TECHNICAL PUBLICATION 84-11

VOLUME II

EVALUATION OF THE WATER MANAGEMENT SYSTEM AT A SINGLE FAMILY RESIDENTIAL SITE: WATER QUALITY ANALYSIS FOR SELECTED STORM EVENTS AT TIMBERCREEK SUBDIVISION IN BOCA RATON, FLORIDA

by

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November 1984

This public document was promulgated at an annual cost of $394.79 or $.79 per copy to inform the public regarding water resource studies of the District. RP 787 R50

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PREFACE

The Timbercreek monitoring program was originally established in mid-1980 as a water quantity (hydrology and hydraulics) program to evaluate the SFWMD's detention/retention (D/R) criteria for stormwater runoff. In July 1982, the study was expanded to include the water quality effects associated with the storm water management system.

Results of the water quantity and quality studies, although interrelated, are reported in two separate volumes. Volume I contains an evaluation of the SFWMD's D/R criteria on a hydrologic basis while Volume II discusses the efficiency of the stormwater management system in reducing pollutant discharge associated with non-point source runoff.

It should be noted that conclusions arrived at in both volumes are for one study site and may be site specific.

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SUMMARY AND CONCLUSIONS

The South Florida Water Management District (SFWMD) has completed the first in a series of water quality site studies designed to evaluate the effect of its regulatory criteria for stormwater management. The District currently employs a detention/retention volume rule for water quality regulatory purposes. The results presented here are for a single site and will have to be compared to and combined with similar site specific studies prior to the development of general findings and conclusions.

Based on the data collected in this study, it is concluded that the combination of swale and one-inch wet detention system at the Timbercreek subdivision provides for significant removal of suspended solids and dissolved nutrients. Removal efficiencies for total nutrients fall within the range of literature values. Excellent attenuation of the stormwater runoff hydrograph is also provided by the detention system.

The detention pond system was evaluated on a storm event water quality basis for eighteen months. In that time, nine storm events were sampled for discrete hydrologic and water quality characteristics and a background biweekly water quality sampling program was conducted.

The nine storm events had rainfall depths ranging from 0.54 to 5.66 inches. These events provided a wide diversity of hydrologic conditions to help evaluate the effectiveness of the detention system in treating stormwater runoff. Stormwater runoff into the detention ponds reached 144 cfs, while attenuation of the runoff peak by the detention system held peak discharge to 1.6 cfs.

The effective detention volume that was available at the onset of the nine storm events ranged from 0.91 to 1.23 inches over the watershed. The average effective detention volume was 1.03 inches. These values allowed analysis of the storm event data with confidence that a minimum of one-inch of detention was being observed. A possibility for future research is to alter the effective detention volume to determine whether different treatment characteristics evolve.

An average runoff coefficient of 0.11 was determined for the nine events. This coefficient represents the fraction of rainfall that results as surface runoff. This low value is partly due to the sandy soils present on site and due to the grassed swales utilized by the Timbercreek subdivision for stormwater collection. It is felt that the swale system helped attenuate the runoff hydrograph prior to surface flow reaching the detention system.

In terms of water quality benefits, it is felt that the swales allowed more time for adsorption of dissolved nutrients and settling of particulates prior to the stormwater entering the catch basins. Comparisons of stormwater runoff quality at Timbercreek to that reported by the National Urban Runoff Program (NURP) support this hypothesis. Timbercreek had extremely low concentrations of TSS, TKN, NO_x, ortho and total phosphate in its runoff relative to the NURP study sites. A similar comparison was found when comparing Timbercreek with suburban/residential sites in the south Florida area.

The efficiency of the detention pond system at Timbercreek in reducing nutrient loads from stormwater runoff was compared to values reported in the literature, including nine NURP detention systems. Evaluation of the treatment effectiveness of the ponds was done for both surface loadings and total loadings, which included rainfall, ET and groundwater flow. The inclusion of flow paths other than surface flow gives a more accurate representation of total system efficiency and eliminates the possibility of elevated efficiencies due to stormwater retention.

The detention system appears to utilize a combination of sedimentation and biological uptake to reduce nutrient loads. The ponds are phosphorus limited based on the evaluation of associated N:P ratios.

The treatment efficiency afforded by the detention system for dissolved nutrients is excellent compared to similar studies. Ortho phosphate and NO_x had greater than 80 percent of their loadings removed from the system. Total suspended solids had a removal efficiency of 64 percent, total phosphate had a removal efficiency of 60 percent, and total nitrogen had 15 percent of its inflow loading removed. Relatively high ammonium levels in the groundwater contribute to the small total nitrogen treatment efficiency. The nutrient removal efficiencies are for the detention system only. Additional treatment of pollutants is provided by the grassed swale system prior to the stormwater runoff entering the ponds. Documentation of the magnitude of this process should be attempted in future studies.

INTRODUCTION

Background

The Florida Department of Environmental Regulation (FDER) has delegated the responsibility of stormwater management in the south Florida area to the South Florida Water Managment District (SFWMD). Currently, the SFWMD maintains a detention/retention (D/R) rule for most new land developments that require a surface water management permit. This rule requires developers to detain either the first inch of runoff from the developed project or the total runoff from a three-year, one-hour rainfall event for wet detention systems, whichever is greater (SFWMD, 1983a). Smaller sized systems are required if dry detention or retention is utilized. Compliance with the D/R rule is usually achieved by use of an outlet structure that is designed to release the permitted detention volume over a period of five days with half of the discharge occurring during the first day. Any runoff in excess of the required D/R volume may exit the detention system at an accelerated rate.

The D/R rule was enacted in December 1976, based on criteria which had been used in the permit process by the Southwest Florida District office of DER since the early 1970's. The D/R rule followed the Orlando 208 study by the East Central Florida Regional Planning Council (ECFRPC, 1978) which recommended the retention of one-half inch of stormwater runoff from commercial and residential areas for the purpose of nonpoint source pollution control. The SFWMD decided at that time that one inch of detention, or the D/R requirement, might provide better treatment results than one-half inch of retention.

The purpose of the Stormwater Management Retention Rule Study (SWMRRS) is to evaluate the D/R rule by determining its effectiveness both hydrologically and chemically. Timbercreek is the first of a series of study sites at which the SFWMD is attempting to evaluate the effectiveness of the D/R rule to reduce nutrient loads to receiving waters. If, following analysis, the D/R rule is deemed unsatisfactory, additional treatment processes may be required. Possibilities could include the addition of more detention volume or an alternative solution, such as filtration. Plans call for continuation of this program at additional sites in the future. A second site is on line and data collection has commenced. Both sites have been designed for the collection of one inch of rainfall over the watershed area and routing of this water through a system of wet detention ponds.

An evaluation of the hydrology and hydraulics at Timbercreek has been presented in a report produced by personnel within the SFWMD (Gregg, 1984). The Timbercreek monitoring program was originally established by the SFWMD with the major emphasis on comparison of theoretical hydrologic predictions derived from engineering literature to actual performace. Following this comparison, a basis would be available for considering changes to the SFWMD's evaluation criteria on a hydrologic basis. Water quality considerations were introduced in accordance to the SWMRRS study after the project was well underway. It was felt that concurrent analysis of the detention pond's hydrologic and water quality characteristics would provide for a more in-depth conclusion concerning detention pond efficiency. The main purpose of this document is to evaluate the detention system at Timbercreek in terms of nitrogen and phosphorus removal efficiency. As hydrology and water chemistry are inextricably related, a large degree of dependence has been placed on the hydrology report, especially in terms of flow estimates used in calculating stormwater runoff quality loadings and removal efficiencies of the detention ponds.

Site Description

Timbercreek is a single-family residential development located in southern Palm Beach County in Boca Raton, Florida (Figure 1). The development consists of 122 acres including 7.9 acres of detention lakes. It contains 311 residences for a gross density of 2.5 units per acre. The drainage system consists of grass swales, catch basins, storm sewers, and an interconnected system of detention lakes (Figure 2). The soils at Timbercreek consist principally of highly permeable sand with little organics or clay. The majority of the soil is classified as Immokalee fine sand, which belongs to the hydrologic group A/D (USDA, 1979). It is felt that due to the manipulation of nearby canals, the soils at Timbercreek are kept relatively dry and exhibit a high infiltration rate typical of Group A.

Timbercreek is bounded on the east by E-3 and on the north by L-44, both of which are Lake Worth Drainage District (LWDD) canals. Both of these canals are maintained at an elevation of approximately 10.0' NGVD. Stormwater runoff is discharged from the development by way of a single flashboard riser structure with a crest at 11.43' NGVD discharging to E-3. The bleeder mechanism is a 1.1' horizontal x 0.3' vertical rectangular slot at elevation 10.24' NGVD. The structure is attached to a 36" x 60' CMP culvert.

Instrumentation utilized at Timbercreek included:

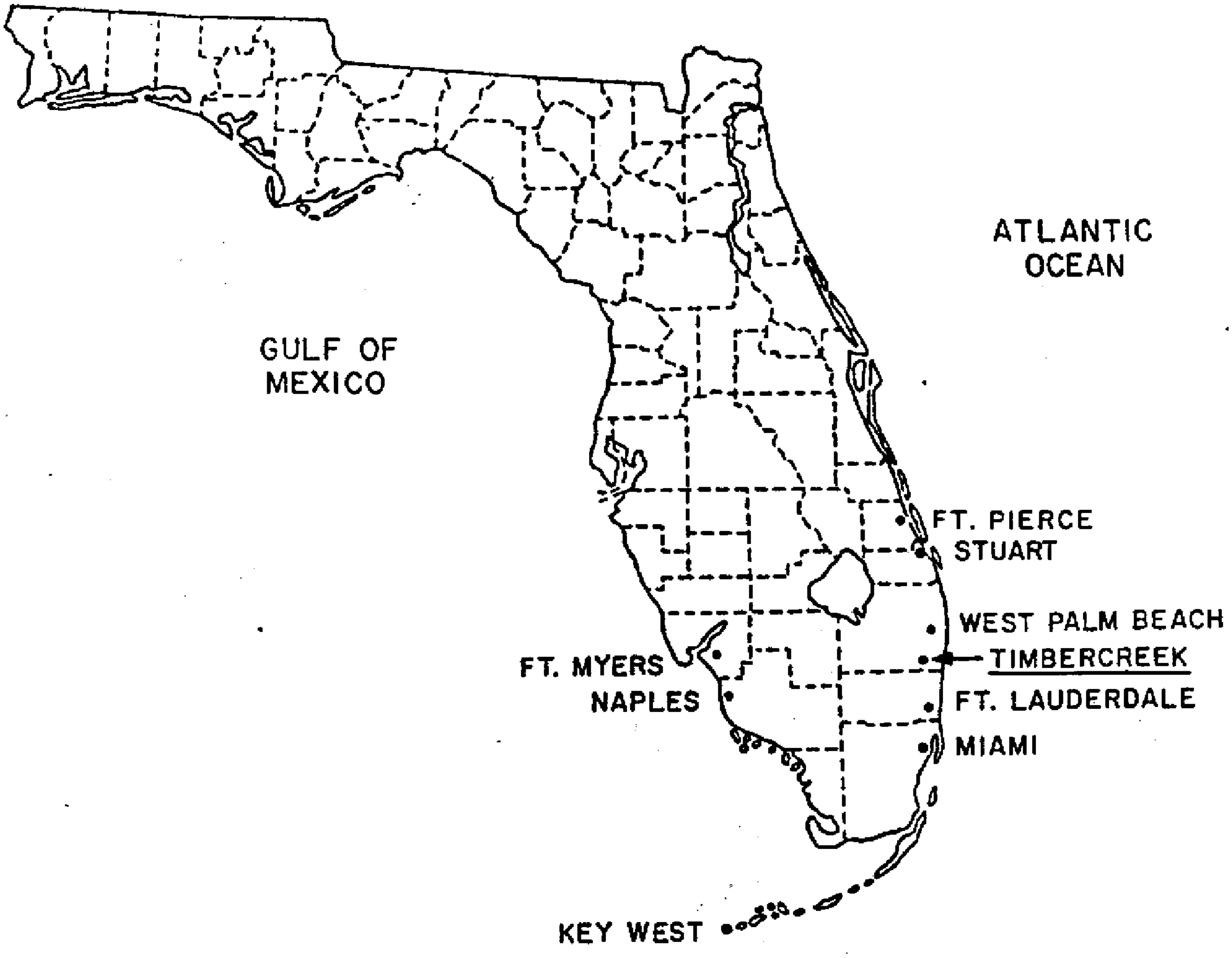
3 groundwater stage recorders

2 surface water stage recorders

2 raingauges

2 automatic samplers for water quality purposes

Figure 2 depicts the subdivision and detention ponds as well as instrument and sampling locations.



LOCATION SKETCH

FIGURE I

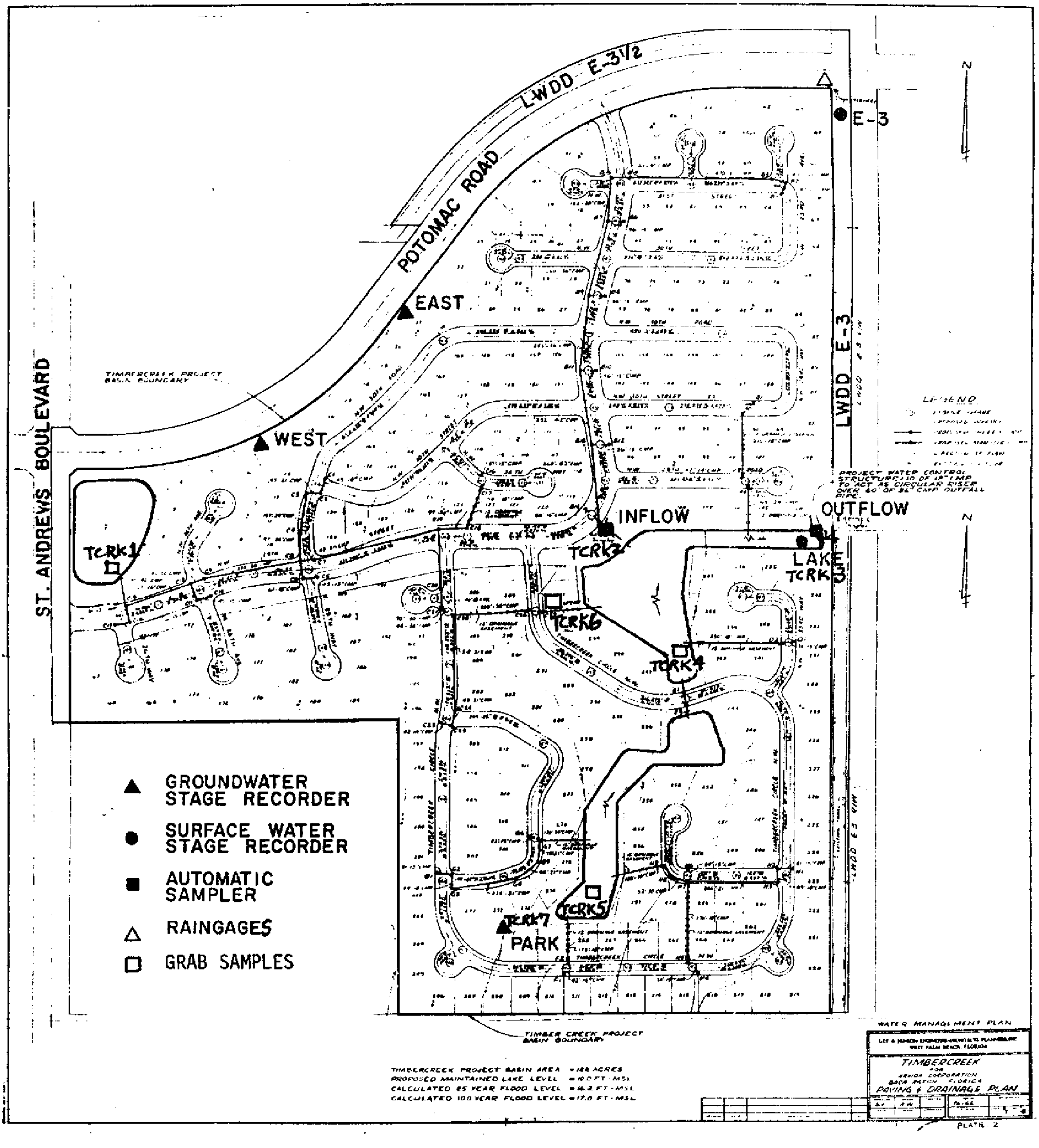

LWDD E-3½
POTOMAC ROAD
ST. ANDREWS BOULEVARD
LWDD E-3
E-3
EAST
WEST
TIMBERCREEK PROJECT BASIN BOUNDARY
INFLOW
OUTFLOW
LAKE
TCRK1
TCRK2
TCRK3
TCRK4
TCRK5
TCRK6
TCRK7
PARK
N
LEGEND
PROJECT WATER CONTROL STRUCTURE: 10' OF 12" CMP TO ACT AS CIRCULAR RISER OVER 60' OF 36" CMP OUTFALL PIPE.
GROUNDWATER STAGE RECORDER
SURFACE WATER STAGE RECORDER
AUTOMATIC SAMPLER
RAINGAGES
GRAB SAMPLES
TIMBER CREEK PROJECT BASIN BOUNDARY
TIMBERCREEK PROJECT BASIN AREA = 122 ACRES
PROPOSED MAINTAINED LAKE LEVEL = 10.0 FT - MSL
CALCULATED 25 YEAR FLOOD LEVEL = 16.2 FT - MSL
CALCULATED 100 YEAR FLOOD LEVEL = 17.0 FT - MSL
WATER MANAGEMENT PLAN
LEE & JENSEN ENGINEERS-ARCHITECTS-PLANNERS INC
WEST PALM BEACH, FLORIDA
TIMBERCREEK
FOR
ARVIDA CORPORATION
BOCA RATON FLORIDA
PAVING & DRAINAGE PLAN
PLATE 2

FIGURE 2

METHODS

Hydrology

Hydrology data are available from January 1981 to the conclusion of the Timbercreek study in November 1983. The methodology for determining the Timbercreek hydrology is presented in Gregg, 1984. During February 1984, some modifications were made to the hydrology data collection methods that are not included in that report. The foremost changes were to reduce the timestep at the two surface water stage recorders from 30 minutes to 5 minutes. It was estimated that the time of concentration in the watershed was 10 to 15 minutes, and that a five minute timestep would better document the inflow hydrograph. The change in timestep was initiated in mid-August 1983. Following this change, four storm events were analyzed and the watershed's temporal rainfall/runoff relationship was determined. Using this information, selected five minute stage data was interpolated from the 30 minute data collected earlier and inflow hydrographs were generated for five selected events that had been previously sampled for water quality. These five events, along with the four measured after the change in methodology, comprise the nine events that were sampled for water quality.

Water Quality

Water quality sampling commenced on June 3, 1982. At the conclusion of the study in November 1983, there were 832 water quality samples collected. Two general sampling regimes were maintained. The first was a bi-weekly routine sampling program at five to seven locations (Figure 2). The purpose of this was to obtain general baseline water quality data throughout the Timbercreek watershed.

Five sample sites were initially chosen for the biweekly water quality monitoring (Figure 2). Site TCRK1 was located in a pond at the extreme western portion of the study area. This pond is hydraulically connected to the main pond by a series of storm sewers. Two sites were located in the main pond near inflow locations (sites TCRK2 and TCRK4). Site TCRK5 was located in a pond at the southern most extreme of the watershed. This pond is also hydraulically connected to the main pond by a storm sewer. The final site was located at the outflow of the main pond (site TCRK3).

Two water quality sites were added towards the end of the first year of sampling. One was located in a storm sewer drain near the lake. That particular sewer drained approximately 40 percent of the Timbercreek watershed (site TCRK6). The second site was a groundwater well near the south pond (site TCRK7). These two sites were added to document the suspected major surface inflow to the main pond and to determine the quality of groundwater entering the detention system, respectively.

Partially through the first sampling year it was decided to relocate the routine biweekly sampling site TCRK2 to the storm drain nearest the inflow pipe entering the main lake. This was the location of the automatic sampler which was utilized during storm events, and it was felt that a consistent sample location would be preferred for both sampling regimes.

The second regime was followed during discrete rainfall events. Nine individual storm events were sampled by use of Sigma Motor automatic samplers at two sites. The inflow site, located at station TCRK2 (Figure 2), received stormwater runoff from approximately 25 percent of the Timbercreek catchment. It was assumed that due to homogeneous land use within the watershed (single-family residential), water quality representative of the entire watershed would generally be present at that site. It was felt that any fluctuations in water quality levels at this site would be similar to those occurring basin-wide on a long term basis. Site TCRK2 is located inside a stormwater catch basin 150 feet from the main detention pond. It had standing water during periods of no flow and samples of this standing water are included in the time series plots of water quality. Mass loading calculations eliminate these samples as coincidental zero flow is used for the calculations. Average stormwater runoff quality calculations also do not include samples collected during zero flow.

Station TCRK3, or the outflow site, is located at the flashboard riser/-bleeder slot which discharges into the Lake Worth Drainage District's E-3 canal (Figure 2). As with station TCRK2, several samples were collected during zero flow, but again these samples were eliminated by mass loading calculations.

The main objective behind the Timbercreek project was to determine the nutrient treatment efficiency of the detention system. Thus, special emphasis on parameter selection centered on the nitrogen and phosphorus series. All samples were analyzed for ortho and total phosphate (OPO_4 and TPO_4) and for total Kjeldahl nitrogen, nitrate, nitrite with nitrate, and ammonium (TKN, NO_2, NO_x, and NH_4). In addition, most samples were also analyzed for turbidity, color, specific conductance, pH, chloride, alkalinity, and total suspended solids. All samples were analyzed at the SFWMD Water Chemistry Laboratory in West Palm Beach, Florida. A list of methods for all parameters can be found in Appendix I.

Mass Loadings

It was felt that treatment efficiencies for the detention system could best be computed on a storm event basis. Several flow paths were identified and pollutant mass loadings for the individual storm events were computed for each pathway in two discrete steps. Initially, an estimate of flow was made for the five separate fluxes into or out of the pond system. The flow paths included rainfall, evaporation, surface outflow, surface inflow, and groundwater flow.

Depth of rainfall was estimated from a tipping bucket raingauge located on-site. An average surface area of 7.9 acres was used with rainfall depth to calculate the rainfall contributed directly to the ponds during the storm event. Rainfall depth was measured in five minute intervals.

Evaporation was estimated over the 7.9 acre pond system from historical data at three long term SFWMD data collection sites. An average of the Ft. Lauderdale site (27 years), Hialeah site (43 years) and the S-5A site (28 years) was used with a pan coefficient of 0.70 to calculate an average daily evaporation for each month.

Surface outflow resulting from the given event was computed using stage and a combination flash-board riser and bleeder slot structure. A linear regression of the recession portion of the outflow hydrograph was used to estimate the surface outflow when additional storm events occurred prior to the cessation of flow from the original event. Similarly, flow occuring at the onset of the storm event was linearly projected and removed from measured values.

Surface inflow was calculated as change in the water budget during periods of rainfall. The water budget, as determined in the hydrology report, consisted of surface outflow, rainfall and change in lake storage for a given timestep. Surface inflow was estimated at a five minute interval.

Groundwater flow was estimated as changes in the water budget during periods of no rainfall. As with surface outflow, a linear regression was used to estimate the tail end of event related groundwater flow when additional storm events occurred prior to the end of the original storm event related flow. Positive and negative groundwater flow estimates were obtained, with the positive groundwater contributions to the ponds usually occurring immediately after an event. Estimates of groundwater flow were made on a 30 minute interval and summed on a daily basis.

The second step in calculating mass loadings into and out of the pond system required the inclusion of water quality data. The product of flow and water quality provided the actual mass loading estimate. Three different procedures were used to calculate this product.

Surface inflow fortunately had discrete water quality samples that coincided closely with storm event related flow. These discrete quality points were matched with corresponding flow to produce discrete mass loading values. During periods of flow when quality was missing, an average of the quality points immediately before and after that flow datum was used. In cases where quality sampling was initiated after the onset of storm related flow, the first quality datum was extended back to the onset of flow for calculation purposes. When flow data extended beyond the cessation of water quality sampling, the final water quality datum was used with the remaining flow data. A summation of the discrete mass loading values for each hydrology time step provided the total event loading.

Attenuation of flow through the detention ponds was provided by the mechanics of the outflow structure. A slight peak in discharge usually occurred shortly after the commencement of the storm event. Flow then gradually decreased for the next one to ten days, depending on storm magnitude. Due to these flow characteristics, average outflow water quality concentrations were computed on a daily basis and multiplied with daily flow to obtain outflow mass loadings.

The final method of calculating mass loadings was used for rainfall, ET and groundwater fluxes. In these cases, an average concentration was used with total flow to obtain a final loading. Rainfall water quality was available from the SFWMD's B-50 site in West Palm Beach. The B-50 site is approximately the same distance from the Atlantic Ocean as Timbercreek, and is expected to experience similar weather patterns. Evaporation was assumed to contain negligible water quality concentrations for mass loading purposes. Groundwater quality data was collected on-site at a shallow well approximately 75 feet from the main south pond for the final five months of the program. Seven samples were collected during that period.

RESULTS

Introduction

This section presents an analysis of results obtained from the 18 month water quality study conducted at the Timbercreek subdivision. Termination of the study occurred due to depressed lake levels which coincided with the operation of a new city of Boca Raton well field (Milleson, 1983).

Two general sections will be discussed. The hydrology section will deal initially with general storm event chacteristics relative to the nine water quality sampled events. Individual detention pond inflow and outflow hydrographs will also be analyzed to provide better understanding of trends and perturbations associated with the water quality results. The final evaluation of hydrologic data will be in the form of mass loadings into and out of the detention ponds. All of the analyses will be conducted on unpublished raw data available on request.

Water quality results will be evaluated for both the routine biweekly sampling scheme and for the storm event monitoring. Stormwater runoff quality will be compared to recent literature values and discrete storm runoff trends will be analyzed. Runoff water quality will be compared to that for surface discharge from the detention system. Finally, mass loadings into and out of the pond system will be analyzed for various pollutants to determine the overall treatment efficiency of Timbercreek's detention ponds.

Treatment pond efficiency will be reported for both surface water loadings and for total system interaction which includes rainfall, evaporation, and groundwater seepage. The reason behind two evaluations is to allow comparison with values in the literature that were compiled for either surface water efficiency or for total system efficiency.

HYDROLOGY

Storm Water Runoff Characteristics

Nine separate storm events were monitored for water quality. The individual runoff events occurred due to rainfall on November 1 and November 16, 1982, and January 20, February 12-13, February 27, August 19, August 24, August 29, and October 22-23, 1983. For the sake of simplicity, these individual events and their resulting effects will be referred to as storms one through nine, respectively.

The nine events had rainfall depths ranging in size from 0.54 inches to 5.66 inches (Table 1). Eight of the nine events, however, were greater than one inch in depth. It has been reported by Wanielista (1981A) that approximately 90 percent of the rainfall events for five years at 13 sites in Florida are less than 1.0 inch. The eight storms at Timbercreek greater than one inch represent a selection of atypical storm magnitudes, but they do provide storm events that the SFWMD's regulatory criteria are addressing with its D/R rule.

The maximum one hour intensities for the nine storms ranged from 0.52 to 2.16 inches per hour (Table 1). Peak flow correlated linearly with the maximum one-hour intensities ($r^2 = 0.88$), and ranged from 23 to 144 cfs (Table 1). This correlation was more significant than that between peak flow and total rainfall depth ($r^2 = 0.55$) which illustrates the responsiveness of the Timbercreek watershed to short-term rain pulses. This responsiveness is due partly to the small size of the watershed (122 acres). Other contributing factors are immediate runoff from the directly connected impervious areas (15 percent of watershed) and rapid groundwater infiltration due to the high permeability of Timbercreek's sandy soils.

TABLE 1. SUMMARY OF STORM EVENT HYDROLOGIC CHARACTERISTICS - TIMBERCREEK

Storm	Total Rainfall (inches)	Storm Duration (hours)	Maximum One Hour Intensity (in/hr)	Peak Inflow (cfs)	Antecedent Dry Period (days)	Runoff Coefficient
1	2.10	10	0.95	46.	2	0.08
2	4.02	9	2.16	144.	7	0.18
3	2.97	16	0.90	28.	10	0.11
4	4.77	21	1.56	105.	2	0.14
5	1.82	12	0.52	23.	11	0.08
6	0.54	1	0.54	35.	1	0.06
7.	1.86	7	1.19	69.	5	0.10
8	1.80	11	1.45	82.	5	0.12
9	5.66	22	1.44	122.	4	0.14

1/ Runoff Coefficient Mean = 0.11 (inches runoff/inches rainfall).

The antecedent dry period, defined as days prior to the given event with less than 0.25 inches of rainfall, ranged from one to eleven days (Table 1). It was felt that since Timbercreek employs deeply sodded swales instead of a conventional curb and gutter system, an initial abstraction on the high side (Viessman, et.al., 1977) was required prior to the generation of surface runoff. The antecedent dry period based on the 0.25 inch depression storage was found to correlate with storm loads of selected water quality parameters in runoff for a south Florida residential community (Miller and Mattraw, 1982).

Individual runoff coefficients or fraction of rainfall as surface runoff for the nine storm events ranged from 0.06 to 0.18 and had a mean value of 0.11 (Table 1). This is significantly lower than the runoff coefficient of 0.21 reported for 33 residential sites in the National Urban Runoff Program (USEPA, 1983). Timbercreek's grassed swale system provides attenuation of stormwater flow prior to its entering the collection system. This attenuation allows additional time for runoff to percolate through the sandy soils and thus lowers the runoff coefficient. Benefits obtained from a lowered coefficient are lower peak flow and decreased mass transport of solids and adsorbed nutrients into the detention system due to typically lower flow velocities.

Attenuation of high flows from stormwater runoff is a primary function of Timbercreek's detention system. The ponds acccomplish this function rather well, as inflow to the ponds exceeded 100 cfs during three of the nine events, yet maximum discharge from the ponds reached only 1.6 cfs (Table 2).

Analysis of the water quality associated with discharge from the nine storm events is limited to the time until the next significant rainfall. The

TABLE 2. SUMMARY OF DETENTION POND EVENT RELATED CHARACTERISTICS - TIMBERCREEK

Storm	Total Rainfall (Inches)	Dry Period Following Event (Days)	Initial[1] Pond Elevation (Feet)	Effective Detention[2] Volume (Inches)	Peak Discharge (cfs)
1	2.10	2	10.30	0.95	0.8
2	4.02	1	10.27	0.98	1.6
3	2.97	2	9.95	1.23	0.7
4	4.77	3	10.32	0.94	1.6
5	1.82	8	10.36	0.91	0.8
6	0.54	4	10.23	1.01	0.1
7	1.86	5	10.08	1.13	0.3
8	1.80	3	10.25	0.99	0.8
9	5.66	11	10.12	1.09	1.6

[1] Outflow occurs when pond elevation reaches 10.24 feet.

[2] Effective Detention Volume Mean = 1.03 inches.

dry periods following the nine events ranged from one to eleven days (Table 2).

As stated earlier, the effective detention volume available for storage of stormwater runoff should ideally be equivalent to a minimum of one inch over the entire watershed as required by SFWMD's regulatory criteria. The pond elevation prior to the onset of a storm event dictates how much detention volume is available for that particular storm. Initial elevations higher than the design elevation reduce the effective detention volume that is available by literally filling it up. This decreases the time available for settling and effectively decreases the detention pond treatment potential. If the initial elevation of the pond is lower than the design elevation, more volume is available for storage prior to discharge and the effective detention volume is increased. This will aid in the treatment process by extending the period available for settling out particulate matter.

In terms of analyzing the D/R rule, the effective detention volume becomes an important physical parameter. For the nine events, the mean effective detention volume was 1.03 inches with a standard deviation of 0.10 inch. This allows analysis of the nine events on either an average basis, or on a storm event basis with confidence that approximately one inch of detention is being observed. The minimum effective detention volume for the nine events was 0.91 inches over the watershed, while the maximum reached 1.23 inches (Table 2).

Storm Hydrographs

Five of the nine quality monitored rainfall events required manipulation of their hydrologic timestep in order to better reflect watershed response. The method used for this change in timestep was discussed in detail in the

Methods section of this report. These events, numbered one through five, generated reasonable runoff or inflow hydrographs when they contained at least one period of relatively intense rainfall. The results of the change were erratic, however, when the event was characterized by low intensity intermittent rainfall, although total runoff volume should be accurate on an event basis.

Three rainfall events generated peak runoff in excess of 100 cfs (Figure 3). Events two and four had maximum one-hour rainfall intensities greater than 1.5 inches, which led to the generation of typical stormwater runoff hydrographs, with the rising limb and recession portions of the hydrographs intact. Event nine consisted of both low intensity intermittent rainfall and an hour of high intensity rainfall (1.44 in.). Response of the watershed to both the low and high intensity rainfall of event nine was in the form of sharp peaks in the runoff hydrograph. The portion of the hydrograph resulting from the hour of high intensity rainfall did, however, exhibit a slight recession following the peak.

Three events generated peak stormwater runoff in the 50 to 100 cfs range (Figure 4). Events one, seven, and eight had maximum one-hour intensities of 0.95, 1.19, and 1.45 inches, respectively. These intensities were near the mid-range of intensities for the nine events. Event one required the manipulation of its hydrology timestep. The generation of the double peak at the height of stormwater runoff and the generation of several small peaks later could be an artifact of this methodology. Events seven and eight both reached peak flow quickly and dropped back to zero flow with only a slight recession of their hydrographs. This quick response could be due to the size of the watershed, the effect of direct runoff from impervious areas, and the high permeability of the local soils.

