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Urban storm runoff : a qualitative and quantitative study.

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URBAN STORM RUNOFF,
A QUALITATIVE AND QUANTITATIVE STUDY

A THESIS

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ABSTRACT

In the current Water Pollution crisis, diffuse sources such as urban storm runoff are becoming more important with the modern advances in the technology of sewage and industrial effluent purification.

So far most of the studies on urban storm runoff have dealt with only water quality problems, and with a limited number of constituents. But the old saying that water quality and quantity problems cannot be divorced is unquestionable. To accomplish this goal an 89 acre residential area with a population density of 8 persons/acre was chosen for this study. The equipment was set up in a storm manhole. Grab samples were collected every two hours by an automatic liquid sampler supplied by Testing Machines International of Canada, and the discharge was measured continuously by an Arkon Water Level Recording Instrument. The samples were collected from January 1971 to December 1971, for 20 storms covering all seasons. In all 83 samples were analyzed for 19 different parameters (chemical and biological) during the study. Rainfall data was obtained from the Geography Department of the University of Windsor.

Besides finding average concentrations annually and seasonally for these parameters the annual and seasonal loads in lbs/acre of these parameters were also calculated by using

measured discharge data and annual rainfall in Windsor. Certain pollutional loads were also compared with that of sanitary sewage. Runoff coefficients for different seasons were determined from field data and their importance in total pollutional loads discharged seasonally to the Detroit River was demonstrated. The effect of rainfall intensity and discharge on concentrations of these constituents was discussed as well as the mutual interdependence of these parameters.

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CHAPTER I

INTRODUCTION

Today the technology of sewage and industrial effluent purification is sufficiently advanced to provide the sanitary engineer with a sound basis for the implementation of control measures to protect surface water supplies. In contrast, the pollution load contributed to water supplies by runoff and drainage from highly developed residential, industrial and agricultural areas during both wet and dry periods is becoming a serious problem. The list of pollutants carried in runoff from these areas runs the whole gamut of human activity but can be broadly classed under organic materials, mineral matters and bacteria.

These materials originate in many ways such as lawn sprays, household refuse, industrial refuse as well as salt applied to roadways, agricultural sprays and fertilizers. Eventually these materials find their way into water courses which drain into larger rivers, lakes and reservoirs, which constitute by far the most important sources of public water supply. The bulk of those polluting materials collect in surface water supplies to form bottom sediments. The rest remains in solution or suspension in the water. The sediments and supernatant water form zones of active biological and bio-chemical activity and play an important role in the process of self-purification.

These diffuse sources of water pollution assume a greater importance as the pollutional loadings from concentrated waste effluents are reduced. Recorded effluents may account for only one-half or one-third of the total B.O.D. loading that enters the river system (1). Under such conditions alternatives to advanced waste treatment, such as instream treatment must be considered. This indicates the need for using the systems approach to the water quality problem within a river system. Long range preservation of the quality of water in Canadian lakes is dependent upon further successful efforts to reduce pollutional loadings from diffuse sources.

In the thirty years from 1928 to 1958 the annual production of synthetic detergents and other surface-active agents in the United States rose from one million lbs. to a tremendous total of 1500 million lbs. while the annual manufacture of insecticides and other agricultural chemicals increased from one million lbs. to the lower but still staggering figure of 550 million (2), and in 1967 the production of pesticidal chemicals rose in the United States to the figure of 1019 million pounds (3). Thus one of the present-day objectives of environmental engineering is the control of mounting chemical hazards, urbanization, industrialization, population growth, stepped-up agricultural production and resource development, all of which create massive increases in the synthesis and manufacture of chemicals. This of course causes a corresponding increase in the pollutional load on the atmosphere and hydrosphere. Lakes, as well as streams, are feeling the impact of chemical contaminants, through accelerated eutrophication.

Sanitary engineers and ecologists must become more responsive to the dangers of lake eutrophication. This awareness must become as keen as that of the Swiss, who are so proud of the beauty of the lakes of Zurich and Geneva; and our determination as firm as that of the Germans who are so careful with Lake Constance, the ultimate source of drinking and industrial water for half their land. In European experience, phosphorus has usually been the controlling element in the eutrophication of lakes, manifest in nuisance blooms of weeds and plankton, the accumulation of bottom deposits, the disappearance of game fish and the acceleration of overall lake destruction. The above observations by Professor G.M. Fair (2) outlines one of the most serious problems confronting the modern practitioner of environmental engineering.

Eutrophic waters are more expensive to treat because of the shorter length of time that a rapid sand filter can be used without backwashing. In a deep thermally stratified lake, undesirable quantities of hydrogen sulfide, iron, or manganese, frequently arise when anaerobic conditions occur in the low-temperature hypolimnetic waters. However, the demand for cool water for drinking and industrial cooling purposes requires the use of such hypolimnetic waters. The eutrophication of a water supply can seriously affect the cooling system through the corrosion of pipes and appurtenances by algal slime growths. Eutrophication is also of concern because of the increased salt content in irrigation waters (4).

It appears that the quality of stormwater from a separate sewer system is very unsatisfactory in spite of the separation of combined sewers into storm and sanitary sewers. Morrison and Fair (5), studied a stream having no known pollution from domestic sewage and concluded that runoff from the surrounding water shed was the most important source of bacterial contamination. A review of water borne disease outbreaks occurring in the United States from 1946 to 1960 lists 228 known outbreaks, at least 29 of which were associated with stormwater runoff (6), caused either by rainfall washing human and animal feces or other sewage into wells, springs, streams and reservoirs. This indicates that rainwater discharged from separate sewers in urban areas can have as great or even more than double the polluting effect of domestic sewage, and can damage the receiving stream particularly if the area is industrialized.

As highly polluted stormwater is usually discharged without treatment into the receiving waters the effect of the separation is thus diminished. There has, however, been vigorous discussion as to whether this direct discharge of stormwater into streams can be justified for the future.

The determination of the quality of surface waters is equally as important as the total volume of the pollutants. The old saying that water quality and quantity problems cannot be divorced is unquestionably true. In the case of a running stream acting as a receiving water, the quality is generally more important. A short high peak of contamination with suspended matter can have disastrous results. A good example is the fish killed in the Missouri River by heavy storm water runoff reaching the river (7). While for stored water in a lake acting as a receiving water, the total quantity of pollutants becomes more important. This amount can be ascertained only if the amount of the effluents as well as the concentration of the contaminants is measured.

The large expansion of housing and highway construction, with the ensuing replacement of permeable surfaces by impervious ones, has reduced infiltration of precipitation to the water table. A dual problem is created by this rapid urbanization; loss of replenishment of underground water supplies, and increased collection and disposal of storm waters.

Some other hazards of increasing quantity and decreasing quality of stormwater are shoaling (mud deposits) in lakes and pollution of bathing beaches during the summer after heavy rains.

Urban stormwater can be used to meet water scarcity problems. Reservoirs can be refilled directly from urban runoff. However, in some cases it may require certain pretreatment. A proposal to use stormwater for recreational purposes has been reported in Minneapolis, Minnesota (8). The use of stormwater for agricultural purposes has also been reported in Israel (9) and elsewhere.

OBJECT

The object of the present study was to determine in a typical residential area,

(i) the variation in the quality of stormwater runoff on a prolonged basis with a two hour sampling interval,

(ii) the quantity and quality relationships of urban stormwater runoff, and

(iii) the effect of the intensity of the rainfall on the quality of the runoff.

CHAPTER II

LITERATURE REVIEW

A limited amount of research has been undertaken to identify the water quality constituents of urban runoff. Until about 1950 engineers were most concerned with developing procedures for estimating and dealing with the exceedingly large quantities of runoff produced during intense storms on urbanized areas. So far the hydrologic and water quality data necessary to compute the total pollutional loadings of various constituents are very meager. However, such data are essential since a knowledge of the total pollutional loading is important, particularly in cases where the objective is to determine the impact of the waste flow on a receiving stream. For example, a short high peaked surface runoff hydrograph of suspended matter could be expected to affect more seriously a receiving water than a hydrograph which released the same volume of suspended matter over an extended period of time.

A translation of a report (10) on the results of a sampling study of stormwater runoff in Moscow, U.S.S.R. in 1936 indicated B.O.D.'s of 186 to 285 mg/l and suspended solids of 1000 to 3500 mg/l. Runoff samples from Leningrad's cobblestone paved streets in 1948-50 contained B.O.D.'s of 36 mg/l and suspended solids of 14,541 mg/l.

Summer rainwater drainage samples mainly from streets and parks in Stockholm, Sweden, from 1945 to 1948 (11) indicated the median value for coliforms at 4,000 per 100 ml, total solids 300 mg/l, fixed residue 210 mg/l and B.O.D. 17 mg/l. The levels for individual samples ranged as high as 200,000/100 ml for coliforms, 3,000 mg/l total solids, and 80 mg/l B.O.D.

Palmer (12) sampled storm runoff from land surfaces at street catchbasins in downtown Detroit in 1949. He found B.O.D.'s on the order of 96 to 234 mg/l, total solids 310 to 914 mg/l and coliform MPN's of 25,000 to 930,000/100 ml. Palmer (13) also reported similar sampling during a number of Detroit storms in 1960. In these instances also the pollutant concentrations were high. Suspended solids means for a number of samples from two storms were 213 and 102 mg/l respectively, coliform MPN's for four storms ranged from 2,300 to 430,000/100 ml. Concentrations varied widely between points and at the same point during the storm runoff. In some cases the quality of the storm runoff became worse as the storm progressed and in others it became better, and in still others no pattern was apparent.

In 1954, a study of surface runoff from a 611 acre estate with separate sewers at Oxney, England (14) indicated B.O.D.'s up to 100 mg/l and suspended solids values of up to 2045 mg/l. B.O.D.'s tended to increase with the length of the antecedent dry weather period up to 8 to 10 days. Computations were made tp compare discharges to the river from the separate systems with a hypothetical combined system wherein all flow would receive treatment on the basis of assumed treatment plant effluent levels of 20 mg/l for B.O.D. and 30 mg/l for suspended solids, it was concluded that the separate system reduced the B.O.D. loading on the stream but increased the suspended solids loadings 600 to 700 percent. First flushes were not much more polluting than subsequent flows, except after long antecedent dry periods.

In a study made by Sylvester in 1959-60, stormwater samples from Seattle (15) street gutters, contained constituent values as follows:turbidities up to 1290 units, colour to 350 units, B.O.D. about 10 mg/l, coliform MPN's to 16,100 per 100 ml. Nutrient values were nitrate nitrogen to 2.80 mg/l and phosphorus to 0.784 mg/l. The highest constituent concentrations usually were found when antecedent rainfall had been low. On this basis Sylvester concluded that stormwaters should not be admitted to Green Lake because they would hasten the lake shoalings, and also because they were high in nutrients and would render useless any method of algal control aimed at limiting the food supply.

Stormwater samples from residential parks, schools and sportsgrounds in Pretoria, South Africa (16), revealed coliform counts of 240,000 per 100 ml, dissolved solids 228 mg/l and B.O.D. 30 mg/l. From business and flat areas the concentrations were coliforms 230,000 per 100 ml, dissolved solids 154 mg/l, and B.O.D. 34 mg/l.

A summary of constituent concentrations found in the runoff from a 27 acre residential and light commercial area in Cincinnati, Ohio (17) (18), by the F.W.P.C.A. 1962-64 is given in Table 1, to point out the degree of pollution and the range of values one might expect from urban surface wash. The authors classify this area as a "relatively clean type of urban use" and therefore infer that untreated runoff from many urban areas is likely to be unacceptable to receiving waters without some pretreatment.

The quantity of nutrients found in the Cincinnati data are of particular interest since they are greater than the 0.3 mg/l inorganic nitrogen and 0.03 mg/l orthophosphates, indicated as threshold levels for algal blooms.

The Cincinnati studies indicated a wide range in coliform group densities. In 90 percent of the samples a density of 2,900/100 ml was found. This considerably exceeds the criterion of 1,000/100 ml commonly used as a maximum for bathing waters in the United States. Both fecal coliforms and fecal streptococci were found. Their presence indicated that pathogenic microorganisms might also be expected.

Constituent loads in the above urban runoff were calculated both on an annual basis and on the basis of daily

TABLE 1

Summary of Constituent Concentrates in the Urban Runoff in Cincinnati, Ohio (1962-64)

Constituent	Range in Values	Mean Storm Value
Turbidity, J.T.U.	30 - 1,000	176
Colour, unit	10 - 460	87
pH	5.3-8.7	7.5
Total Alkalinity (mg/l)	10 - 210	59
Total Hardness as $CaCO_3$ (mg/l)	19 - 364	81
Chlorides (mg/l)	3 - 428	12
Suspended Solids (mg/l)	5 - 1,200	227
Volatile Suspended Solids (mg/l)	1 - 290	57
B.O.D. (mg/l)	1 - 173	17
Inorganic Nitrogen (mg/l)	0.1-3.4	1.0
Hydrolyzable PO_4 (mg/l)	0.02-7.3	1.1
Coliform organisms MPN per 100 ml	2,900-460,000	-

discharges during storms and were compared with sanitary sewage production at a 9 person/acre population density. These indicate that the pounds of suspended solids discharged annually in the runoff equals 160 percent of those produced as sanitary sewage, B.O.D., 7 percent, total hydrolyzable phosphate 5 percent, and total nitrogen 14 percent. During runoff, stormwater runoff constituent discharge rates, expressed as percentages of average raw sewage constituent production rates at the same population density mentioned above are suspended solids, 2,400 percent and total nitrogen 200 percent.

Burm, Krawczyk, Harlow and Vaughan (19)(20), made a study in Ann Arbor, Michigan in the period 1963-65. Table 2 gives maximum values observed and the annual means of different constituents.

Total coliform and fecal coliform densities showed a significant increase in magnitude during the warmer summer months. Initial counts from both combined and separate storm sewer discharges were either moderately higher than the rest of the results or at about the same level. This indicates that any effect of "first flushing", (that is the initial part of the storm), is minimal. For B.O.D. mean values from the initial time were significantly higher than those observed during the remainder of the discharges. The reason for this phenomenon is that the sewers are scoured clean during the

TABLE 2

Analysis of Urban Storm Water in Ann Arbor, Michigan (1963-65)

Analysis	Maximum Value Observed	Annual Mean
B.O.D. (mg/l)	62	28
Ammonia (mg/l)	2.0	1.0
Suspended Solids(mg/l)	11,900	2,080
Volatile Suspended Solids (mg/l)	570	218
Orthophosphates (mg/l)	3.4	0.8
Nitrate (mg/l)	3.6	1.5
Total Coliform/100 ml	49,000,000	
Fecal Coliform/100 ml	4,300,000	

initial flow and as the sewers flush themselves out, the B.O.D. value diminishes. The mean value for ammonia nitrogen with the exception of the fall values remained relatively constant throughout the year. Suspended solid values in the Spring, especially those observed during April and the first half of May, were consistently higher in Ann Arbor storm sewer. This is probably due to the washing of the Winter's accumulation from the city streets. Average concentrations for soluble phosphates showed a significant drop in the storm sewer discharge during the late Summer and throughout the Fall. Use of fertilizer in the area as determined by sales was greatest in the Spring and early Summer and that could be the primary reason for the drop in soluble phosphate values late in the year. Average nitrate nitrogen concentrations in the storm sewer discharge showed a drop in the Fall. This also may be caused by the diminishing use of fertilizer. Changes were minor as the discharges progressed.

The results of a study made in Ottawa (1) in 1968 are given in Table 3. The B.O.D. was found to vary considerably in a given storm as the storm progressed, decreasing rapidly towards a minimum value. Even though the antecedent period was longer than one day initial values of 28-32 mg/l were generally not exceeded. Solids tended to decrease as the storm progressed but not as markedly as the B.O.D.

TABLE 3

Results of the Urban Storm Runoff Study Made in Ottawa (1968)

Constituent	Range	Mean
B.O.D.	5-32	21
Suspended Solids	10-1105	150
Sulfate	10-400	96
Nitrate	0.2-5.5	1.3
Nitrite		.16
Orthophosphate	0.1-6.4	1.2
Chlorides		
a) Snowmelt		233
b) Rainfall runoff		14

Recorded values of sulfate in the Spring were generally above average, while those in the Summer and Fall were below average. The concentration of sulfate had reduced as a given rainstorm progressed. This effect was probably due to the cleansing of the ground surface as well as the "scrubbing" of the air since both air and ground serve as sources of sulfate. The nitrate source seems to be mainly air for this particular area, and the level of nitrates, remained relatively constant throughout an individual storm.

In 1968 Inaba (21), reported on the extent of stormwater pollution from two typical areas in Tokyo, Japan. One area was served by a combined sewer system and the other by a separate sewer system. Samples were taken and analyzed for B.O.D., suspended solids and volatile suspended solids. This study emphasizes the importance of the "first flush" pollution and recommends that all combined sewers be replaced by a dual separate system.

In 1969, Soderlund (22) chose three separate drainage areas in Stockholm, Sweden, for a comparative study of storm-runoff waste characteristics. The parameters studied included pH, phosphorus, lead, oil, dry solids, volatile suspended solids, chlorides and coliform bacteria. The importance of roadway material transported with removed snow and deposited into the sewerage system was noted. Other sources of pollution included, industries and laundries with cutting oils, emulsions, cleaning compounds from industry and waste from dry cleaning establishments. Soderlund concluded that:-

a) the dumping of snow from heavily trafficked areas contributes greatly to the pollution of the recipient streams and inland waters with oil and heavy metals

b) traffic routes give a high degree of contamination as compared with the other test areas. This constitutes a serious problem, as the area covered by roads are rapidly increasing today in the urban centres.

Friedland (23) carried out two studies in the San Francisco area of five combined sewer systems and one storm sewer system. A determination was made of the relative flows and pollutional loads in wet and dry periods and the efficiency of storage was compared with that of treatment. The authors attempted to present results in terms of storm mass emission equations for numerous parameters. It was claimed that correlation with dry weather flow load conditions and other statistical and background data could be used to estimate wastewater loads for storm-runoff.

Most of these studies included the determination of concentrations of constituents from isolated samples without attempting to relate the pollutional load to the rate of runoff from the study area, although the San Francisco and Cincinnati studies have made some attempt in this direction.

CHAPTER III

DESCRIPTION OF THE STUDY AREA TESTING PROCEDURES AND EXPERIMENTAL SETUP

The City of Windsor has mostly combined sewers, but a newly developed area in the east side of the city has a separate sewer system. A drainage area of about 89 acres was selected for this study. Its location within Windsor, and a detailed layout map are shown in Figures 1 and 2. The area is residential, composed of middle to upper middle class people. The buildings include single family homes, apartments and two schools. Figure 3 shows the general nature of the builtup area. It also has some paved parking lots, asphalt and concrete paved streets, trees, lawns, backyard gardens and two parks. The ground is almost flat throughout the study area.

The residential population is about 700 - a density of 8 persons/acre. The particular manhole chosen for this study joins a 54" dia. sewer upstream and 60" dia. sewer downstream. The upstream and downstream sewers have a grade of .19% and .14% respectively. The sewers at this stage of the development are overdesigned, as there is a fairly large undeveloped area to be drained by this sewer system as development continues. The 60" dia. sewer ultimately discharges the untreated flow into the Detroit River. The

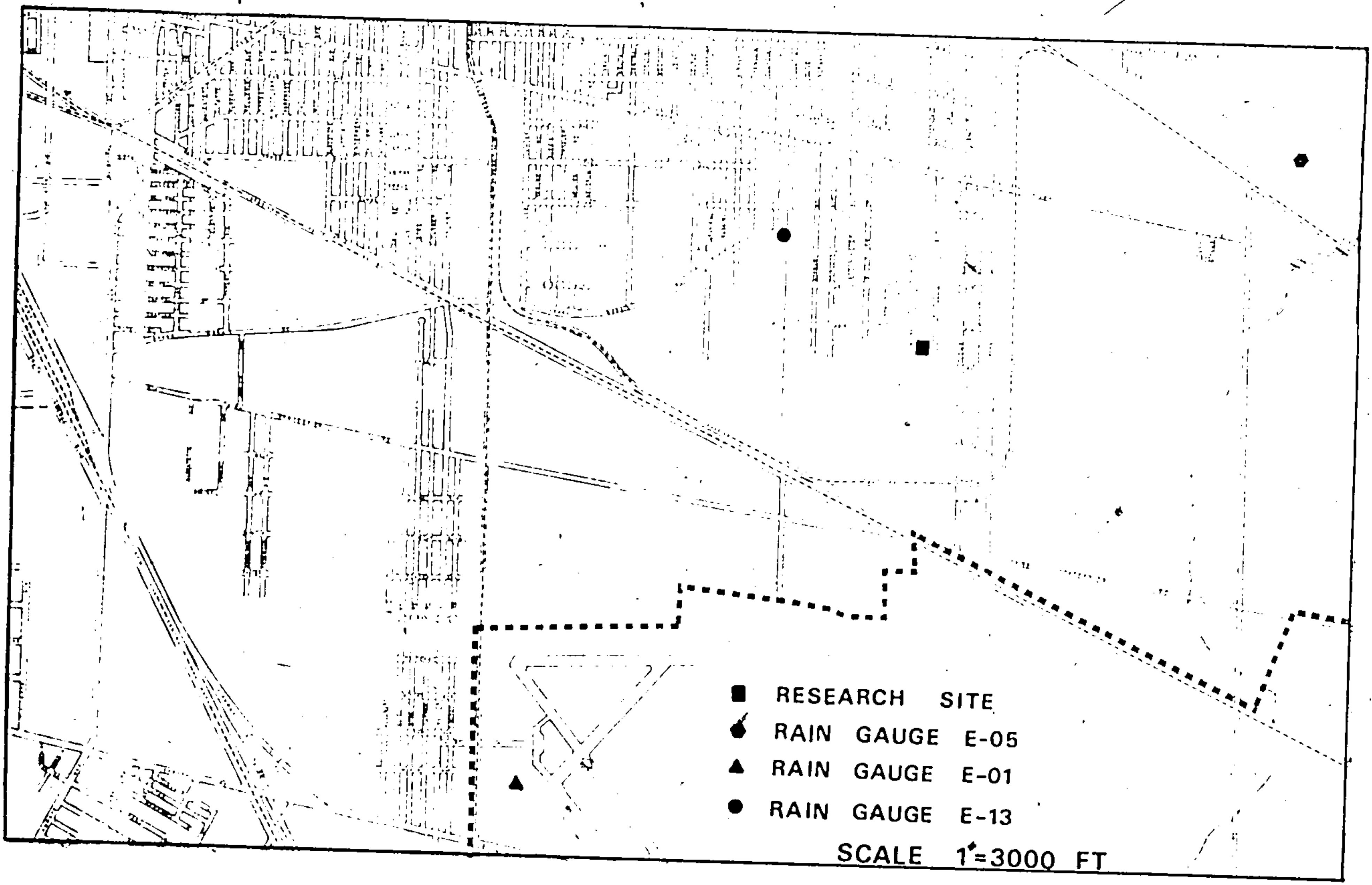


Figure 1. Partial Map of the City of Windsor Showing Research Site and Location of Rain Gauges used during the Study.

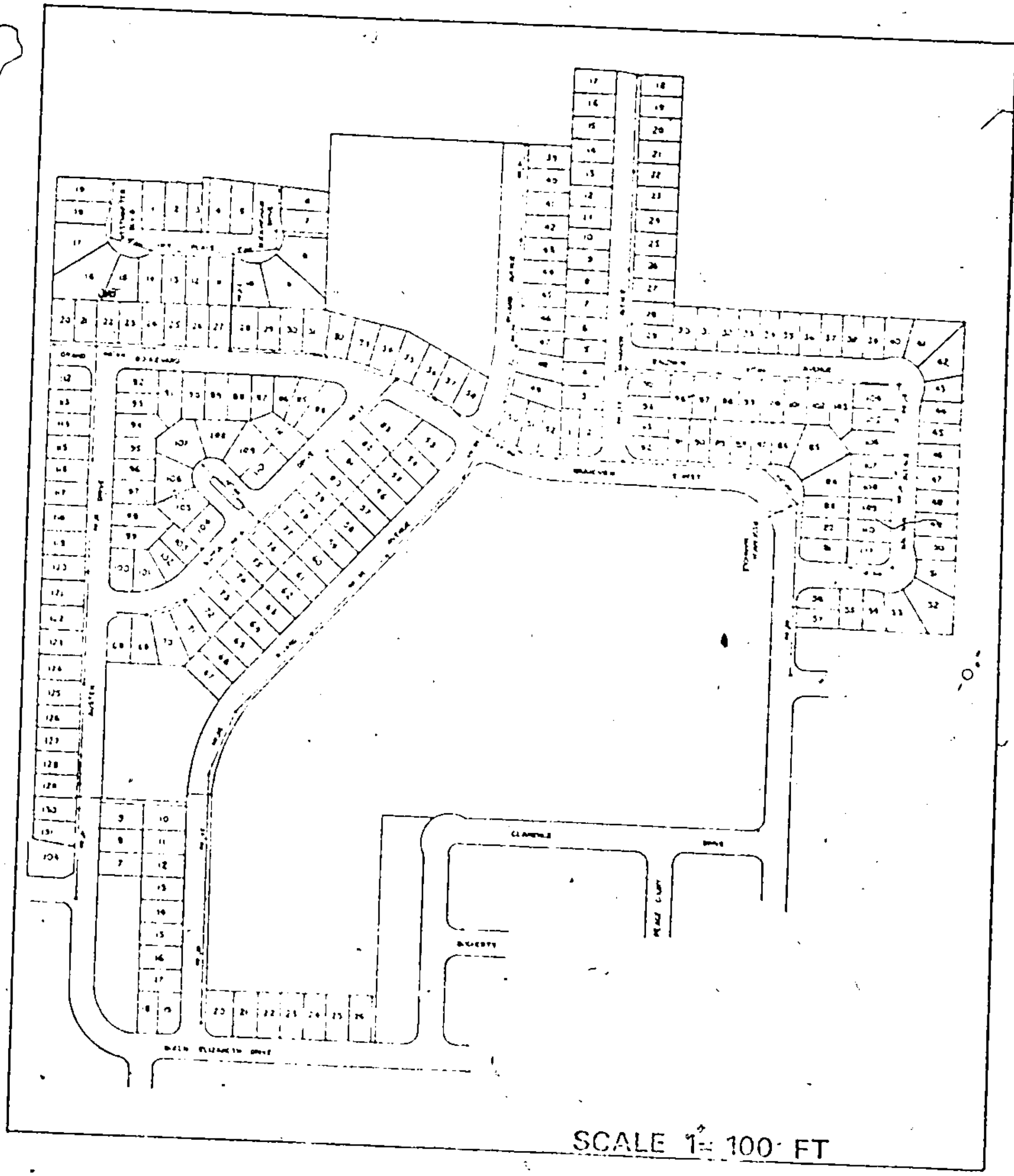


Figure 2. Detailed Plan of the Drainage Area.

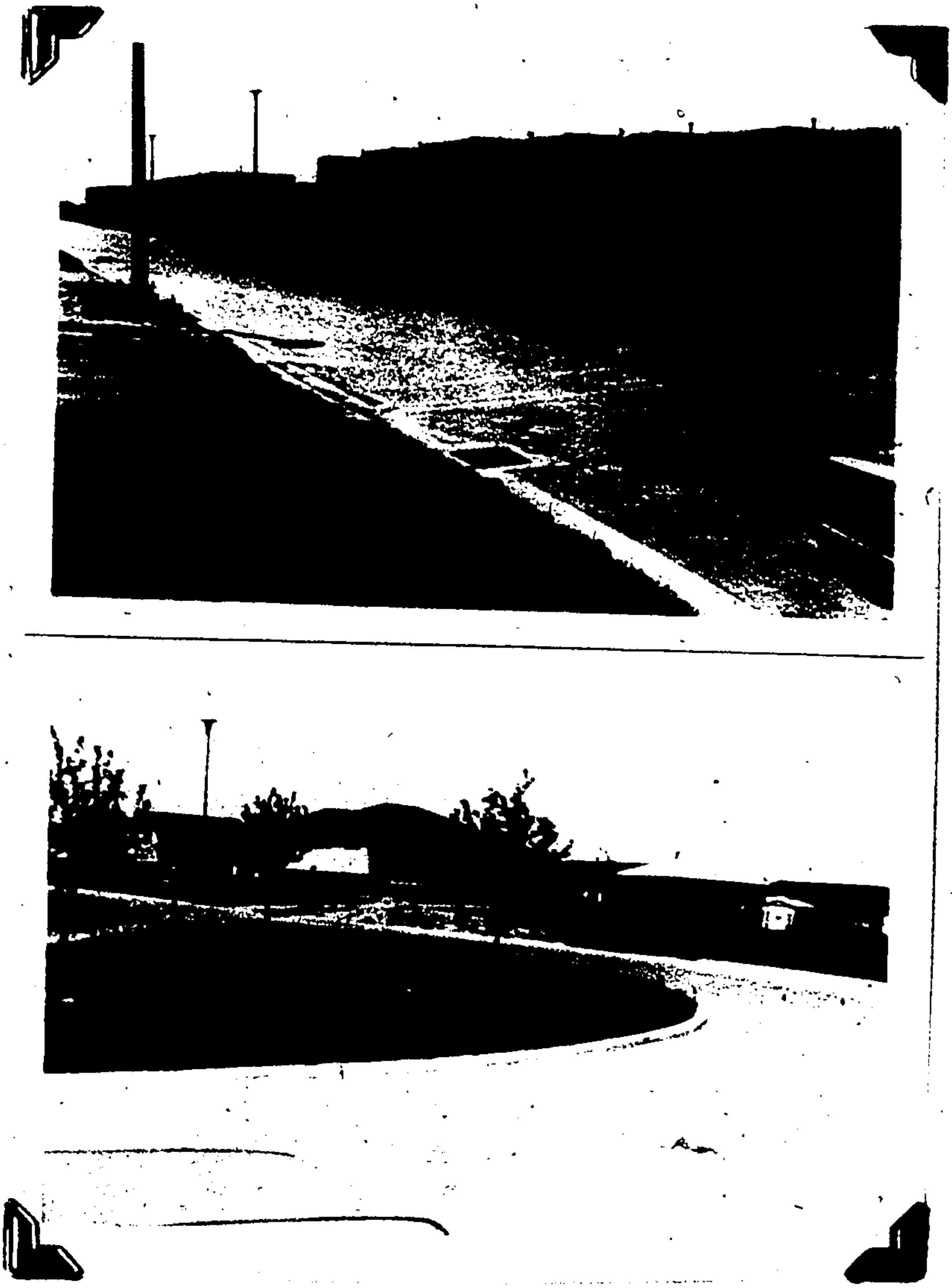


Figure 3. A View of the Builtup Study Area.

general arrangement of the experimental setup inside the manhole is shown in Fig. 4.

The rainfall records were obtained from the Geography Department of the University of Windsor and the exact location of the rain gauges used for the study are shown in Figure 1.

The climate (24) is temperate with a growing season averaging 210 days, 165 of which are frost-free. The mean annual temperature is 47°F, with a winter mean of 26°F and a summer mean of 70°F. Air temperature extremes vary from -25°F to 100°F. The mean annual rainfall ranges from 18 to 39 inches with the mean value of 32½ inches. The mean monthly variance is from 1.75 inches in February to 3 inches in June. Drought conditions occur on an average of two out of every five years.

In all 83 runoff samples were collected from the manhole during the period from January, 1971 through December, 1971. Nineteen parameters were determined for most of these samples. These parameters are as follows: (1) Water Temperature (2) Colour (3) Turbidity (4) Specific Conductance (5) pH (6) Total Suspended Solids (7) Volatile Suspended Solids (8) Alkalinity (9) Total Hardness (10) Calcium Hardness (11) Chlorides (12) Orthophosphates (13) Sulfates (14) Ammonia Nitrogen (15) Nitrite Nitrogen (16) Nitrate Nitrogen (17) Five Day Biochemical Oxygen Demand (18) Total Coliform Count (19) Fecal Coliform Count.

