materials (measured by chemical oxygen demand [COD] or 5-day biochemical oxygen demand [BOD_5]) can be relatively high in concentration, although the organics usually are associated with particulate material, which may settle rapidly before the demand can be exerted. Furthermore, dissolved oxygen depletion can be compensated by stream reaeration during stormflow periods.

Relatively high levels of pathogenic bacteria of non-human origin can be detected in runoff from highways, that routinely are used to haul livestock and/or are subjected to large amounts of bird droppings.

2.2.1 Biological Effects and Toxicity Testing

Bioassays using environmental samples often are preferred, since full scale biological surveys to determine the effects of highway runoff are often difficult and costly. In addition, bioassays integrate the effects of all toxics contained in a sample and can indicate toxicity even if the concentrations of priority organic pollutants do not exceed EPA criteria levels (Peterson et al., 1985).

Dupuis et al. (1985) reported that runoff from highways with various traffic densities (12,000 to 120,000 vehicles daily) had little effect on the biota of receiving waters. The results of flow-through in situ bioassay studies at a lake site did not indicate an impact on six species of invertebrates. Bioassay testing included sampling for benthic macroinvertebrates and macrophytes. The data show that highway runoff had little or no influence on cattails.

Acute toxicity tests on heterotrophic organisms (bacteria, fungi, protozoa), algae, fish, and fish eggs using runoff from a period of snow melt did show negative effects on growth or behavior (Gjessing et al., 1984). Heterotrophic organisms were stimulated by the runoff at the maximum concentrations tested (90%), and neither the fish eggs or one-year-old salmon appeared to be affected by undiluted runoff water. Potential chronic effects and the bioaccumulation potential were not evaluated in this study.

Five 12-day bioassays were conducted by Kszos et al. (1990) to evaluate the toxicity of runoff from a bridge to young-of-the-year bluegill sunfish. One bioassay used fall runoff, two used winter runoff, and one used spring runoff. Survival of the sunfish exposed to 1%, 10%, and 25% concentrations of spring runoff were similar to survival rates in lake water. Fish exposed to the 25% concentration of fall bridge runoff and to the 50% concentrations of fall and spring runoff had significantly greater survival than the respective controls. The sunfish exposed to 50% winter runoff had significantly lower survival than controls, but fish in the 1%, 10%, and 25% winter runoff did not. The concentration of salt in the winter runoff was high enough to account for most of the observed toxicity.

The effects of runoff from highway surfaces and cut slopes on the primary productivity of algae were studied by Winters and Gidley (1980). The response of indigenous algae to various levels of runoff with a 5-day bioassay using the carbon-14 method was measured. Runoff could be either stimulatory to algal growth or, in cases where the runoff came from heavily used highways, mildly to severely inhibitory. The nutrient load in runoff was generally stimulatory, but the concentration of metals dictated the final bioassay results.

Portele et al. (1982) found that the growth rate of the algae *Selenastrun capricornutum* was reduced as the ratio of highway runoff to dilution water increased. Stormwater enriched with nutrients to levels that were equivalent to controls consistently demonstrated greater than 85% inhibition of maximum algal biomass. Rainbow trout exposed to filtered stormwater showed no harmful effects in a four-day exposure. Bioassays conducted with unfiltered samples resulted in significant mortalities in both 50% and 100% dilutions. The clear implication was that either the particulates present in the runoff or the pollutants associated with the solids were responsible for the deaths. The suspended solids concentrations observed were lower than those normally considered harmful to fish, but this study incorporated fish at life stages earlier than those used in other studies. Portele et al. (1982) also documented significant differences in the toxicity of the runoff from two similar highway sites in Seattle.

Yousef et al. (1985) demonstrated that hardness, alkalinity, and organic complexes reduced the toxicity of cadmium, lead, zinc, and copper in natural water. They compared the toxicity of copper to mosquito fish (*Gambusio affinis*) in water from a retention pond receiving highway runoff to the toxicity of copper in deionized tap water. The concentration resulting in 50% mortality with pond water was about 50 times higher than with tap water.

The effect of rural highway runoff on the abundance and composition of benthic macroinvertebrates was studied by Smith and Kaster (1983). The numbers and biomass of organisms were higher at a site receiving highway runoff than at the control site. Annual mean numbers and biomass at another station receiving intermediate amounts of highway runoff were similar to the control. Their study suggested that runoff from roadways with light traffic density (7000-8000 vehicles per day) had only a minimal effect on macroinvertebrate populations.

Stream sediments store heavy metals and are the primary source for the bioconcentration of metals (Van Hassel et al., 1980). Concentrations of lead, zinc, nickel, and cadmium in the water columns of streams near highways with low to moderate traffic volumes (around 15,000 vehicles per day) were comparable to concentrations in uncontaminated waters. However, the dry-weight concentrations of metals in benthic insects and fish were comparable to values reported in the literature for animals from contaminated waters. This observation suggests that accumulation of metals in bed sediments is important in the bioaccumulation of metals.

The effects of highway runoff on the ecology of stream algae were documented by Dussart (1984). The number of algae, algal abundance, species diversity, and the relative abundance of filamentous organisms increased downstream of the highway. These effects were apparently the result of highway runoff acting as a source of nutrients in an upland, nutrient-poor area.

The effects of the control of vegetation using herbicides were investigated by Kramme and Brosnan (1985). Two sites were monitored in the herbicide study; one was treated with 2,4-D and the other with picloram. Post-treatment concentrations of these chemicals in runoff were below those estimated to impact aquatic life. No significant effects on the growth of hypocotyl were detected in bioassays of the runoff.

Kramme and Brosnan (1985) also investigated the effects of surface treatment (seal coating) on runoff quality. An asphalt roadway located in a rural area was treated with an asphalt emulsion and limestone gravel. Three runoff samples were collected following treatment and analyzed for polycyclic aromatic hydrocarbons (PAH). No PAHs were measured in the runoff at a detection limit of 3 µg/L, and the samples were relatively nontoxic as demonstrated by the low mortality of *Daphnia magna* in static bioassays.

Metal loadings to receiving waters are of particular concern because of the potential toxicity and relative abundance of metals in highway runoff. Dupuis et al. (1985) studied several highways with a wide range of traffic densities (between 12,000 and 120,000 vehicles per day). Lead was the only constituent in the water column even slightly affected by runoff, with a maximum concentration in excess of 0.20 mg/L reported at two of the three influenced stations; concentrations of lead at the control stations never exceeded 0.05 mg/L. Metal concentrations in the sediments showed little difference between the control and influenced stations.

Solids, pH, sulfate, turbidity, total organic carbon (TOC), oil and grease, COD, nutrients, sodium, chloride, alkalinity, specific conductivity, calcium, indicator bacteria, and total Kjedahl nitrogen (TKN) concentrations also were measured in the sediments. At only one of the sites were TKN concentrations higher for the stations influenced by highway runoff. During the August survey, concentrations at the control station were always below 1500 mg/kg dry weight, while concentrations at the stations influenced by runoff were almost always above 2000 mg/kg and ranged as high as 4000 mg/kg (Dupuis et al., 1985).

Harned (1988) described the effects of highway runoff on stream flow and water quality in a rural area of North Carolina. Stream flow in basins traversed by a highway rose and fell more rapidly during storm runoff than in undeveloped basins. The runoff had little or no effect on suspended sediment, water temperature, dissolved oxygen, and pH. The highway runoff also did not consistently increase heavy metal concentrations.

The toxic effects of metals in highway runoff can be greatly reduced by natural processes within the receiving water. Yousef et al. (1985) described the complexation of ionic species to reduce incoming trace metals. Lead often exists as $PbCO_3$, and much of the copper is associated with organic complexes. Most of the metal species in runoff eventually reside in the top few centimeters of the sediment and are unlikely to be released to the water column under aerobic conditions.

The accumulation of heavy metals in the sediment of roadside streams was investigated by Mudre and Ney (1986). Metals concentrations at several sites receiving highway runoff were two to five times higher than at upstream sites. However, this pattern was not observed at three of the six streams monitored. The interstream variation was more strongly related to distance of the stream from the road surface, stream velocity, and organic content of the sediment than to traffic volume. Precipitation volume was found to affect the upstream/downstream ratio.

2.3 Summary

The results of many studies have documented the effects of highway construction on the quality of surface waters. In general, changes in water quality are the result of an increase in suspended sediments discharged from construction sites. The higher suspended solids levels result in reduced diversity and density of fauna in the affected area. These changes are usually temporary, and conditions eventually return to pre-construction levels. There is little evidence that normal construction activities contribute significant amounts of oil and grease, metals, or other toxic materials.

Highway runoff generally does not result in acute toxicity in bioassay tests of organisms from streams and lakes receiving runoff, although site-specific conditions may produce a toxic response. Little is known about the chronic toxicity that might result from bioaccumulation of metals or other toxic materials. Nutrient levels in highway runoff appear to be generally higher than in runoff from undeveloped land and may cause an increase in the growth of algae and other vegetation.

3. DESCRIPTION OF THE STUDY AREA

The Danz Creek watershed lies in the southwestern portion of Travis County, Texas. This creek is a first-order ephemeral stream and is a tributary of Slaughter Creek. Slaughter Creek in turn contributes flow to Onion Creek, which joins the Colorado River southeast of Austin. Figure 3.1 shows a portion of the Signal Hill USGS quadrangle topographic map that illustrates the approximate location of Danz Creek in relation to State Highway 45 (the Outer Loop) between Loop 1 and FM 1826.

A number of potential sampling locations on Danz Creek were identified early in the project. The paired locations, labeled on Figure 3.1 as "D1N/D1S," "D2N/D2S," "D3N/D3S," "D4E/D4W," "D5E/D5W," and "D6N/D6S," were selected to represent conditions upstream and downstream of a section of the TxDOT construction project. The impact of highway construction may be assessed if water quality and quantity are measured at any of the paired locations.

The watershed consists of approximately 256 hectares (ha) underlain by the Glen Rose Limestone above location D2N. In this reach, the creek receives baseflow from perched water tables in the Glen Rose. Land uses above the highway crossing include low-density residential, ranching/undeveloped, and a golf course. Below D2N, the creek lies on the outcrop of the Edwards Limestone, and the creek loses water to the aquifer below. A large pond below D2N captures all of the runoff except from the largest events. Many sections of the creek remain dry even after fairly intense storm events because of the pond and flow losses in the creek bed. Flow rarely occurs at the downstream road crossings. Therefore, the locations "D2N" and "D2S" shown on Figure 3.1 were selected as the best available sites for permanent water quality sampling sites. These locations will be referred to as the upstream and downstream monitoring locations, respectively, in the remainder of this report.

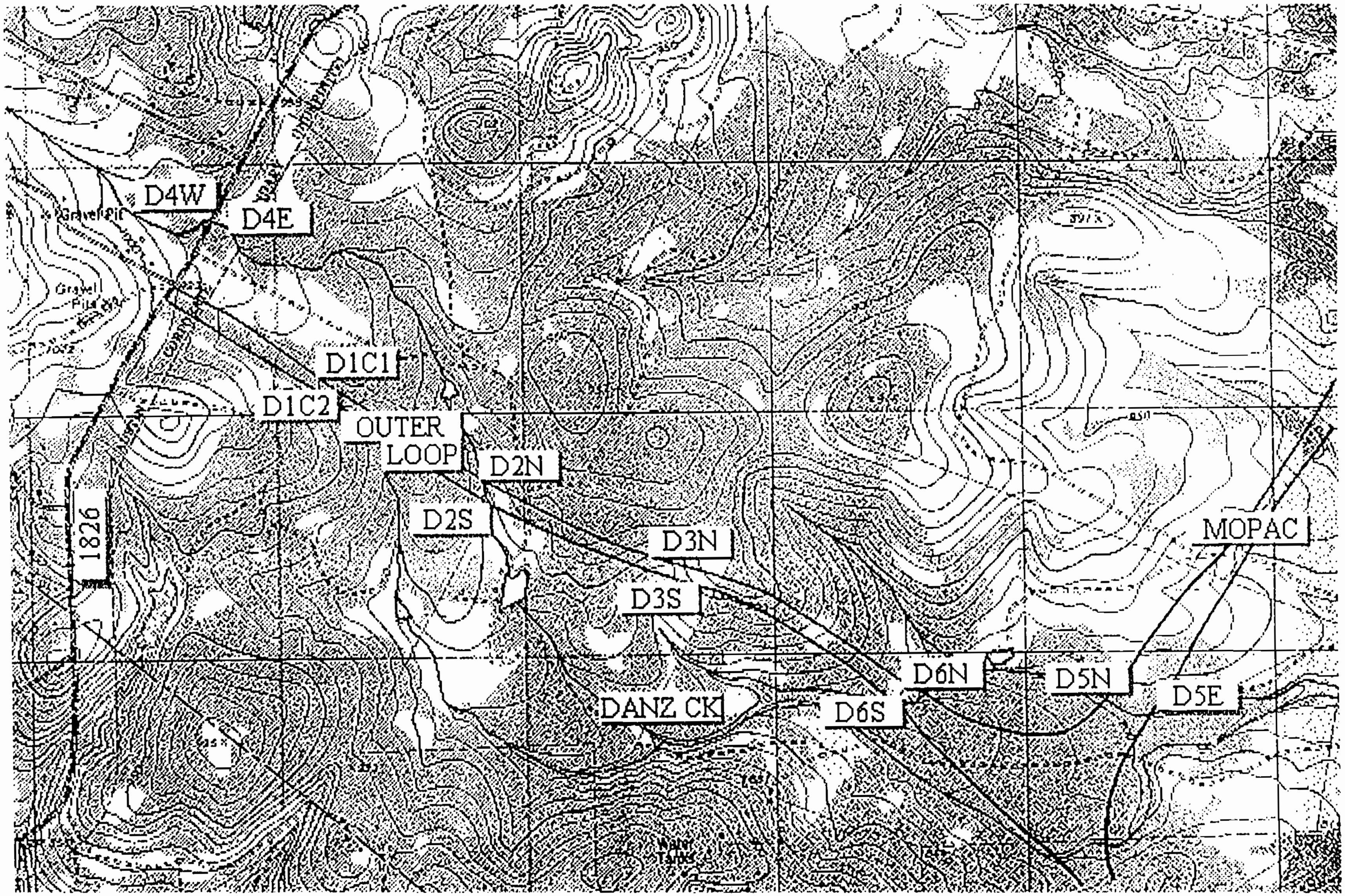

Figure 3.1 Location of Study Area

An elaborate system of silt fences and rock berms was used to reduce suspended solids loads in the vicinity of Danz Creek during the construction phase of the highway. Silt fences were the most prevalent control, providing a continuous barrier along both sides of the creek as the stream passed through the construction corridor. The rock berms were used to slow the concentrated flows in the swales bordering the right-of-way. Weekly inspections of these controls were conducted by the contractor and staff from TxDOT, the Barton Springs/Edwards Aquifer Conservation District, and the Texas Natural Resources Conservation Commission. This practice was effective in ensuring that all the controls were installed properly and operated at maximum effectiveness.

After completion of the highway, the creek received direct runoff from the unpaved portions of the shoulders and median areas, as well as some runoff from undeveloped areas along the highway right-of-way. Runoff from the paved portions is collected in a storm sewer system and routed to two permanent stormwater control systems. The control systems consist of a 38 m^3 hazardous material trap (HMT), a sedimentation basin designed to capture the first 13 mm of runoff, and a vertical sand filter. The hazardous material trap is designed to capture accidental spills of materials such as petroleum products or pesticides. The sedimentation basin creates a pond where the heavier solids and attached pollutants can settle to the bottom for later removal. The filter, which is constructed as part of the wall of the basin, should remove the smaller particles that remain in the runoff. The configuration of the filter was altered numerous times during the course of the monitoring program. The performance and configuration of the systems are described more fully in CRWR Technical Report # 265.

A schematic drawing of the highway crossing is presented in Figure 3.2. The relative positions of the upstream and downstream monitoring sites labeled "CN" and "C," and the two runoff control systems labeled "HMT M" and "HMT N," are shown.

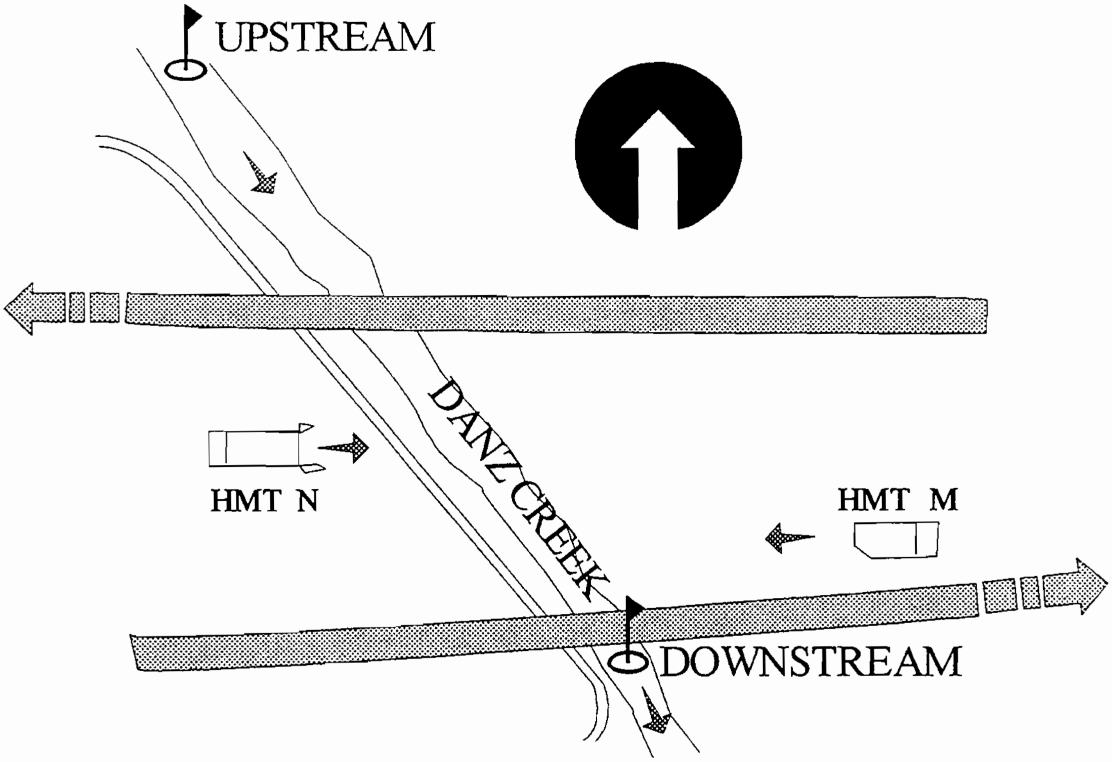

Figure 3.2 Relationship of Monitored Sites to Highway Runoff Controls

4. METHODS

A two-phase sampling program was undertaken at the highway crossing of Danz Creek. The initial phase consisted of paired grab samples collected above and below the highway crossing. The second phase occurred after the installation of a permanent control section in the creek bed below the crossing, which allowed accurate measurement of flow and collection of flow-weighted composite samples. Samples were analyzed for the set of constituents listed in Table 4.1. These parameters were chosen to provide a general indication of water quality in the creeks receiving highway runoff.

Table 4.1 Constituents Monitored at Danz Creek

Constituent	Method (*APHA et al., 1992)
Total Coliform	Membrane Filtration (9222 B)
Fecal Coliform	Membrane Filtration (9222 D)
Fecal Strep	Membrane Filtration (9230 C)
Total Suspended Solids (TSS)	TSS Dried at 103 Degrees C (2540 D)
Volatile Suspended Solids (VSS)	Solids Ignited at 500 Degrees C (2540 E)
Turbidity	Nephelometric (2130 B)
Biochemical Oxygen Demand (BOD_5)	5-Day BOD (5210 B)
Chemical Oxygen Demand (COD)	Closed Reflux Colorimetric (5220 C)
Total Organic Carbon	Combustion-Infrared (5310 B)
Total Dissolved Carbon	Combustion-Infrared (5310 B)
Nitrate (NO_3-N)	Selective Electrode (4500-NO3-D)
Total Phosphorus (TP)	Colorimetric (4500-P C)
Oil and Grease (O&G)	Partition Infrared (5520 C)
Cadmium (Cd)	Inductively Coupled Plasma (3120 B)
Chromium (Cr)	Inductively Coupled Plasma (3120 B)
Copper (Cu)	Inductively Coupled Plasma (3120 B)
Iron (Fe)	Inductively Coupled Plasma (3120 B)
Lead (Pb)	Inductively Coupled Plasma (3120 B)
Nickel (Ni)	Inductively Coupled Plasma (3120 B)
Zinc (Zn)	Inductively Coupled Plasma (3120 B)

* American Public Health Association.

4.1 Grab Samples

Paired grab samples were collected at the highway crossing of Danz Creek during and immediately after storm events to begin the monitoring process during the highway construction phase. The ability to collect samples at the beginning and during periods of peak flow was limited by the distance to the sampling site and inadequate information about current conditions in the creek. Numerous trips were made to the site for rainfall events that turned out to be too light to generate runoff. Most samples collected during this period were collected some hours after the peak flow had occurred and are probably not representative of conditions that would be encountered during the periods of highest flow. This phenomenon is especially true for suspended solids concentrations, which are highly dependent on flow rates.

4.2 Flow-Controlled Sampling

Construction of flow measuring stations upstream and downstream of the highway was considered. However, the upstream cross-section of the creek is very flat, making construction of a control section prohibitively expensive. Below the highway, the creek bed is better defined and a flat-V weir was selected for measuring flow. This design was chosen on the basis of cost, wide range of flow measurement, and maintenance considerations. Cross-sections of the upstream and downstream sites are shown in Figure 4.1 and Figure 4.2, respectively.

Choosing the appropriate size control was difficult since no measurements had ever been made of flow rates in this section. A small pond located about 200 m upstream of the highway crossing also affected expected flow rates, and the runoff coefficient of the watershed was unknown and probably very dependent on antecedent moisture conditions. The creek is normally dry except during periods of direct runoff and during extended wet conditions. Visits to the site during the wet winter months indicated that base flow was less than 10 L/s, so the structure would need to be capable of measuring very low flows.

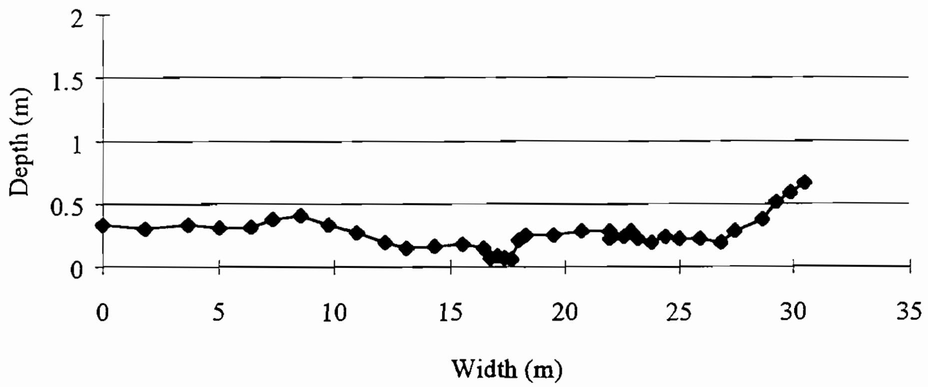

Figure 4.1 Cross-Section of Upstream Monitoring Site

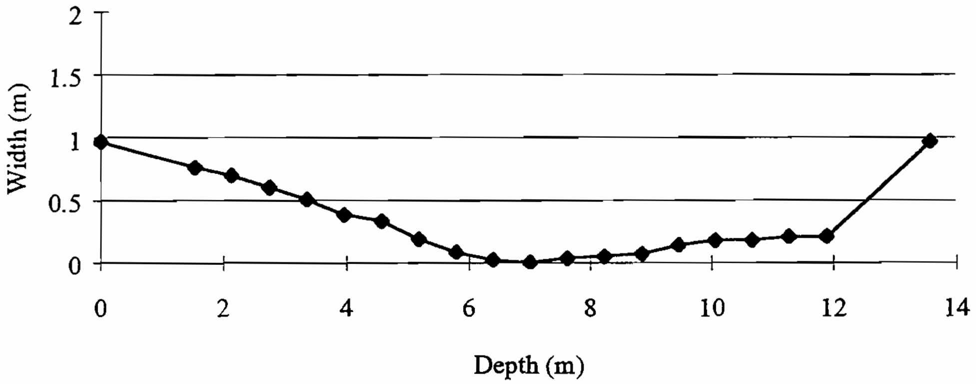

Figure 4.2 Cross-Section of Downstream Monitoring Site

The maximum expected flow rate was calculated based upon the area of the watershed area and 2-year rainfall data for Austin. The first step in calculating flow rate was to determine the time of concentration (tc), according to the metric form of the Kirpich formula:

$$tc = 0.0196(L^{0.77})(S^{-0.385})$$

where:

- L is the length of the channel from headwater to outlet (m), and
- S is the average watershed slope (m/m)

Using the USGS topographic map, the length and slope were estimated to be 3352 m and 0.0082 m/m, respectively. These data result in a tc value of 1 hour. The maximum 1 hour, 2-year rainfall in the Austin area is 5 cm.

The metric form of the rational formula is as follows:

$$Q = 0.28ciA$$

where:

- Q (L/s) is the expected flow rate
- c is the estimated runoff coefficient;
- i is the rainfall intensity for the tc, determined to be 5 cm per hour; and
- A is the watershed area, determined to be 256 ha.

The contributing watershed to the upper station is estimated to have approximately 5% impervious cover. According to published watershed studies (City of Austin, 1990) the average annual runoff coefficient for an Austin area watershed with about 5% impervious cover is 0.07, leading to a peak flow rate of 2,500 L/s.

A flat-V weir has the ability to measure a very wide range of flows; however, no simple installation could accommodate the expected range. Therefore, the structure was designed so that all of the small flows as well as most runoff events could be measured. Accurate stream flow could be measured in a range of about 3 to 1300 L/s with the installed weir.

A rating curve was developed for the upstream monitoring station based on data from the control section downstream of the road. During periods of continuous flow in the creek when there was no contribution from the intervening area, the flow at the weir was downstream of the road used to create a rating curve for the upstream station.

However, practical problems were encountered in applying this method. The channel upstream of the highway was broad and shallow; therefore, very small changes in the channel geometry could introduce large errors in the rating curve. Accumulation of debris in the channel during runoff events, as well as seasonal changes in the channel vegetation, reduced the accuracy of the upstream flow rates. A picture of the channel at the upstream monitoring site is presented in Figure 4.3.

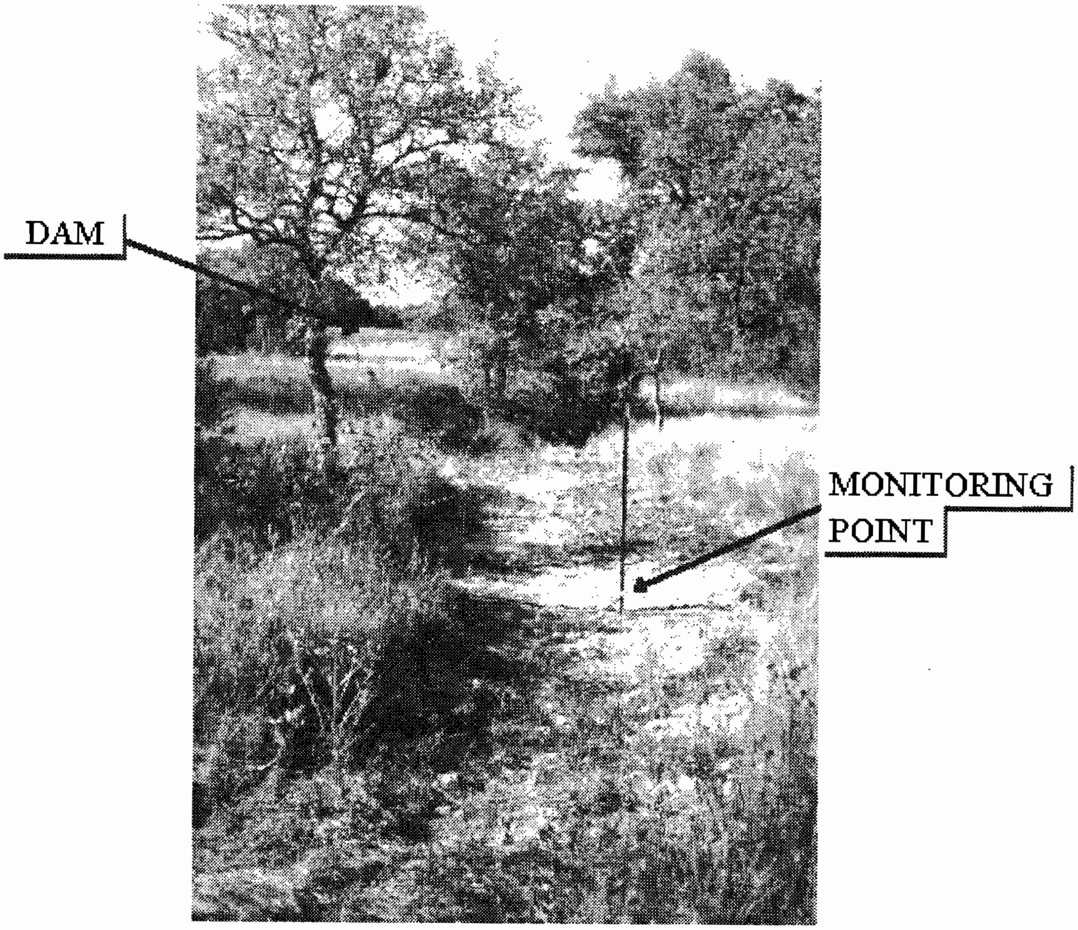

Figure 4.3 Danz Creek at Monitoring Site Above Highway Crossing

The two monitoring sites were instrumented with equipment to record and measure flow (ISCO bubbler flow meter 3230) and rainfall (ISCO 674). An automatic water quality sampler (ISCO 3700) was installed at each site as well. The sampler downstream of the road contained a single 9.7 L plastic bottle for collecting a single flow-weighted composite sample. The sampler above the road was configured with 24 glass jars (350 mL). It was programmed to take four samples of six jars each to provide a sufficient volume of sample to allow all analyses to be performed. Samples were taken at predetermined time intervals before a rating curve was developed for this site. Then four samples were taken based on equal volumes of flow following development of a rating curve. Each sampler was initiated when an increase in water level in the creek occurred. A picture of the downstream weir and sampling site is shown in Figure 4.4.

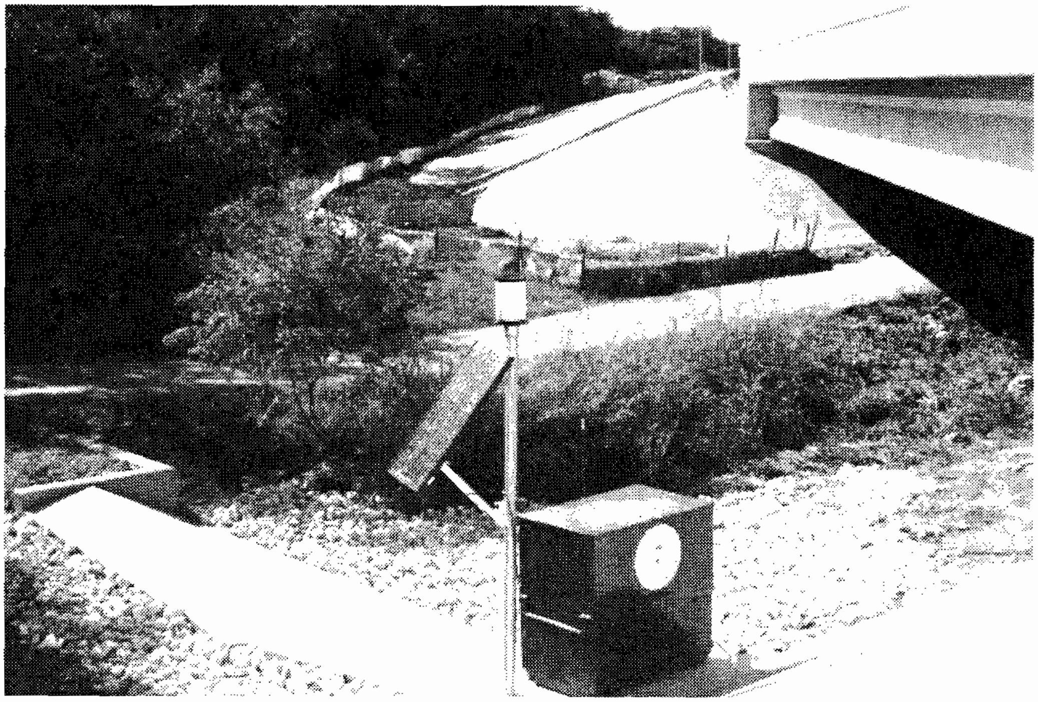

Figure 4.4 Downstream Monitoring Station Installation

5. RESULTS

5.1 Water Quality Effects of Highway Construction

A total of 14 samples from 10 storms were collected at each of two monitoring sites at Danz Creek. Nine of the storms were sampled at both locations and one storm at each site was not sampled at the other location. These samples were collected during the period from 11 June 1992 through 10 October 1993, coincident with the construction of the new highway.

A summary of the data collected at the two sites is contained in Table 5.1, and a complete list in presented in Appendix A. There was a large range of concentrations for many of the parameters measured in this study. The limited number of data points and the large range indicate that the median concentration tends to give a better estimate of the central tendency of the population than does the mean, which is highly influenced by a few large values. Consequently, the percentage increase from upstream to downstream is calculated on the basis of the median value. The greatest differences between upstream and downstream concentrations are shown by suspended solids, turbidity, iron, and zinc. Relatively small differences in the concentrations of the other constituents were observed between the two sites.

Events were not sampled during the peak of the runoff hydrograph because of logistical problems. Therefore, it is likely that the concentrations of solids below the construction site were at times significantly greater than the measured value of any of the grab samples. The suspended solids (TSS) concentration in the first automatic sample collected at this site reinforces this notion. This sample was a discrete sample of the initial runoff from the construction site and had a TSS concentration of 1556 mg/L, more than twice that of any grab sample analyzed. The turbidity of the creek increased more than did the concentration of TSS. The larger increase can be attributed to the relative ineffectiveness of silt fences in reducing turbidity.

Table 5.1 Effects of Highway Construction on Danz Creek

Parameter	Upstream Conc. (mg/L) Mean	Upstream Conc. (mg/L) Median	Downstream Conc. (mg/L) Mean	Downstream Conc. (mg/L) Median	Increase (%)
Total Coliform (CFU)	2853	1875	2385	2050	9
Fecal Coliform (CFU)	2533	1825	10225	1750	-4
Fecal Strep (CFU)	6078	3900	4234	4200	8
TSS	34.8	13.9	179	79	470
VSS	4.8	2.1	20	4	88
Turbidity (NTU)	28	6	112	72	1100
BOD_5	2.8	2.7	3.2	2.2	-19
COD	16.3	11.2	14.8	13.3	18
Tot. Organic Carbon	22.9	19.1	22.1	18.4	-4
NO_3-N	0.78	0.48	0.67	0.65	35
Oil and Grease	ND	ND	ND	ND	NA
Cadmium	<0.009	0.004	<0.007	0.004	0
Chromium	<0.012	0.007	<0.019	0.007	0
Copper	<0.043	0.041	<0.048	0.046	11
Iron	0.699	0.358	2.697	2.489	595
Lead	<0.154	0.042	<0.126	0.042	0
Nickel	ND	ND	ND	ND	NA
Zinc	<0.029	0.023	<0.048	0.043	85

The increase in the concentrations of suspended solids below an active construction site was expected; however, the relative increase in iron compared to other metals was surprising. The iron concentration apparently is related to the concentration of suspended solids. The concentration of TSS in stormwater runoff above the highway explains 94% of the variance in iron concentration at that location. The correlation below the highway was lower, but still significant at about 40%. The next largest increase in concentration of the metals was for zinc; however, no particular source was identified.

Although accumulation of sediment in the creek bed occurred during this period, by the end of the study period (May 1995) the creek below the highway had returned to preconstruction conditions. Establishment of vegetation on the right-of-way reduced the sediment input to the creek, and subsequent storms dispersed the sediment deposits.

5.2 Water Quantity and Quality Effects of Highway Operation

The weir and two automatic samplers were installed in October 1993 and were active from that time until June 1995. October 1993 also marked the opening of the new road. Consequently, the sampling program was able to establish the hydrologic effects of a new operating highway. Stormwater control systems constructed to treat runoff from the impervious surfaces were not in operation during the period from October 1993 through April 1994. No flow was observed at the upstream monitoring site during the same time period; therefore, water quality at the downstream site was representative of the runoff from the paved portion of the right-of-way.

5.2.1 Water Quantity Effects

Daily records of flow and rainfall were recorded for the two sites on Danz Creek during the time the automatic samplers were in place. A detailed list of these measurements is included in the Appendix.

The period from July 1993 to July 1994 was unusually dry. The rainfall in the area was only about one-half of the normal rainfall. No flow was recorded in Danz Creek above the highway crossing from the time the weir was installed (October 1993) until May 1994, even though the largest storm produced 60.2 mm of rainfall. The lack of flow was the result of the high level of pervious cover above the road, low soil moisture, and a small storage pond on the golf course upstream of the highway that captured any runoff generated.

Measurable rainfall occurred on 49 days between October 1993 and May 1994, generating runoff below the highway right-of-way on 18 occasions. The storm hydrographs below the highway are typical of those produced by areas with high impervious cover. The rising limb is extremely steep and the runoff duration is not much longer than the rainfall event that produced the runoff. The stormwater runoff control systems were not operational at this time; therefore, runoff from the paved surfaces was discharged directly to the creek. A typical hydrograph from this period is shown in Figure 5.1.

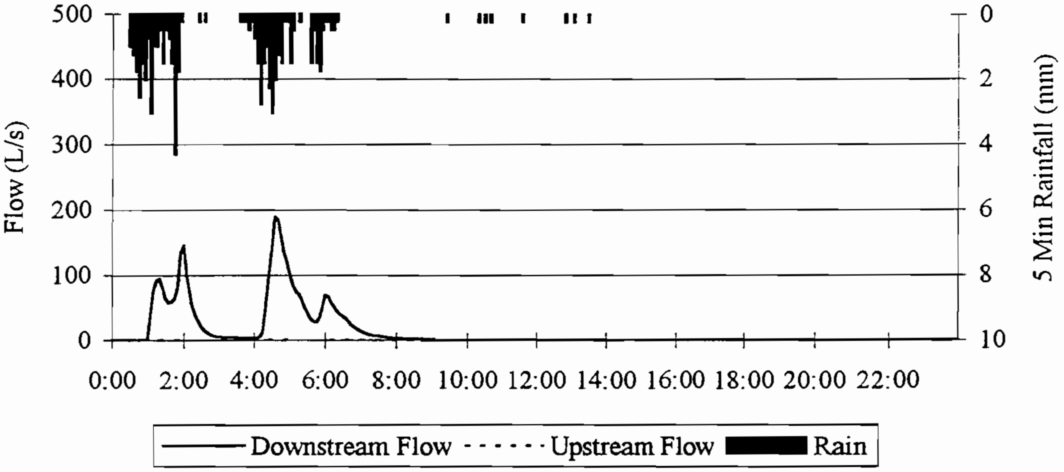

Figure 5.1 Danz Creek Hydrograph 10/20/93

The runoff control systems were completed in late April 1994. The vertical sand filters became clogged during the first storm so that the detention pond never drained. Runoff from subsequent storms bypassed the detention pond, resulting in runoff discharging directly into the creek. Therefore, the water quality impact on the creek was the same as if no controls were in place. The runoff controls on this segment of SH 45 finally became fully operational in October 1994 when the sand in the filter was replaced with gravel. This attenuated the flows from the highway pavement and created a delay between the start of rainfall and the start of runoff.

Runoff at this location on Danz Creek was characterized by abrupt changes in flow rate even before road construction because of the pond on the golf course located upstream of the highway crossing. Capacity was nearly always available in the golf course pond at the start of each runoff event because of evaporation and seepage. Consequently, the initial slow runoff from the upstream catchment would accumulate in the pond until the water level reached the height of the spillway. At that time, the flow in the upstream channel would be transmitted directly through to the creek bed below the pond. The combined hydrologic effects of the runoff from the road and the pond can be clearly seen in Figure 5.2.