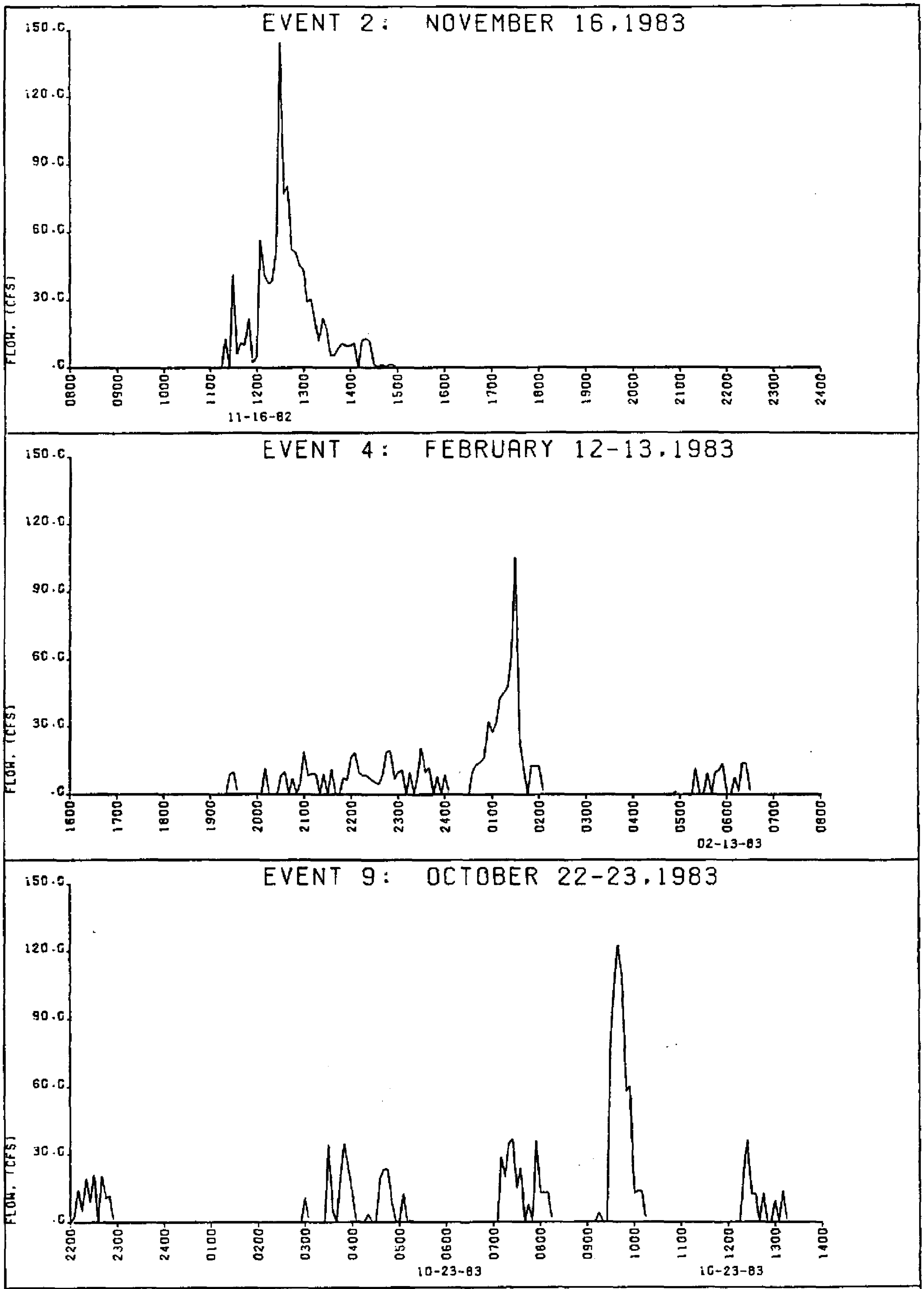


FIGURE 3 : TIMBERCREEK INFLOW, (CFS)

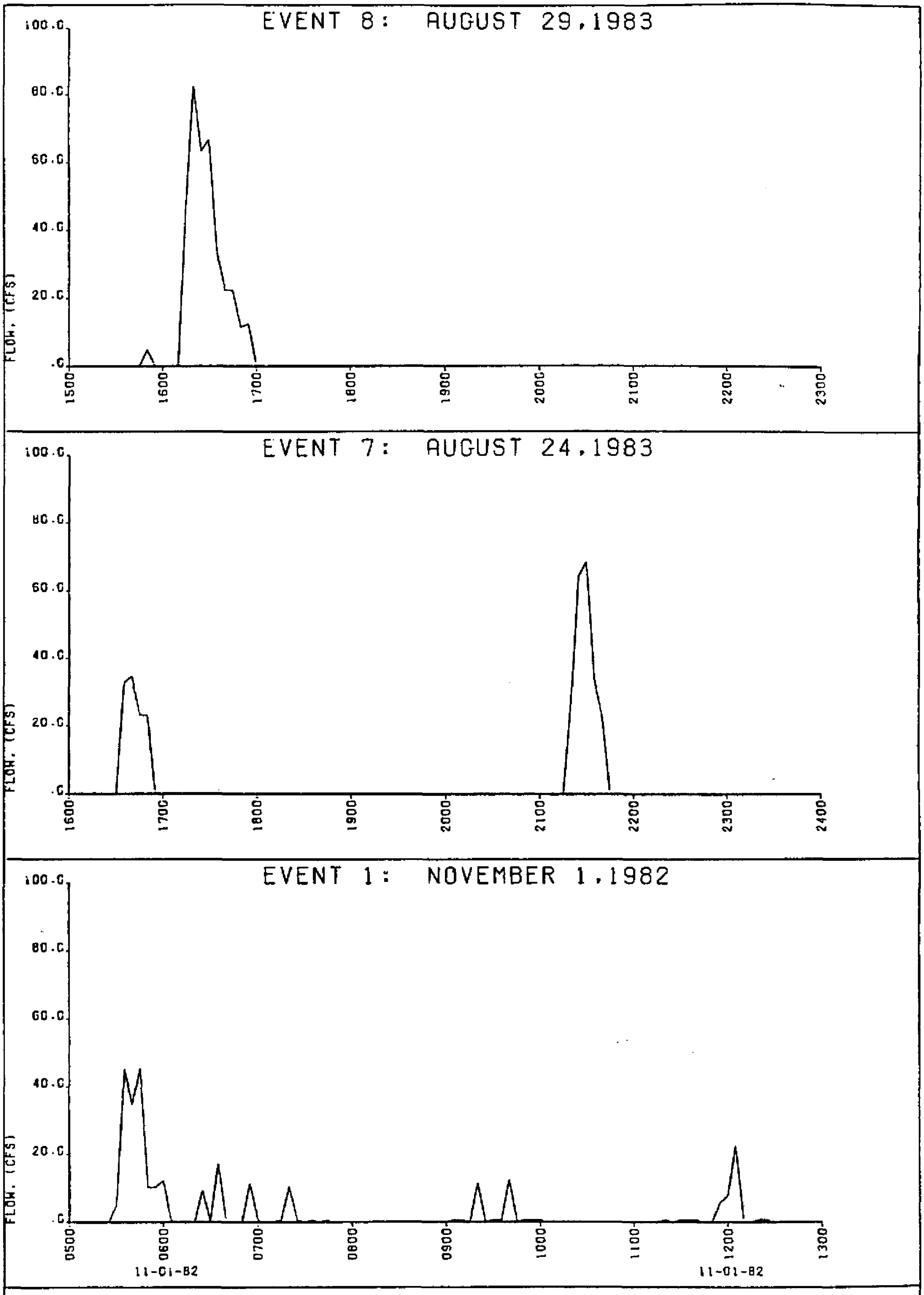
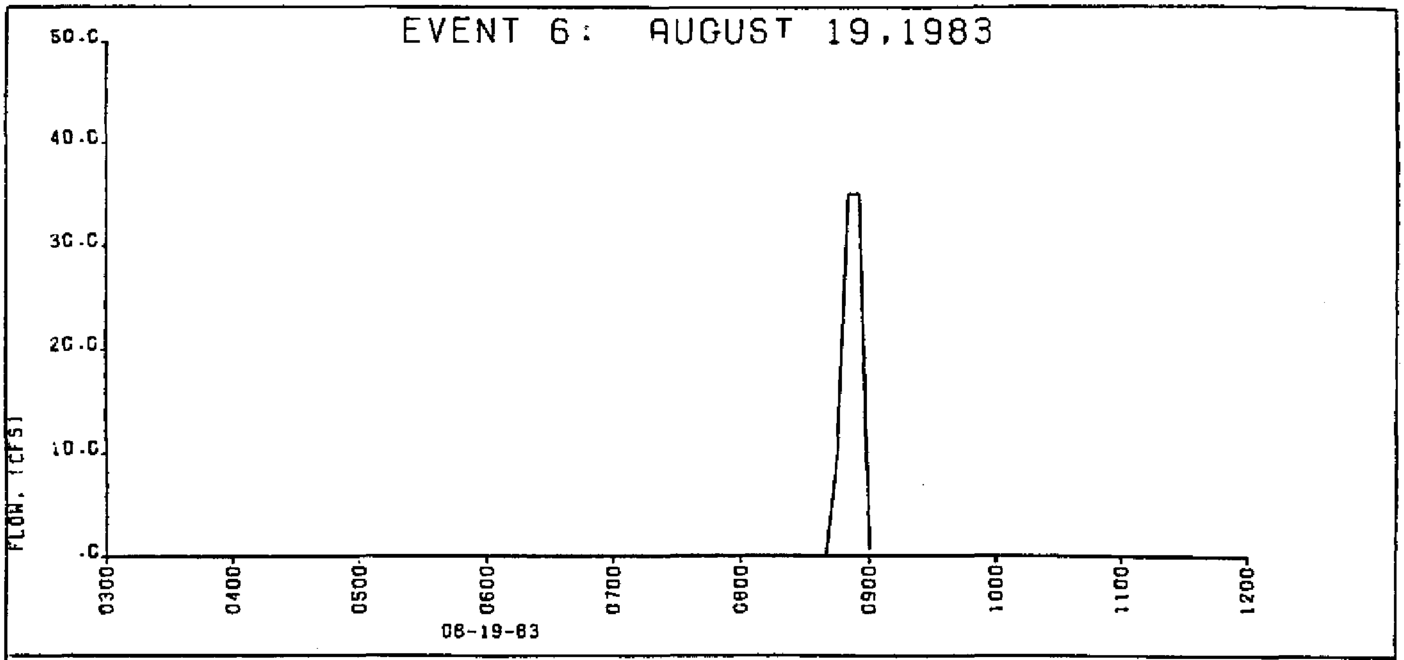


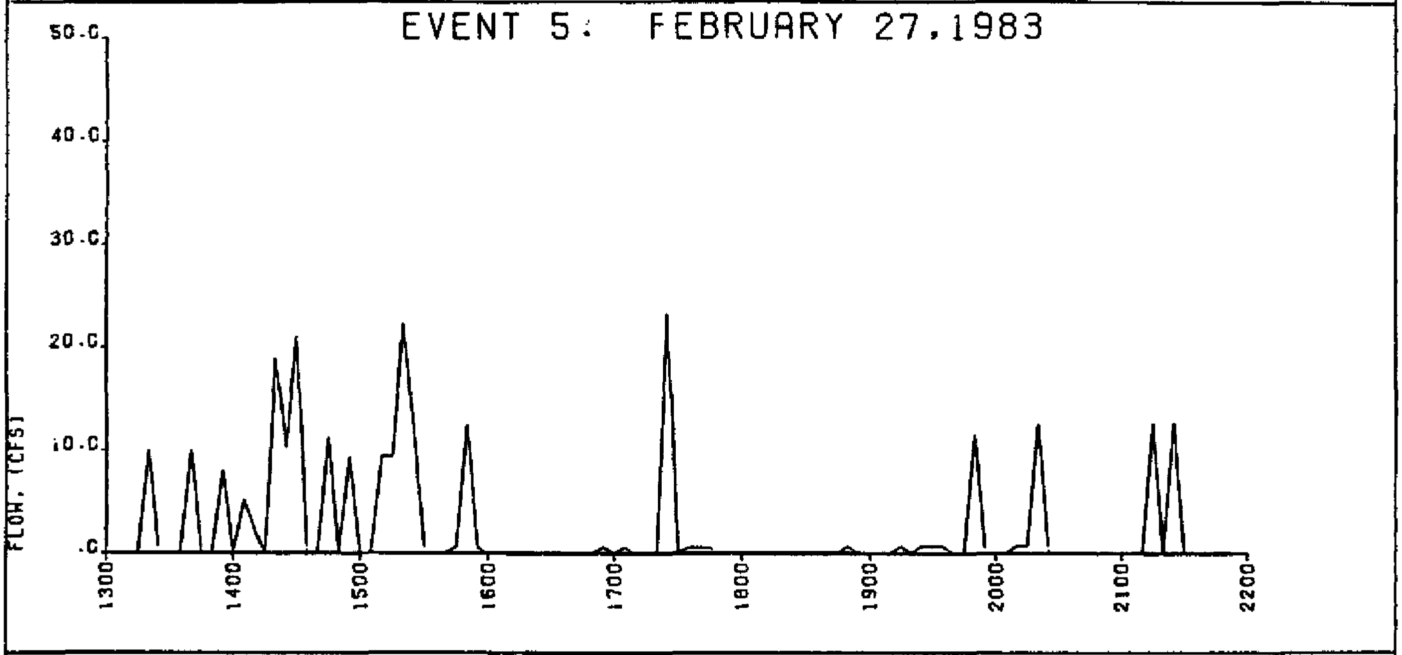
FIGURE 4 : TIMBERCREEK INFLOW, (CFS)

The inflow hydrographs for the remaining three events were composed mainly of sharp small peaks with maximum flow falling below 50 cfs (Figure 5). Hydrographs for events three and five were developed after manipulation of their timestep. This may have resulted in generating the series of small sharp peaks which were also noted for event one. A maximum one-hour rainfall intensity of 0.90 inch for event three resulted in a period of semi-constant flow. The hydrograph for event six was in the form of one sharp peak, a direct result of 0.54 inch of rainfall in one hour. This was the extent of rainfall and resultant runoff for the entire event.

Outflow hydrographs for the nine events emphasize the high level of attenuation provided by the detention system. A maximum event related discharge of 1.6 cfs was measured, compared to the peak runoff rate of 144 cfs. The maximum discharge of 1.6 cfs occurred during events two, four, and nine. The remaining events never reached one cfs, and event six peaked at 0.1 cfs. The outflow hydrographs have a resolution of 0.1 cfs, which has caused them to appear as a step function.

Most of the events had additional flow generated from additional storms before the complete recession of their outflow hydrographs. Storm one, which reached a peak of 0.8 cfs, had an increase in flow two days following the event while event two had additional flow on the day immediately following the event (Figure 6). Events three and four had additional flow added to their hydrographs two and three days following their initial flow, respectively (Figure 7). Events five and eight also had flow from a separate event added to their discharge hydrographs. This occurred eight and three days after the beginning of their events, respectively, (Figures 8 and 9). Three events had their outflow hydrographs recede to zero flow without interference from other


EVENT 6: AUGUST 19,1983


EVENT 5: FEBRUARY 27,1983

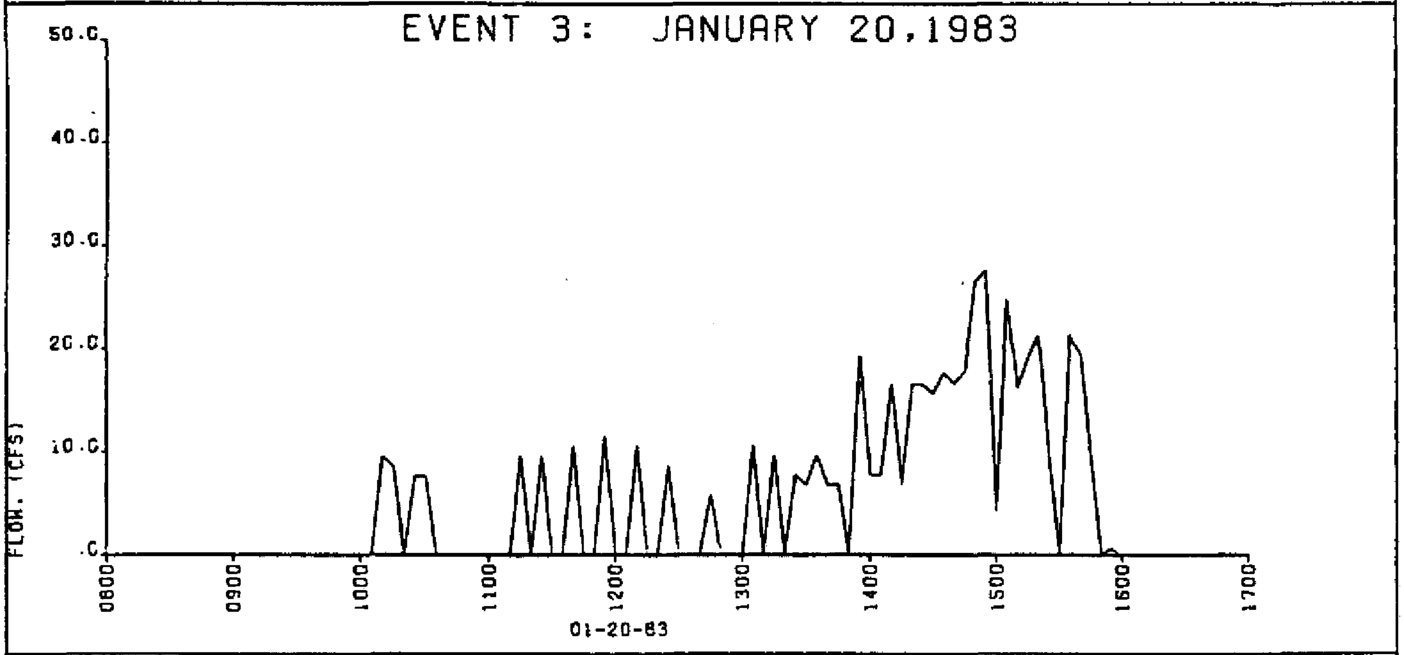

EVENT 3: JANUARY 20,1983

FIGURE 5 : TIMBERCREEK INFLOW, (CFS)

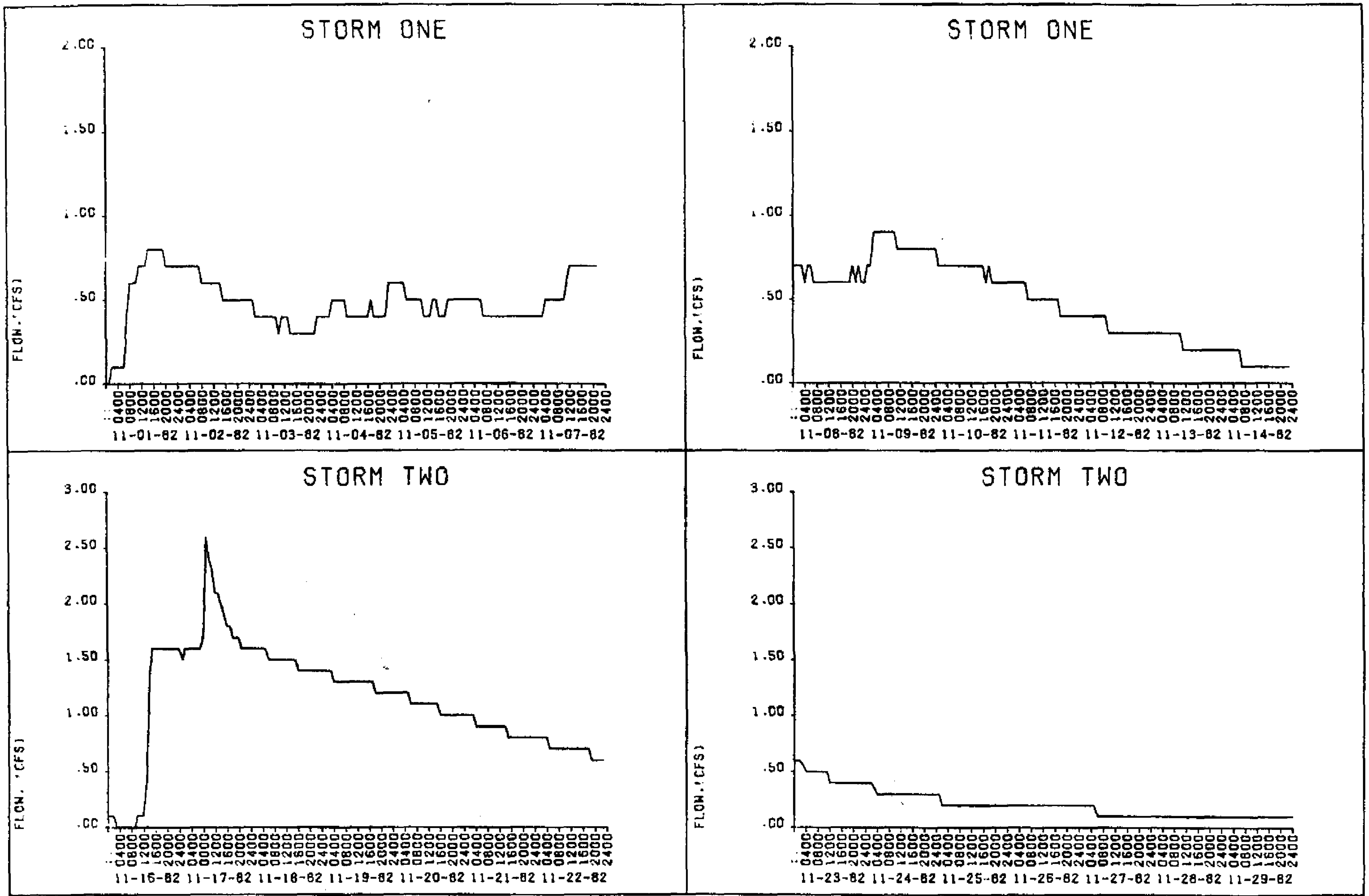


FIGURE: 6 STORM WATER DISCHARGE STORMS ONE AND TWO storm generated flow. These were events six and seven, which had discharge for one and four days following the onset of storm discharge and event nine, which had uninterrupted flow for eight days. Computation of pollutant mass loadings has a higher degree of confidence when the event has uninterrupted flow. A linear interpolation was used to estimate the recession portion of the outflow hydrograph for those events with added flow during the outflow period.

Overall, the nine events that were sampled for water quality provided a wide range of hydrologic diversity. Estimates of surface inflow during low flow periods were erratic, but it is felt that total storm volumes are accurate. Surface outflow was well attenuated and peaks in the flow were minimally discernable.

Detention Pond Hydrologic Budget

Hydrologic loadings into and out of the detention pond system were computed for six separate flow paths. Flow into the pond system consisted of surface runoff, direct rainfall, and groundwater seepage. Flow from the system was delineated into surface discharge, evaporation and groundwater recharge. The inflow portion of the hydrologic budget was principally based on the volume of inflow due to direct rainfall on the pond surface and direct surface runoff generated from the given event. Groundwater flux was estimated from change in lake stage data after rainfall ceased and evaporation and surface discharge were used to balance the inflow components of surface runoff and rainfall. Methodology used to estimate the components of the hydrology budget is presented in the Methods section.

Direct rainfall accounted for 21 - 40 percent of the inflow budget for the detention system for the nine events (Table 3). Event six, which had only

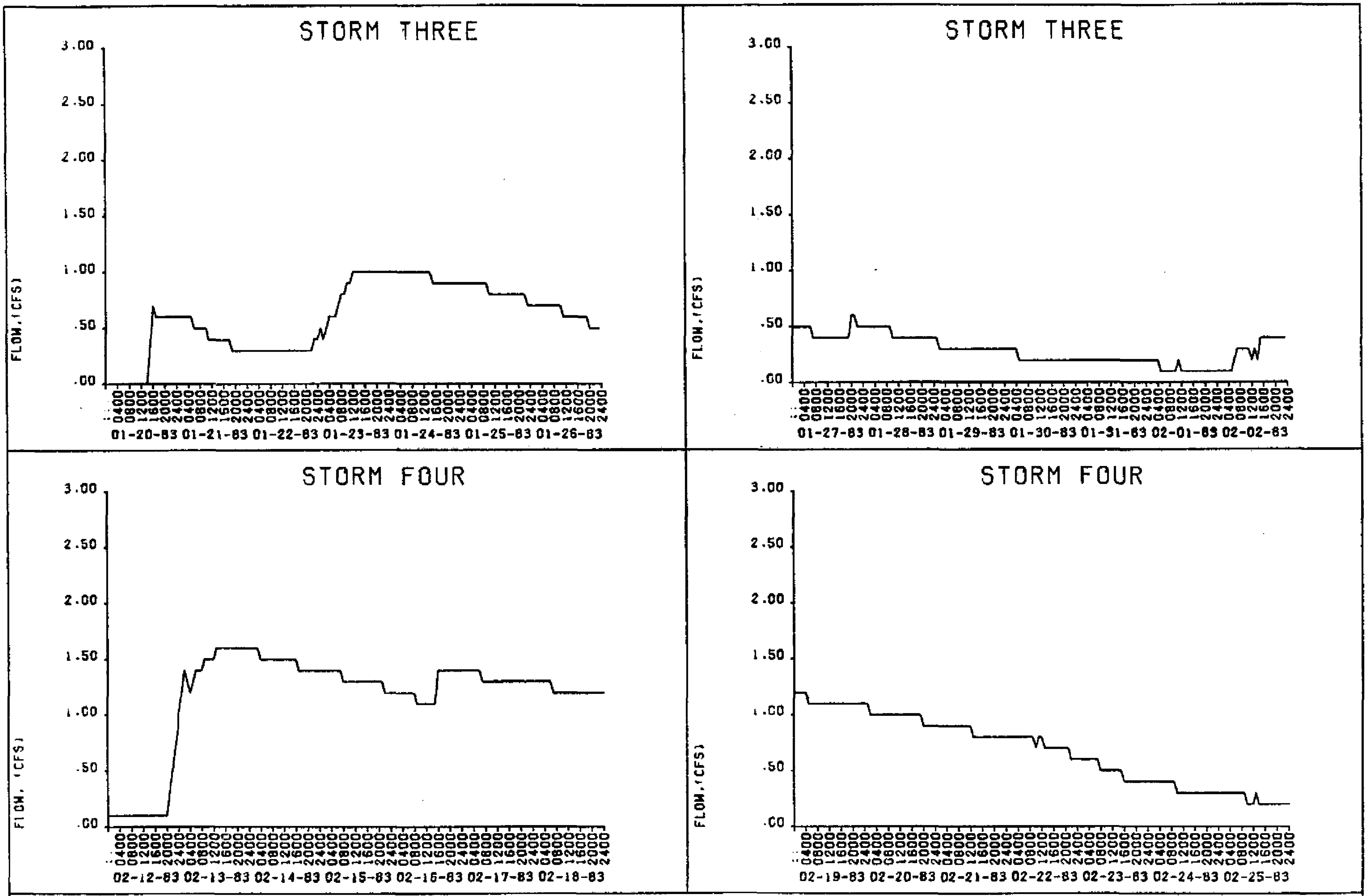


FIGURE: 7 STORM WATER DISCHARGE STORMS THREE AND FOUR

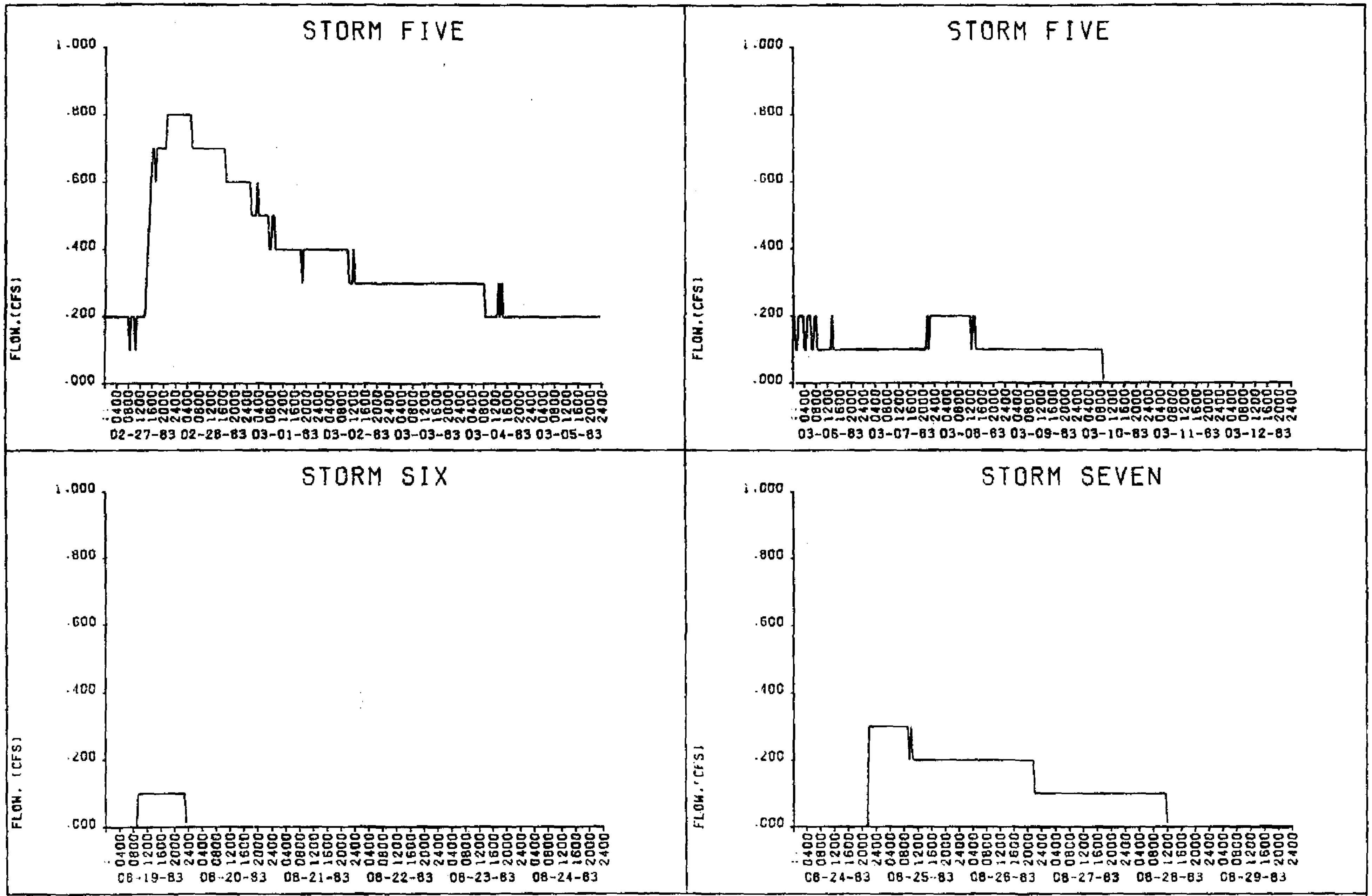


FIGURE: 8 STORM WATER DISCHARGE STORMS FIVE,SIX AND SEVEN

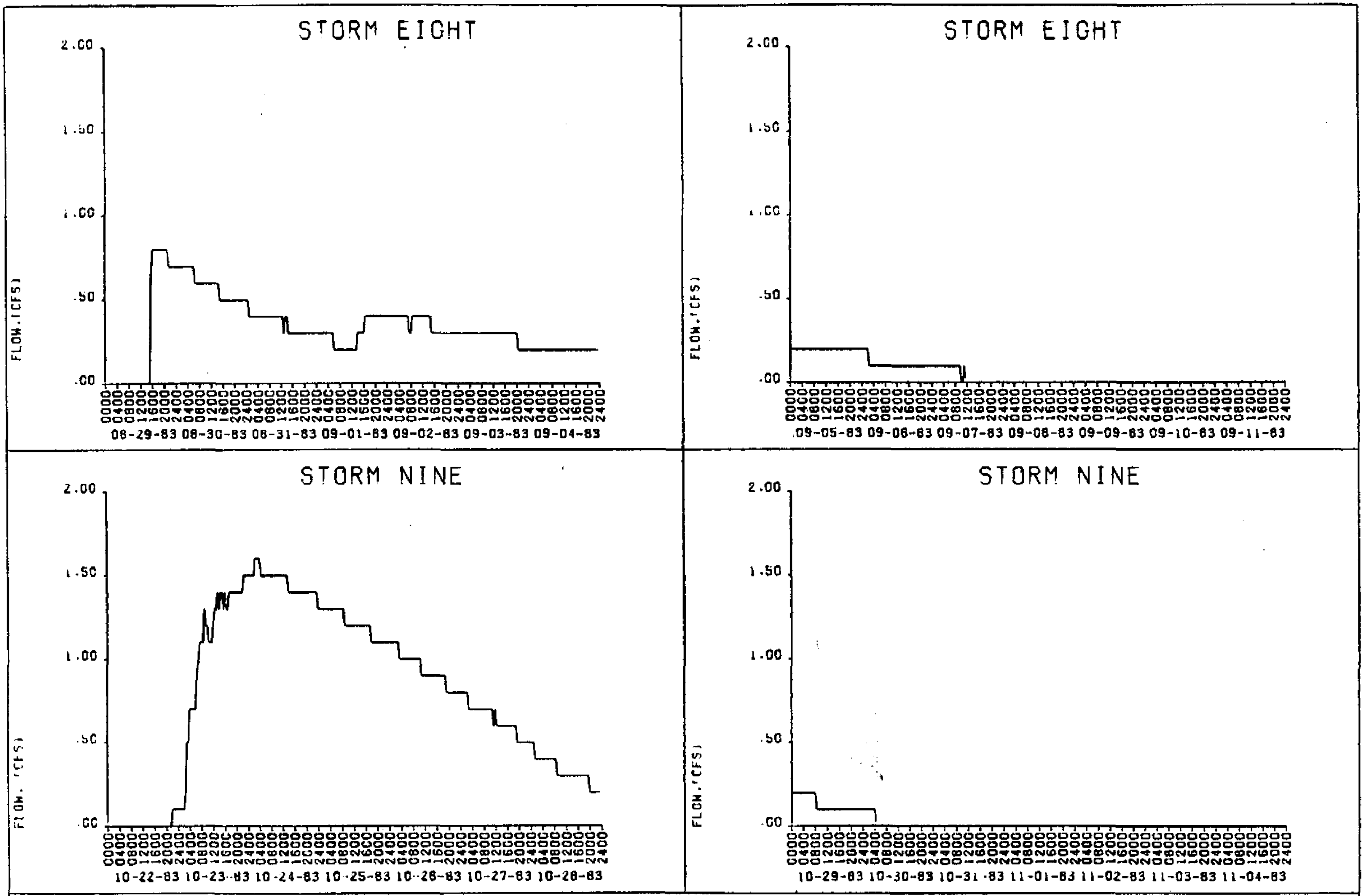


FIGURE: 9 STORM WATER DISCHARGE STORMS EIGHT AND NINE

0.54 inch of rainfall, did not produce sufficient rainfall to raise the detention system was reflected in the high relative contribution of rainfall for the event (40 percent).

Surface runoff into the detention system ranged between 44 and 64 percent of the inflow budget for eight of the nine events. Low intensity rainfall during event five, along with an initial low soil moisture due to eleven days of antecedent dry weather, combined to generate only 31 percent of the inflow as surface runoff.

Groundwater seepage made up the remainder of the inflow to the detention system. A depressed pond elevation prior to events three and seven, and the low level of precipitation during event six, caused little inflow to the pond system to be in the form of groundwater seepage. Conversely, the high pond and associated groundwater elevations during event five helped in generating 47 percent of the inflow for that event as groundwater seepage. The remaining events had groundwater contributions ranging from 12 to 35 percent of the inflow budget. Higher initial pond elevations generally resulted in higher percentages of groundwater inflow.