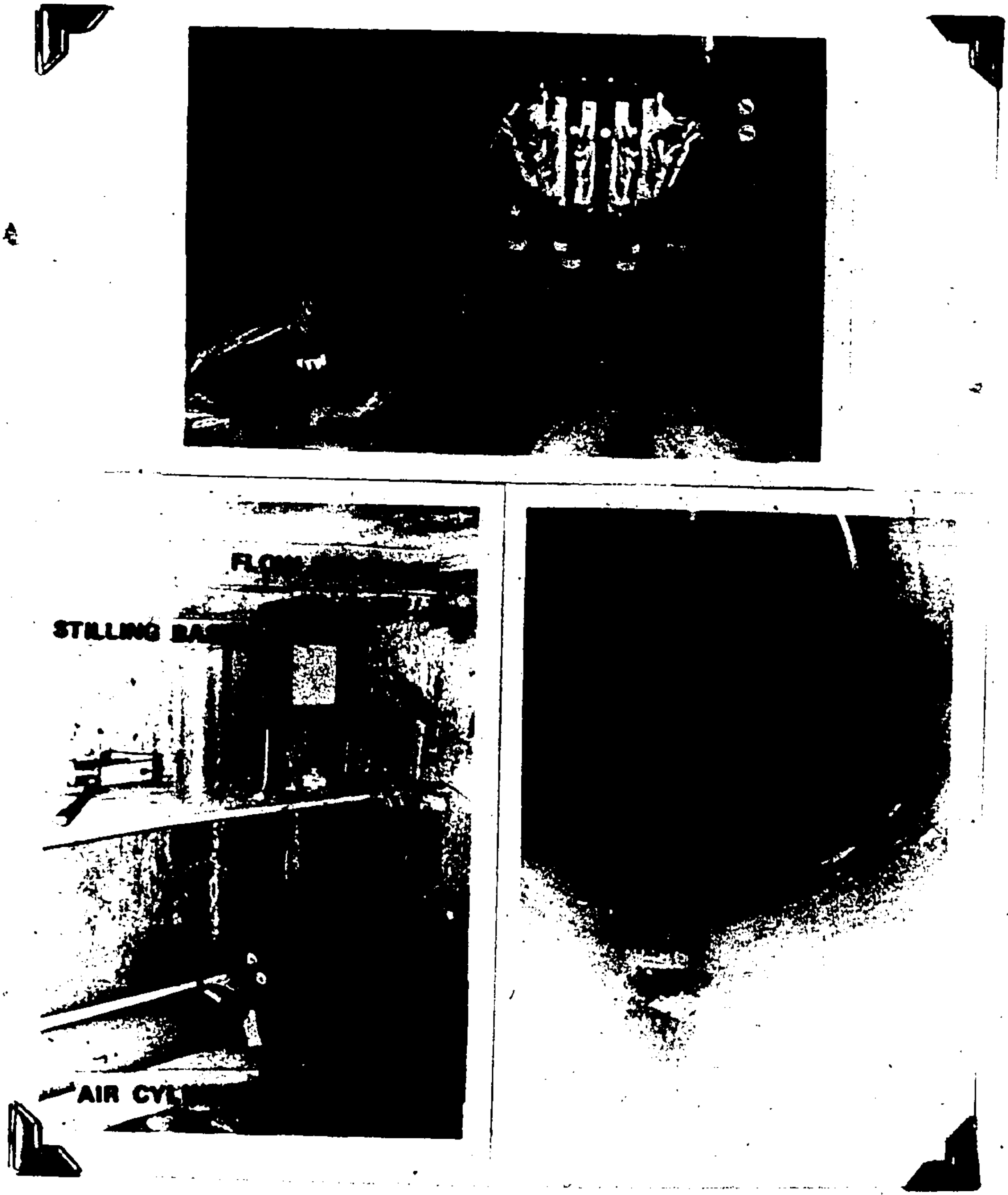


Figure 4. A View of the Experimental Setup inside the Manhole.

The sanitary importance (25) and the methods of analysis of these constituents are described below. Generally the test procedures given in Standard Methods for the Examination of Water and Wastewater (26) were followed.

Water Temperature

Temperature is a very important parameter since most of the chemical reactions are temperature dependent. In limnologic studies, water temperatures at different depths in reservoirs are important in locating the zones of mixing and relative stagnation. Industrial plants often require data on the temperature of water for process use or heat transmission calculations.

Colour

Water containing colouring matter derived from natural substances undergoing decay in swamps and forests are not considered to possess harmful or toxic properties. The natural colouring materials however give a yellow-brownish appearance to the water and there is a reluctance on the part of the water consumer to drink such waters because of the association involved.

The Hellige Aqua Tester was used for the colour test.

Turbidity

Turbidity is an important consideration in public water supplies for three major reasons:

a) Aesthetic - Laymen are aware that domestic sewage is highly turbid. Any turbidity in the drinking water is automatically associated with possible sewage pollution and the health hazards occasioned by it. That is why consumers of public water supplies expect and have the right to demand turbidity-free water.

b) Filterability - Filtration of water is rendered more difficult and costly when turbidity increases. The use of sand filters has become impractical in most areas because high turbidity shortens filter runs and increases cleaning costs. In addition the efficiency of rapid sand filters is drastically reduced with increased turbidity.

c) Disinfection - In turbid waters, most of the harmful organisms are exposed to the action of disinfection like chlorine and ozone. However, in cases in which turbidity is caused by sewage solids, many of the pathogenic organisms may be encased in the particles and protected from the disinfectant.

The instrument used for determination of turbidity was the Hach Laboratory Turbidimeter Model 1860A.

Specific Conductance

A rapid estimation of the dissolved solids content of water supply can be obtained by specific conductance measurement. Such measurements indicate the capacity of a sample to carry an electrical current which in turn is related to the concentation of ionized substances in the water.

A conductivity meter type CDM2c by Radiometer Inc. Copenhagen was used for this test.

pH

Both physical structure and biological treatment processes are adversely affected by high or low pH. Therefore corrective measures are usually required for wastes causing pH lower than 5.5 or higher than 9.0 in sewage treatment plant effluents.

The instrument used to determine the pH was the Fischer Accumet pH Meter, Model 210.

Total Suspended and Volatile Suspended Solids

The total suspended and volatile suspended solids determinations are used to evaluate the strength of domestic and industrial wastes. In larger treatment plants suspended solids determinations are used routinely as one measure of the effectiveness of treatment units. From the viewpoint of stream pollution control the removal of suspended solids is usually as important as B.O.D. removal.

The methods given on pages 424-425 of the Standard Methods (26) were used for their determination.

Alkalinity

As far as is known, moderate alkalinity of water has very little sanitary significance. Highly alkaline waters are usually unpalatable and consumers tend to seek other supplies. For its determination the titrimetric method with standard sulfuric acid and phenolphthalein and methyl orange indicators were used.

Hardness

Hard waters are as satisfactory for human consumption as soft waters. Because of their adverse reaction with soap, their use for cleansing purposes is quite unsatisfactory if the level of hardness is too high. Hardness values above 150 mg/l are considered too high and it is recommended that they be municipally softened.

The test used for determining the hardness was the E.D.T.A. Titrimetric Method.

Chlorides

Chlorides in reasonable concentration are not harmful to human beings. At concentrations above 250 mg/l they give a salty taste to the water which is objectionable to many people.

The Argentometric Method was used for its determination.

Orthophosphates

Phosphorus data is becoming more and more important in sanitary engineering practice as engineers appreciate its significance as a vital factor in the life process. In the past the data has been used principally to control phosphate dosages in water systems for corrosion prevention and in boilers for control of scale. Phosphorus determinations are extremely important in assessing the potential biological productivity of surface waters.

The test used to determine orthophosphate was the Stannous Chloride Method.

Sulfates

The sulfate ion is one of the major anions occurring in natural waters. It is of importance in public water supplies because of its cathartic effect upon humans when it is present in excessive amounts (250 mg/l). Sulfates are also of considerable concern because they are indirectly responsible for two serious problems often associated with the handling and treatment of wastewaters. These are odour and sewer-corrosion problems resulting from the reduction of sulfates to hydrogen sulfide.

The test used to determine the sulfate concentration was the Turbidimetric Method.

Nitrogen, Ammonia, Nitrite and Nitrate

At the present time data concerning the nitrogen compounds that exist in water supplies are used largely in connection with disinfection practice. The amount of ammonia nitrogen present in water determines to a great extent the chlorine needed to obtain free chlorine residuals in breakpoint chlorination. Nitrate determinations are important in determining whether water supplies meet recommendations for the control of methemoglobinemia in infants.

Nitrogen data is extemely important in connection with sewage and industrial waste treatement. The productivity of natural waters in terms of algal growths is related to the fertilizing matter that gains entrance to them. Nitrogen in its various forms is of major significance. Also reduced forms of nitrogen are oxidized in natural waters, thereby affecting the dissolved-oxygen resources. For these reasons nitrogen data are required for any programme involving pollution control.

The following methods were used to determine the different types of nitrogen:

Ammonia - Direct Nesslerization Method

Nitrite - Standard Method

Nitrate - Diazotization Method

Five Day Biochemical Oxygen Demand

B.O.D. is the major criterion used in stream pollution control, where organic loadings must be restricted to maintain desired dissolved oxygen levels. Information concerning the B.O.D. of wastes is an important consideration in the design of treatment facilities.

Dissolved oxygen was measured using a Galvanic Cell Oxygen Analyser manufactured by the Precision Scientific Company, Chicago.

Total and Fecal Coliform

Most coliforms indicate pollution caused by human activity, and fecal coliforms definitely indicate pollution caused by the waste products of human or warm blooded animals. These tests also give an indication of the pollutional load and some idea of the likelyhood of finding pathogens present.

The Millipore Filter Technique was employed in these tests.

Method of Sampling

Grab samples were collected every two hours by an automatic liquid sampler (Figure 4) supplied by Testing Machines International of Canada. The bottles were autoclaved before use and were connected through rubber tubes to the inlet manifold. Each tube passes through a pinch valve. The air was evacuated from the bottles by means of a vacuum pump until a vacuum of about 640 m.m. Hg was reached. Then the pinch valves on the connecting tube was closed and the vacuum pump detached. The sampling hose was attached to the inlet manifold by means of a ring nut and the hose end provided with a filter was immersed in the flowing water. A time clock released the pinch valves one by one at two hour intervals causing the sample to be drawn into the bottle.

One of the problems encountered in using this instrument in the field was that much of the time the flow in the manhole was not deep enough to submerge the 3 inches deep sampling filter head. Therefore, a special type of head (Figure 4) was designed which could collect samples at a depth of one inch, and it proved to be quite successful.

Method of Measuring Discharge

The discharge was measured by an Arkon Water Level Recording Instrument, Model 63 (Figure 4). The recorder was connected by a small bore impulse pipe to a diptube (Figure 4), which was inserted in the flowing water about 11 feet upstream from the manhole. It was kept 1/8 inch above the invert and was held in position by a special steel frame (Figure 4) fixed in the sewer.

About .5 cu ft/min of air from a compressed air cylinder (Figure 4) was fed continuously into the system, sufficient to allow a continuous stream of bubbles at the end of the dip tube. The air pressure developed in the diptube and in the connection to the recorder was equivalent to the head of liquid on the diptube. As the flow rate in the sewer varied, the liquid head and consequently the air pressure to the recorder varied. The instrument then continuously recorded the information on a chart which was moving at a constant speed.

On various odcassions the actual depth of flow was measured at the probe by using a cylinder with a grooved bottom to act as stilling basin (Figure 4), and this depth was compared with the corresponding depth recorded on the chart. Using a large number of these comparison recordings at a variety of depths the calibration curve shown in Figure 5 was obtained, this shows the actual depth related to the recorded depth on the chart.

The actual depth of flow was used to determine the rate of flow in the sewer. In order to accomplish this the velocity of flow at various depths was required. Velocities at different depth were measured by using Uranine (Sodium Fluorescein) dye. Two stations, 24 feet apart, were chosen such that the probe was midway between them. The dye was injected at the upstream station and the time required to reach the downstream station was measured with a stopwatch. The distance divided by time gave the mean velocity. The product of mean velocity and area of flow gave the discharge corresponding to a particular depth of flow. A log-log plot shown in Figure 6 relates the depth of flow in inches to the corresponding discharge in cubic feet, per second.

Storage of Samples

Following tests were done immediately after the samples were brought to the laboratory:

a) pH

b) Alkalinity

c) B.O.D.

d) Total Coliform

e) Fecal Coliform

The samples were then stored in the refrigerator for completing the rest of the tests within the next few days.

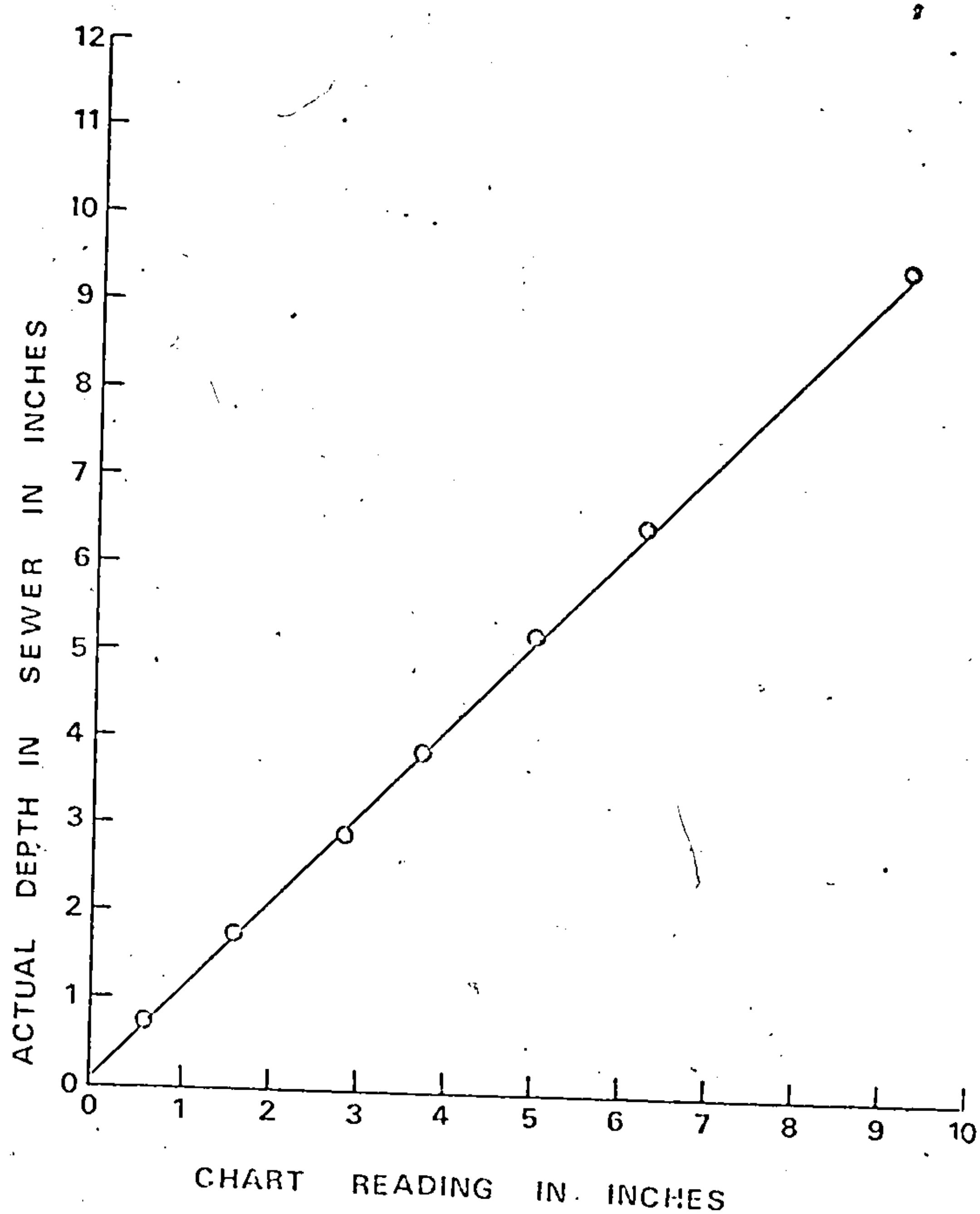


Figure 5. Calibration Curve for the Actual Depth observed in the Sewer versus the Chart Depth.

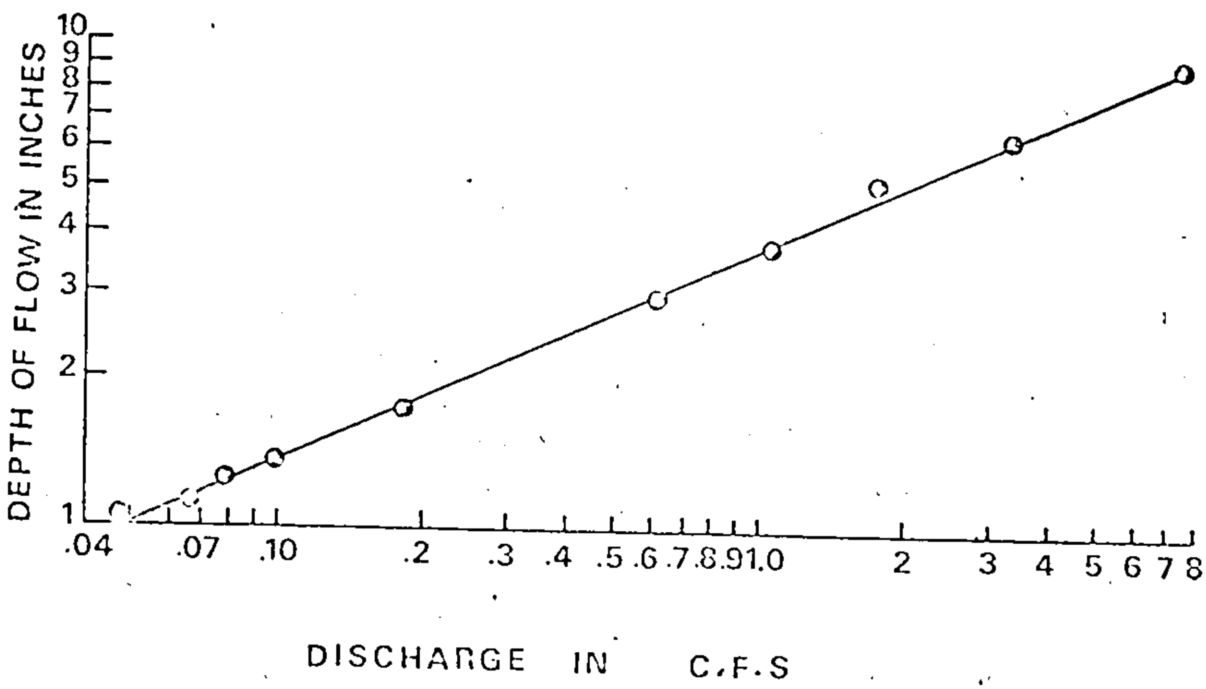


Figure 6. Curve used for Estimating Discharge from the Actual Depth observed in the Sewer.

CHAPTER IV

OBSERVATIONS AND DISCUSSION

In all 20 sets of samples were collected during the period from January to December 1971, on days and dates shown in Table 4. The analysis results of these 20 experiments are plotted from page 78 to page 118.

The precipitation values have been determined from the readings at three rain gauge stations (Figure 1) surrounding the study area and by using the principle of weighted means.

The horizontal scale in the Arkon Water Level Recording Instrument is divided in hour intervals, whereas the vertical reading on the chart represents depth of flow and is related to the total discharge flowing in the manhole as shown in Figure 6. Since samples were taken every two hours, a two hour base interval was used in the charts for plotting. The average discharge every two hours was found by calculating the total area under the hydrograph with a planimeter and replacing this with an equivalent rectangular area with the same two hour base interval and a height equal to the average discharge during two hour period.

Average Concentrations

Table 5, contains a summary of the arithmetic means of the different paramoters studied. The mean values listed are for the four seasons and the annual mean for comparison.

TABLE 4

Summary of the Dates Samples were Analysed

Experiment No.	Date
1	January 4-5, 1971
2	February 4-5, 1971
3	February 11-13, 1971
4	February 17-19, 1971
5	March 11, 1971
6	March 13-14, 1971
7	April 28, 1971
8	May 12, 1971
9	May 20-21, 1971
10	May 24-25, 1971
11	June 1-2, 1971
12	June 6, 1971
13	June 7, 1971
14	July 5, 1971
15	July 15, 1971
16	July 30-31, 1971
17	August 10-11, 1971
18	August 27, 1971
19	October 22, 1971
20	December 6-7, 1971

TABLE 5

Average Concentrations of the Constituents Analyzed During the Study

Constituent	Winter Mean	Spring Mean	Summer Mean	Fall Mean	Annual Mean	Range
Colour, Unit	134	419	177	151	220	30-1650
Turbidity, J.T.U.	76	249	118	91	134	14-1020
Sp. Conductance, milli mhs/cm	1.18	0.33	0.35	0.46	.58	0.12-7.70
*pH	7.22	7.43	7.45	7.39	7.35	6.3-8.7
T.S.S., mg/l	94	741	297	86	305	2-4122
V.S.S., mg/l	39	90	47	22	59	0-350
Total Alkalinity, mg/l	90	100	125	110	106	8-232
Total Hardness, mg/l	199	146	205	292	211	48-585
Calcium Hardness, mg/l	138	110	136	190	144	40-348
Chloride, mg/l	345	27	33	36	110	4-2580
Orthophosphate, mg/l	1.42	1.94	0.32	0.24	0.98	0-34
Sulfate, mg/l	100	64	97	165	106	32-325
Ammonia, mg/l	0.075	0.134	0.115	.025	.087	0-1.80
Nitrite, mg/l	0.06	0.11	0.16	0.04	0.09	0.01-0.53
Nitrate, mg/l	1.33	2.64	0.82	0.81	1.40	0.05-6.30
B.O.D., mg/l	9	8	16	16	12	2-52
Total Coliform/ 100 ml	263,530	5,730,430	2,998,500	630,834	2,405,800	1400-17,750,000
Fecal Coliform/ 100 ml	23,400	10970	490	160	8760	0-230,000

* These means are the arithmetic mean of observed pH values.

Runoff Coefficients

Runoff coefficients for the different seasons (winter, spring, summer and fall) have been calculated and are shown in Table 6. For calculation of these runoff coefficients six storms were considered, one in the winter, two each in the spring and summer and one in the fall. The area under the discharge-time curve was measured by planimeter and from this area, the base flow was estimated and subtracted to give the discharge caused by the precipitation. The total precipitation for the storm was used to find out the total volume of precipitation over the area of 89 acres. The ratio of actual discharge measured in the sewer to the total volume of precipitation gives the runoff coefficient.

The runoff coefficient depends upon many factors, notably the length of the preceding dry period, temperature, moisture content of the soil etc. This can be seen by comparing the two storms of June 1-2, 1971 and July 5, 1971. In the storm of June 1-2, 1971 the peak rainfall intensity was 0.078 inches/hr with a peak discharge of 1.6 cfs, whereas for the storm of July 5, 1971 the peak rainfall intensity was 0.2 inches/hr and the peak discharge was only 1 cfs. This difference can be explained by taking into consideration the previously mentioned factors affecting the runoff.

The storm analyzed before that of June 1-2, 1971 was on May 24-25, 1971 and in between these two storms there

TABLE 6

Runoff Coefficients for Different Seasons as Calculated for the Study

Season	Runoff Coefficient
Winter	0.84
Spring	0.33
Summer	0.19
Fall	0.14

were some scattered showers and the mean temperature during the storm was 11°C. However between June 7, 1971 and July 5, 1971 there was hardly any rain and the temperature during the storm of July 5, 1971 was 15°C. Thus the soil was considerably drier at the time of the storm of July 5, 1971. This combination of a prolonged dry spell, higher temperature and dry soil was responsible for the low discharge for the storm of July 5, 1971 even though the rainfall intensity was substantially higher.

The higher runoff coefficient during winter is because of the highly impermeable frozen soil, low temperatures and high moisture content. As the seasons progress the runoff coefficient continues to drop from 0.84 in the winter, 0.33 in the spring to 0.14 in the fall.

The overall mean annual runoff coefficient taking the arithmetic mean of the four seasonal coefficients comes out to be 0.375, which is very close to 0.37 estimated in Cincinatti (18), for calculating total pollutional loads. The summer runoff coefficient of 0.19 is much lower than that of 0.40 assumed in Ann Arbor (19). However Ann Arbor is a much hillier area and this could account for part of the difference, not to mention the fact that assumed values are somewhat risky.

Estimation of Pollutional Loads in Pounds per Acre

An estimation of the total quantity of various pollutants (in lb/acre), contributed by this area and entering the Detroit River seasonally and annually are shown in Table 7. In order to estimate these loadings, typical storms from the various seasons like Feb. 17-19, 1971, May 24-25, 1971, June 1-2, 1971, July 30-31, 1971, August 10-11, 1971 and October 22, 1971 were taken. For each storm, all the concentration values observed for each pollutant were multiplied by corresponding discharges in cubic feet and were added up giving values in lbs/acre of pollutants entering the Detroit River. Then the seasonal and the annual loads were calculated by using the 30 year mean precipitation values (Table 8) and the seasonal loads determined during this study to give a picture of what one could expect in an average year.

In Ann Arbor (19), the total load in lbs/acre for summer for different constitutents are higher than this study. This is perhaps because of the higher runoff coefficient assumed in the Ann Arbor study. On the contrary the Cincinnati study (18), for the total load in lbs/acre/year for T.S.S., B.O.D. and orthophosphates is in fairly close agreement with this study.

The important role played by the runoff coefficient in the total amount of load in lb/acre is very well illustrated in Table 7. Although the average winter concentrations of total alkalinity, B.O.D., T.S.S., orthophosphates and nitrites is lower than that of the spring, the total load in lbs/acre for the winter for these constituents is higher

TABLE 7

Pollutional Loads of Stormwater in Pounds per Acre

Pollutant	Winter	Spring	Summer	Fall	Annual
T.S.S.	114	68	214	44	440
Total Alkalinity	87	49	46	17	199
Total Hardness	132	47	65	27	271
Calcium Hardness	90	39	47	23	199
Chlorides	122	5	16	3	146
Orthophosphates	7.50	0.15	0.27	0.04	7.96
Sulfates	87	25	32	22	166
Nitrite	0.080	0.054	0.073	0.012	0.219
Nitrate	0.67	1.34	0.31	0.31	2.63
B.O.D.	9	4	5	4	22

TABLE 8

30 Year Mean Precipitation Values for the City of Windsor

Season	Average Precipitation in Inches
Winter	7.15
Spring	9.51
Summer	8.50
Fall	7.45
Annual	32.61

than the spring.

With a runoff coefficient in the order of 0.84 for winter, most of the precipitation finds it way into the storm sewer and winter discharges could be the highest during the whole year. This results in certain pollution parameters like total alkalinity, B.O.D., calcium hardness, total hardness, chlorides, sulfates, orthophosphates and nitrites having highest lbs/acre loading during the winter months. This points out very clearly the danger of overreliance on concentrations of pollutants and disregarding the quantity of discharge.

Comparison of Annual Storm and Sanitary Loads

The annual estimated storm loads in lbs/acre for T.S.S., orthophosphates and B.O.D. were compared with that of sanitary loads in the following manner:

For the month of May 1971, which had very litte rainfall and thus very little storm water had entered the Little River Treatment Plant through combined sewers, the average flow was 2.60 million gallons per day (27). The population contributing to this sewage flow, as determined from drainage maps and city population data is in the order of 38,700 persons. This works out to 67 gallons of sewage per day per capita. The mean concentrations of T.S.S., orthophosphates and B.O.D. in domestic sewage for the month of May were 133 mg/l, 10.60 mg/l and 142 mg/l respectively (27). Based upon the population density of 8 persons/acre for this area and 67 gallons of sewage per day per capita, the annual loads of T.S.S., orthophosphates and B.O.D. are calculated at 261 lbs/acre, 20.8 lb/acre and 278 lbs/acre respectively. A comparison of these loads with that of storm runoff loads is shown in Table 9.

It shows that even on the basis of total annual load, T.S.S. are greater in stormwater runoff than in sanitary sewage. Bear in mind that the sanitary loads reported are before treatment, whereas the storm loads are the same as received by the river with no treatment.

Load versus Time Curves

"The first part of a storm is generally more polluted". The correctness of this statement can be demonstrated by plotting total pollutant in lbs/second versus time for the storm of July 30-31, 1971. The parameters which exhibit this phenomenon are chlorides, orthophosphates and B.O.D. (Figure 7), total hardness, total alkalinity and sulfates (Figure 8).

Discussions of Individual Pollution Parameters

Colour and Turbidity

Colour and turbidity seem to follow each other within their respective units. This can be best illustrated with Figure 9, plotted for the storm of 11-13, Feb. 1971. In the case of snowmelt they tend to follow the discharge curve and in other seasons for small rainfall intensities they tend to decrease in value as the storm progresses.

The annual average values for colour and turbidity were 220 and 134 respectively. Thus turbidity was 61 percent of colour value. This ratio is remarkably close to the ratio's experienced in winter, spring, summer, and fall which were

TABLE 9

Comparison of Annual Storm and Sanitary Loads in Pounds per Acre.

Constituent	Annual storm Load in lbs/acre	Annual Sanitary Load in lbs/acre	Percentage of Storm Load to that of Sanitary Load
T.S.S.	440	261	168
Orthophosphates	7.96	20.8	38
B.O.D.	22	278	8

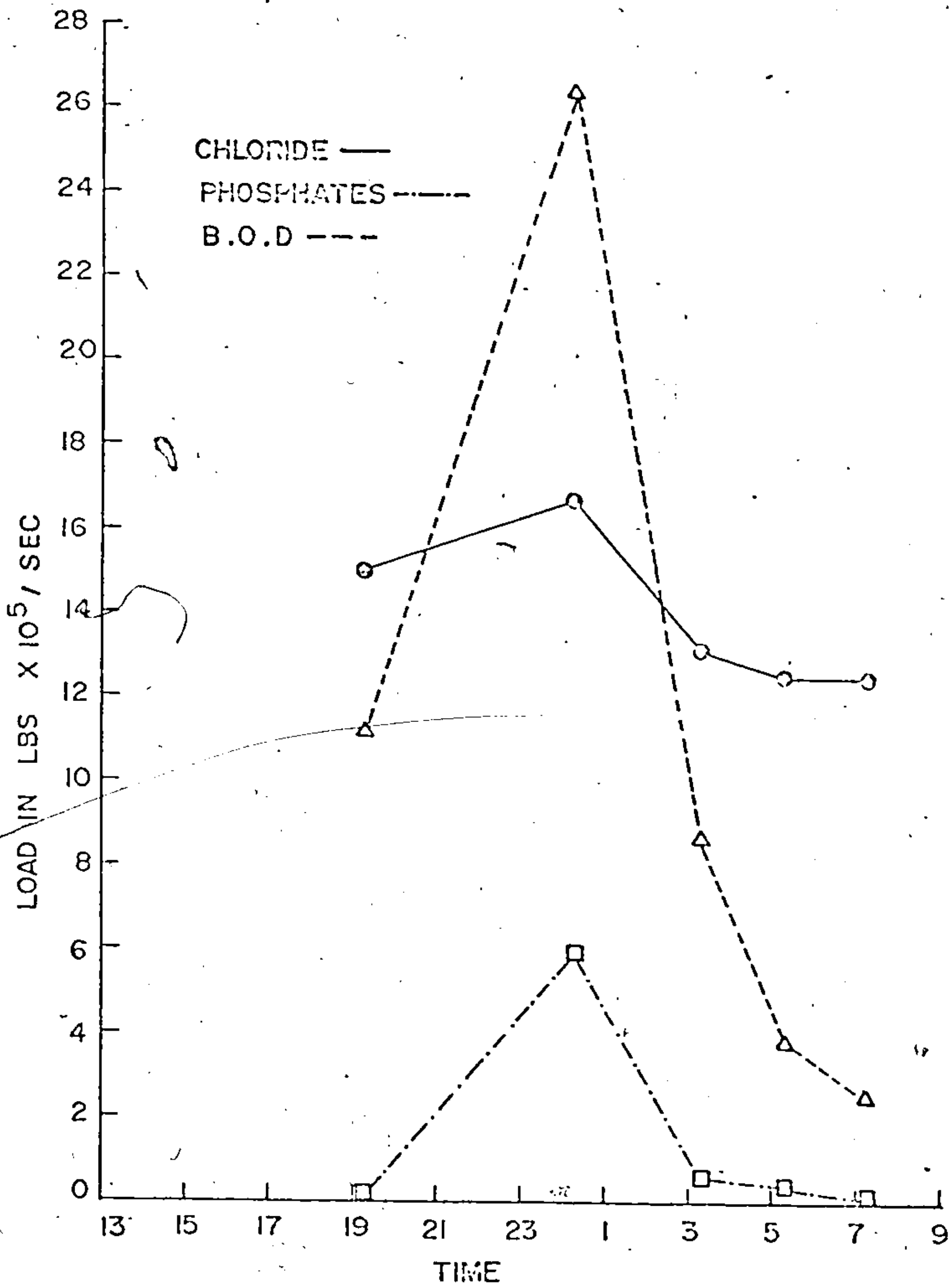


Figure 7. Load vs. Time Curves, Showing decrease of Loads with the Progress of a Storm.