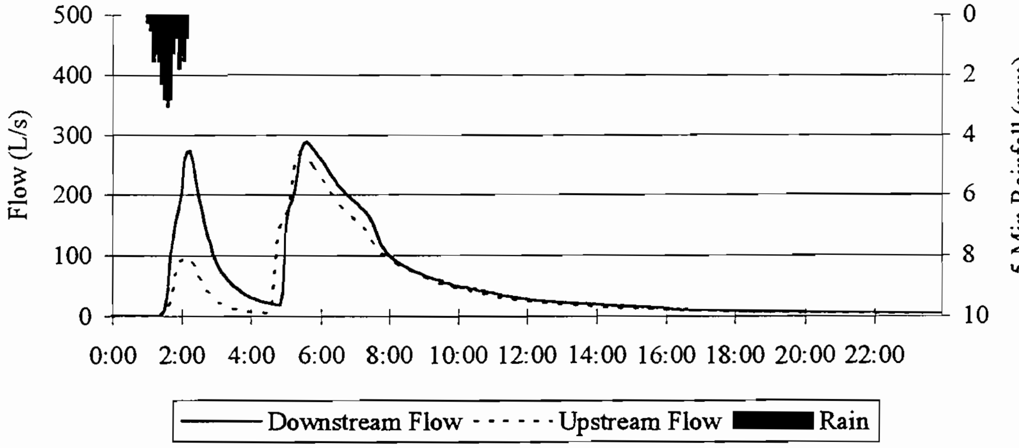

Figure 5.2 Danz Creek Hydrograph 11/5/94

Rainfall occurring between 1:00 AM and 2:00 AM produced immediate runoff from the highway right-of-way and the intervening area between the pond on the golf course and the upstream monitoring station. Most of the flow during the early part of the runoff event was contributed by the highway. Flow quickly peaked and began to recede. The flow continued to decrease until about 4:30 AM when the water in the golf course pond upstream of the road topped the spillway, resulting in another rapid increase in flow rate and a longer recession.

The hydrologic effects of the new highway are similar to those normally associated with an increase in impervious cover. Runoff from the paved portions of the highway resulted in higher flow rates and larger discharge volumes than in an undeveloped area of the same size. Collecting the runoff in a storm water collection system reduced the time of concentration and increased the flow rate of Danz Creek. The storm sewer system also resulted in less infiltration than would have occurred in a grassy swale, causing a greater volume of runoff to reach the creek and runoff control system. The advantage of the storm sewer system is the direct transport of accidental spills of hydrocarbons or other toxic chemicals during dry weather into the hazardous material traps.

5.2.2 Water Quality Effects

Water quality samples were collected during 34 runoff events after the opening of the new highway. Fourteen of these events were sampled both above and below the highway right-of-way. The other events were sampled only below the road because no flow was measured upstream. The samples were collected between 13 October 1993 and 8 May 1995. A list of all samples collected and the event mean concentrations for the upstream and downstream sites is contained in the Appendix. Hydrographs for each of the sampled events showing when sampling occurred also are included in the Appendix.

A comparison of the water quality during rain storms monitored at the upstream and downstream sites is shown in Table 5.2. The percent change in concentrations is based on the median value for each parameter. Only suspended solids (TSS), oil and grease, and zinc showed significant increases due to highway runoff. With the exception of iron, concentrations of other metals were often near or below the detection limit, and differences between upstream and downstream concentrations are within the measurement error of the instrumentation. Parameters showing marked reductions include bacteria, oxygen demand, carbon, and nutrients (nitrate and phosphorus).

The increase in the concentrations of suspended solids (TSS), oil and grease, and zinc was expected. These constituents have been identified at elevated concentrations in many studies of highway runoff quality. The downstream concentration of TSS was approximately twice as high upstream; however, increases in the concentrations of volatile solids (VSS) and turbidity were smaller. The median oil and grease concentration in the creek below the highway increased to 1.3 mg/L from 0.8 mg/L. The constituent with the largest increase in concentration was zinc, showing a three-fold increase to 0.020 mg/L, but this concentration still is well below the chronic criteria for aquatic life protection of 0.230 mg/L in water typical of this area (Texas Water Commission, 1991).

Somewhat surprising is the number of parameters showing a reduction in concentration. This reduction was caused by the dilution of the creek water with highway runoff, which contained lower concentrations of these constituents. The differences in

Table 5.2 Effect of Highway Operation on Danz Creek

	Upstream Concentration (mg/L)		Downstream Concentration (mg/L)		Increase
Parameter	**Mean**	**Median**	**Mean**	**Median**	**%**
Total Coliform (CFU)	25727	27805	16343	12000	-57
Fecal Coliform (CFU)	12380	12380	8650	2000	-84
Fecal Streptococcus (CFU)	35192	36000	23779	20500	-43
TSS	64	36	109	70	93
VSS	12	5	14	8	47
Turbidity (NTU)	25	20	34	29	43
BOD_5	5.6	6.0	4.3	4.0	-33
COD	45	41	30	26	-37
Total Carbon	45	46	34	26	-44
Dissolved Total Carbon	43	43	27	21	-52
NO_3-N	0.30	0.28	0.17	0.11	-60
Total Phosphorus	0.36	0.26	0.12	0.13	-50
Oil and Grease	0.8	0.8	1.2	1.3	62
Cadmium	<0.001	0.001	<0.002	0.001	0
Chromium	<0.005	0.003	<0.009	0.002	-13
Copper	<0.005	0.002	<0.003	0.002	-14
Iron	1.756	1.184	2.634	1.365	15
Lead	<0.024	0.014	<0.049	0.014	0
Nickel	<0.007	0.005	<0.006	0.005	0
Zinc	<0.009	0.006	<0.024	0.020	235

the water quality of the highway runoff and creek can be explained by the type of land uses above the highway right-of-way. Higher bacteria counts in the creek compared to the highway runoff are likely the result of ranching activities in the watershed above the highway right-of-way. In addition, bacteria often are present in soil and could survive in the pond on the golf course above the right-of-way. Nutrients (nitrate and phosphorus) in the creek above the road were also higher. The source of the nutrients most likely is fertilizer used on the golf course. Runoff from the golf course drains to Danz Creek. The concentration of carbon and organic materials also was higher in the creek water. These substances also may have been derived from the pond upstream of the highway right-of-way or from the undeveloped land in the watershed.

6. SUMMARY AND CONCLUSIONS

6.1 Construction Effects

Grab samples collected during the construction of a freeway in southwestern Travis County, Texas, indicate that suspended solids are the most important constituent present in storm water runoff from the construction corridor. Despite the presence of an extensive system of temporary controls (primarily silt fences), the concentration of suspended solids in Danz Creek increased at least five-fold during and immediately after storm events. Other solids-related parameters such as turbidity and iron also increased.

The increase in suspended solids concentration is consistent with the results of the temporary control monitoring performed as part of this overall study and described by Barrett et al. (1995). That study reported a median concentration of suspended solids below silt fences systems of about 500 mg/L. Dilution of the construction runoff with water from upstream could account easily for the median observed concentration downstream of the highway right-of-way of approximately 180 mg/L.

Despite the high concentrations of suspended solids, no permanent change in the channel resulting from runoff during construction was obvious. The effects of construction on Danz Creek were temporary, and similar to that reported in the literature for other rivers and streams. Of particular concern in this area are the effects of construction on the water quality in the Edwards. Approximately 85% of the recharge into the Barton Springs portion of the Edwards occurs in the beds of the creeks that cross the recharge zone (Slade et al., 1986). The portion of Danz Creek affected by this construction project lies on the recharge zone; therefore, higher concentrations of suspended solids could be expected to enter the aquifer during the period when runoff from the construction site occurred. Estimating the effect of higher sediment loads on water quality and storage in the aquifer was beyond the scope of this study.

6.2 Highway Operation Effects

The volume of water derived from a given highway crossing will be relatively small and changes in water quality will probably not be measurable for bodies of water with large catchments. Monitoring of a small ephemeral stream near Austin, Texas, allowed documentation of changes in water quality and quantity resulting from highway runoff. In this case, storm water runoff from the highway caused significant changes in both the quantity and quality of water in Danz Creek.

The paved surfaces and storm sewer system combined to increase both the total volume and maximum flow rate of the creek. Even small storm events were sufficient to generate runoff below the highway right-of-way.

Storm water runoff from the highway caused increases in suspended solids, oil and grease, and zinc in Danz Creek. These constituents commonly are found in highway runoff. Although the increases were substantial, the resulting water quality was well within levels appropriate for aquatic life or at concentrations commonly reported for streams during the elevated flows following storm events in undeveloped watersheds. Because of the nature of the surrounding land use, ambient concentrations of many constituents in the creek were higher than those in the runoff from the new highway. High concentrations of fecal bacteria in the creek probably were derived from livestock and wildlife in the watershed upstream of the highway right-of-way. Nutrients (nitrate and phosphorus) in the creek may have been the result of fertilization of the golf course, which is crossed by the highway. Dilution of the creek with highway runoff reduced the concentrations of these constituents and improved the quality of the receiving water.

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APPENDIX A

Table A-1 Downstream Grab Samples (Non-metals)

Date	Time	Total Coliform (CFU)	Fecal. Coliform (CFU)	Fecal Strep (CFU)	TSS (mg/L)	VSS (mg/L)	Turbidity (NTU)	BOD (mg/L)	COD (mg/L)	TOC (mg/L)	NO_3-N (mg/L)	O&G (mg/L)
6/11/92		3000	3000	3000	5.3	0	14	1.4	5	32	1.3	<0.1
6/18/92		280	NA	4200	20	3.5	2.5	<1	40	62	0.7	<0.1
11/19/92		5300	4350	4250	309	33	245	10	18	5.3	0.6	<0.1
11/1/92		7350	7350	3500	186	32	140	2.2	<5	18	1.7	<0.1
1/12/93	12:10	NA	NA	NA	1.66	0	1.2	2.24	23.5	0	0.29	<0.1
1/19/93	9:50	1950	1150	5500	734	66.5	380	3.1	10.3	30.9	0.2	<0.1
1/19/93	12:20	2250	800	4850	230	72.5	280	1.9	20.6	26.4	0.1	<0.1
1/19/93	13:40	2350	1000	4800	166	40.5	180	2.2	15.7	13.4	0.1	<0.1
2/28/93	14:50	70	ND	50	0	0	18	2.3	12.1		N/A	<0.1
2/28/93	15:50	480	110	150	15.8	3.9	39	2.2	<5.0		N/A	<0.1
2/28/93	16:50	1150	160	695	42	1.8	120	1.9	6.1		N/A	<0.1
4/7/93	12:10	2050	1750	12700	644	18	4.6	4.4	14.4	18.8	NA	<0.2
5/23/93	9:45	cf.	2800	9200	98	2	72	0.9	27	13.8	0.9	<0.2
10/20/93		NA*	90000	2150	60	4	72	9	5		0.76	<0.2

Table A-2 Downstream Grab Samples (Metals)

Date	Time	Cd (mg/L)	Cr (mg/L)	Cu (mg/L)	Fe (mg/L)	Pb (mg/L)	Ni (mg/L)	Zn (mg/L)
6/11/92		0.008	<0.007	<0.006	0.166	<0.042	<0.015	0.007
6/18/92		<0.004	<0.007	<0.006	0.135	<0.042	<0.015	<0.002
11/19/92		<0.004	<0.007	0.064	5.757	0.112	<0.015	0.019
11/1/92		<0.004	<0.007	0.053	4.149	0.141	<0.015	0.089
1/12/93	12:10	<0.004	<0.007	0.047	0.075	0.102	<0.015	<0.002
1/19/93	9:50	<0.004	<0.007	0.063	7.054	0.678	<0.015	0.081
1/19/93	12:20	<0.004	<0.007	0.06	5.765	<0.042	<0.015	0.091
1/19/93	13:40	<0.004	<0.007	0.059	3.911	<0.042	<0.015	0.032
2/28/93	14:50	0.020	<0.007	0.037	0.236	<0.042	<0.015	0.052
2/28/93	15:50	<0.004	<0.007	0.034	0.3	<0.042	<0.015	0.033
2/28/93	16:50	0.025	<0.007	0.044	0.577	<0.042	<0.015	0.057
4/7/93	12:10	<0.004	0.1	0.18	3.85	<0.042	<0.015	0.11
5/23/93	9:45	<0.004	<0.007	<0.007	1.128	<0.042	<0.015	<0.002
10/20/93		<0.004	0.076	<0.006	4.658	0.348	<0.015	0.09

Table A-3 Upstream Grab Samples (Non-metals)

Date	Time	Total Coliform (CFU)	Fecal Coliform (CFU)	Fecal Strep (CFU)	TSS (mg/L)	VSS (mg/L)	Turbidity (NTU)	BOD (mg/L)	COD (mg/L)	TOC (mg/L)	NO_3-N (mg/L)	O&G (mg/L)
6/11/92		9000	9000	9000	27	4.6	28	3.2	10	32	1.5	<0.1
6/18/92		500	NA	3900	5.8	2.1	2.7	1.1	5	56	1.1	<0.1
6/25/92		3400	1400	NA	8.8	2.1	3.9	2.7	10	57	0.6	<0.1
11/19/92		3600	2050	6250	259	23	240	9.6	13	8.3	0.1	<0.1
1/12/93	11:30	NA	NA	NA	1.62	0	2.7	2.62	18.4	0	0.22	<0.1
1/19/93	9:30	5800	3100	12750	64.5	14	33	2.9	54.1	20.7	0.48	<0.1
1/19/93	12:00	5700	4100	10700	19.5	10.5	15	2.4	22.2	17.8	0.3	<0.1
1/19/93	13:20	4600	3350	10400	14.5	8.5	15	2.7	10.3	13.4	0.3	<0.1
2/25/93	8:00	900	ND	65	0	0	1.5	1.4	8	NA	N/A	<0.1
2/25/93	9:00	650	100	80	1.6	0.05	1.9	1.6	10.1	NA	N/A	<0.1
2/25/93	9:15	550	100	110	1.5	0.3	1.6	1.3	14.1	NA	N/A	<0.1
2/25/93	9:40	535	ND	100	1.4	0.2	1.6	1.1	10.1	NA	N/A	<0.1
2/28/93	15:15	950	140	255	30.6	1.7	2.8	2.1	12.1	NA	N/A	<0.1
2/28/93	16:15	1100	1000	800	13.2	2.6	15	3.5	<5.0	NA	N/A	<0.1
4/7/93	11:45	2650	1600	24600	81.4	ND	73	3.15	ND	3.5	NA	<0.2
5/23/93	9:30	cf	4450	TNTC	25.8	2.3	8.3	3.2	31	20.3	2.4	<0.2

Table A-4 Upstream Grab Samples (Metals)

Date	Time	Cd (mg/L)	Cr (mg/L)	Cu (mg/L)	Fe (mg/L)	Pb (mg/L)	Ni (mg/L)	Zn (mg/L)
6/11/92		0.014	<0.007	<0.006	1.001	<0.042	<0.015	<0.002
6/18/92		0.011	<0.007	<0.006	0.159	1.652	<0.015	0.007
6/25/92		<0.004	<0.007	<0.006	0.178	<0.042	<0.015	0.003
11/19/92		<0.004	<0.007	0.067	4.284	0.116	<0.015	0.022
1/12/93	11:30	<0.004	<0.007	0.045	0.114	0.144	<0.015	<0.002
1/19/93	9:30	<0.004	<0.007	0.046	1.461	<0.042	<0.015	0.026
1/19/93	12:00	<0.004	<0.007	0.042	0.624	<0.042	<0.015	0.016
1/19/93	13:20	0.022	<0.007	0.044	0.741	<0.042	<0.015	0.03
2/25/93	8:00	0.024	<0.007	0.046	0.385	<0.042	<0.015	0.012
2/25/93	9:00	0.023	<0.007	0.042	0.084	<0.042	<0.015	0.024
2/25/93	9:15	<0.004	<0.007	0.039	0.102	<0.042	<0.015	0.042
2/25/93	9:40	<0.004	<0.007	0.039	0.065	<0.042	<0.015	0.041
2/28/93	15:15	<0.004	<0.007	0.038	0.068	<0.042	<0.015	0.041
2/28/93	16:15	<0.004	<0.007	0.04	0.448	<0.042	<0.015	0.046
4/7/93	11:45	<0.004	0.08	0.18	1.14	<0.042	<0.015	0.13
5/23/93	9:30	<0.004	<0.007	<0.007	0.33	<0.042	<0.015	0.013

Table A-5 Downstream Event Mean Concentrations (Non-metals)

Event Date	Volume (m^3)	Total Coliform (CFU)	Fecal Coliform (CFU)	Fecal Strep (CFU)	TSS (mg/L)	VSS (mg/L)	Turbidity (NTU)	BOD (mg/L)	COD (mg/L)	Total Carbon (mg/L)	Dis. Tot. Carbon (mg/L)	NO_3-N (mg/L)	Total P (mg/L)	Oil and Grease
10/13/93	59	NA	105500	19500	1556	80	370	33	195	179	116	4.7	0.74	1.2
10/20/93	1142	NA	17000	3400	524	12	180	14	38	39.7	20	0.4	0.32	1.5
10/29/93	33	NA	NA	NA	20	12	28	NA	94	39.1	35.2	0.53	0.18	NA
11/3/93	58	NA	NA	NA	20	4	16	8	33	16.9	19.5	0.61	0.09	0.7
12/22/93	66	NA	NA	NA	NA	NA	NA	NA	13	21.2	21.2	NA	NA	0.7
1/22/94	125	NA	NA	NA	12	4	NA	NA	113	34.4	31.6	NA	1.25	1.4
1/25/94	15	NA	NA	NA	8	4	21	4	45	35.4	34.4	NA	1.05	<0.2
2/22/94	592	17790	1220	12247	122	13.3	74	5	19	14.4	12.2	2.18	0.35	0.7
3/1/94	77	1600	200	2650	4	4	16	5	28	23.2	20.4	0.75	0.28	3
3/9/94	240	1500	NA	3350	20	4	32	4	38	14.9	13.6	1.05	0.13	1.4
3/15/94	78	600	NA	2500	32	0	NA	6	28	24.5	19.4	1.05	0.14	1.4
3/15/94	78	3250	NA	4200	36	4	41	4	34	23.2	16.9	2.6	0.16	0.5
4/29/94	133	44500	42500	33000	124	12	NA	5	21	21.8	21.7	0.64	NA	0.8
5/13/94	1758	NA	NA	NA	528	36	81	7	30	34.9	13.5	0.24	0.29	1.3
5/15/94	4203	13000	6000	28000	288	28	77	7	36	25.5	13.5	0.39	0.17	0.8
5/16/1994	439	NA	NA	NA	24	12	9.6	<2	38	33.6	34.9	NA	0.08	1.1
5/28/94	596	NA	NA	NA	72	16	27	6	36	31.8	33.3	0.27	0.16	1.6
6/20/94	111	NA	NA	NA	120	20	44	6	NA	25.9	18.1	NA	NA	NA
8/9/94	2233	43000	45500	63500	228	36	NA	5	59	22.4	10.7	0.18	0.13	1.5
8/15/94	10	120500	cf	28500	32	4	15	8	44	24.8	27.5	<0.10	0.11	NA
10/7/94	5223	NA	NA	NA	124	4	50	4	24	<10.0	<10.0	<0.10	0.1	<0.2
10/15/94	501	NA	NA	NA	8	8	NA	NA	25	NA	NA	NA	<0.01	NA
10/18/94	4378	12000	5500	18000	4	4	12	3	36	40.6	35.7	<0.10	0.06	NA
11/5/94	4706	NA	NA	NA	36	8	NA	NA	NA	NA	NA	NA	NA	NA
12/15/94	25606	NA	NA	NA	80	12	NA	NA	23	27.8	23	<0.10	0.13	0.5
1/13/95	812	NA	NA	NA	0	0	3.3	4	NA	64.4	55.4	<0.10	NA	NA
2/24/95	1269	NA	NA	NA	84	8	NA	NA	26	18.6	13	0.48	0.18	2.3
3/7/95	1276	750	50	1450	12	8	8	<2	16	48.1	46.2	0.17	0.01	NA
3/13/95	18085	1150	650	11000	68	4	34	3	25	29.8	18.5	0.11	0.11	2
3/16/95	794	1200	150	200	4	0	3.2	<2	8	53.5	47.4	0.86	0.04	1.4
4/4/95	2337	18500	3250	12000	12	12	13	3	NA	33.3	28.7	0.07	0.08	NA

4/19/95	1611	10000	850	20500	4	0	13	3	19	37.2	33.6	0.09	NA	1.8
5/8/95	27410	34500	2000	24000	76	28	31	3	27	18.8	13.5	NA	0.14	1.2
5/18/95	235	NA	12000	67000	20	16	NA	NA	36	24.9	16.5	NA	0.07	1.7

Table A-6 Downstream Event Mean Concentrations (Metals)

Event Date	Cd (mg/L)	Cr (mg/L)	Cu (mg/L)	Fe (mg/L)	Pb (mg/L)	Ni (mg/L)	Zn (mg/L)
10/13/93	<0.004	0.135	0.025	4.481	<0.50	<0.015	0.219
10/20/93	<0.004	<0.007	0.059	6.955	<0.042	<0.015	0.12
10/29/93	<0.004	<0.007	<0.006	1.44	<0.042	<0.015	0.073
11/3/93	<0.004	<0.007	0.047	0.466	<0.042	<0.015	0.061
12/22/93	0.057	<0.033	0.035	0.91	0.103	<0.033	0.054
1/22/94	NA	NA	NA	NA	NA	NA	NA
1/25/94	<0.017	<0.033	<0.0017	0.976	<0.033	<0.033	0.022
2/22/94	<0.0013	<0.007	<0.002	4.019	0.099	<0.005	0.019
3/1/94	0.01	0.014	0.004	0.564	0.032	0.006	0.024
3/9/94	<0.0013	<0.0023	<0.002	1.063	<0.014	<0.005	0.006
3/15/94	<0.0013	<0.0023	<0.002	1.05	<0.014	<0.005	0.023
3/15/94	<0.0013	<0.0023	<0.002	1.983	0.018	<0.005	0.022
4/29/94	0.012	0.017	0.012	2.675	NA	<0.005	0.009
5/13/94	<0.0013	0.036	<0.002	8.74	0.161	<0.005	0.062
5/15/94	<0.0013	0.032	<0.002	7.657	0.145	<0.005	0.048
5/16/94	0.008	0.008	0.017	0.532	0.06	<0.005	0.017
5/28/94	<0.0013	0.017	<0.002	1.537	0.059	<0.005	0.029
6/20/94	NA	NA	NA	NA	NA	NA	NA
8/9/94	<0.0013	<0.0023	<0.002	5.256	<0.014	<0.005	0.026
8/15/94	<0.0013	<0.0023	<0.002	0.52	<0.014	<0.005	<0.0007
10/7/94	<0.004	<0.007	<0.006	3.091	<0.042	<0.015	0.014
10/15/94	<0.0013	<0.0023	0.003	0.076	<0.014	0.005	0.01
10/18/94	<0.0013	<0.0023	0.002	0.518	<0.014	<0.005	0.04
11/5/94	NA	NA	NA	NA	NA	NA	NA
12/15/94	<0.0013	<0.0023	<0.002	1.133	NA	<0.005	0.003
1/13/95	NA	NA	NA	NA	NA	NA	NA
2/24/95	NA	NA	NA	NA	NA	NA	NA
3/7/95	<0.0013	<0.0023	<0.002	0.331	<0.014	<0.005	0.043
3/13/95	<0.0013	<0.0023	<0.002	1.395	<0.014	<0.005	<0.0007
3/16/95	<0.0013	<0.0023	<0.002	0.13	<0.014	<0.005	<0.0007
4/4/95	<0.0013	<0.0023	<0.002	0.234	<0.014	<0.005	0.008
4/19/95	<0.0013	<0.0023	<0.002	0.535	<0.014	<0.005	<0.0007
5/8/95	<0.0013	<0.0023	0.004	1.334	NA	<0.005	0.011
5/18/95	<0.0023	<0.0013	<0.002	0.373	NA	<0.005	<0.0007

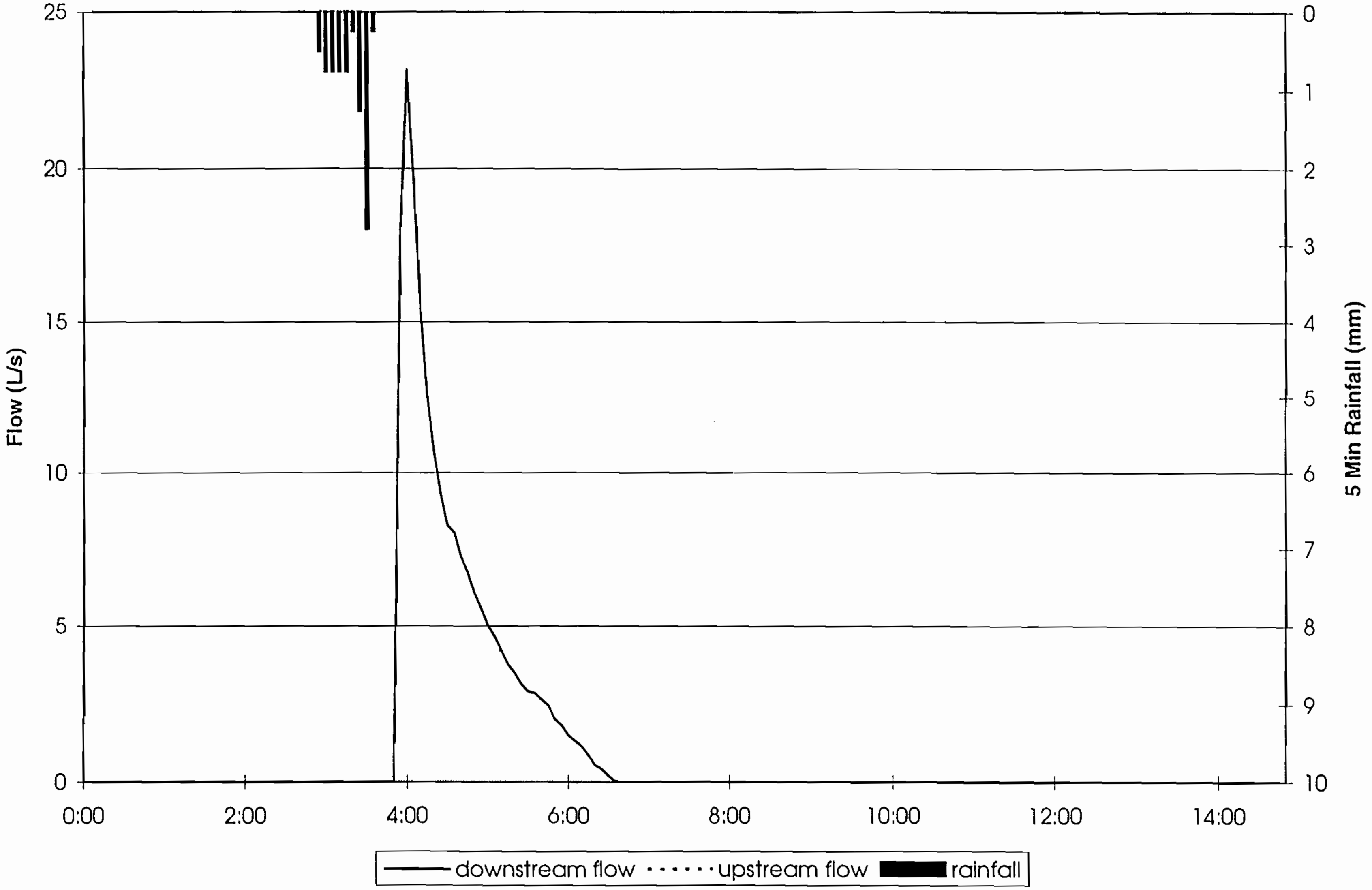
Table A-7 Upstream Event Mean Concentrations (Non-metals)

Event Date	Flow Volume (m^3)	Total Coliform	Fecal Coliform	Fecal Strep	TSS	VSS	Turbidity	BOD	COD	Total Carbon	Dis. Tot. Carbon	NO_3-N	Total Phosphorus	Oil and Grease
5-29-94	47	NA	NA	NA	54	18	21	6.9	84	59	53	0.22	0.26	NA
8/9/94	115	27804	18996	37679	266	44	NA	<2.6	66	29	<11.2	0.44	0.58	NA
10/8/94	15365	NA	NA	NA	16.8	1.8	25	6.1	44	28	25	0.30	0.24	NA
10/15/94	67	NA	NA	NA	1	1	NA	NA	29	NA	NA	NA	<0.01	NA
10/18/94	622	17875	5764	31896	18	15	13	5	37	51	50	<0.1	<0.11	NA
11/5/94	3444	NA	NA	NA	4	4	NA	NA	NA	NA	NA	NA	NA	NA
12/16/94	25255	NA	NA	NA	82	6.9	59	NA	44	31	30	<0.1	0.18	0.8
1/13/95	1300	NA	NA	NA	5.3	2.6	1.4	3.6	17.0	66	63	<0.1	0.06	NA
3/7/95	234	200	100	1600	24	20	7	4	24	56	57	0.3	0.05	NA
3/13/95	14400	NA	NA	NA	59	4	16.9	4.7	NA	NA	NA	NA	NA	NA
4/19/95	180	31500	NA	36000	NA	NA	41.5	7	38	49.55	35.6	0.26	0.965	NA
5/8/95	4800	NA	NA	NA	129	27	19.5	6	NA	41.7	NA	NA	0.26	NA

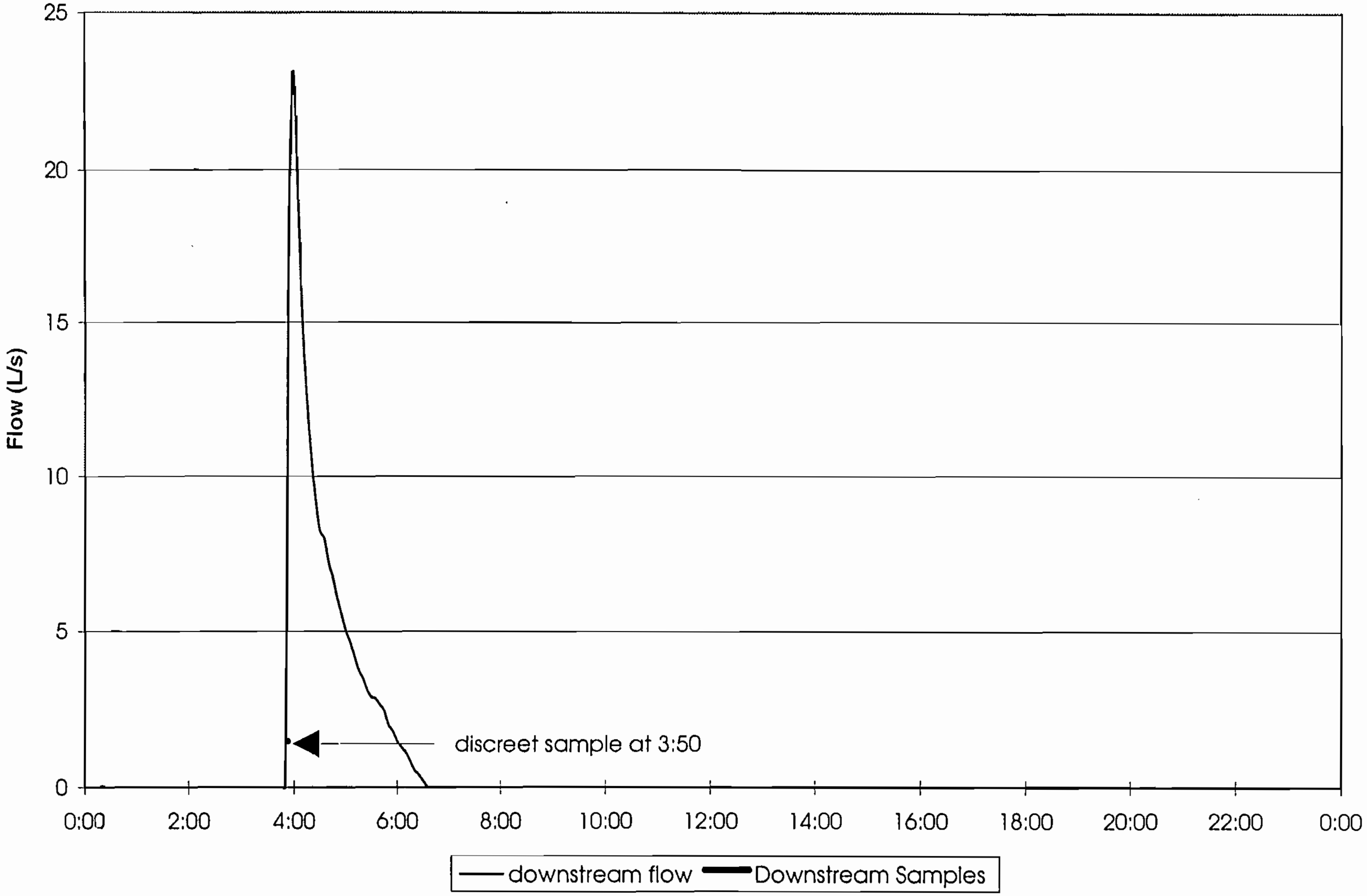
Table A-8 Upstream Event Mean Concentrations (Metals)

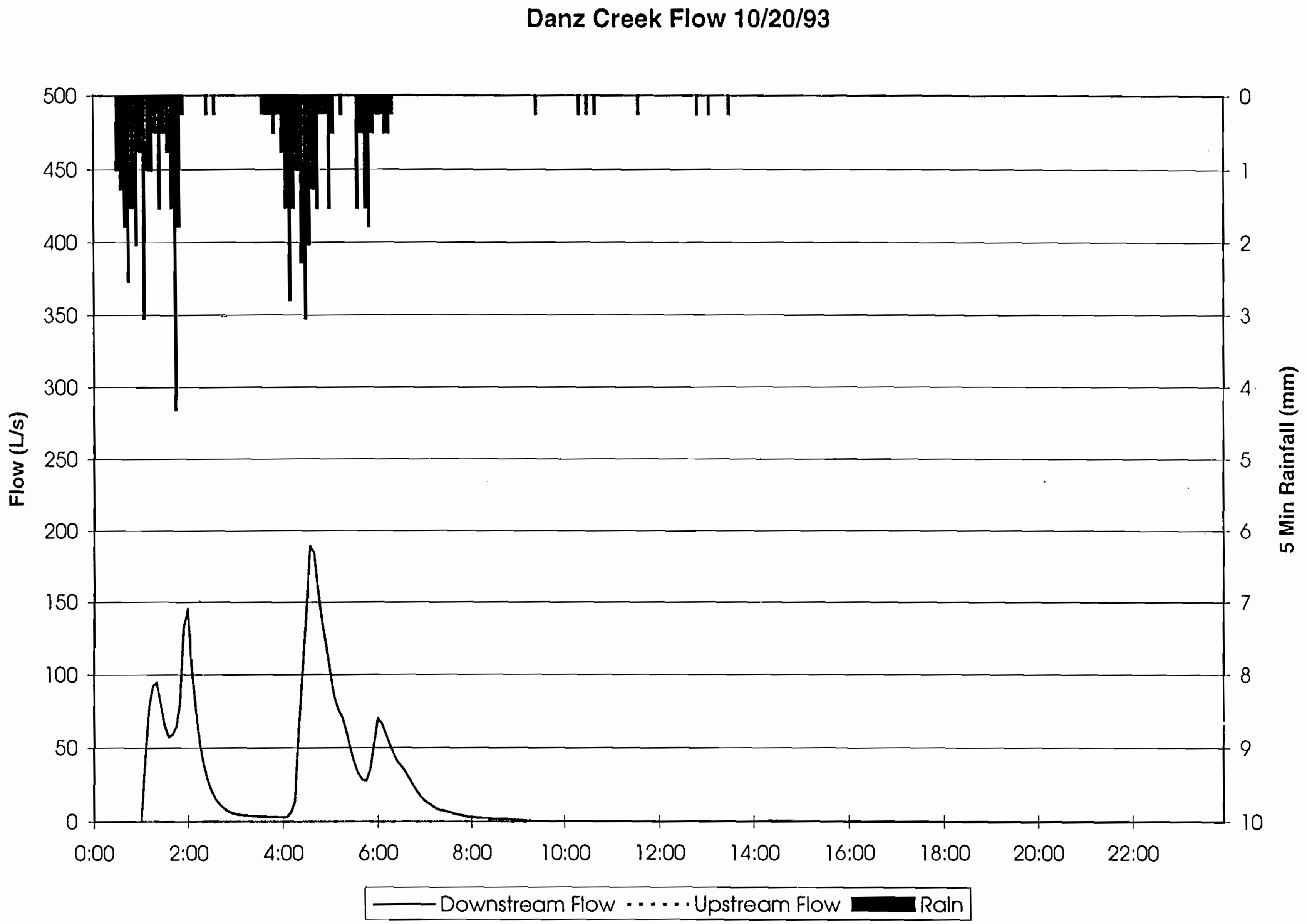
Date	Cd (mg/L)	Cr (mg/L)	Cu (mg/L)	Fe (mg/L)	Pb (mg/L)	Ni (mg/L)	Zn (mg/L)
5-29-94	<0.0013	0.026	0.023	1.246	0.092	0.019	0.034
8/9/94	<0.0013	<0.0023	<0.002	7.561	<0.014	<0.005	<0.016
10/8/94	<0.0013	<0.003	0.002	1.175	<0.014	<0.005	0.004
10/15/94	<0.0013	<0.0026	<0.002	0.169	<0.015	<0.005	<0.0023
10/18/94	<0.0013	0.0026	<0.002	0.774	<0.014	<0.005	<0.0081
11/5/94	NA	NA	NA	NA	NA	NA	NA
12/16/94	<0.0013	<0.0023	<0.003	2.202	<0.014	<0.005	0.014
1/13/95	<0.0013	<0.0023	<0.002	0.045	<0.014	0.006	0.004
3/7/95	<0.0013	<0.0023	0	1	NA	<0.005	<0.0007
3/13/95	NA	NA	NA	NA	NA	NA	NA
4/19/95	<0.0013	<0.00415	0.004	2.604	NA	<0.005	0.0075
5/8/95	<0.003	<0.007	<0.003	1.193	<0.016	NA	<0.003