Two physical parameters were found to influence the relative magnitudes of the outflow for a given event. The combination of the depth of rainfall and the initial pond elevation determined the relative percentage of surface discharge, groundwater flow and evaporation that occurred. Large events that filled the detention system regardless of the initial pond elevation had the same effect as having a high initial pond elevation. Elevated pond levels lead to a quick release of event related flow by means of surface discharge. This did not allow groundwater levels time to recede and consequent seepage out of the pond to occur prior to satisfying the hydrologic budget with the

TABLE 3. HYDROLOGIC BUDGET FOR NINE STORM EVENTS, MAGNITUDE[1/] AND PERCENTAGE OF TOTAL FLOW

					Surface Flow				Groundwater Flow			
Event	Rainfall	%	Evap	%	Inflow	%	Outflow	%	Inflow	%	Outflow	%
1	1.43	34	0.42	10	1.95	46	3.08	73	0.86	20	0.74	17
2	2.84	25	0.30	3	7.31	64	10.52	91	1.36	12	0.69	6
3	1.99	36	0.36	6	3.55	64	2.52	45	0.05	1	2.71	48
4	3.34	21	0.49	3	6.81	44	14.54	93	5.46	35	0.58	4
5	1.24	22	0.59	10	1.75	31	5.04	90	2.64	47	0.00	0
6	0.36	40	0.26	29	0.55	60	0.11	12	0.00	0	0.54	59
7	1.33	35	1.10	29	2.28	60	1.19	31	0.22	6	1.54	40
8	1.22	28	0.48	11	2.52	58	2.87	66	0.60	14	0.99	23
9	3.89	27	0.80	6	8.89	63	11.52	81	1.42	10	1.88	13
Average		30		12		54		65		16		23

[1/] In ac-ft

surface outflow. Under these conditions, greater than 65 percent of the outflow was in the form of surface discharge.

When a small storm occurred, or when the initial pond level was below the bleeder elevation, less that 50 percent of the total outflow was in the form of surface discharge. In these cases, event related outflow was delayed, and removal due to groundwater flow and evaporation assumed a higher percentage of the total outflow.

WATER QUALITY

Background Monitoring

Mean concentrations of nitrate plus nitrite (NO_x) were slightly higher at the two pond influent sites (TCRK2, TCRK6) than in the pond. All mean concentrations at all seven sample sites were very low however, especially when compared to rainfall quality data from a nearby station (Table 4).

Ammonium concentrations were near the detection level of 0.02 mg/l at five of the six surface water sites. The average concentration was slightly higher at the site TCRK1, which was located in a pond where a cypress dome once existed. A small island in the pond still supports a stand of cypress. The decomposition of cypress needles underwater has been reported to cause ammonification of organic matter (Dierberg, 1981), which could lead to the slightly higher average concentration. The groundwater sample site has a mean ammonium concentration one order of magnitude higher than several of the surface water sites. Due to typical anoxic conditions found in groundwater, reduction of nitrate and nitrite to ammonium was the suggested cause of the higher mean concentration.

Total Kjeldahl nitrogen (TKN) at all seven sites maintains relatively constant levels. The average concentration for the seven sites was about 50-75 percent higher than average TKN concentrations recorded at the local rainfall site. A comparison of other nitrogen species of Timbercreek to nitrogen levels in ambient rainfall shows ammonium to be generally similar while NO_x levels in the rainfall is significantly higher (Table 4).

Ortho phosphate (OPO_4) concentrations recorded at Timbercreek were at the detection level of 0.004 mg/l for the majority of the study period. Elevated concentrations at one of the inflow sites (TCRK2) and at the groundwater site

TABLE 4. WATER QUALITY SUMMARY FOR BIWEEKLY BACKGROUND MONITORING - MEAN CONCENTRATION LEVELS AND RANGE

Sample Site	NO_x	NH_4	TKN	OPO_4	TPO_4	TSS
TCKR1	.017 .004-.061	.09 .01-.35	.73 .20-1.26	.004 .004-.009	.020 .008-0.51	7.3 1.0-86.1
TCRK2	.065 .004-.336	.03 .01-.30	.77 .26-1.65	.022 .004-.155	.050 .013-.184	7.1 1.0-45.0
TCRK3	.017 .004-.168	.02 .01-.09	.84 .30-1.70	.004 .004-.013	.036 .017-.171	5.8 1.0-22.7
TCRK4	.010 .004-.069	.02 .01-.08	.76 .28-1.44	.004 .004-.006	.028 .011-.052	6.9 1.0-81.8
TCRK5	.012 .004-.072	.03 .01-.11	.72 .28-1.43	.004 .004-.006	.028 .010-.055	5.5 1.0-16.0
TCRK6	.069 .009-.275	.04 .01-.13	.82 .27-1.21	.010 .004-.034	.042 .019-.075	6.1 1.0-29.0
TCRK7[2]	.026 .004-.073	.26 .17-.39	.87 .70-1.16	.026 .010-.052	.039 .017-.079	3.5 1.0-8.1
Rainfall Site						
B-50	.178	.09	.45	.012	.024	

[1] All as mg/L except Turb (JTU), Color (units), Sp. Cond. (umhos/cm), pH, and Alk (meq/L)
[2] Groundwater site

TABLE 4 (continued). WATER QUALITY SUMMARY FOR BIWEEKLY BACKGROUND MONITORING - MEAN CONCENTRATION LEVELS AND RANGES

Sample Site	Turb[1]	Color[1]	Sp Cond[1]	Cl	Alk[1]	pH[1]
TCRK1	3.0	64.	135.	16.7	.21	5.72
	1.1-9.1	25.-165.	99.-122.	10.2-22.3	.10-.36	4.82-7.56
TCRK2	2.9	68.	163.	19.7	.62	6.69
	1.1-5.5	20.-123.	57.-194.	4.1-107.4	.35-4.71	5.99-7.46
TCRK3	3.5	72.	173.	19.4	.50	6.98
	1.8-6.0	22.-122.	131.-199.	14.1-26.6	.32-1.03	6.05-7.54
TCRK4	3.0	65.	171.	19.4	.48	6.90
	1.7-8.7	15.-104.	133.-209.	15.1-26.6	.32-.62	6.31-7.61
TCRK5	2.9	66.	198.	23.9	.49	6.96
	1.2-6.6	13.-122.	152.-260.	20.2-31.9	.36-.62	6.46-7.60
TCRK6	2.7	54.	147.	17.1	.37	6.22
	1.1-8.1	14.-93.	67.-190.	4.0-30.9	.16-.92	5.69-6.80
TCRK7[2]	1.8	44.	258.	29.9	1.02	5.92
	1.0-2.6	13.-65.	228.-284.	22.6-40.8	.33-1.46	5.53-6.13

Rainfall Site	Turb	Color	Sp Cond	Cl	Alk	pH
B-50					3.8	0.18

[1] All as mg/L except Turb (JTU), Color (units), Sp. Cond. (umhos/cm), pH, and Alk (meq/L)
[2] Groundwater site

(TCRK7) during the final six months of the study helped raise the mean OPO_4 level at these two sites. Total phosphate at site TCRK1 averaged slightly lower than the rest of the watershed. The pond at site TCRK1 has houses on only one side, which may reduce human contributions of phosphate to that site relative to the other sites. It is also at the top of the catchment area, which would preclude contributions of phosphate from upstream sources.

Total suspended solids (TSS) and turbidity maintained their lowest levels at the groundwater site (TCRK7). This would be due to filtration of solids as water passes through Timbercreek's sandy soils and indicates adequate development of the groundwater well. Little difference in mean TSS or turbidity was found between the six surface water sites. Most of the samples collected during the biweekly monitoring were collected under quiescent conditions, which would explain the lack of differences between the various sites.

Chloride exhibited its highest mean concentration at the groundwater site. Similarily, specific conductance was highest at the same site, most likely due to the high chloride levels. This result is typical of what would be expected when comparing groundwater and surface water sources. The mean chloride and specific conductance levels were slightly lower at site TCRK1 than at the other surface water sites. This might be due to site TCRK1 being located at the top of the watershed. Concentration of conservative constituents such as chloride may not have occurred that early in the flow path.

Alkalinity concentrations follow the trend of that reported for chloride. Elevated levels of alkalinity in the groundwater may be due to dissolved - 38 -calcite or dolomite carbonates. The lowest mean alkalinity level was recorded at site TCRK1 although reasons for this are ill-definied.

Average pH was lowest at the groundwater site and at site TCRK1. The entire watershed maintained pH levels below 7.0.

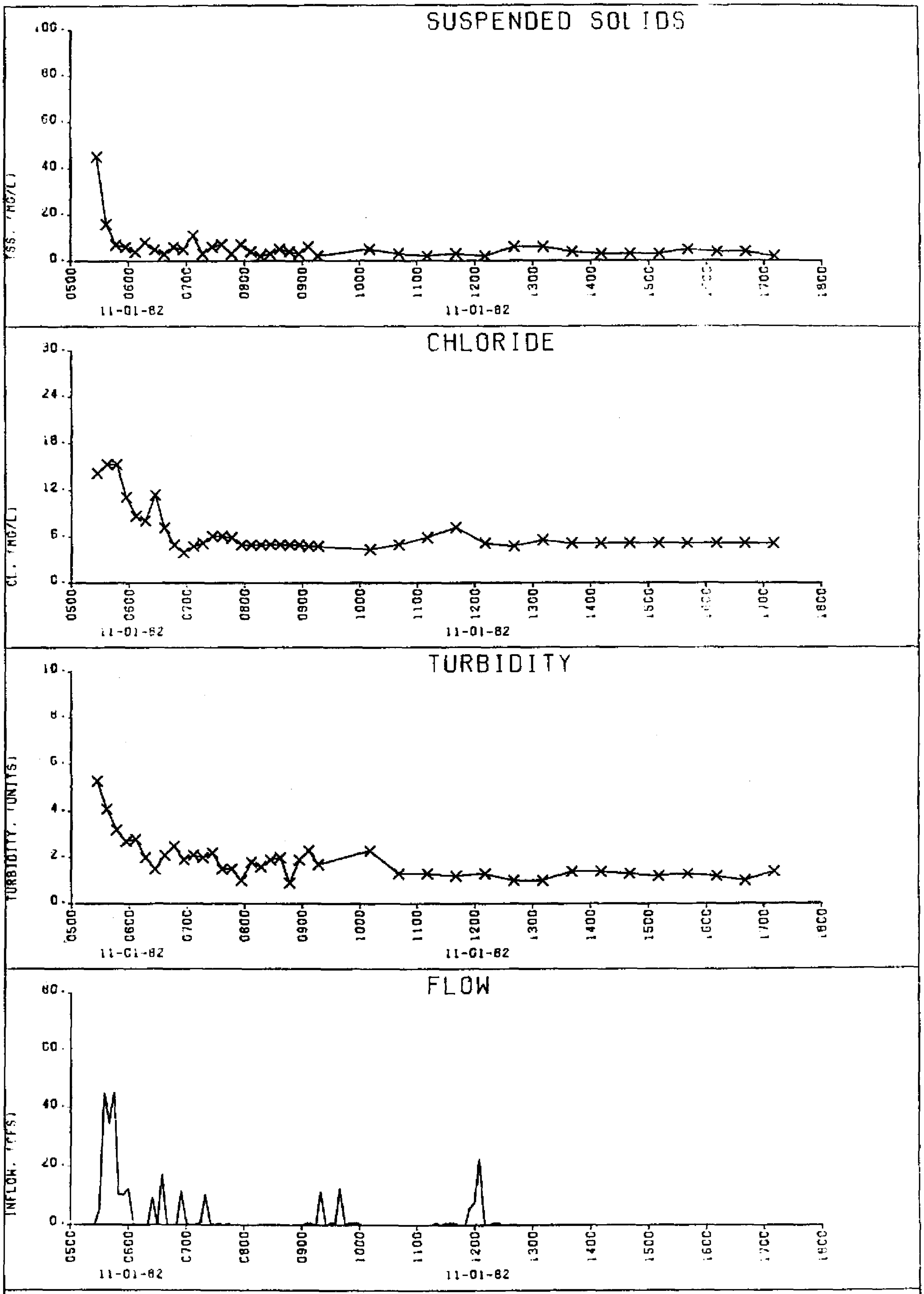
Color was lowest at the groundwater site but little difference was found between the six surface water sites.

Storm Event Runoff Analysis

The first event to be successfully monitored for water quality was 2.10 inches in depth and began at 0300 on November 1, 1982. It continued intermittently until 1250 on the same day with runoff commencing at 0525 and peaking around 0540. Two antecedent dry days preceded the event.

Water quality samples were collected at the inflow site beginning at 0527 at a constant time interval of ten minutes for four hours. Following this, inflow samples were collected every 30 minutes. The initial sample, collected during the rising limb of the inflow hydrograph, showed high levels of total suspended solids (TSS), turbidity and total Kjeldahl nitrogen (TKN), (Figures 10 and 11). This is characteristic of the first flush of solid particles associated with the beginning of storm generated flow. TSS, turbidity, and TKN concentrations dropped off exponentially following the first flush.

Dissolved parameters, such as chloride, alkalinity, soluble reactive or ortho phosphate (OPO_4), nitrate with nitrite (NO_x), and color peaked in concentration 20 to 40 minutes after the onset of the storm related flow (Figures 10, 11, 12, and 13). This is also to be expected, as flow volumes become reduced while dissolution of soluble species still occurs after the first flush. Low concentrations of ammonium were present throughout the event (Figure 11). A second peak of TKN and OPO_4, along with total phosphate (TPO_4) was observed approximately two hours after the beginning of the storm related


SUSPENDED SOLIDS

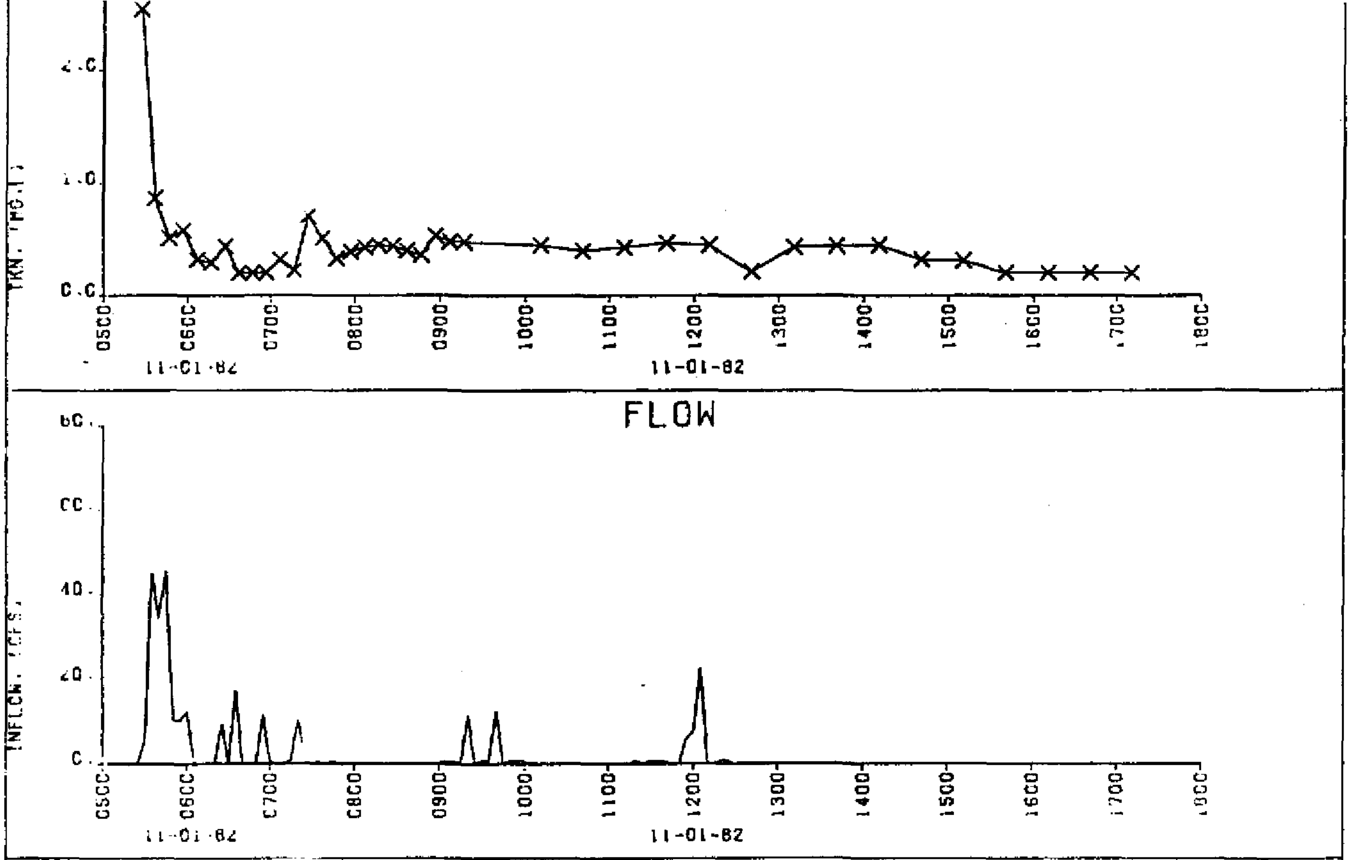
CHLORIDE

TURBIDITY

FLOW

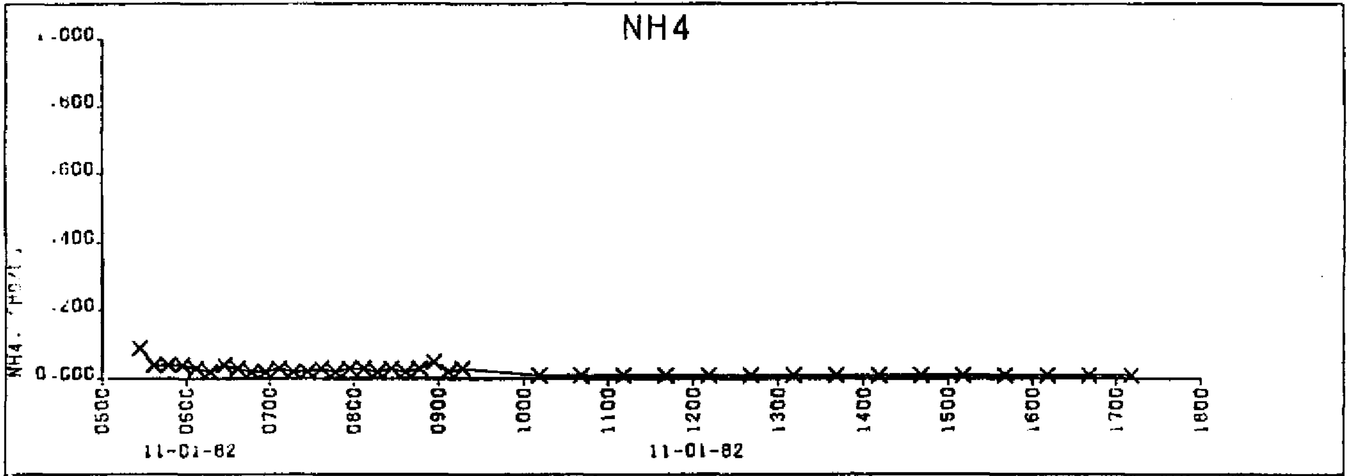
WATER QUALITY AT INLET TO POND, 11/01/82 EVENT 1

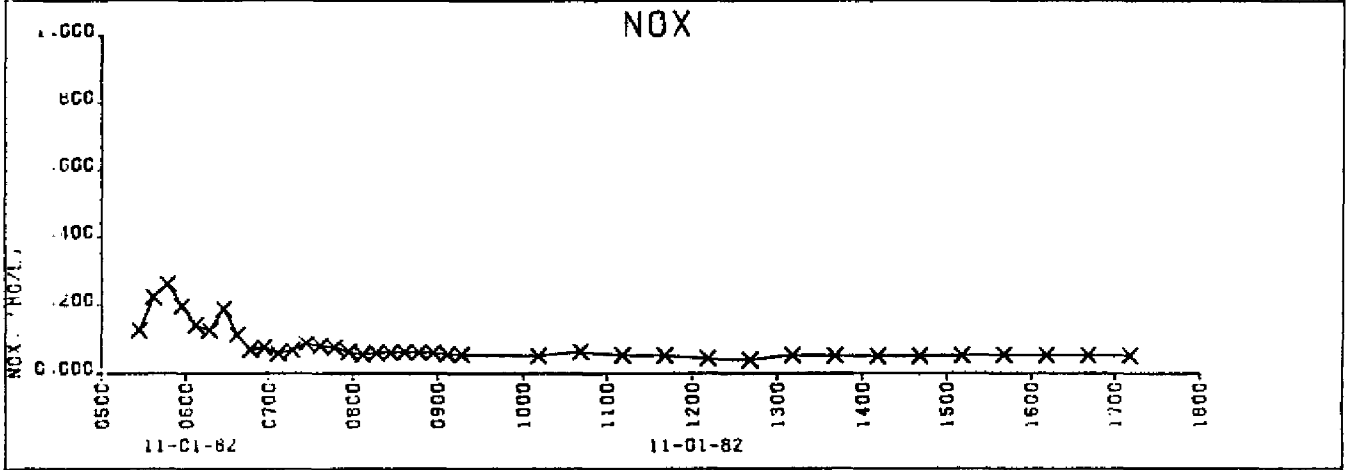
FIGURE 10



WATER QUALITY AT INLET TO POND, 11/01/82 EVENT 1

FIGURE 11


NH4
NH4. (MG/L)
1.000
.800
.600
.400
.200
0.000
0500
0600
0700
0800
0900
1000
1100
1200
1300
1400
1500
1600
1700
1800
11-01-82
11-01-82


NOX
NOX. (MG/L)
1.000
.800
.600
.400
.200
0.000
0500
0600
0700
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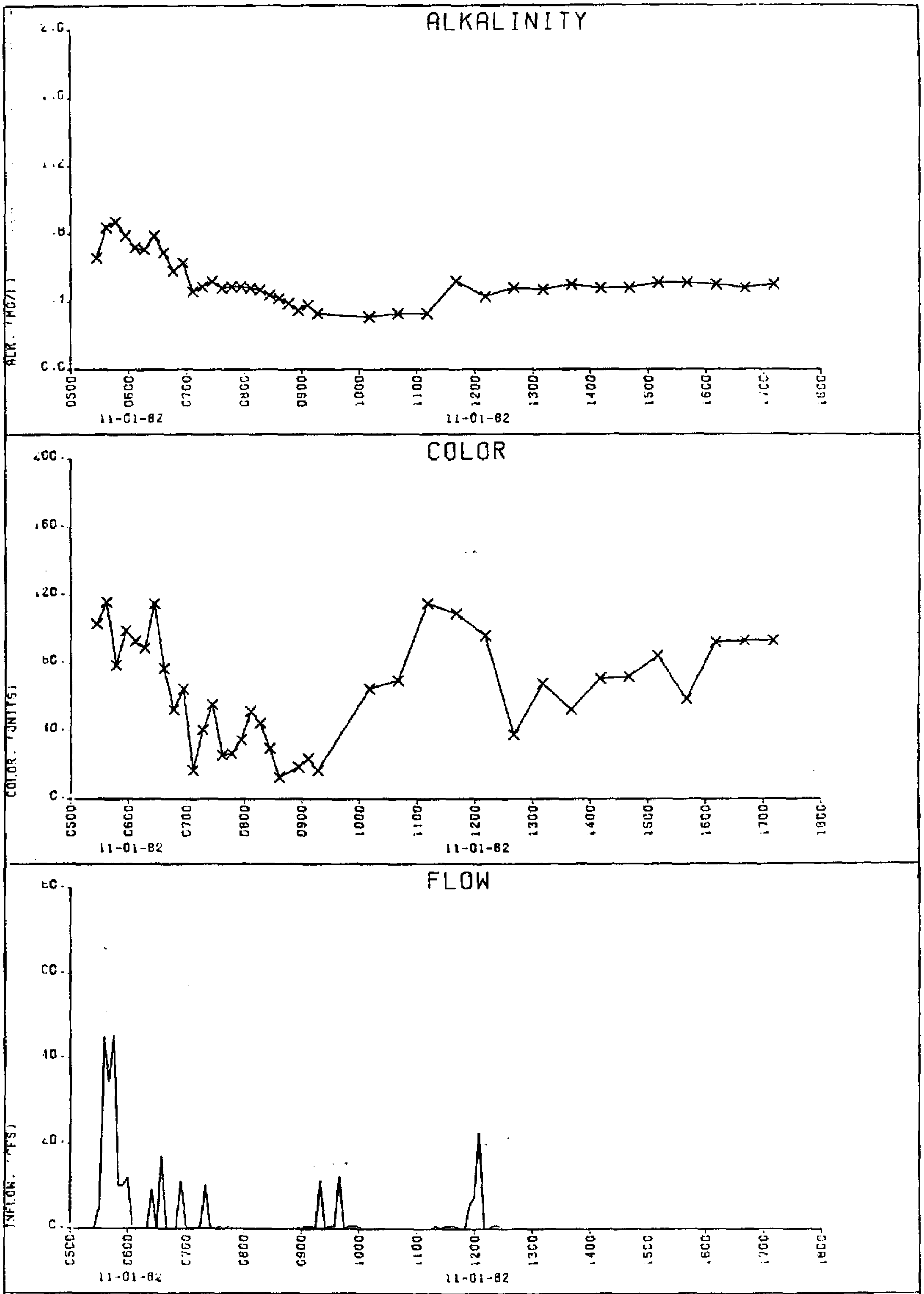
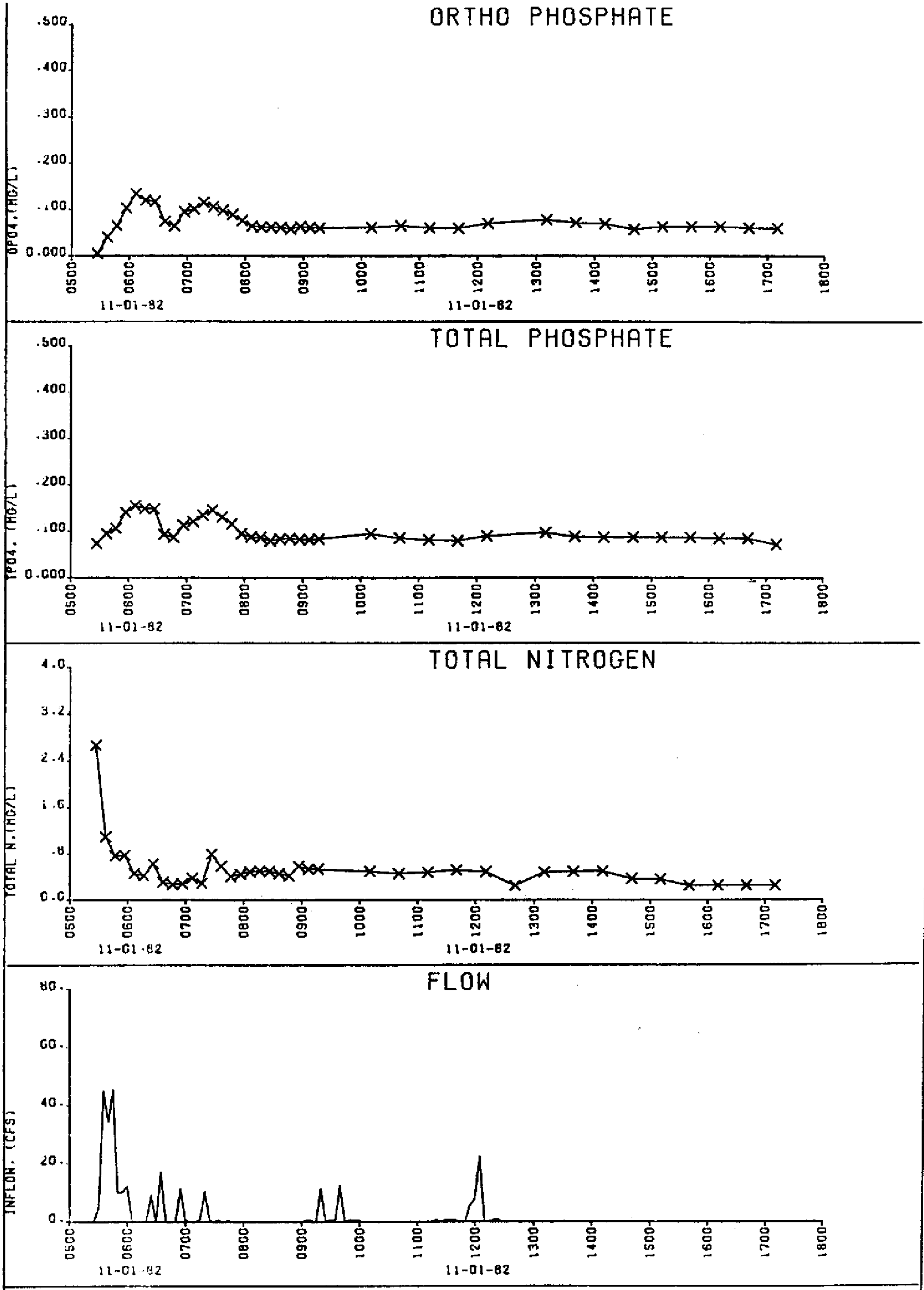
TKN
5.0



WATER QUALITY AT INLET TO POND, 11/01/82 EVENT 1

FIGURE 12



WATER QUALITY AT INLET TO POND, 11/01/82 EVENT 1

FIGURE 13

flow. This could be due to isolated lawn fertilization in the upper reaches of the watershed.

It appears that two days of antecedent dry weather provided sufficient time for solids and nutrients to build up in the watershed. The generation of peak runoff fifteen minutes into the event caused a flushing effect on the watershed for solid particles with less effect on dissolved species.

The second event commenced at 0820 on November 16, 1982 and consisted of 4.02 inches of rainfall. The inflow hydrograph peaked around 1230, although several small peaks occurred prior to that time. There were seven days of antecedent dry weather, which would be sufficient time for pollutant build up to occur on the watershed.

Water quality samples were collected every ten minutes beginning at 1157. Maximum concentrations occurred for TSS, turbidity, and TKN at 1207, which corresponds to the rising limb of the runoff hydrograph peak (Figures 14 and 15). The concentration of these parameters declined in exponential fashion once the first flush of particulate matter passed into the detention ponds. Dissolved species, such as chloride, ammonium, NO_x, OPO_4, and alkalinity, along with physical measurements indicative of dissolved species, such as color and conductivity, maintained higher concentrations during the beginning of the storm and slowly decreased with time, (Figures 14, 15, 16, and 17).

In general, it appears that a flush of the watershed occurred in the early portion of this event and that better quality water reached the detention ponds following the flush.

Event three consisted of 2.97 inches of rainfall occurring intermittently for eleven hours on January 20, 1983. Peak discharge into the detention ponds

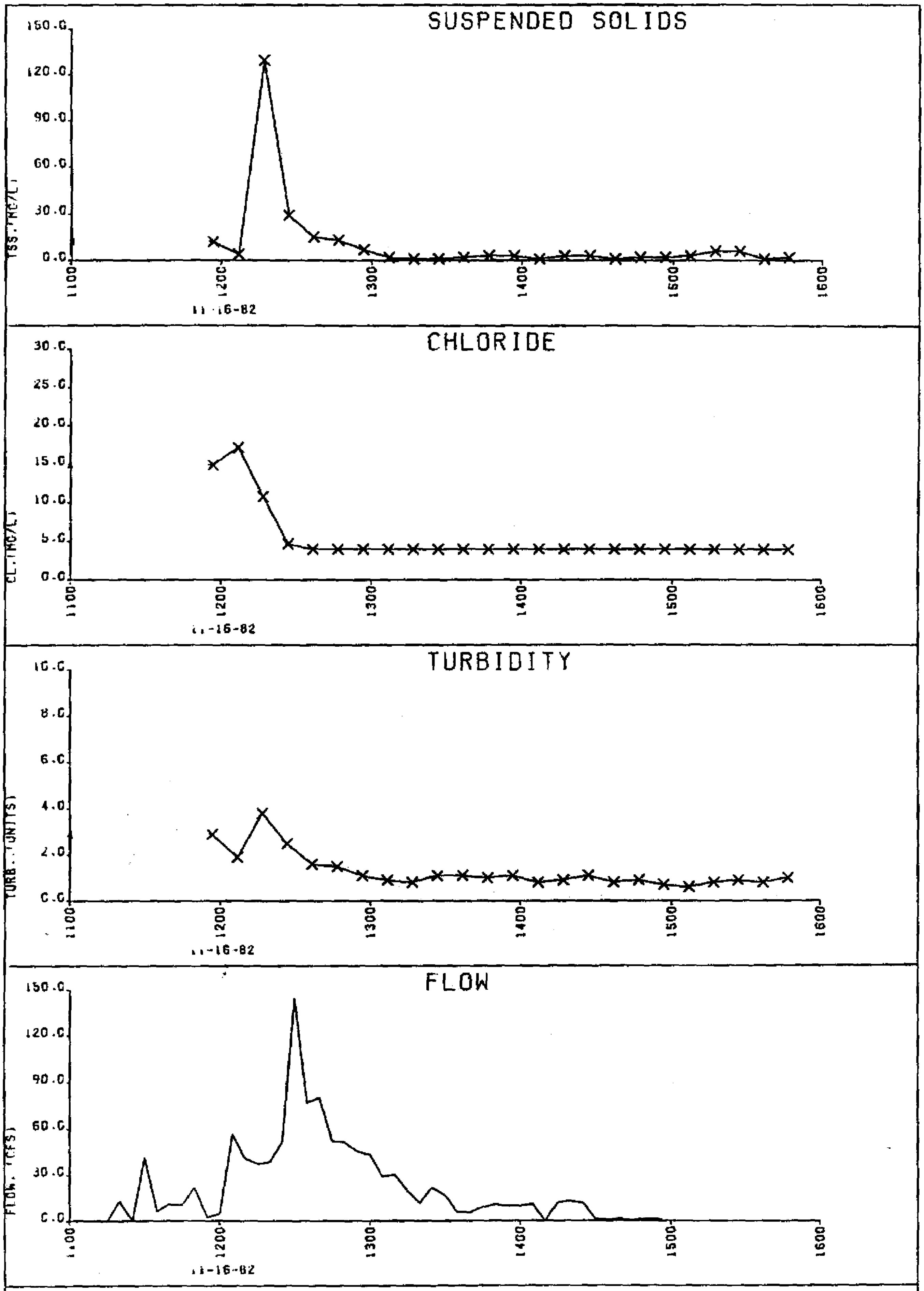


FIGURE: 14 INFLOW WATER QUALITY 11/16/82.