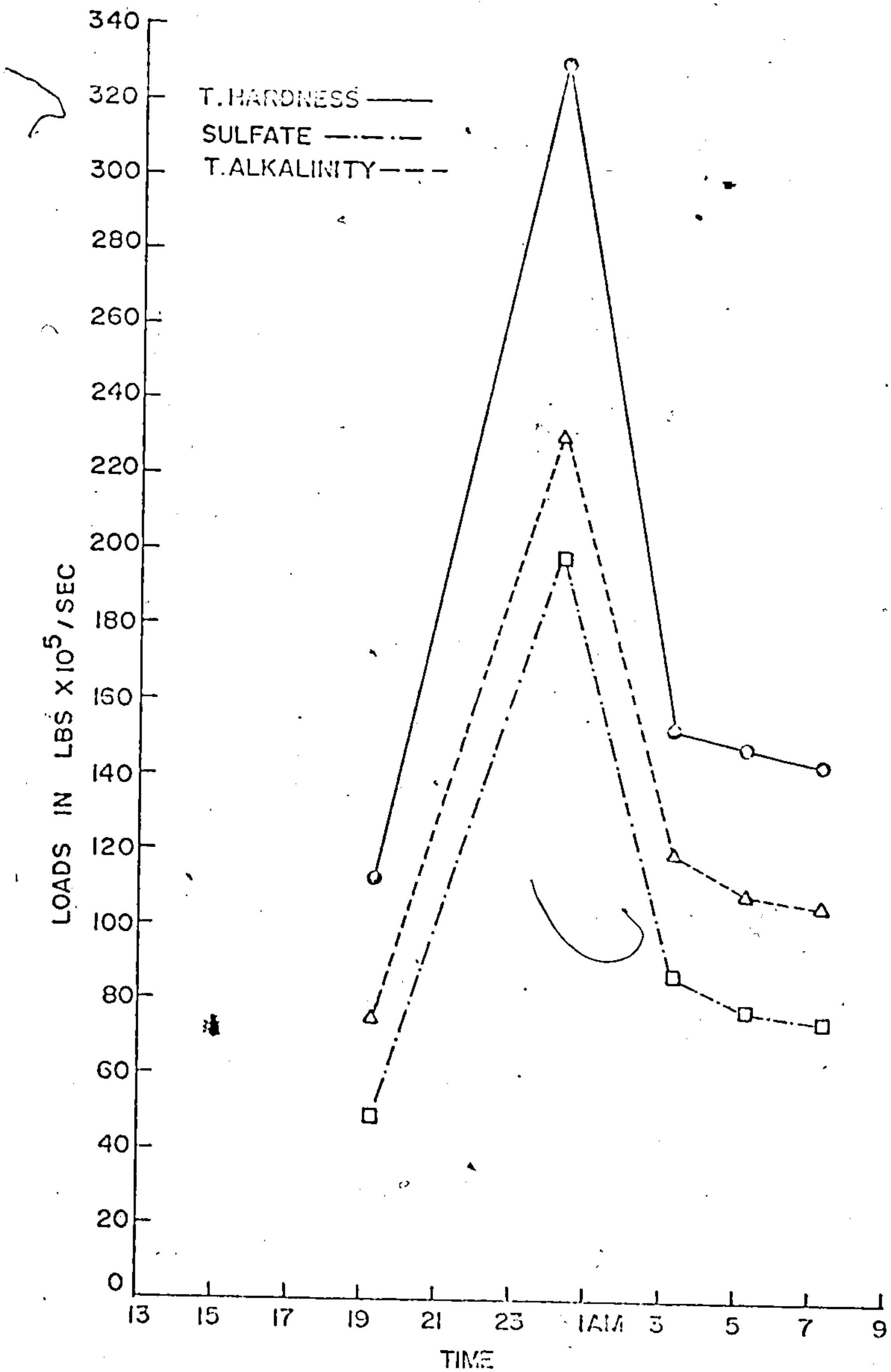


Figure 8. Load vs. Time Curves, Showing decrease of Loads with the Progress of a Storm.

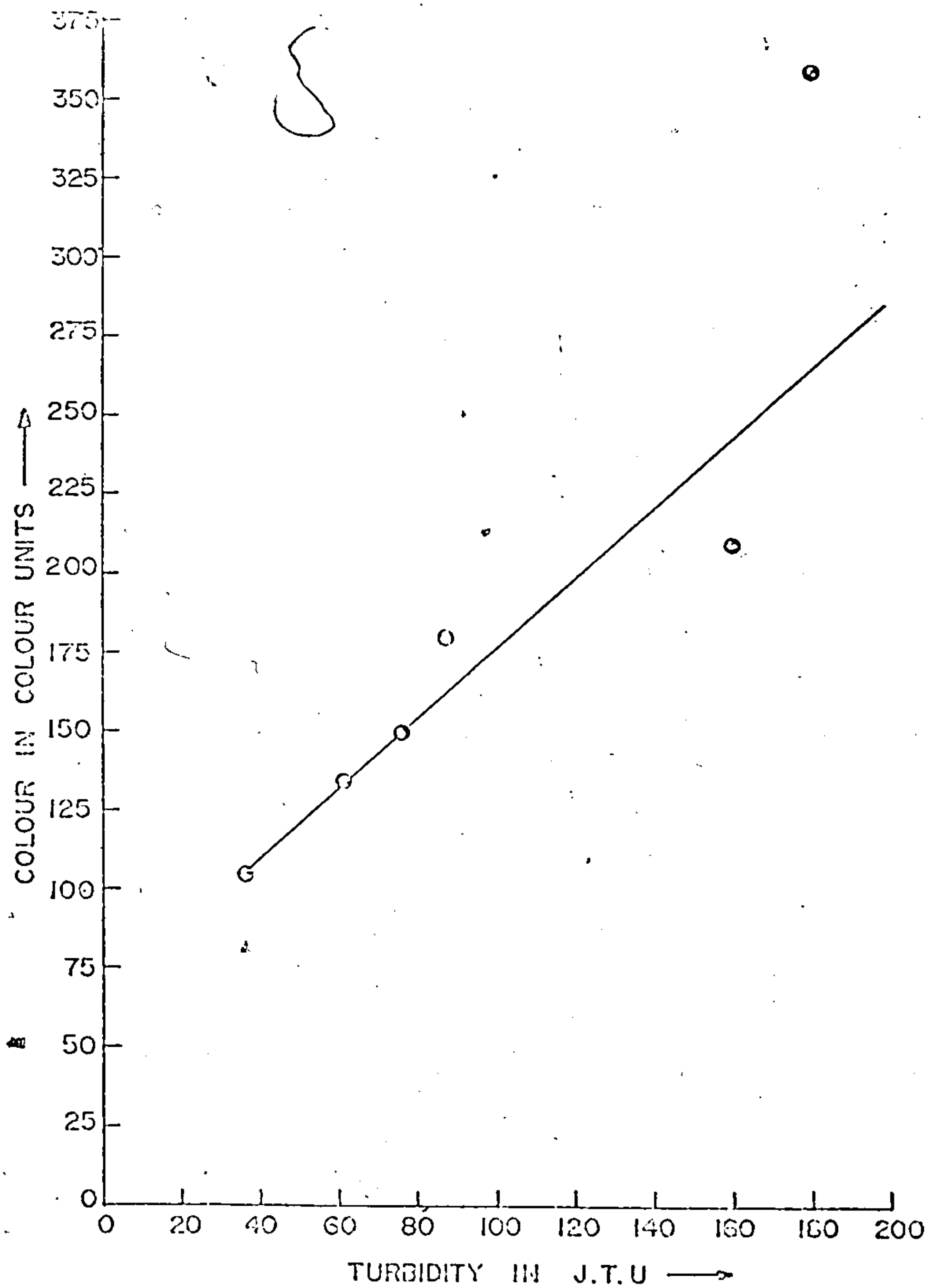


Figure 9. Turbidity vs. Colour Curve
(Storm of 11-13, February, 1971)

56.7%, 59.4% 66.7% and 60.3% respectively.

Colour and turbidity seem to be a function of solids and in turn the rainfall intensity. This is evident from the fact that the highest colour and turbidity values recorded were 1650 and 1020 respectively for a rainfall intensity of 0.61 inches/hour, which is the highest for the study.

pH

The maximum and minimum values observed for the whole study were 8.7 and 6.3 with an annual average of 7.35. These values are in agreement with the values observed in Cincinnati (18), ranging between 5.3 and 8.7 and a mean of 7.50.

Since in this study the values fall within the limits of 9.0 and 5.5, no corrective measures are required for this type of runoff.

Total and Volatile Suspended Solids

Since the natural filteration and sedimentation that removes solids in runoff from land with vegetative cover is entirely lacking in runoff from paved areas, suspended solids represents the most evident indicator of pollution due to urbanization. For total suspended solids the maximum concentration of 4122 mg/l and the minimum concentration of 2 mg/l was recorded. The annual average of total suspended solids was 305 mg/l. These values compare favourably with that observed in Sweden (11), U.S.A. (13)(18), and Canada (1), but are rather less than those observed in the U.S.S.R. (10) and the U.S.A. (19).

The "first flush" phenomenon was non-existent in relation to the suspended solids concentration. The rainfall intensity has a definite relation to the suspended solids concentration which can be seen from Table 10. Also total rainfall in a particular storm has an effect upon total suspended solids discharged and a curve between total rainfall in a storm and the corresponding load of total suspended solids is shown in Figure 10. Weibel, Weidnes, Christianson and Anderson (18), have reported that suspended solids concentrations tended to vary with discharge, that high concentrations of total suspended solids only occured when high rainfall intensity and corresponding runoff rates developed and not in the initial part of a storm unless it was a case of high rainfall intensity.

In this study too, this behaviour is very much apparent for almost all the storms. For example a plot of T.S.S. versus discharge (Figure 11), for the storm of February 17-19, 1971 showed the increase in concentration of T.S.S. with increase in discharge. These results indicate that solids are abundant in this area and are a function of rainfall and discharge.

Besides the total annual load in lbs/acre of T.S.S. in stormwater being more than in domestic sanitary sewage, the annual average of 305 mg/l of T.S.S. for stormwater is

TABLE 10

Effect of Rainfall Intensity on T.S.S. Concentration

Date	Peak Rainfall Intensity in inches/hour	Peak T.S.S. Concentration in mg/l
June 7, 1971	0.61	4122
August 10-11, 1971	0.58	1712
August 27,1971	0.37	786
July 5, 1971	0.20	268

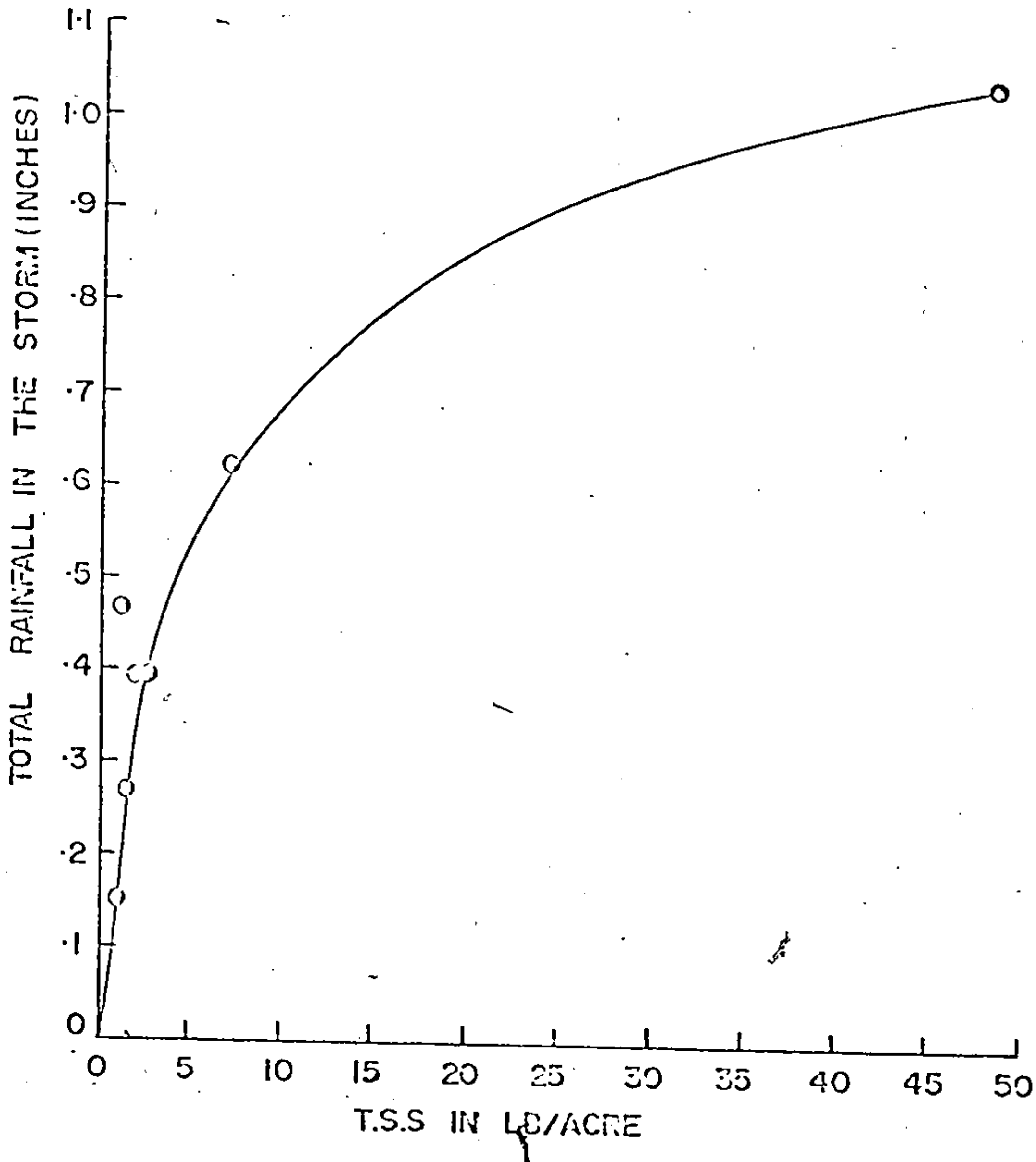


Figure 10. A Typical Curve Showing the effect of Total Rainfall in a Storm on Total Suspendod Solids.

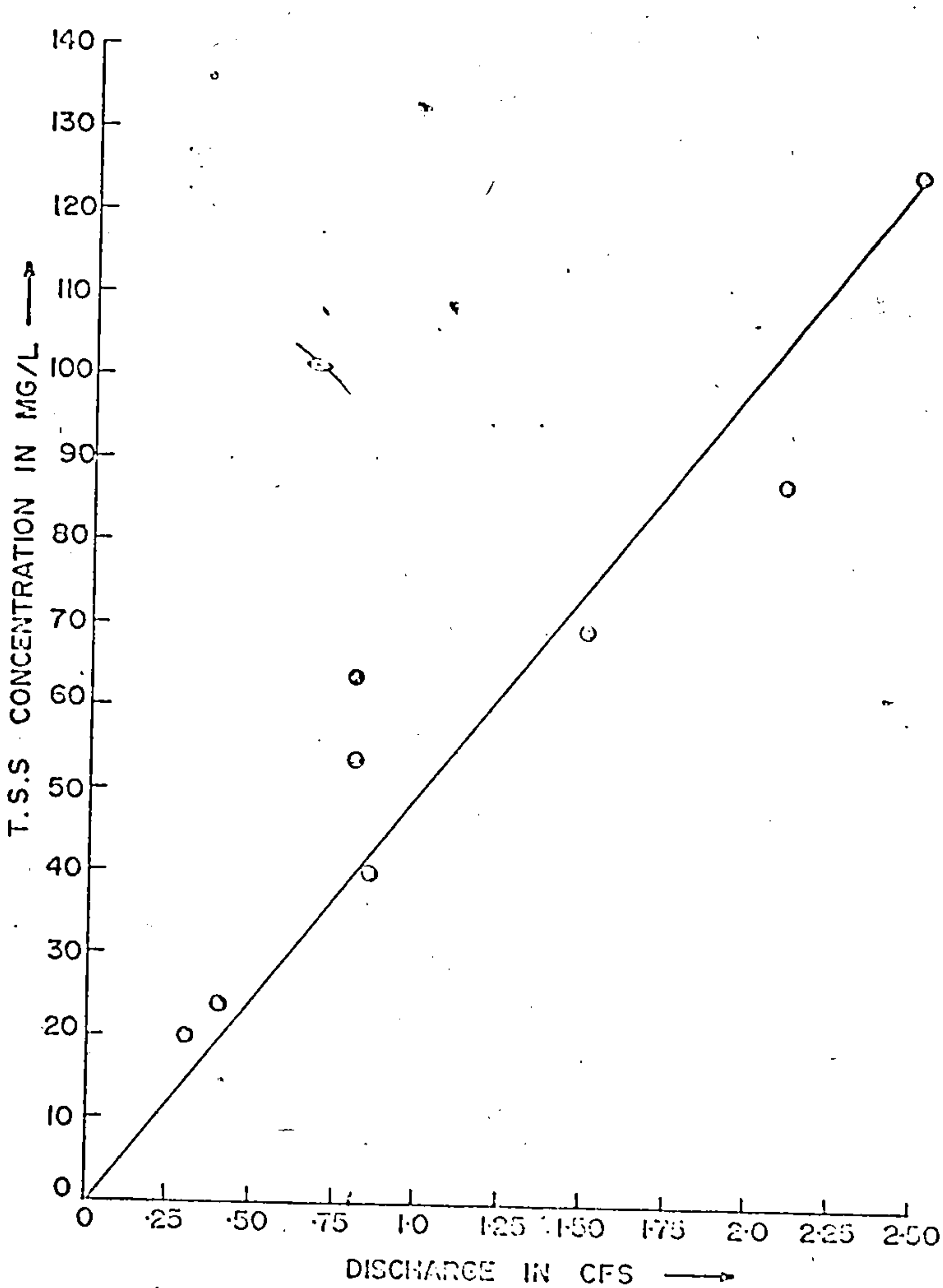


Figure 11. Curve Showing dependence of Total Suspended Solids on Discharge (Storm of February 17-19, 1971).

much higher than that of 133 mg/l for domestic sanitary sewage (27), showing that this is one parameter in which stormwater is of greater significance than sanitary sewage.

For volatile suspended solids the same pattern as for total suspended solids was observed. The volatile material in the total suspended solids formed 19.3% annually, 41.5% in winter, 12.15% in spring, 15.8% in summer and 18.9% in fall. The percentage of 19.3 is much less than that of 60-70% for domestic sanitary sewage. But this value compares favourably with that of 25.1% and 10.0% found in Cincinnati (18) and Ann Arbor (19) respectively.

Alkalinity

The extreme values for alkalinity ranged from 8 mg/l to 232 mg/l with an annual mean of 106 mg/l. The only other study which reported alkalinity values is Cincinnati (18) and it had a range of 10-210 mg/l with 59 mg/l as mean value. The alkalinity values in this study were highest in summer and lowest in winter.

Alkalinity follows the dilution phenomenon, i.e., the concentration decreases with increase in discharge. This is very well illustrated with Figure 12, plotted for the storm of July 30-31, 1971. This type of curve is in very close agreement with that obtained by Friedland, Shea and Ludwig (23). However the dilution phenomenon is not very profound in winter.

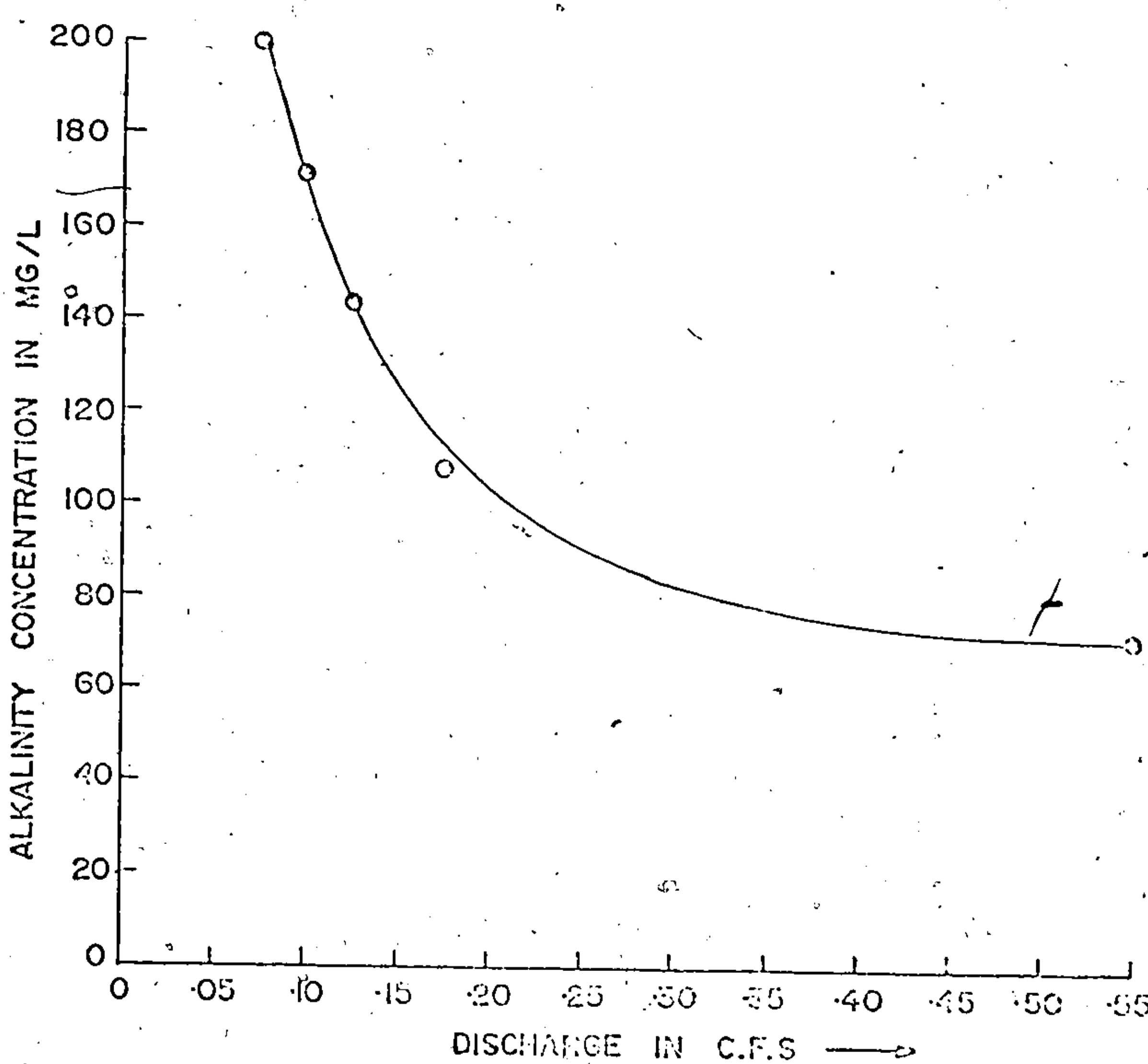


Figure 12. Dilution Curve for Alkalinity (Storm of July 30-31, 1971).

The major source of alkalinity is the soil and bicarbonates represent the major form of alkalinity, since they are formed in considerable amounts from the action of carbon dioxide upon basic materials in the soil.

Calcium Hardness and Total Hardness

These parameters also follow the dilution phenomenon which is illustrated in Figure 13.

The range for total hardness for the whole year was 48-585 mg/l, with the annual mean of 211 mg/l. This is much higher than that of 81 mg/l found in Cincinnati (18) and could be attributed to the difference in soil. The annual mean for calcium hardness was 144 mg/l. The hardness values were maximum in fall. The ratio of calcium hardness to total hardness on the annual basis was 68.2%, whereas on seasonal basis it was 69.4% for winter, 75.3% for spring, 66.3% for summer and 65.1% for fall.

The major source of hardness also is the soil, as the hardness in water is derived largely from contact with soil and rock formation. Rainwater as it falls upon the earth is incapable of dissolving the large amounts of solids found in many natural waters. The ability to dissolve minerals from soil is gained when carbon dioxide is released by bacterial action forming weak carbonic acid.

Chlorides and Specific Conductance

These parameters are considered together because of

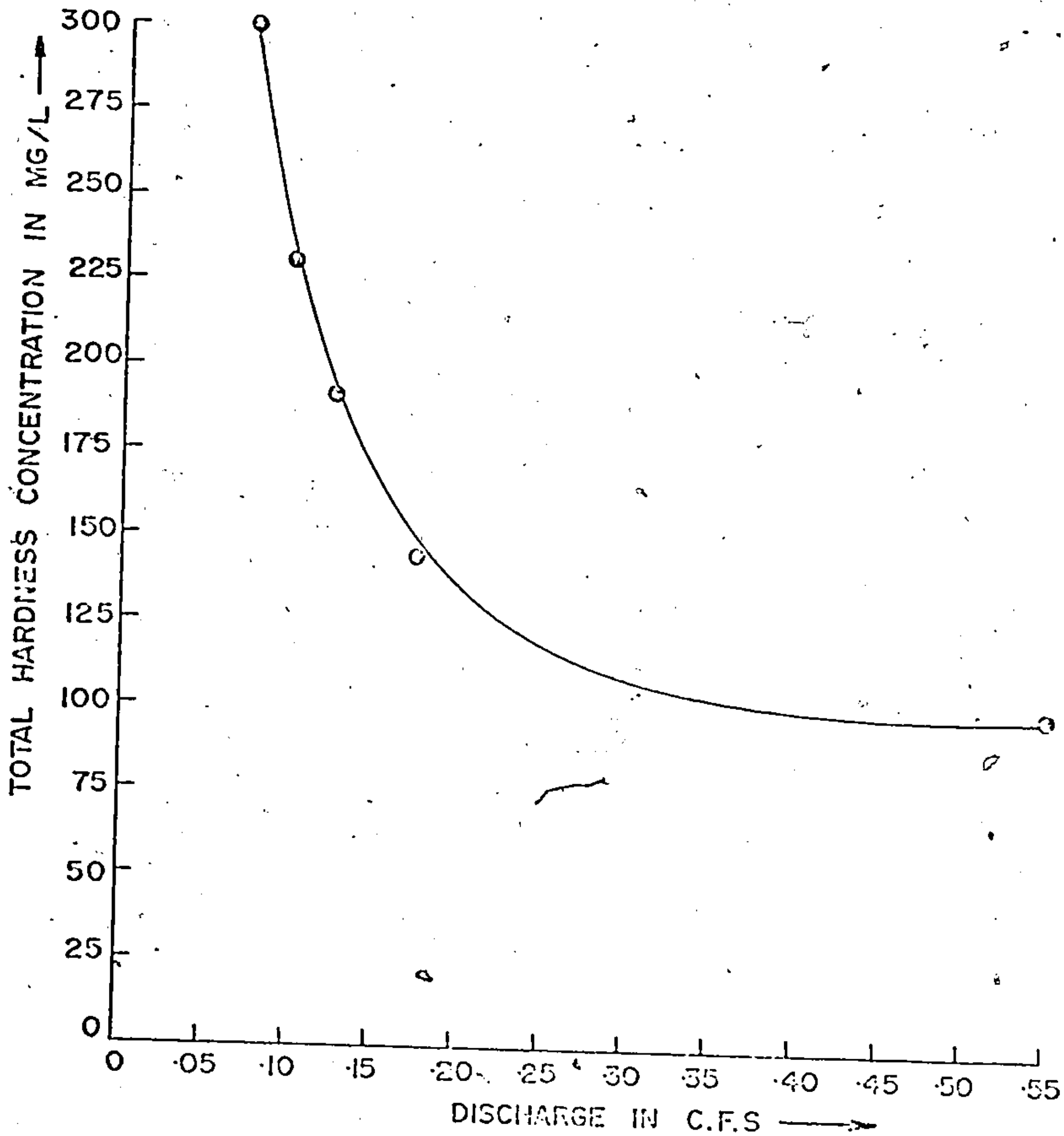


Figure 13. Dilution Curve for Total Hardness
(Storm of July 30-31, 1971)

the closeness in the manner of their occurrence. For the winter runoff of February 11-13, 1971 their complete dependence on each other (See Figure 14) can be very well appreciated. But with the decrease in chloride concentrations in the subsequent seasons this dependence is not so noticeable. Then specific conductance depends upon Sulfates as well as Chlorides as shown in Figures 15 and 16.

Chlorides varied from 4 mg/l to 2580 mg/l, understandably with winter values being higher than other seasons. The annual average of chlorides was 110 mg/l with winter average of 345 mg/l. The winter mean is more than that of 233 mg/l reported in Ottawa (1), since the Cincinnati study (18) does not take into consideration the winter runoff, there is a drastic difference between the annual mean of 110 mg/l of this study and that of 12 mg/l reported in Cincinnati.

Runoffs of the long periods of freezing temperatures resulted in increased chloride concentrations with the progress of discharge as in the runoff of Jan. 4-5, 1971 shown on page 79 of the Appendix. Whereas runoffs after only a few days of freezing temperatures showed a decrease in chloride concentrations with the progress of the storm runoff. A typical example is the runoff of Feb. 11-13, 1971 which is shown on page 83 of the Appendix. The most probable reason for this is the accumulation of road salts with the increased length of the antecendent freezing periods.