Danz Creek Flow 10/13/93



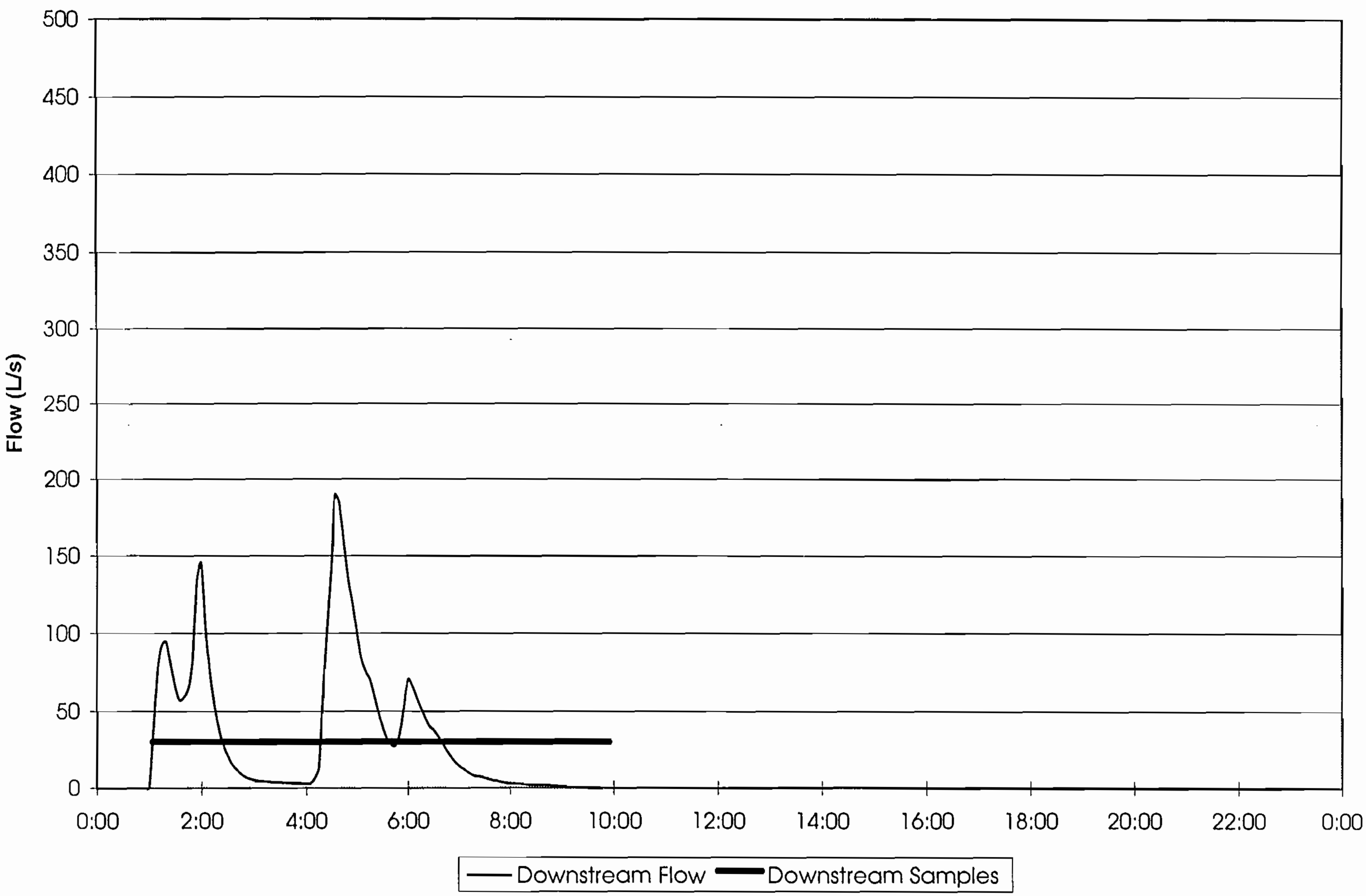
Downstream Sampling Interval 10/13/93



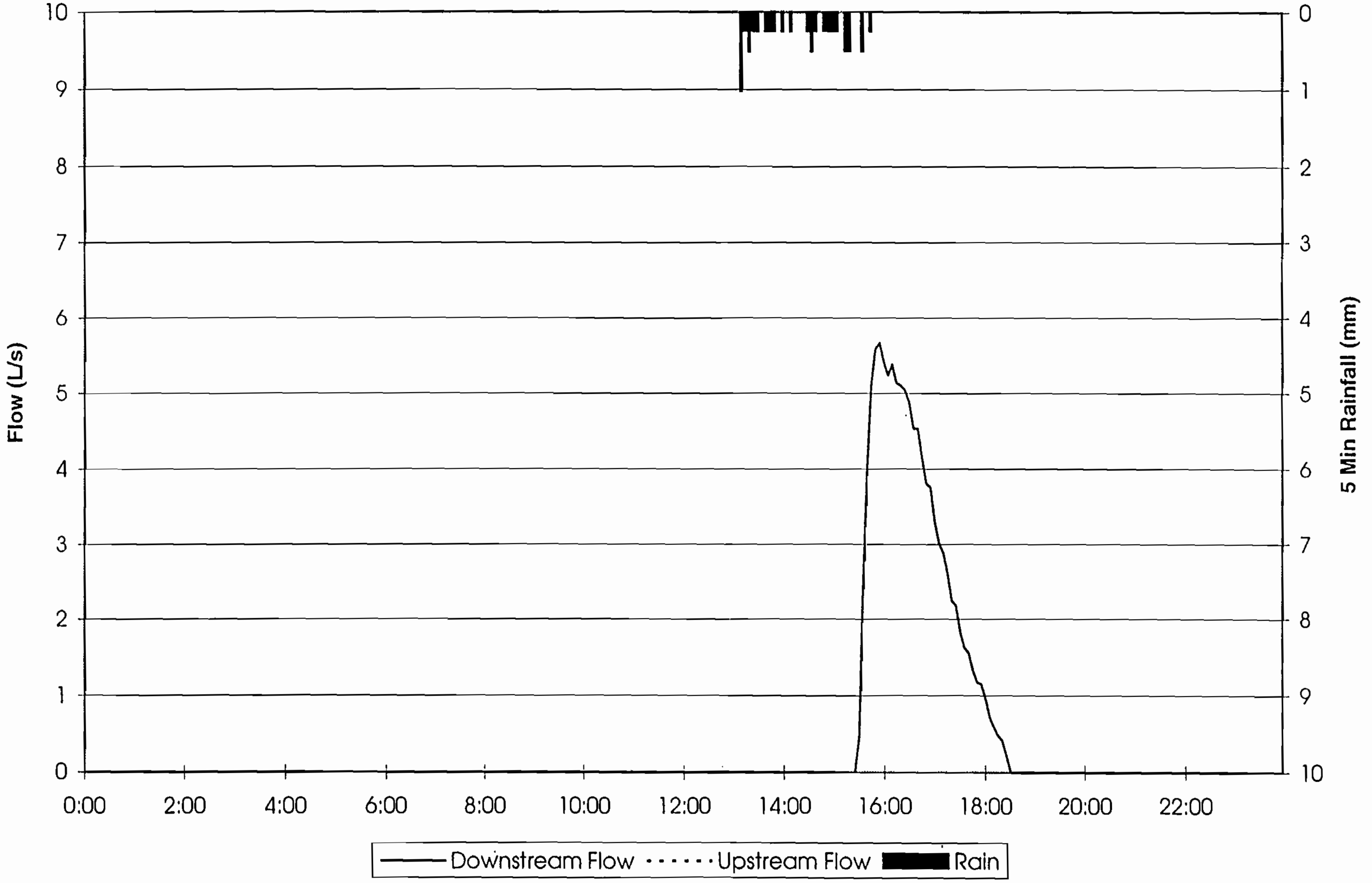


Danz Creek Flow 10/20/93

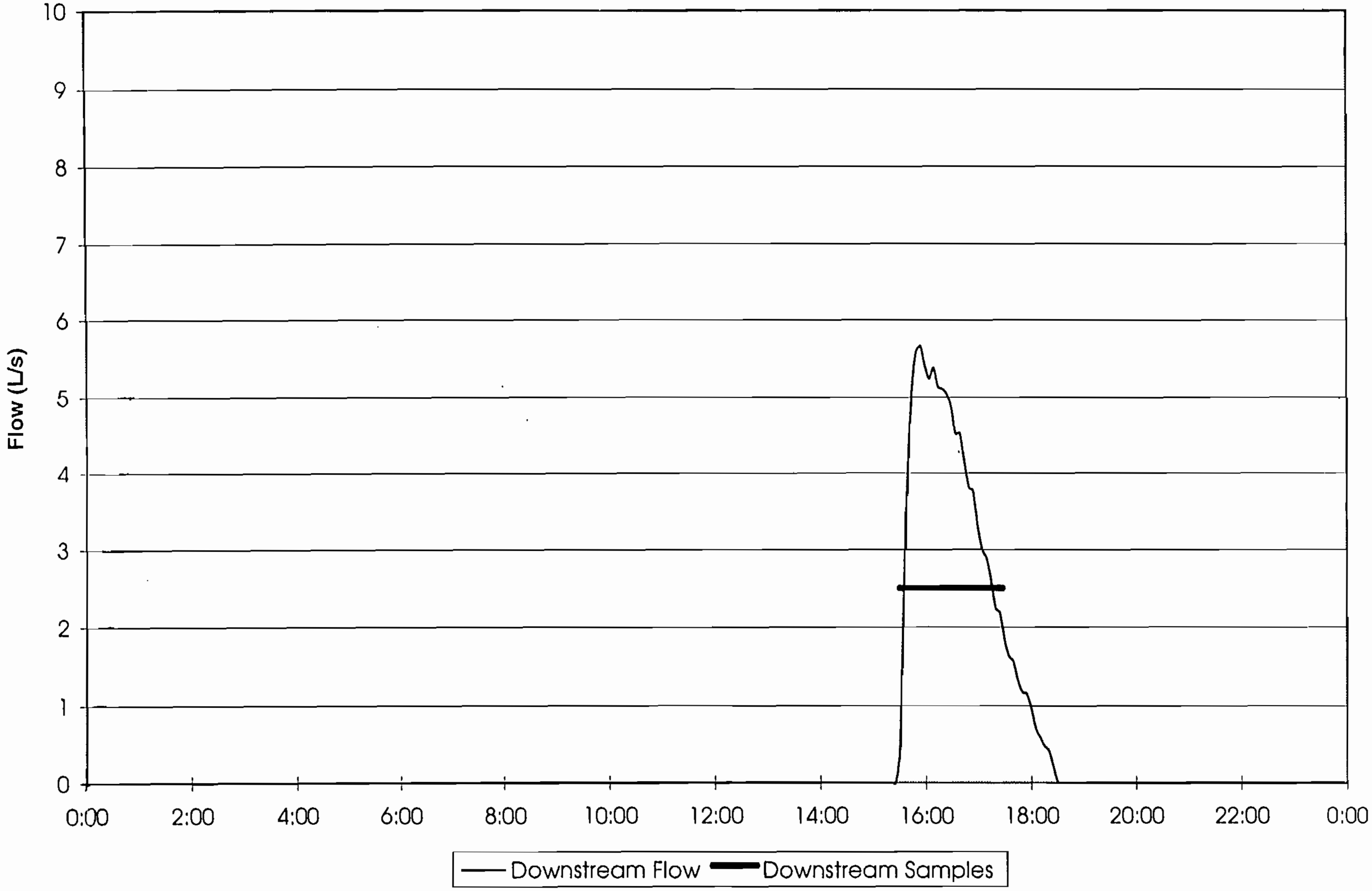
Downstream Sampling Interval 10/20/93

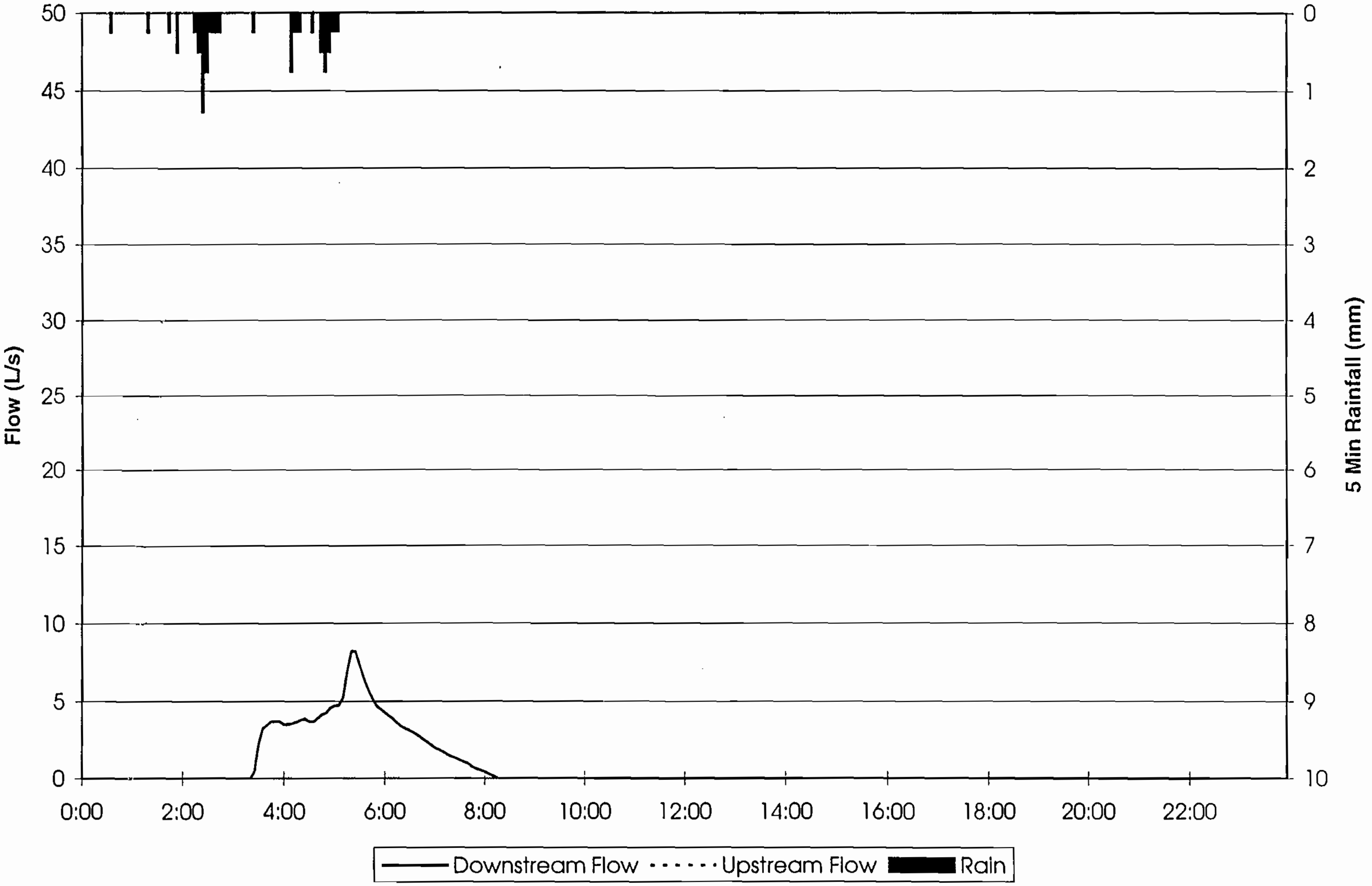


Danz Creek Flow 10/29/94



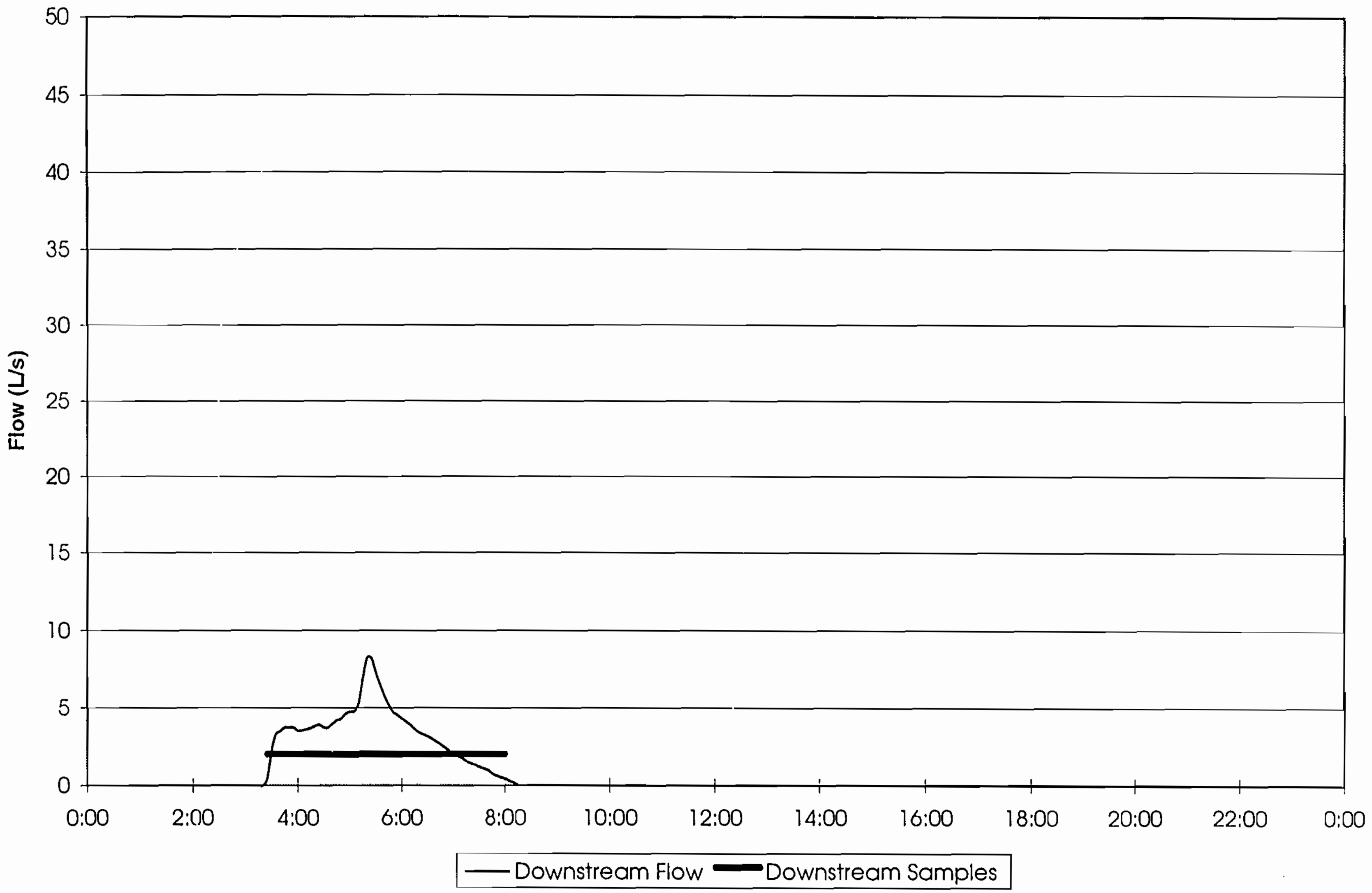
Downstream Sampling Interval 10/29/93



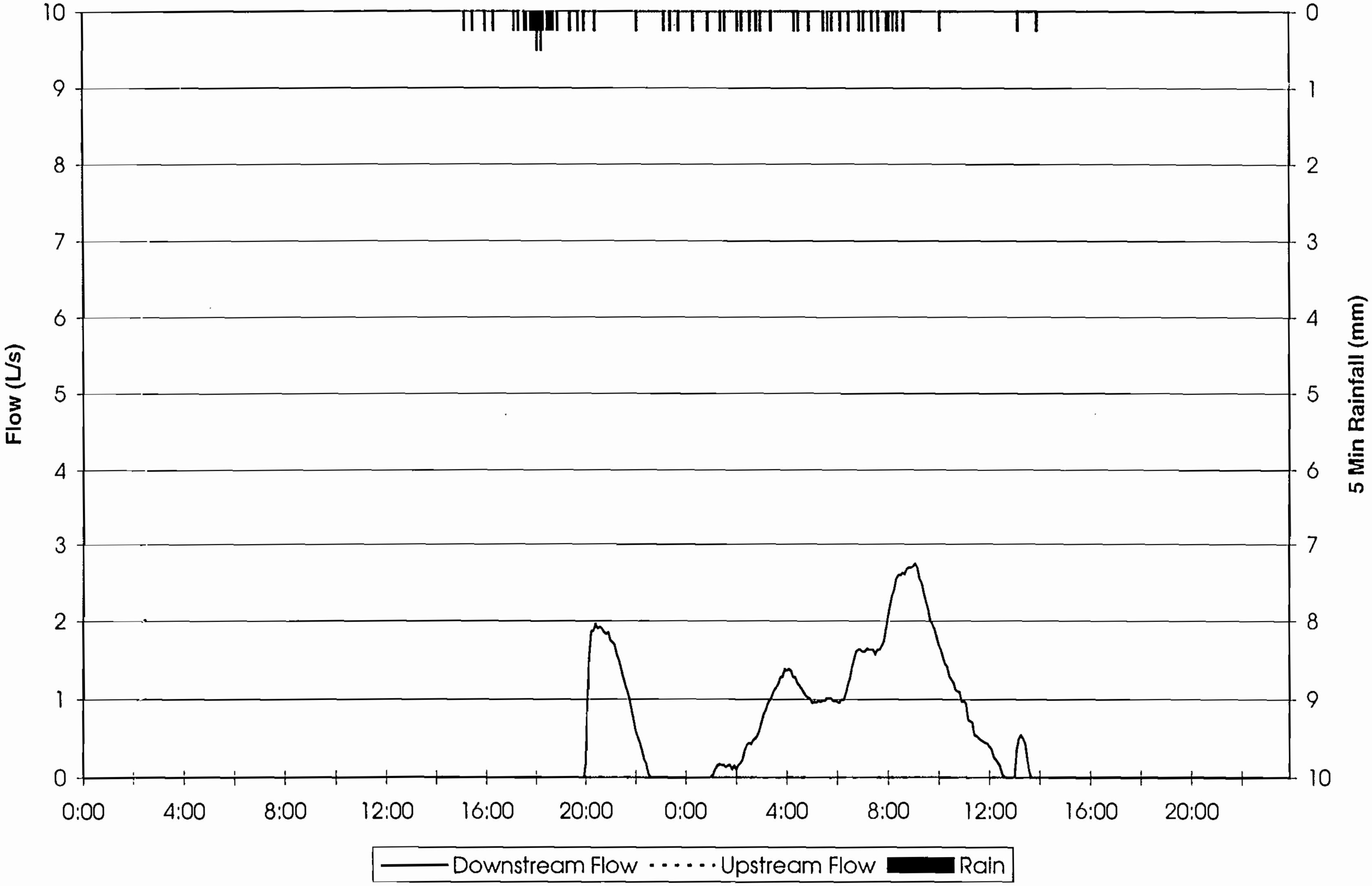


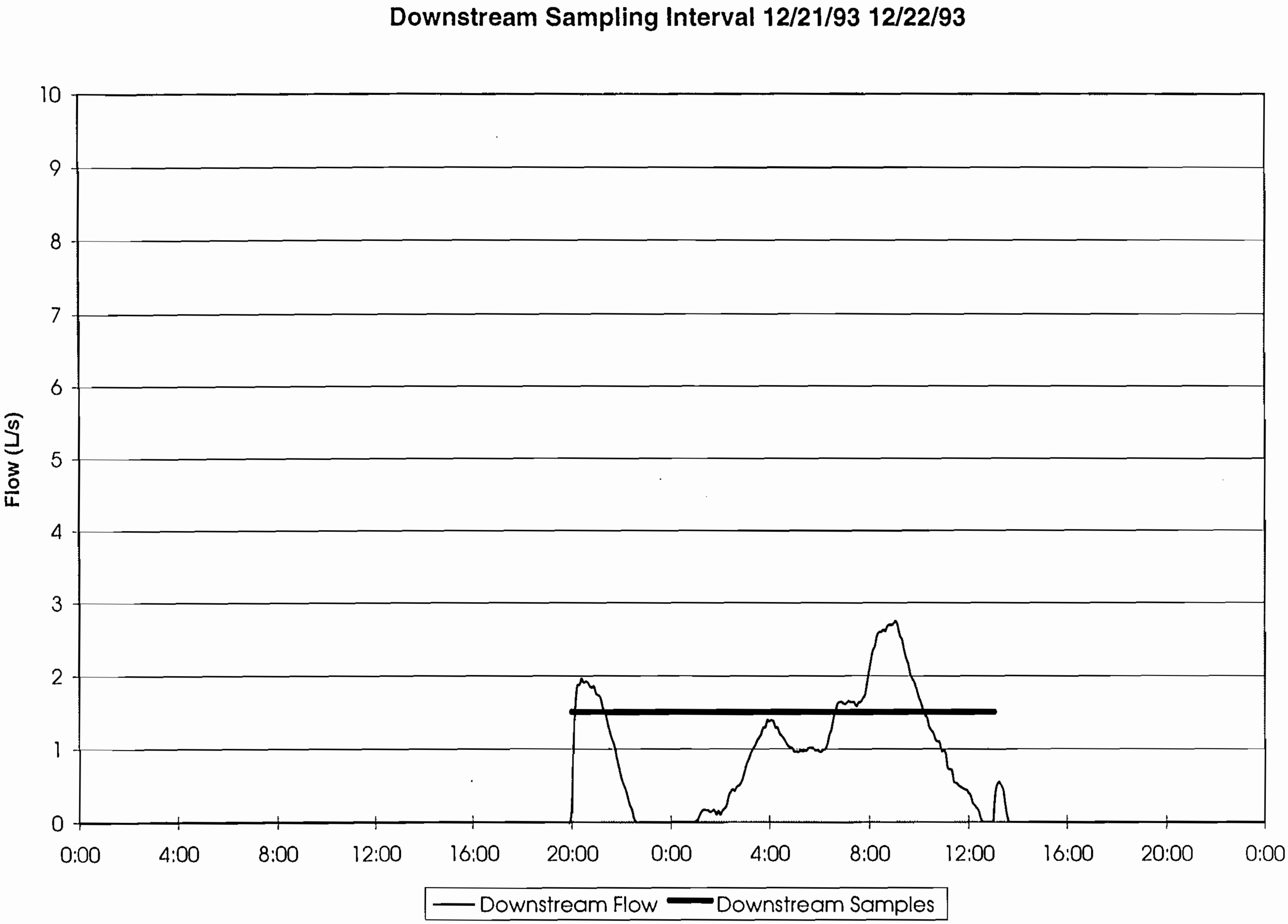
Danz Creek Flow 11/3/93

Downstream Sampling Interval 11/3/93

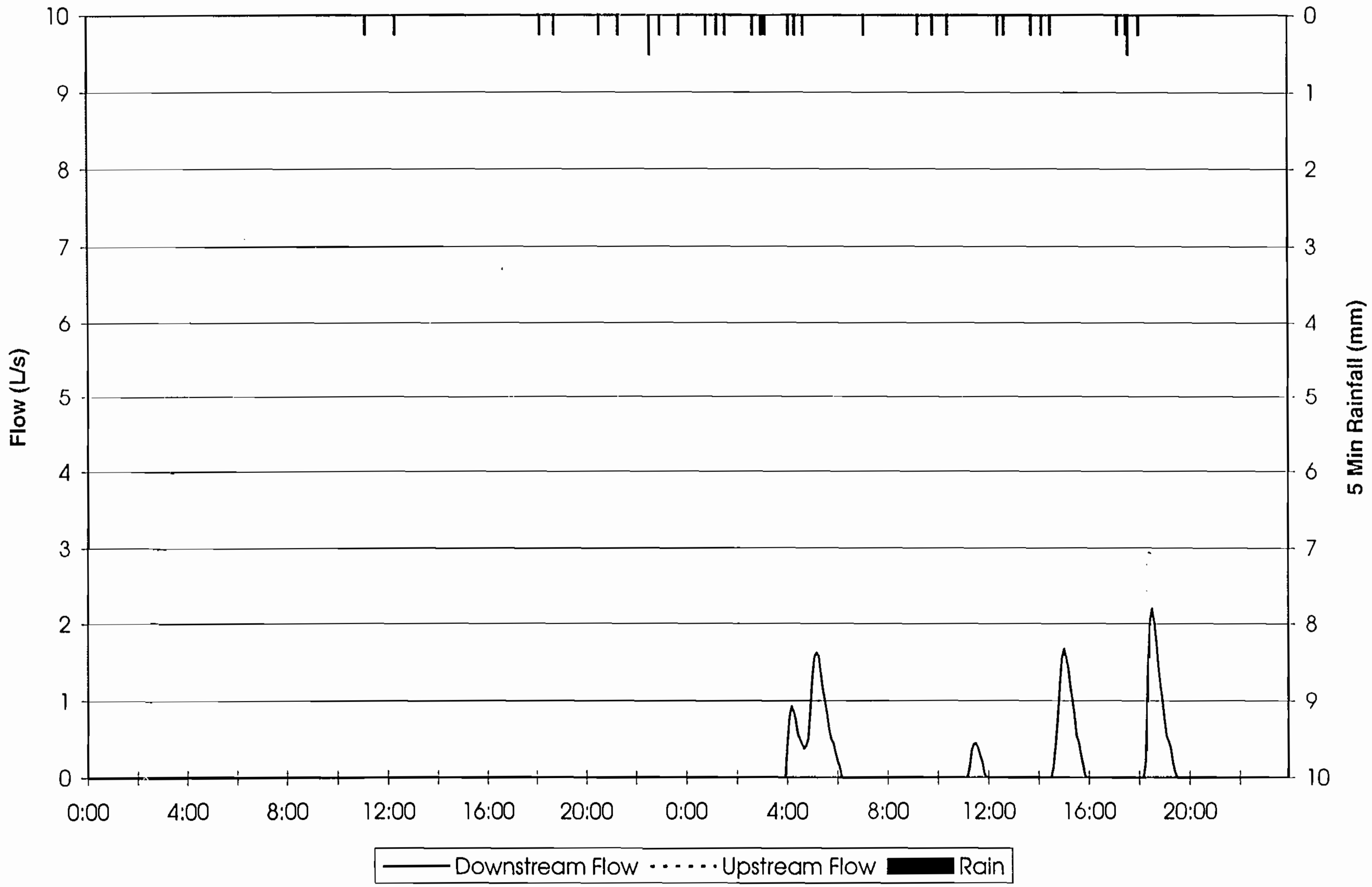


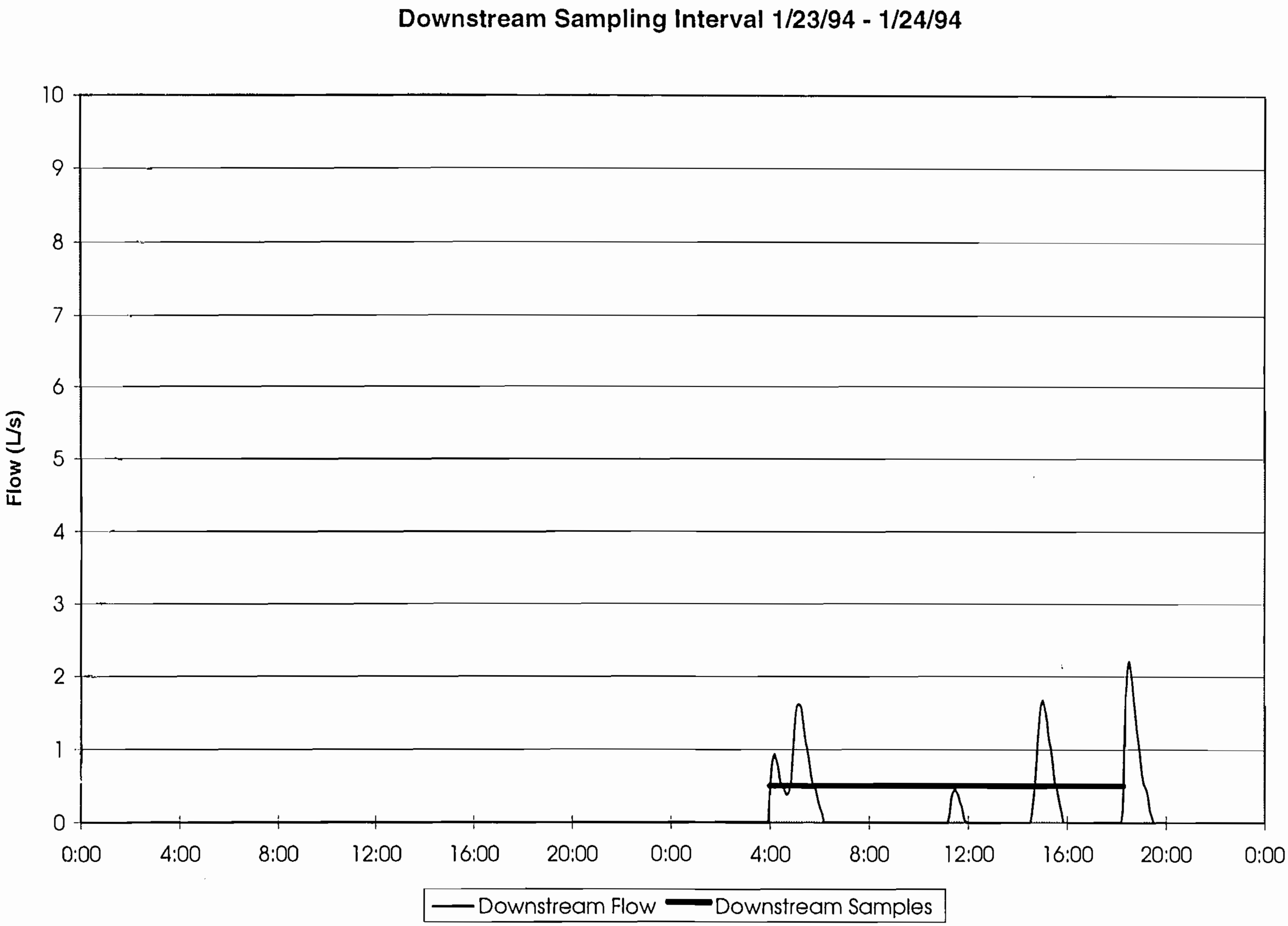
Danz Creek Flow 12/21/93 - 12/22/93




Downstream Sampling Interval 12/21/93 12/22/93
Flow (L/s)
10
9
8
7
6
5
4
3
2
1
0
0:00
4:00
8:00
12:00
16:00
20:00
0:00
4:00
8:00
12:00
16:00
20:00
0:00
Downstream Flow
Downstream Samples

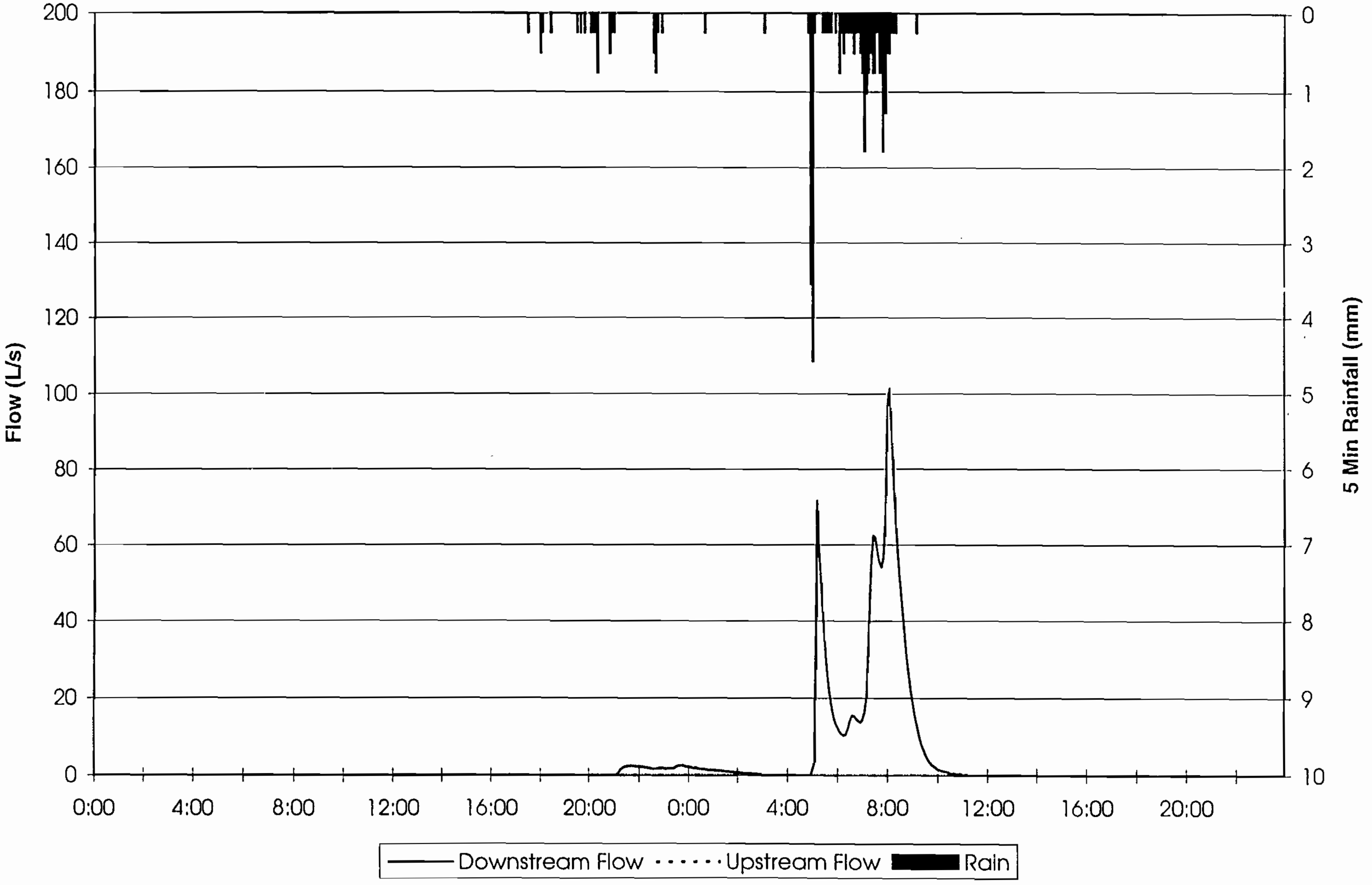
Danz Creek Flow 1/23/94 - 1/24/94



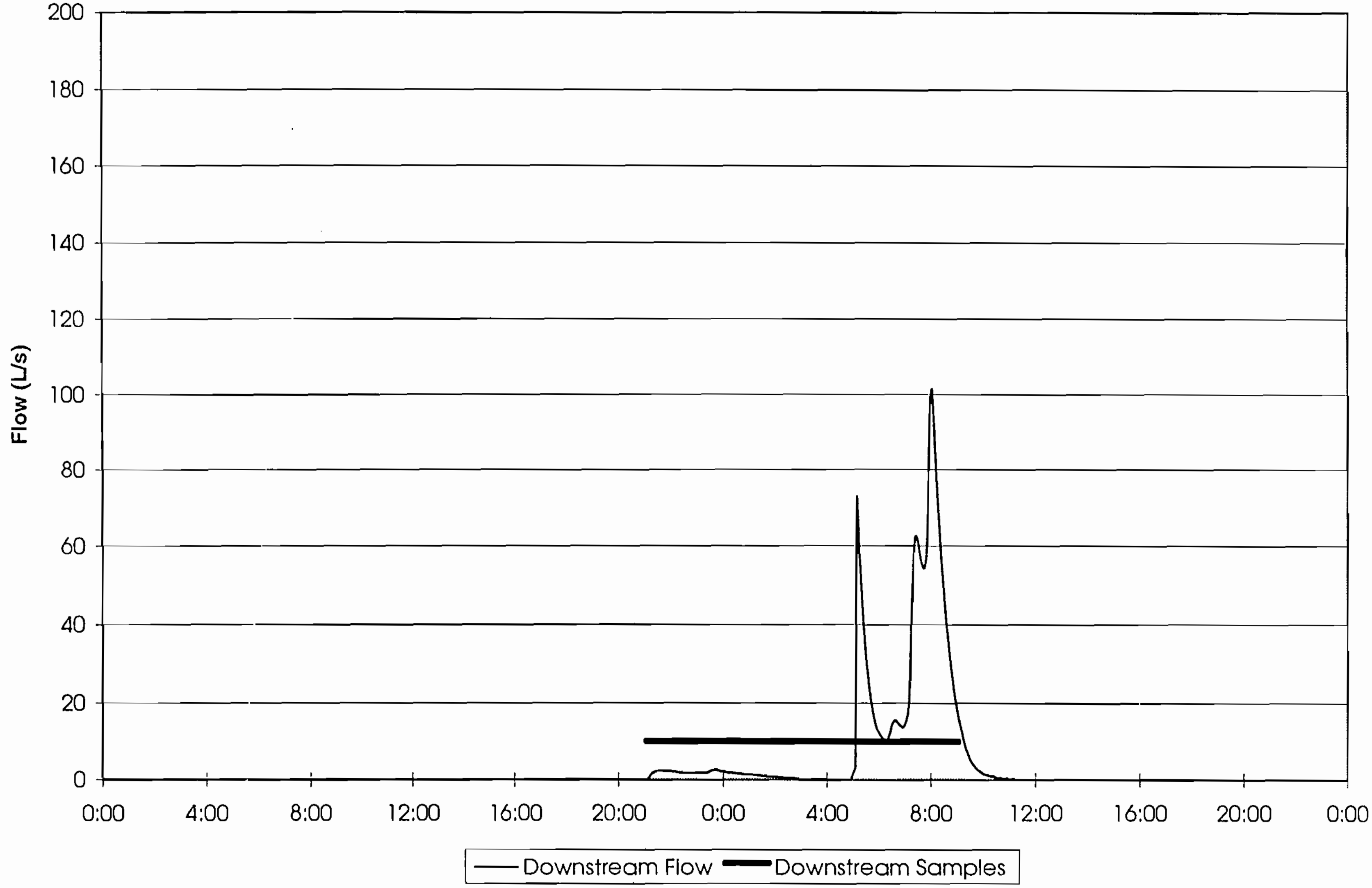


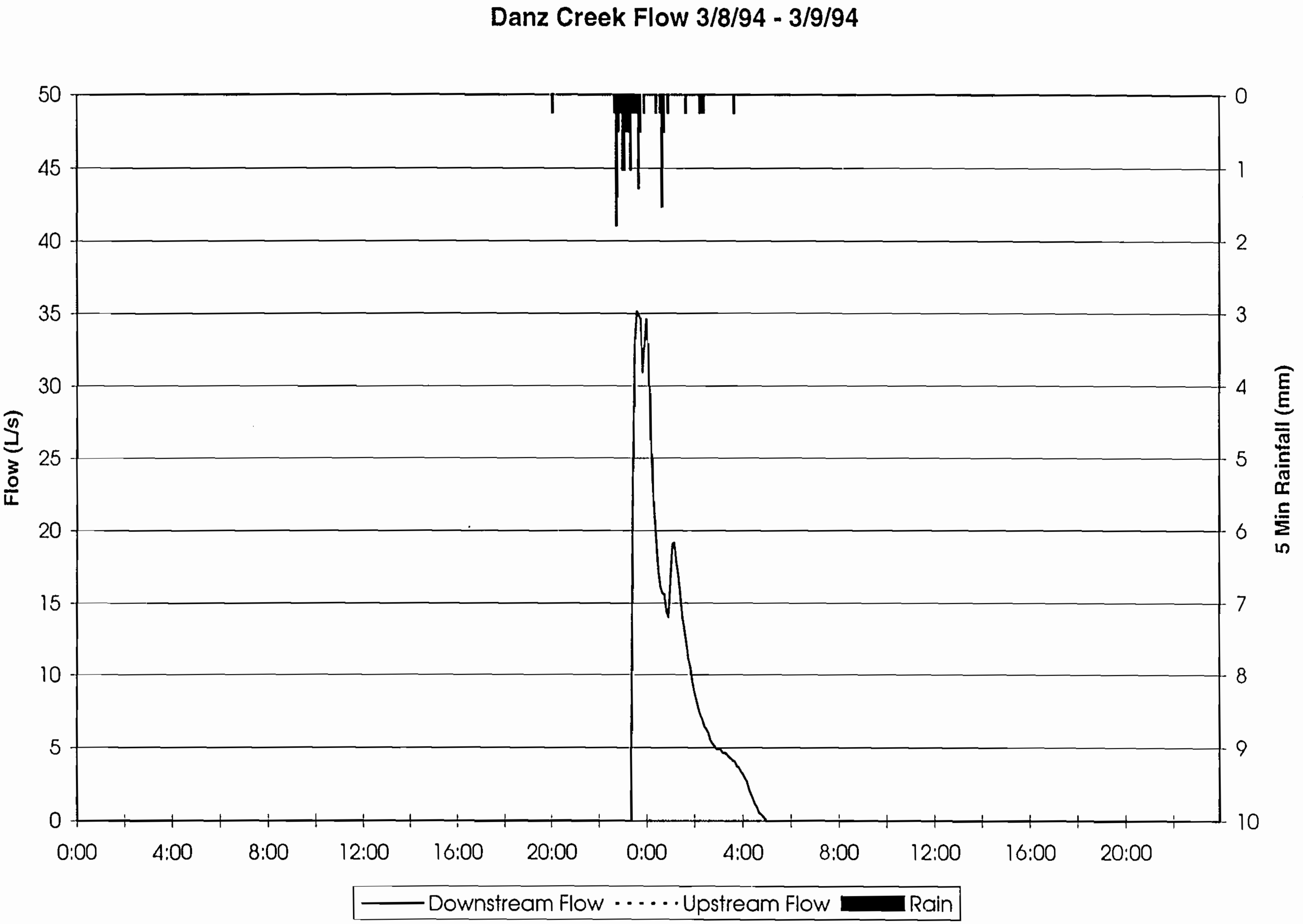
Downstream Sampling Interval 1/23/94 - 1/24/94