EVENT 2

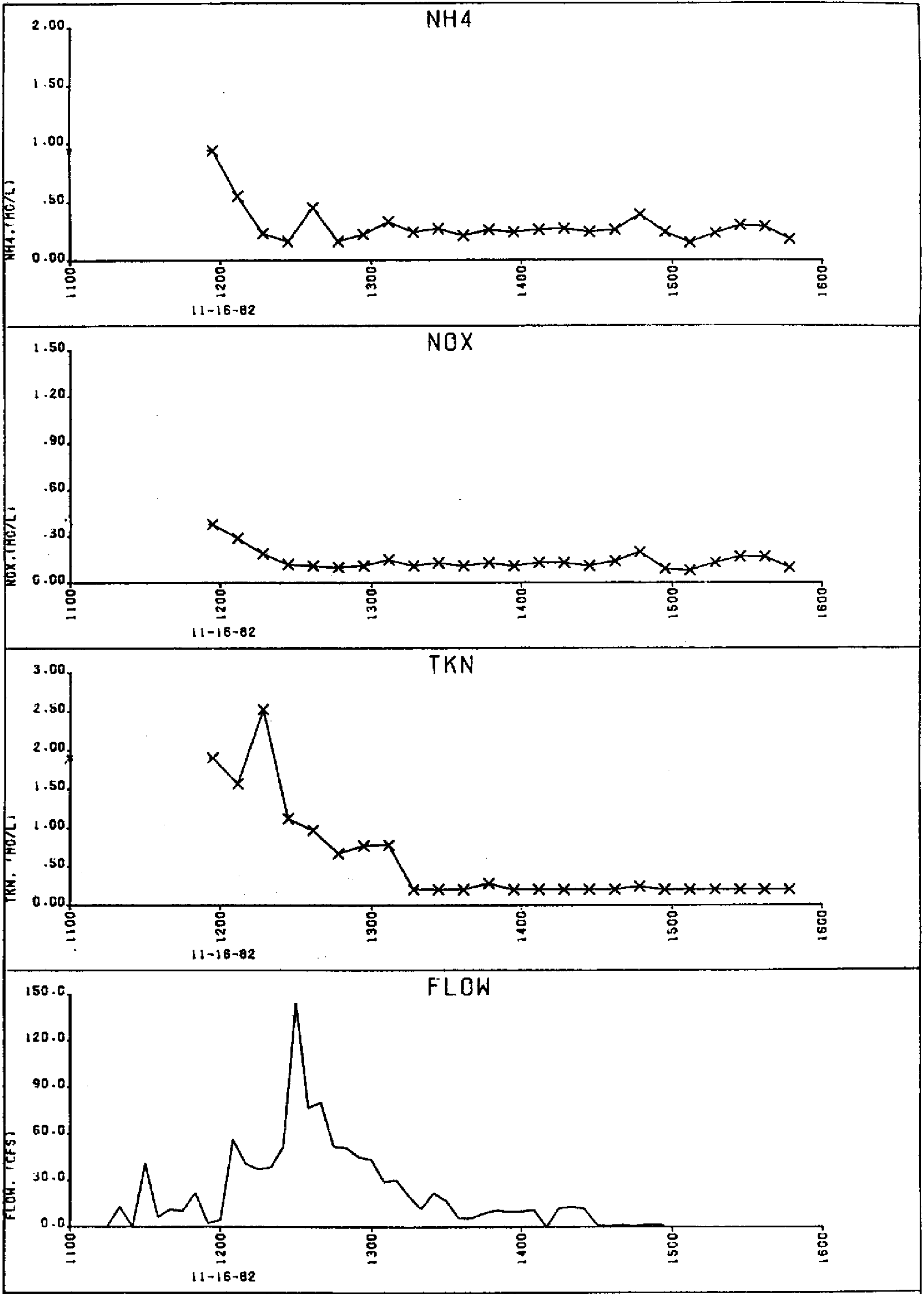


FIGURE: 15 INFLOW WATER QUALITY 11/16/82.

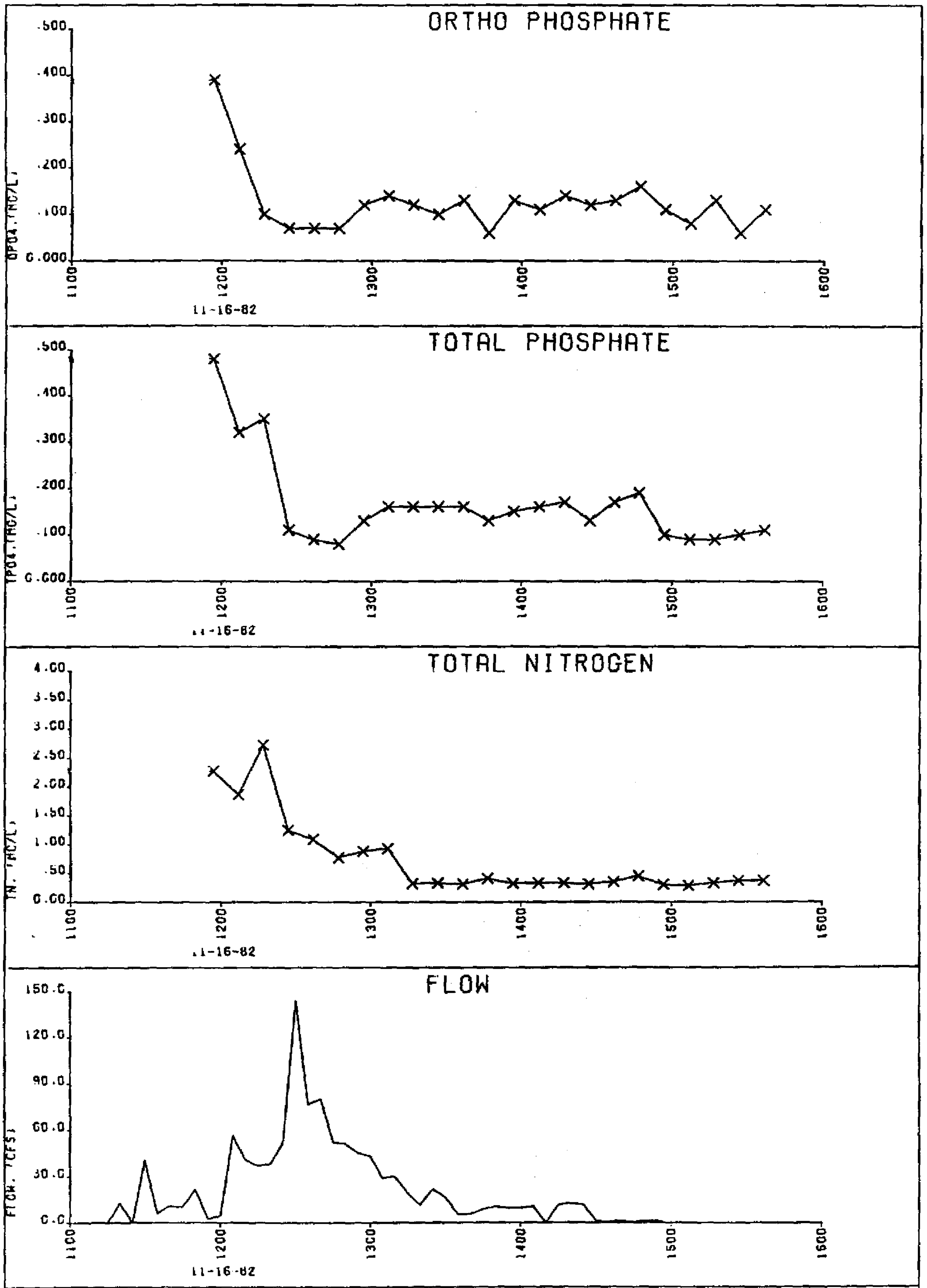


FIGURE: 16 INFLOW WATER QUALITY 11/16/82.

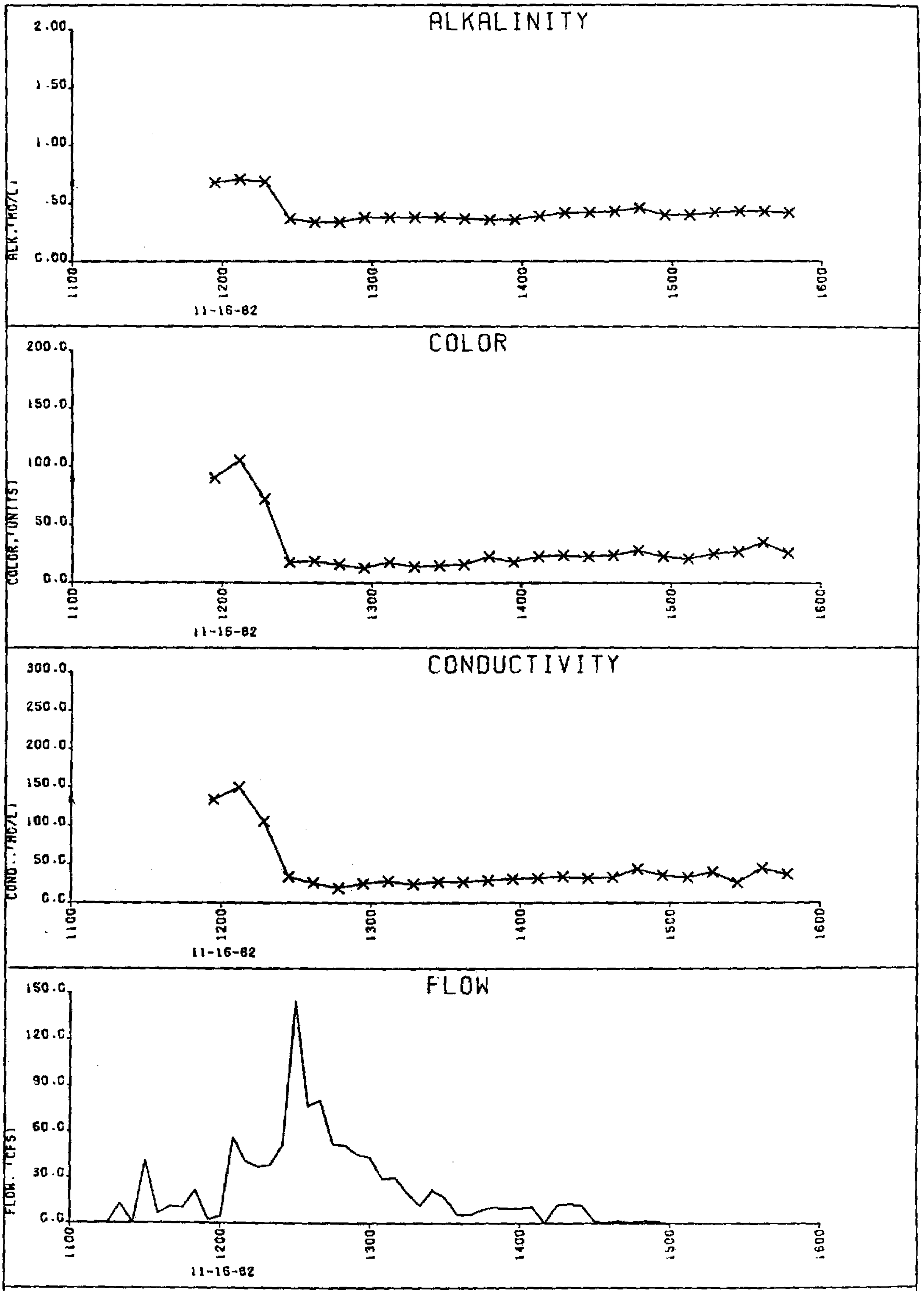


FIGURE: 17 INFLOW WATER QUALITY 11/16/82

EVENT 2

occurred around 1500, although many small peaks were evident earlier in the day. There were eleven days of antecedent dry weather.

Water quality samples were collected at the inflow site every ten minutes begining at 1403. As inflow had been occurring intermittently since before 0800, the water quality parameters normally associated with solids showed little if any effect of a first flush preceding peak runoff. Turbidity, TSS, and chloride all showed gradually decreasing concentrations with time (Figure 18). Following an initial peak of 1.4 mg/l, TKN also decreased gradually (Figure 19). Dissolved nitrogen, in the form of ammonium and NO_x along with phosphates (ortho and total) experienced little change with time (Figures 19 and 20). Alkalinity and color exhibited slightly decreasing concentrations with time (Figure 21).

It is unlikely that a first flush of any magnitude would occur with temporally distributed rainfall such as experienced with this event. The majority of the total runoff volume from this event did have associated water quality data, and mass calculations were performed using this data.

The fourth event to be documented with water quality data occurred on February 12-13, 1983 and consisted of 4.77 inches of rainfall. The event commenced around 1900 on the twelfth and ended at about 0600 on the thirteenth. Maximum rainfall intensity occurred between 0030 and 0130 on the morning of the thirteenth. The remainder of the storm can best be described as a steady light drizzle. There were two days of antecedent dry weather.

Water quality sampling of the inflow began at 0054 during the generation of substantial runoff. Four samples were taken at ten minute intervals during the major rising limb of the inflow hydrograph. Sampling continued every ten minutes until cessation of inflow later in the day. Elevated TSS, turbidity,

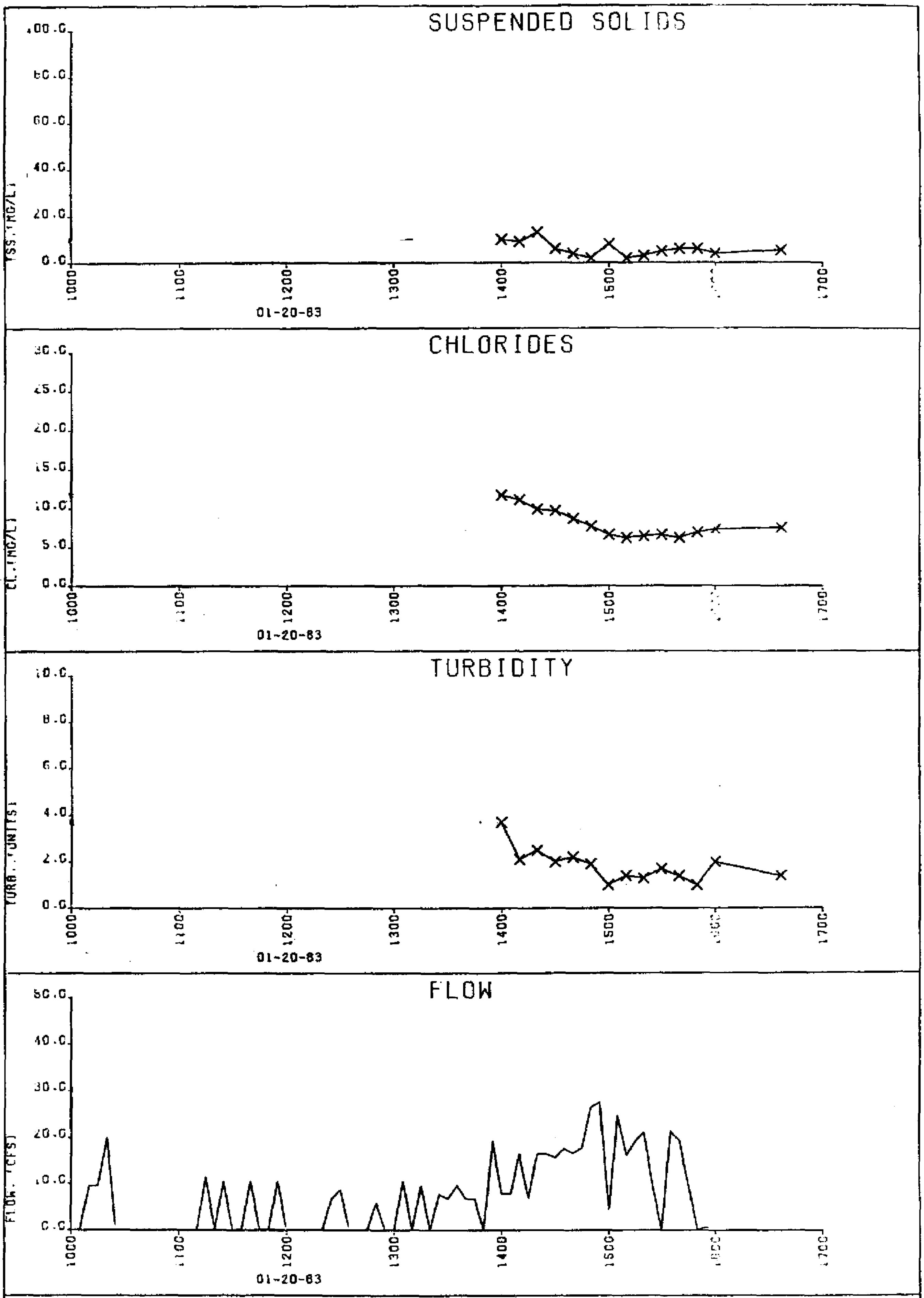


FIGURE: 18 INFLOW WATER QUALITY 01/20/83.

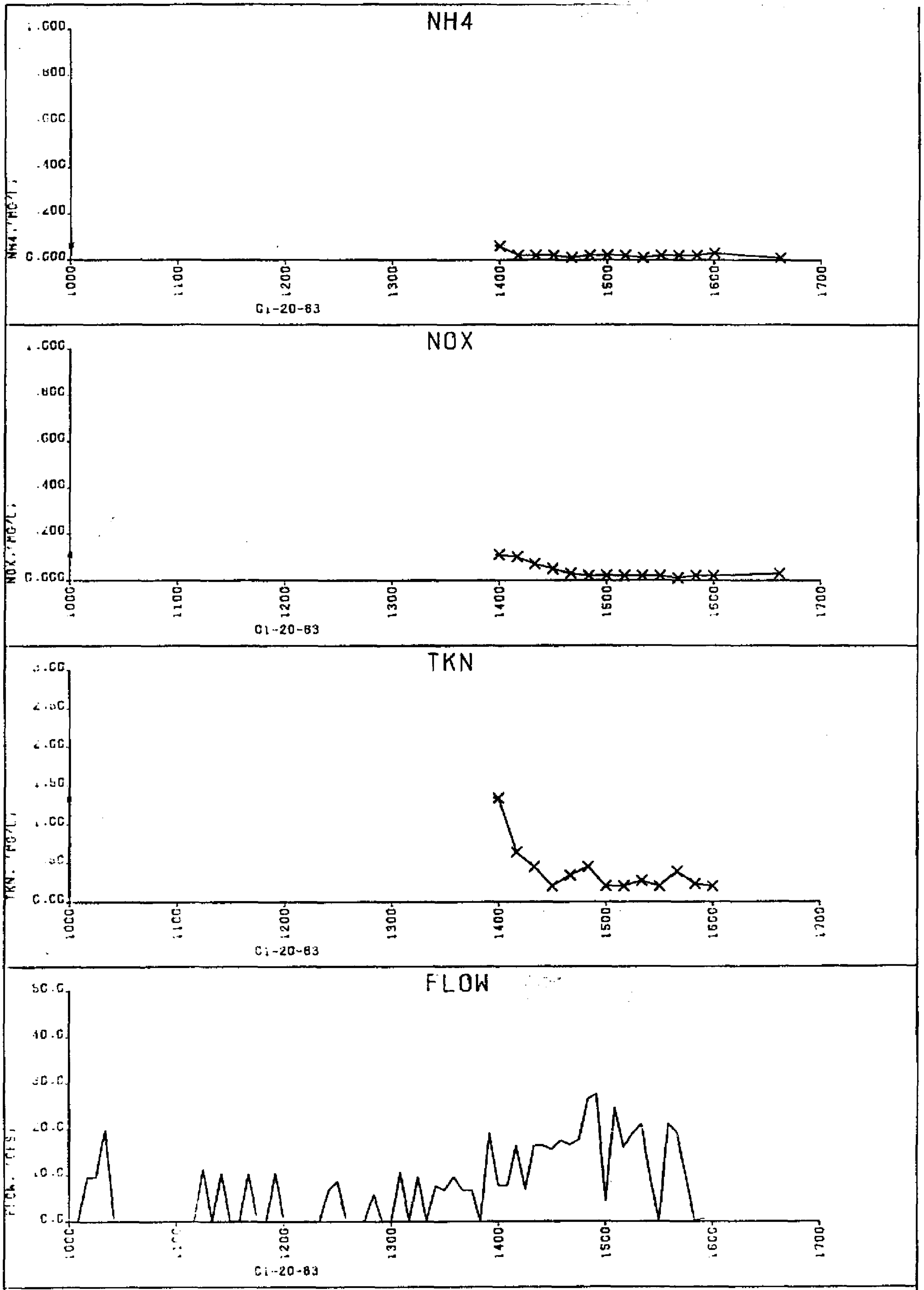


FIGURE: 19 INFLOW WATER QUALITY 01/20/83.

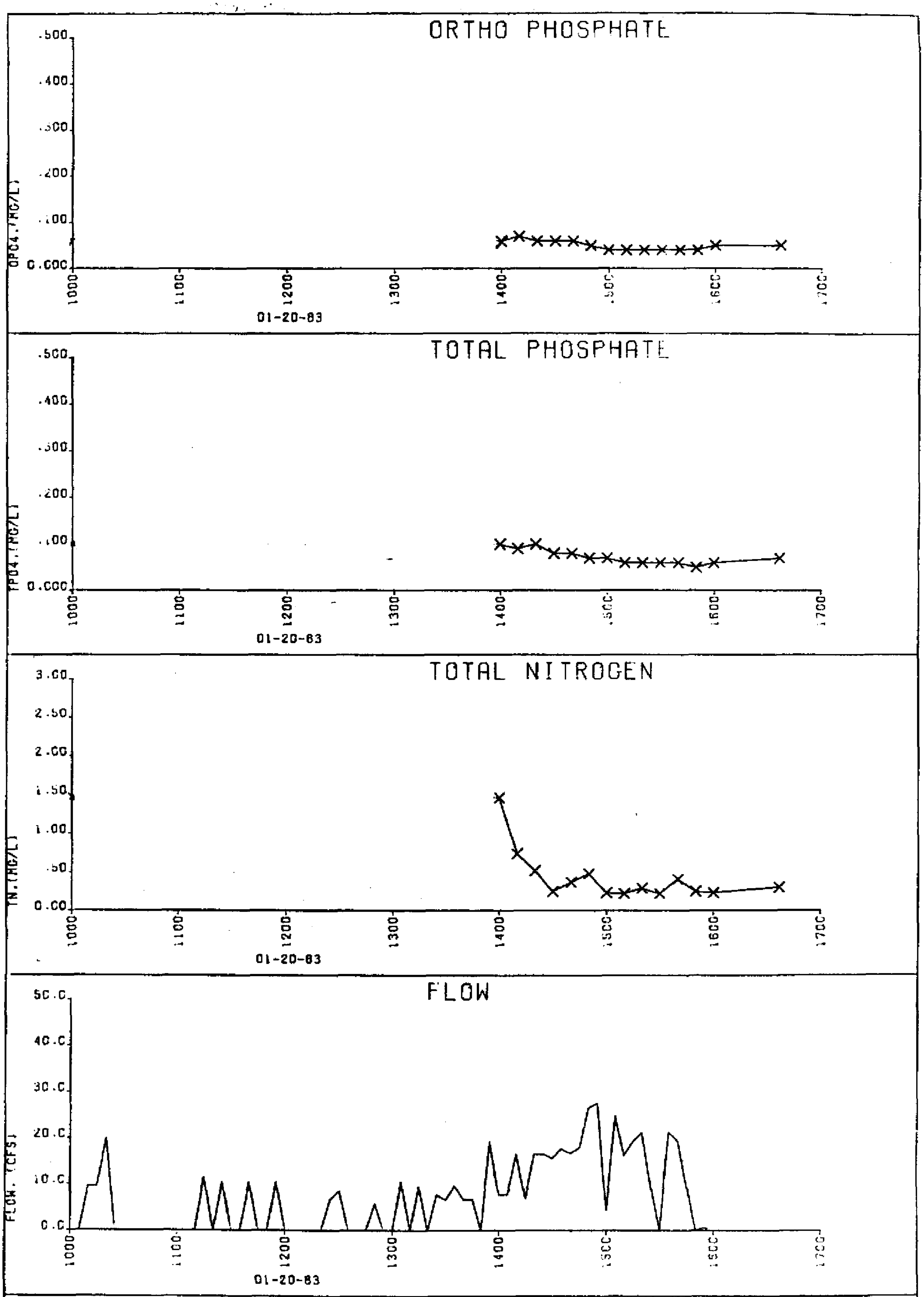


FIGURE: 20 INFLOW WATER QUALITY 01/20/83

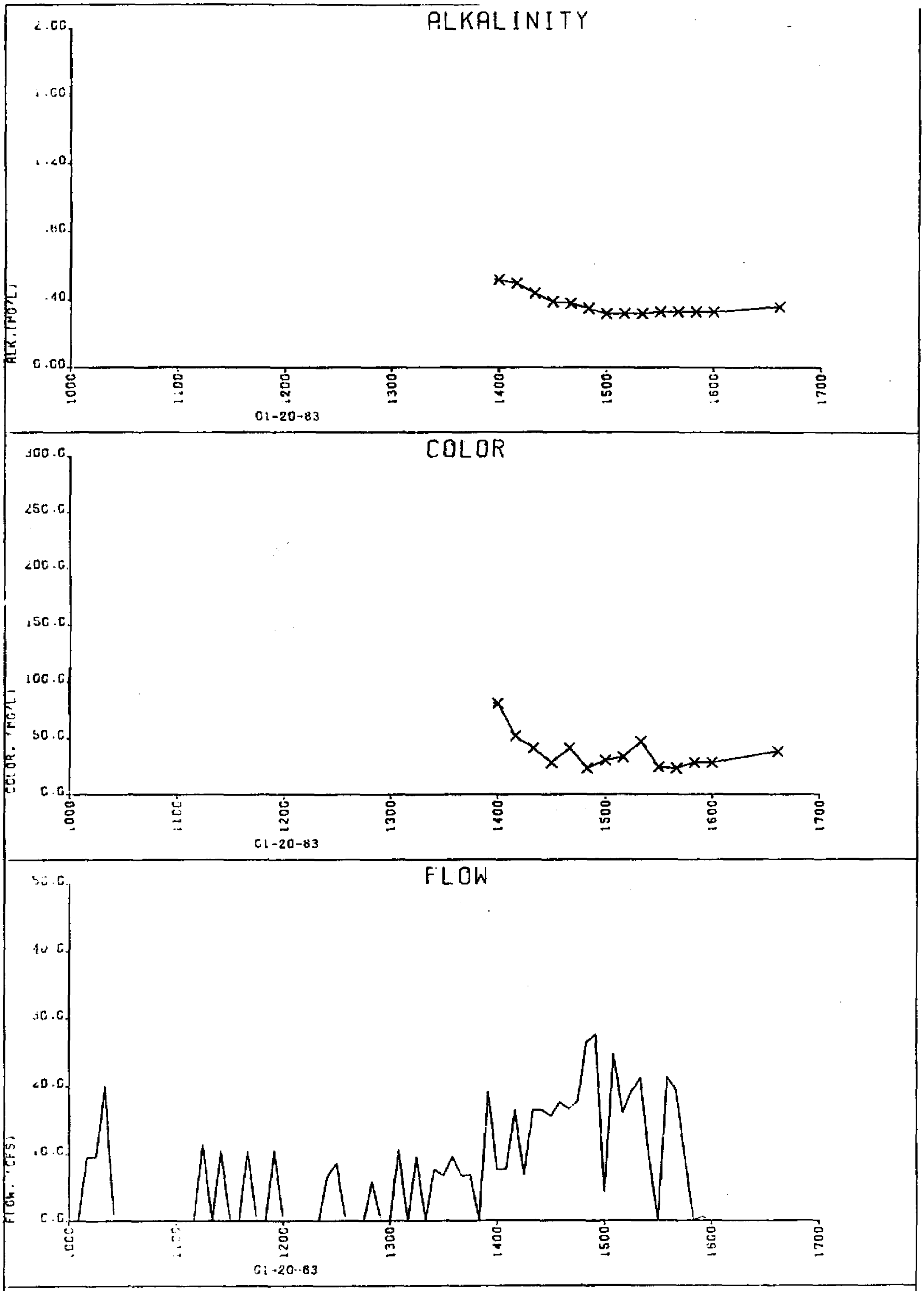


FIGURE 21 INFLOW WATER QUALITY 01/20/83.

TKN, and TOP_4 levels were present just prior to and during peak inflow due to the flushing effect of rainfall on the watershed (Figures 22, 23, and 24). These values were not as high as those reported for earlier storms. This may be due to the short time of antecedent dry weather not allowing more build up of pollutants on the watershed, or it may be due to a slight washoff of pollutants during the low volume runoff earlier in the day. Following the flow maximum, all four parameters decreased exponentially as would be expected. Dissolved species such as chloride, OPO_4, ammonium, and NO_x maintained relatively constant levels through the sampling period, although an increase in OPO_4 is slightly discernable (Figures 22, 23, and 24). Physical parameters associated with dissolved species, such as alkalinity, color, and conductivity, exhibited a similar non-trend (Figure 25).

Event five occurred on February 27, 1983. A total of 1.82 inches of rainfall occurred in eight hours. The maximum hourly intensity of only 0.52 inch occurred between 1330 and 1430. Water quality sampling commenced at 1441. This event was similar to events three and four in that it consisted of a slight drizzle over an extended period of time and had no period of high intensity runoff during the event. The maximum flow was only 23 cfs.

The small magnitude of the stormwater runoff resulted in consistent levels of pollutant concentrations in the runoff for all measured parameters. Both solid and dissolved species maintained constant or slightly decreasing concentrations throughout the period of runoff (Figures 26, 27, 28, and 29). This event recorded the smallest peak flow of all nine events, and the first flush effect usually associated with stormwater runoff was not discernable. The event, however, did provide a good example of a low intensity frontal type storm which occurs in south Florida during the dry season (November to May).

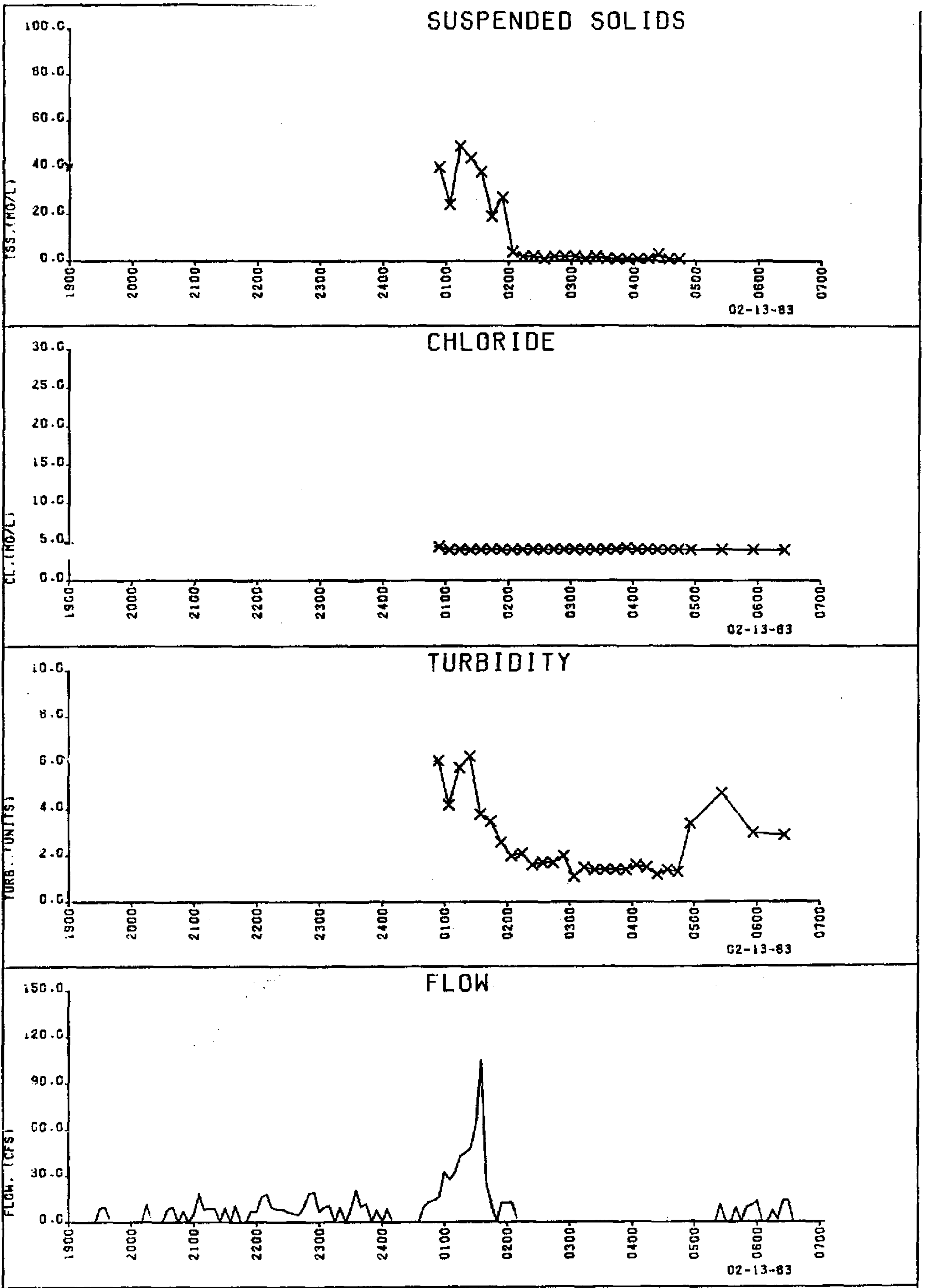


FIGURE: 22 INFLOW WATER QUALITY 02/13/83.