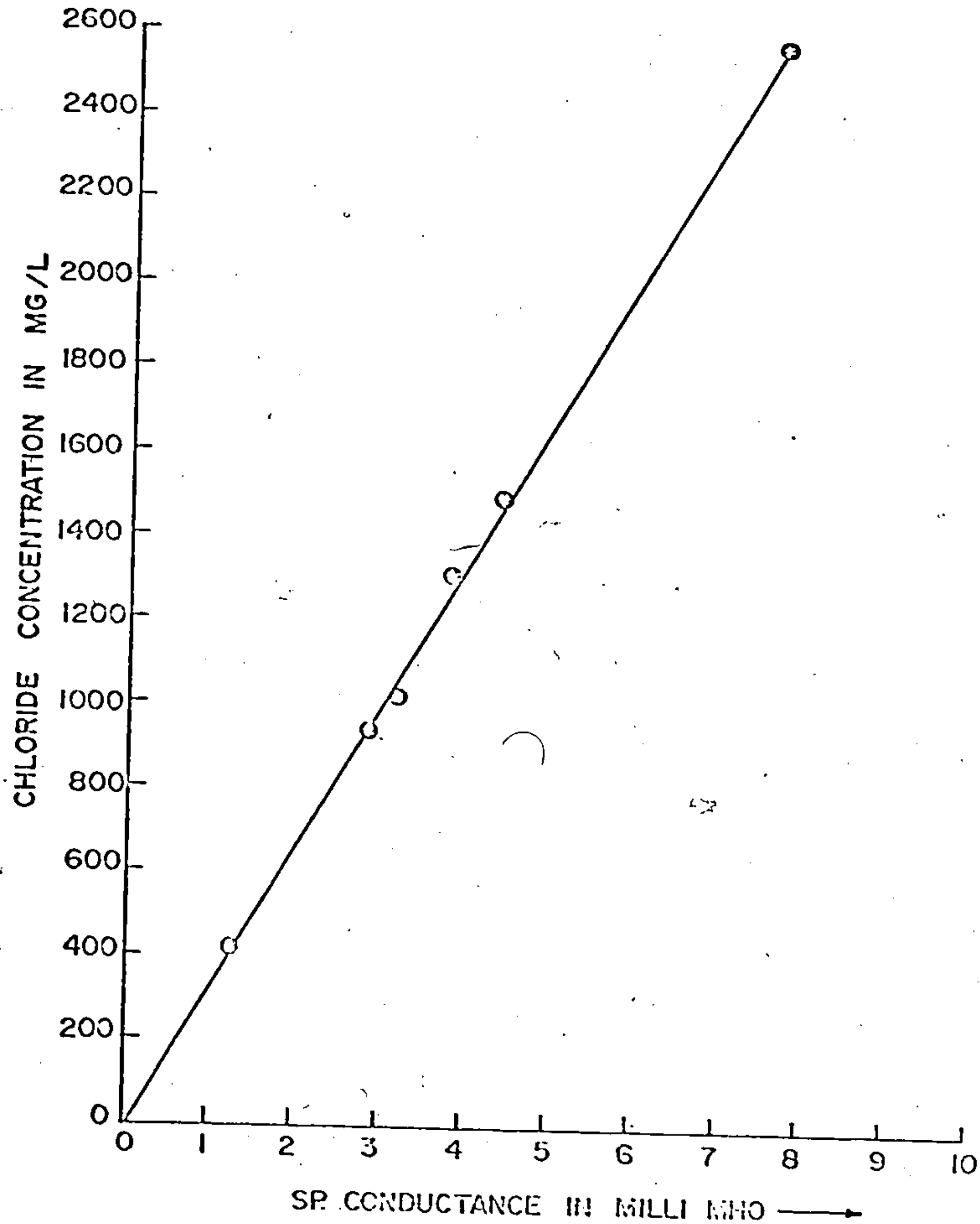


Figure 14. Plot to Show dependence of specific Conductance on Chlorides (Runoff of February 11-13, 1971)

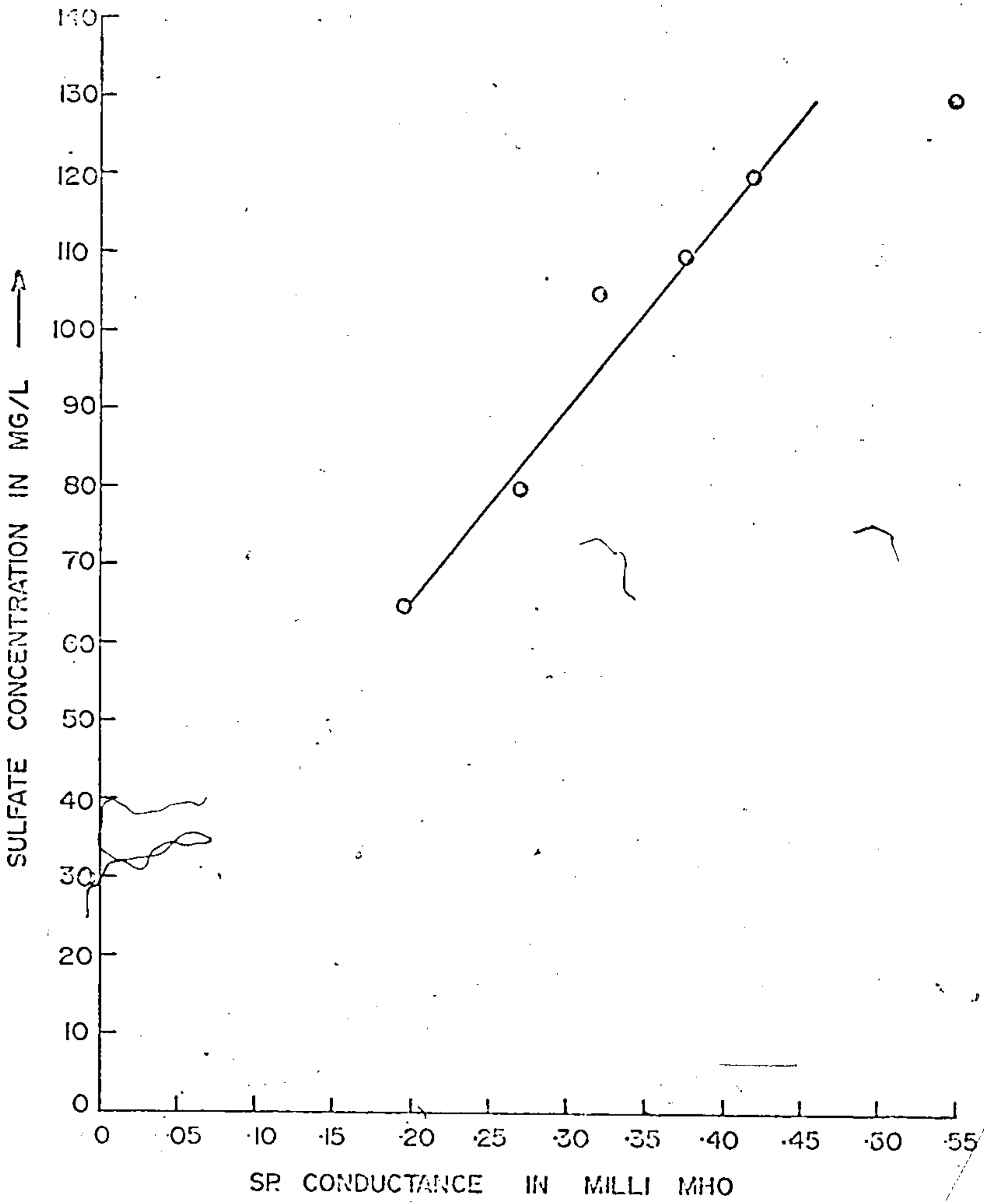


Figure 15. Curve Showing dependence of Specific Conductance on Sulfate Concentration (Storm of July 30-31, 1971).

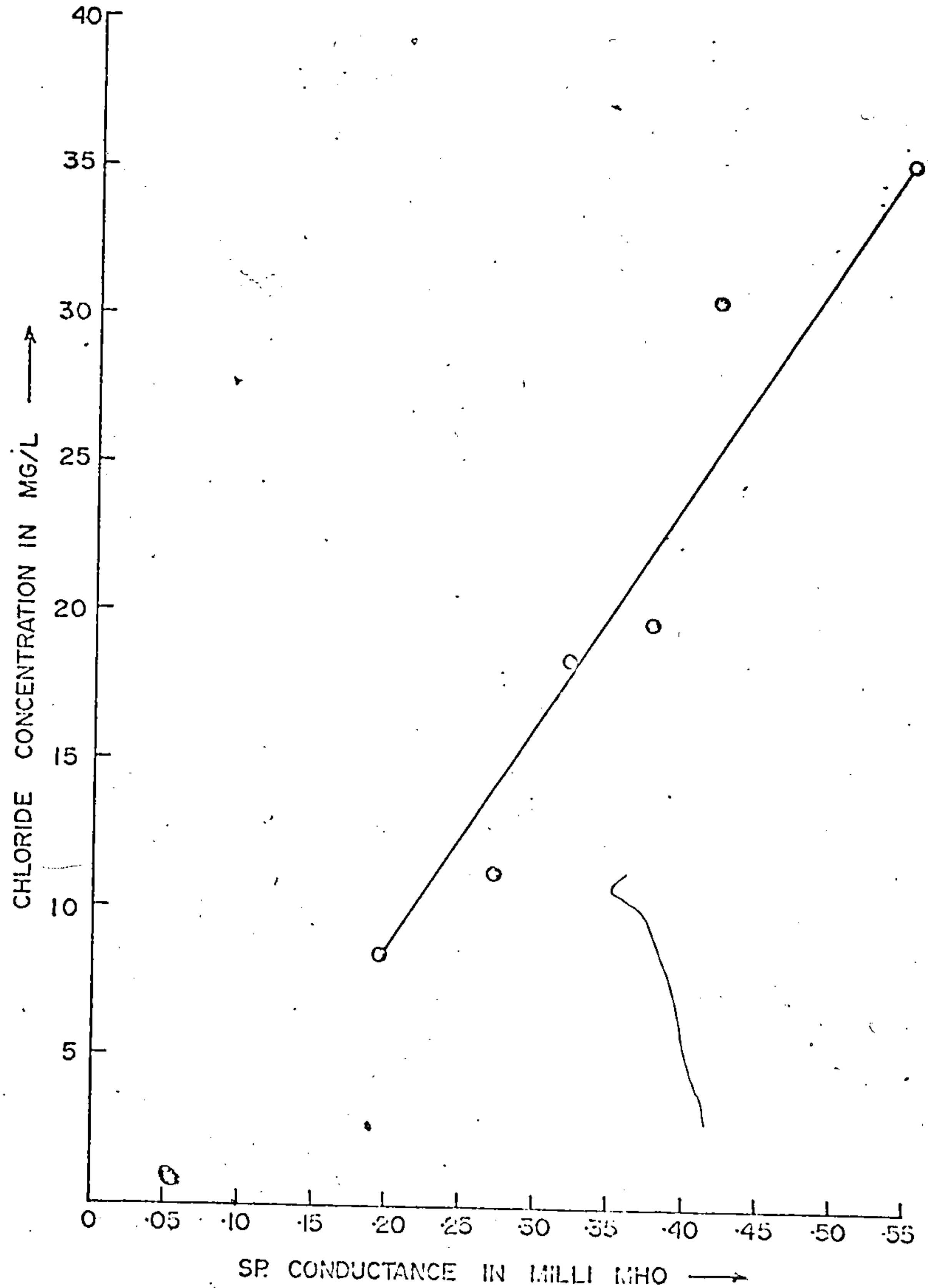


Figure 16. Curve showing dependence of Specific Conductance on Chloride Concentration (Storm of July 30-31, 1971)

For the other seasons chlorides followed the dilution phenomenon (Figure 17).

The annual average value for specific conductance was 0.58 milli mho/cm and the average for winter was 1.18. This is in agreement with high usage of salt on the streets during the winter months.

Orthophosphates

The level of orthophosphates is comparable to that of nitrates. An average value of 0.98 was found for this study, this is in agreement with that found in Seattle (15), Cincinnati (18), Ann Arbor (19) and Ottawa (1). Average concentrations of orthophosphates showed a significant drop between summer and fall with 1.94 mg/l in spring, 0.32 mg/l in summer and 0.24 mg/l in fall. Use of fertilizers is probably greatest in the spring season and this could be the primary reason for the drop in soluble phosphates values later in the year. The annual average of 0.98 mg/l is significantly greater than 0.03 mg/l, which is considered to be the threshold limit for algal blooms according to Sawyer (18). Orthophosphates are flushed out with moderate rainfall intensity and this is achieved quickly. This can be observed by a triangular phenomena, in which there is an abrupt rise and an abrupt fall making the shape of a triangle.

This phenomenon can be illustrated by the storm of July 30-31, 1971 shown on page 108 of the appendix.

Slug values of 14 mg/l during the storm of Feb. 17-19, 1971 and 34 mg/l during the storm of May 20-21, 1971 were

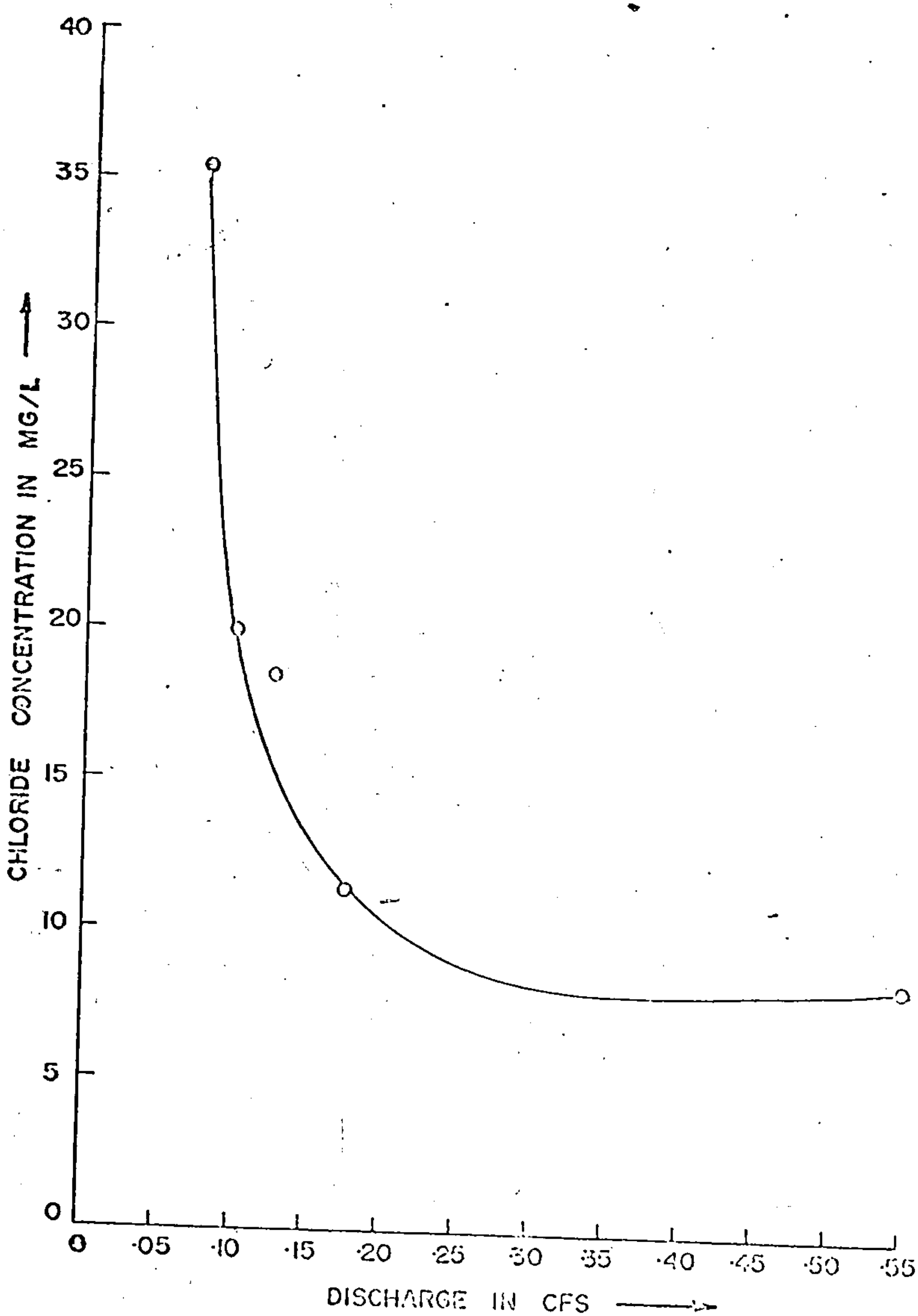


Figure 17. Dilution Curve for Chloride
(Storm of July 30-31, 1971).

observed during the study. Other than spillage of laundry detergents near the research manhole no exploration is possible for these two isolated high recordings.

Sulfates

Both ground as well as air serve as sources of sulfates and it is one of the predominant ions present in the urban runoff. Measurements in this study also indicate that sulfate is abundant in the Windsor area.

The annual average value of sulfates in the runoff was found to be 106 mg/l. This value compares favourably with 94 mg/l found in Ottawa (1). According to the Ottawa study the average value of 5.5 to 7.5 mg/l was found in unpolluted forest areas. Thus the big difference in sulfate levels for urban and nonurban forest areas effectively demonstrates that the increase in this consituent in runoff is due to the urban environment. In the Windsor area the annual average for SO_2 concentration is as high as 0.04 ppm well above the acceptable annual average value of 0.02 ppm set by the Ontario Standards (28). Since SO_2 is one of the major sources of sulfates, the high sulfate concentrations found in this study are justified. The range of values determined in this study was 32-325 mg/l. The values in the fall were higher than in winter, spring and summer. Sulfate concentrations did not follow any pattern in the progress of a storm on time basis although the dilution effect is apparent as shown in Figure 18.

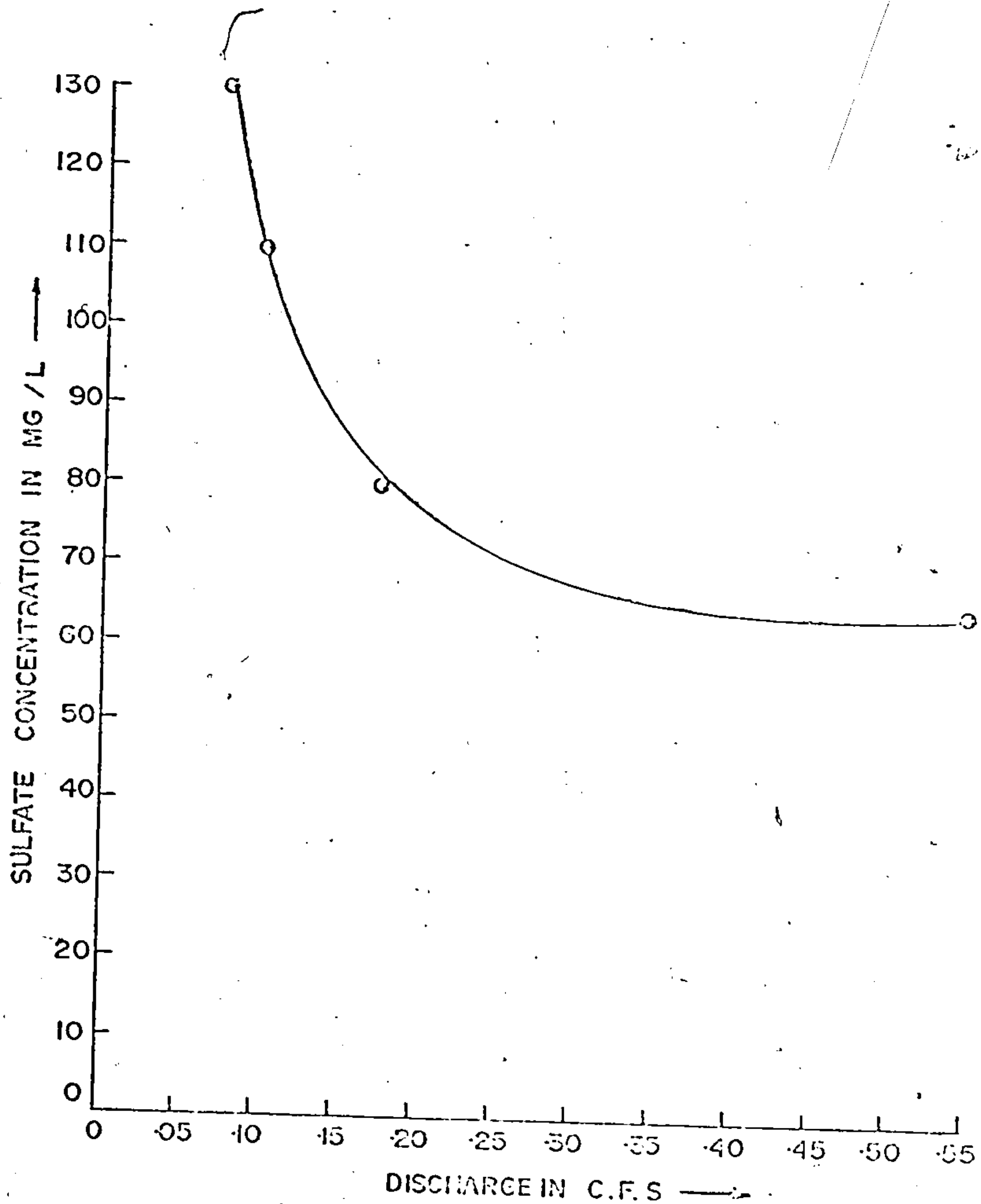


Figure 18. Dilution Curve for Sulfate
(Storm of July 30-31, 1971)

The study in Ottawa (1) suggestsa reduction of sulfate concentration with the progress of a storm, this behaviour is not apparent in this study. The possible reasons could be:

a) dilution effect which gives rise to reduction in concentration.

b) difference in characteristics of this 89 acres residential area and the 0.30 acres of paved parking area in Ottawa.

Ammonia Nitrogen

Out of 65 samples analyzed for ammonia only 11 showed detectable concentration. The maximum observed value was 1.8 mg/l and the average of the detectable readings was .087 mg/l. There were no slug values which could show industrial dumping. As for the storm of August 10-11, 1971 shown on page 110 of Appendix, ammonia was in higher concentration in the beginning of the storm with concentration reducing with the progress of tho storm.

Nitrate and Nitrite Nitrogen

The average value for nitrates was found to be 1.40 mg/l, with a range of 0.05 - 6.30 mg/l. This average value is comparable with studies made in Ann Arbor (19) and Ottawa (1) but is a little less than that found in Seattle (15). An average concentration of 2.64 mg/l for spring was the highest and it dropped to 0.81 mg/l in the fall. This could also be attributed to the diminishing use of fertilizers from spring to fall.

Changes were minor as the discharge progressed but there was an abrupt rise toward the end of the storms. Study in Ottawa (1) showed an average level of nitrates in rainfall sample as 0.89 mg/l. This value suggests that the source of nitrates is largely from the air. The atmosphere serves as a reservoir from which nitrogen in constantly removed by the action of electrical discharge and nitrogen fixing bacteria. During electrical storms large amounts of nitrogen are oxidized to N_2O_5 and its union with water produces HNO_3 which is carried to the earth in the rain.

For nitrites an annual average of .09 mg/l was found with 0.01 mg/l and 0.53 mg/l being the extreme values. The readings in summer and spring were above average while in winter and fall they were below average. There is a tendency for nitrites to remain relatively constant. Even when they fall with the progress of a storm, the reduction is not dramatic as shown in Table 11.

Five-day Biochemical Oxygen Demand

In this study the B.O.D. values ranged from 2 mg/l to 52 mg/l with the annual mean value being 12 mg/l. Seasonal means are given in the Table 5. The mean values for the summer and fall were approximately double that of the winter and spring. The annual mean of 12 mg/l is comparable with the studies made Leningrad (10), Stockholm (11), Seattle (15), Pretoria (16),

TABLE 11

Reduction in the Nitrites Concentrations with the Progress of Storm.

Date	Initial Concentration in mg/l	Final Concentration in mg/l	Percentage Reduction
March 13-14, 1971	0.08	0.05	38
June 6, 1971	0.19	0.14	27
August 10-11, 1971	0.10	0.05	50
October 22, 1971	0.04	0.03	25

Cincinnati (18), Ann Arbor (19) and Ottawa (1), but it is less than those observed in Detroit (12).

The B.O.D. was found to be relatively constant in winter runoffs as shown on page 79 to page 90 of the Appendix. This is probably due to the fact that snowmelt is a relatively slow process and thence a fairly constant B.O.D. is fed to the sewer system. Whereas the B.O.D. was found to vary considerably in a given storm decreasing rapidly towards a minimum value for spring, summer and fall seasons. This effect is illustrated in Table 12, where the B.O.D. at the beginning of the storm is compared to that at the end.

One of the possible reasons for this phenonmenon is that the sewers are being scoured clean during the storm and as the sewers flush themselves out the B.O.D. value diminishes.

Antecedent dry period of the order of one or two days resulted in the initial B.O.D. values of the order of 20-35 mg/l and it was not exceeded even when the antecedent dry period was more than a couple of days. Antecedent dry period of at least one day was also necessary to demonstrate the effect of rainfall intensity on the removal of B.O.D. from the area. The storm of June 7, 1971 had antecedent dry period of 8 hours and a peak rainfall intensity of 0.61 inches/hour resulted in B.O.D. of only 6 mg/l. On the contrary all the B.O.D. values shown in Table 12 were the result of storms with more than one day antecedent dry period and peak rainfall intensity less than 0.61 inches/hour.

TABLE 12

Comparison of Initial and Final B.O.D. in the Progress of a Storm.

Date	B.O.D. at the Start of Sampling in mg/l	B.O.D. at the End of Sampling in mg/l
6 June, 1971	17	4
5 July, 1971	32	7
30-31, July, 1971	30	4
10-11, August, 1971	29	6
22 October, 1971	21	2

Total Coliform and Fecal Coliform

Because rain falling on the earth contains insignificant bacterial contamination (29), the major bacterial contamination of stormwater then must occur on contact with the polluted land environment. Soil in areas remote from man and his culture receives insignificant levels of occasional contamination from wild animals and therefore generally does not contain fecal coliforms (30). In contrast soil in areas populated by man, either on farms or in cities receives varying levels of pollution from warm-blooded animals, e.g., humans, pets, farm animals and rodents. In the urban community fecal contamination in separate stormwater systems is derived mostly from the fecal material deposited on soil by cats, dogs and rodents.

The minimum value of fecal coliforms observed in the whole study was zero, whereas total coliforms were 1400/100 ml. The maximum values were 230,000/100 ml for fecal coliforms and 17,750,000/100 ml for total coliforms. The annual arithmetic average for total coliforms was 2,405,800/100 ml and for fecal coliforms it was 8760/100 ml, the ratio of fecal coliforms to total coliforms being 0.36%. This ratio is much less than that of 8.6% observed in Cincinnati (29).

The results as shown in the Appendix show that total coliform densities show significant increases in magnitude during warmer months especially in late spring and summer.

Initial counts in the storm sewer on a number of occasions showed high initial counts with a subsequent decrease signifying the effect of first flushing (storm of March 13-14, 1971 page 90 Appendix), this is also comparable with the study made by Weibel, Weidner, Christianson and Anderson (18). But on some other occasions like storm of Feb. 17-19, 1971 (page 86 Appendix), initial counts were at about the same level as the rest and in a few cases the first samples gave low results (storm of June 1-2, 1971 page 100 Appendix). Heavy rainfall intensities such as that experienced during the storm of July 30-31, 1971 (page 109 Appendix), showed a rapid removal of total coliforms. Whereas the more gentle, storm of relatively constant intensity gives less variation in total coliform counts.

CHAPTER V

CONCLUSIONS

1. The study of stormwater runoff from an 89 acre residential area in Windsor indicates a fairly considerable pollutional load. The following are the storm runoff concentrations: colour 220 units, turbidity 134 J.T.U., specific conductance 0.58 milli mho/cm, pH 7.35, total suspended solids 305 mg/l, volatile suspended solids 59 mg/l, total alkalinity 106 mg/l, total hardness 211 mg/l, calcium hardness 144 mg/l, orthophosphates 0.98 mg/l, sulfates 106 mg/l, ammonia 0.087 mg/l, nitrites 0.09 mg/l, nitrates 1.40 mg/l, B.O.D. 12 mg/l, total coliform 2,405,800/100 ml and fecal coliform 8760/100 ml. Since the percentage of people living in urban areas in Canada is likely to go up to 90% by the end of this century from 70% at present (31), these figures will be more and more significant in future. In addition to the increase in urban percentage the total population will double.

2. A runoff coefficient of the order of 0.84 for winter results in pollution parameters like total alkalinity, B.O.D., total hardness, calcium hardness, chlorides, sulfates, orthophosphates and nitrites having the highest lbs/acre loading during the winter months, even though the concentrations were not the highest at this time. This points out very clearly the danger of overreliance on concentrations

of pollutants and disregarding the quantity of discharge.

3. A comparison of storm and sanitary loads in lb/acre showed that total suspended solids, orthophosphates and B.O.D. in stormwater were 168 %, 38 % and 8 % respectively that of sanitary sewage. Thus total suspended solids is one parameter in which stormwater is of greater significance than sanitary sewage.

4. The correctness of the statement that "the first part of a storm is generally more polluted" was demonstrated for orthophosphates, B.O.D., chlorides, sulfates, total hardness and total alkalinity.

5. Under normal circumstances colour and turbidity follow each other with turbidity being about 60% of colour units. That they are affected by rainfall intensity has been demonstrated.

6. Higher rainfall intensity results in higher suspended solids concentration and higher total rainfall in the storm results in higher suspended solids load. The volatile material in the total suspended solids formed about 19% as on annual average.

7. Dilution phenomenon was apparent for parameters like total alkalinity, hardness, sufates and chlorides.

8. Specific conductance depends mostly upon chlorides during winter. In other seasons the ions affecting specific conductance are chlorides as well as sulfates.

9. Fertilizers are the most likely source of ortho-phosphates and nitrates, declining use of fertilizers from spring to fall correspond to declining average concentrations of these parameters in those seasons. Annual averages of 0.98 mg/l for orthophosphates and 1.40 mg/l for nitrates exceed Sawyer's threshold levels for algal bloom by a very wide margin.

10. In Windsor double the concentration of sulphur dioxide than acceptable standard annual average is partially responsible for high concentrations of sulfates in storm run-off.

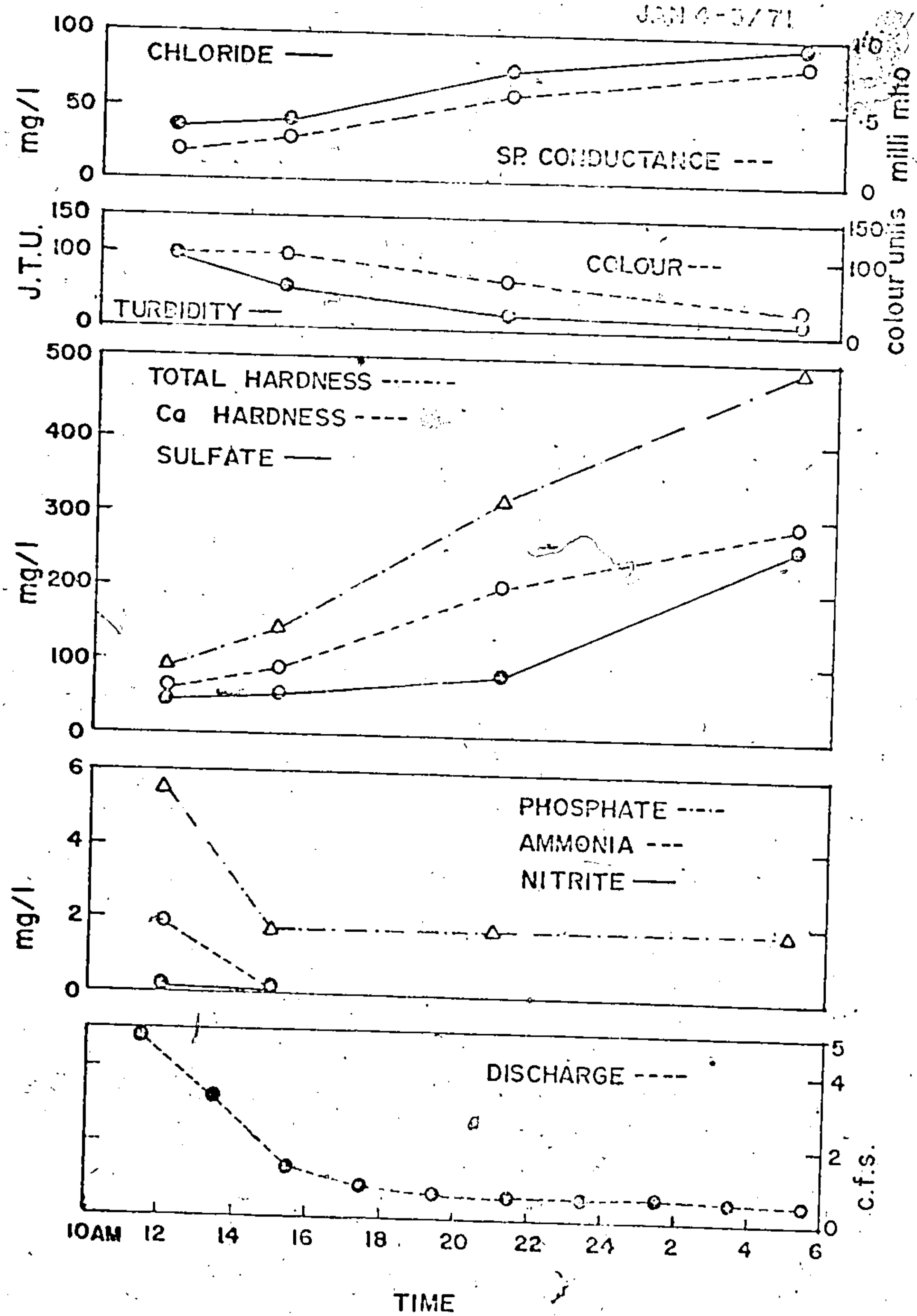
11. The B.O.D. remains relatively constant during winter but drops in other seasons with the progress of the storm. Rainfall intensity would only effect B.O.D. if the antecedent dry period is at least a day.