Danz Creek Flow 2/21/94 - 2/22/94



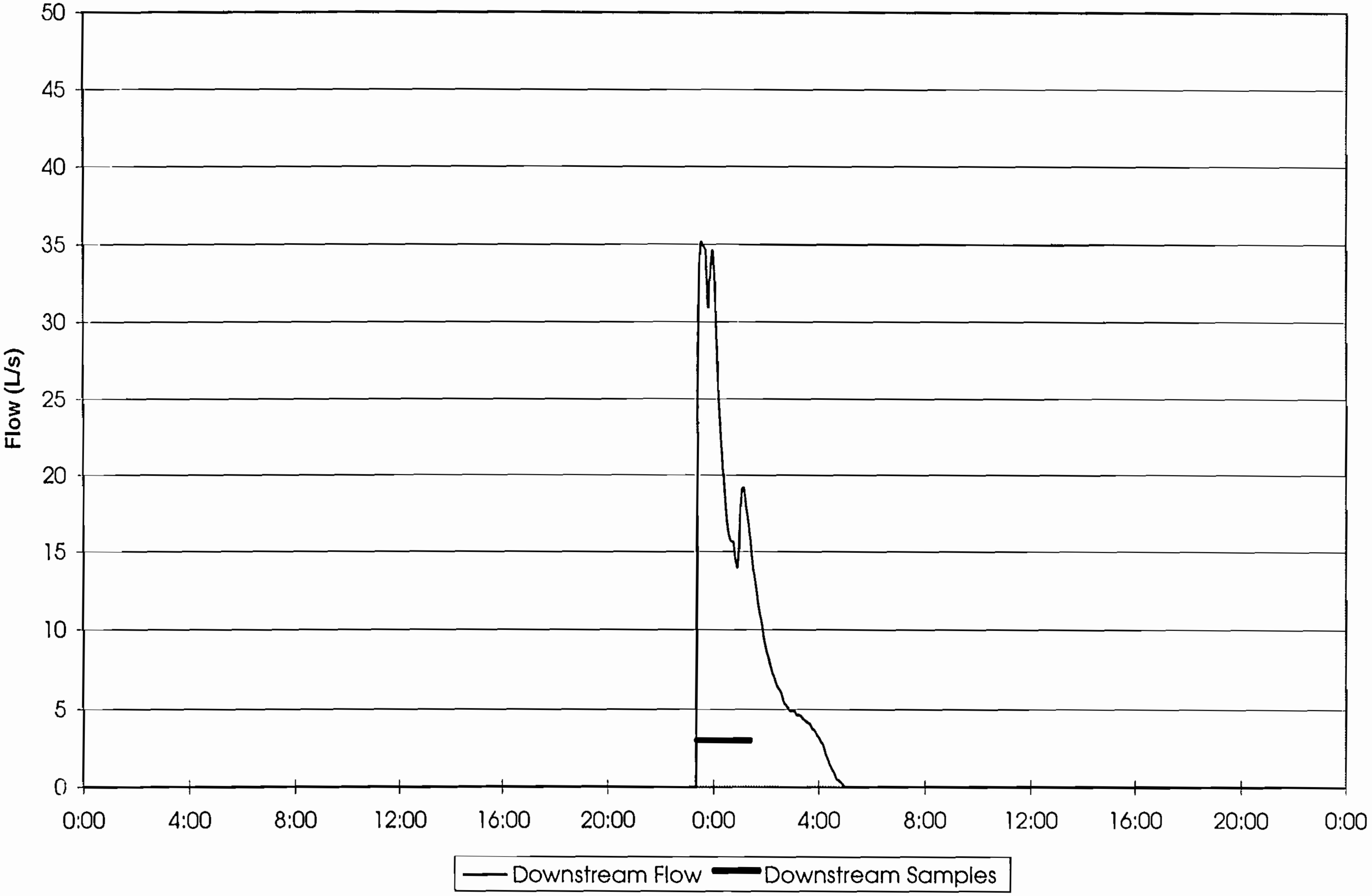
Downstream Sampling Interval 2/21/94 - 2/22/94



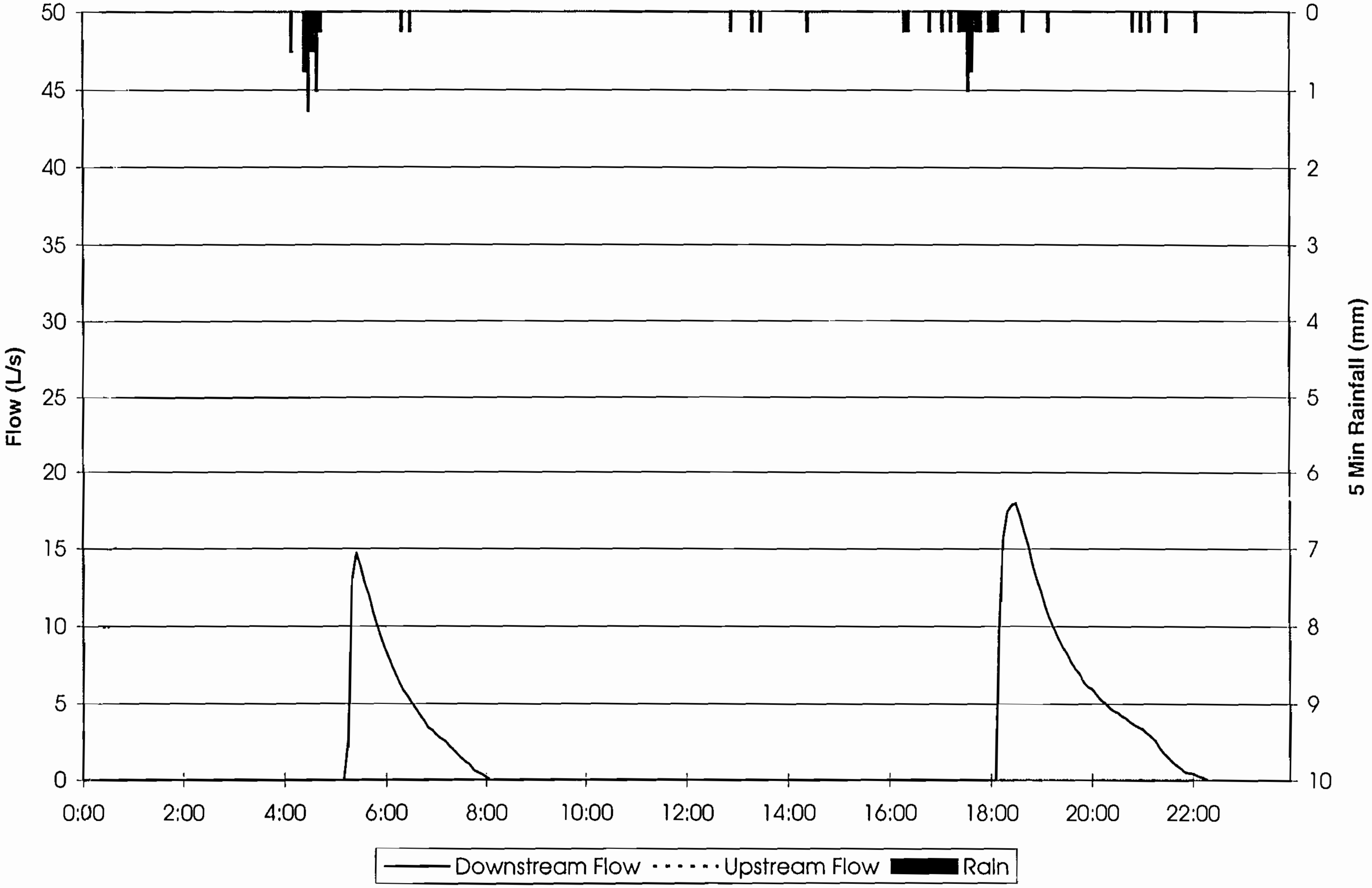


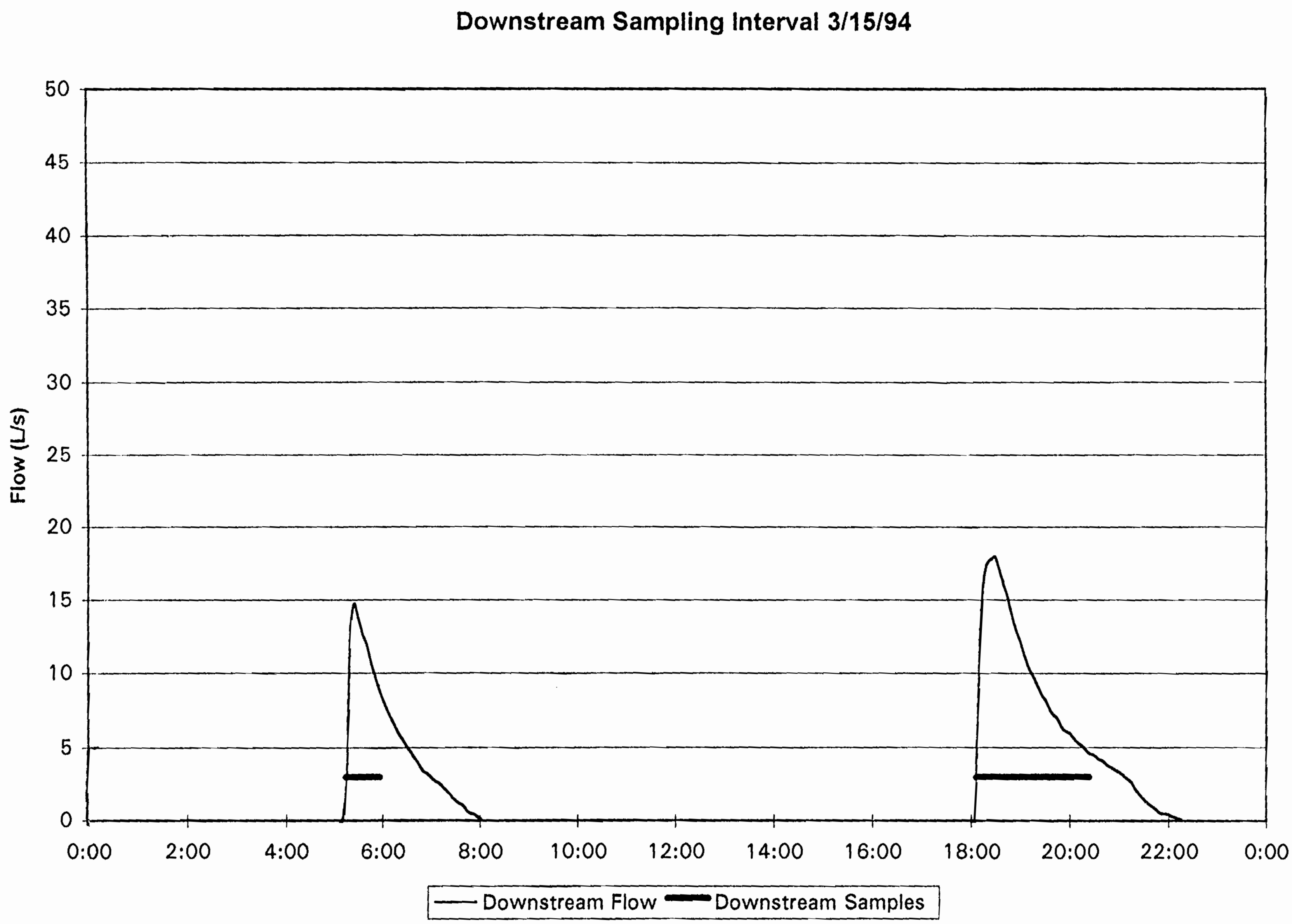
Danz Creek Flow 3/8/94 - 3/9/94

Downstream Sampling Interval 3/8/94 - 3/9/94

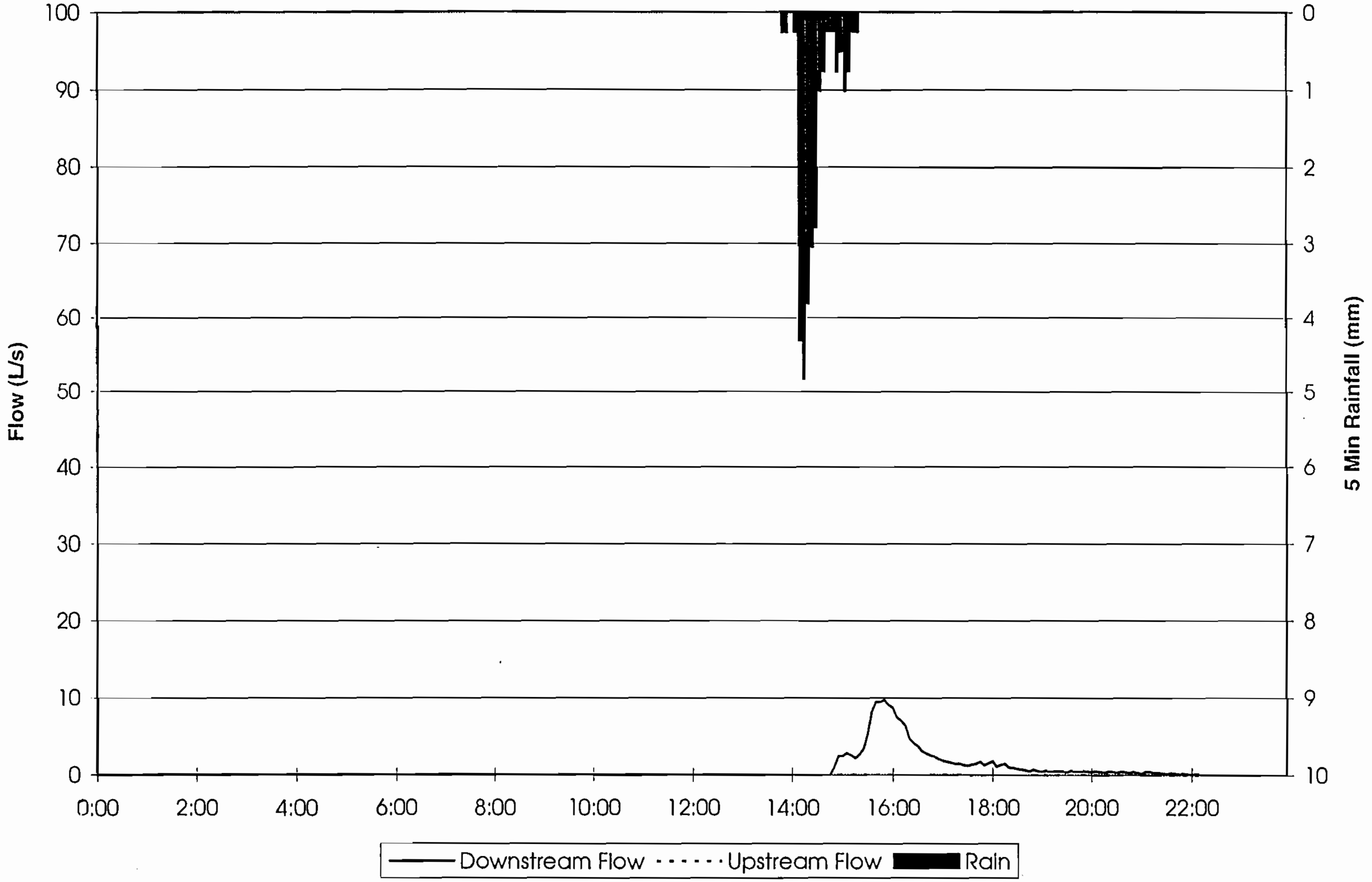


Danz Creek Flow 3/15/94

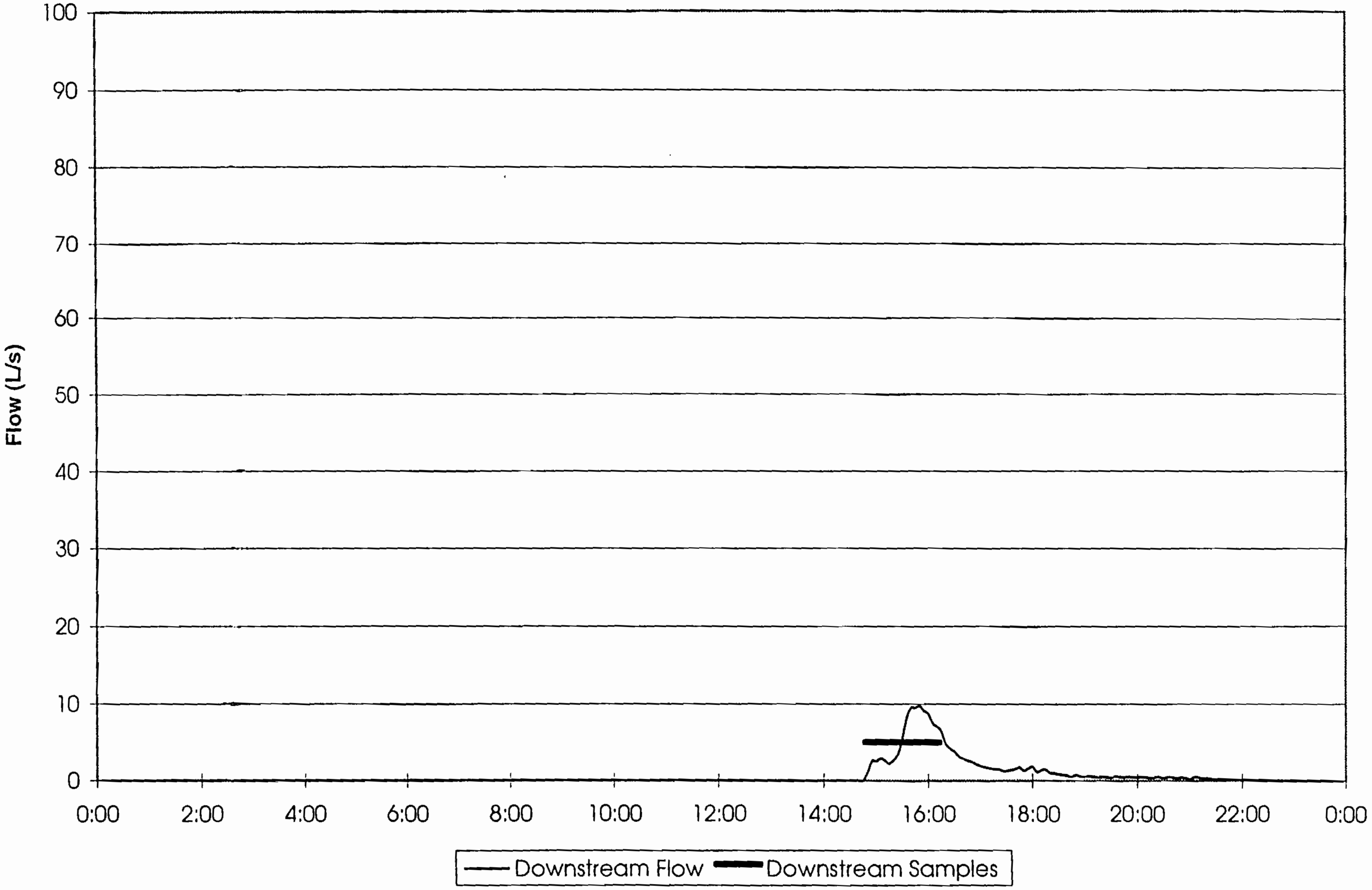



Downstream Sampling Interval 3/15/94
Flow (L/s)
50
45
40
35
30
25
20
15
10
5
0
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00
Downstream Flow
Downstream Samples

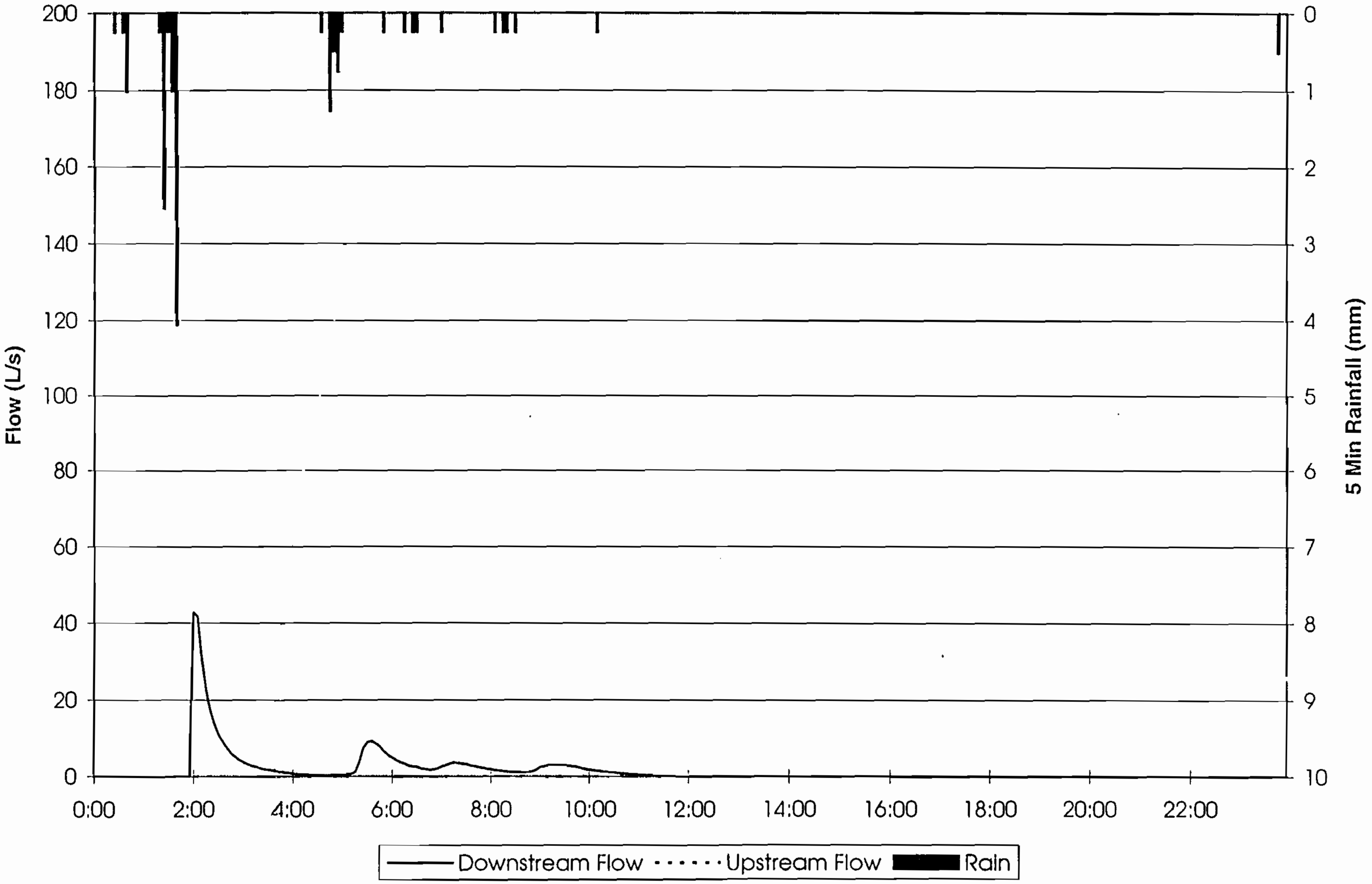
Danz Creek Flow 4/22/94



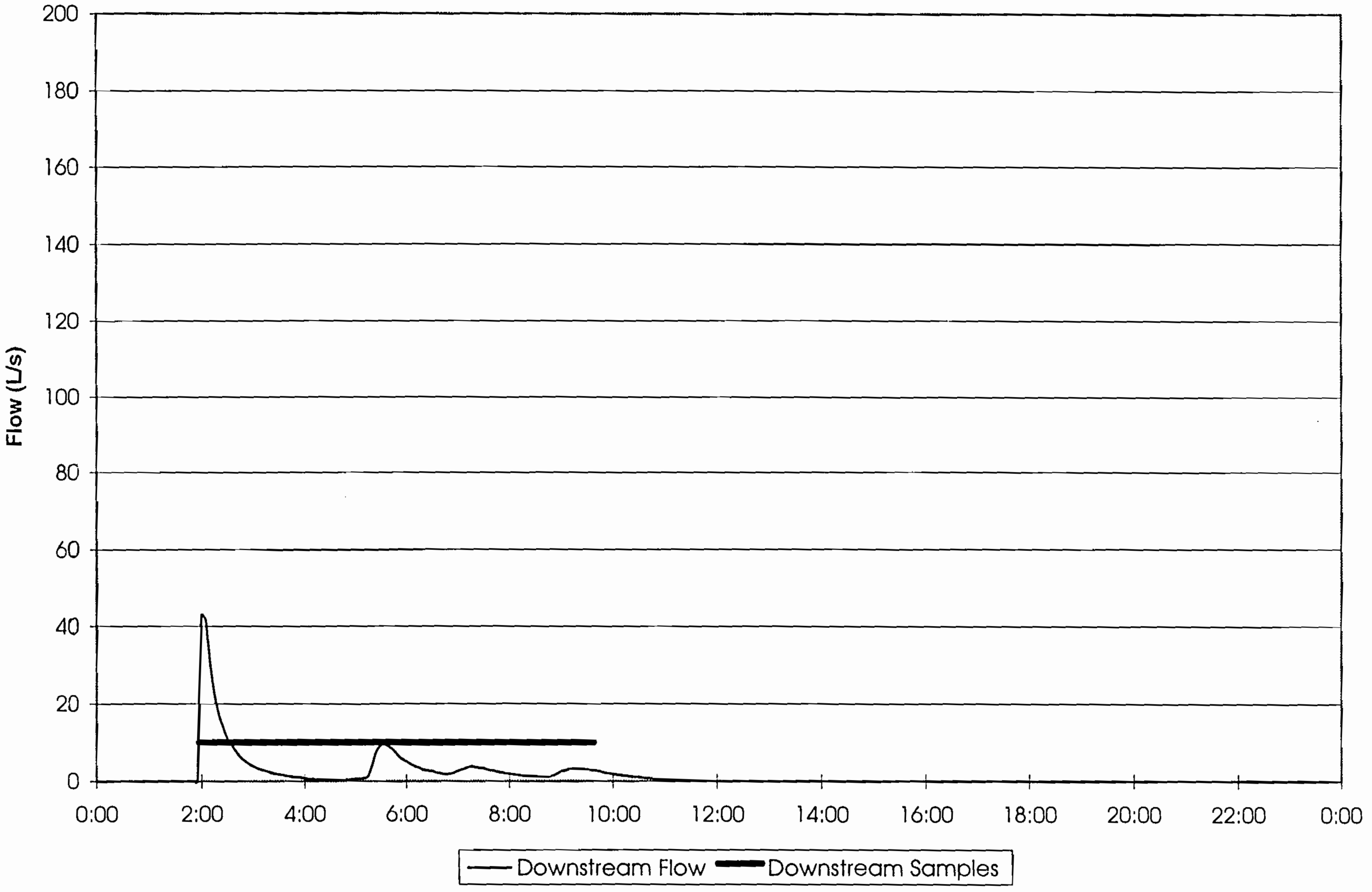
Downstream Sampling Interval 4/22/94

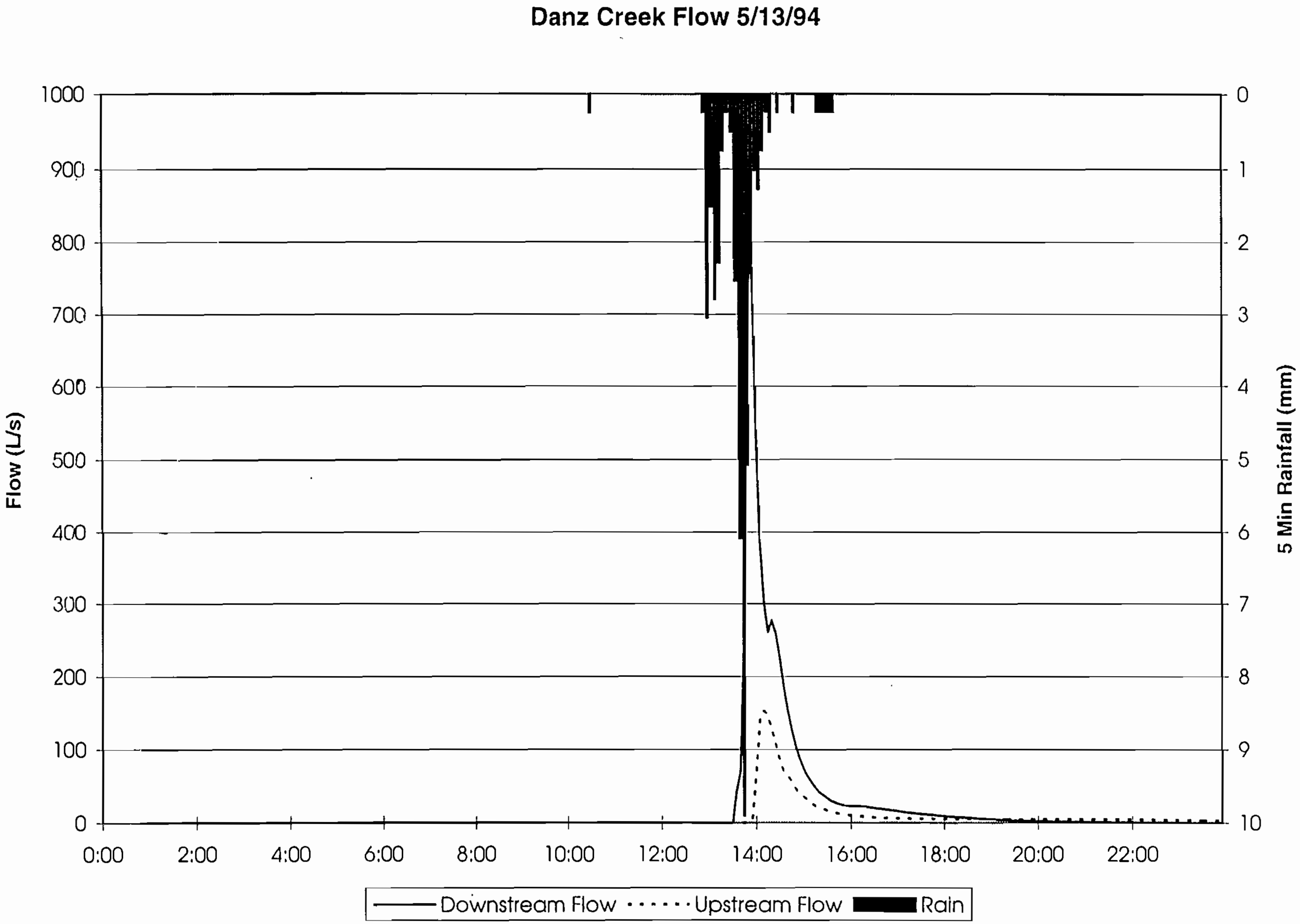


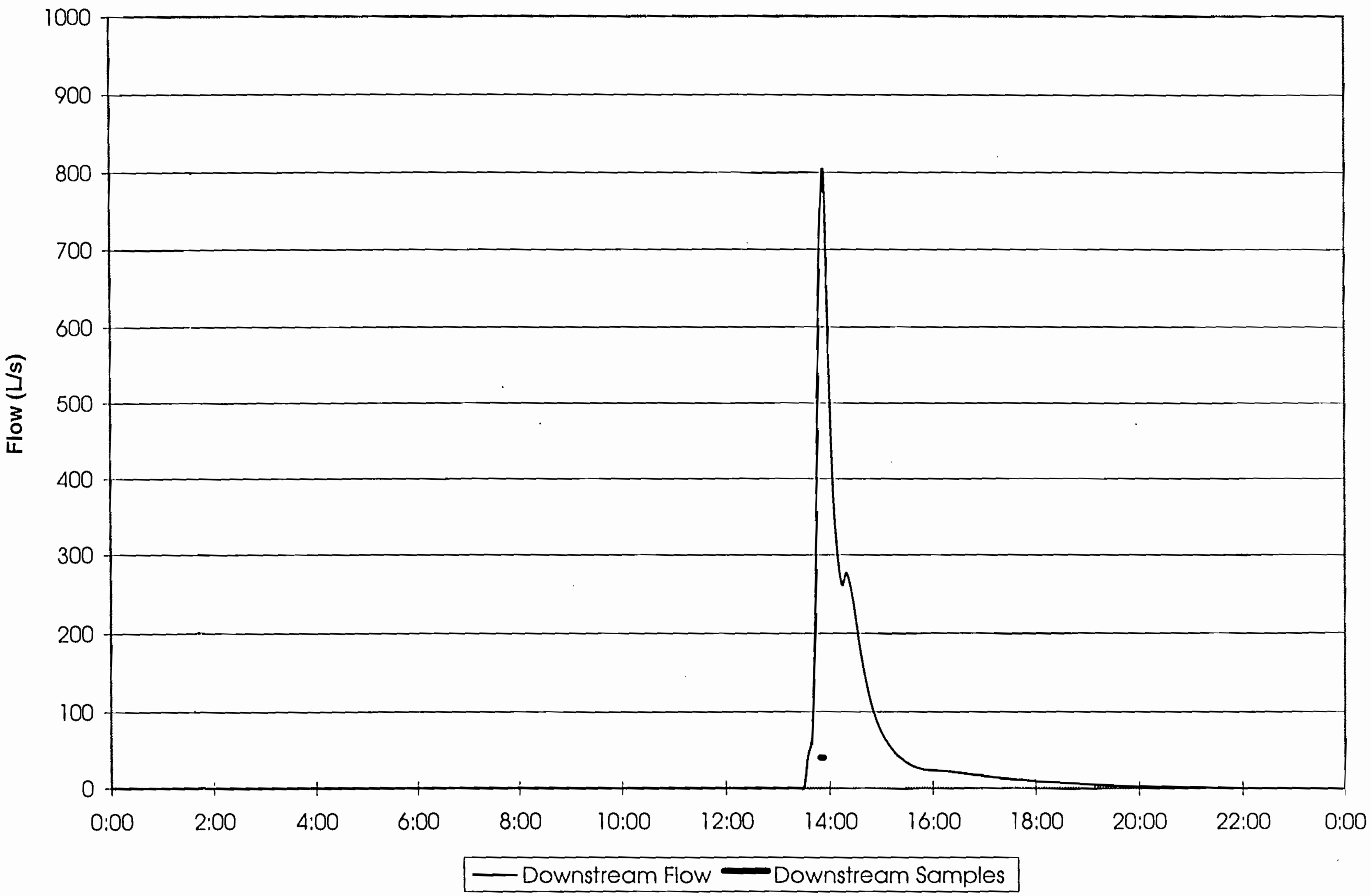
Danz Creek Flow 4/29/94



Downstream Sampling Interval 4/29/94

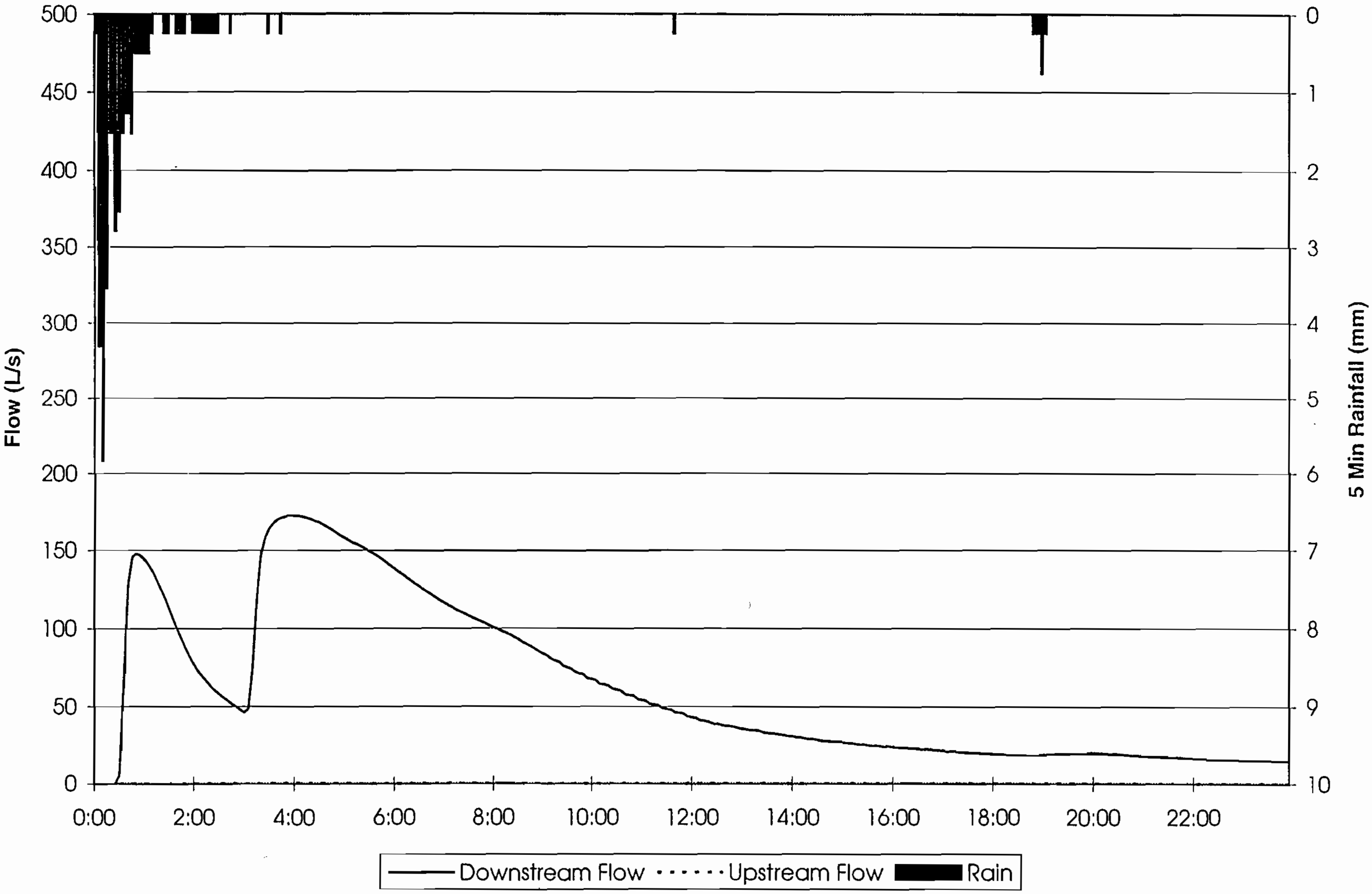



Danz Creek Flow 5/13/94
Flow (L/s)
1000
900
800
700
600
500
400
300
200
100
0
5 Min Rainfall (mm)
0
1
2
3
4
5
6
7
8
9
10
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
Downstream Flow
Upstream Flow
Rain