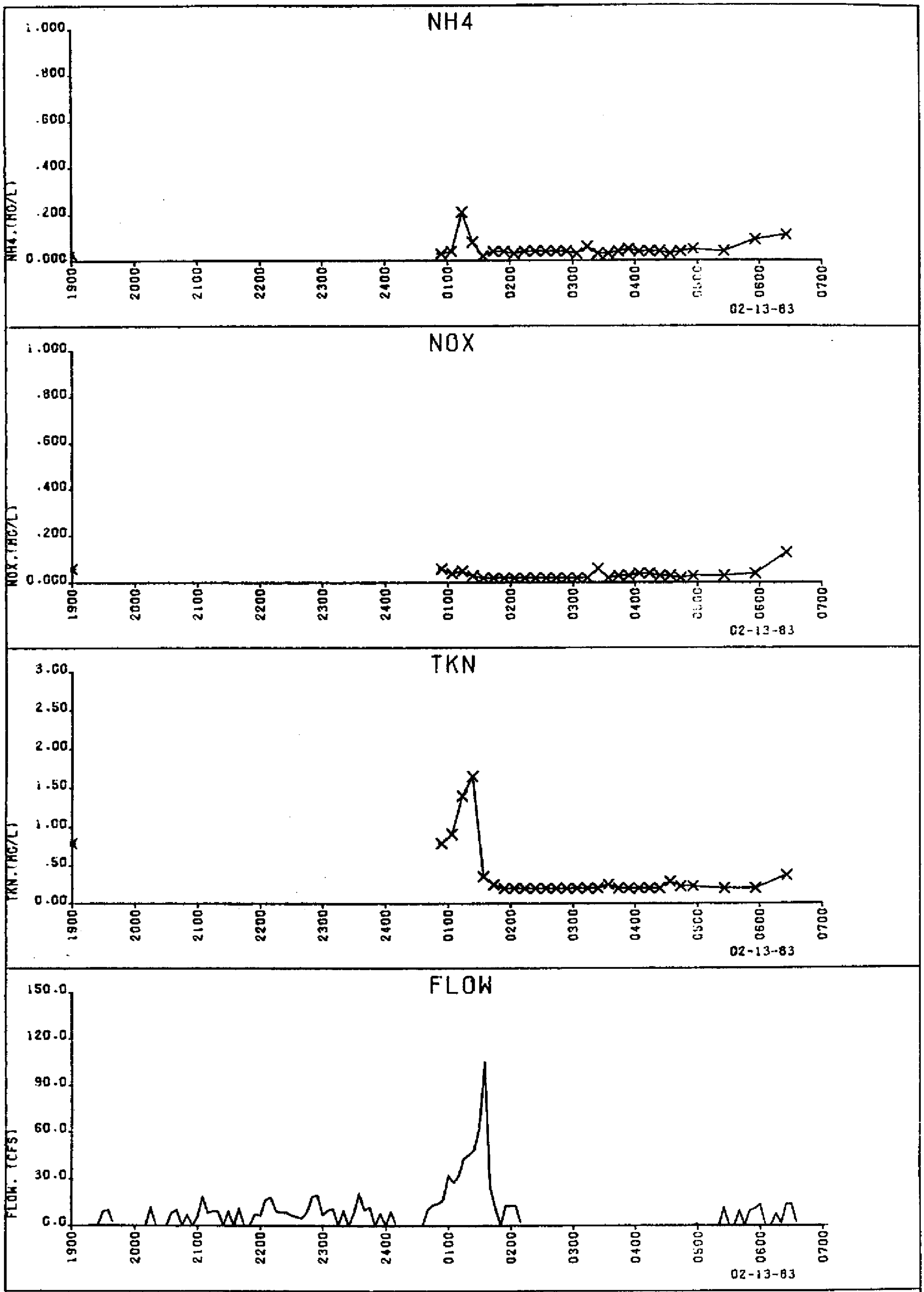


FIGURE: 23 INFLOW WATER QUALITY 02/13/83.

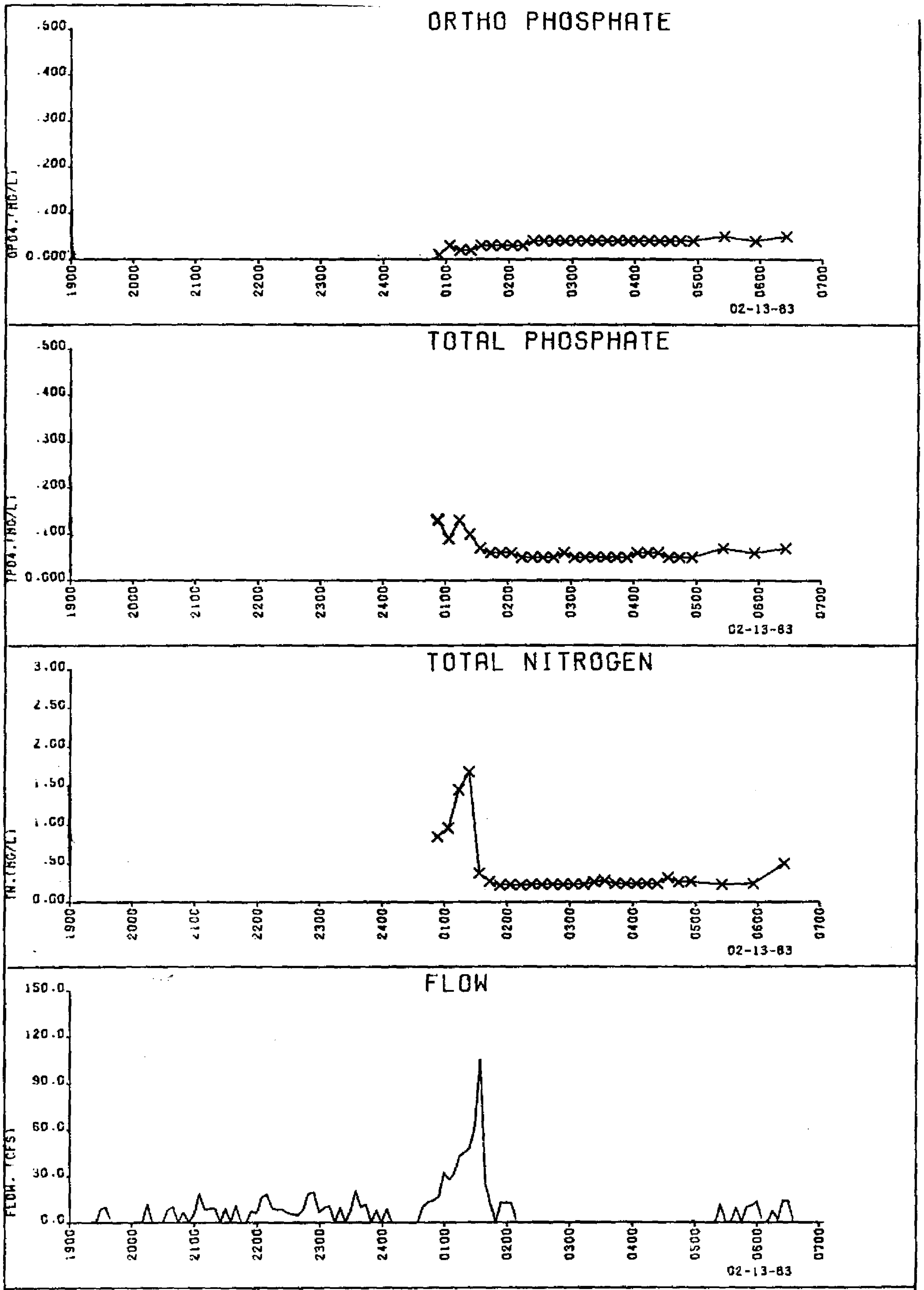


FIGURE: 24 INFLOW WATER QUALITY 02/13/83.

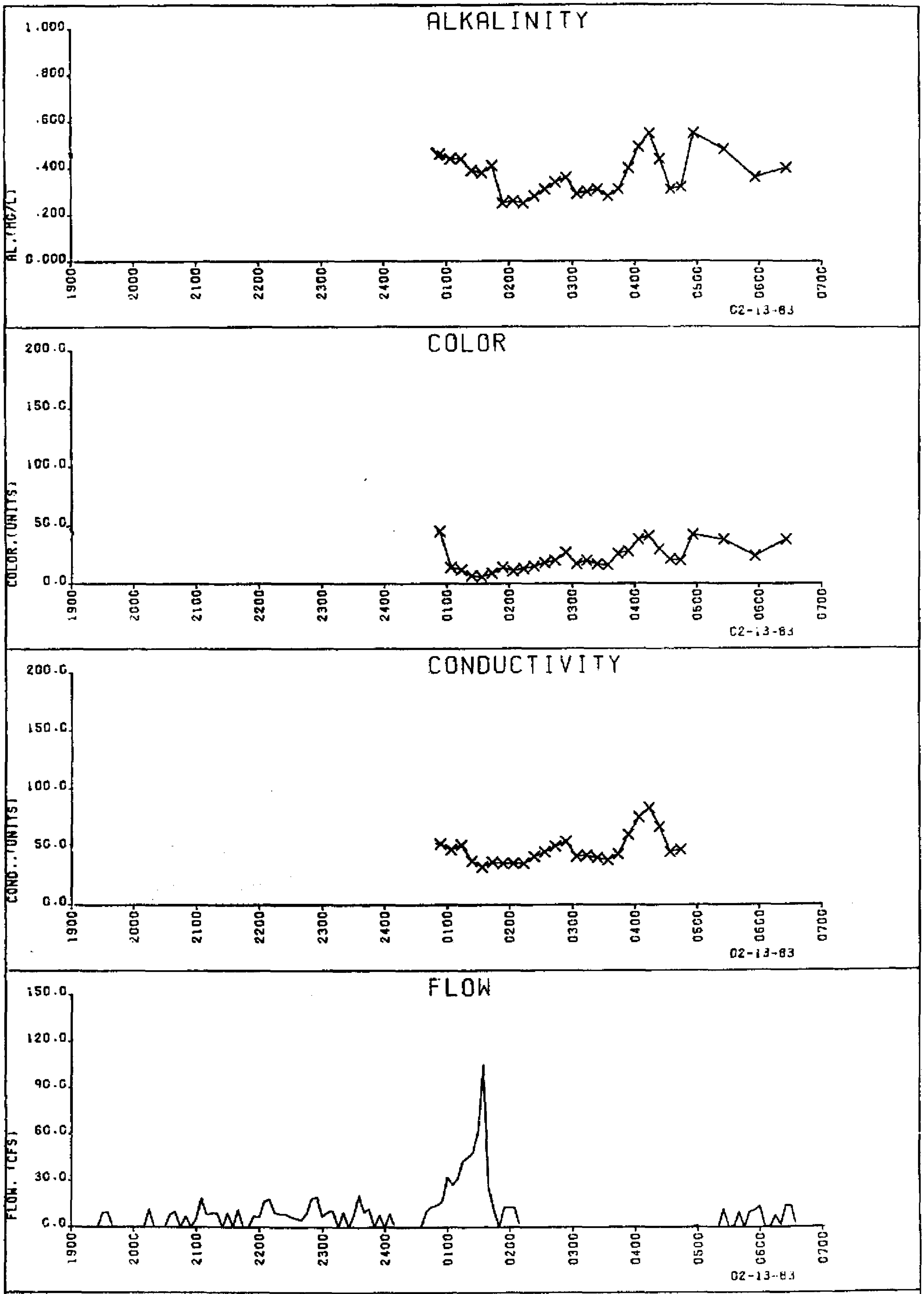


FIGURE: 25 INFLOW WATER QUALITY 02/13/83.

EVENT 4

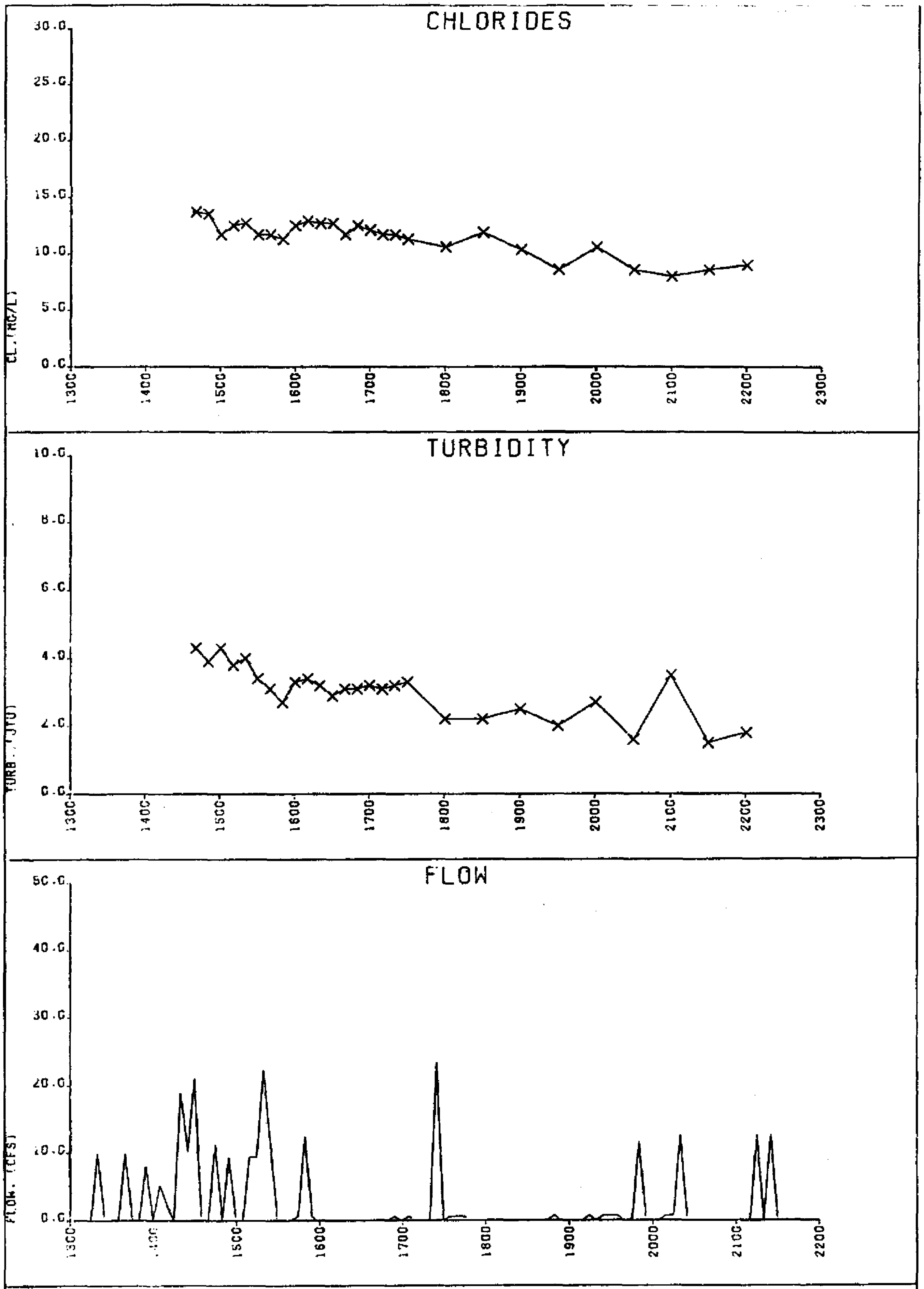


FIGURE: 26 INFLOW WATER QUALITY 02/27/83.

EVENT 5

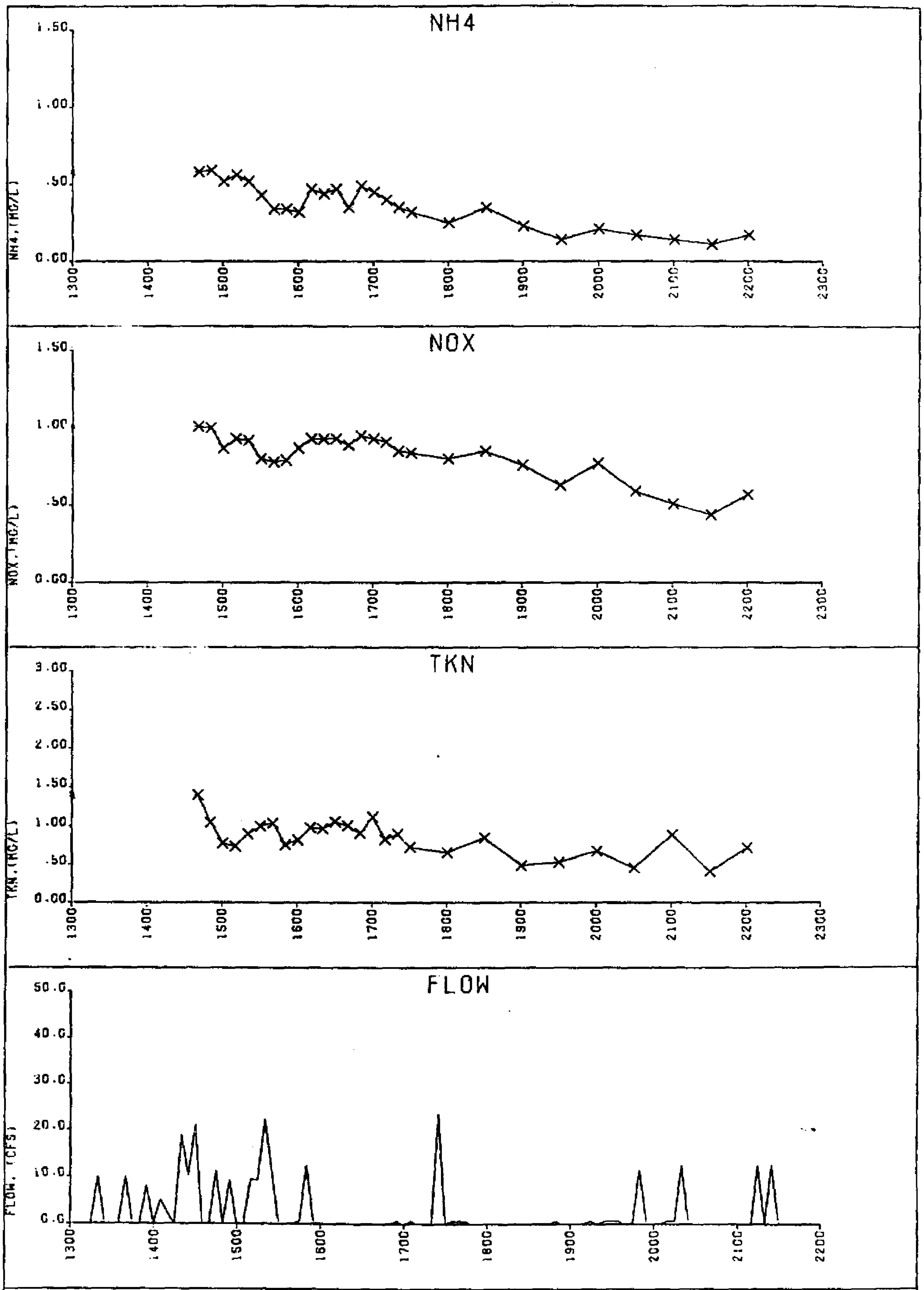


FIGURE: 27 INFLOW WATER QUALITY 02/27/83.

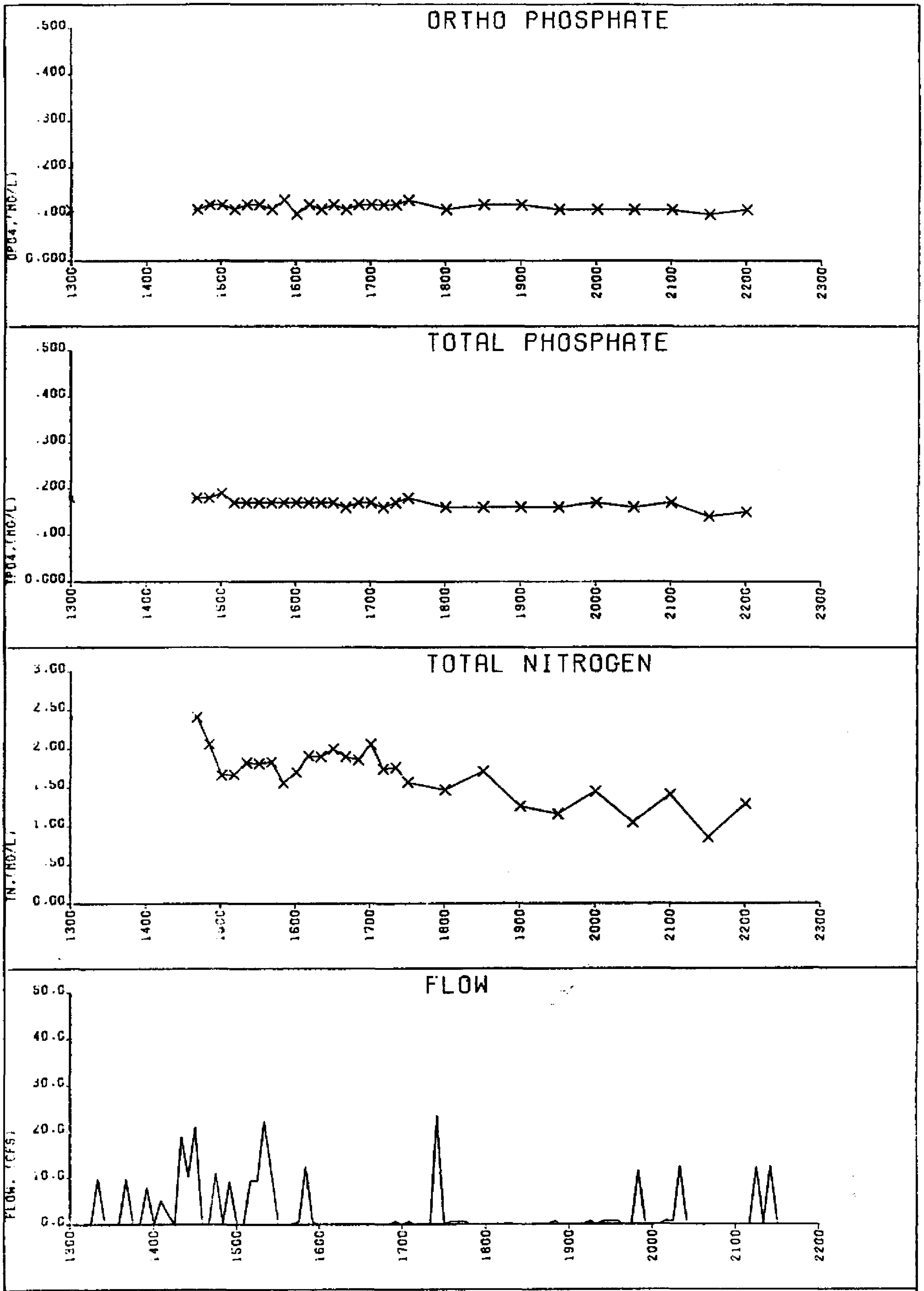


FIGURE: 28 INFLOW WATER QUALITY 02/27/83.

EVENT 5

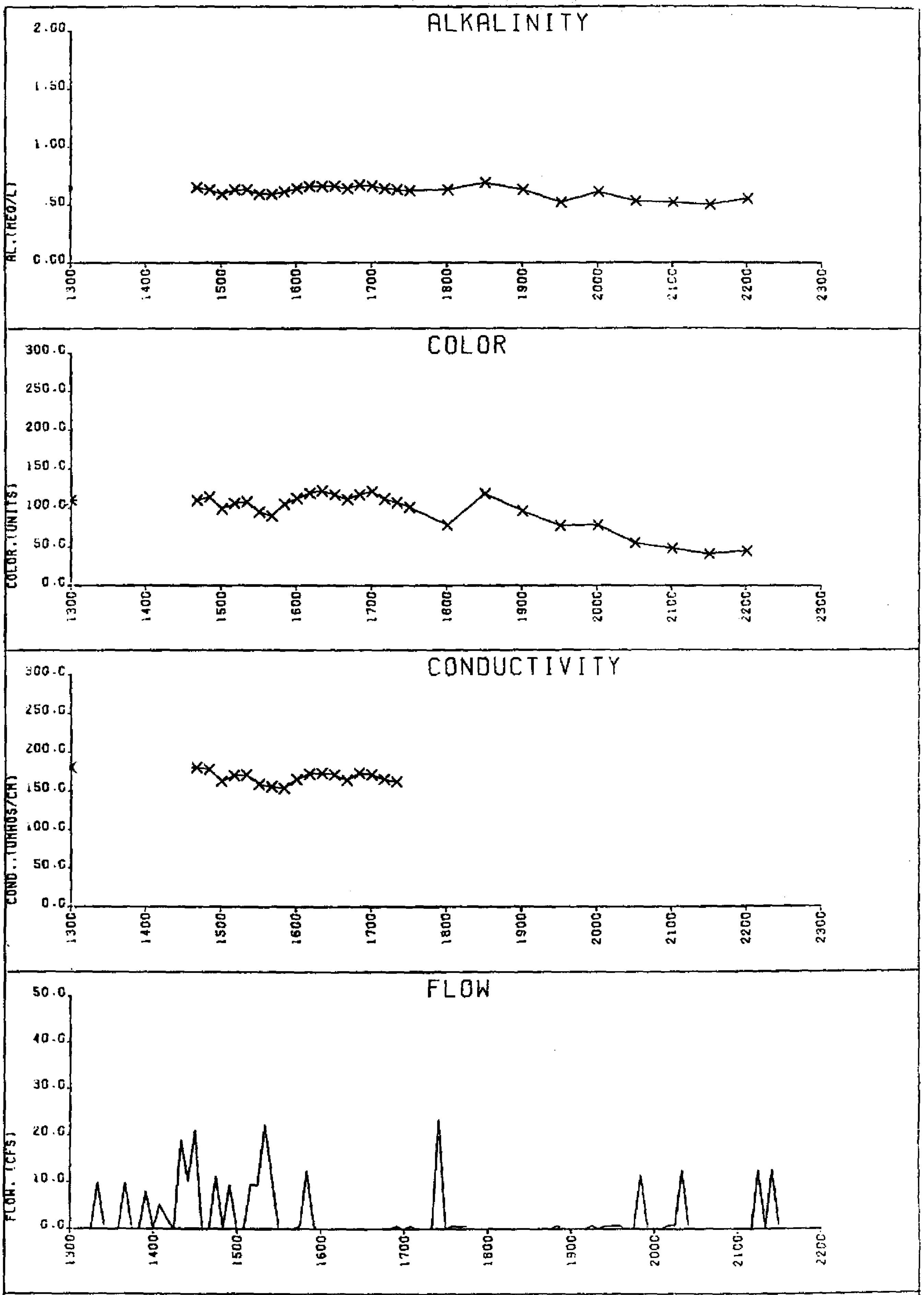


FIGURE: 29 INFLOW WATER QUALITY 02/27/83.

Event six consisted of 0.54 inch of rainfall during a 25 minute period on August 19, 1983. Runoff from this event occurred between 0940 and 1000. This event is typical of the afternoon convective thunder showers that occur in south Florida during the wet season (June to October).

The total volume of the storm precludes accurate determination of a one hour intensity value which was used to compare relative intensities of the nine events, but the half hour of intense precipitation did provide a measurable flush of solids in the form of TSS, turbidity, and TKN from the watershed (Figures 30 and 31). Build up of pollutants would have occurred during the five days of antecedent dry weather. Total phosphate and dissolved species concentrations remained relatively constant through the sampling period which began at 0947 (Figures 30, 31, 32, and 33). Only three samples were collected during storm runoff for this event.

Event seven was comprised of two discrete periods of rainfall occurring on August 24, 1983. Runoff from the first period only was sampled for water quality. The second occurred five hours following the first and was twice the magnitude. Cumulatively, 1.86 inches of rainfall occurred.

Although there were five days of antecedent dry weather prior to storm seven, little evidence of a first flush was present. Limited sampling of suspended solids precluded the determination of any trend concerning that parameter and no trend was present in the turbidity measurements (Figure 34). Dissolved parameters such as chloride, ammonium, NO_x, and ortho phosphate maintained relatively constant concentrations with time (Figures 34, 35, and 36). Total phosphate, existing predominately in the ortho form, followed the same trend, as did alkalinity, color and conductivety (Figures 36 and 37). A single sample however, did exhibit a slightly higher concentration of TKN during peak flow (Figure 35).

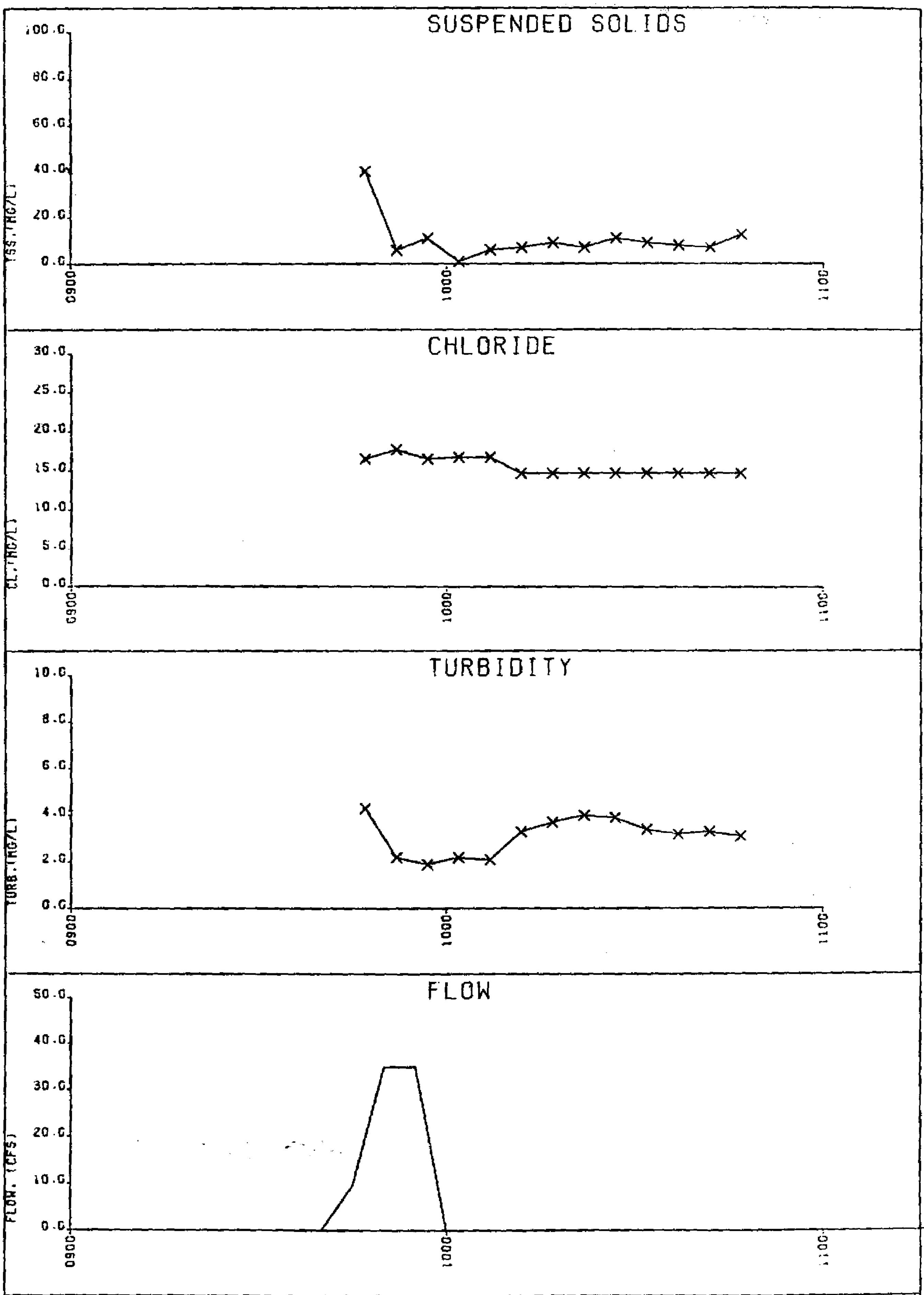


FIGURE: 30 INFLOW WATER QUALITY 08/19/83.

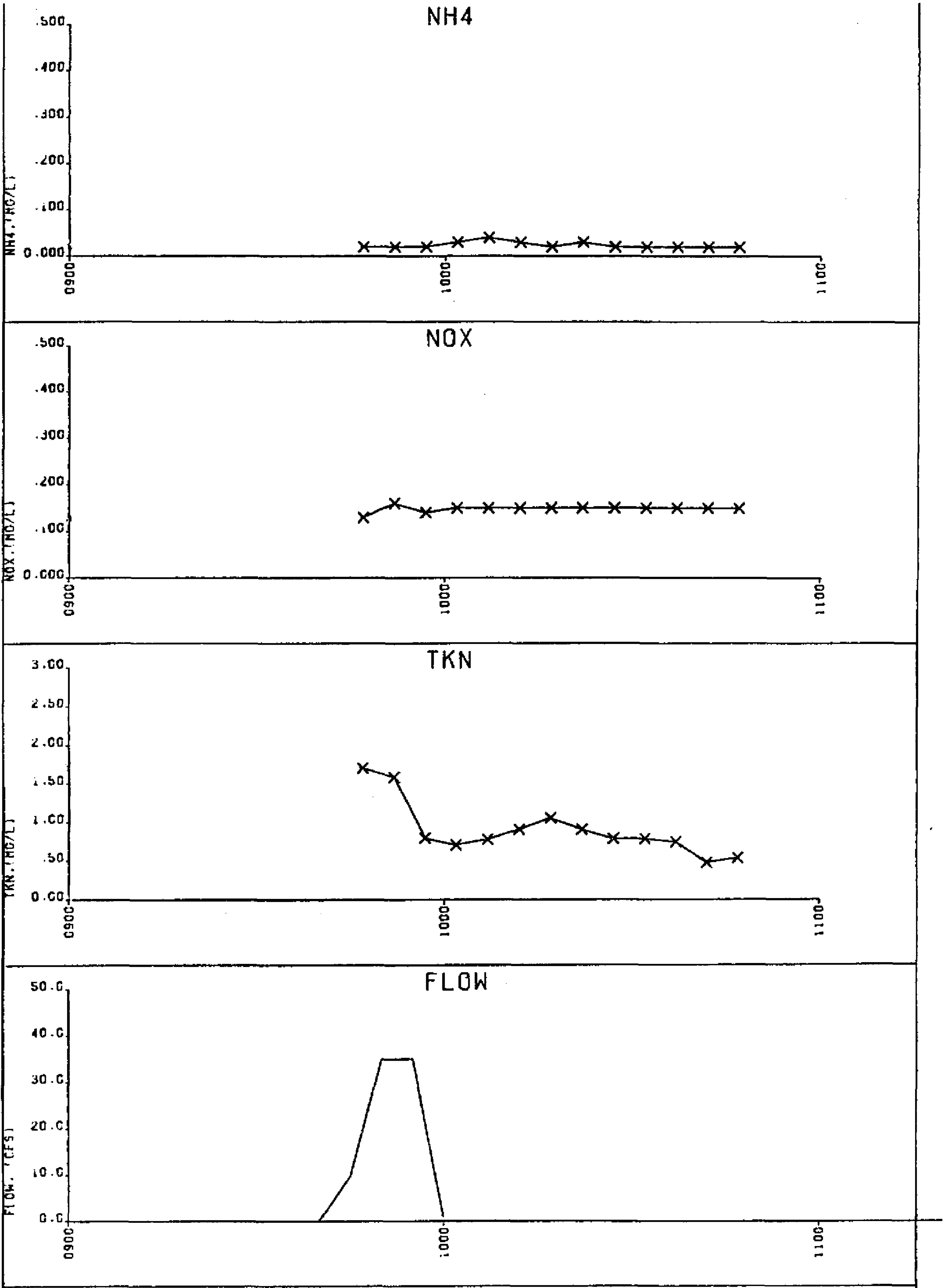


FIGURE: 31 INFLOW WATER QUALITY 08/19/83.