12. The annual ratio of fecal coliforms to total coliforms was only 0.36% as compared to 8.6% in Cincinnati (29), this shows that the area was relatively clean. Coliform densities were significantly higher during warmer spring and summer months and in all cases during the study the total coliform density was greater than 1000/100 ml, criterion for swimming water quality, in use in many places in North America.

APPENDIX

FIGURES SHOWING
TEST DATA IN GRAPHICAL FORM

STORM WATER CHARACTERISTICS



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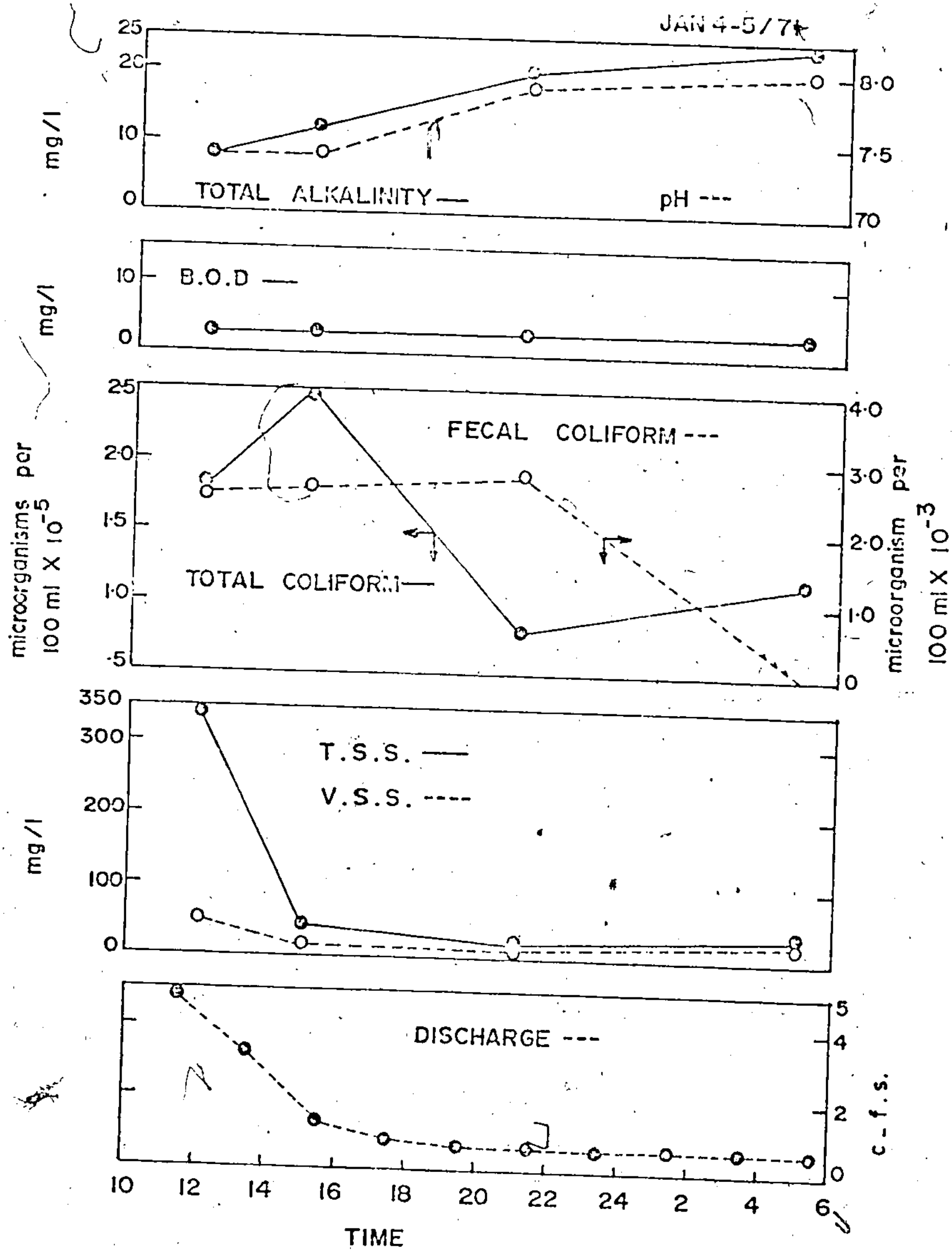
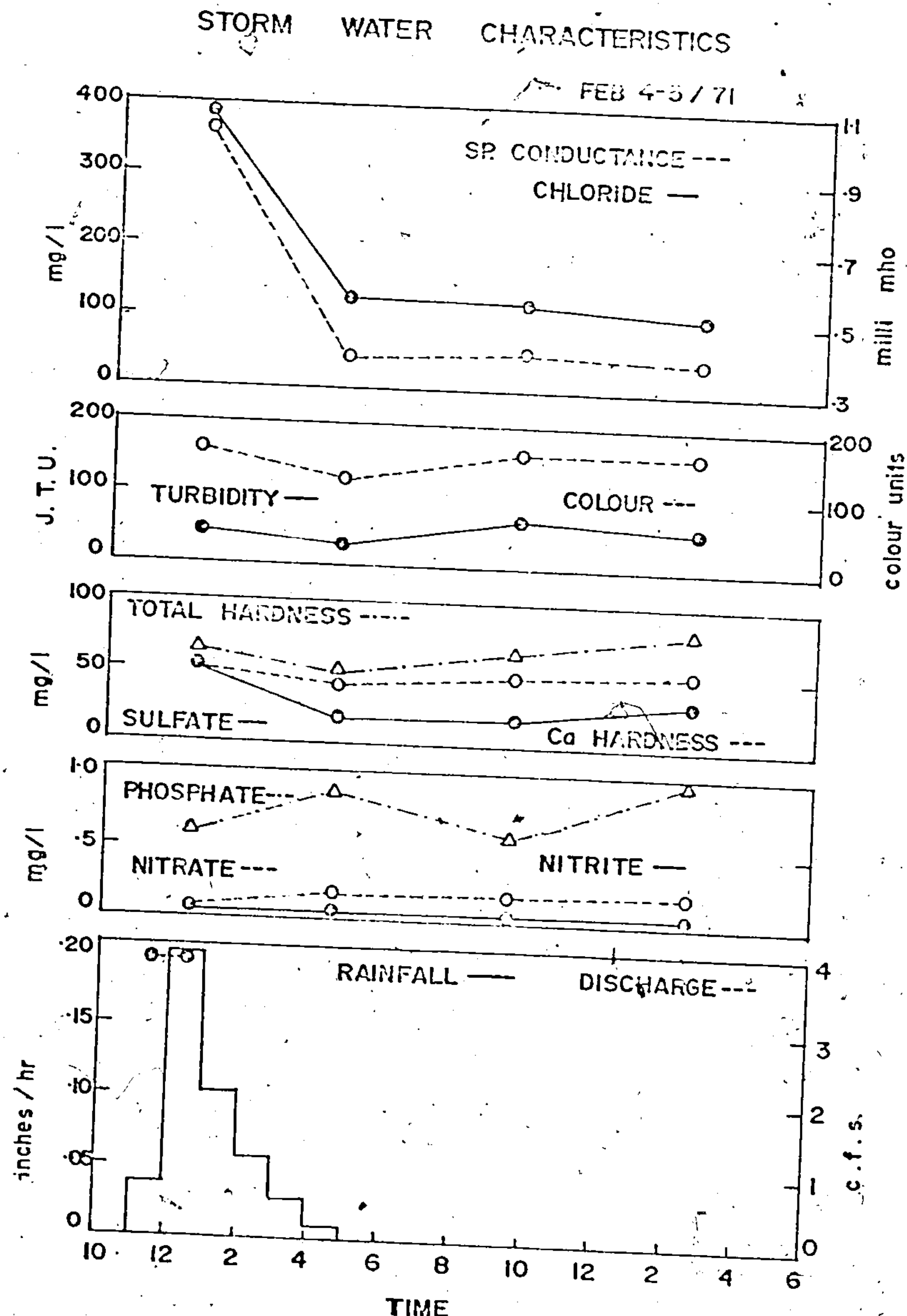
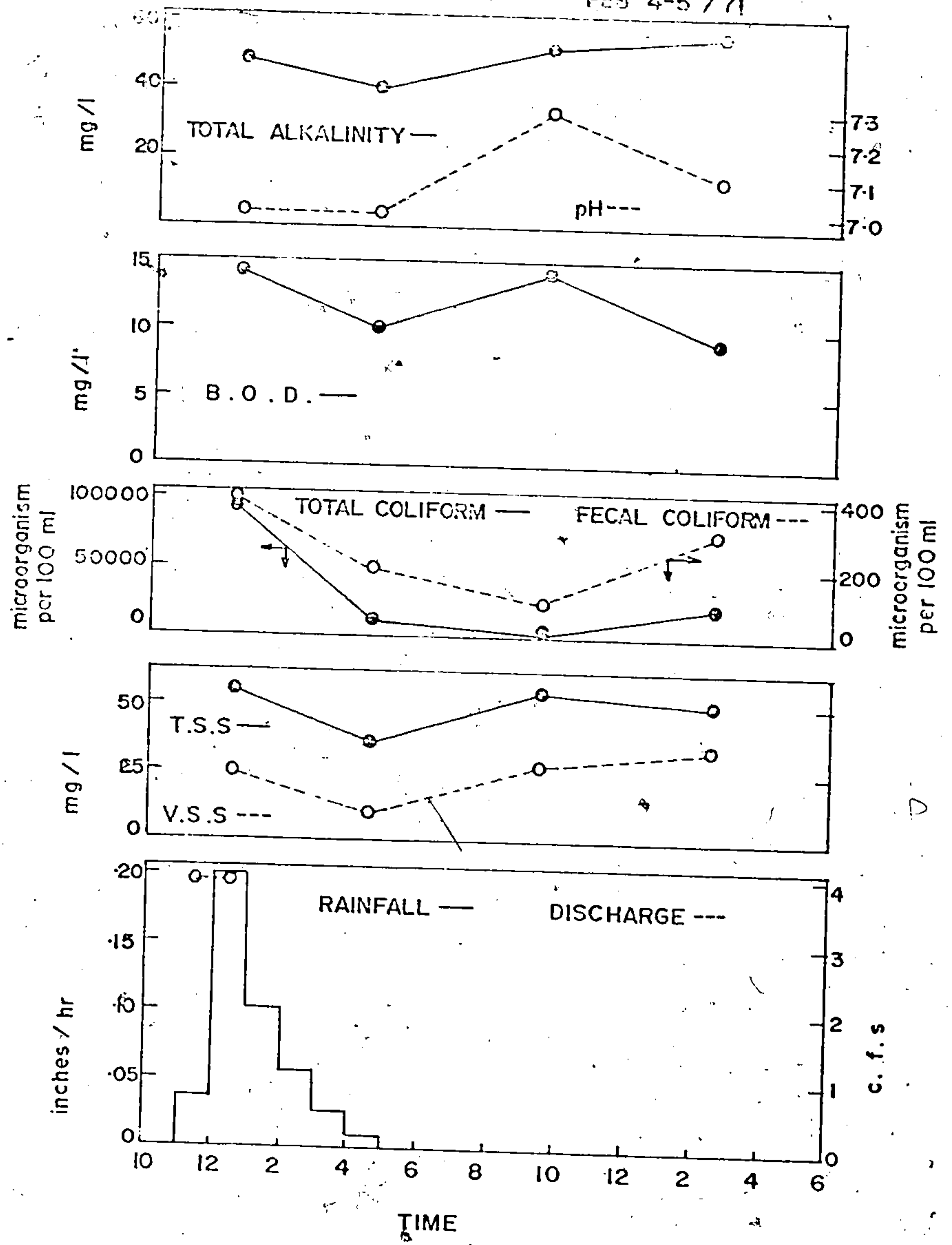



STORM WATER CHARACTERISTICS
FEB 4-5 / 71
SP. CONDUCTANCE ---
CHLORIDE —
mg/l
milli mho
400
300
200
100
0
1·1
·9
·7
·5
·3
J. T. U.
colour units
TURBIDITY —
COLOUR ---
200
100
0
TOTAL HARDNESS -·-·-
SULFATE —
Ca HARDNESS ---
mg/l
100
50
0
PHOSPHATE -·-·-
NITRATE ---
NITRITE —
mg/l
1·0
·5
0
RAINFALL —
DISCHARGE ---
inches / hr
c.f.s.
·20
·15
·10
·05
0
4
3
2
1
0
10
12
2
4
6
8
10
12
2
4
6
TIME

STORM WATER CHARACTERISTICS

FEB 4-5 / 71



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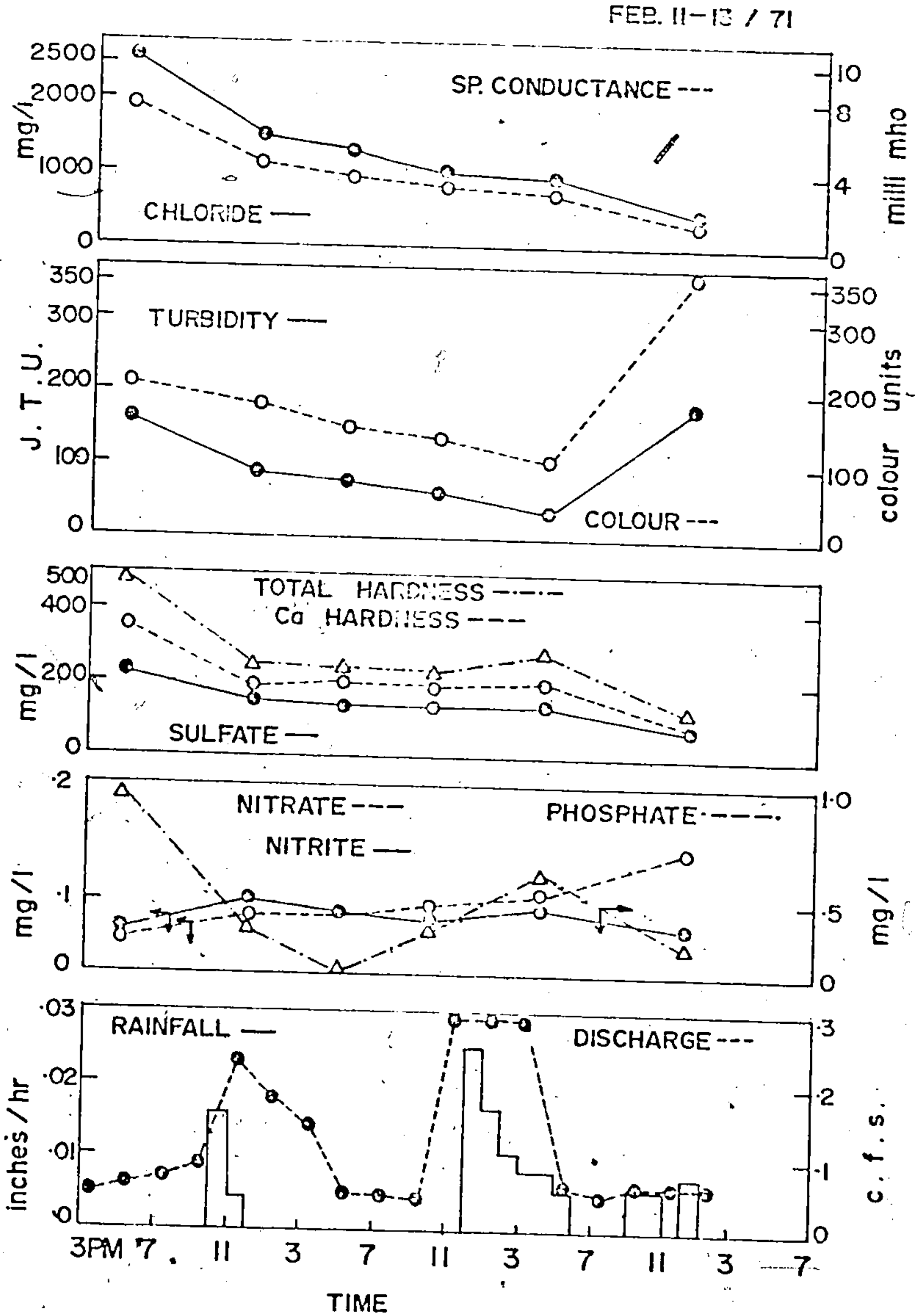

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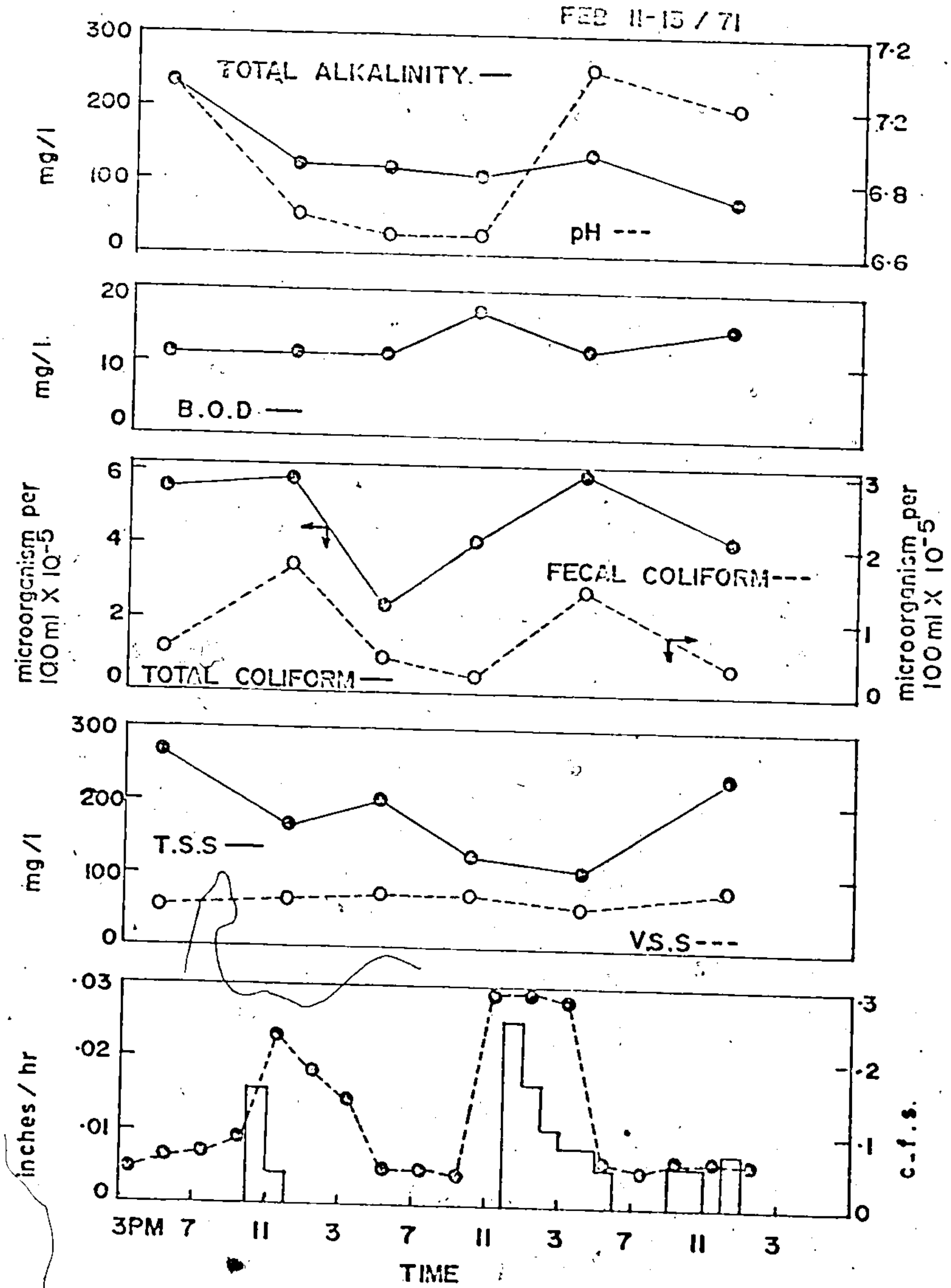

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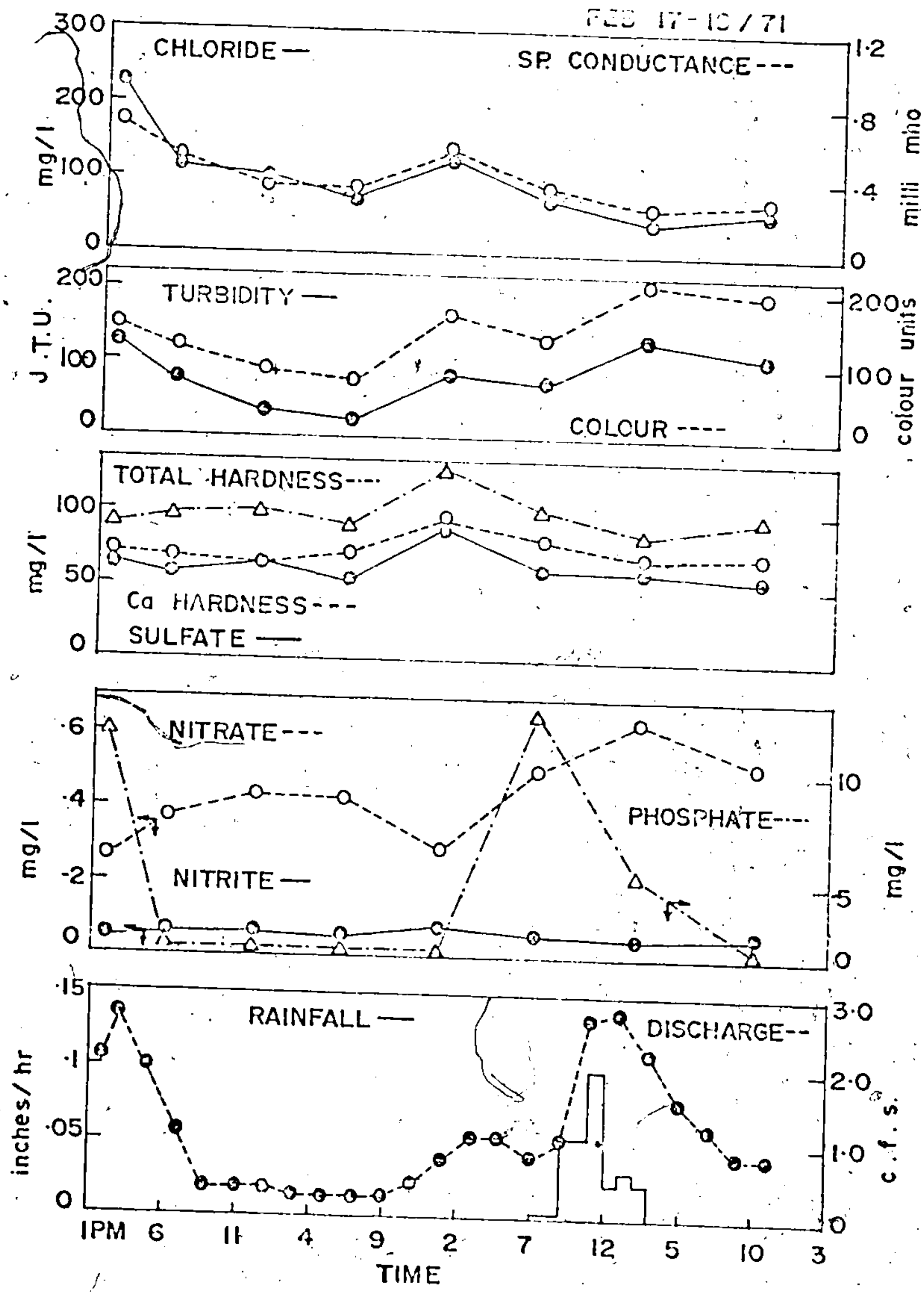

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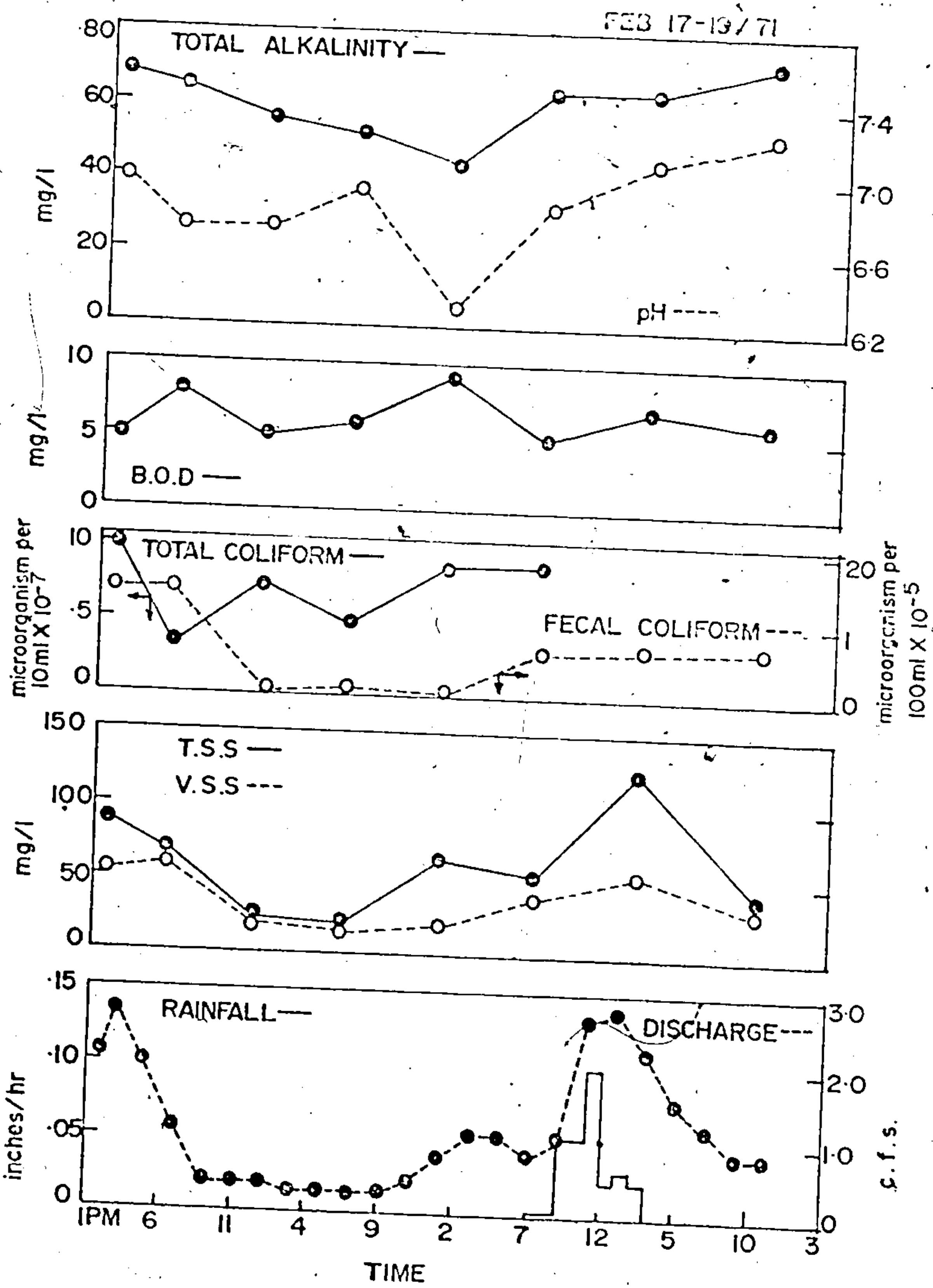

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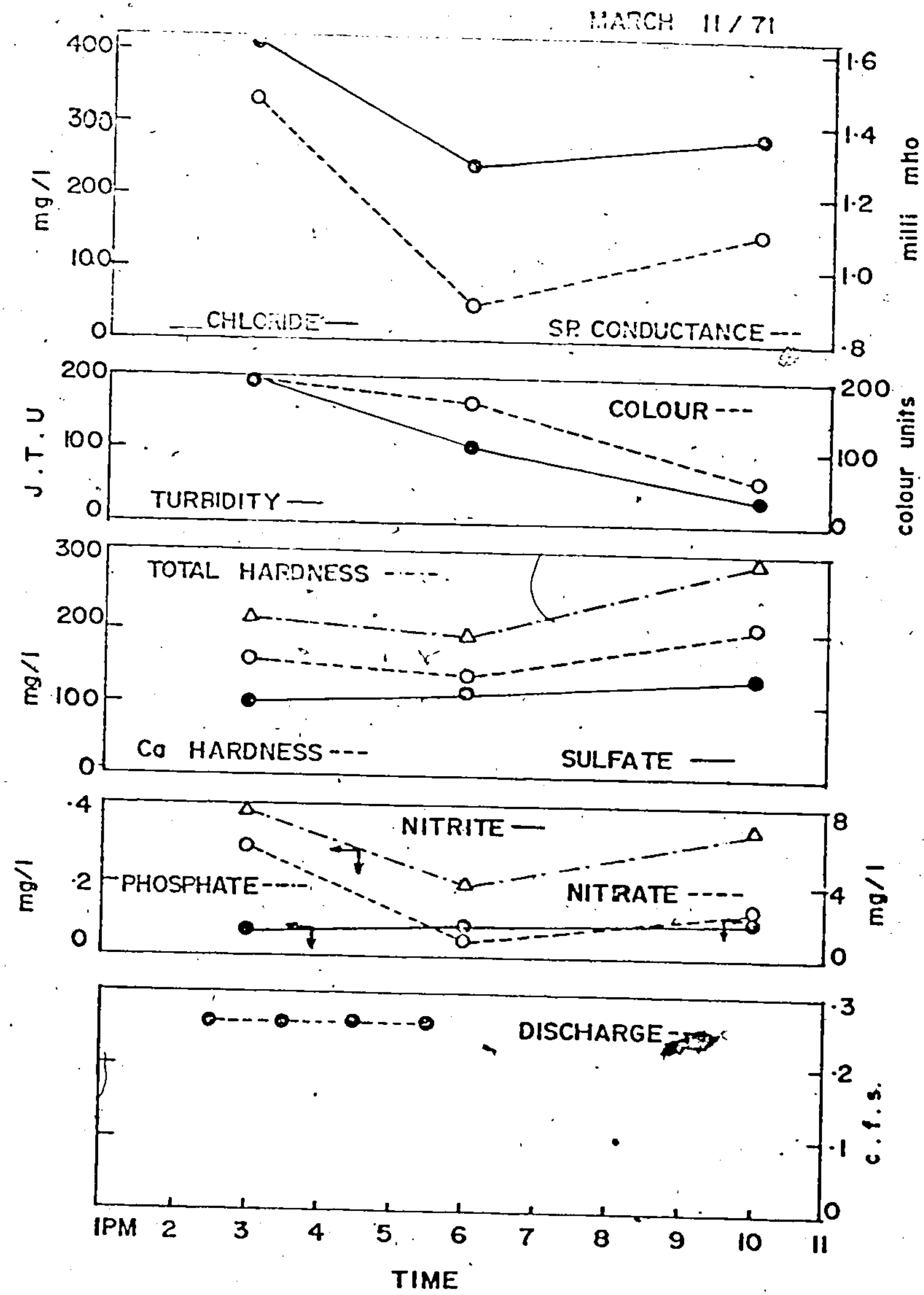