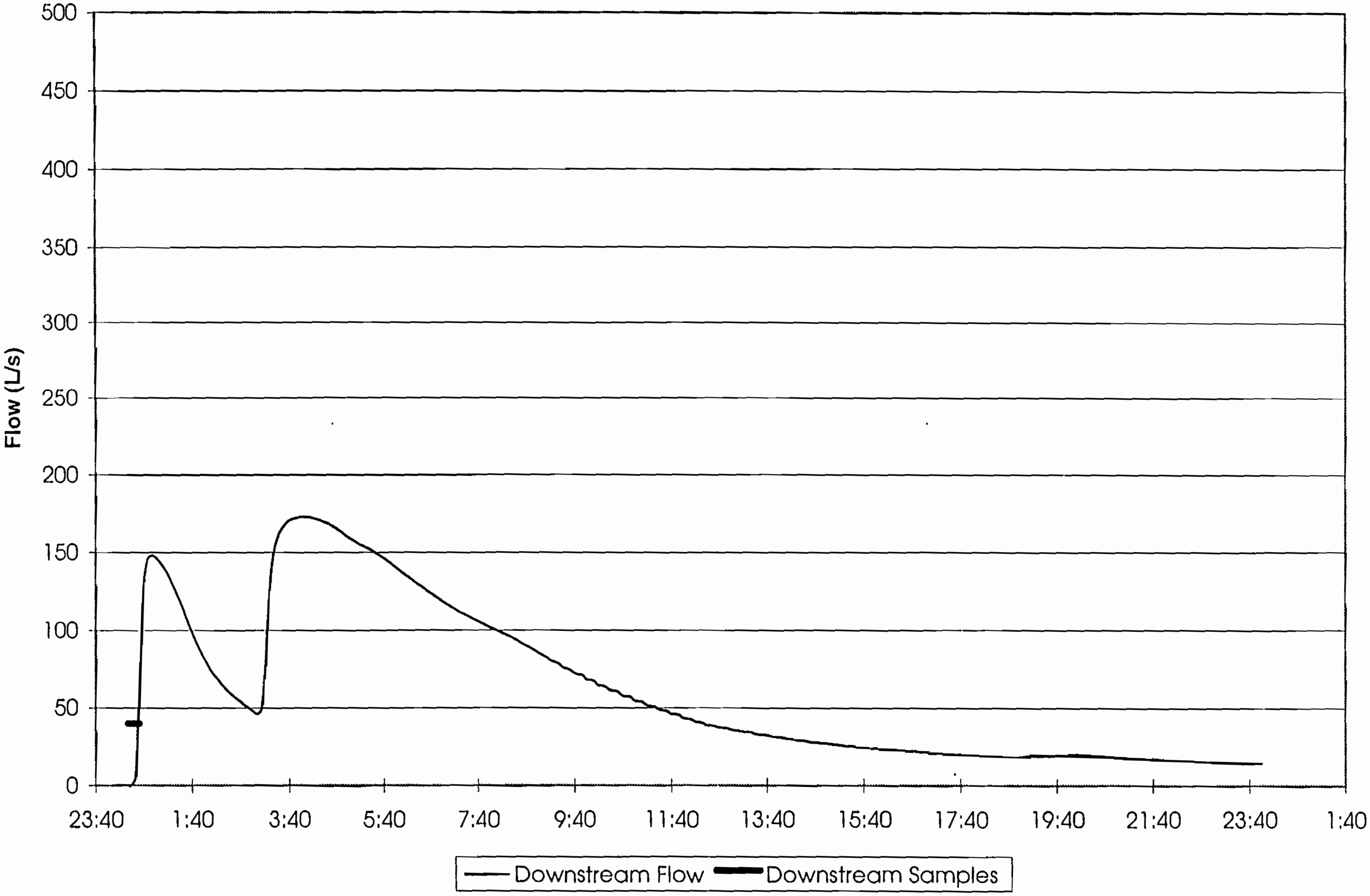


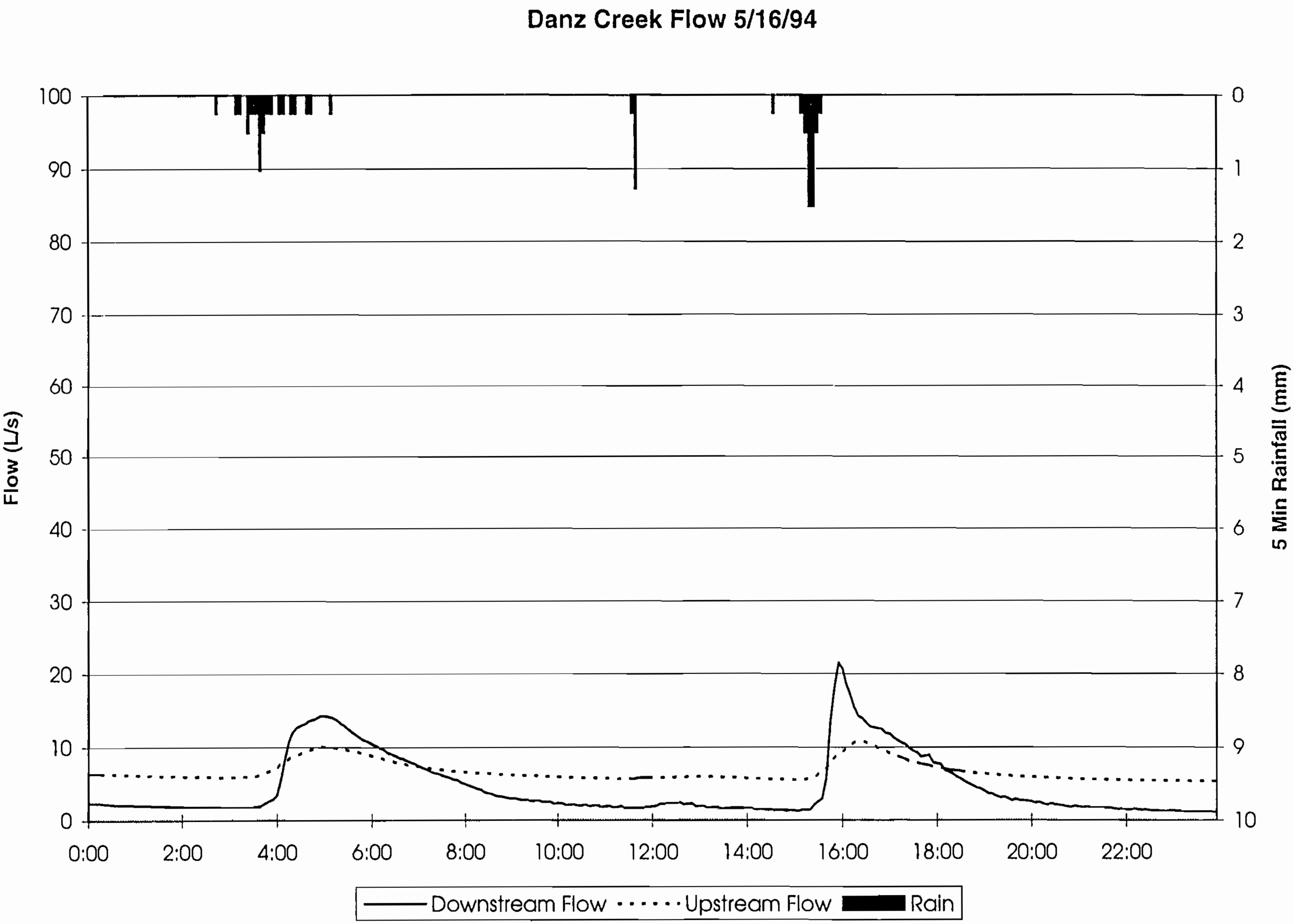
Downstream Sampling Interval 5/13/94

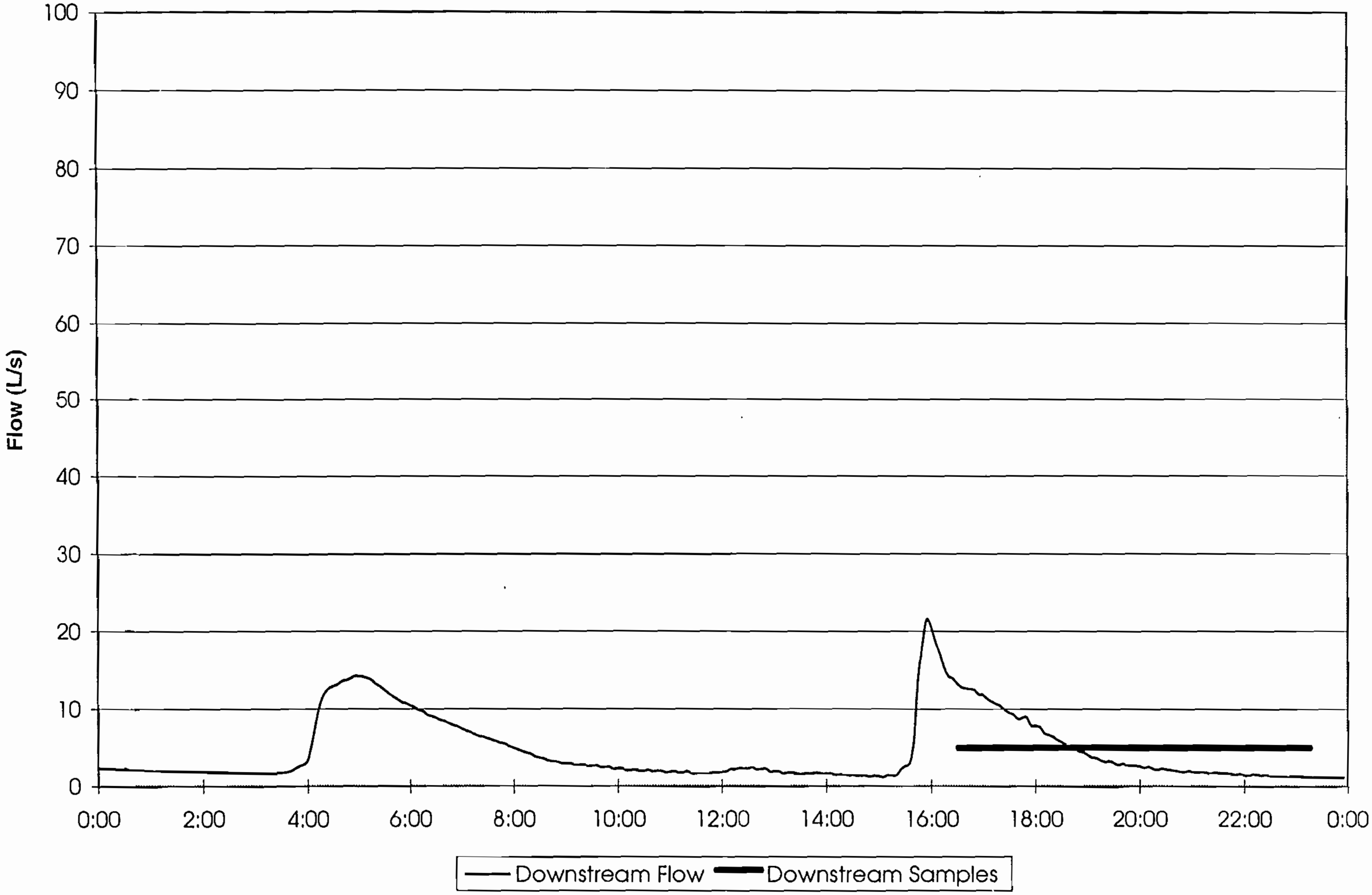
Danz Creek Flow 5/15/94



Downstream Sampling Interval 5/15/94

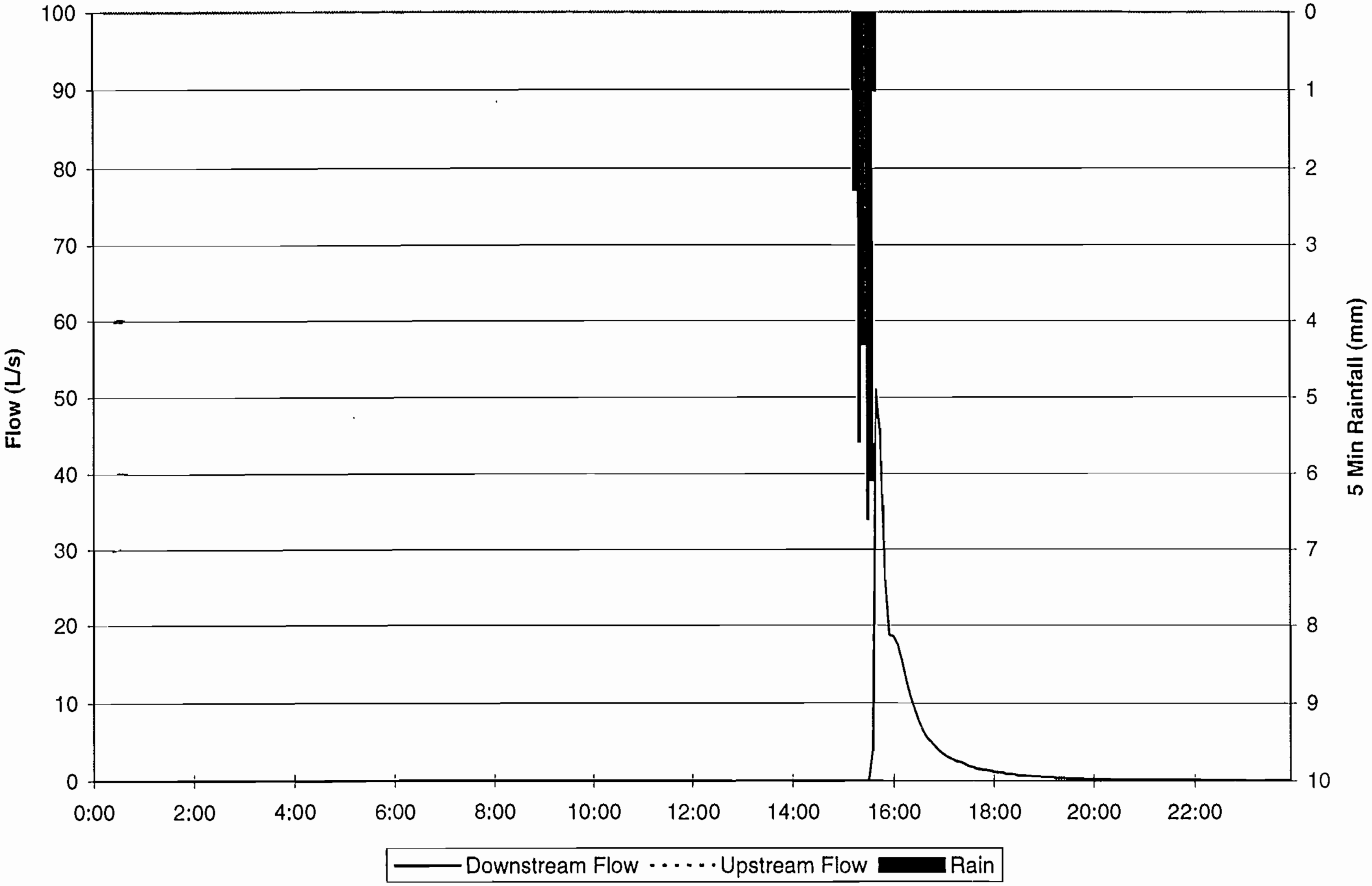


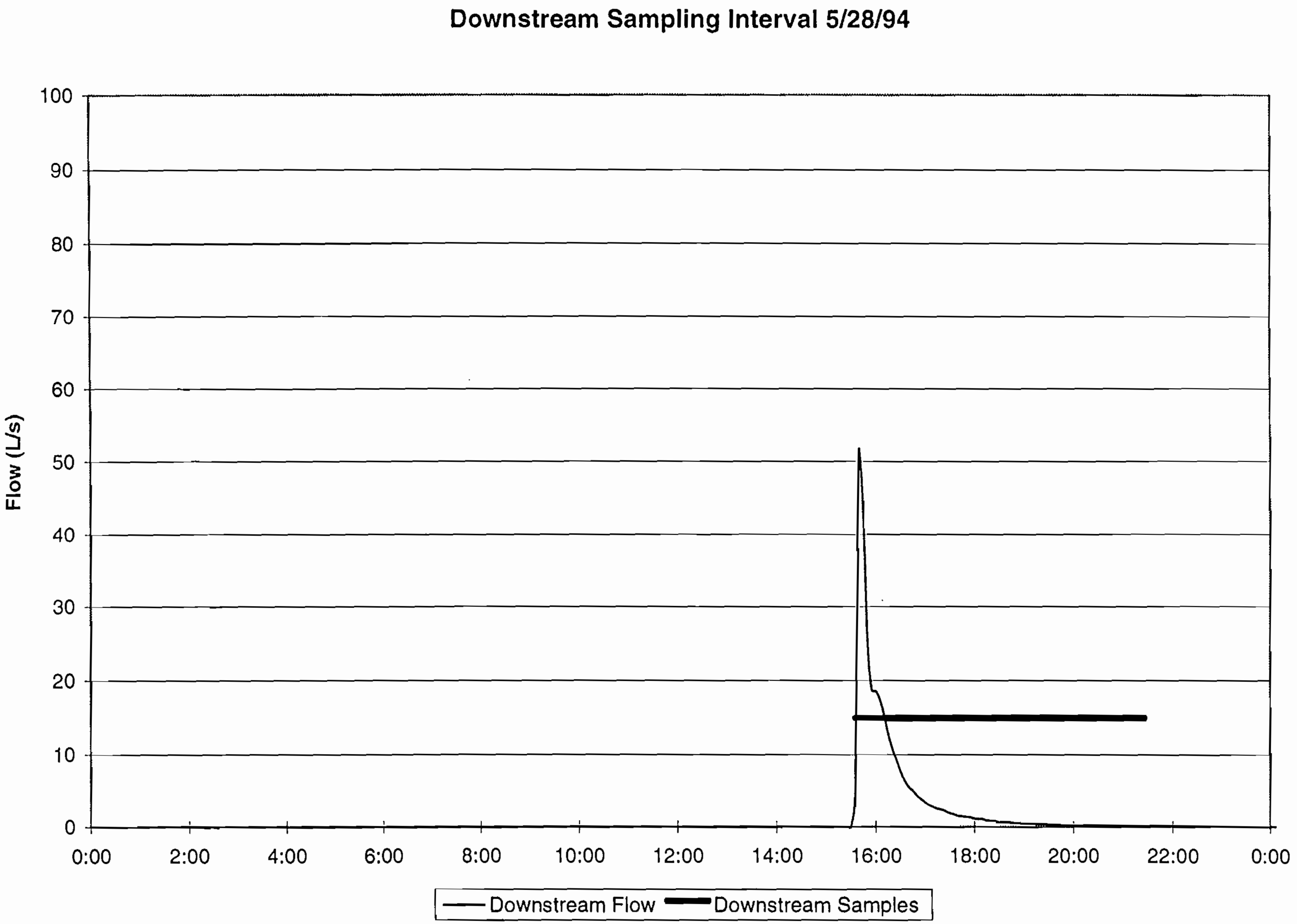

Danz Creek Flow 5/16/94
Flow (L/s)
100
90
80
70
60
50
40
30
20
10
0
5 Min Rainfall (mm)
0
1
2
3
4
5
6
7
8
9
10
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
Downstream Flow
Upstream Flow
Rain

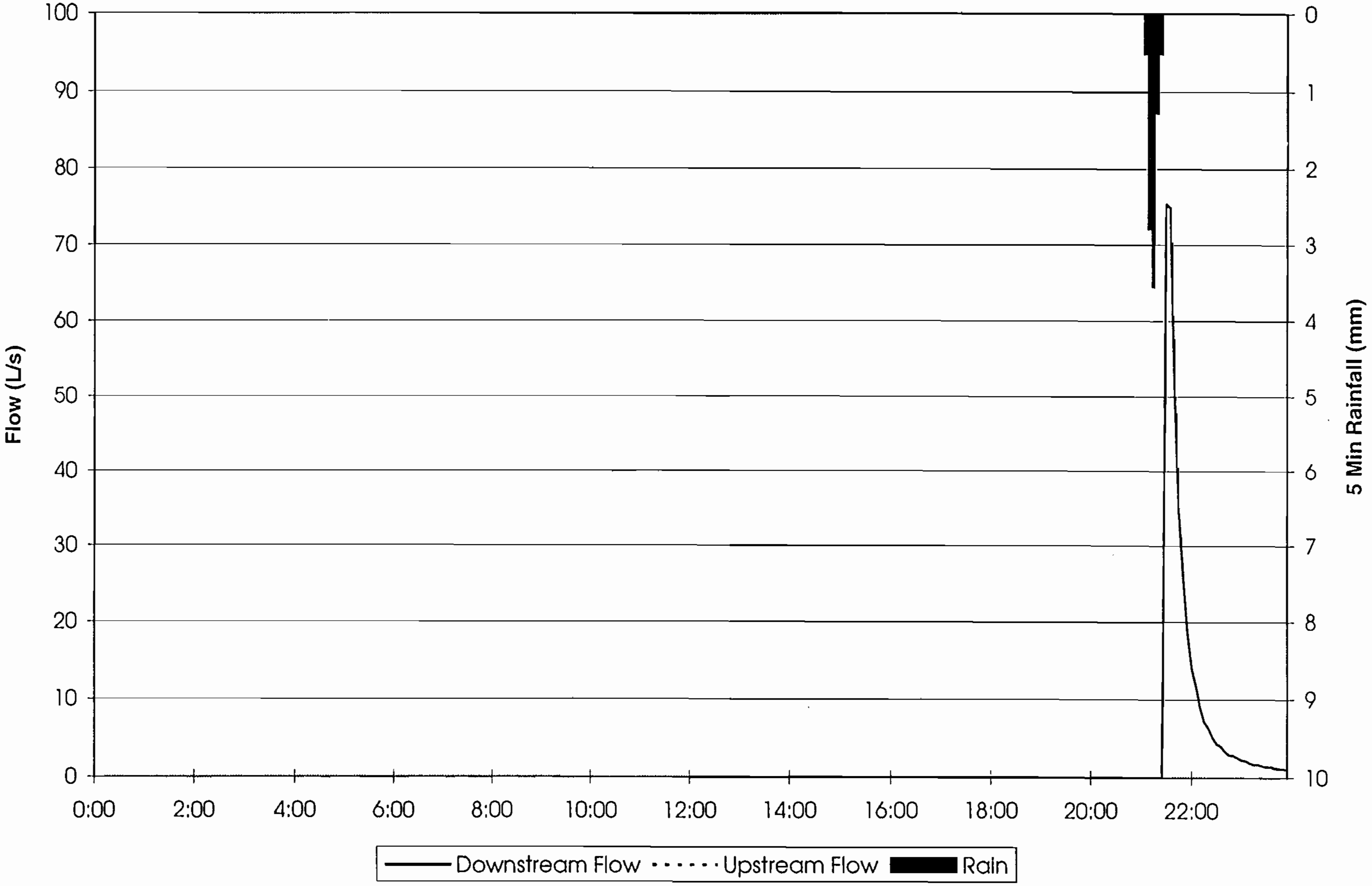


Downstream Sampling Interval 5/16/94

Danz Creek Flow 5/28/94

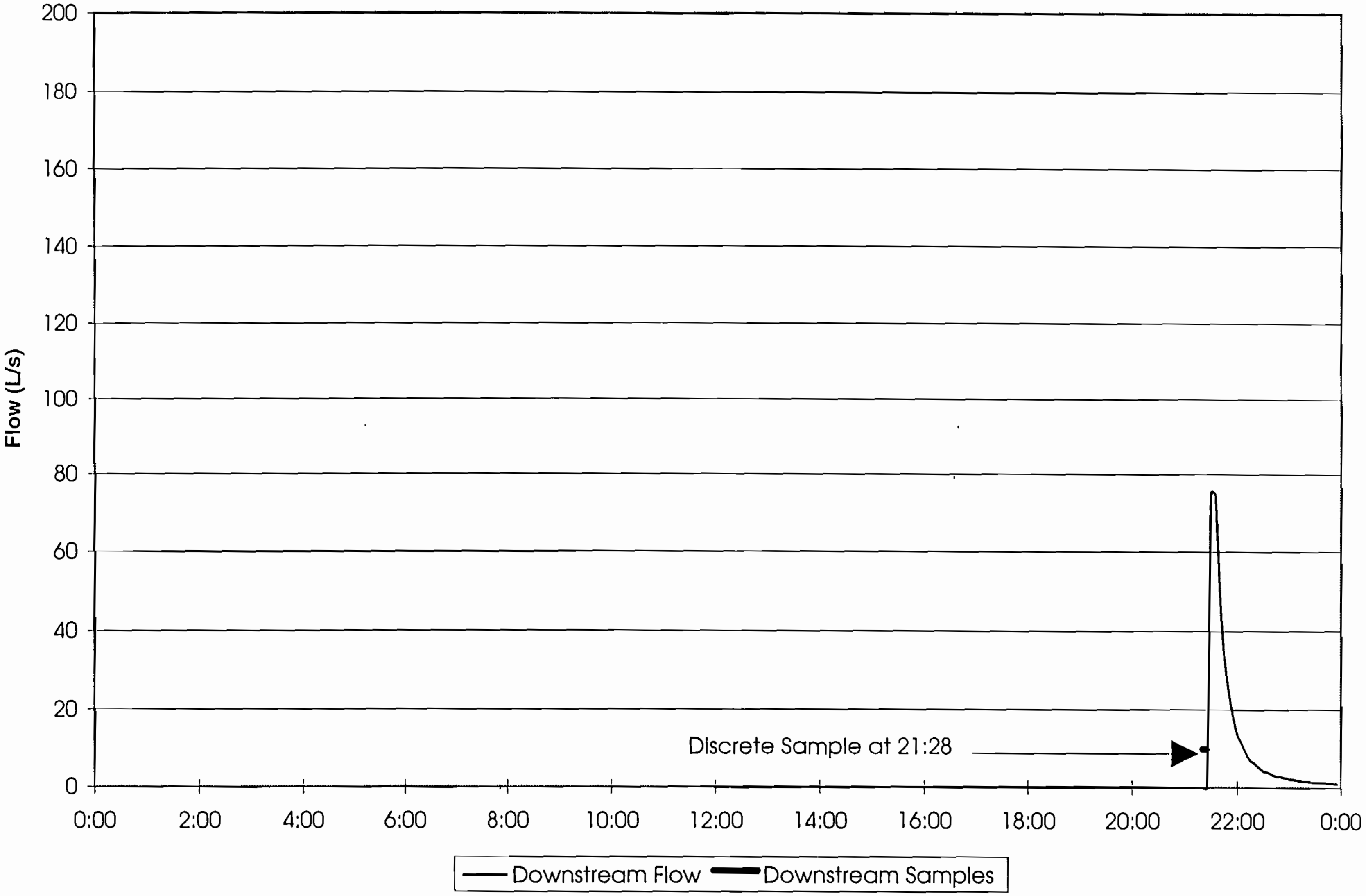


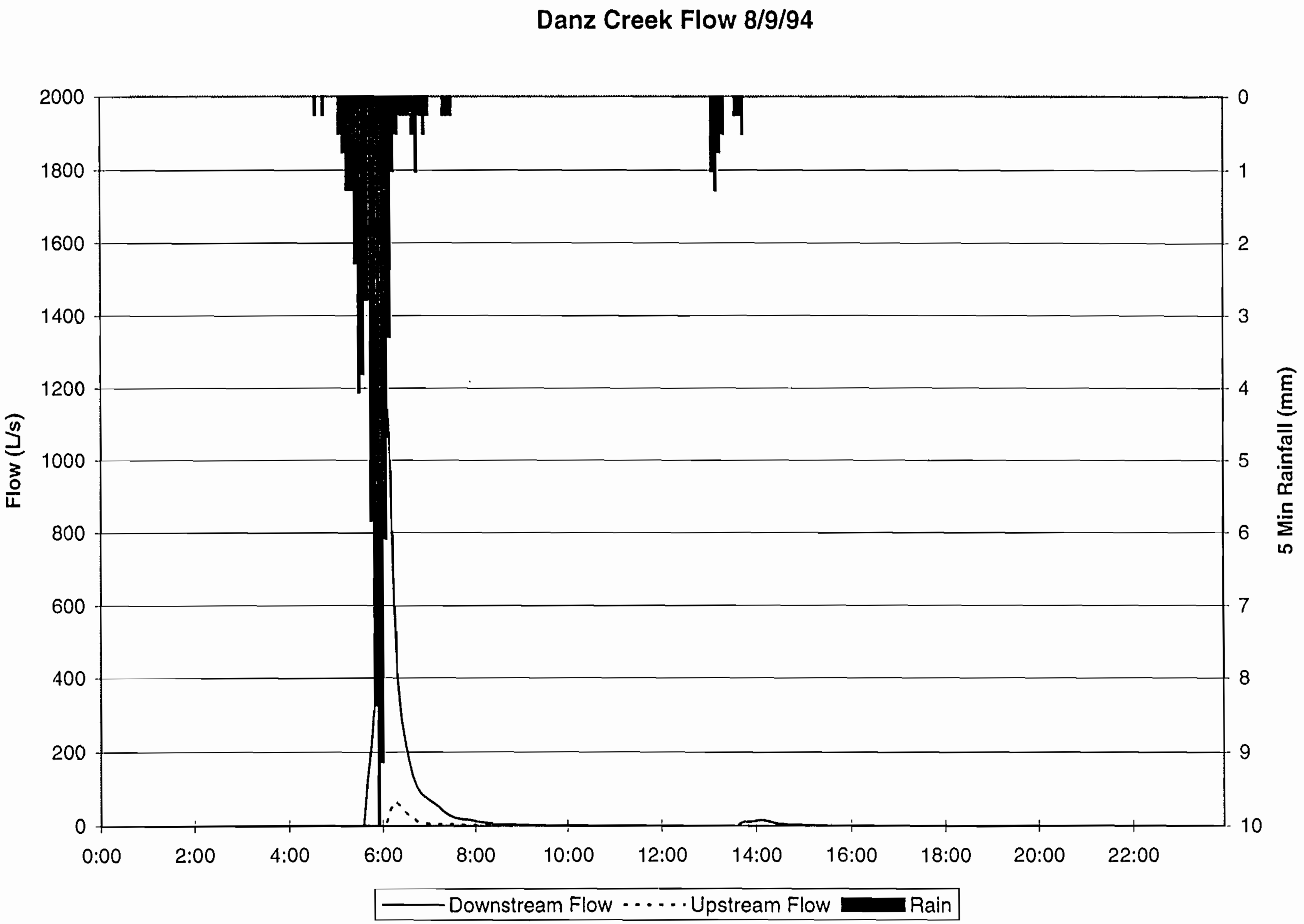

Downstream Sampling Interval 5/28/94
Flow (L/s)
100
90
80
70
60
50
40
30
20
10
0
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00
Downstream Flow
Downstream Samples



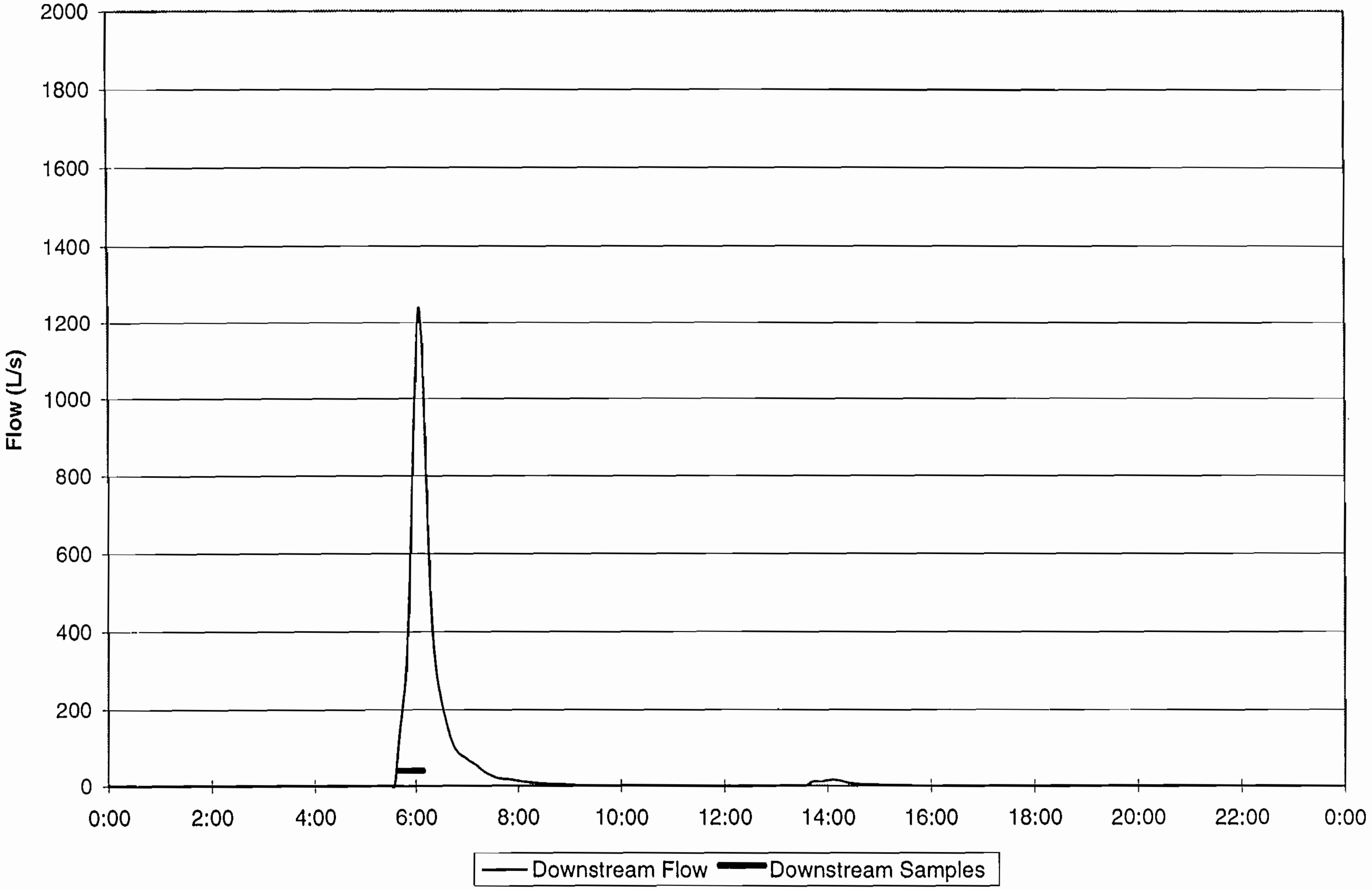
Danz Creek Flow 6/20/94

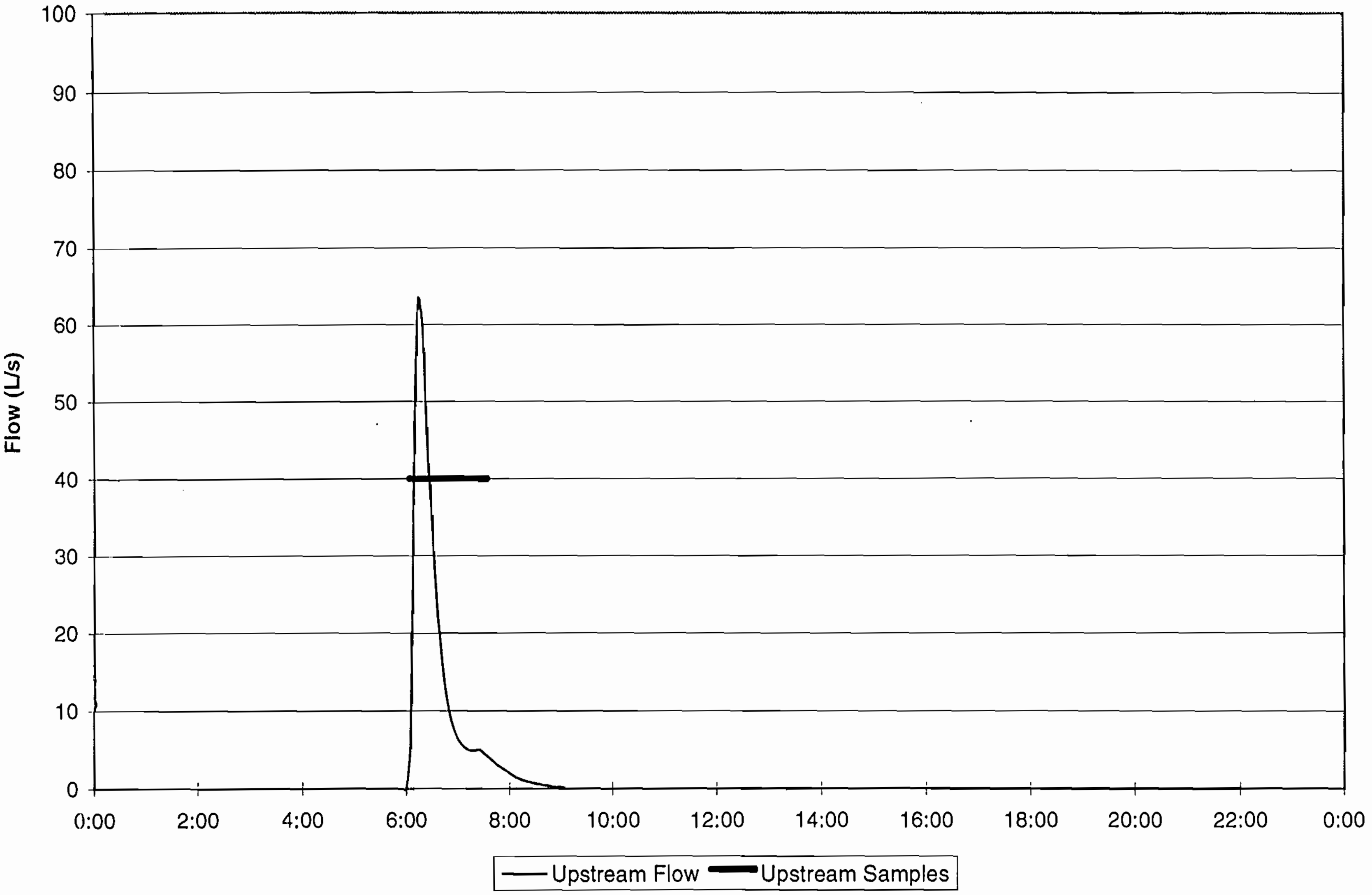
Downstream Sampling Interval 6/20/94



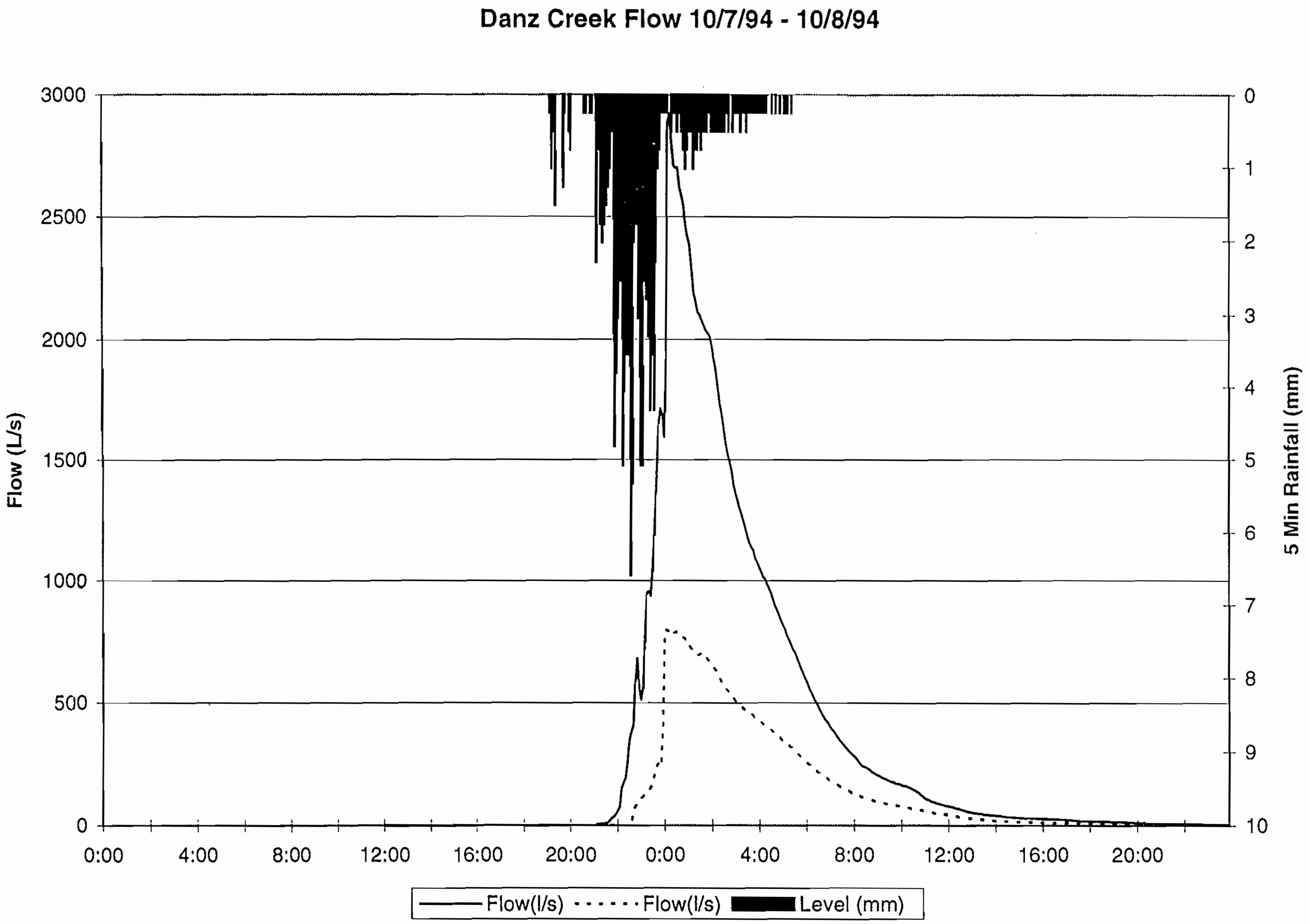

Danz Creek Flow 8/9/94
Flow (L/s)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
5 Min Rainfall (mm)
0
1
2
3
4
5
6
7
8
9
10
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
Downstream Flow
Upstream Flow
Rain