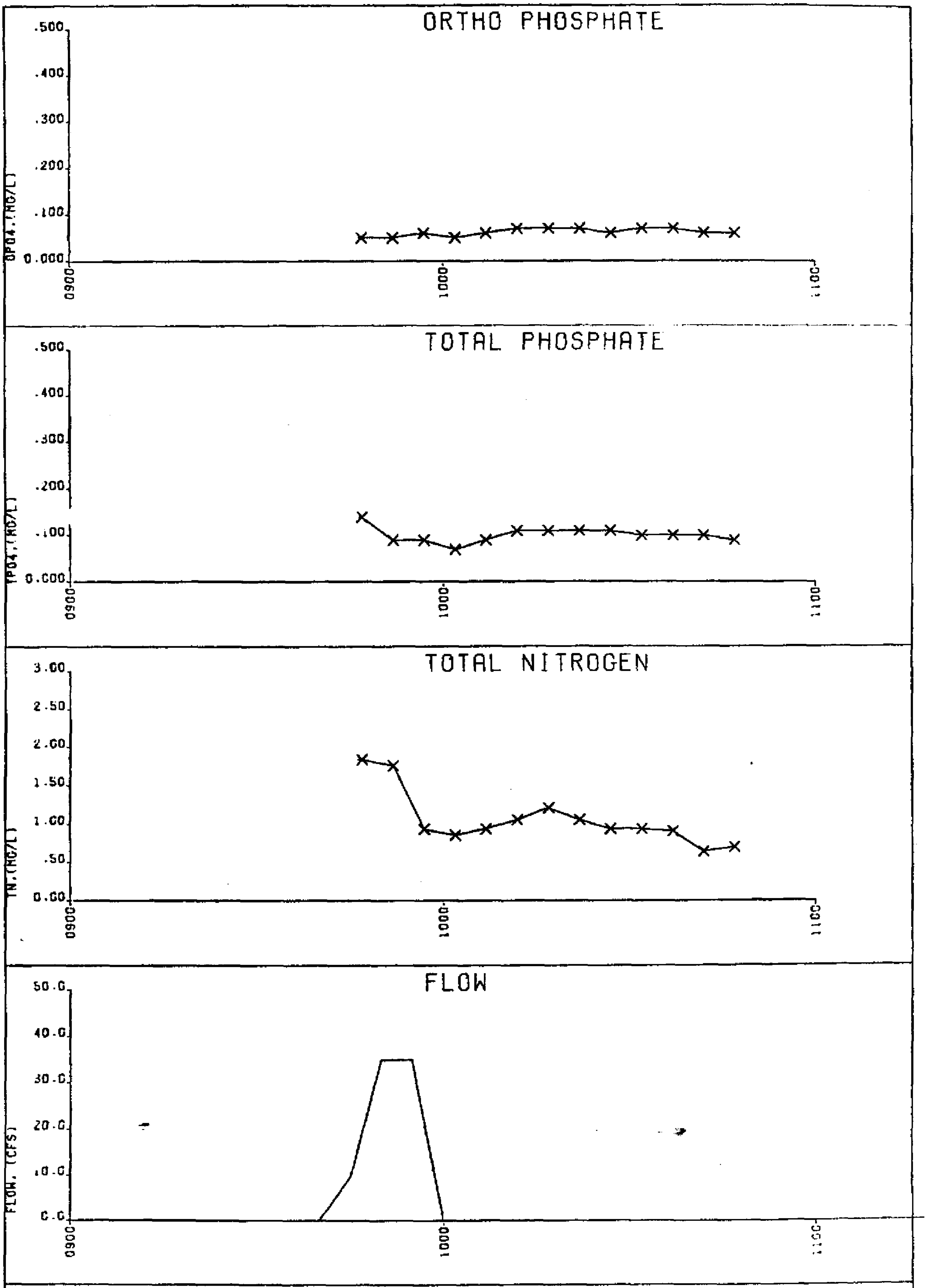


FIGURE: 32 INFLOW WATER QUALITY 08/19/83.

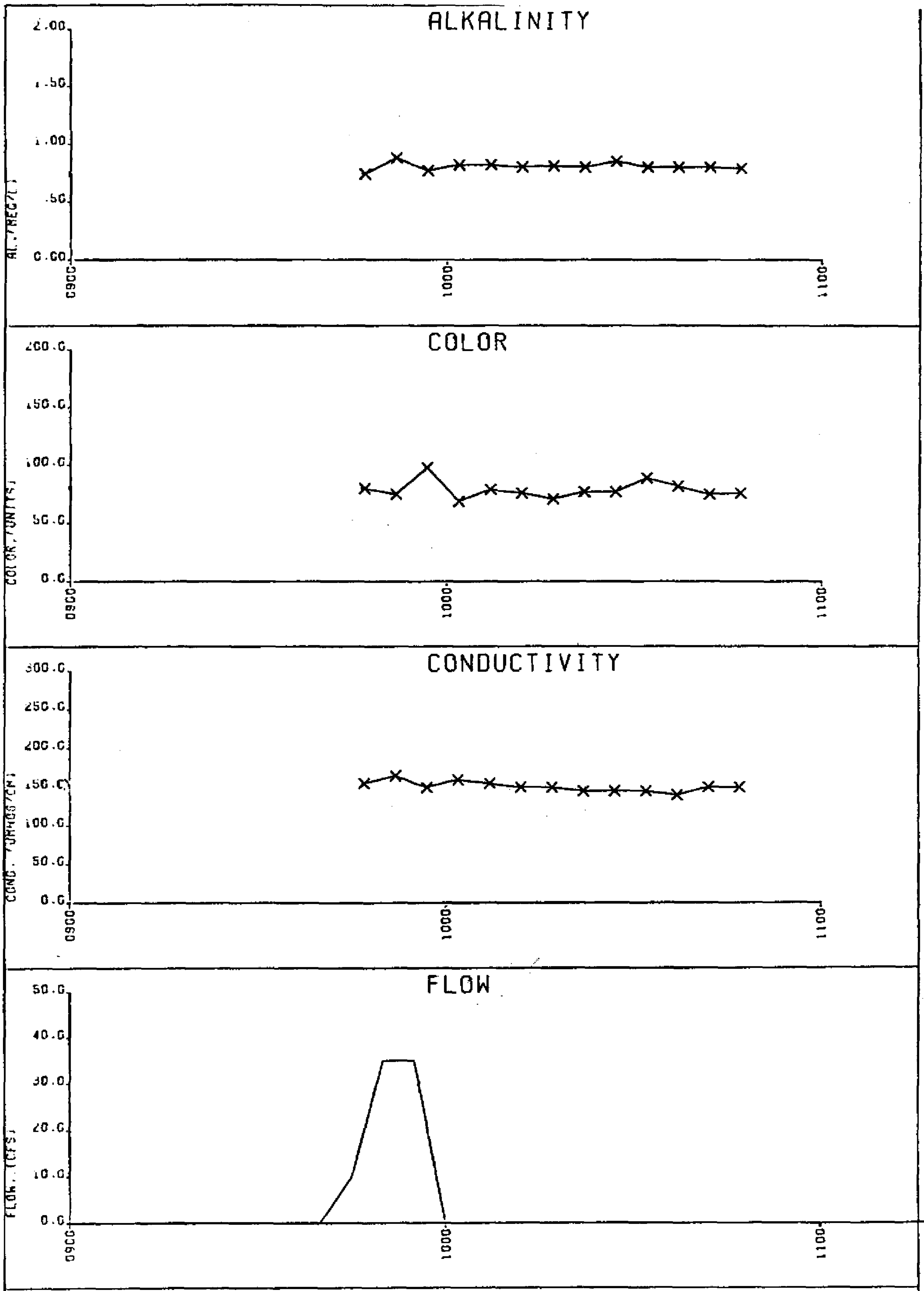


FIGURE: 33 INFLOW WATER QUALITY 08/19/83.

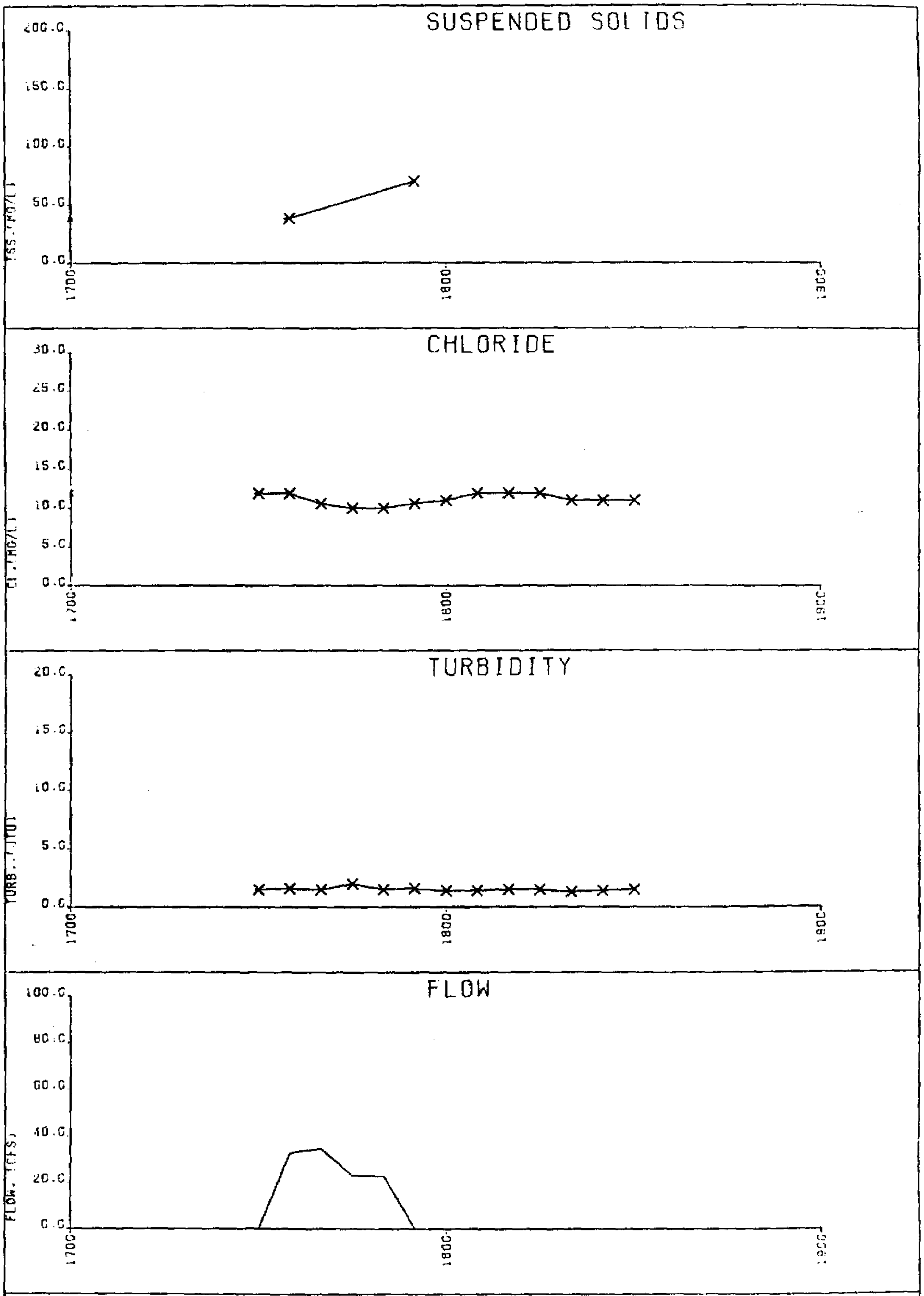


FIGURE: 34 INFLOW WATER QUALITY 08/24/83

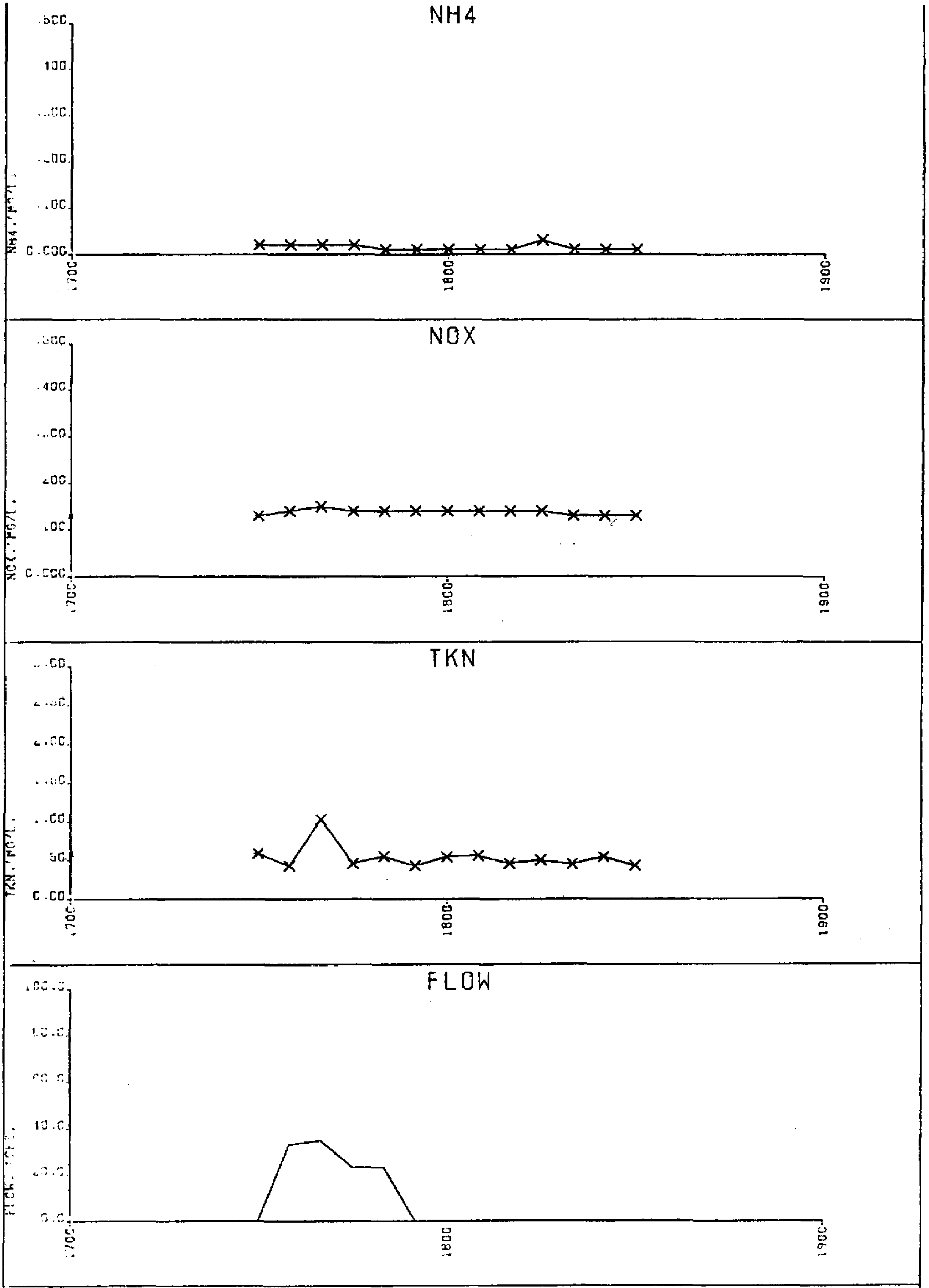


FIGURE : 35 INFLOW WATER QUALITY 08/24/83

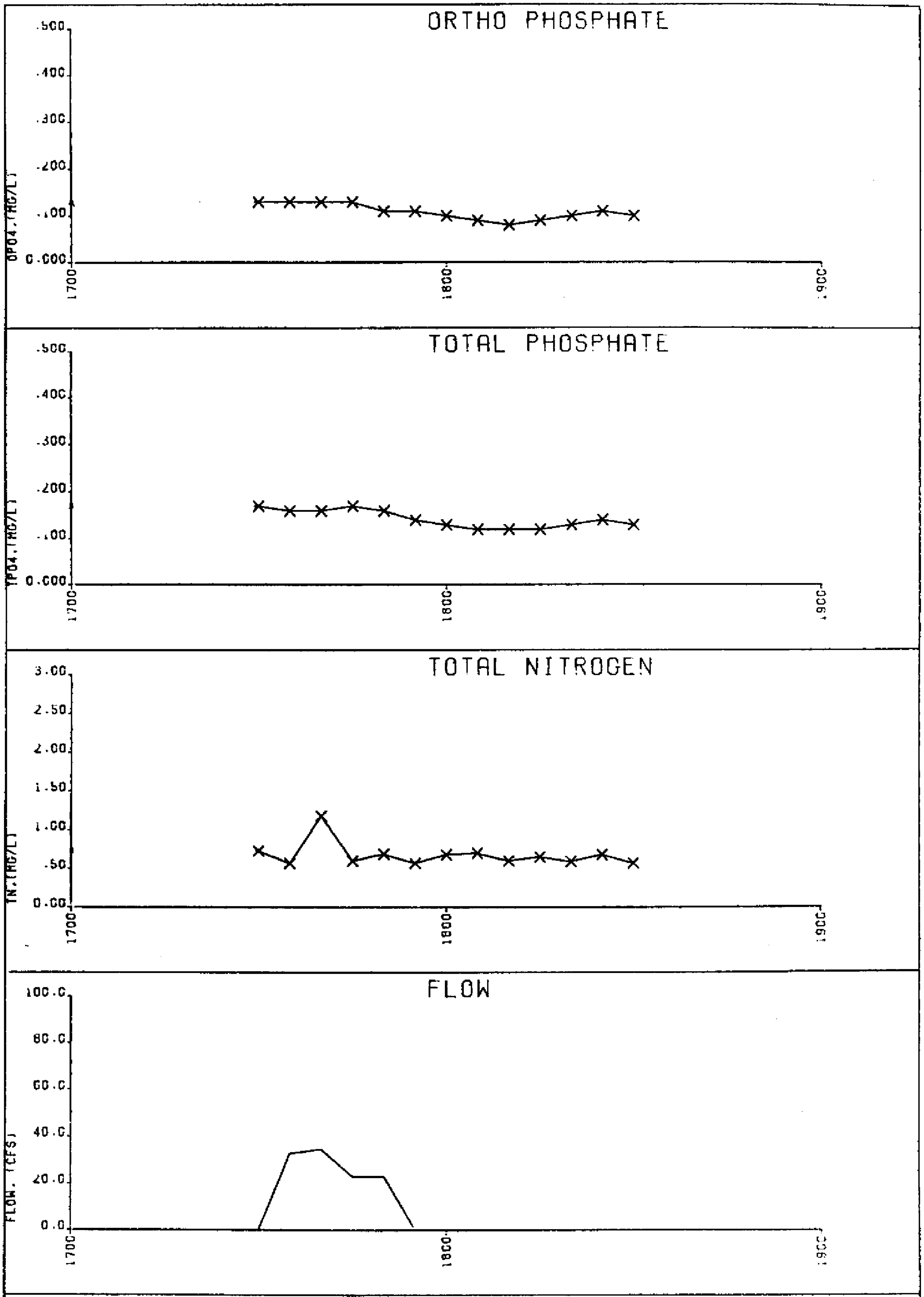


FIGURE: 36 INFLOW WATER QUALITY 08/24/83.

EVENT 7

In general, the runoff from this event did not respond as would be expected. A first flush of pollutants from the watershed should have occurred. It is possible that an error exists in the timing between runoff hydrology and water quality measurements. Several water quality samples having elevated pollutant levels typical of a first flush were collected prior to the generation of storm related flow. The water quality sampler is triggered by rising water in a catch basin, thus should have begun sampling with the onset of stormwater runoff. (This event was the only event where this problem was evident).

Stormwater runoff from event eight occurred from 1610 to 1700 on August 29, 1983 and was generated from 1.80 inches of rainfall. Peak flow was reached ten minutes into the event as maximum rainfall intensity occurred during the early stages of the event. Water quality sampling began at 1608.

There were five days of dry weather preceding event eight, which led to a build up of pollutants on the Timbercreek watershed. Washoff of these pollutants in the solid form, as reflected by TSS, turbidity, and TKN concentrations, occurred during the event's first flush (Figures 38 and 39).

Dissolved species exhibited contradictory trends. Chloride, alkalinity, color, and conductivity all had elevated concentrations during and preceding peak flow (Figures 38 and 40), while NO_x and ortho phosphate increased in concentration through the event (Figure 39 and 41). Ammonium maintained consistently low concentrations throughout the event. The possibility exists that dissolved nutrients from fertilized lawns could have leached through the soil profile during the event. This would have allowed the NO_x and OPO_4 to increase independently of the other dissolved parameters.

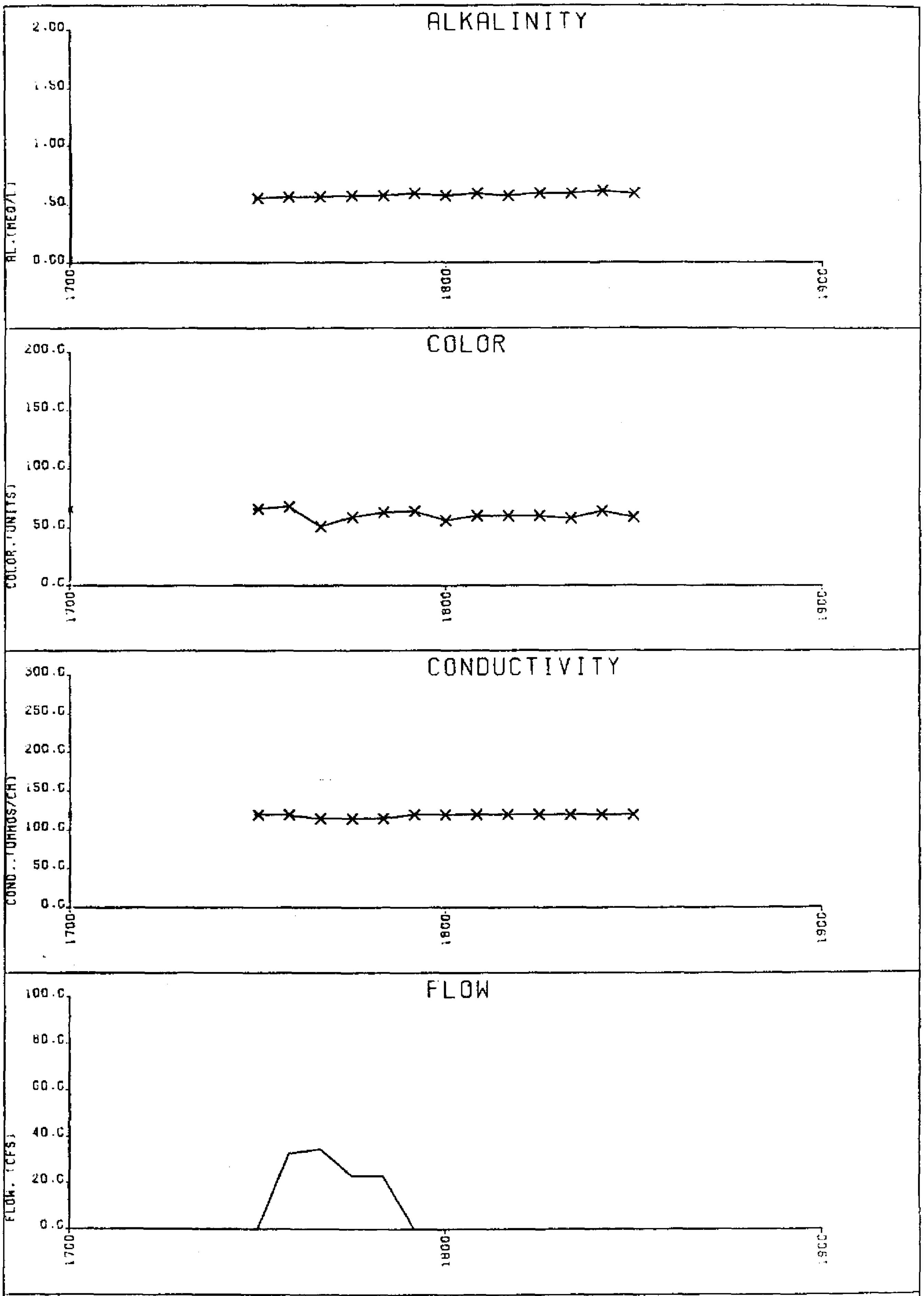


FIGURE: 37 INFLOW WATER QUALITY 08/24/83

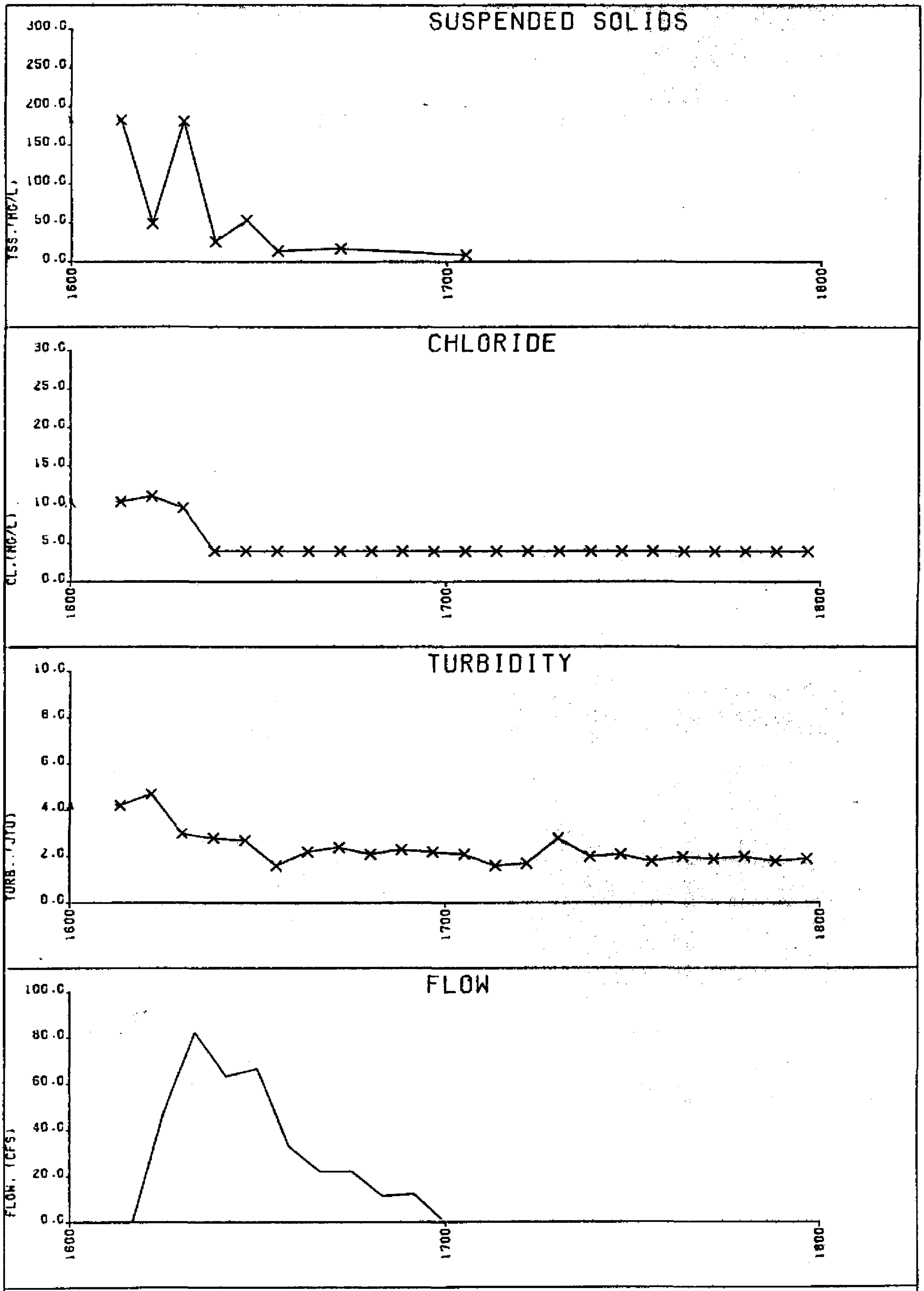


FIGURE: 38 INFLOW WATER QUALITY 08/29/83.

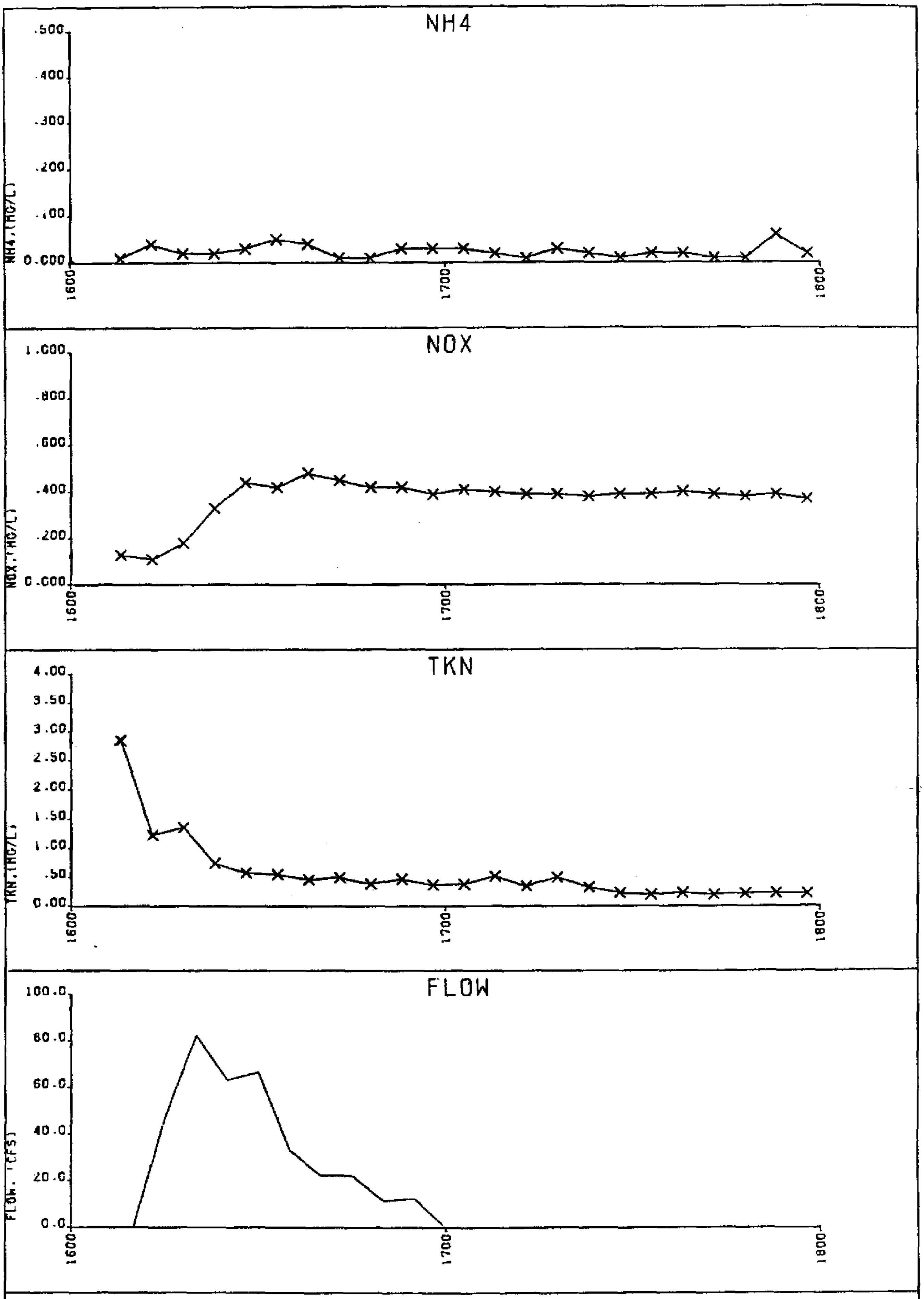


FIGURE: 39 INFLOW WATER QUALITY 08/29/83.

EVENT 8

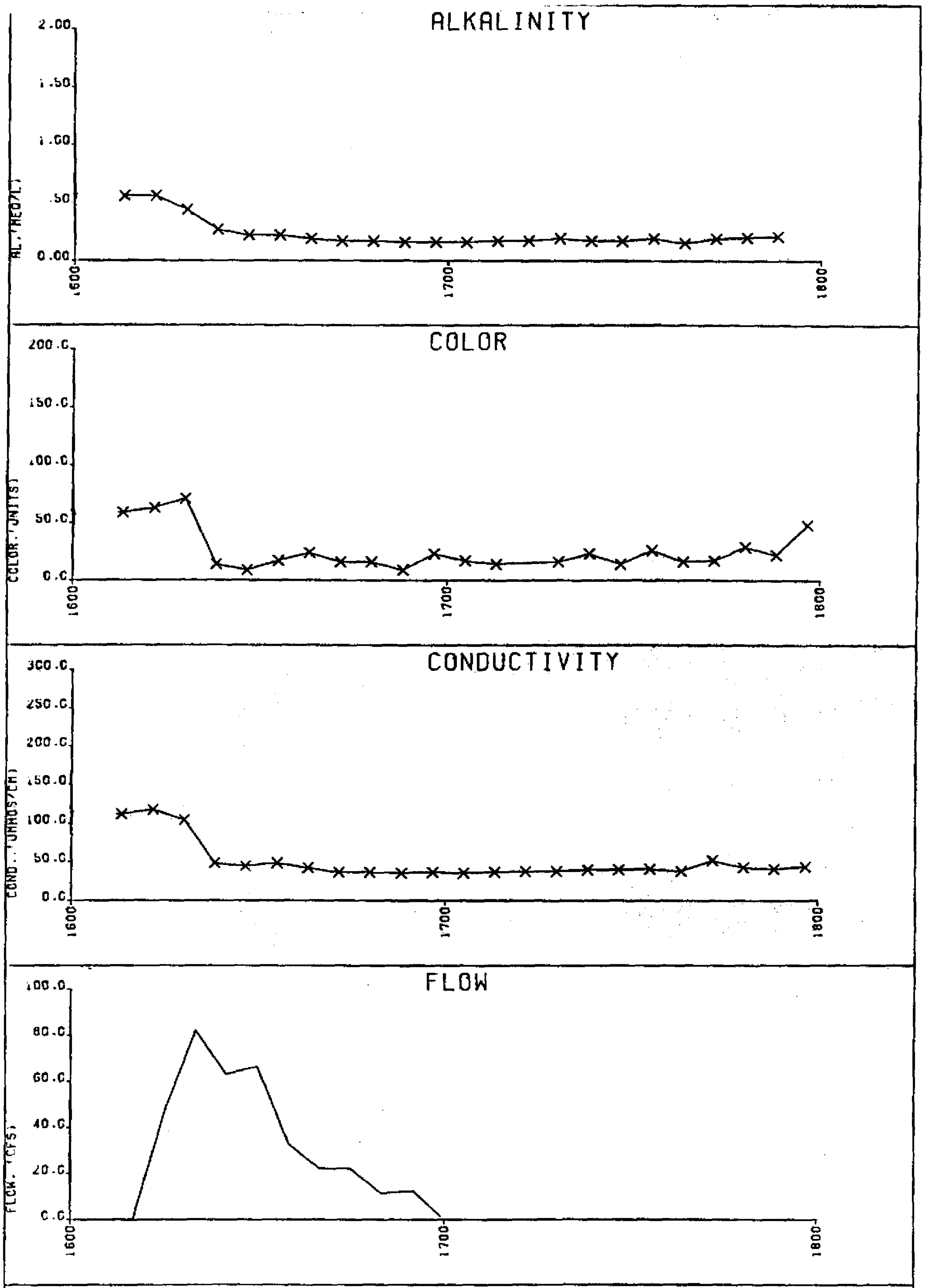


FIGURE: 40 INFLOW WATER QUALITY 08/29/83.