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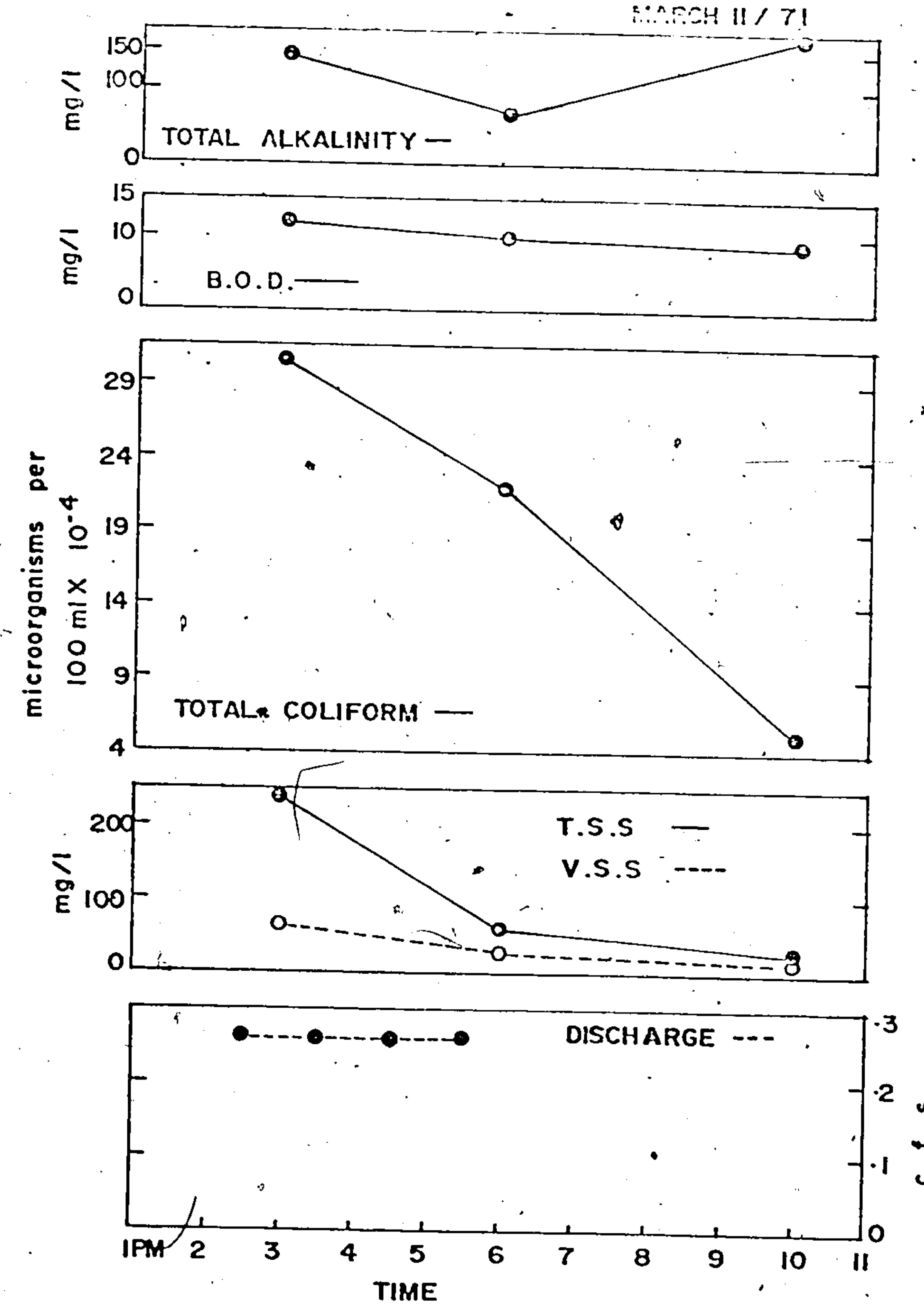

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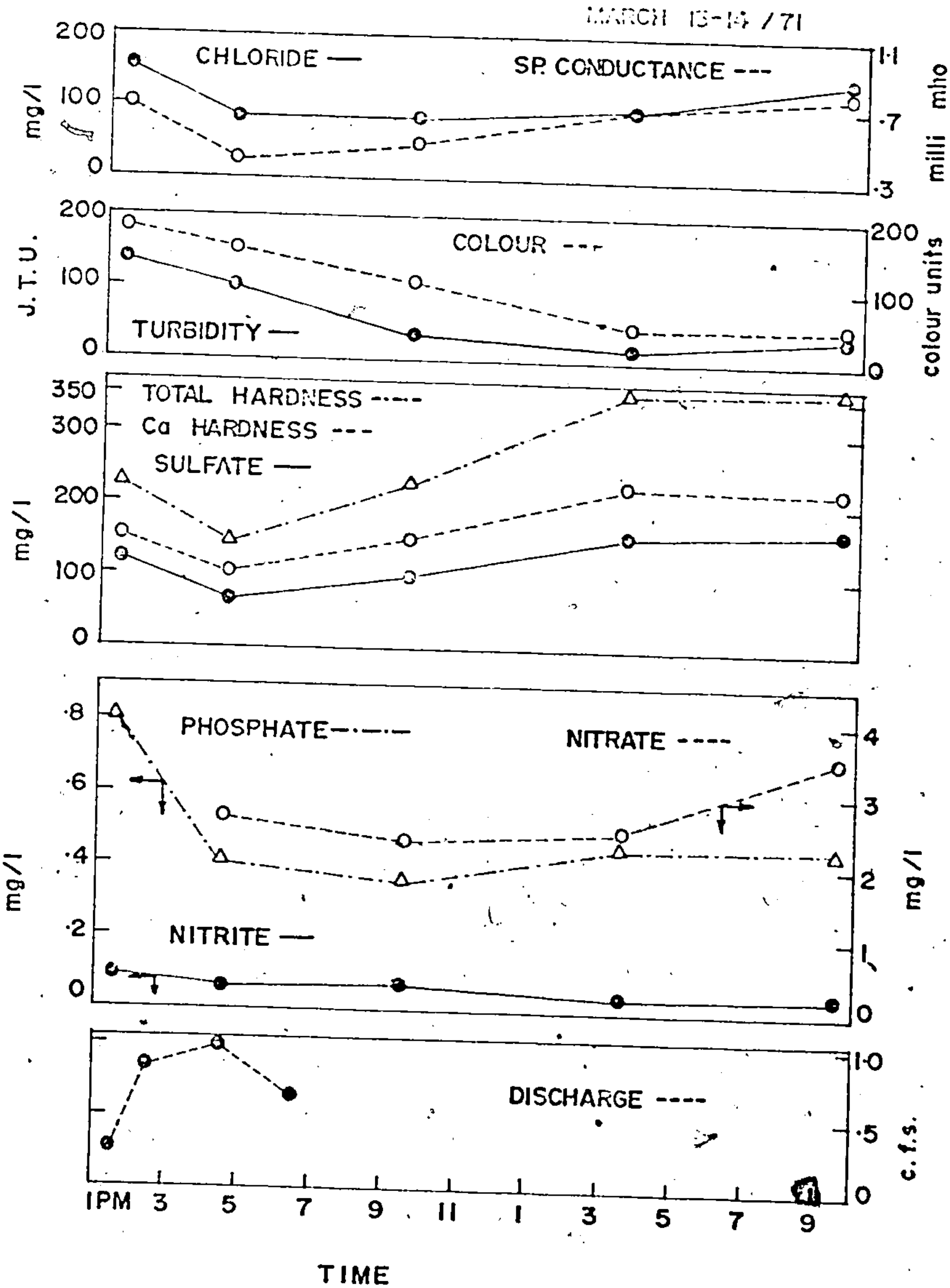

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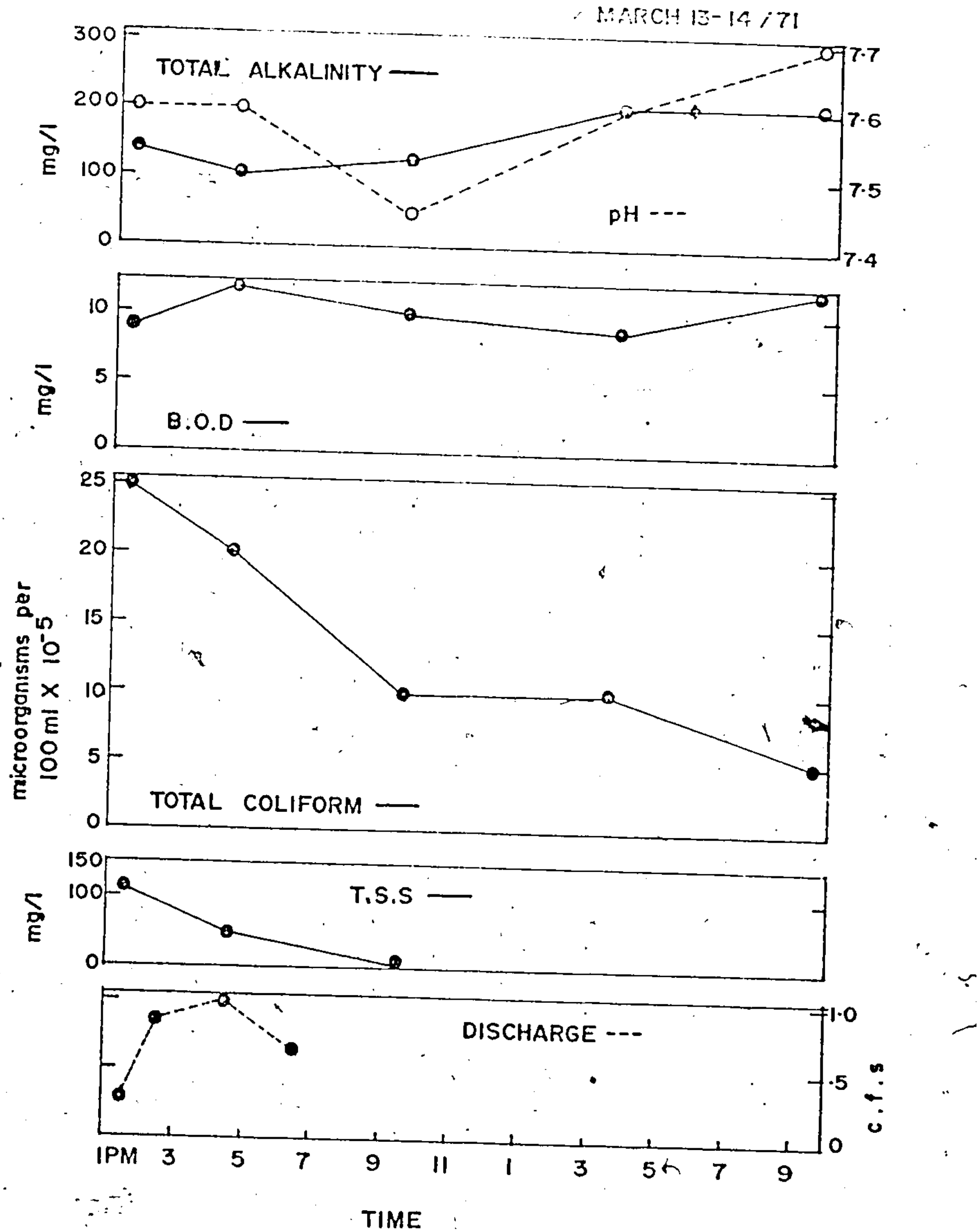

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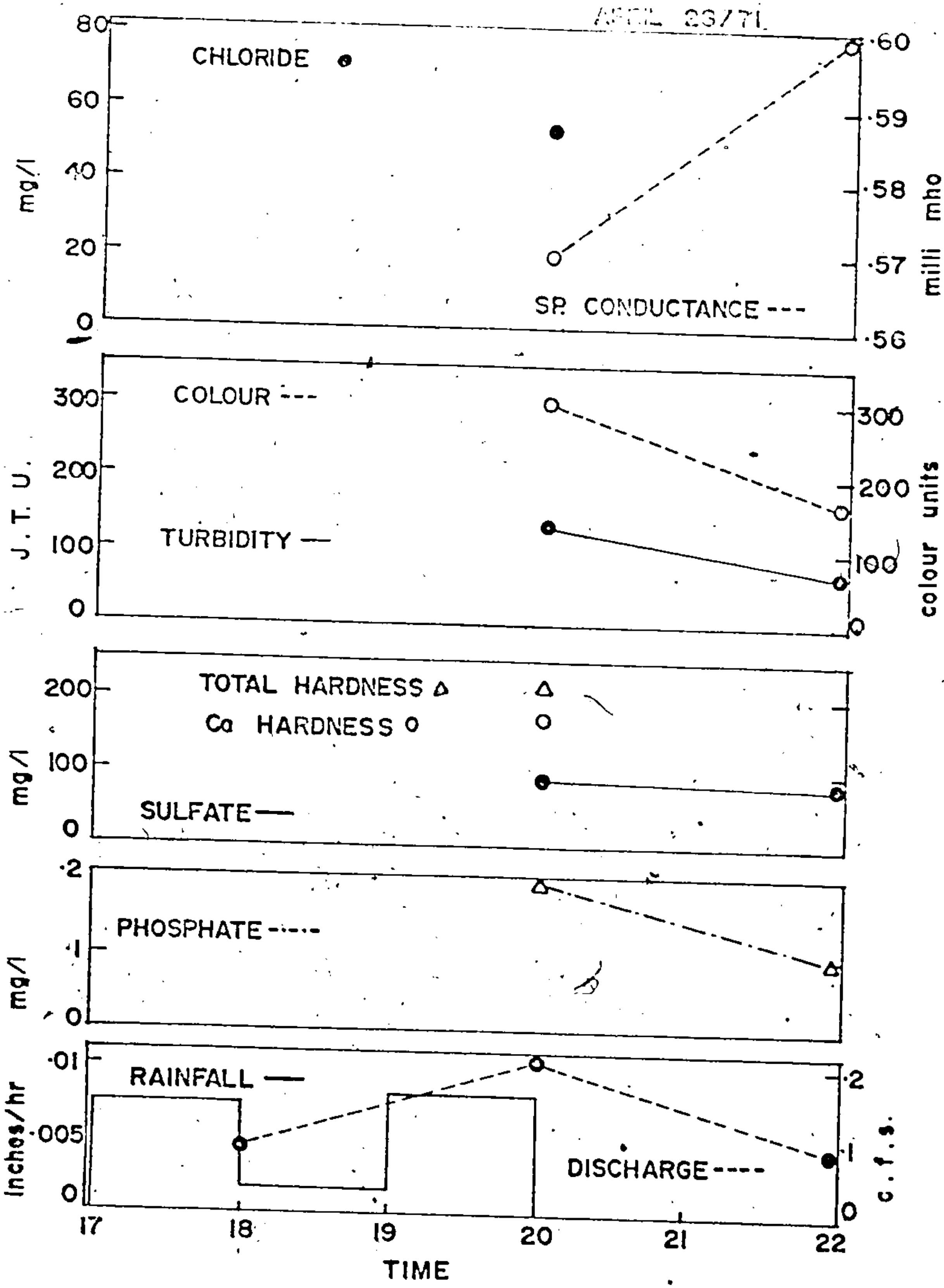

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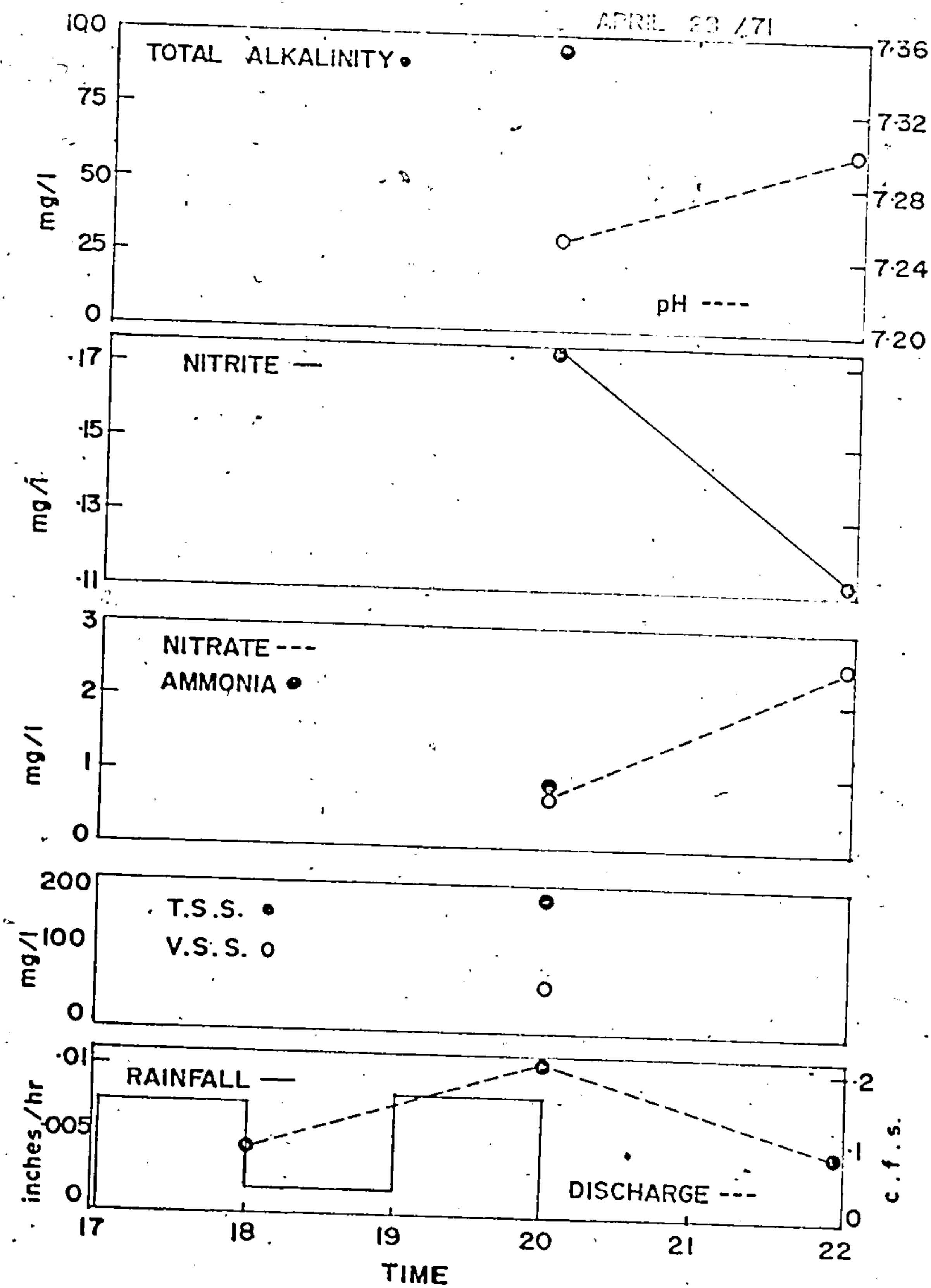

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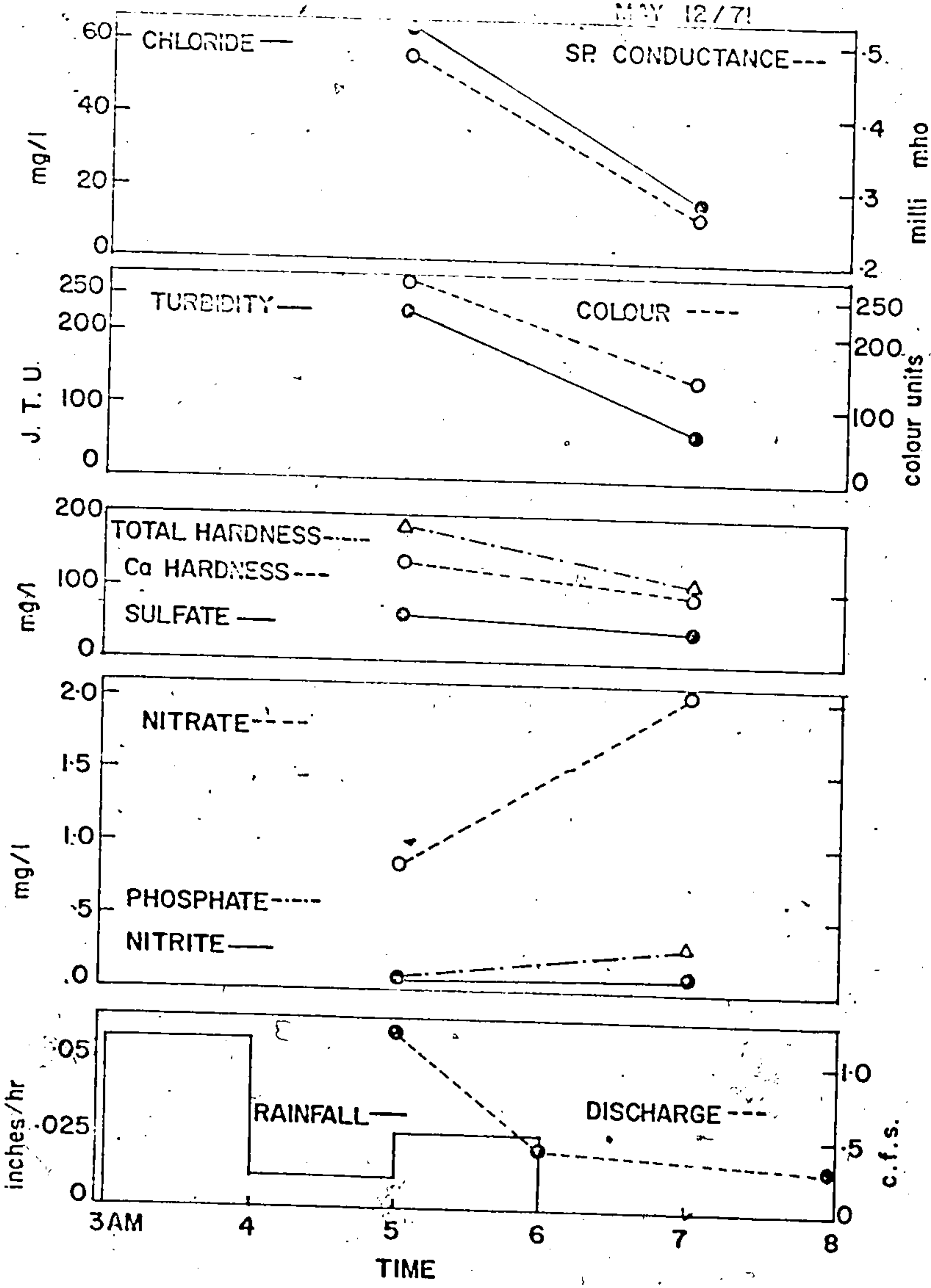
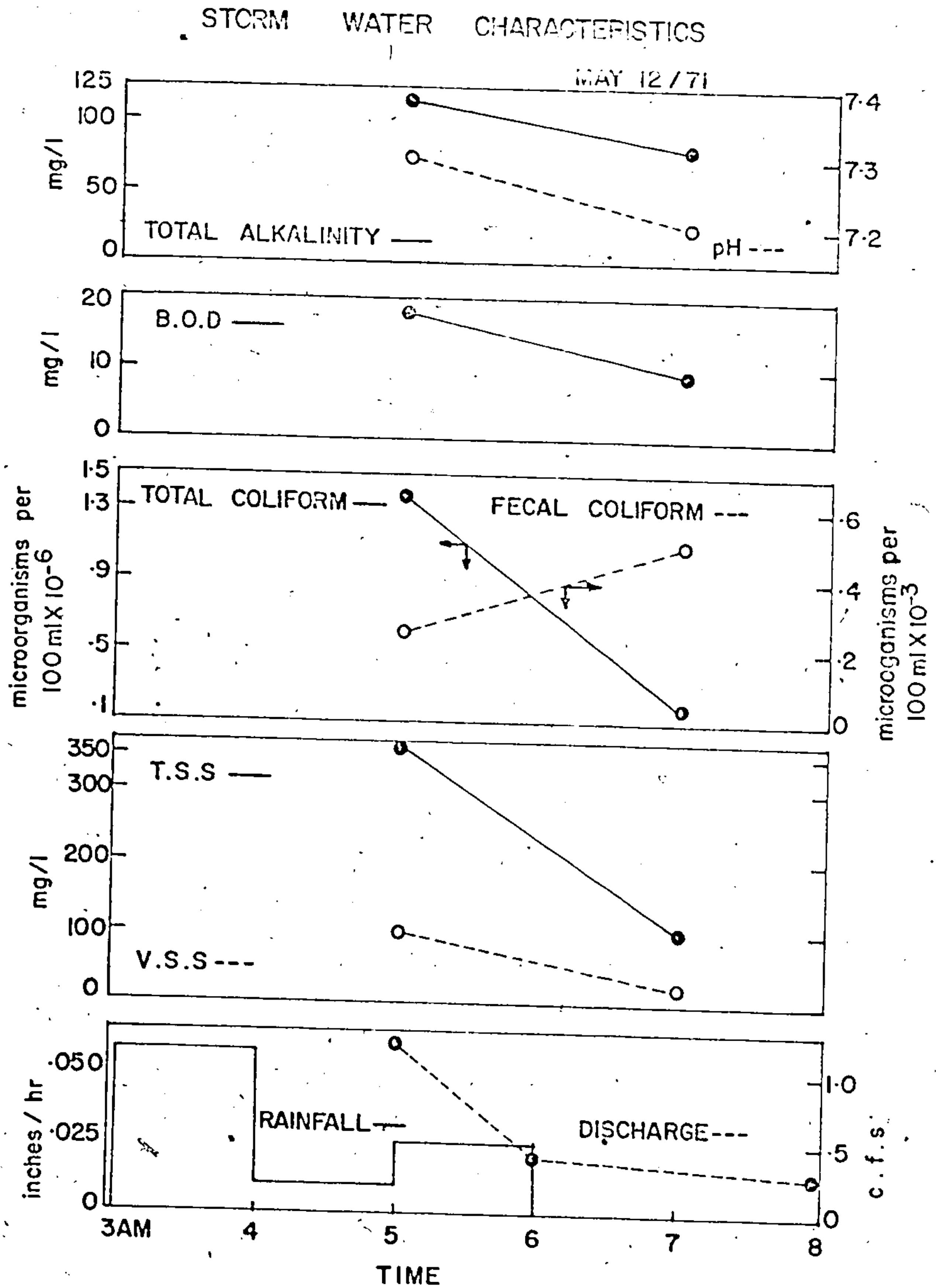
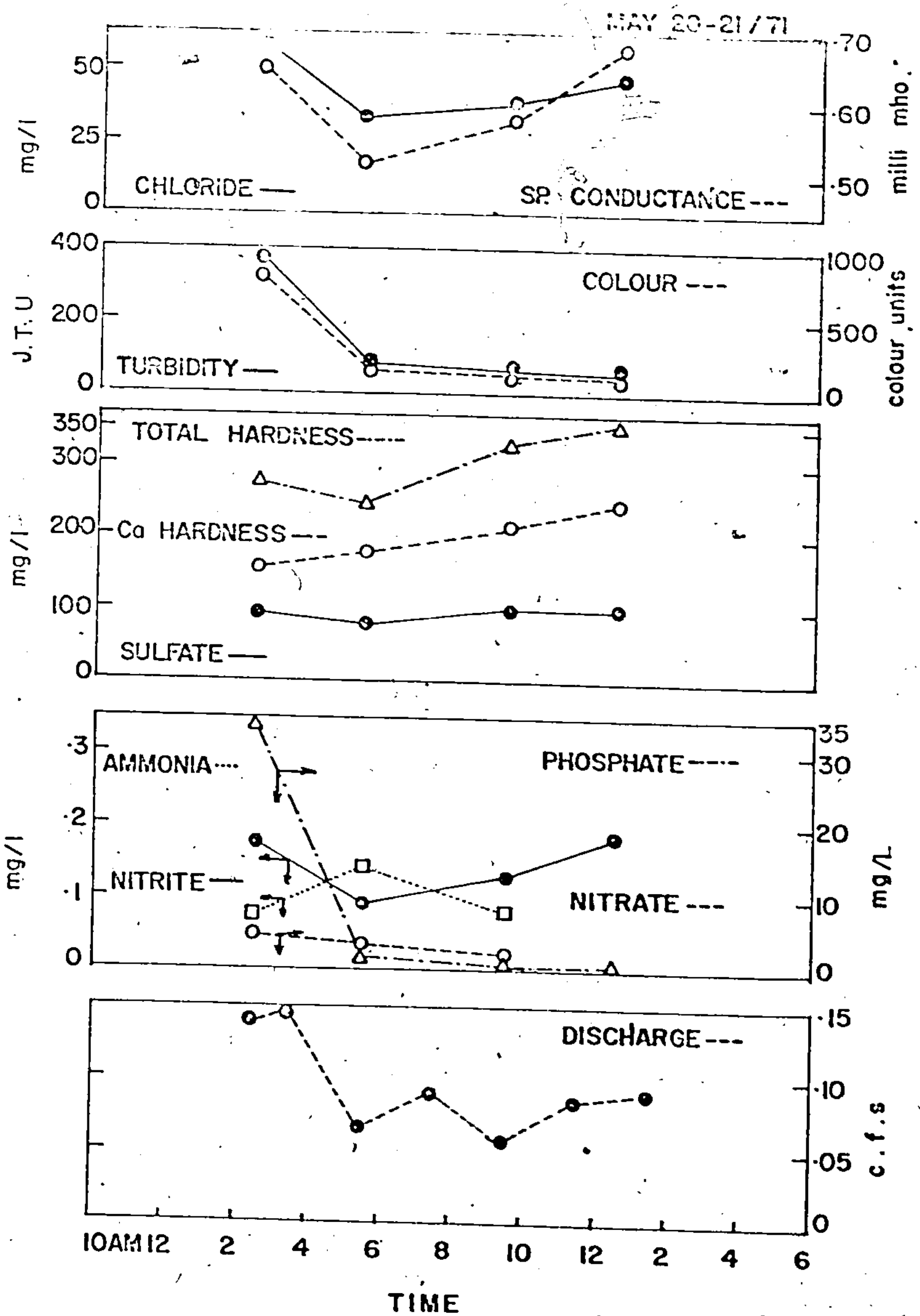



STORM WATER CHARACTERISTICS
MAY 12/71
125
100
50
0
mg/l
TOTAL ALKALINITY
pH
7·4
7·3
7·2
20
10
0
mg/l
B.O.D
1·5
1·3
·9
·5
·1
microorganisms per 100 ml X 10^-6
TOTAL COLIFORM
FECAL COLIFORM
·6
·4
·2
0
microorganisms per 100 ml X 10^-3
350
300
200
100
0
mg/l
T.S.S
V.S.S
·050
·025
0
inches / hr
RAINFALL
DISCHARGE
1·0
·5
0
c.f.s.
3AM
4
5
6
7
8
TIME