Downstream Sampling Interval 8/9/94

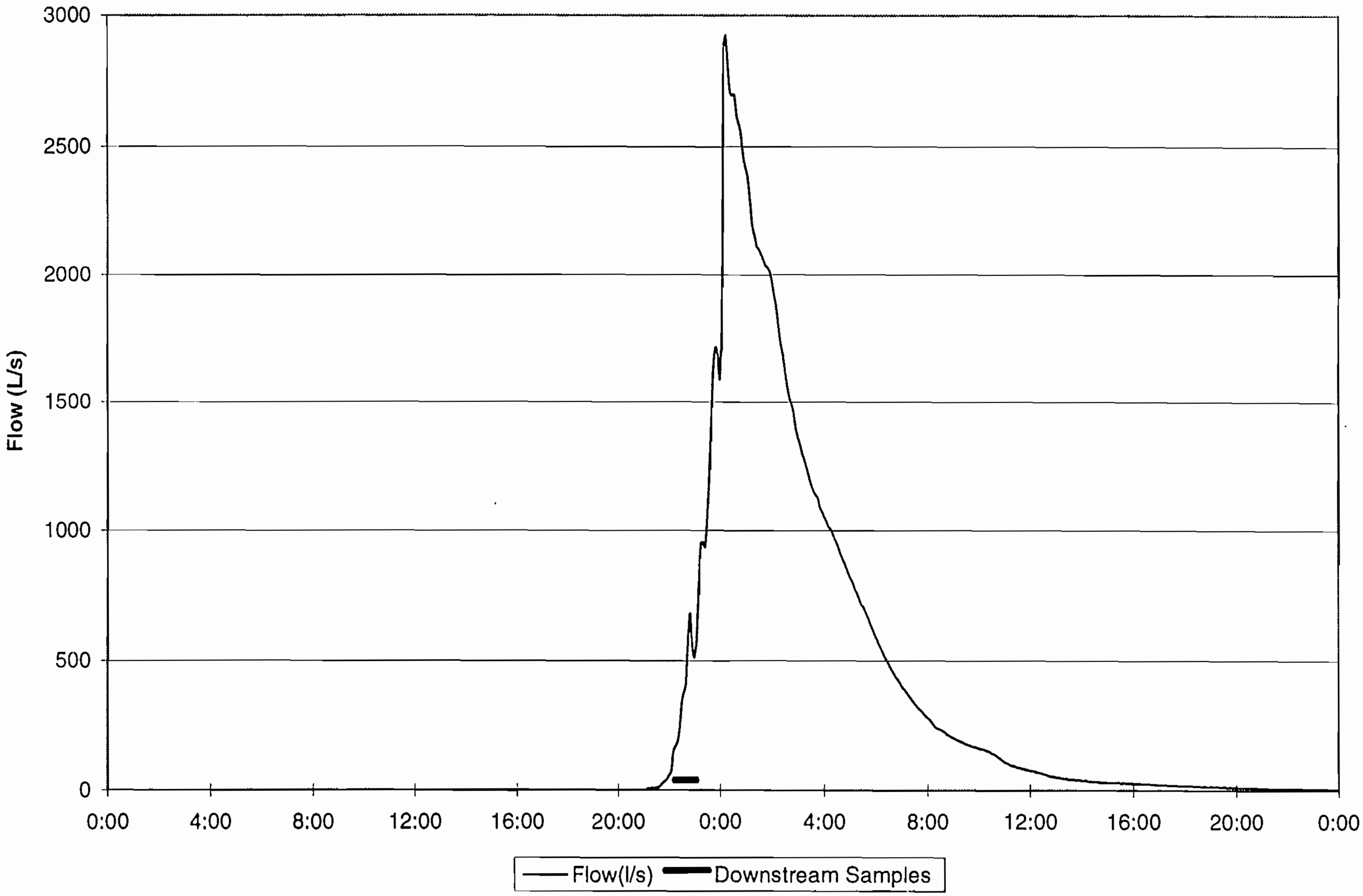




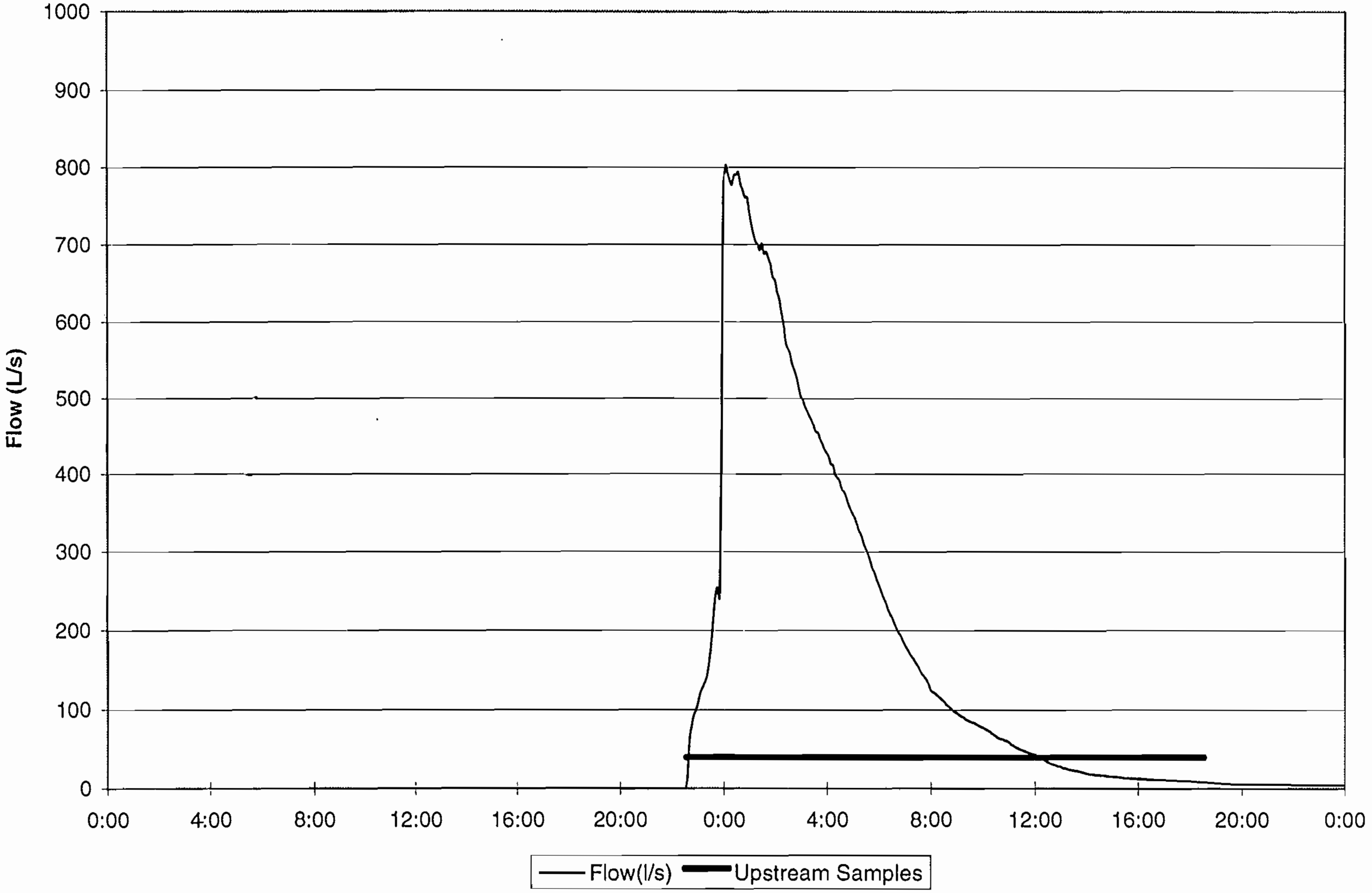
Upstream Sampling Interval 8/9/94



Danz Creek Flow 10/7/94 - 10/8/94

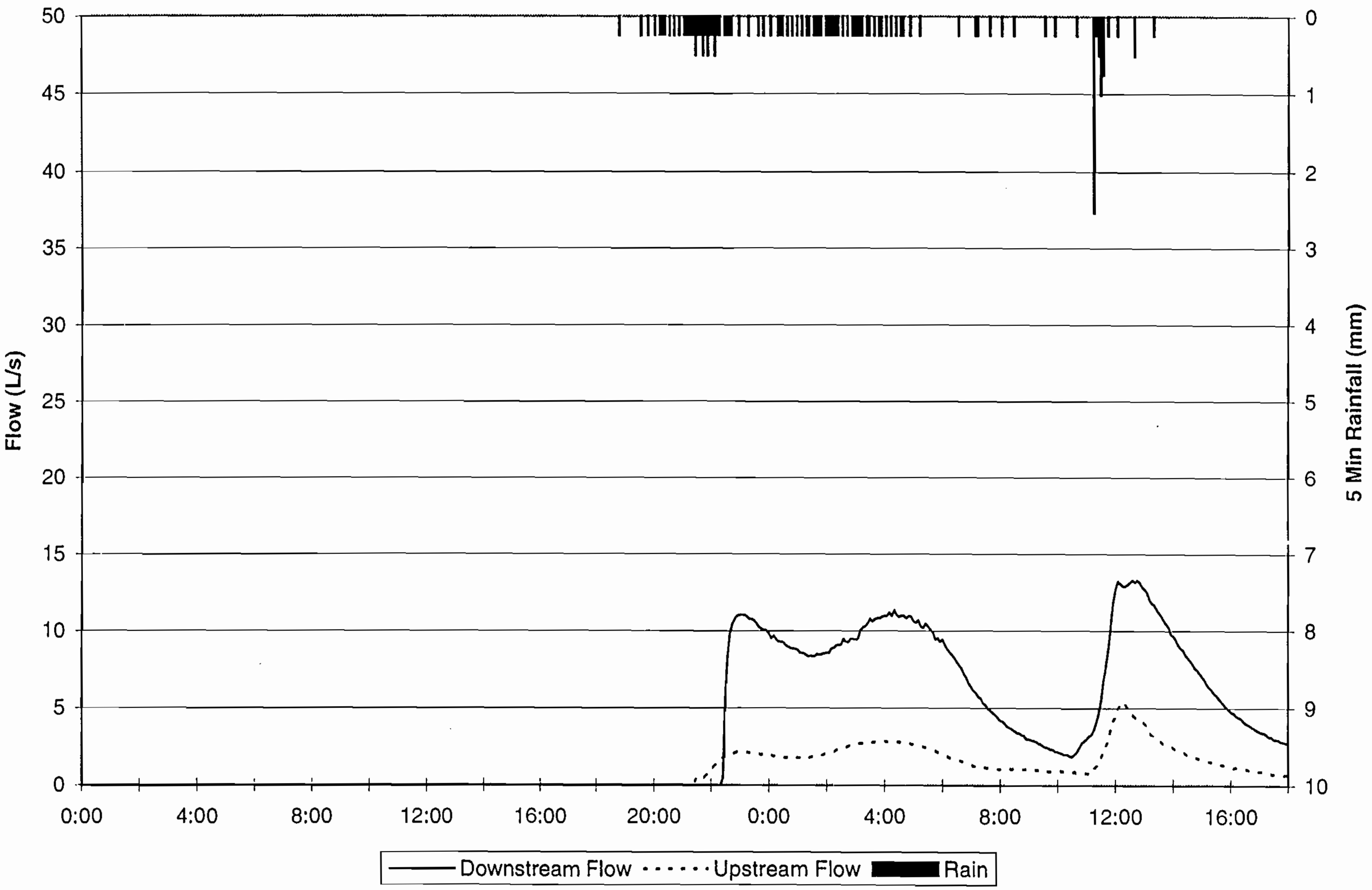


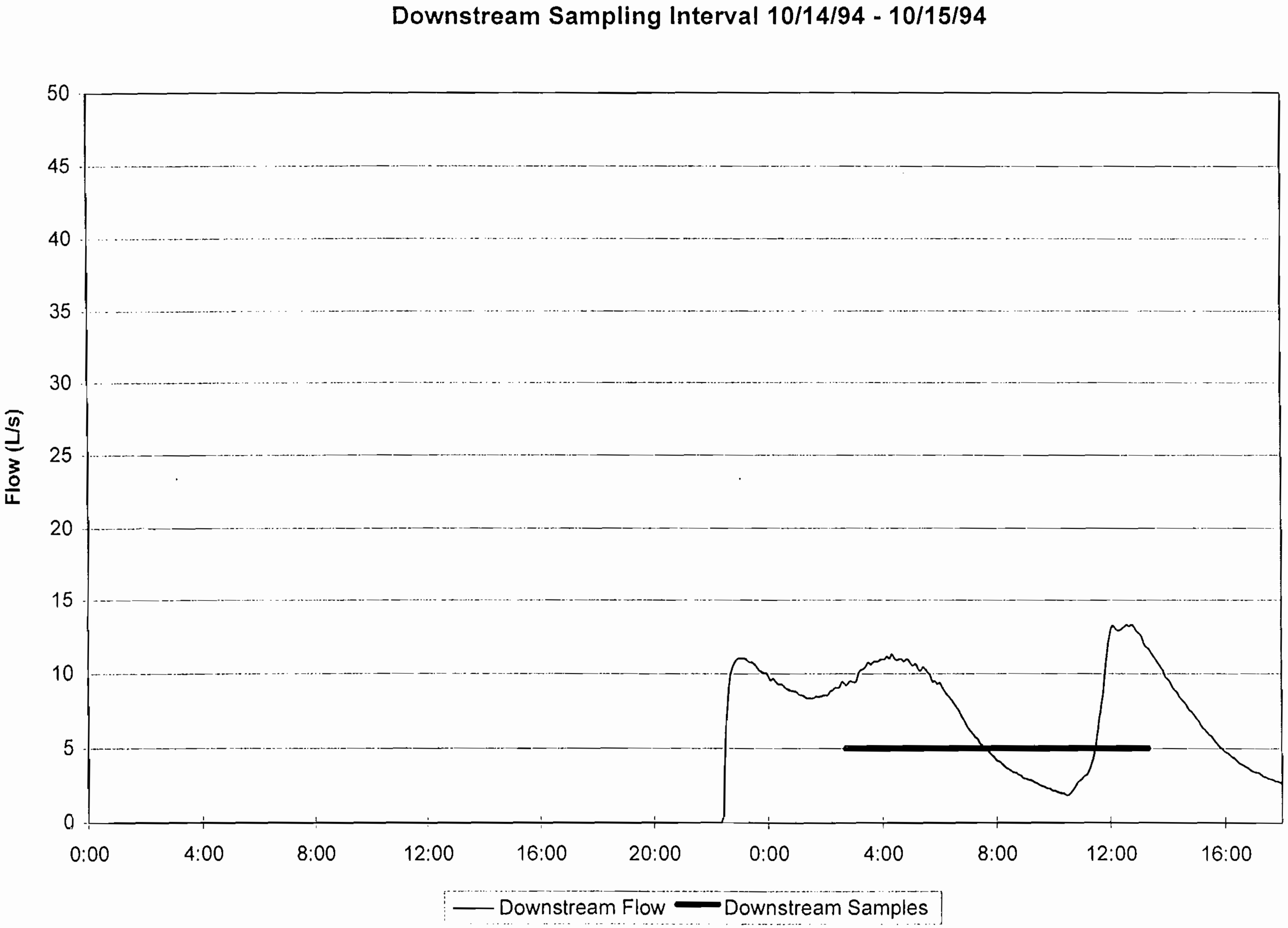
Downstream Sampling Interval 10/7/94 - 10/8/94



Upstream Sampling Interval 10/7/94 - 10/8/94

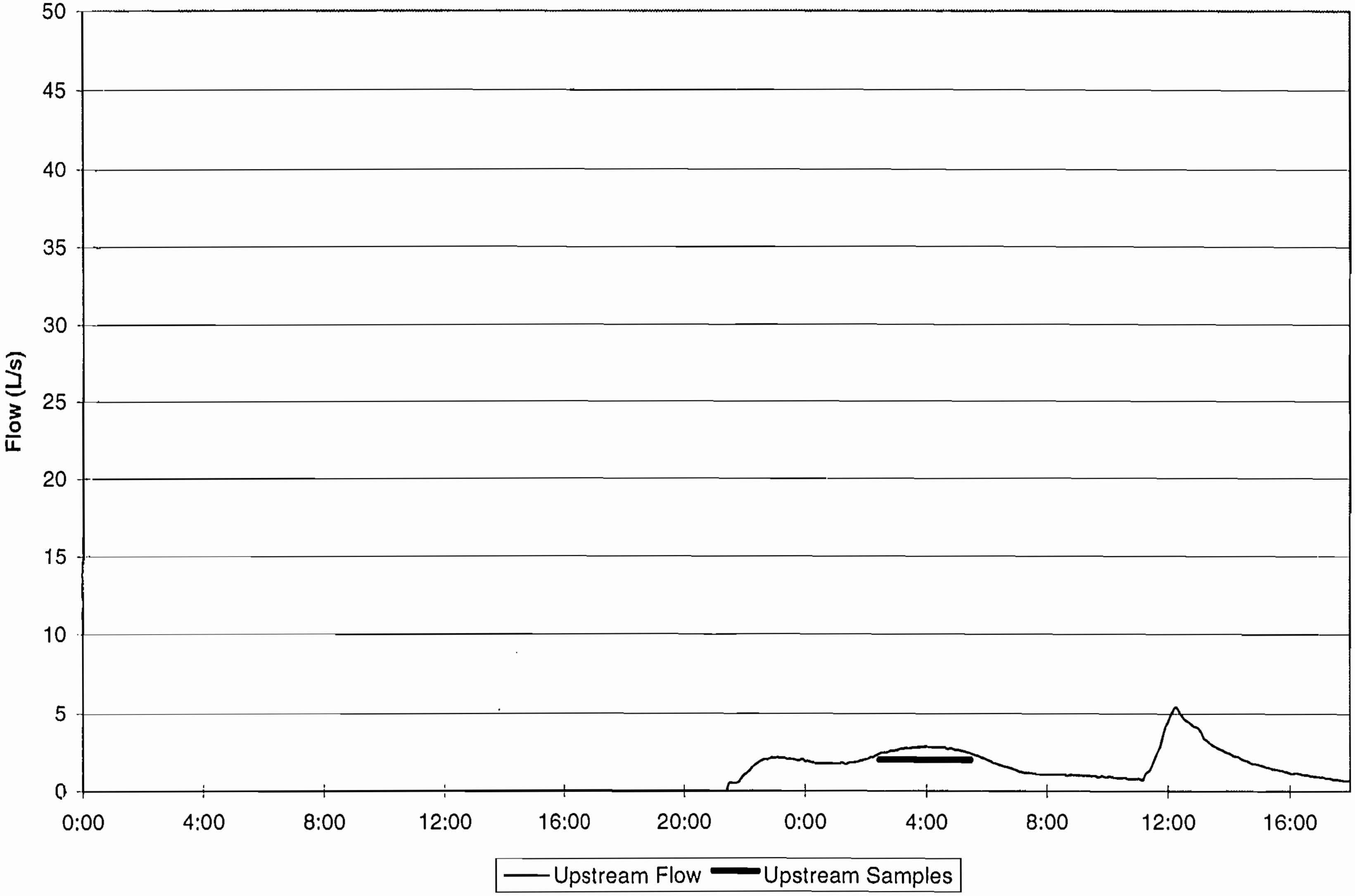
Danz Creek Flow 10/14/94 - 10/15/94



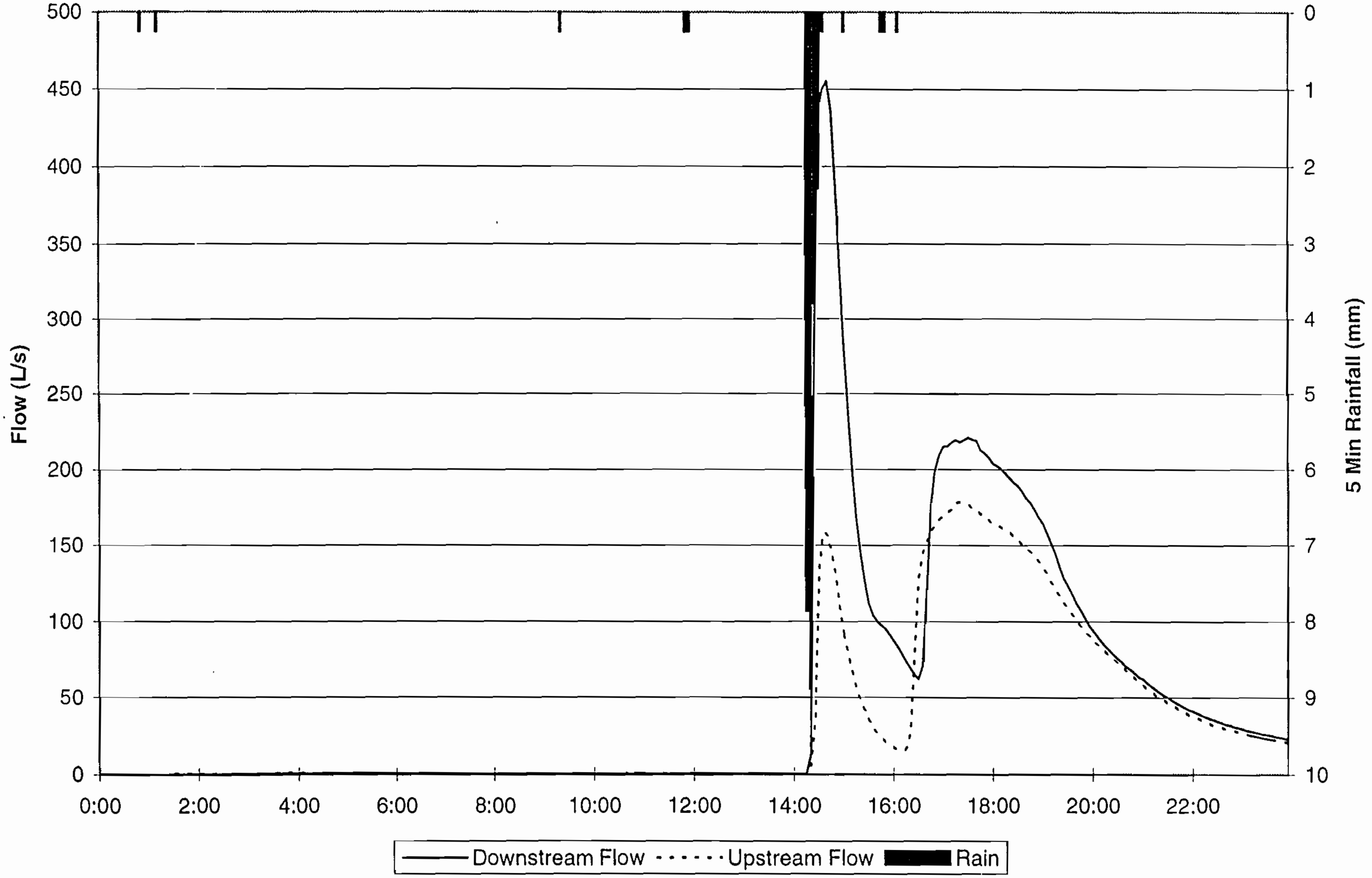


Downstream Sampling Interval 10/14/94 - 10/15/94

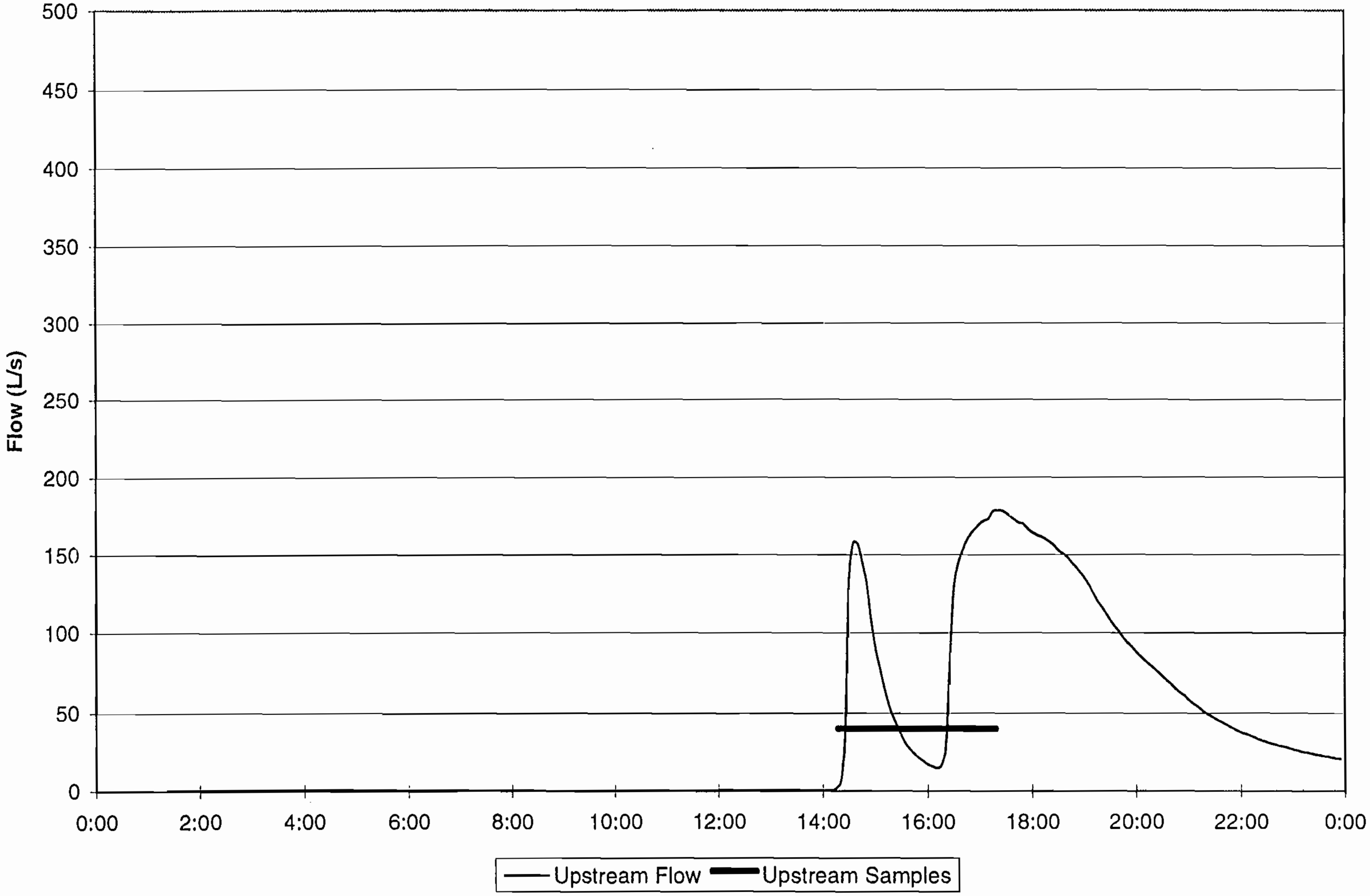
Upstream Sampling Interval 10/14/94 - 10/15/94