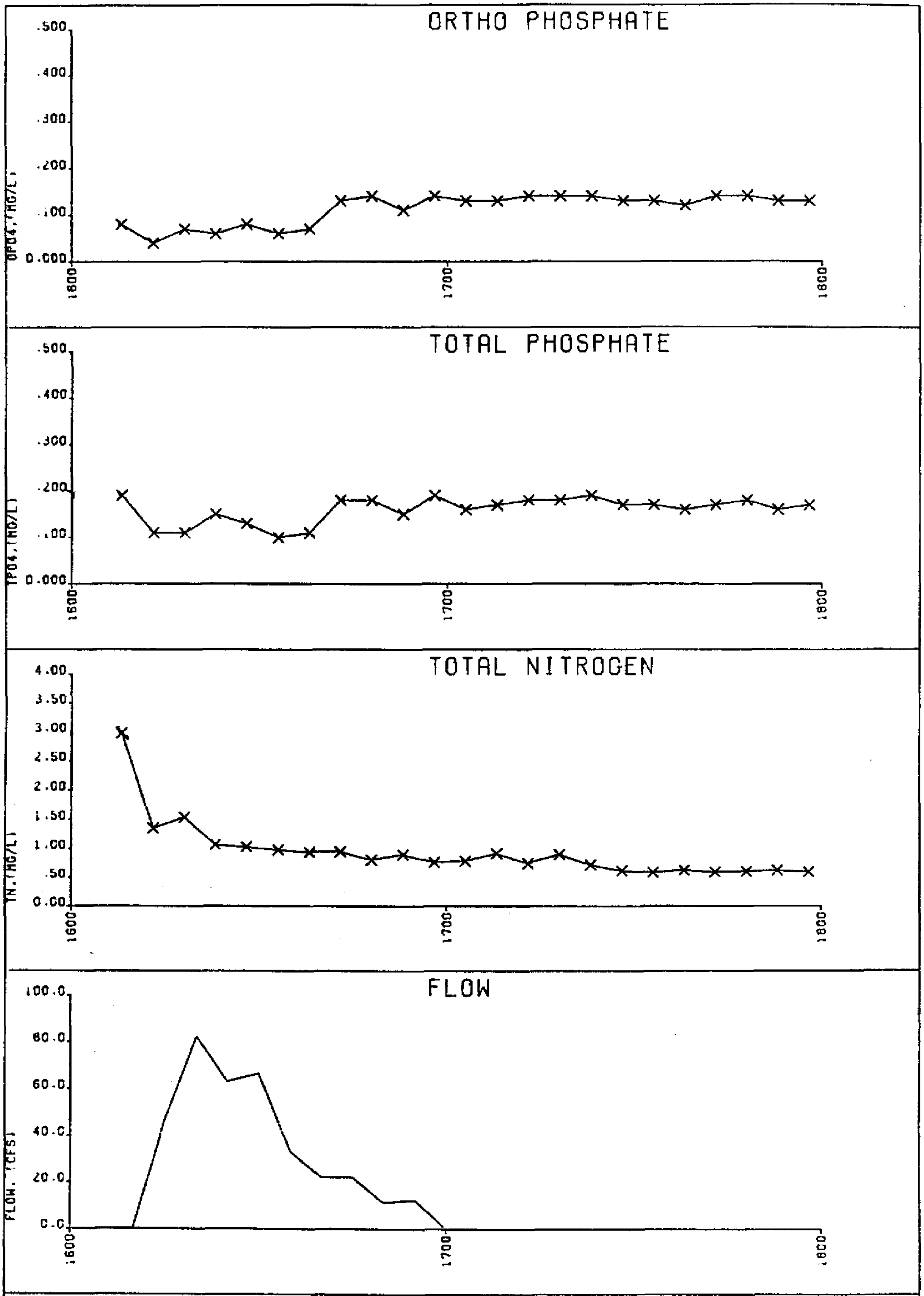


FIGURE: 41 INFLOW WATER QUALITY 08/29/83.

Event nine occurred on October 22-23, 1983. A total of 5.66 inches of rainfall produced runoff during five discrete periods that spanned a total of 16 hours. Water quality samples were collected only during the first period of runoff. There were four days of antecedent dry weather prior to the event.

A slight flush at the beginning of the runoff hydrograph was observed for TSS, turbidity and TKN (Figures 42 and 43). Maximum flow during the early stages of the event reached only 20 cfs, which may not have been sufficient to effectively remove solids from the watershed. Chloride, NO_x, ammonium, and ortho phosphate all maintained relatively constant concentrations through the sampling period (Figures 42, 43, and 44). Similarly color, alkalinity, and conductivity (Figure 45) also maintained constant concentrations.

Event nine had 90 percent of its runoff occur after the cessation of water quality sampling. It is possible that the majority of the pollutants deposited on the watershed since the previous event were washed off during these subsequent high intensity rainfall periods that were not sampled for water quality. Event four, which had peak flow that followed five hours of low volume runoff (Figure 7), was hydrologically similar to event nine. Event four did not have its low volume runoff sampled for water quality, but did exhibit a flushing effect when water quality during and following peak flow was evaluated. Conversely, several other events in this study showed that with initial low intensity runoff, concentration levels experienced later in the event were either constant or depressed (Events one, three, and five). Unfortunately, these three events were hydrologically dissimilar to event nine in that peak runoff was much lower for the three former events.

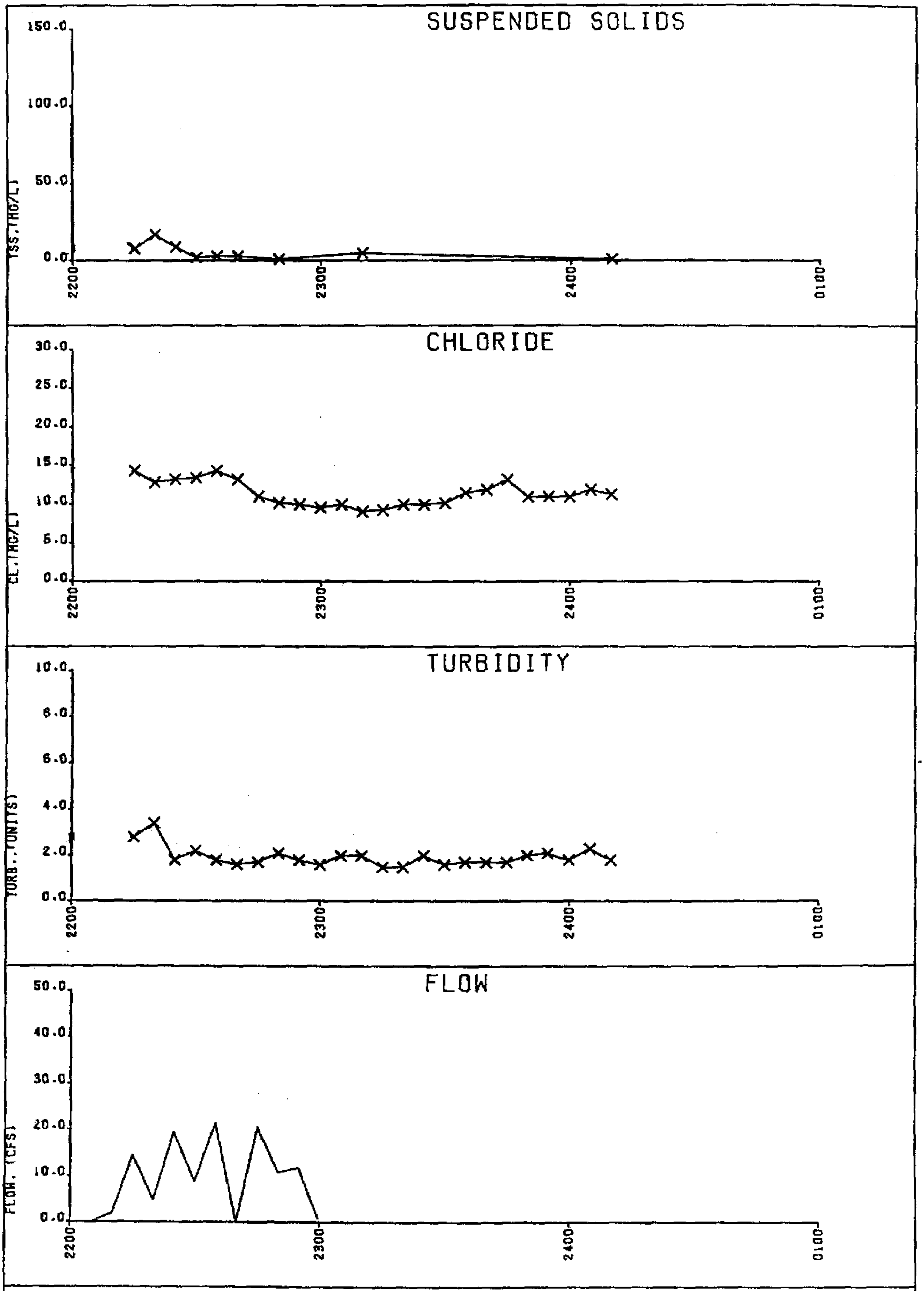


FIGURE: 42 INFLOW WATER QUALITY 10/22/83.

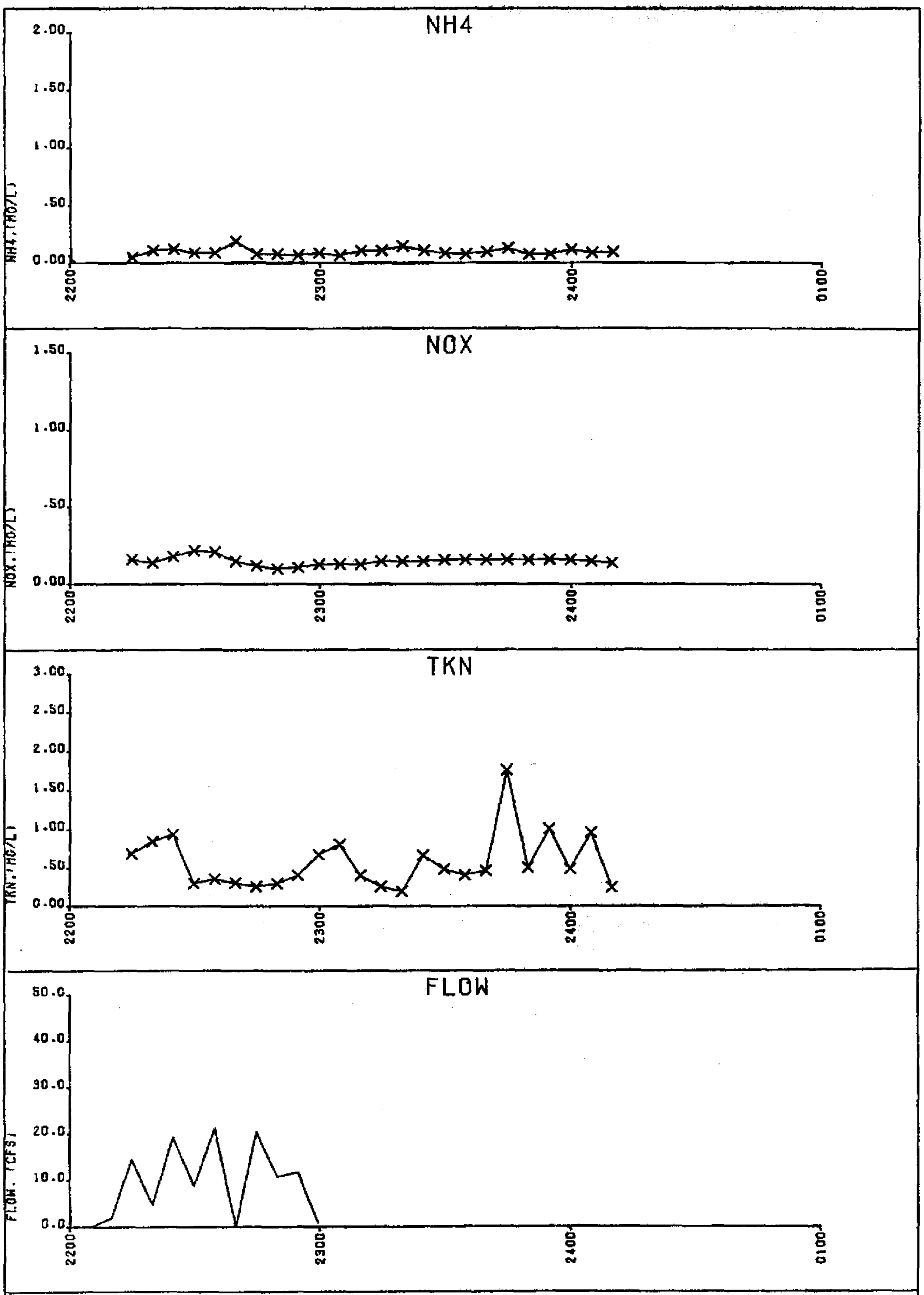


FIGURE: 43 INFLOW WATER QUALITY 10/22/83.

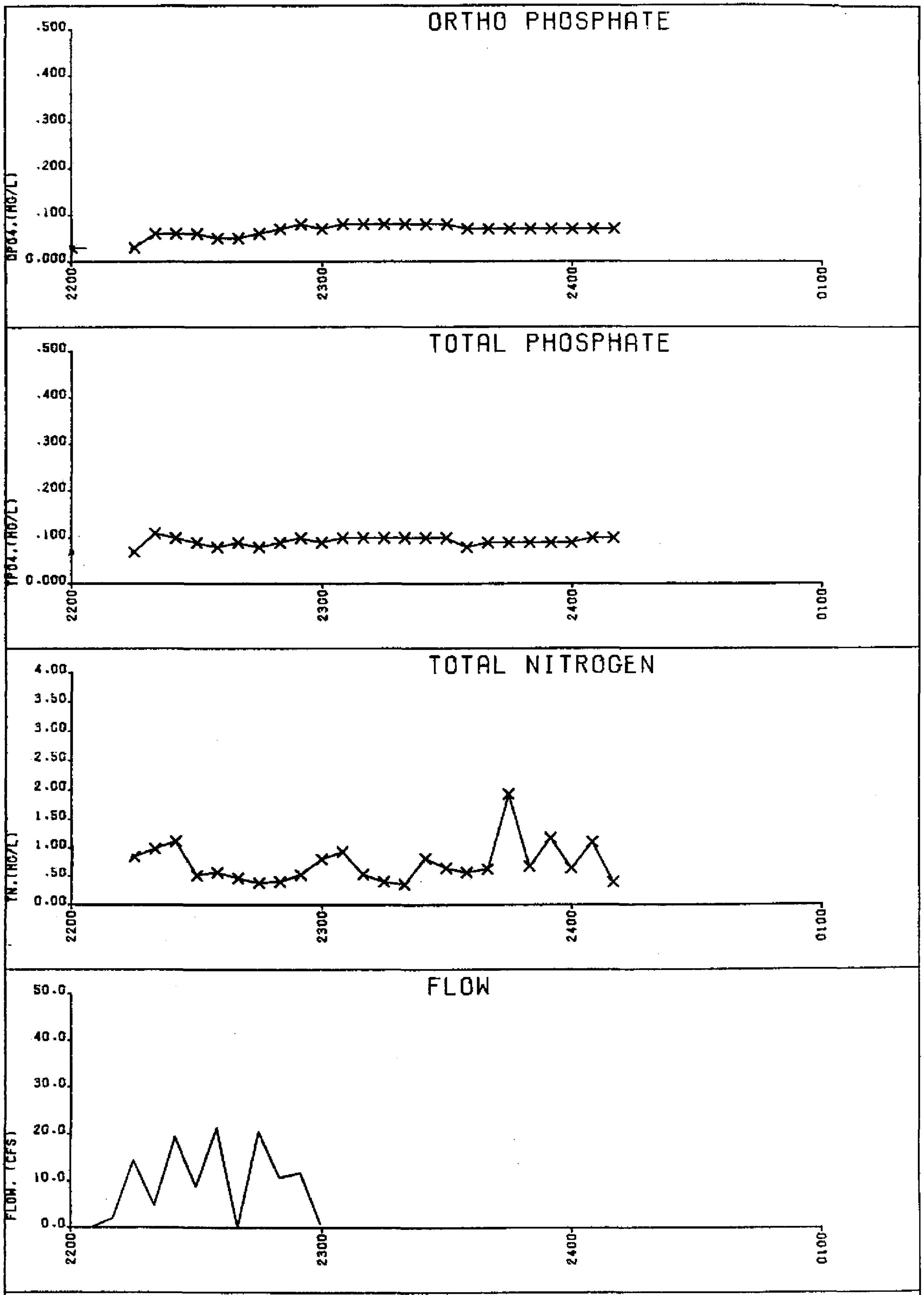


FIGURE: 44 INFLOW WATER QUALITY 10/22/83.

EVENT 9

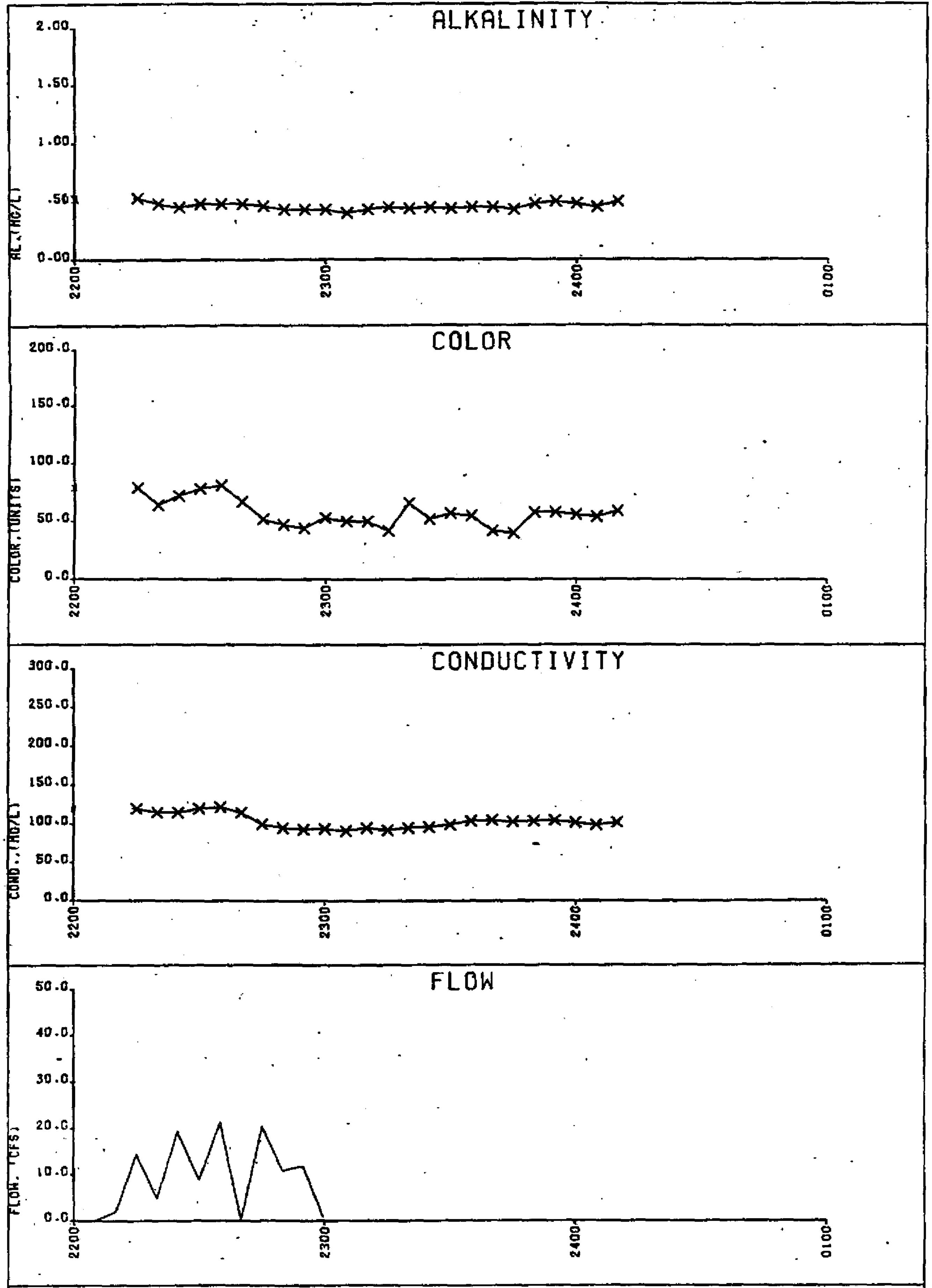


FIGURE: 45 INFLOW WATER QUALITY 10/22/83.

Storm Event Related Discharge Analysis

Water quality concentrations in the outflow were generally consistent following the beginning of the storm event. In the case of large events, a flush of pollutants occurred, but only for a short duration. Smaller events exhibited little or no such flush. Following the initial period of flow, consistently low concentrations of pollutants were present in the detention pond discharge for all events. Time series plots of selected pollutants during selected events will exhibit these phenomenon.

Event nine, the largest of the events in total rainfall (5.66 inches) exhibited a short period when a flush of particulate matter in the form of TKN, TSS, and total phosphate was observed, followed by consistently lower concentrations (Figure 46). Dissolved parameters during event nine showed little change throughout the event, with the exception of one NO_x sample (Figure 47).

Event one, an average sized storm for the study period, briefly exhibited increased pollutant concentrations at the very onset of storm generated discharge. Suspended solids, TKN, and total phosphate all had higher concentrations for the first sample, but remained consistently low after that (Figure 48). The maximum one hour rainfall intensity of event one was 0.95 inches, which is near the mean (1.19 inches) for the nine events.

Surface discharge associated with a low intensity event does not exhibit elevated pollutant concentrations during the early portions of the event. The concentrations of chloride, TKN, and total phosphate during event five remained consistent throughout that event (Figure 49). Event five had a maximum hourly rainfall intensity of 0.54 inches, which was near the minimum recorded value for the nine storm events (0.52 inches).

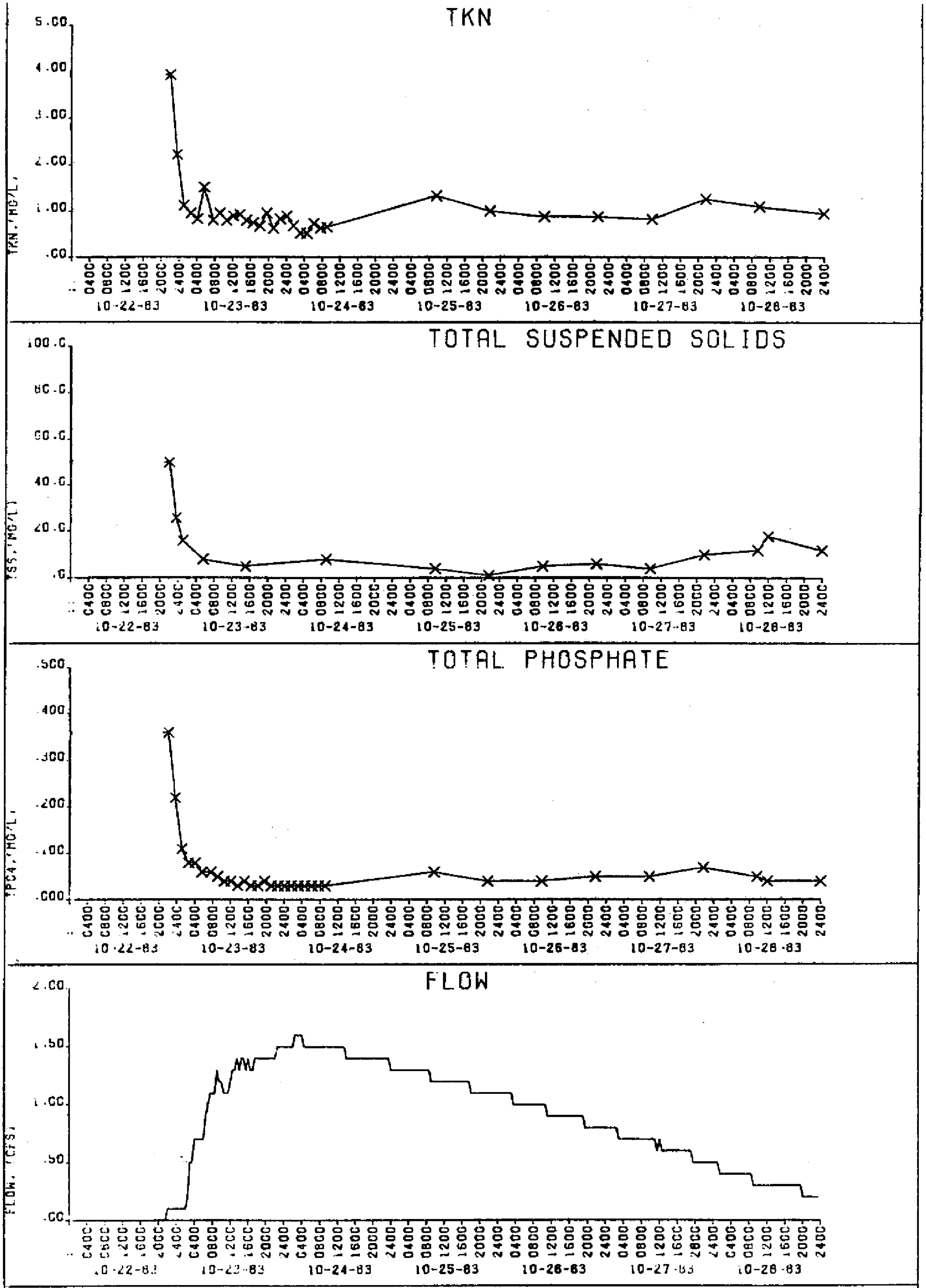


FIGURE: 46 OUTFLOW WATER QUALITY STORM NINE.

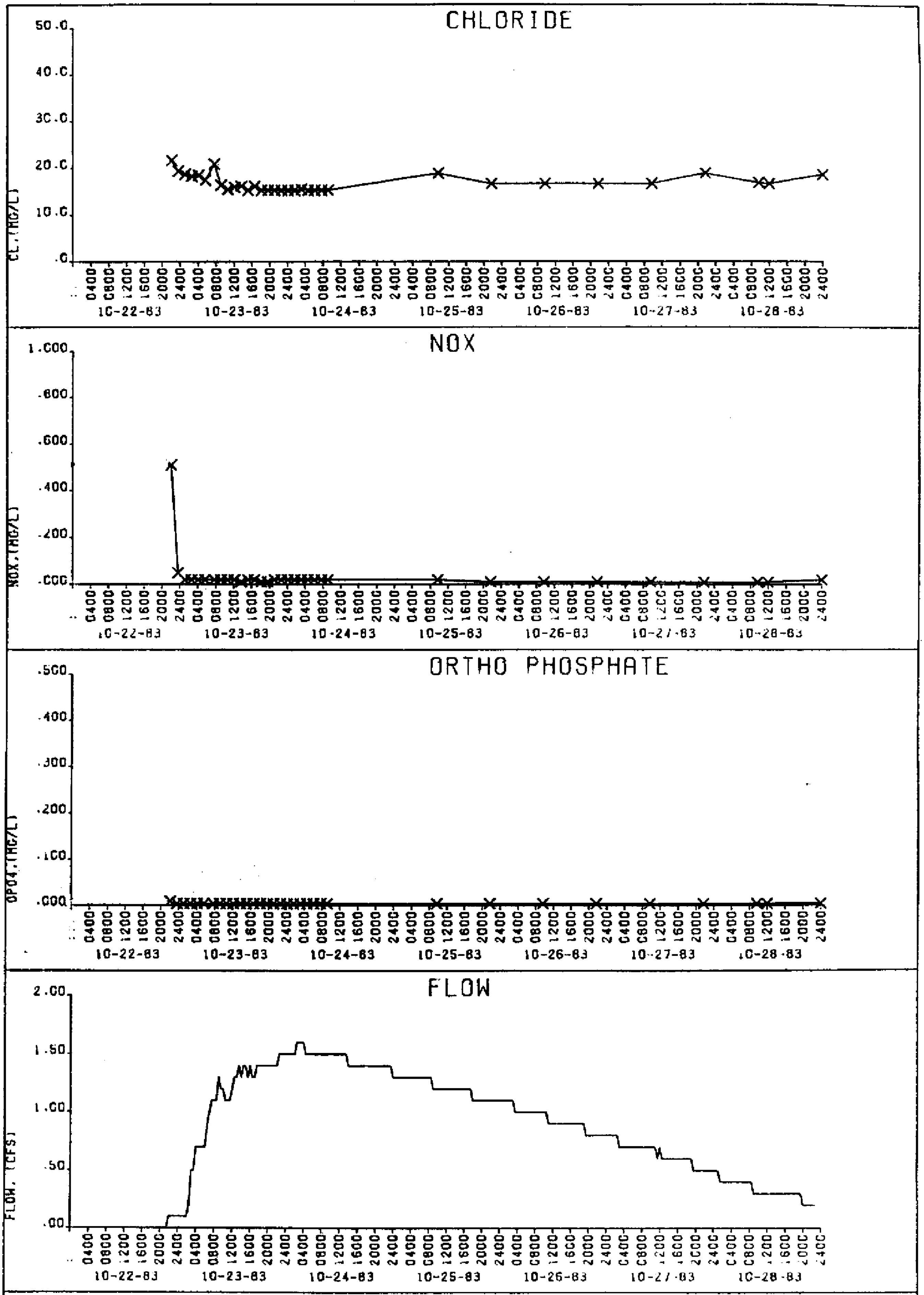


FIGURE: 47 OUTFLOW WATER QUALITY STORM NINE.

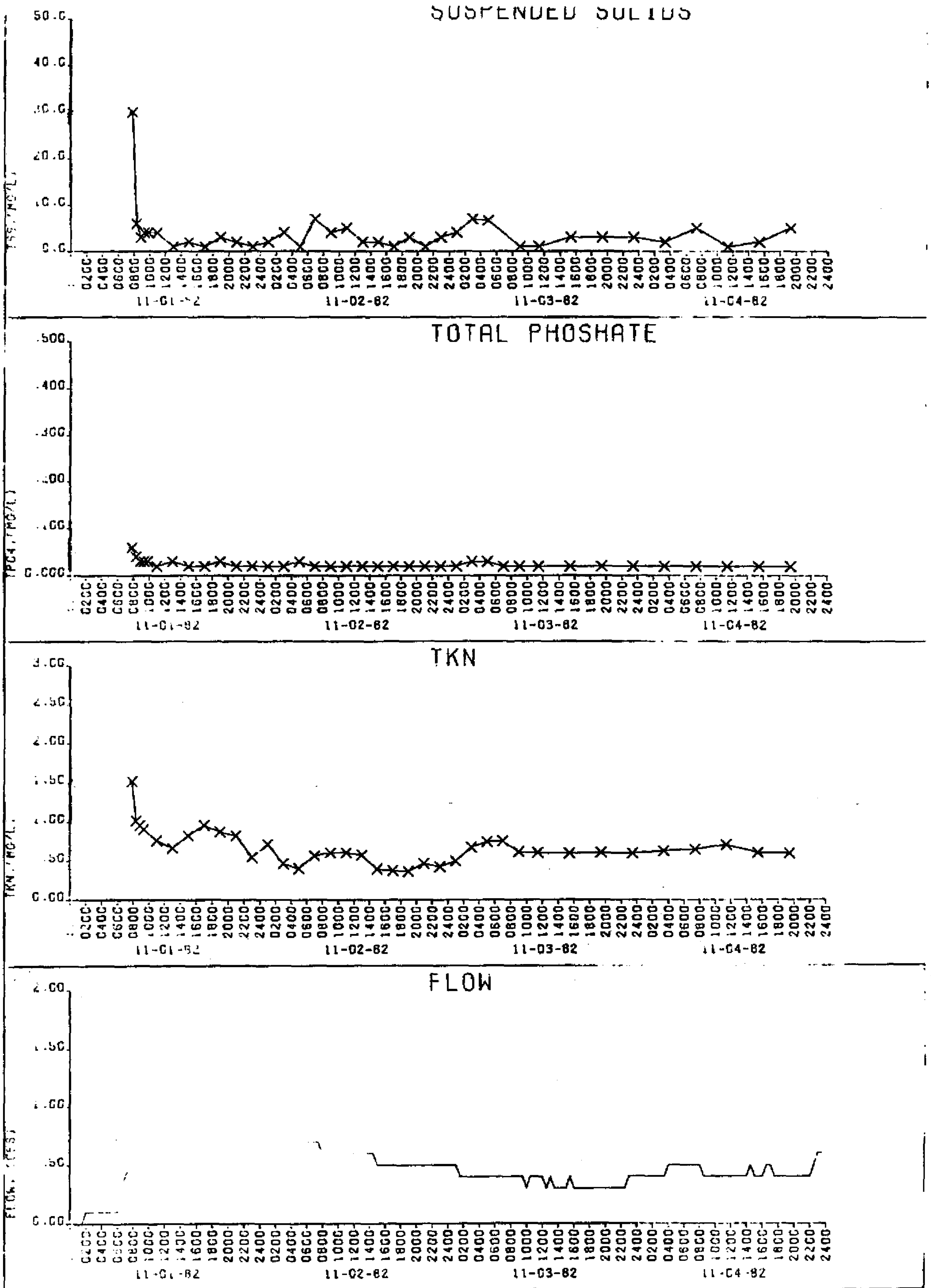


FIGURE : 48 OUTFLOW WATER QUALITY STORM ONE

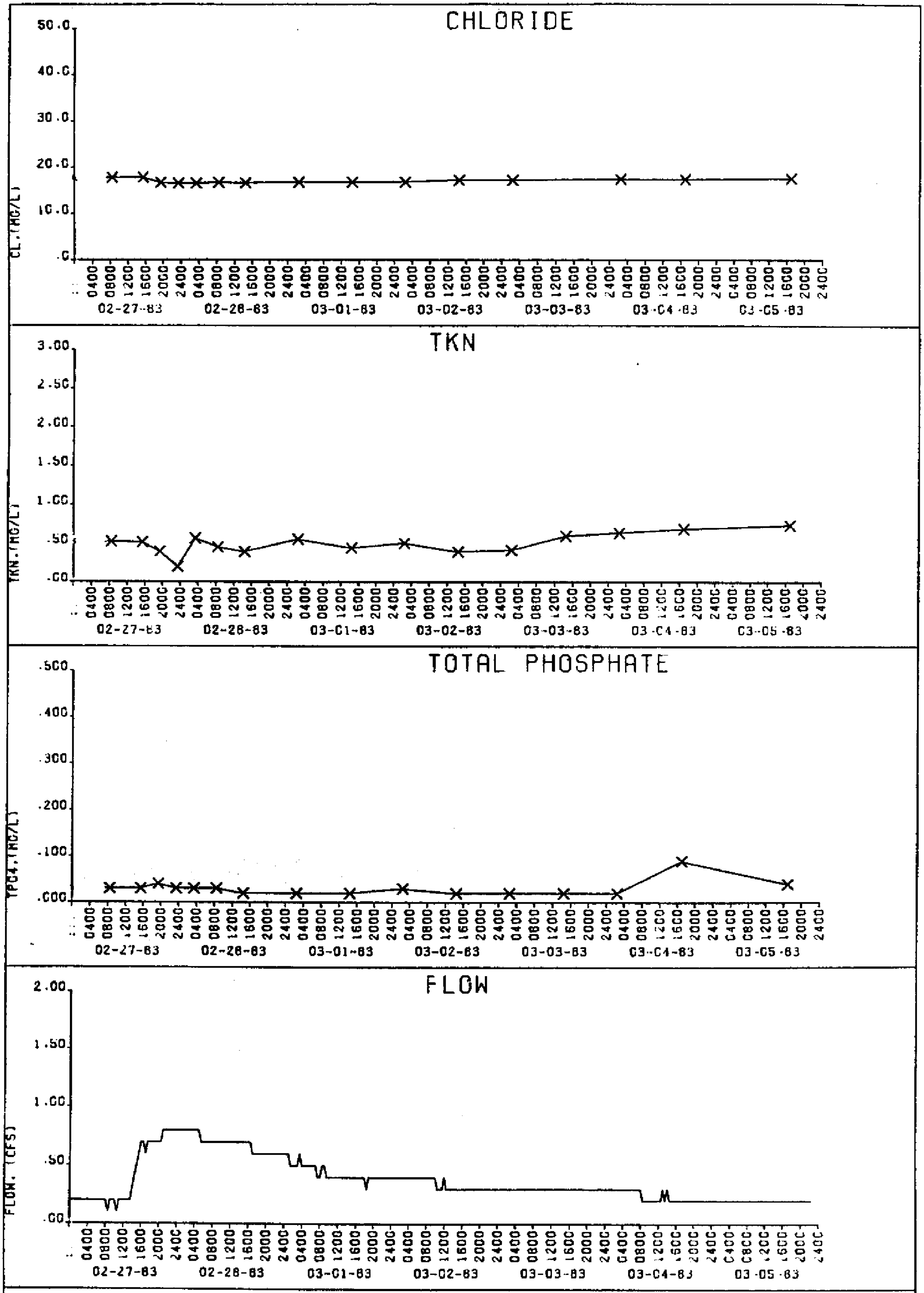


FIGURE: 49 OUTLFOW WATER QUALITY STORM FIVE.