STORM WATER CHARACTERISTICS



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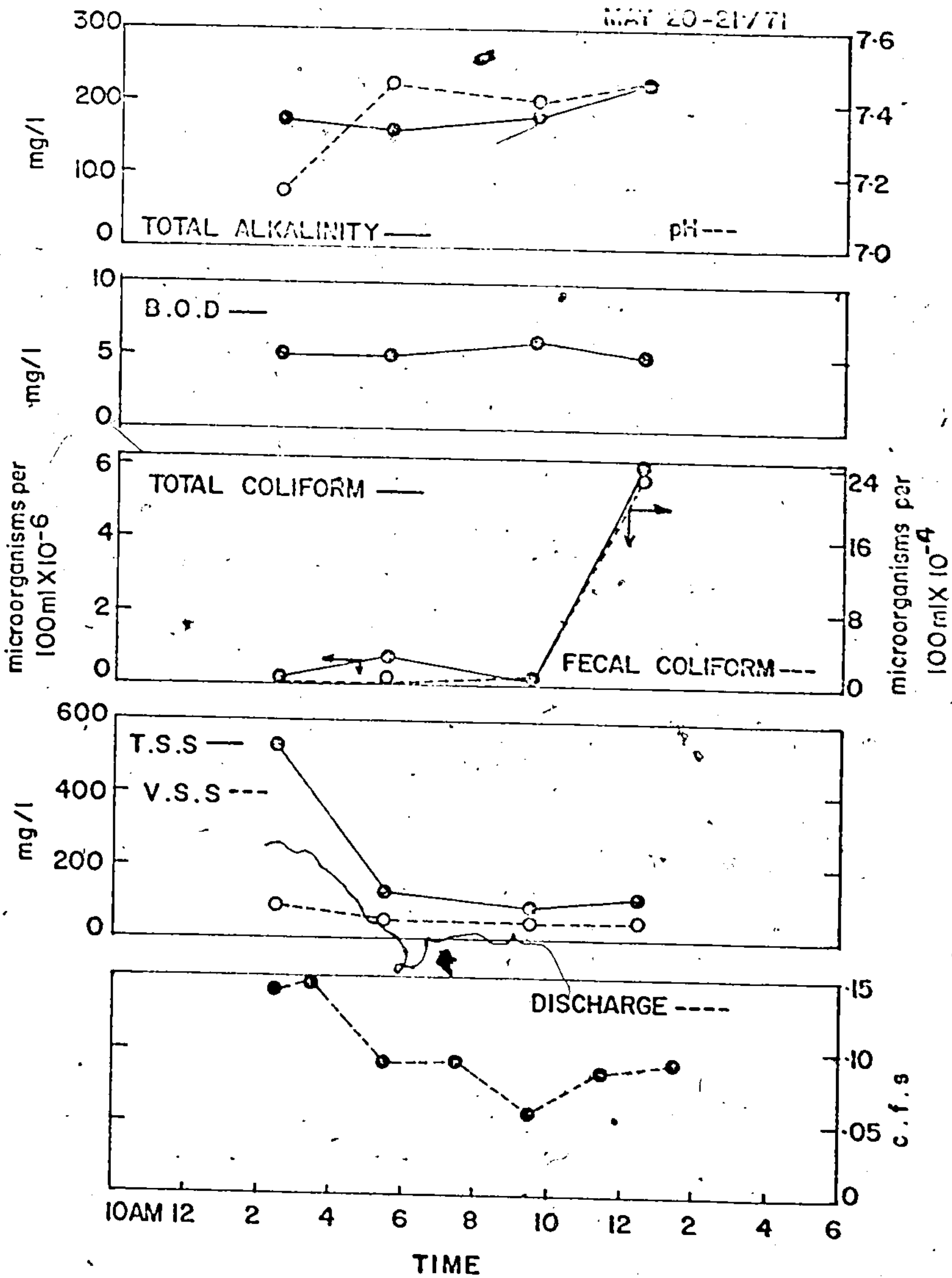
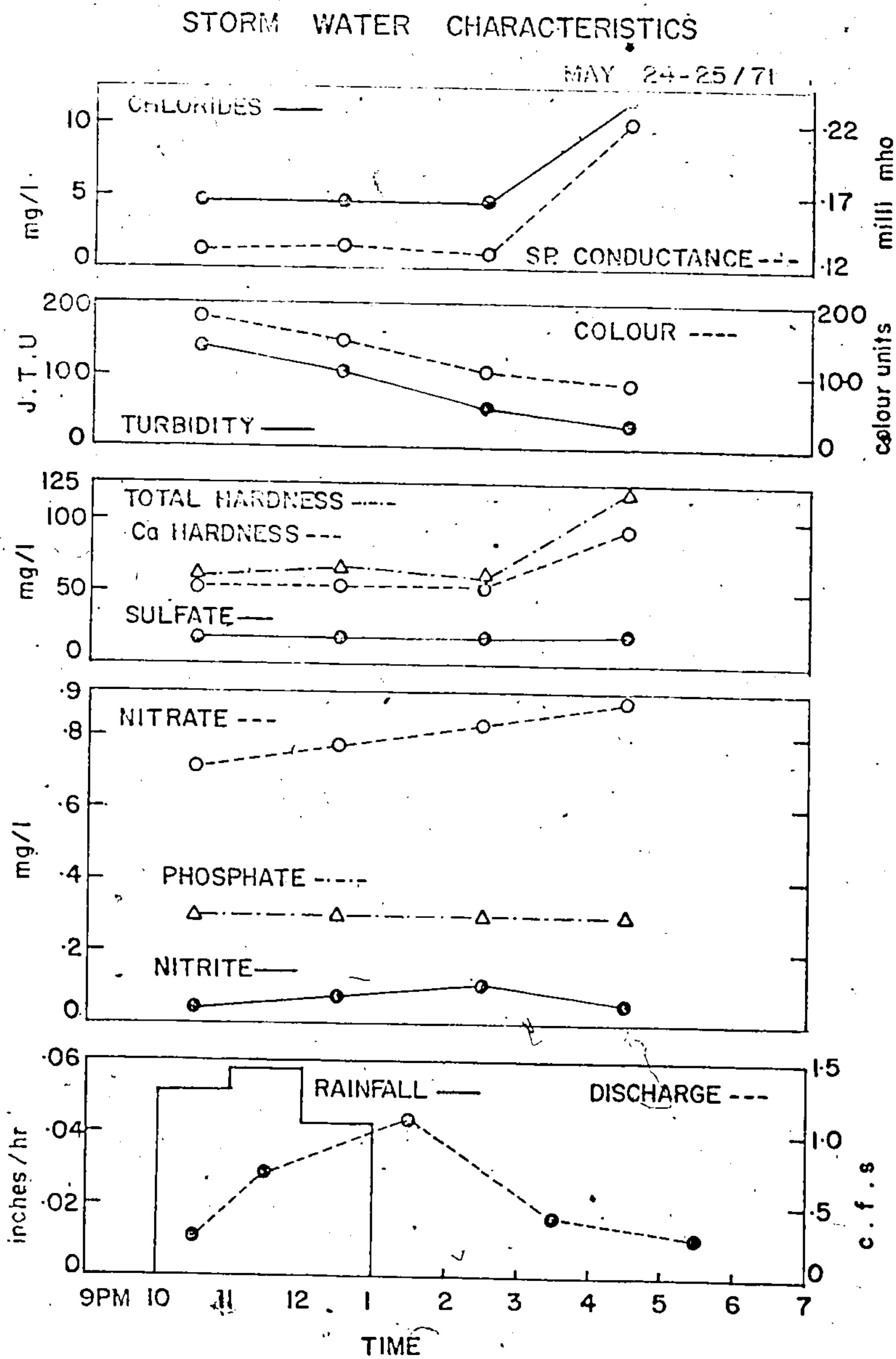
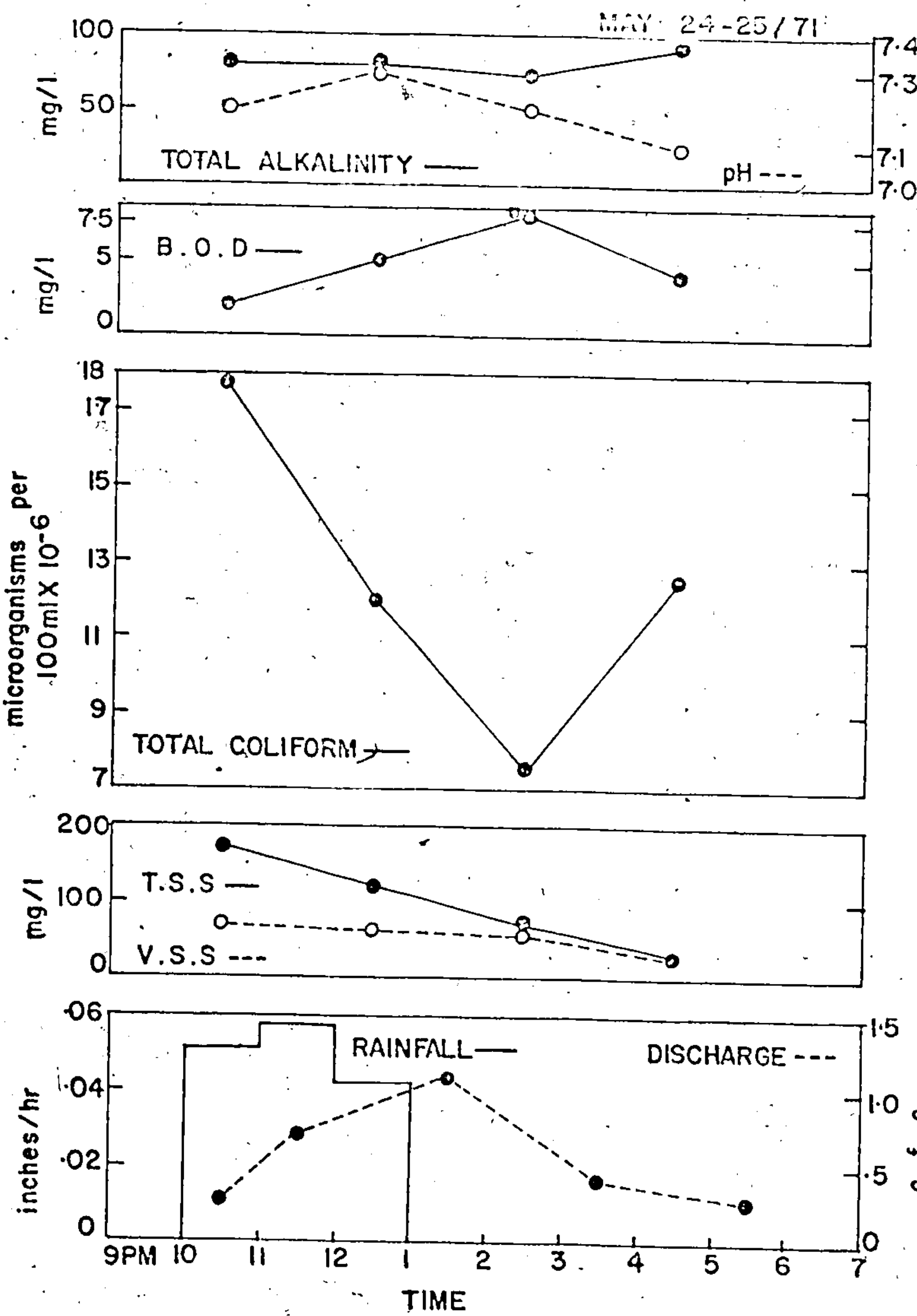
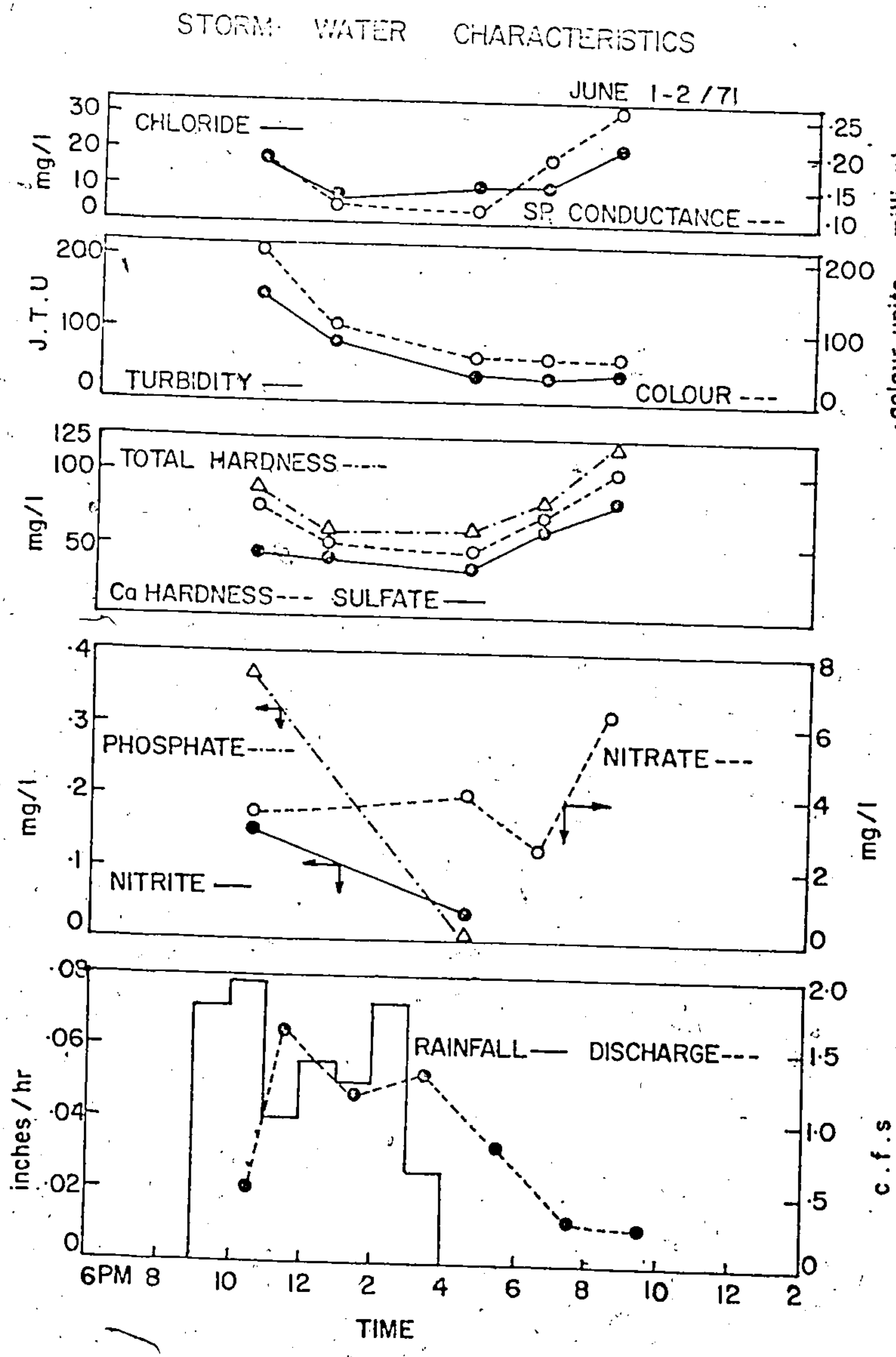


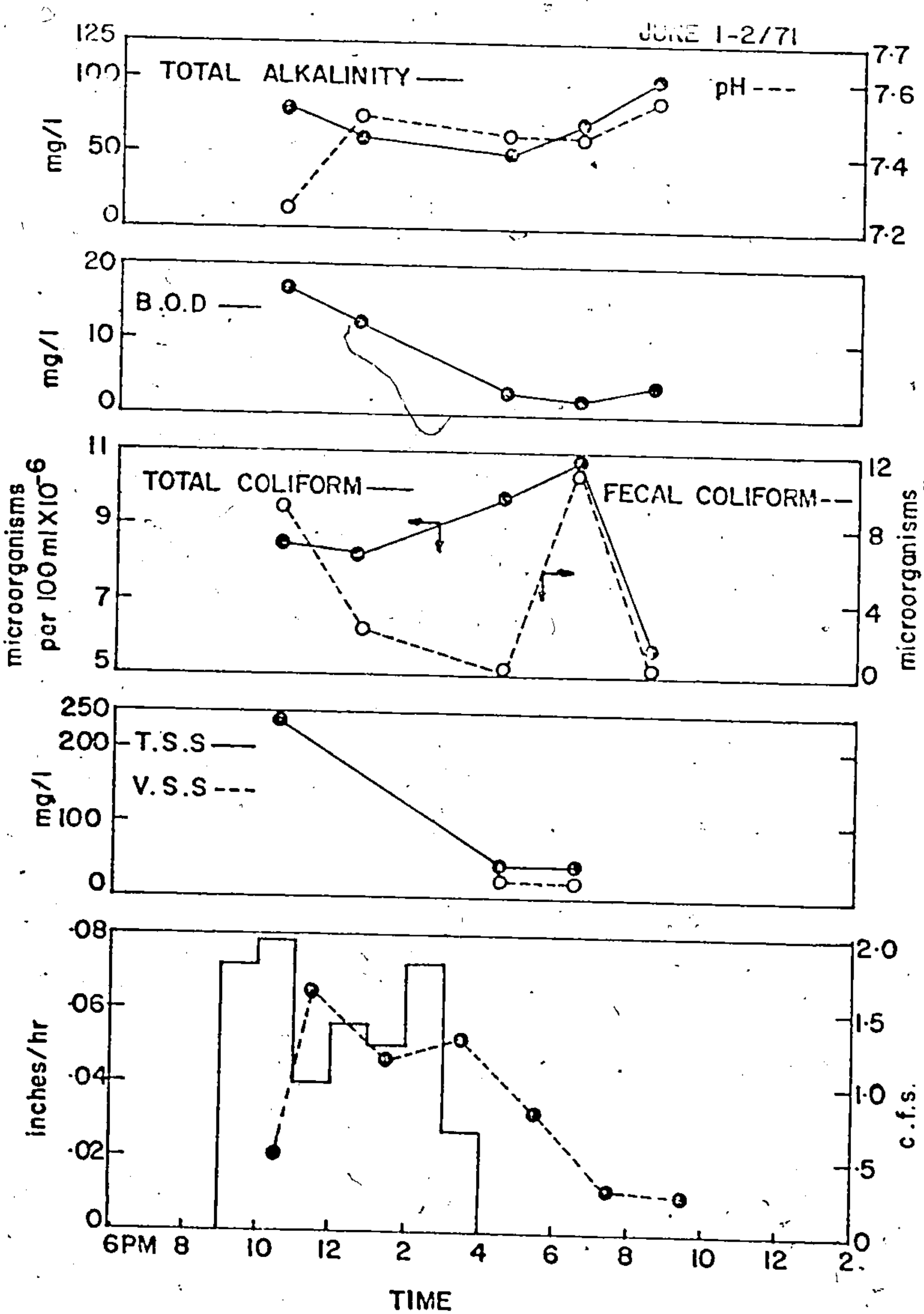

STORM WATER CHARACTERISTICS
MAY 24-25/71
CHLORIDES
mg/l
SP. CONDUCTANCE
milli mho
J.T.U
COLOUR
TURBIDITY
colour units
TOTAL HARDNESS
Ca HARDNESS
SULFATE
NITRATE
PHOSPHATE
NITRITE
RAINFALL
DISCHARGE
inches/hr
c.f.s
9PM 10 11 12 1 2 3 4 5 6 7
TIME

STORM WATER CHARACTERISTICS




STORM WATER CHARACTERISTICS
JUNE 1-2 /71
CHLORIDE
SP. CONDUCTANCE
mg/l
milli mho
TURBIDITY
COLOUR
J.T.U
colour units
TOTAL HARDNESS
Ca HARDNESS
SULFATE
mg/l
PHOSPHATE
NITRATE
NITRITE
mg/l
RAINFALL
DISCHARGE
inches / hr
c.f.s
6PM 8 10 12 2 4 6 8 10 12 2
TIME

STORM WATER CHARACTERISTICS



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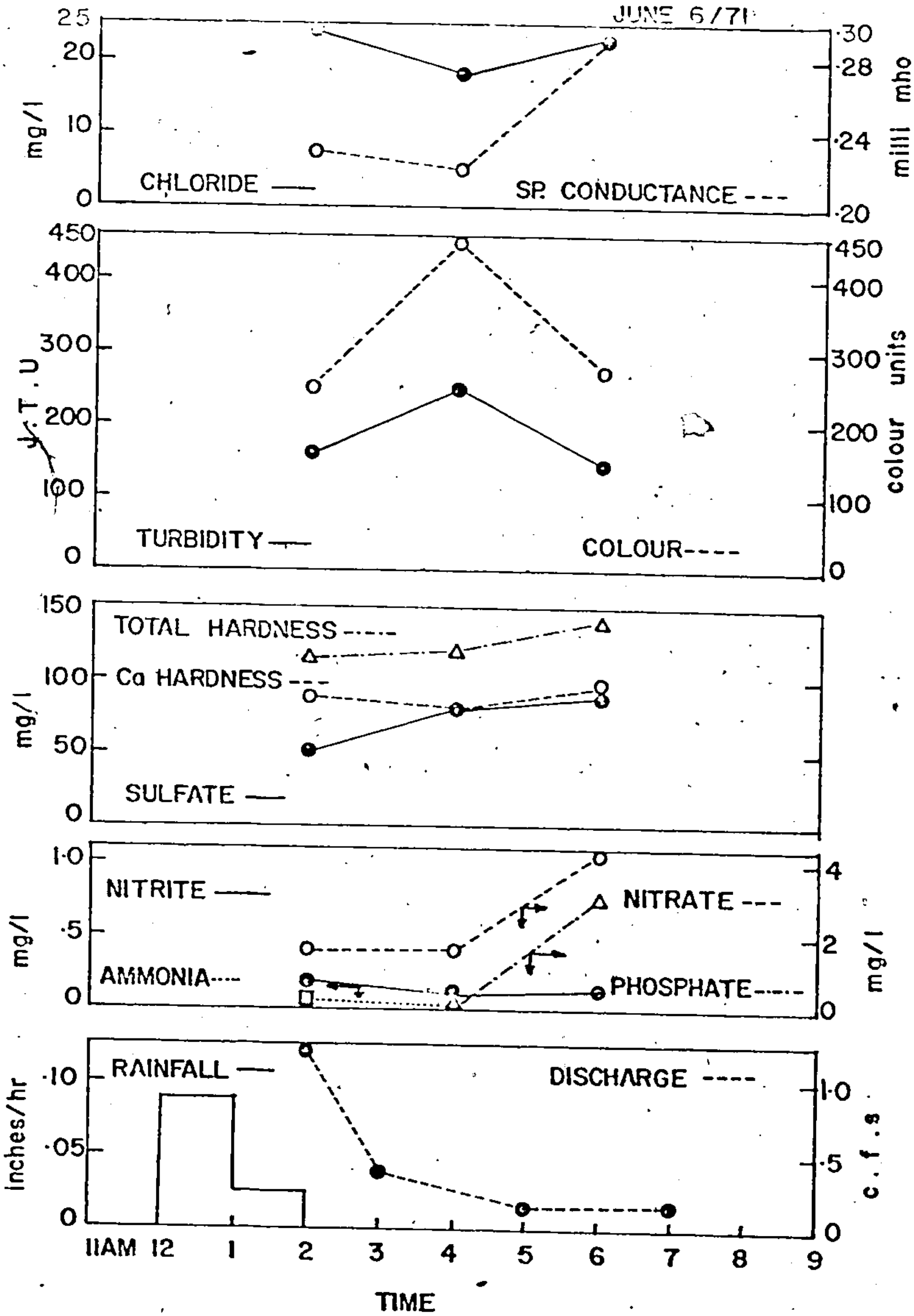

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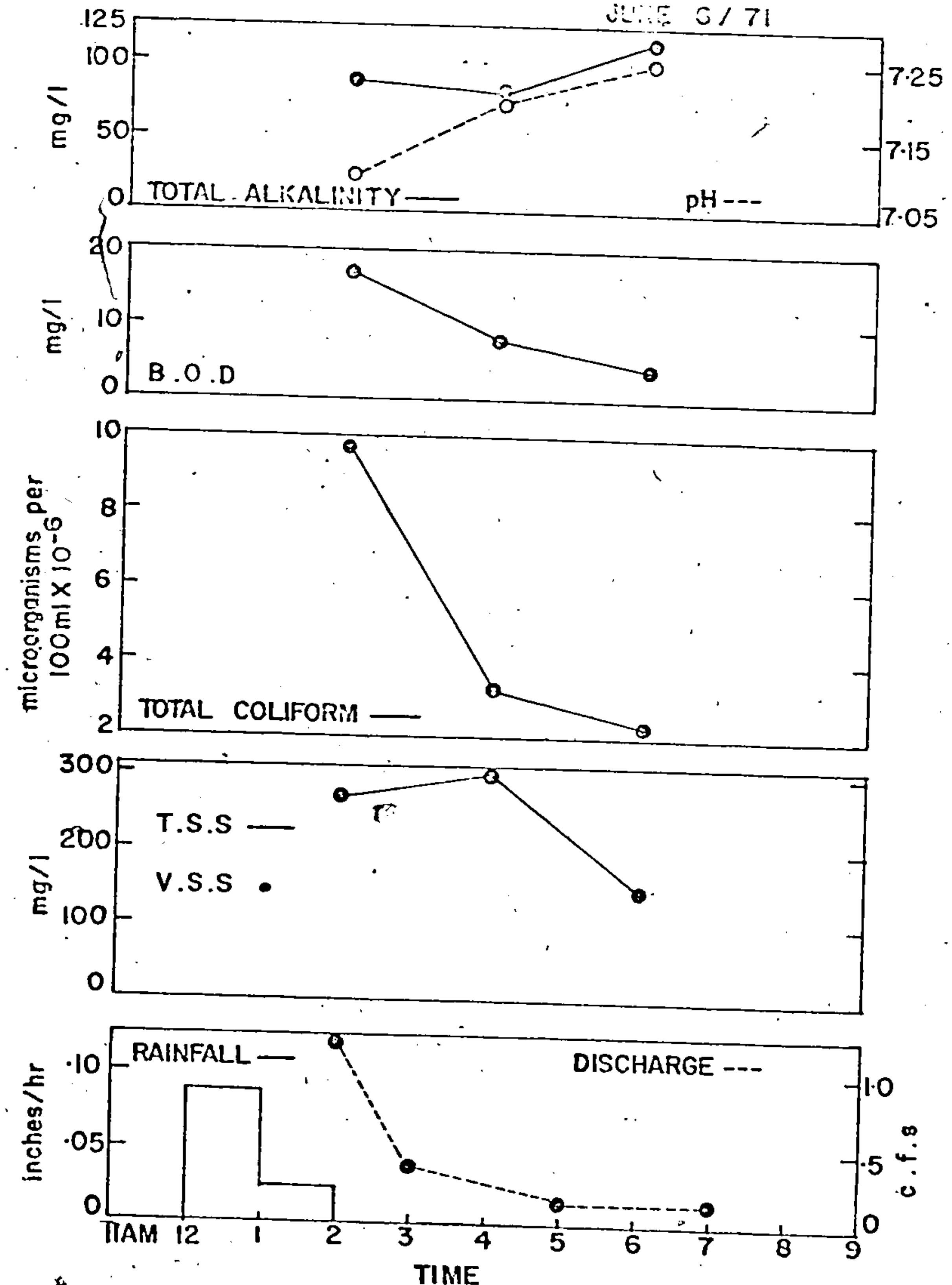


STORM WATER CHARACTERISTICS

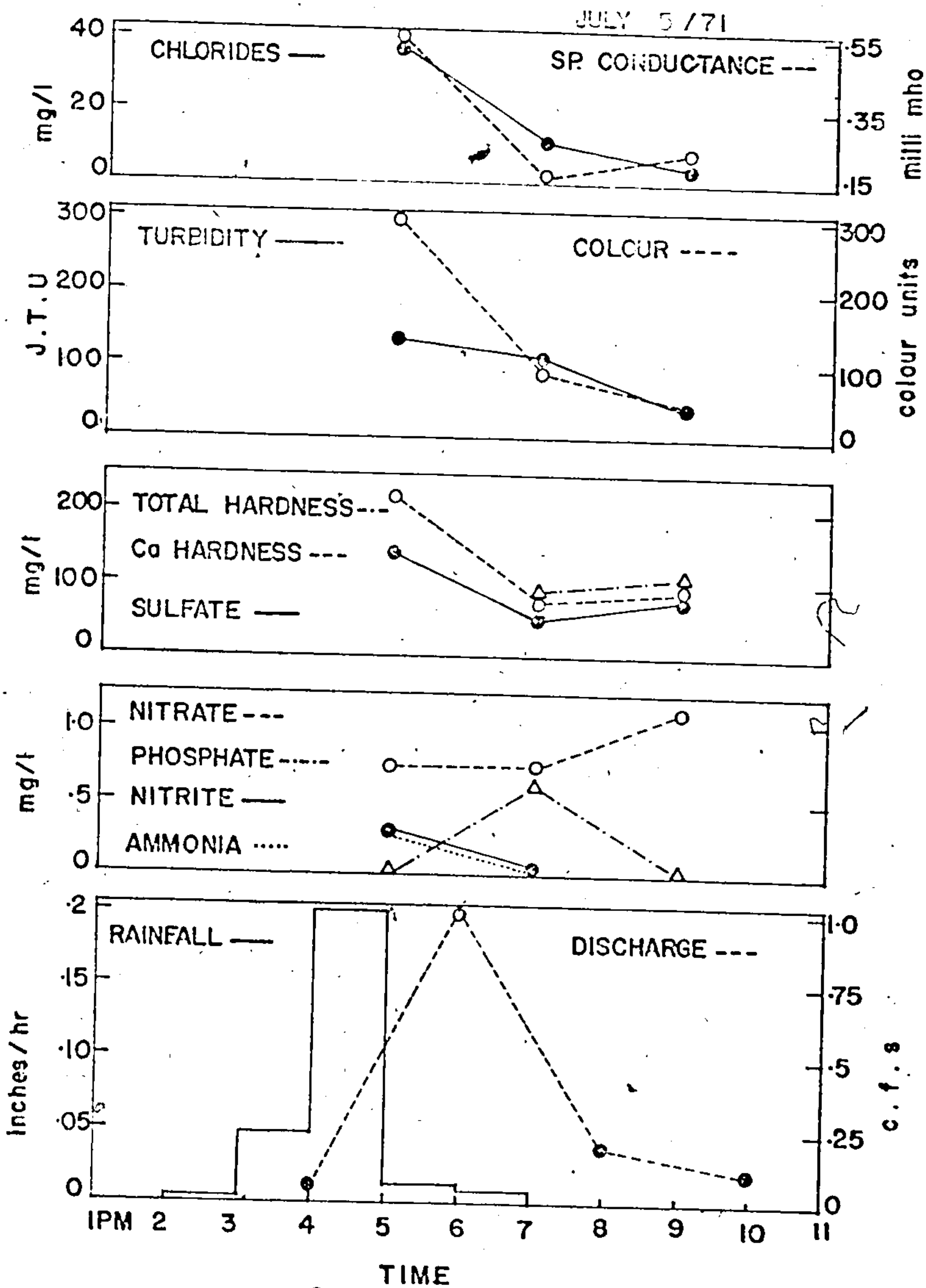
June 7, 1971

Rainfall Intensity between 6-7 p.m. = 0.61 inches/hours.