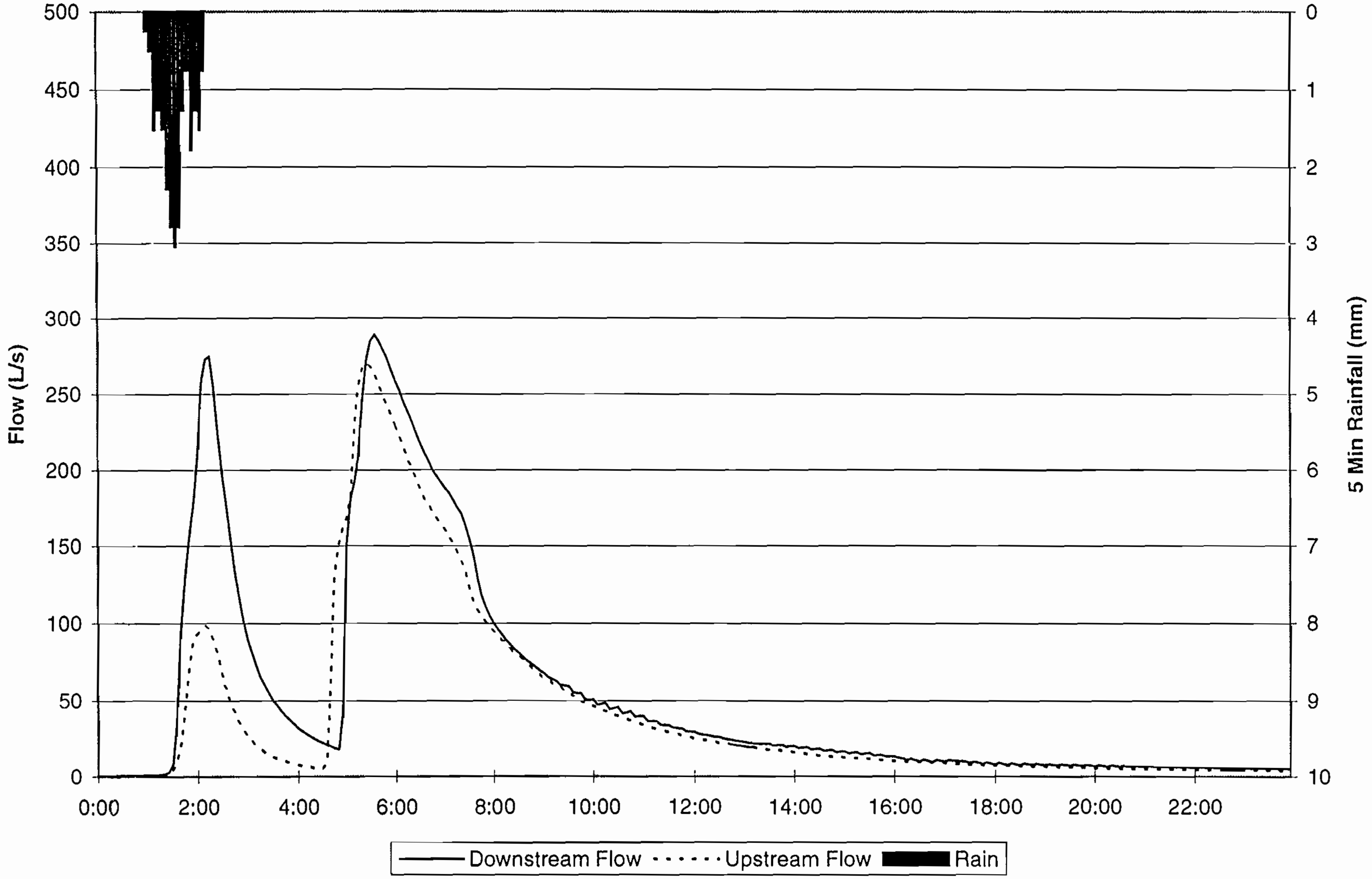


Danz Creek Flow 10/18/94

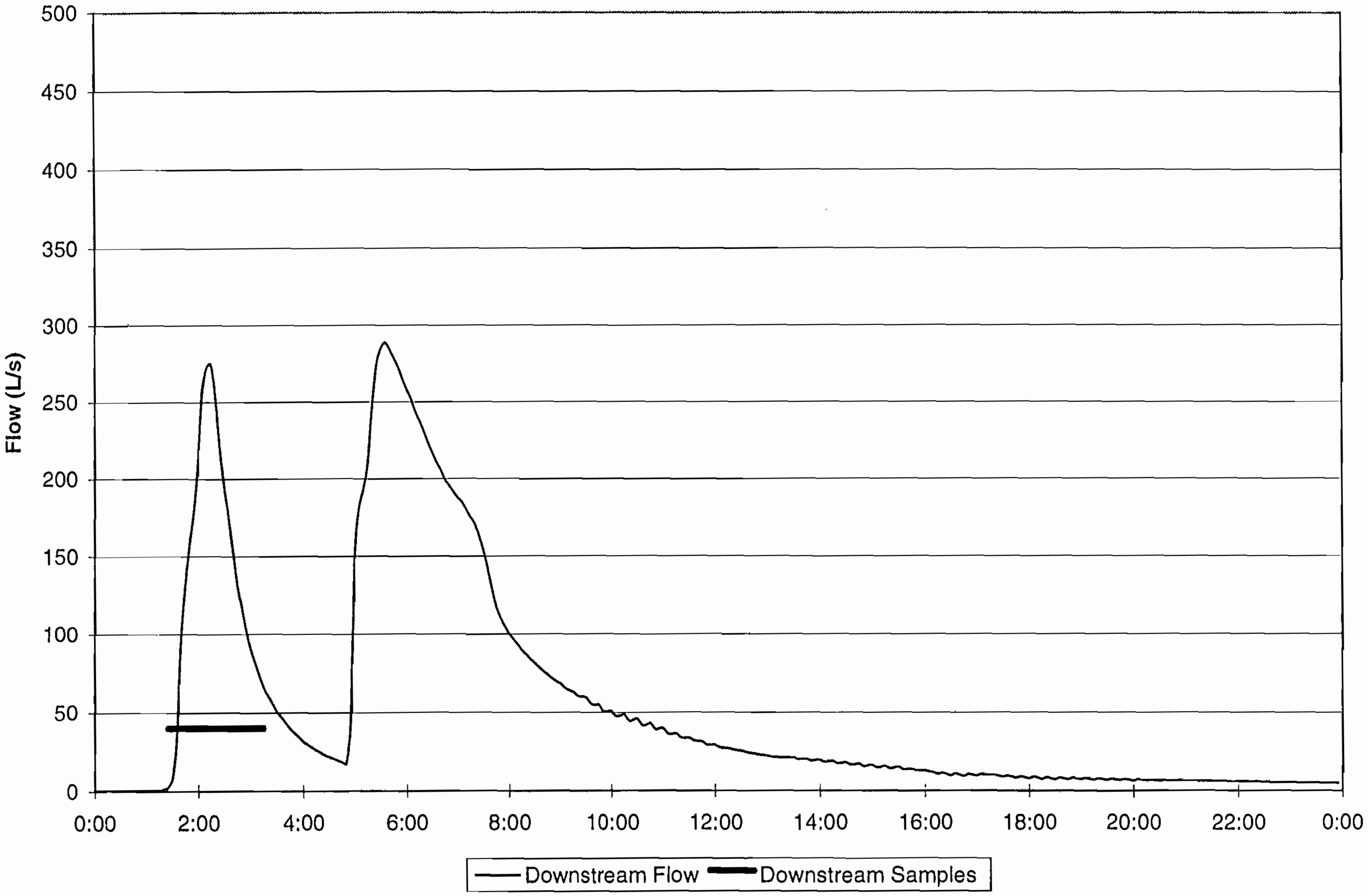


Upstream Sampling Interval 10/18/94



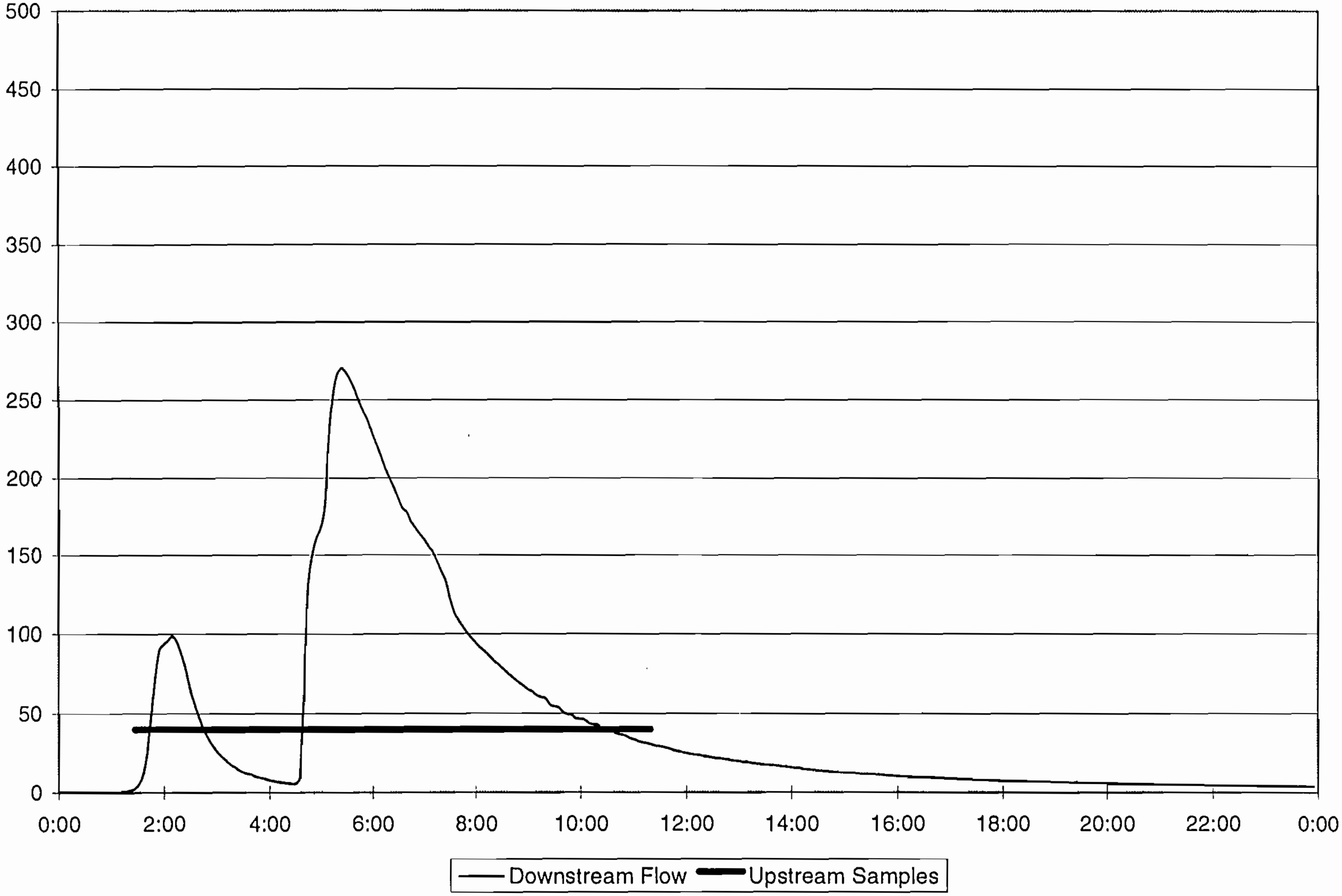


Danz Creek Flow 11/5/94

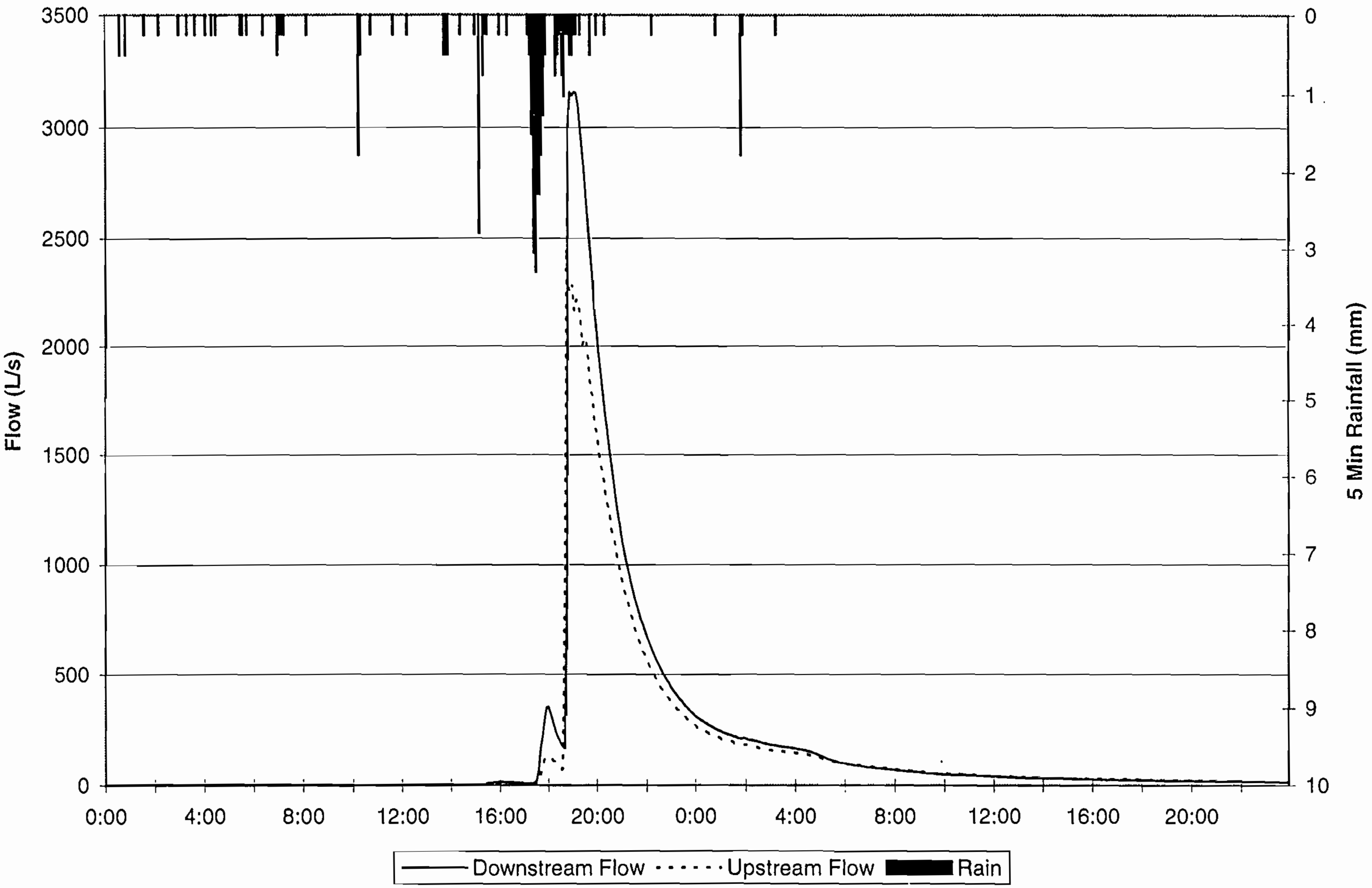


Downstream Sampling Interval 11/5/94

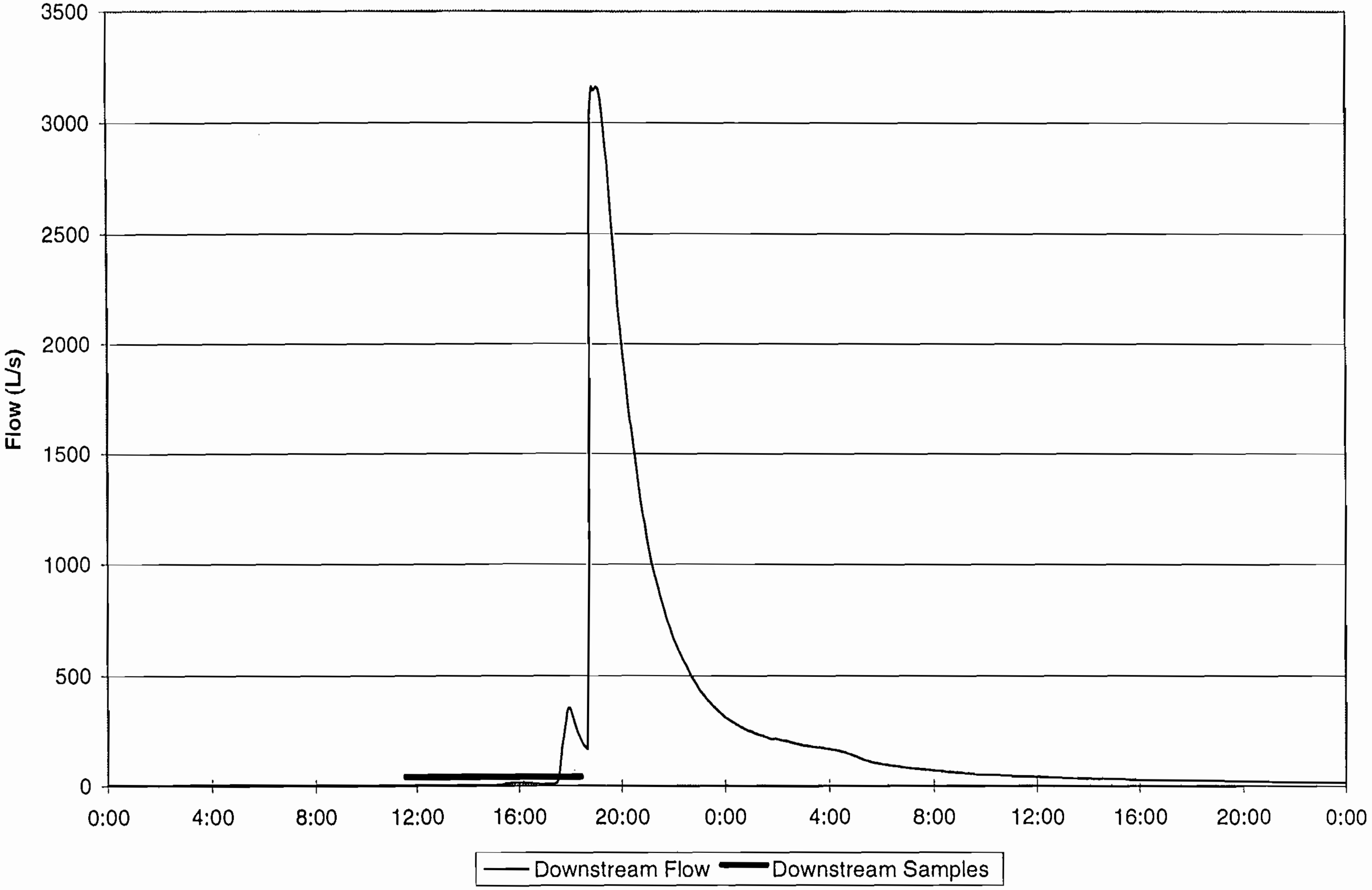
Upstream Sampling Interval 11/5/94

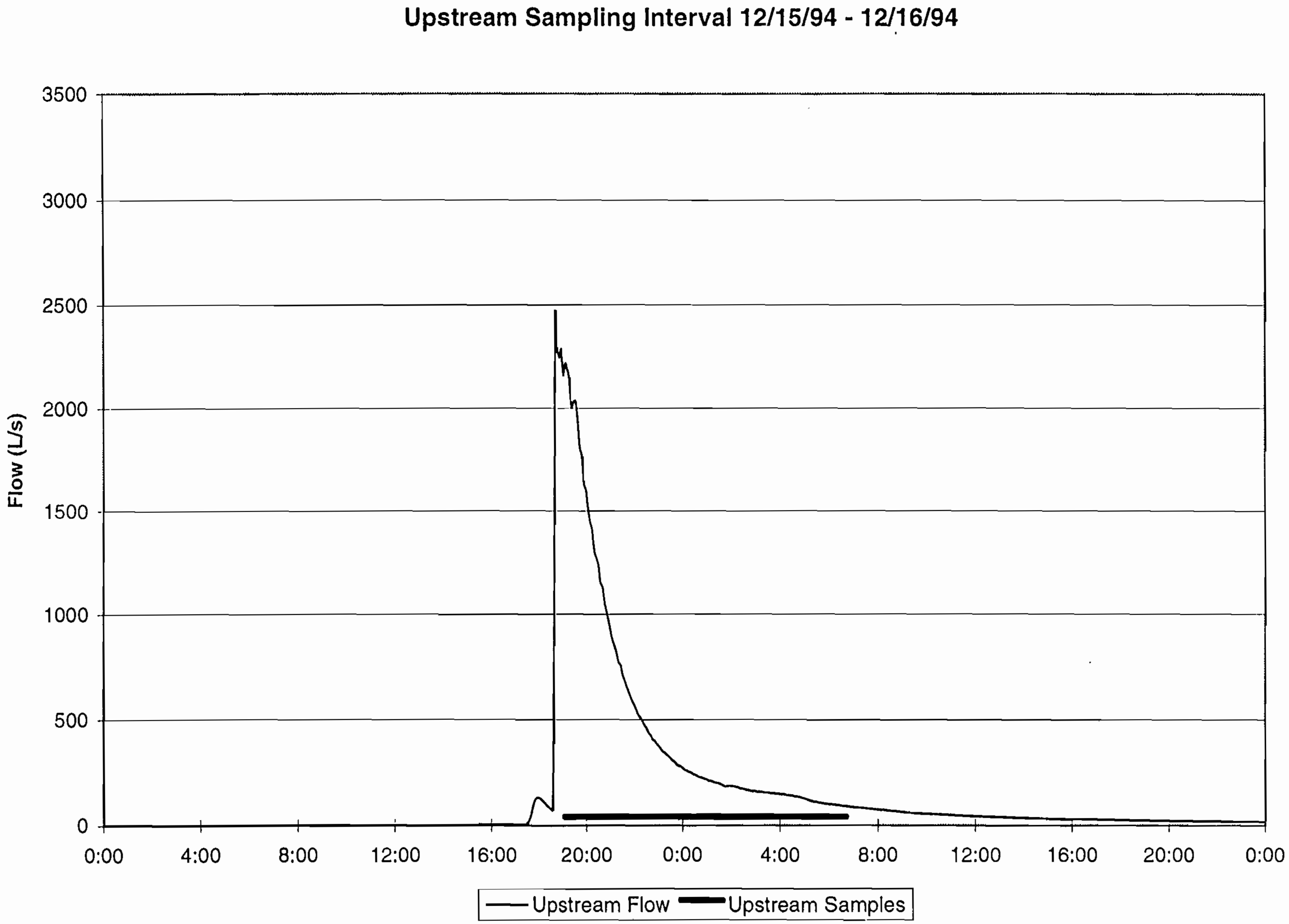


Danz Creek Flow 12/15/94 - 12/16/94

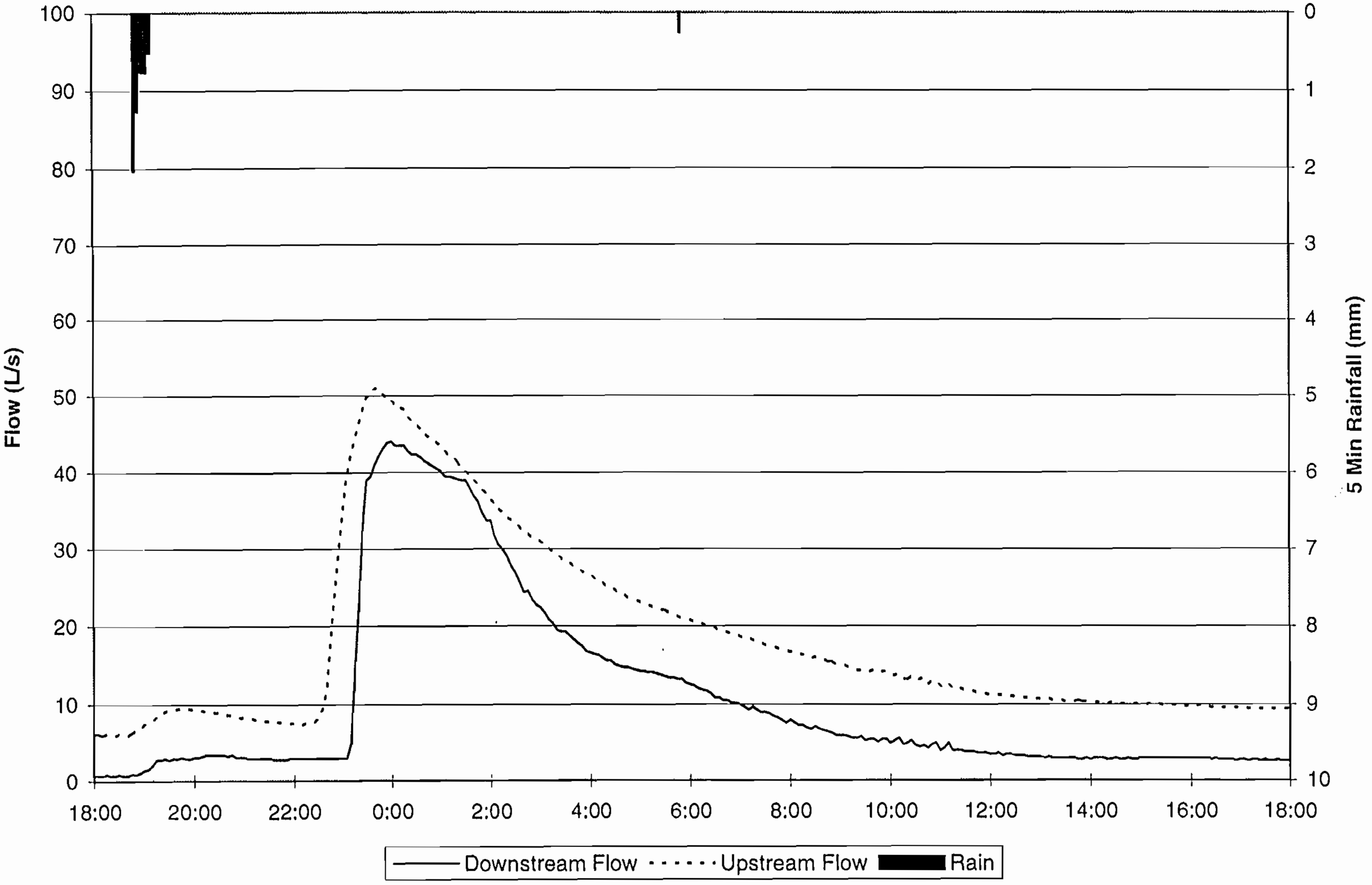


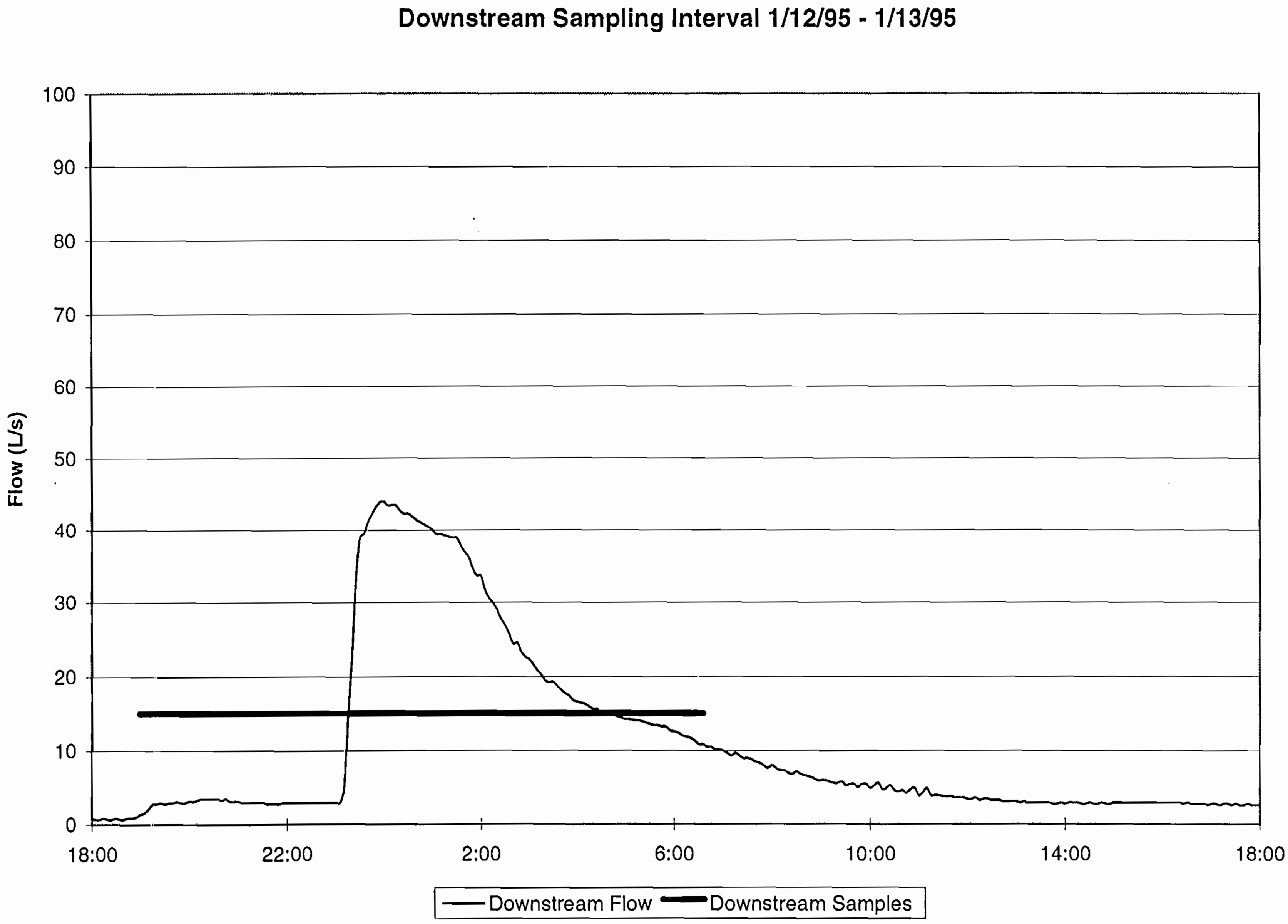
Downstream Sampling Interval 12/15/94 - 12/16/94

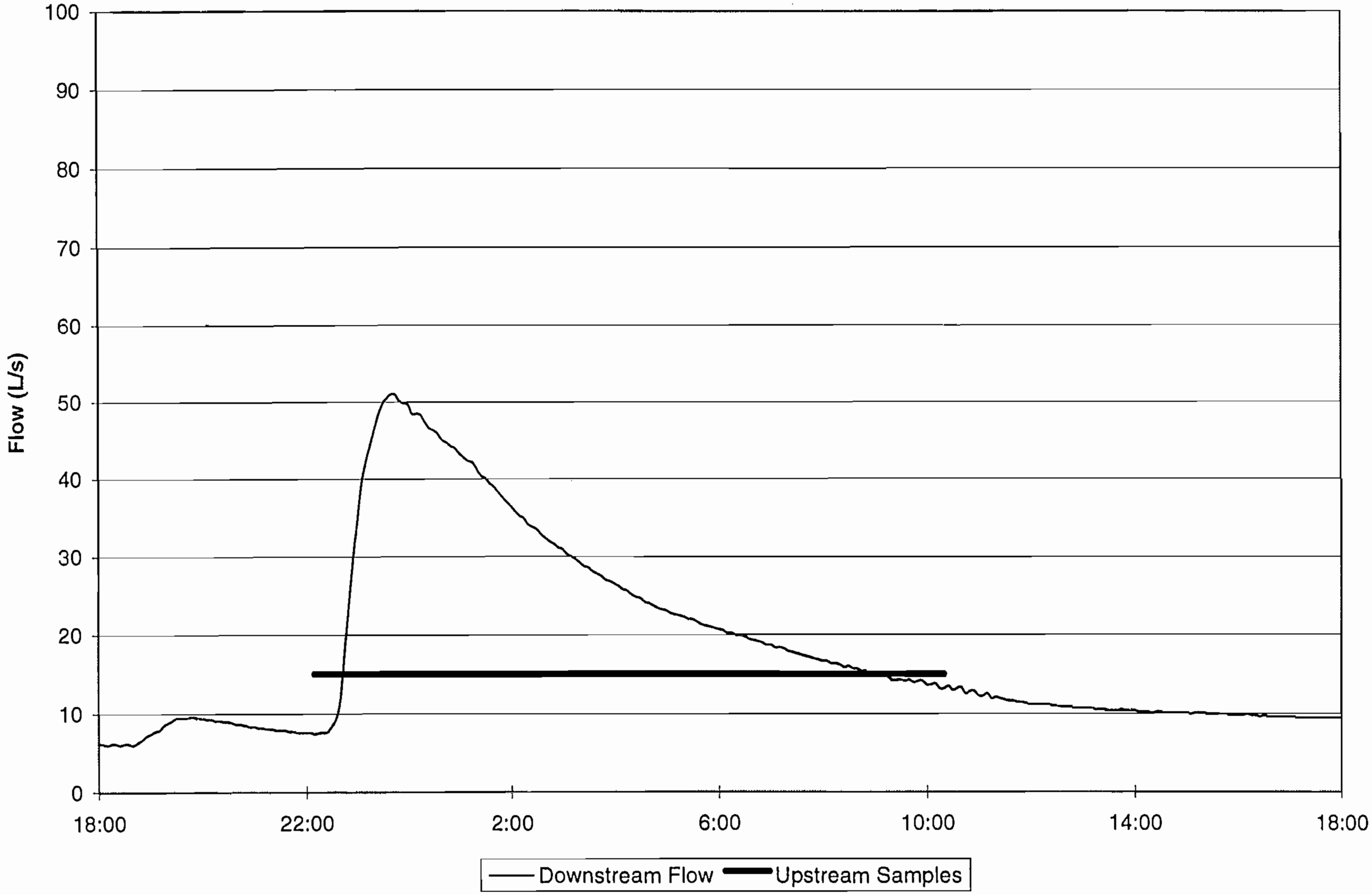



Upstream Sampling Interval 12/15/94 - 12/16/94
Flow (L/s)
3500
3000
2500
2000
1500
1000
500
0
0:00
4:00
8:00
12:00
16:00
20:00
0:00
4:00
8:00
12:00
16:00
20:00
0:00
Upstream Flow
Upstream Samples