Surface outflow water quality concentrations for events five, one, and nine are characteristic for the low, average, and high intensity storm events sampled at Timbercreek, respectively. The mechanism responsible for elevated pollutant concentrations during the early part of storm related discharge is probably resuspension of bottom sediments, although it is possible that a flush of stormwater runoff with high pollutant concentrations could make its way to the discharge site during extreme events. This is unlikely, however.

Comparison of Stormwater Runoff Quality with NURP Results

The quality of Timbercreek's stormwater runoff was superior to most stormwater quality cited in the literature. A comparison of Timbercreek's water quality with that recorded at 35 sites in the Environmental Protection Agency's recently completed National Urban Runoff Program (USEPA, 1983) shows the average total suspended solids, total phosphate and nitrate plus nitrite levels at Timbercreek to be lower than all of the event mean concentration levels at the NURP study sites (Table 5). Only the mean total Kjeldahl nitrogen and ortho phosphate levels at Timbercreek were within range of those reported from NURP and both were at the extreme low end. Other studies in the south Florida area have produced stormwater runoff quality within range of the NURP data (USGS, 1983), (Mattraw, et.al., 1978), (SWFRPC, 1983), and (Wanielista, et. al., 1981b).

Timbercreek employs a system of grassed swales which intercept the stormwater runoff prior to its reaching the catch basins. These swales are highly maintained and are most likely the reason behind the superior quality of the stormwater runoff. Studies have indicated that grassed swales can remove an average of from 30 percent (P. Oakland, 1983) to over 99 percent (Brevard

TABLE 5. SELECTED STORMWATER RUNOFF QUALITY

	NATIONAL URBAN RUNOFF PROGRAM (NURP)			TIMBERCREEK
	Concentration			Concen
Parameter	Event[1/] Mean (mg/L)	Range (mg/L)	Number of Sites	Event[1] Mean (mg/L)
Total Suspended Solids	249	22-2216	35	20.6
Total PO_4	0.640	0.210-4.10	34	0.136
Ortho-PO_4	0.182	0.069-0.313	16	0.084
Nitrate + Nitrite	1.56	0.33-7.84	24	0.18
Total Kjeldahl Nitrogen	2.71	0.48-10.79	32	0.75

[1/] Flow Weighted Mean

County, 1982) of nutrients and solids from stormwater runoff before it reaches the collection system. It should be noted, however, that Brevard County used a grassed swale system that had significant retention capacity for small and intermediate sized storms.

Detention Pond Influent and Effluent Concentrations

The differences in surface water quality entering and leaving the detention ponds varied with the parameter in question. Dissolved nutrients exhibited the largest positive degree of difference as nitrate, nitrite and ortho phosphate all had 88 percent or greater difference between their average inflow and outflow concentrations (Table 6). Ammonium showed a 62 percent difference. The lower reduction in average ammonium concentration is probably due to high contributions of ammonium from groundwater sources. Due to anoxic conditions present in groundwater, chemical reduction of nitrates and nitrites to ammonium has led to an average groundwater concentration twice that of the average surface inflow concentration. Total phosphate concentrations diminished by 74 percent but TKN decreased by only 16 percent. Allowing for the large positive difference in ammonium ion, TKN-NHN_4 or organic nitrogen had a net decrease in concentration through the pond system of only 2 percent. Average total nitrogen concentrations in the outflow were lower by 30 percent (Table 6).

Parameters indicative of solids had both positive and negative changes in concentrations. Total suspended solids, for example, showed a 68 percent reduction from surface inflow to surface outflow, while turbidity increased by 38 percent.

Groundwater seems to play an integral part in the hydrology of the Timbercreek detention pond system. This can be partially supported by

TABLE 6. AVERAGE DETENTION POND INFLOW AND OUTFLOW AND SHALLOW GROUNDWATER CONCENTRATIONS

Parameter[1]	Average[2] Inflow Concen.	Average[2] Outflow Concen.	Percent Difference	Average Groundwater Concen.
TSS	20.6	6.5	68	3.5
Turbidity	2.4	3.3	-38	1.8
$O\text{-}OPO_4$	0.084	0.004	95	0.026
$T\text{-}PO_4$	0.136	0.035	74	0.039
Total N	0.93	0.65	30	0.90
$NO_2 + NO_3$	0.18	0.02	89	0.026
NO_3	0.17	0.02	88	0.023
NH_4	0.13	0.05	62	0.260
TKN	0.75	0.63	16	0.87
$TKN\text{-}NH_4$	0.62	0.58	6	0.62
Cl	8.6	17.0	-98	29.9
Alkalinity (meq/L)	0.49	0.48	2	1.02
Color (units)	50.9	72.0	-41	44.0
Sp. Cond. (umhos/cm)	84.	134.	-60	260.0

[1] mg/L unless noted

[2] Flow Weighted Mean

observing the negative changes in chloride and specific conductance through the detention system. A negative difference of 98 percent in outflow chloride concentration, coupled with a 60 percent negative difference in specific conductance, indicates the significant groundwater interaction. Groundwater quality measurements at a shallow well near the detention ponds had average concentrations which were 3.5 and 3.1 times higher than those at the surface inflow for chlorides and specific conductance, respectively (Table 6). Groundwater had the same effect, although to a lesser degree, on other parameters such as alkalinity, which decreased in concentration by 2 percent through the pond system. An evaluation of groundwater mass loadings will further describe the effect of groundwater on the pond system from a chemical standpoint.

While differences in concentrations of 74 percent for total phosphate, 30 percent for total nitrogen and 68 percent for suspended solids appear significant, these results are differences in concentration and should only be used as a rough estimate of nutrient removals. More emphasis should be placed on mass loading calculations to determine detention pond treatment efficiency, although the lower nutrient levels in the outflow do indicate a positive response by the detention pond system in the effort to reduce nonpoint source pollution at Timbercreek. It should also be remembered that the grassed swales have provided an unknown degree of reduction in pollutant concentration prior to the stormwater runoff reaching the detention ponds.
This suggests the possibility of even higher pollutant removals from the stormwater runoff source.

The concentrations of ammonium and NO_x relative to that for ortho phosphate may be utilized to identify the limiting nutrient in the Timbercreek detention system. As suggested by the Environmental Protection Agency (EPA, 1978) an available N:P ratio of less than 7-8:1 suggests nitrogen as the limiting nutrient, while a ratio above that implies phosphorus limitation. The N:P ratio in the stormwater runoff at Timbercreek was approximately 4:1. The ratio at the surface water discharge site was almost 18:1, with the detection level of 0.004 mg/L being used for ortho phosphate. This suggests that the pond system is strongly limited in available phosphate, even with a fairly large surface contribution. The N:P ratio in the groundwater is 11:1.

Detention Pond Treatment Efficiency

Pollutant loadings into the detention system were generated by three sources. Rainfall, surface runoff and groundwater all contributed significant levels of pollutants during the nine storm events. Outflow by means of surface discharge and groundwater seepage also occurred. Negligible pollutant transport was assumed for evaporation.

Mass loadings of pollutants into and out of the detention system varied with the individual storm event. Large variances in hydrologic loadings caused resultant effects when pollutant loads were computed. Individual pollutant loadings for selected parameters can be found on a storm event basis and is summarized for surface and total system analysis in Appendix II.

The majority of the water quality sampling effort at Timbercreek was placed on surface water sampling. It is generally perceived that surface runoff from the watershed and surface discharge from the detention pond outlet structure constitute the major flow sites in a watershed. Resultant calculation of pollutant removal efficiencies based only on the surface components are commonly the only reported values in the literature. Timbercreek however, maintains a complex hydrologic system of detention ponds, with contributions by both surface and sub-surface flow. This system cannot be evaluated realistically by determination of only surface water contributions and removals. A comparison of treatment efficiencies of the system for surface water only and total mass flow scenarios were generated for the study period. Treatment efficiencies for the separate scenarios indicate that there is significant impact from rainfall and groundwater loadings. Due to the variability of results obtained from the individual storm events, median values of pollutant removal efficiencies are reported.

The removal efficiency associated with dissolved nutrients in the form of OPO_4 and NO_x was quite impressive (Table 7). Surface loadings of ortho phosphate and NO_x were both reduced through the pond system by 93 percent. When adding rainfall and groundwater sources, the removal efficiency for ortho phosphate dropped to 82 percent, while the NO_x removal efficiency was 87 percent. Constant concentrations were assigned for groundwater regardless of flow direction, thus a dilution of the surface water ortho phosphate and NO_x treatment efficiencies occurred when the other sources and sinks were added. The high removal rate of NO_x for the total system can be attributed in part to the high NO_x concentration in the direct rainfall on the pond system along with zero NO_x leaving the pond via evaporation.

The surface water treatment efficiency for ammonium, based on the median value, was much lower than that for the other dissolved nutrient species (54 percent). Groundwater ammonium concentrations were very high relative to the surface water. Including groundwater in the mass balance dilutes the high treatment efficiency associated with the surface water only evaluation.

The detention system removal efficiencies for total nitrogen and total phosphate were 60 and 15 percent, respectively. Total phosphate removals were

TABLE 7. MASS LOADING REMOVAL EFFICIENCIES OF TIMBERCREEK DETENTION PONDS FOR SELECTED POLLUTANTS

PARAMETER	SURFACE WATER ONLY		TOTAL SYSTEM	
	Median	Range	Median	Range
TSS	68	(600)-84	64	(79)-84
OPO_4	93	67-98	82	44-94
TPO_4	55	25-89	60	28-82
Tot N	12	(186)-91	15	(69)-60
TKN	(31)	(335)-91	0	(127)-48
NO_x	93	(8)-98	87	64-98
NH_4	54	(16)-78	12	(225)-87
Cl	(159)	(602)-73	(75)	(187)-22
Alk	(19)	(115)-71	(10)	(88)-42

( ) Depicts Negative Removal

consistent on a storm basis, while total nitrogen removals were quite variable. Slightly lower total nitrogen and total phosphorus removals were observed in the surface water scenario (55 and 12 percent, respectively). The poor total nitrogen removal efficiency is primarily due to the organic fraction. TKN actually increased through surface water loadings even though ammonium experienced a net decrease. There appears to be some mechanism for nutrient removal aside from sedimentation. It appears that biological conversion of dissolved nitrogen to organic nitrogen, along with biological utilization as suggested by the N/P ratio analysis, is the mechanism.

Suspended solids had consistent removals for both scenarios with the exception of event nine, when the discharge rate from the ponds was 600 percent higher than deposition into the ponds by the surface water component. This was probably due to a limited number of water quality inflow samples being collected for event nine. The median removal rate was 64 percent for the total system.

The influence of the groundwater system is demonstrated by the removal rate associated with chloride and alkalinity. High concentrations for both parameters are present in surface outflow and groundwater. For the surface scenario, this led to median treatment efficiencies of -159 and -19 percent for chloride and alkalinity, respectively. When adding the flux of groundwater through the system, a dilution of this negative treatment comes into effect, and median treatment efficiencies become -75 and -10 percent, respectively.

The hydrologic complexity of Timbercreek's detention system precludes any single physical parameter from greatly influencing the treatment efficiency associated with a given pollutant. Rainfall depth of an event does slightly impact the treatment process for several pollutants, however. Correlation of rainfall depth with surface removal of total nitrogen (r^2 = 0.61), TKN (r^2 = 0.49) and total suspended solids (r^2 = 0.38), indicate that there is a possibility that resuspension of the detention pond sediments occur during large events. These correlation coefficients decrease to r^2 = 0.39, 0.35, and 0.34, respectively, when pollutant removals for the entire system are used. Other physical parameters such as effective detention volume, maximum one-hour rainfall intensity, antecedent dry period and peak inflow do not correlate with treatment efficiencies on either a surface only basis or total system basis. A change in the effective detention volume should cause a direct response in the treatment efficiency of the detention system. For this study, storage volumes available at the onset of each of the nine events were very close to one inch over the entire watershed as is prescribed by the design criteria. This characteristic is necessary for evaluating the current SFWMD surface water regulatory requirement, but does not allow for the effect of alternative storage volumes to be analysed.

Comparison with Other Studies

Treatment efficiencies of wet detention systems reported in the literature are summarized in Table 8 for selected parameters. This list contains results recently published in the NURP study, along with others, but is by no means comprehensive. Comparison of the median treatment efficiencies for the Timbercreek detention pond system are included in the table.

Compared to the reported data, Timbercreek's detention system appears to provide relatively excellent treatment for dissolved nutrients in the form of ortho phosphate and NO_x. Surface water removal efficiencies for ortho phosphate exceed all reported values except for the ECFRPC system that has

TABLE 8. REPORTED DETENTION POND TREATMENT EFFICIENCIES FOR SELECTED WATER QUALITY PARAMETERS

Site		TSS	TP	OP	TKN	NO_x
NURP[1]						
Chicago, IL		92	61	62		82
Lansing, MI	1	87	69	56	30	54
	2	22	6	0	-5	-20
	3	-6	-10	-26	10	-1
Ann Arbor, MI	1	38	28	-2	11	8
	2	83	-38	21	21	77
	3	2	38	63	19	28
Nashcog	1		59	70	20	28
	2		54	67	14	79
ECFRPC[2]		85	61	93	91	92[5]
Rolla, MO[3]		88	65		1	22
Callahan, MO[4]		85	35	43		37
Mean		57	36	41	21	40
Median		85	46	56	17	33
Timbercreek- (Median)	Total	64	60	82	0	87
	Surface	68	55	93	-31	93

[1] (NURP, 1983)
[2] (ECFRPC, 1983)
NOTE: Retention Associated with Small Storms
[3] (Oliver and Grigoropoulos, 1981)
[4] (Rausch and Schreiber, 1981)
[5] As NO_3

some capacity to retain small storm events. Treatment efficiency at Timbercreek is actually higher in terms of ortho phosphate due to the majority (98 percent) of measurements in the surface outflow being at the detection level of 0.004 mg/l. When this occurred, a value of 0.004 mg/l was used tocalculate the discrete mass loading. The removal efficiency for NO_x at Timbercreek was higher than all of the reported values except for the ECFRPC study. As with the ortho phosphate, the detection level concentration of NO_x (for 20 percent of samples) in the surface outflow was used to compute mass load

The treatment efficiency at Timbercreek for total phosphate was in the upper half of the reported values. The total phosphate entering the detention system from stormwater runoff consists primarily of ortho phosphate and the excellent treatment of ortho phosphate explains the good treatment efficiency associated with total phosphate.

The treatment efficiency associated with TKN doesn't exceed 30 percent in the selected literature except for the ECFRPC study. The median treatment efficiency of the Timbercreek detention system is negligible. As suggested earlier, the Timbercreek detention system appears phosphorus limited, which may explain the perceived absence of TKN removal. An alternative suggestion is that dissolved nitrogen is converted to the organic form and flushed from the system.

Overall, treatment efficiencies at Timbercreek are similar to those reported in the literature for particulates, but superior when comparing dissolved nutrients. The swale system at Timbercreek reduces pollutant concentrations prior to stormwater runoff reaching the detention system. Lower pollutant loadings entering the detention system due to these swales may have caused some bias when calculating pollutant removal efficiencies. Water quality at the surface discharge site is at or near the detection level for both dissolved nitrogen and phosphorus. Higher loads into the pond may be able to be assimilated without affecting effluent quality. This would result in better removal efficiency being associated with the detention system. Direct effect of a swale system will be evaluated in the second phase of this program and pollutant removal by the combined swale/detention pond system will be evaluated.

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APPENDIX I

SOUTH FLORIDA WATER MANAGEMENT DISTRICT

Water Chemistry Laboratory

Analytical Methods

AutoAnalyzer II Method

Determination				
Alkalinity	Colorimetric Automated Methyl Orange, Technicon AA II Method #111-71W, Modified EPA Method #310.2	0-5.0 meq/L	0.1 meq/L	0.1 meg/L
Ammonia	Colorimetric Automated Phenate, Technicon AA II Method #154-71W, Modified EPA Method #350.1	0.2.0 mg/L	0.01 mg/L	0.01 mg/L
Chloride	Colorimetric Automated Ferricyanide, Technicon AA II Method #99-70W, Modified EPA MEthod #325.2	0-200.0 mg/L	2.0 mg/L	4.0 mg/L
Nitrite	Colorimetric Automated Diazotization with Sulfanilamide and Coupling with N-(1 Naphthy) Ethylendiamine Eihydrochloride, Technicon colorimetric, Automated AA II Method #1200-70W, Modified EPA Method #353.2	0-0.200 mg/L	0.002 mg/L	0.004 mg/
Nitrate with Nitrite	Same as Nitrite with Cadmium Reduction Column Technicon AA II Method #100-70W, Modified EPA Method #353.2	0.0.200 mg/L	0.002 mg/L	0.004 mg/
Total Kjeldahl	Colorimetric, Semi-Automated Block Digestor, Technicon AA II Method #376-75W, 334-74A, Modified EPA Method #351.2	0-0.10 mg/L	0.001 m/L	0.002 mg/
Ortho Phosphate	Colorimetric, Automated, Phosphomolybdenum Blue Complex with Ascorbic Acid Reduction, Technicon AA II Method $155-71W, Modified EPA Method #365.1	0-2.00 mg/L	0.01 mg/L	0.002 mg/
Total Phosphate	Colorimetric, Semi-Automated Persulfate Digestion followed by same Method as Ortho Phosphate Technicon AA Method #155-71W, Modified EPA Method #365.1	0-2.0 m/L	0.001 mg/L	0.002 mg/

Analytical Methods (Continued)

Physical Parameters

Determination	Method	Range	Detention Range
Suspended Solids	Gravimetric Standard Methods Procedure #2080, 14th Ed., pp 94, 1975, EPA Methods $160.1 to 160.4	20-20,000 mg/L	1.0 mg/L or 5% whichever is greater
pH	Electrometric, EPA Method $150.1 in situ.	0.14 pH	(Sensitivity 0.01 pH)
Turbidity	Nephelometric, Standard Methods #214A, 14th Ed., pp 132, 1975, EPA Method #180.1	0-500 mg/L	1.0 mg/L
Color	Colorimetric, Modified Standard Method #204A, 14th Ed., pp 64, 1975 (Modified as per N.C.A.S.I. Technical Bulletin #253) Modified EPA Method #110.2	0-500 mg/L as Platinum in Platinum-Cobalt Solution	1.0 mg/L
Conductivity	Electrometric, Specific Conductance in situ., Modified Standard Methods #205, 14th Ed., pp 71, 1975, Modified EPA Method #120.1	0-250,000 Micro-Siemens	

APPENDIX II

MASS LOADING SUMMARIES

TABLE II - 1

MASS LOADINGS FOR EVENT ONE

(November 1, 1982)

			Surface			Groundwater		Total		
Parameter 1/	Rainfall	Evap	In	Out	% Diff	In	Out	In	Out	% Diff
Flow (ac-ft)	1.43	0.42	1.95	3.08	-58	0.86	0.74	4.24	4.24	0
TSS	33.0	0.0	62.3	36.2	42	8.2	7.00	103.5	43.20	58
OPO_4	0.05	0.0	0.32	0.03	91	0.06	0.05	0.43	0.08	81
TPO_4	0.09	0.0	0.53	0.24	55	0.09	0.08	0.71	0.32	55
TDT-N	2.29	0.0	4.87	6.18	-27	2.1	1.81	9.26	7.99	14
TKN	1.71	0.0	4.03	5.96	-48	2.0	1.75	7.74	7.71	0
NO_x	0.71	0.0	0.83	0.22	73	0.06	0.05	1.60	0.27	83
NH_4	0.35	0.0	0.19	0.22	-16	0.61	0.53	1.15	0.75	35
Cl	14.4	0.0	58.9	152.7	-159	69.9	60.1	143.2	212.8	-49
Alk (as $CaCO_3$)	33.0	0.0	182.0	207.0	-14	119.0	103.0	334.0	310.0	7

1/ As lbs unless noted.

TABLE II - 2
MASS LOADINGS FOR EVENT TWO
(November 16, 1982)

			Surface			Groundwater		Total		
Parameter[1]	Rainfall	Evap	In	Out	% Diff	In	Out	In	Out	% Diff
Flow (ac-ft)	2.84	0.30	7.31	10.52	-44	1.36	0.69	11.51	11.51	0
TSS	65.59	0.0	441.5	78.37	82	12.9	6.6	520.0	84.97	84
OPO_4	0.09	0.0	3.09	0.11	96	0.09	0.04	3.27	0.15	95
TPO_4	0.18	0.0	4.27	0.74	83	0.14	0.07	4.59	0.81	82
TOT-N	4.55	0.0	26.59	23.45	12	3.33	1.69	34.47	25.14	27
TKN	3.40	0.0	22.93	23.09	-1	3.21	1.63	29.54	24.72	16
NO_x	1.40	0.0	3.55	1.33	62	0.09	0.04	5.04	1.37	73
NH_4	0.69	0.0	7.74	1.69	78	0.96	0.49	9.39	2.18	77
Cl	28.55	0.0	145.1	483.8	-233	110.5	56.1	284.1	539.9	-90
Alk (as $CaCo_3$)	66.0	0.0	465.0	566.0	-22	189.0	96.0	720.0	662.0	8

[1] As lbs unless noted

TABLE II - 3

MASS LOADINGS FOR EVENT THREE

(January 20, 1983)

			Surface			Groundwater		Total		
Parameter[1]	Rainfall	Evap	In	Out	% Diff	In	Out	In	Out	% Diff
Flow (ac-ft)	1.99	0.36	3.55	2.52	9	0.05	2.71	5.59	5.59	0
TSS	46.0	0.0	77.9	47.0	40	0.5	25.8	124.3	72.8	42
OPO_4	0.06	0.0	0.64	0.03	95	0.004	0.19	0.704	0.22	69
TPO_4	0.13	0.0	0.94	0.23	75	0.005	0.29	1.07	0.52	51
TOT-N	3.19	0.0	8.40	3.30	61	0.12	6.63	11.71	9.93	15
TKN	2.38	0.0	7.65	3.67	52	0.12	6.41	10.15	10.09	0
NO_x	0.98	0.0	0.75	0.04	95	0.004	0.19	1.73	0.23	87
NH_4	0.49	0.0	0.36	0.20	44	0.04	1.91	0.89	2.11	-137
Cl	20.00	0.0	100.8	113.5	-13	4.1	220.2	124.9	333.7	-167
Alk (as $CaCo_3$)	46.0	0.0	228.0	151.0	34	6.0	376.0	280.0	527.0	-88

[1] As lbs unless noted

TABLE II - 4

MASS LOADINGS FOR EVENT FOUR

(February 12 - 13, 1984)

			Surface			Groundwater		Total		
Parameter[1/]	Rainfall	Evap	In	Out	% Diff	In	Out	In	Out	% Diff
Flow (ac-ft)	3.34	0.49	6.81	14.54	-114	5.46	0.58	15.61	15.61	0
TSS	79.5	0.0	655.4	212.7	68	51.9	5.5	786.8	218.2	72
OPO_4	0.11	0.0	0.48	0.16	67	0.39	0.04	0.98	.20	80
TPO_4	0.22	0.0	2.16	1.07	50	0.58	0.06	2.96	1.13	62
TOT-N	5.51	0.0	16.72	22.19	-33	13.35	1.42	35.58	22.48	37
TKN	4.11	0.0	15.73	21.09	-34	12.91	1.39	32.75	22.48	31
NO_x	1.70	0.0	1.00	1.08	-8	0.39	0.04	3.09	1.12	64
NH_4	0.84	0.0	1.28	0.59	54	3.86	0.41	5.98	1.0	83
Cl	34.58	0.0	79.2	556.1	-602	443.5	47.1	557.3	603.2	-8
Alk (as $CaCo_3$)	80.0	0.0	408.0	857.0	-110	757.0	80.0	1245.0	937.0	25

[1/] As lbs unless noted

TABLE II - 5

MASS LOADINGS FOR EVENT FIVE

(February 27, 1983)

			Surface			Groundwater		Total		
Parameter[1/]	Rainfall	Evap	In	Out	% Diff	In	Out	In	Out	% Diff
Flow (ac-ft)	1.24	0.59	1.75	5.04	-250	2.64	0.00	5.63	5.63	0
TSS	28.64	0.0	ND	ND	-	25.1	0.0	-	-	-
OPO_4	0.04	0.0	0.55	0.05	91	0.19	0.00	0.78	0.05	94
TPO_4	0.08	0.0	0.85	0.46	46	0.28	0.00	1.21	0.46	62
TOT-N	1.99	0.0	8.98	6.96	22	6.46	0.00	17.43	6.96	60
TKN	1.48	0.0	4.83	6.91	-43	6.24	0.00	12.55	6.97	42
NO_x	0.61	0.0	4.11	0.09	98	0.19	0.00	4.91	0.09	98
NH_4	0.30	0.0	2.11	0.54	74	1.86	0.00	4.30	0.54	87
Cl	12.47	0.0	57.5	221.2	-285	214.5	0.00	284.4	221.2	22
Alk (as $CaCo_3$)	29.0	0.0	147.0	315.0	-115	366.0	0.00	541.0	314.0	42

[1/] As lbs unless noted

ND No Data Available

TABLE II - 6

MASS LOADINGS FOR EVENT SIX

(August 19, 1983)

			Surface			Groundwater		Total		
Parameter[1/]	Rainfall	Evap	In	Out	% Diff	In	Out	In	Out	% Diff
Flow (ac-ft)	0.36	0.26	0.55	0.11	80	0.0	0.54	0.91	0.91	0
TSS	8.31	0.0	37.3	5.80	84	0.0	5.14	45.61	10.94	76
OPO_4	0.01	0.0	0.08	0.01	87	0.0	0.04	0.09	0.05	44
TPO_4	0.02	0.0	0.18	0.02	89	0.0	0.06	0.20	0.08	60
TOT-N	0.58	0.0	2.69	0.23	91	0.0	1.32	3.27	1.55	53
TKN	0.43	0.0	2.47	0.22	91	0.0	1.28	2.90	1.50	48
NO_x	0.18	0.0	0.22	0.01	95	0.0	0.04	0.40	0.05	88
NH_4	0.09	0.0	0.03	0.01	67	0.0	0.38	0.12	0.39	-225
Cl	3.62	0.0	25.4	6.87	73	0.0	43.9	29.02	50.7	-75
Alk (as $CaCo_3$)	8.5	0.0	60.0	17.5	71	0.0	74.8	68.5	92.3	-35

[1/] As lbs unless noted

[2/] Outflow loading based on one water quality sample

TABLE II - 7

MASS LOADINGS FOR EVENT SEVEN

(August 24, 1983)

			Surface			Groundwater		Total		
Parameter[1/]	Rainfall	Evap	In	Out	% Diff	In	Out	In	Out	% Diff
Flow (ac-ft)	1.33	1.10	2.28	1.19	48	0.22	1.54	3.83	3.83	0
TSS	30.7	0.0	ND	38.5	ND	2.09	-	-	-	-
OPO_4	0.04	0.0	0.60	0.01	98	0.02	0.11	0.66	0.12	82
TPO_4	0.09	0.0	0.81	0.13	84	0.02	0.16	0.92	0.29	68
TOT-N	2.13	0.0	3.72	1.68	55	0.54	3.77	6.39	5.45	15
TKN	1.59	0.0	2.83	1.65	42	0.52	3.64	4.94	5.29	-7
NO_x	0.66	0.0	0.89	0.02	98	0.02	0.11	1.57	0.13	92
NH_4	0.33	0.0	0.08	0.03	63	0.16	1.09	0.57	1.12	-96
Cl	13.4	0.0	48.5	65.3	-35	17.9	125.1	66.4	190.4	-187
Alk (as $CaCo_3$)	31.0	0.0	164.0	84.0	49	31.0	214.0	226.0	297.0	-32

[1/] As lbs unless noted

[2/] Outflow loading based on one water quality sample

TABLE II - 8

MASS LOADINGS FOR EVENT EIGHT

(August 29, 1983)

Parameter[1/]	Rainfall	Evap	Surface In	Surface Out	Surface % Diff	Groundwater In	Groundwater Out	Total In	Total Out	Total % Diff
Flow (ac-ft)	1.22	0.48	2.52	2.87	-14	0.60	0.99	4.34	4.34	0
TSS	28.2	0.0	462.5	169.3	63	5.7	9.4	496.4	178.7	64
OPO_4	0.04	0.0	0.52	0.03	94	0.04	0.07	0.60	0.10	83
TPO_4	0.08	0.0	0.91	0.60	34	0.06	0.10	1.05	0.70	33
TOT-N	1.96	0.0	8.16	7.96	2	1.47	2.42	11.59	10.38	10
TKN	1.46	0.0	5.97	7.82	-31	1.42	2.34	8.85	10.16	-15
NO_x	0.60	0.0	2.19	0.15	93	0.04	0.07	2.83	0.22	92
NH_4	0.30	0.0	0.19	0.11	42	0.42	0.70	0.91	0.81	11
Cl	12.26	0.0	42.8	149.0	-248	48.7	80.4	103.8	229.4	-121
Alk (as $CaCO_3$)	28.0	0.0	109.0	210.0	-93	830	137.0	220.0	347.0	-58

[1/] As lbs unless noted

TABLE II - 9

MASS LOADINGS FOR EVENT NINE

(October 22, 1983)

			Surface			Groundwater		Total		
Parameter[1]	Rainfall	Evap	In	Out	% Diff	In	Out	In	Out	% Diff
Flow (ac-ft)	3.89	0.80	8.89	11.52	-30	1.42	1.88	14.20	14.20	0
TSS	89.8	0.0	32.0	224.2	-600	13.5	17.9	135.3	242.1	-79
OPO_4	0.13	0.0	1.84	0.13	93	0.10	0.13	2.11	0.26	88
TPO_4	0.25	0.0	2.46	1.85	25	0.15	0.20	2.86	2.05	28
TOT-N	6.24	0.0	10.21	29.16	-186	3.47	4.60	19.92	33.76	-69
TKN	4.65	0.0	6.56	28.57	-335	3.36	4.44	14.57	33.01	-127
NO_x	1.92	0.0	3.63	0.62	83	0.10	0.13	5.65	0.75	87
NH_4	0.95	0.0	2.38	2.46	-3	1.00	1.33	4.33	3.79	12
Cl	39.1	0.0	275.2	490.7	-78	115.4	152.7	429.7	643.4	-50
Alk (as $CaCo_3$)	90.0	0.0	599.0	712.0	-19	197.0	261.0	886.0	973.0	-10

[1] As lbs unless noted

TABLE II - 10

SUMMARY OF SURFACE POLLUTANT LOADING REMOVAL EFFICIENCIES AT TIMBERCREEK

Event	TSS	OPO_4	TPO_4	TN	TKN	NO_x	NH_4	Cl	Alk
1	42	91	55	-27	-48	73	-16	-159	-14
2	82	96	83	12	-1	62	78	-233	-22
3	40	95	75	61	52	95	44	-13	34
4	68	67	50	-33	-34	-8	54	-602	-110
5	ND	91	46	22	-43	98	74	-285	-115
6	84	87	89	91	91	95	67	73	71
7	ND	98	84	55	42	98	63	-35	49
8	63	94	34	2	-31	93	42	-248	-93
9	-600	93	25	-186	-335	83	-3	-78	-19
Mean	-32	90	60	0	-34	77	45	-174	-26
Median	63	93	55	12	-31	93	54	-159	-19

TABLE II - 11

SUMMARY OF TOTAL POLLUTANT LOADING REMOVAL EFFICIENCIES AT TIMBERCREEK

Event	TSS	OPO_4	TPO_4	TN	TKN	NO_x	NH_x	Cl	Alk
1	58	81	55	14	0	83	35	-49	7
2	84	95	82	27	16	73	77	-90	8
3	42	69	51	15	0	87	-137	-167	-88
4	72	80	62	37	31	64	83	-8	25
5	ND	94	62	60	42	98	87	22	42
6	76	44	60	53	48	88	-225	-75	-35
7	ND	82	68	15	-7	92	-96	-187	-32
8	64	83	33	10	-15	92	11	-121	-58
9	-79	88	28	-69	-127	87	12	-50	-10
Mean	45	80	56	18	-1	85	-17	-80	-16
Median	64	82	60	15	0	87	12	-75	-10

FIGURE II-1 TIMBERCREEK DETENTION SYSTEM MASS REMOVAL MEANS AND RANGES FOR NINE EVENTS NOVEMBER 1982 - OCTOBER 1983