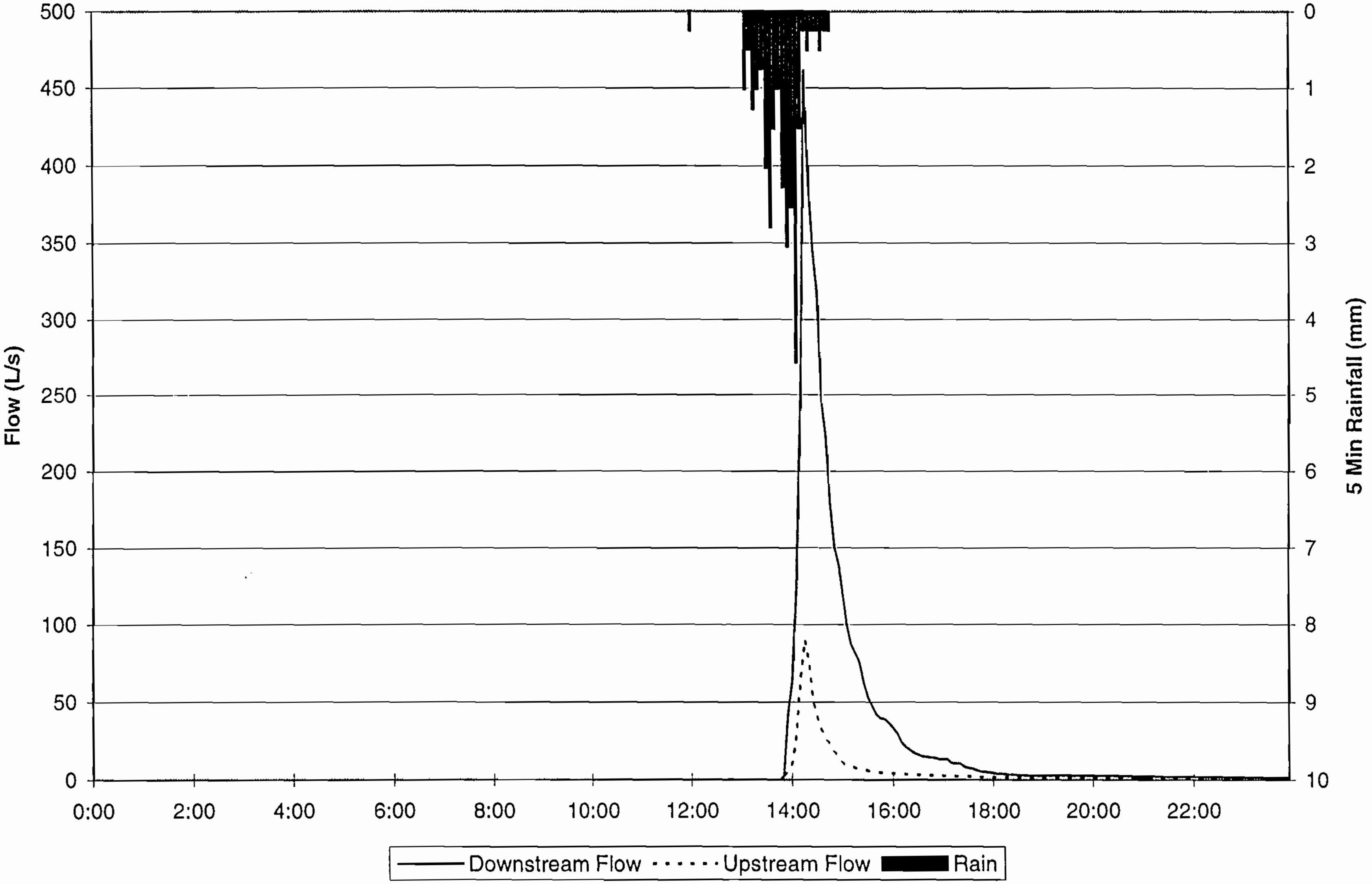
Danz Creek Flow 1/12/95 - 1/13/95

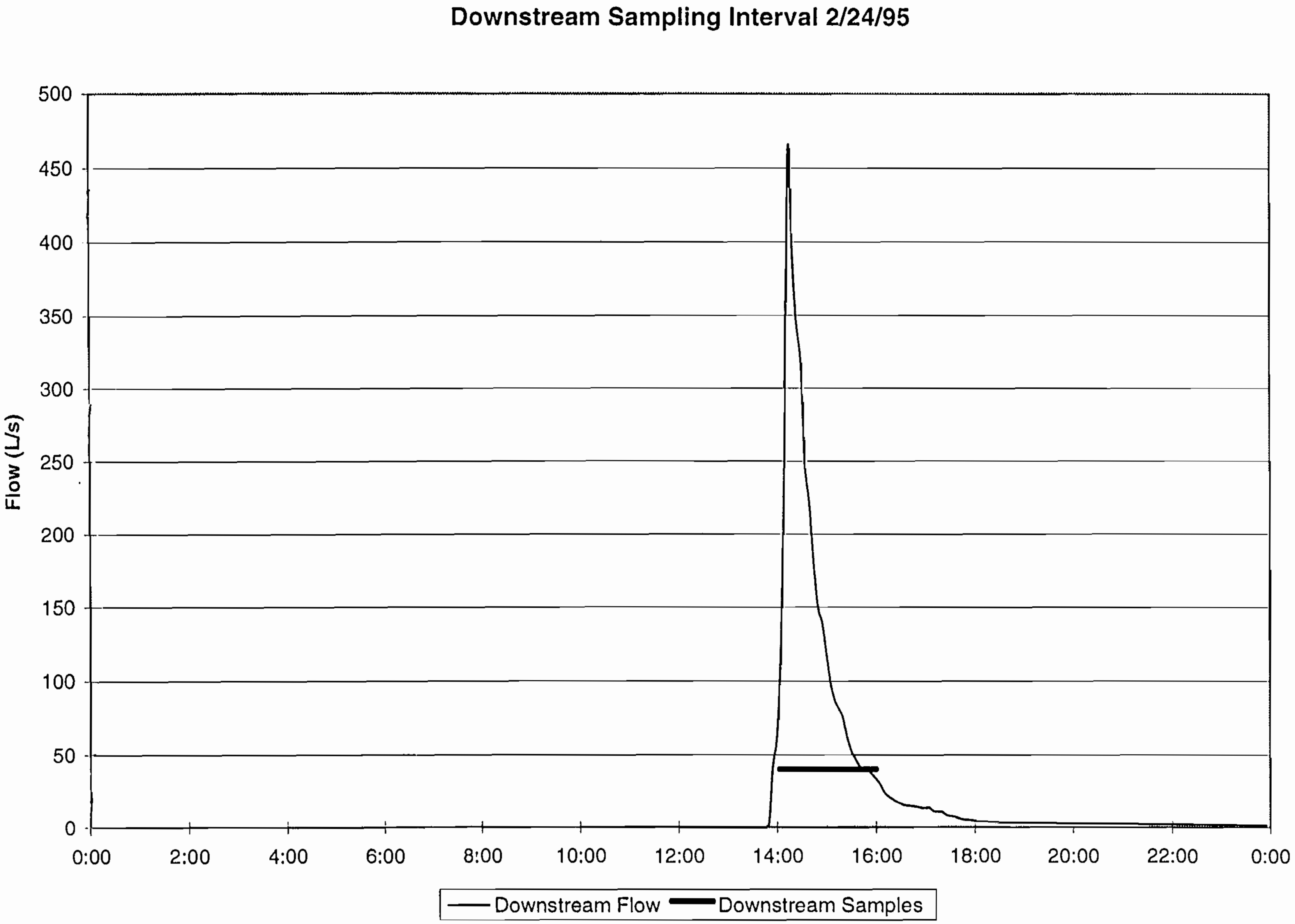



Downstream Sampling Interval 1/12/95 - 1/13/95


Upstream Sampling Interval 1/12/95 - 1/13/95

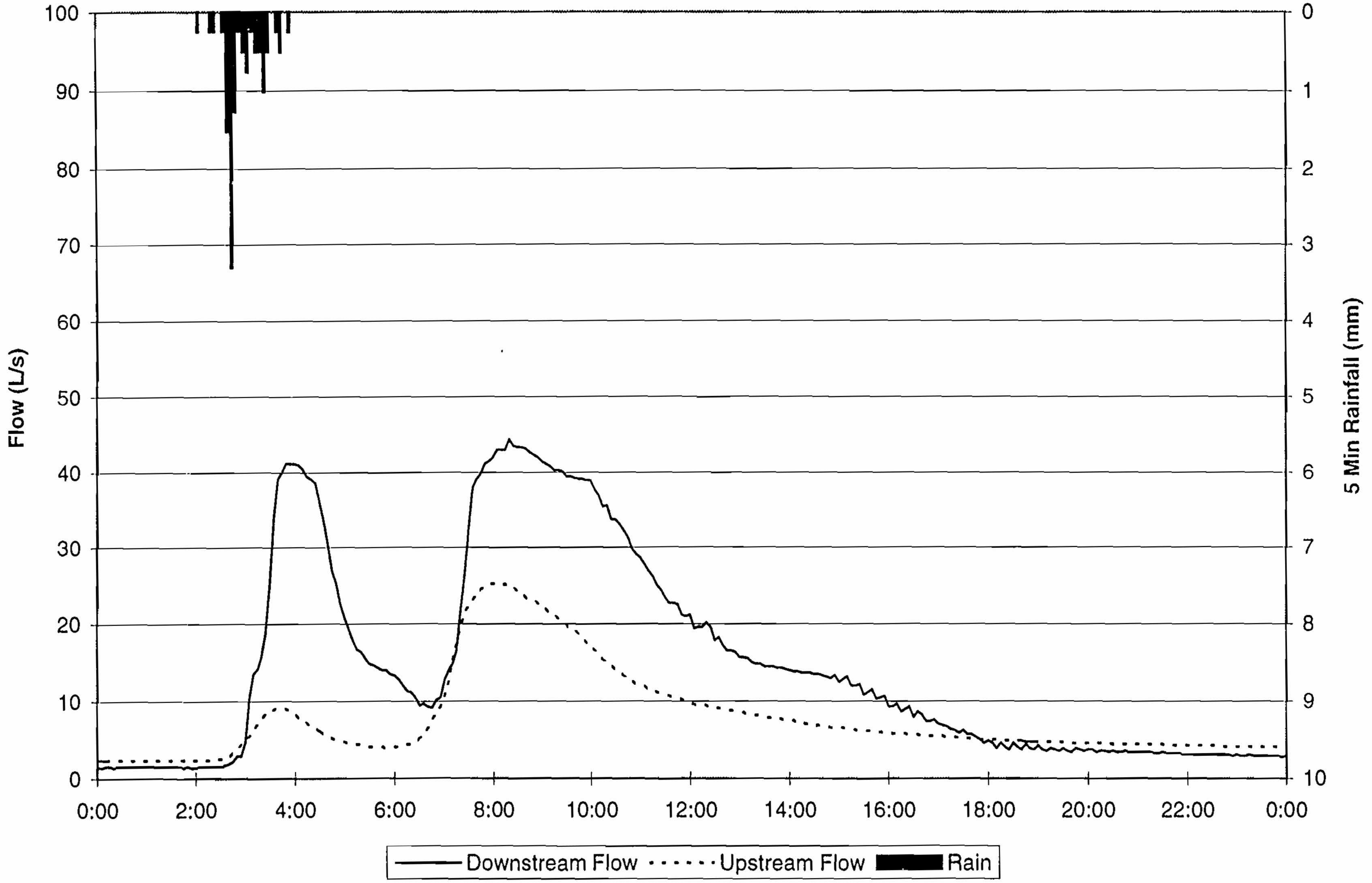
Danz Creek Flow 2/24/95



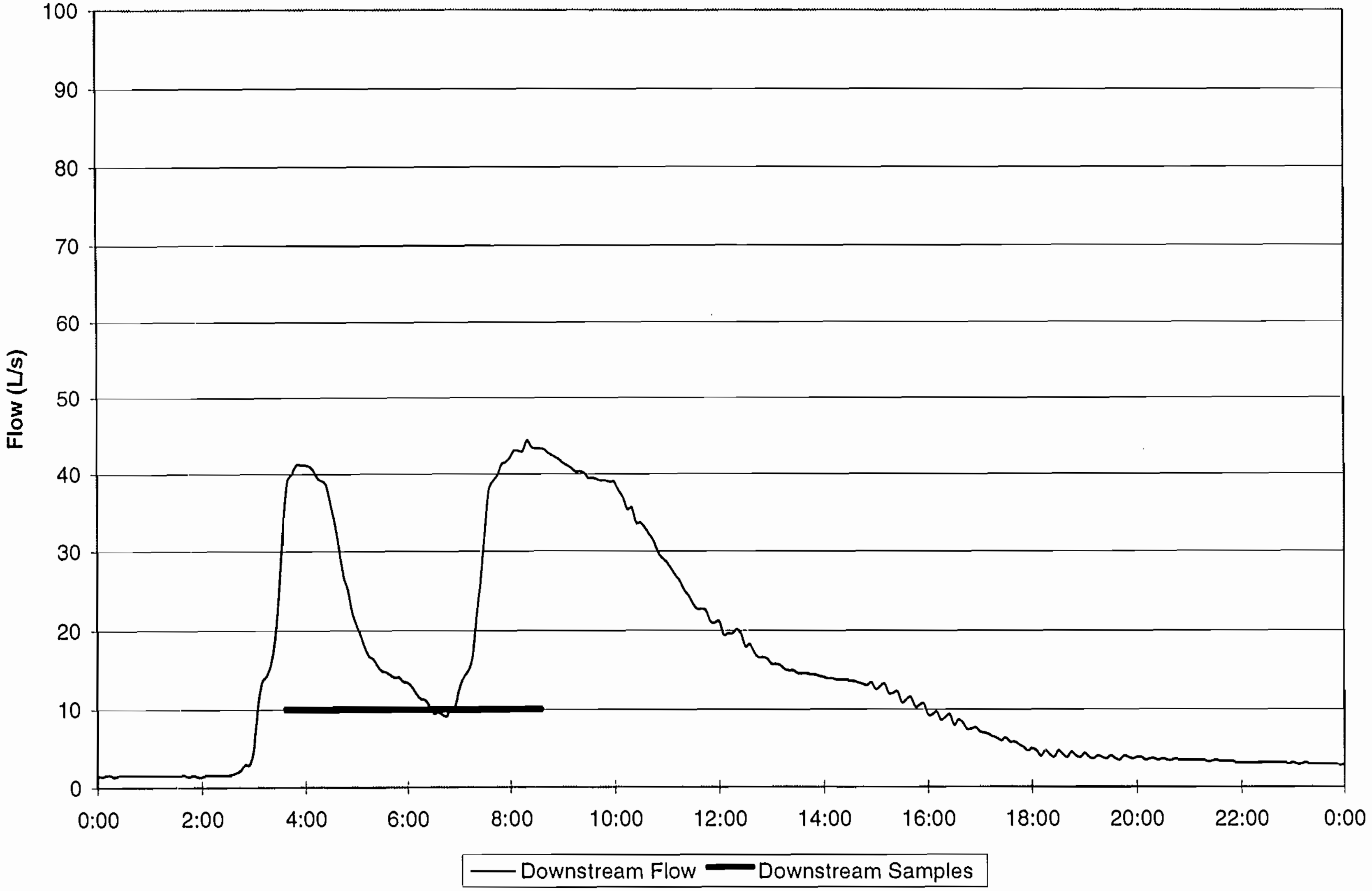


Downstream Sampling Interval 2/24/95

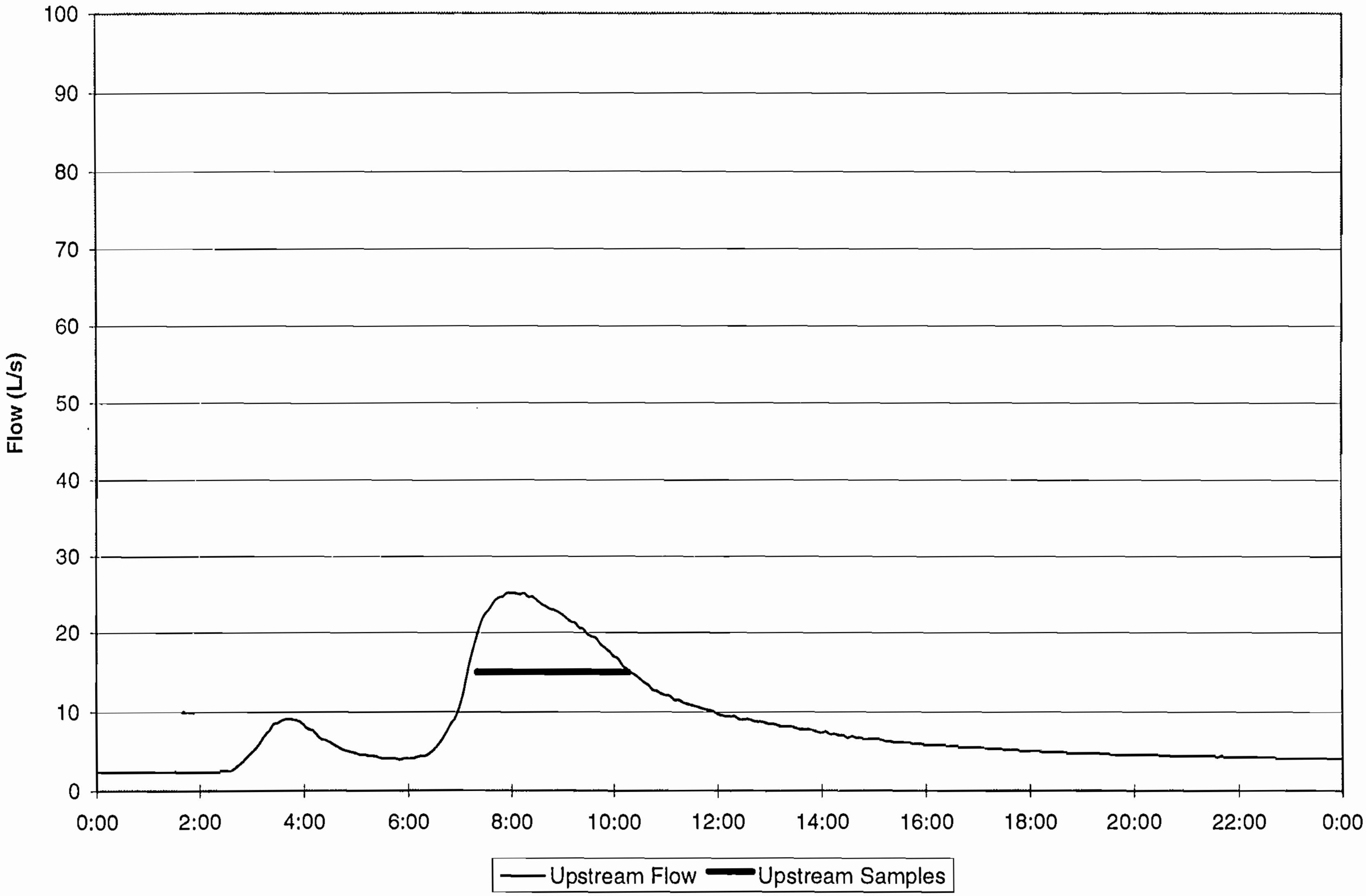
Danz Creek Flow 3/7/95



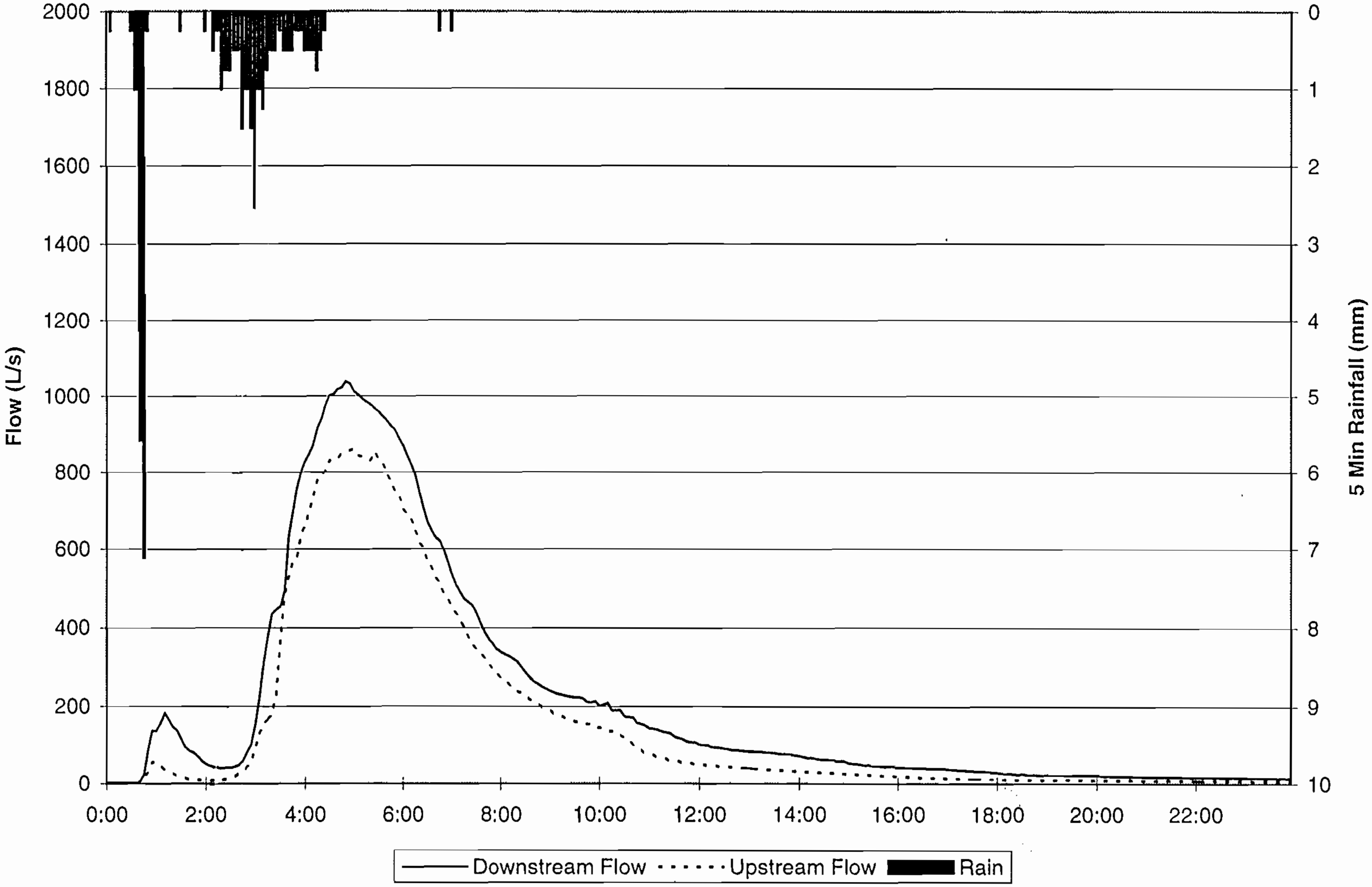
Downstream Sampling Interval 3/7/95



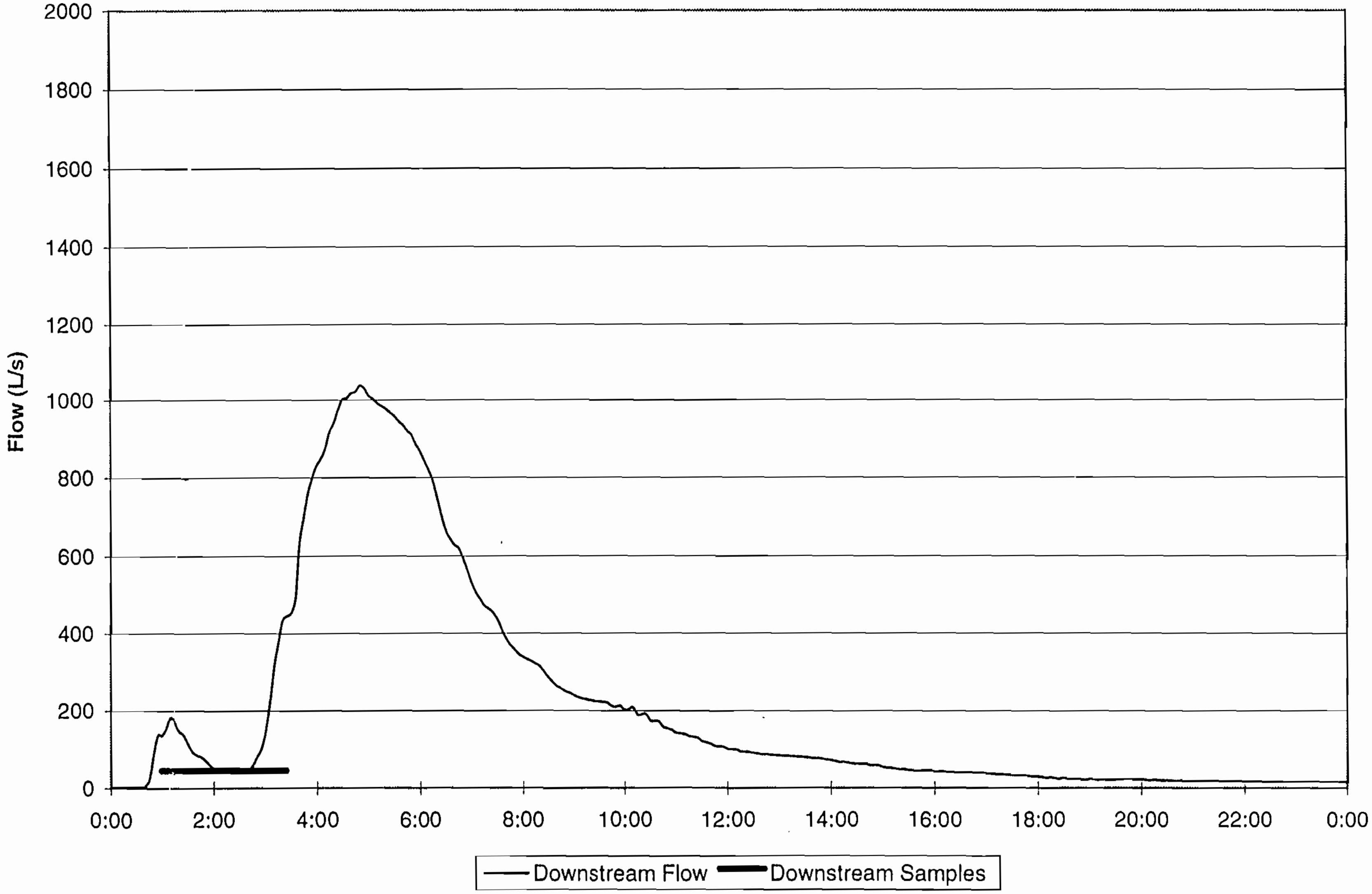
Upstream Sampling Interval 3/7/95



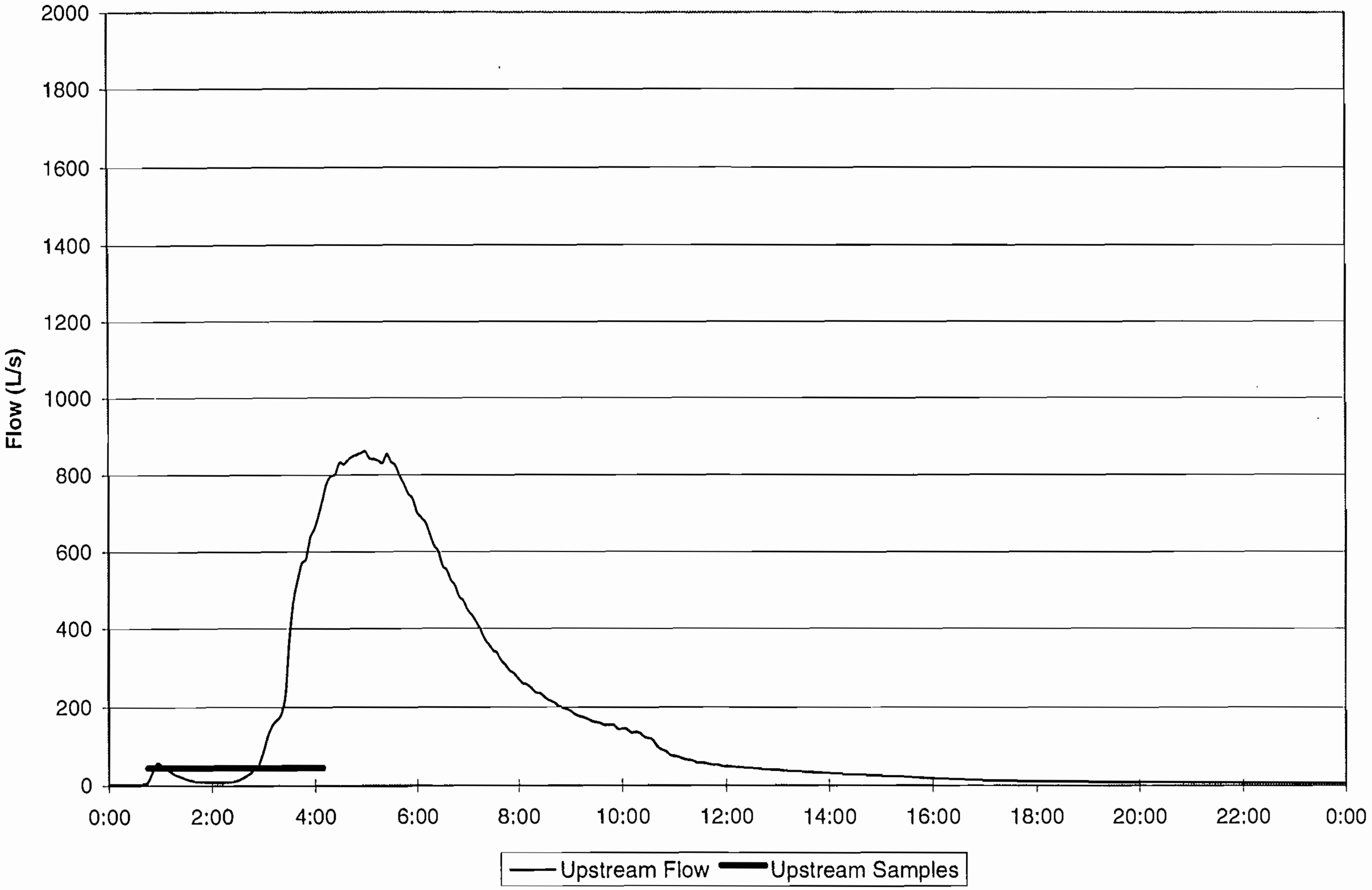
Danz Creek Flow 3/13/95

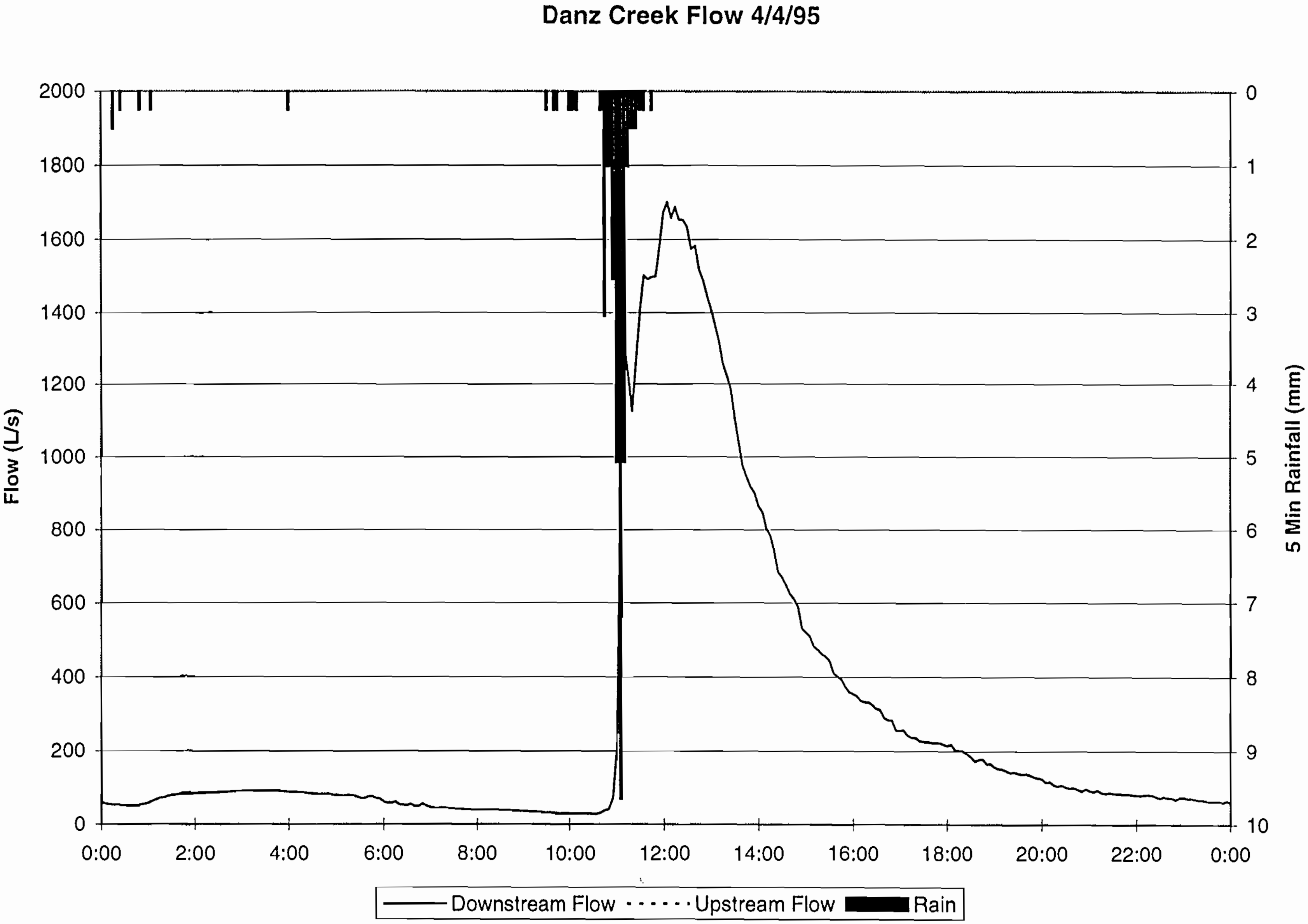


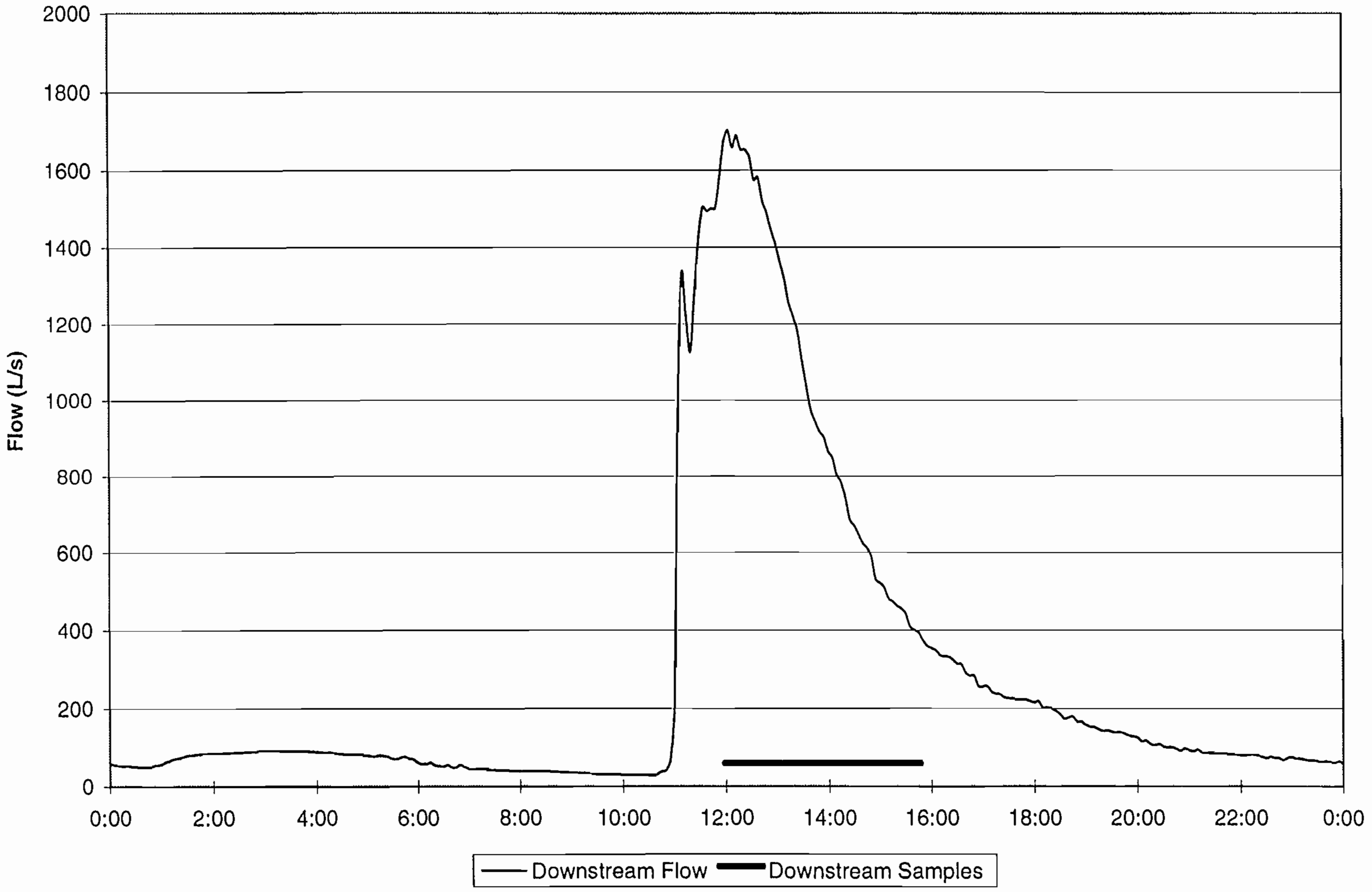
Downstream Sampling Interval 3/13/95



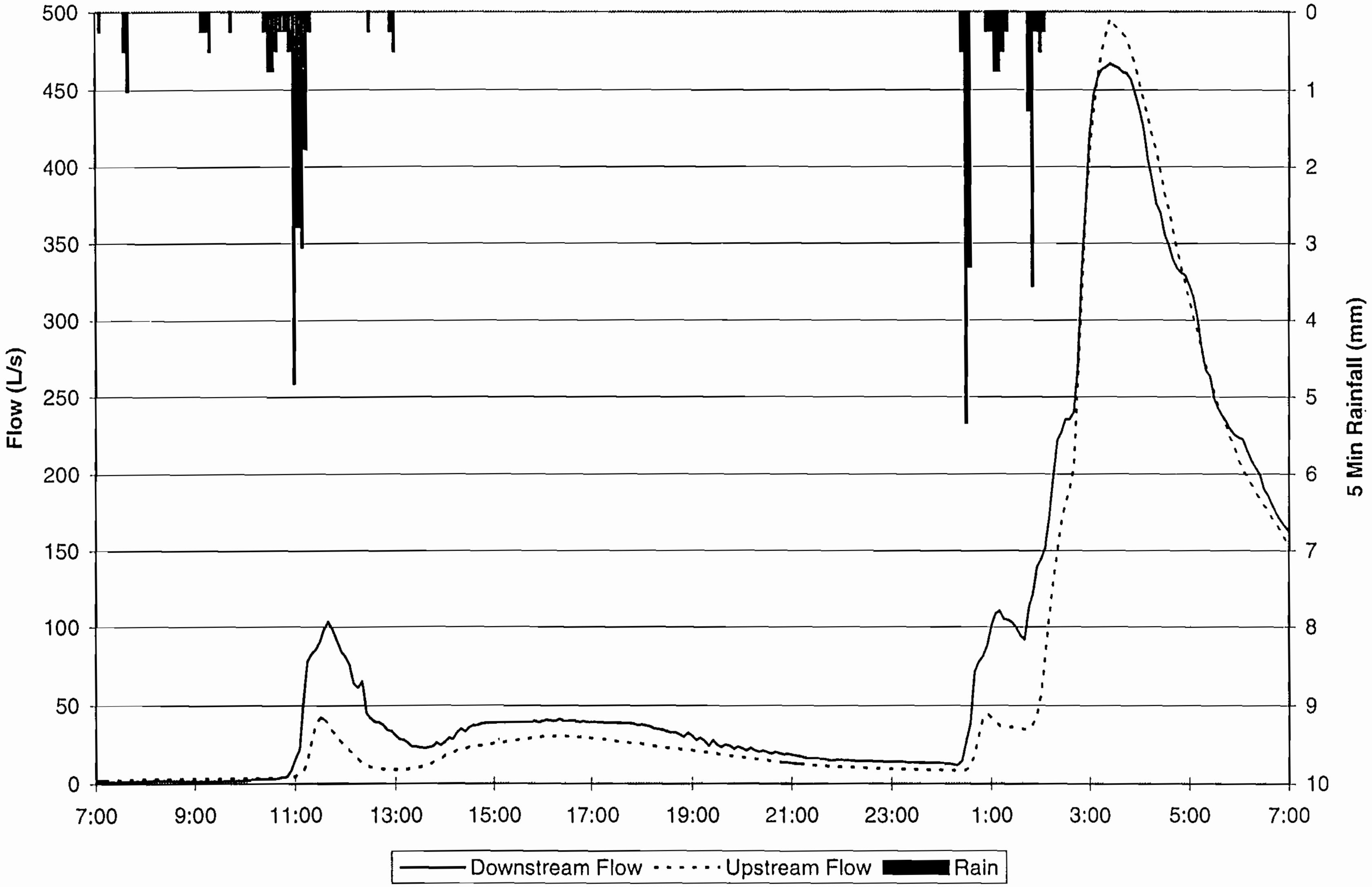
Upstream Sampling Interval 3/13/95




Danz Creek Flow 4/4/95
Flow (L/s)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
5 Min Rainfall (mm)
0
1
2
3
4
5
6
7
8
9
10
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00
Downstream Flow
Upstream Flow
Rain

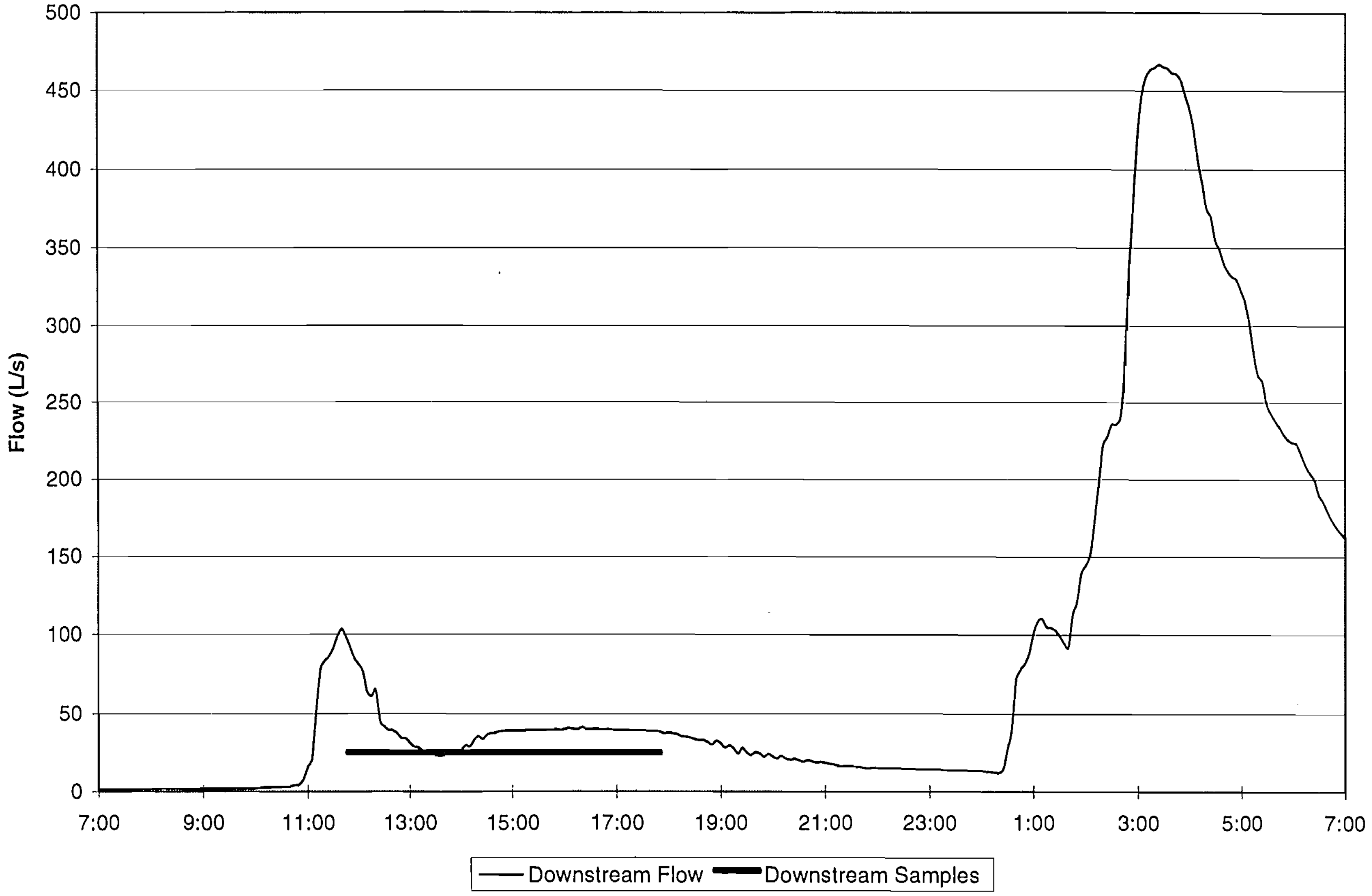


Downstream Sampling Interval 4/4/95

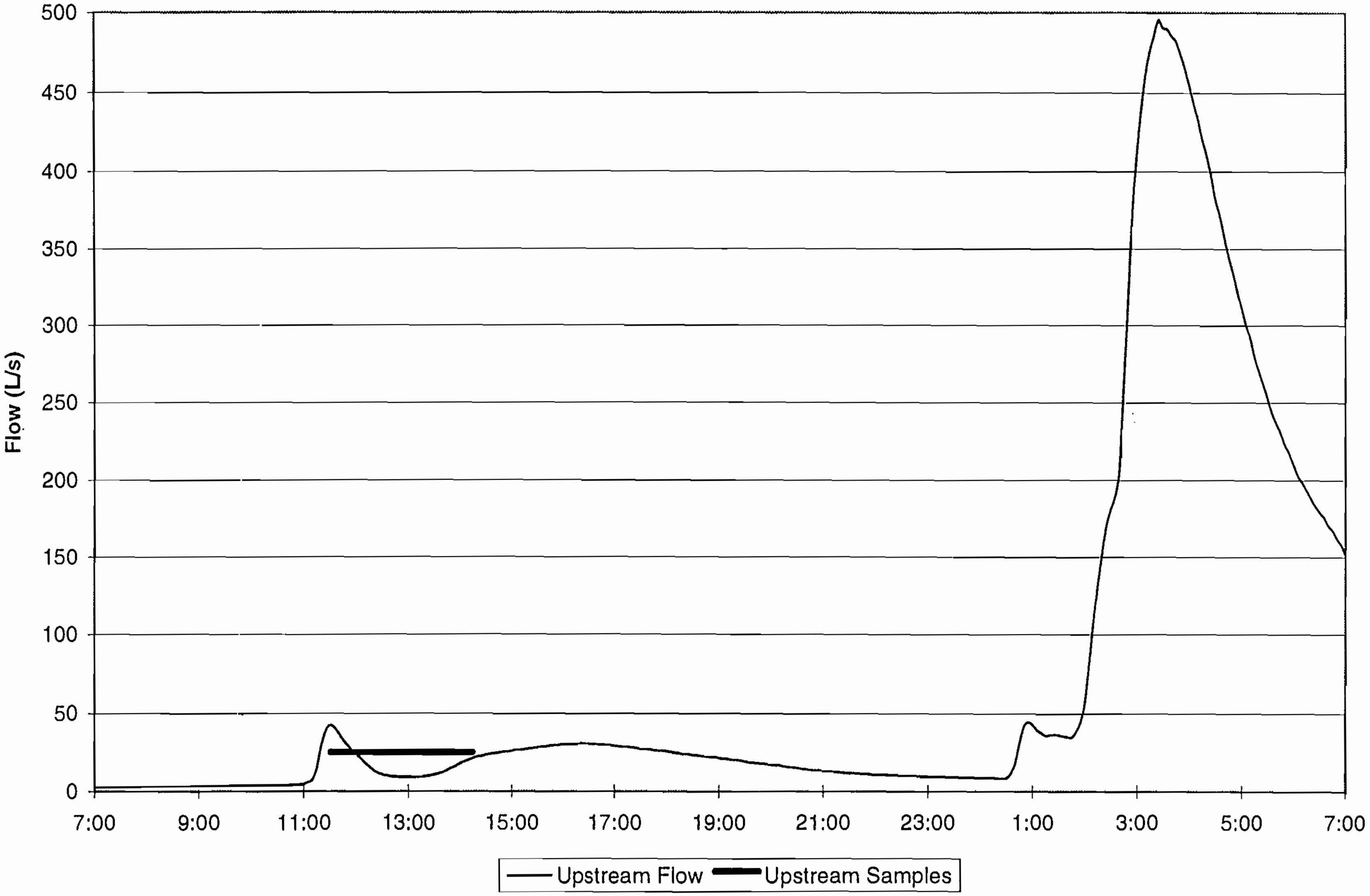


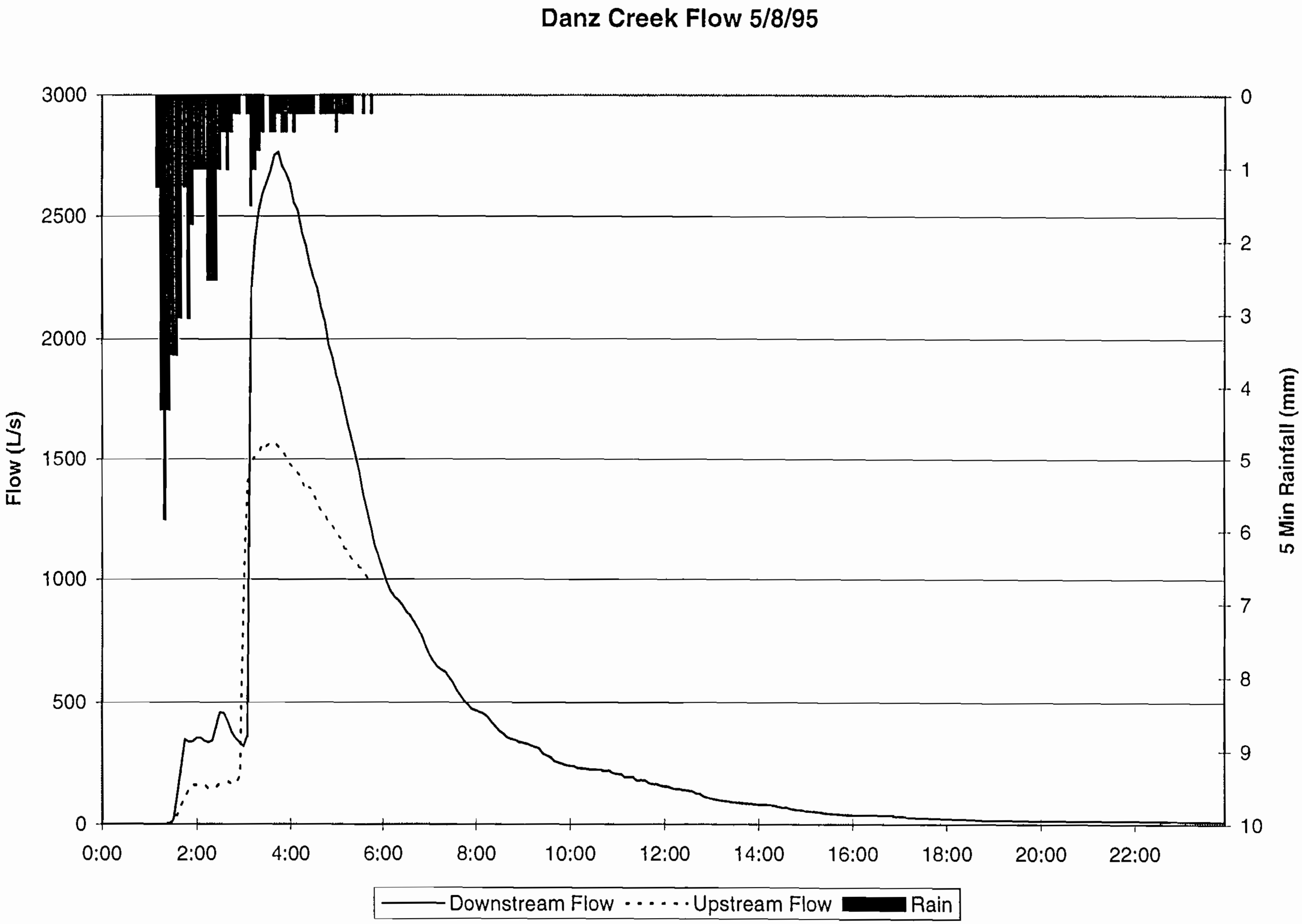
Danz Creek Flow 4/19/95 - 4/20/95

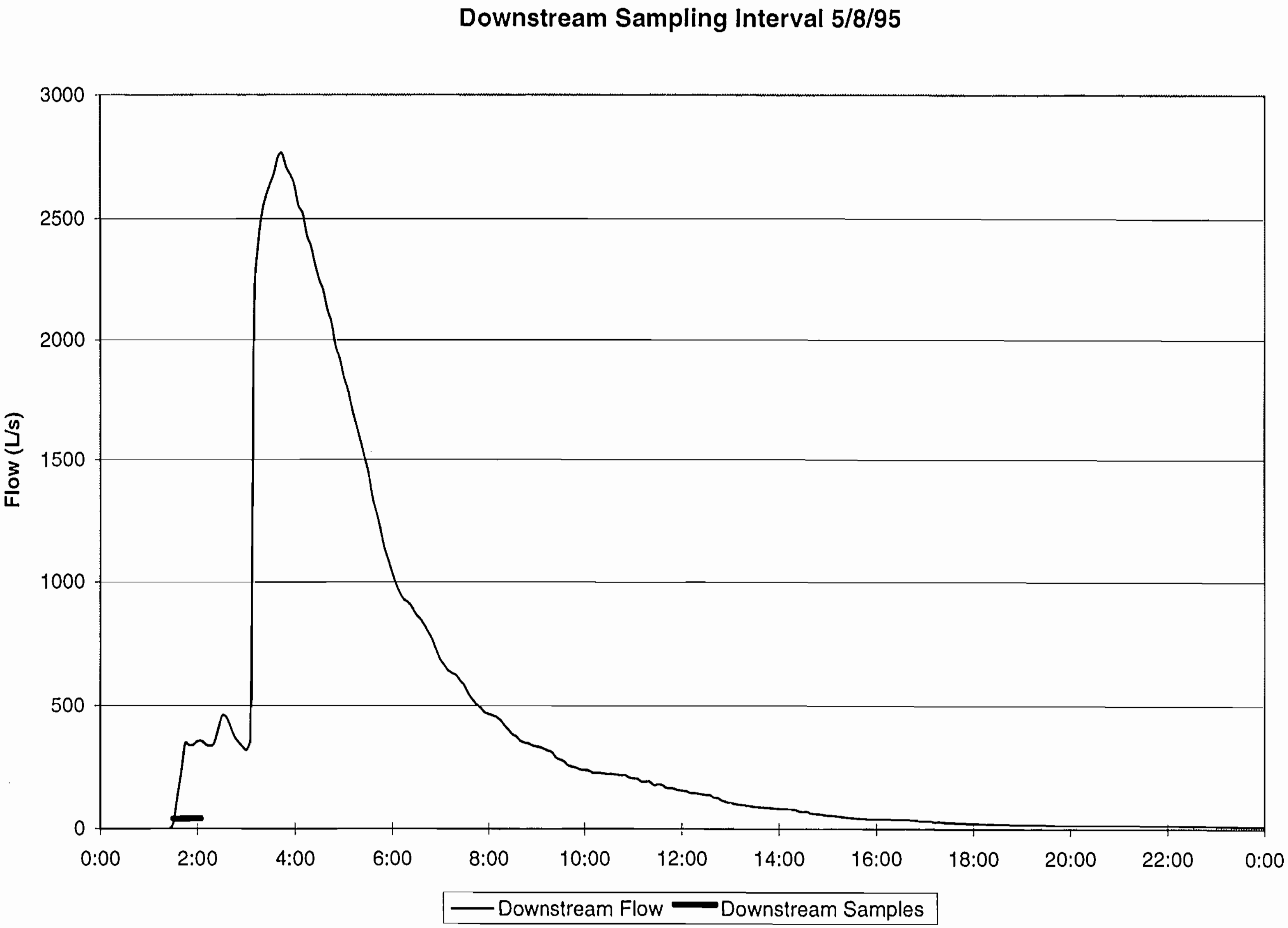
Downstream Sampling Interval 4/19/95 - 4/20/95

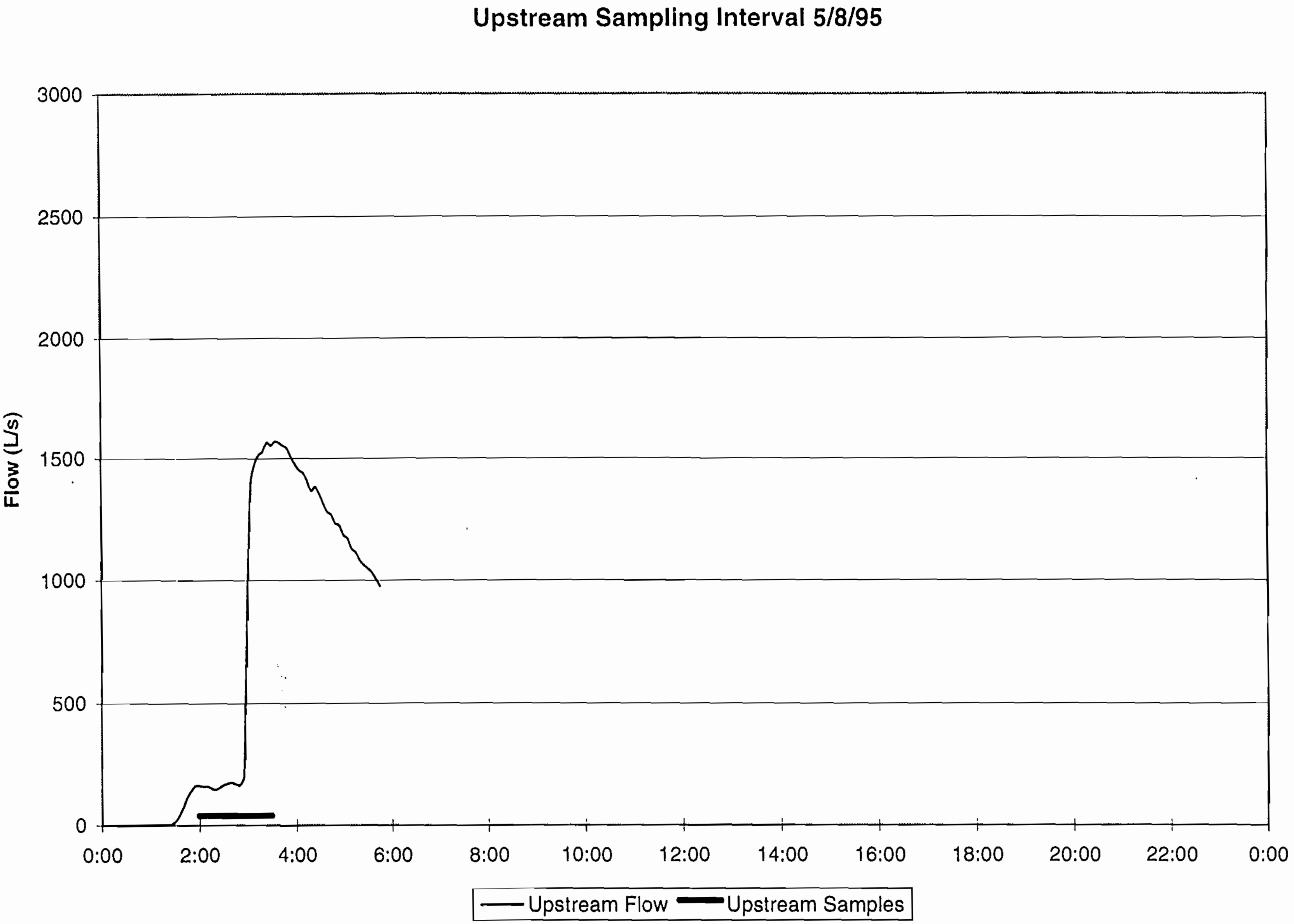


Upstream Sampling Interval 4/19/95-4/20/95




Danz Creek Flow 5/8/95
Flow (L/s)
3000
2500
2000
1500
1000
500
0
5 Min Rainfall (mm)
0
1
2
3
4
5
6
7
8
9
10
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
Downstream Flow
Upstream Flow
Rain


Downstream Sampling Interval 5/8/95
Flow (L/s)
3000
2500
2000
1500
1000
500
0
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00
Downstream Flow
Downstream Samples


Upstream Sampling Interval 5/8/95
Flow (L/s)
3000
2500
2000
1500
1000
500
0
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00
Upstream Flow
Upstream Samples