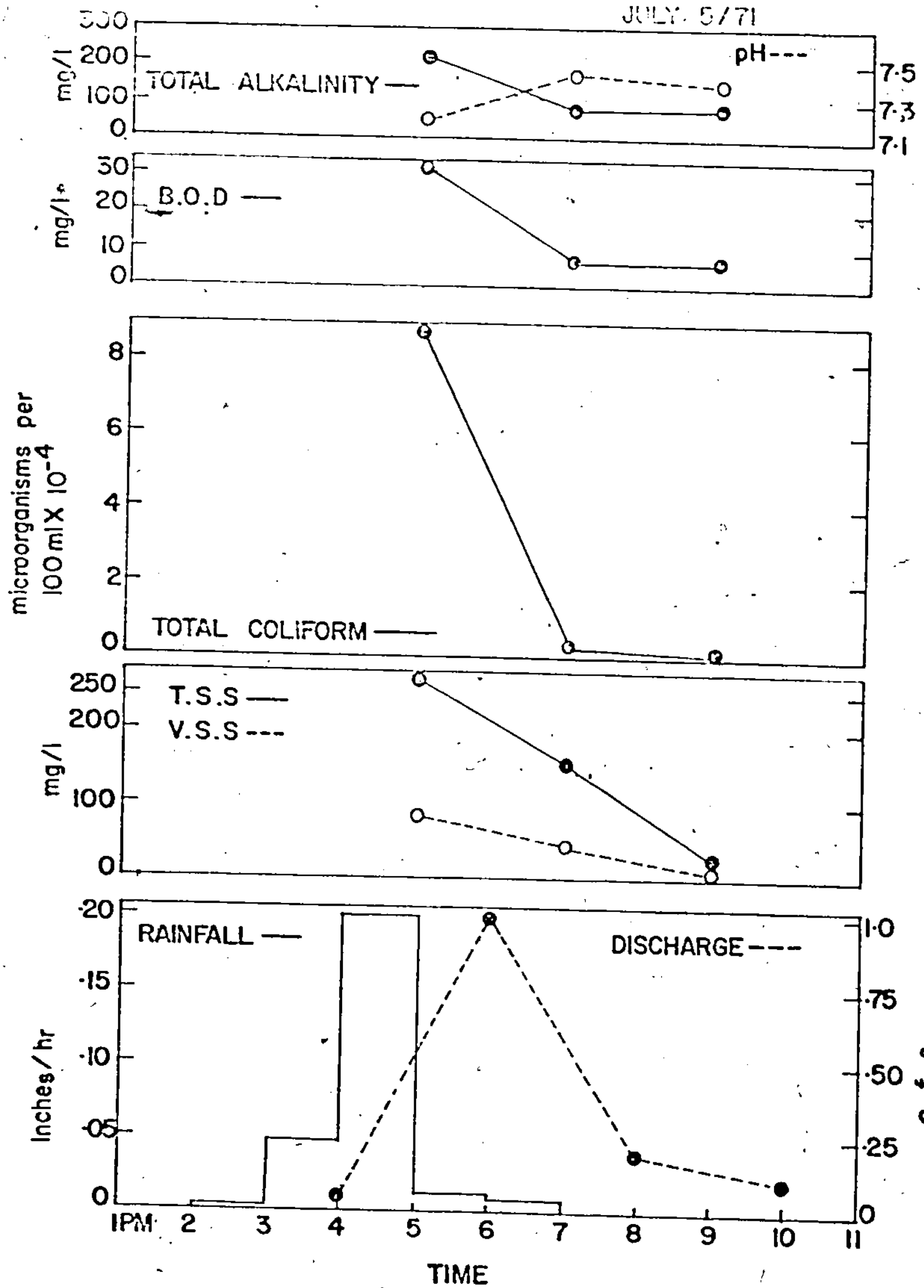
Average Discharge = 8.5 cfs

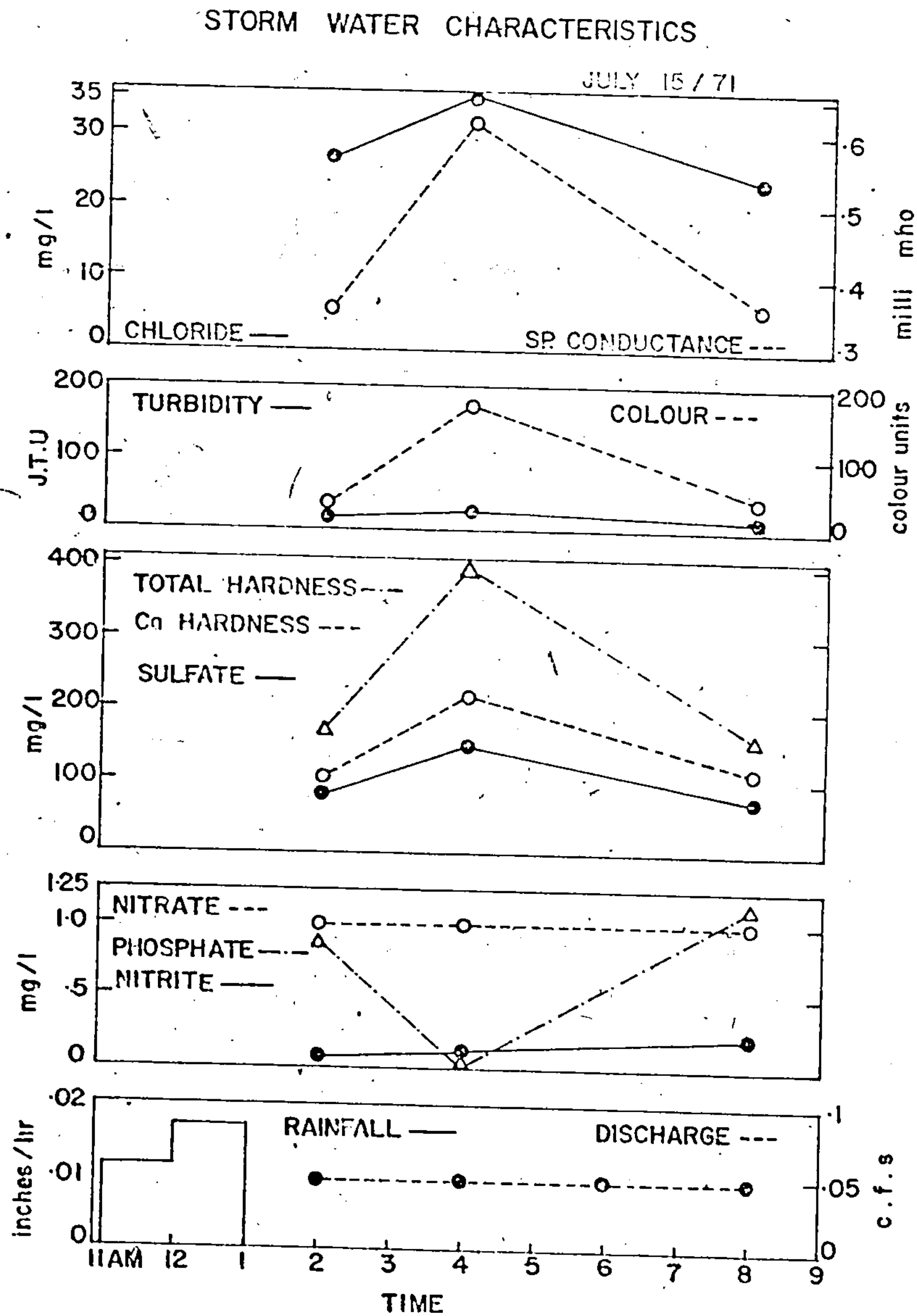
Constituent	Concentration
pH	8.30
P-Alkalinity, mg/l as $CaCO_3$	0
Total Alkalinity, mg/l as $CaCO_3$	72
B.O.D., mg/l	6
Coliform (Confirmed), MPN/100 ml	5,250,000
Fecal Coliform/100 ml	0
Colour, Units	1650
Turbidity, J.T.U.	1020
Specific Conductance, milli-mhos/cm	0.13
T.S.S., mg/l	4122
V.S.S., mg/l	350
Calcium Hardness, mg/l as $CaCO_3$	64
Total Hardness, mg/l as $CaCO_3$	72
Chlorides, mg/l	10
Sulfates, mg/l	50
Phosphates as PO_4, mg/l	3.50
Ammonia, mg/l N	Trace
Nitrates, mg/l N	4.50
Nitrites, mg/l N	0.125

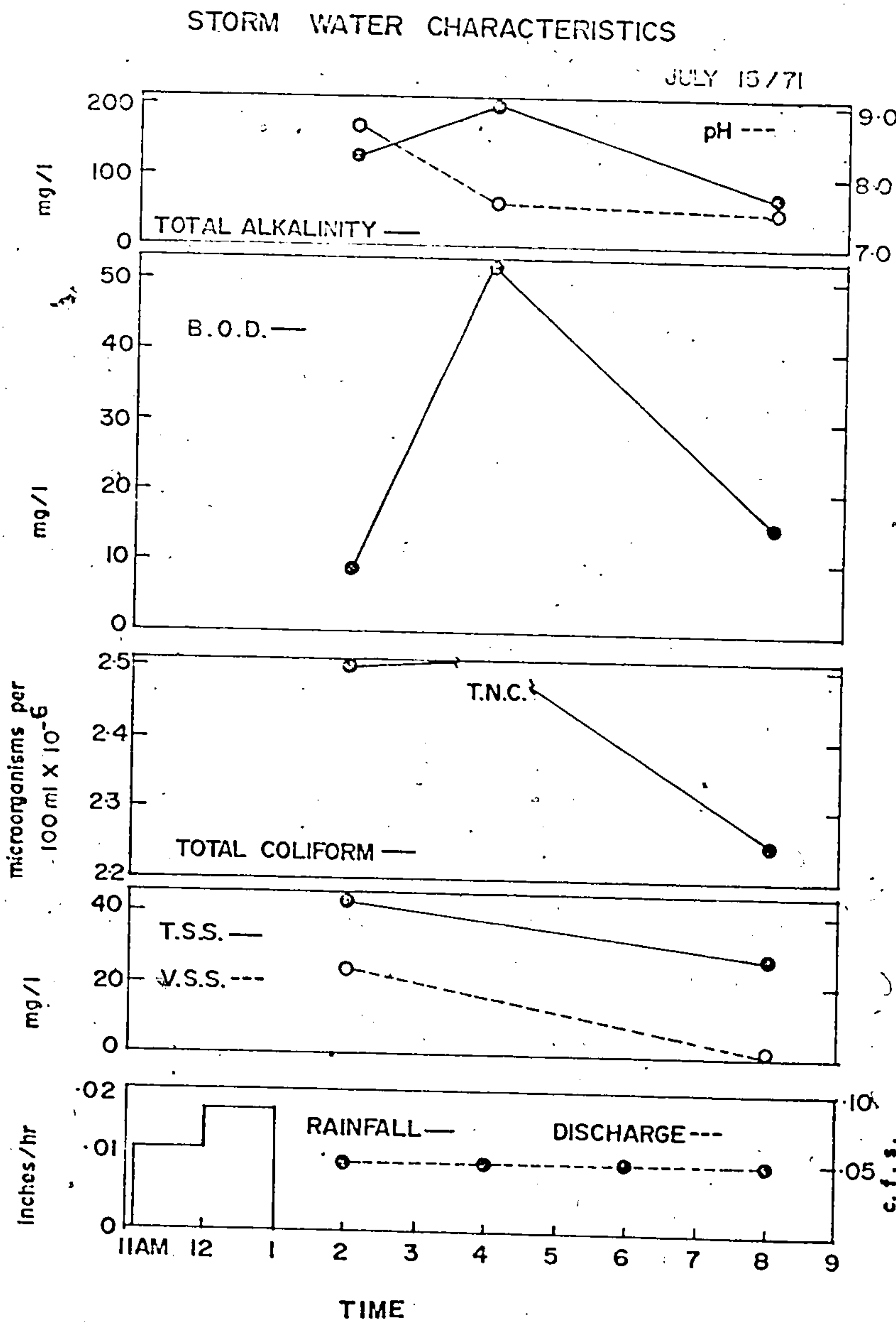
STORM WATER CHARACTERISTICS



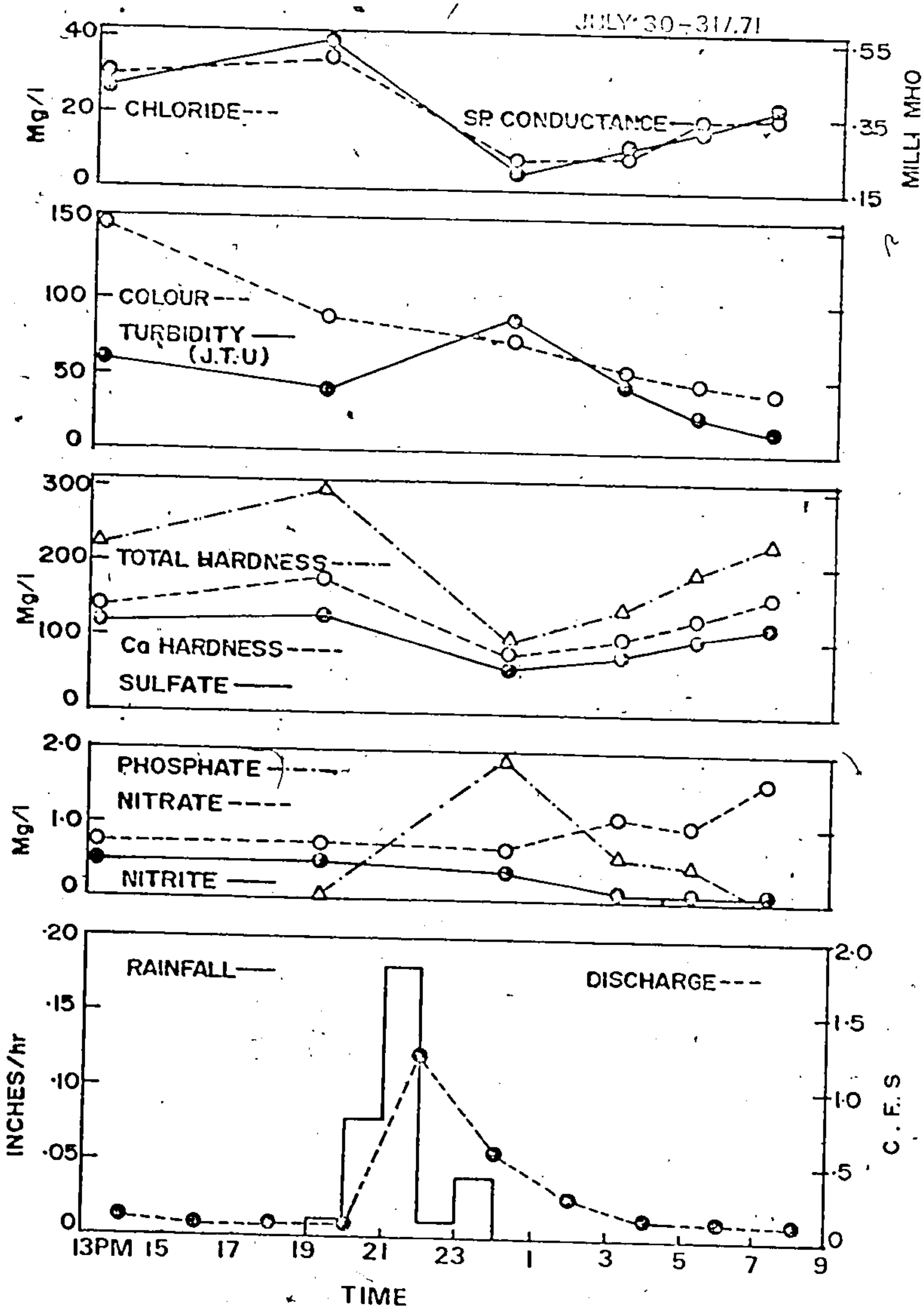
STORM WATER CHARACTERISTICS

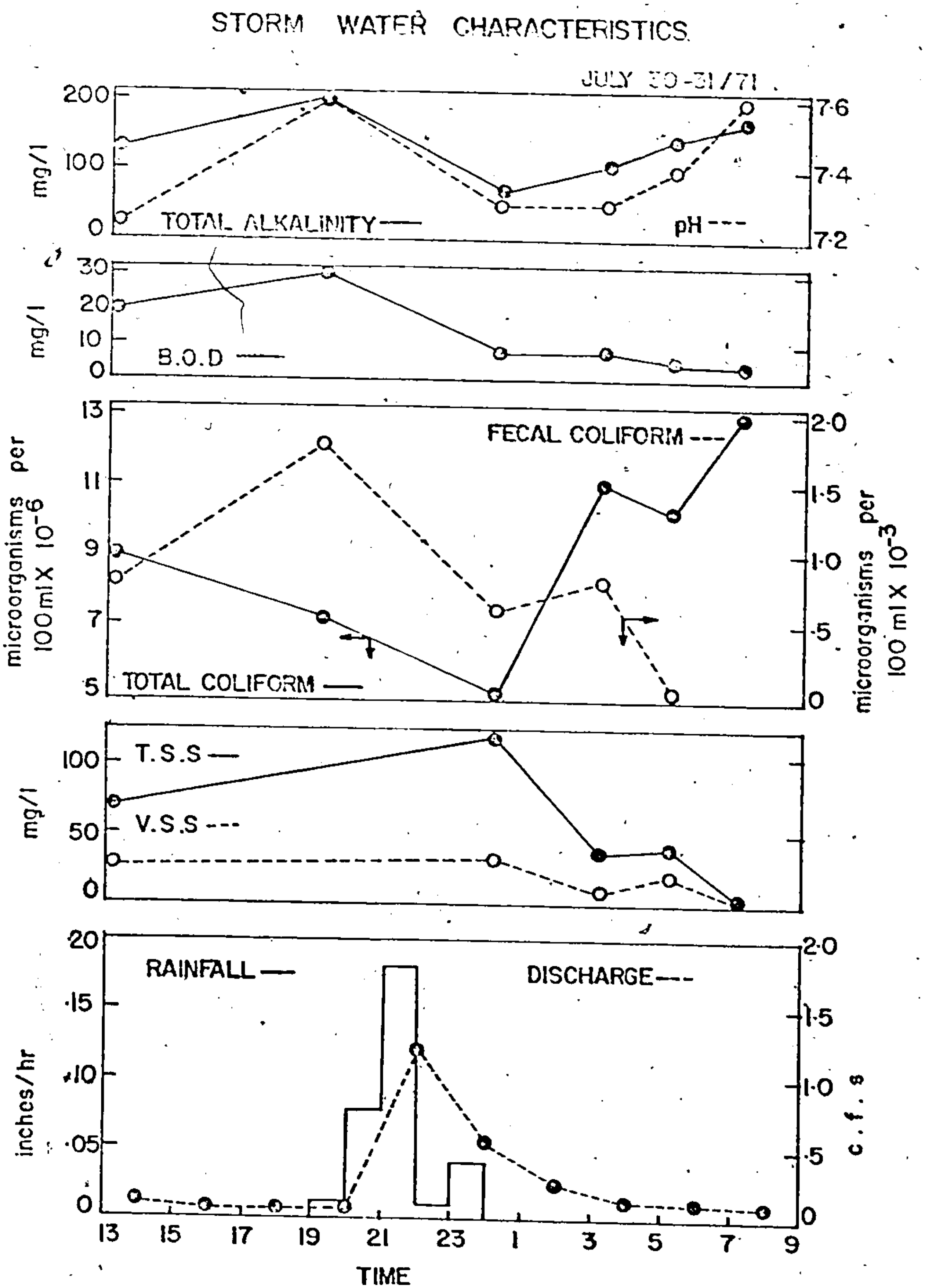



STORM WATER CHARACTERISTICS
JULY 15 / 71
CHLORIDE ——
SP. CONDUCTANCE ---
mg/l
milli mho
TURBIDITY ——
COLOUR ---
J.T.U
colour units
TOTAL HARDNESS -·-
Ca HARDNESS ---
SULFATE ——
mg/l
NITRATE ---
PHOSPHATE -·-
NITRITE ——
mg/l
RAINFALL ——
DISCHARGE ---
inches/hr
c.f.s
11AM
12
TIME


STORM WATER CHARACTERISTICS
JULY 15/71
200
100
0
mg/l
pH ---
9·0
8·0
7·0
TOTAL ALKALINITY —
50
40
30
20
10
0
mg/l
B.O.D. —
2·5
2·4
2·3
2·2
microorganisms per 100 ml X 10^-6
T.N.C.
TOTAL COLIFORM —
40
20
0
mg/l
T.S.S. —
V.S.S. ---
·02
·01
0
Inches/hr
RAINFALL —
DISCHARGE ---
·10
·05
c.f.s.
11AM
12
1
2
3
4
5
6
7
8
9
TIME

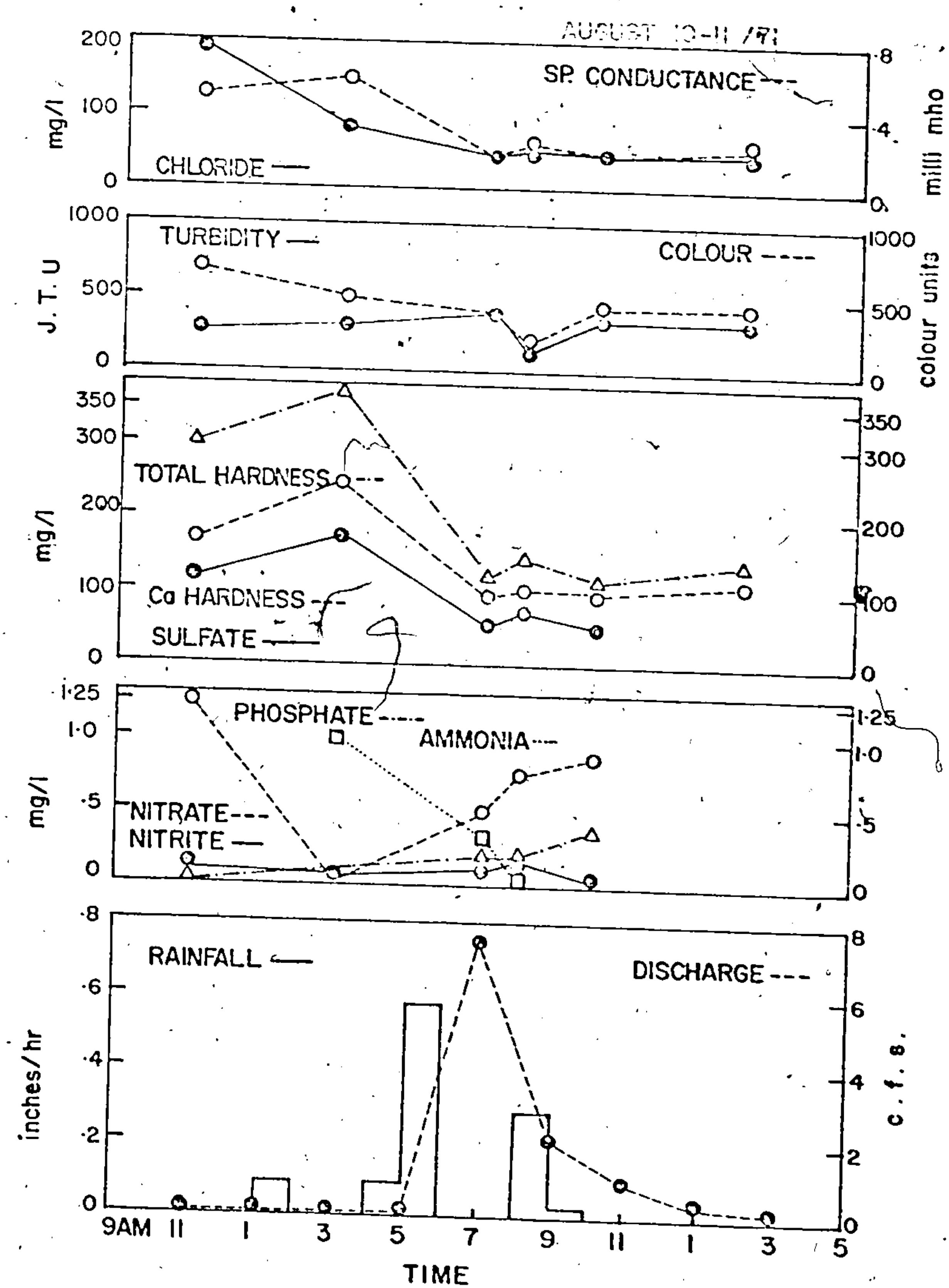
STORM WATER CHARACTERISTICS

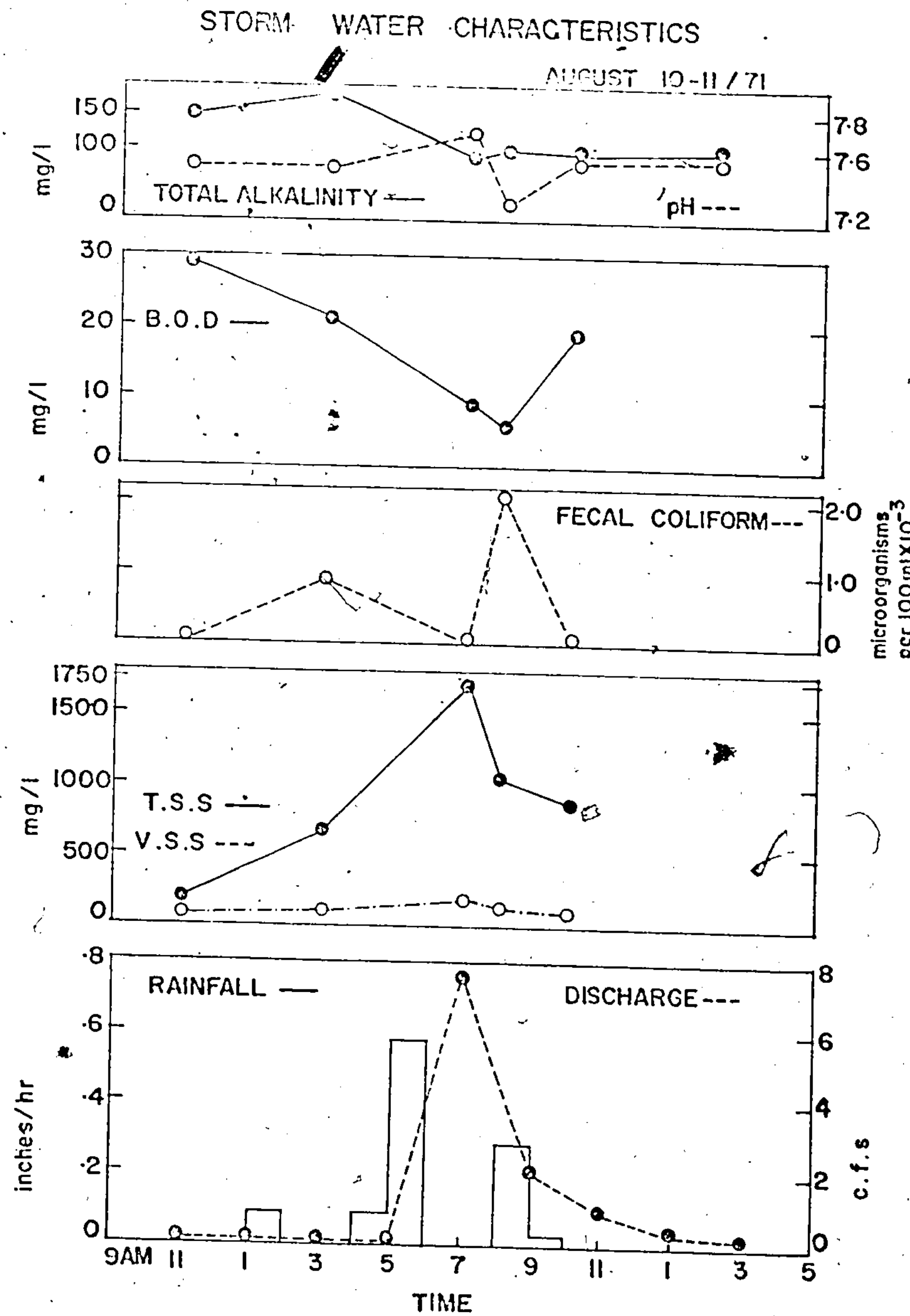




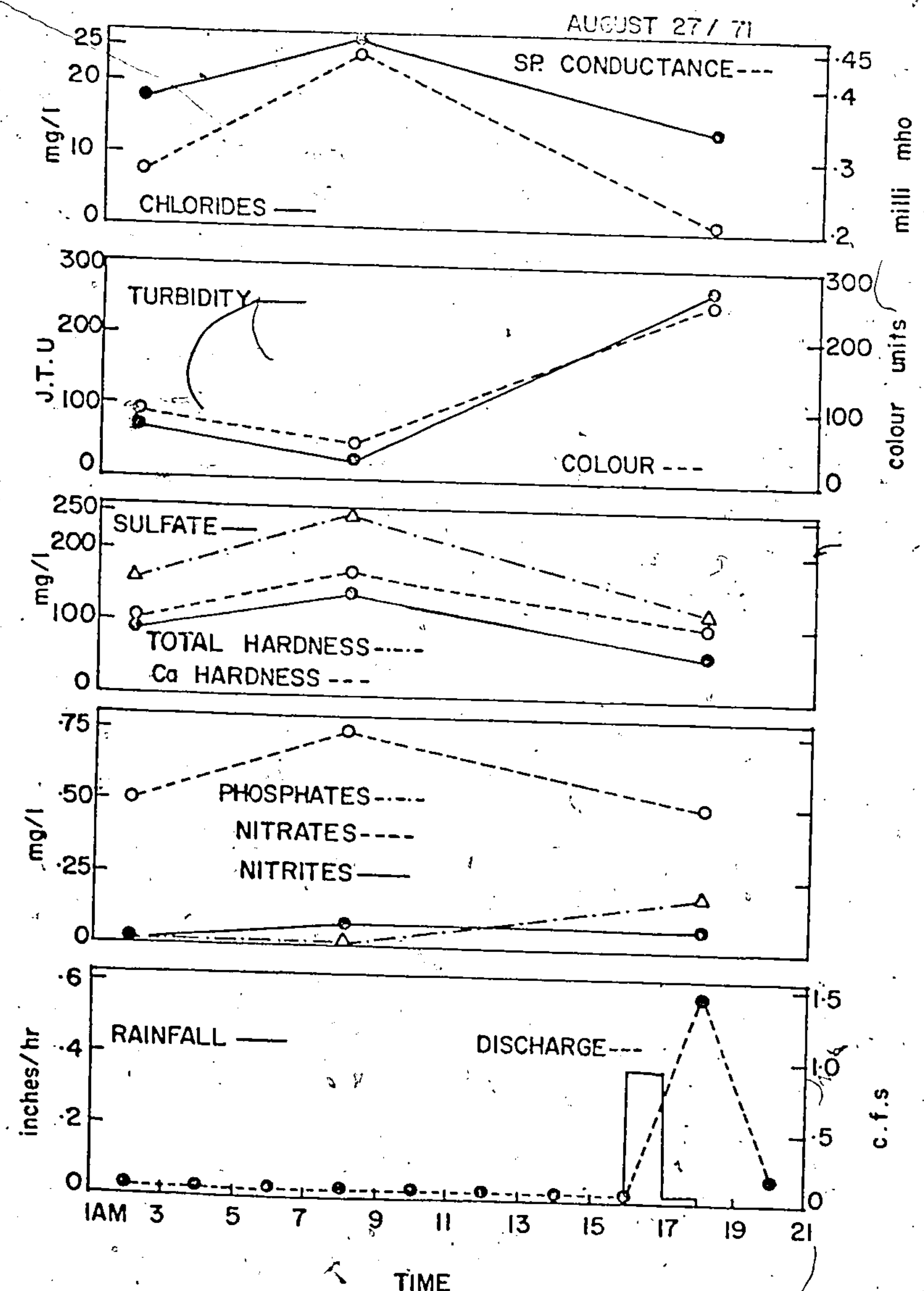
STORM WATER CHARACTERISTICS
JULY 30-31/71
200
100
0
mg/l
TOTAL ALKALINITY —
pH ---
7·6
7·4
7·2
30
20
10
0
mg/l
B.O.D —
13
11
9
7
5
microorganisms per 100 ml X 10^-6
FECAL COLIFORM ---
TOTAL COLIFORM —
2·0
1·5
1·0
·5
0
microorganisms per 100 ml X 10^-3
100
50
0
mg/l
T.S.S —
V.S.S ---
·20
·15
·10
·05
0
inches/hr
RAINFALL —
DISCHARGE ---
2·0
1·5
1·0
·5
0
c.f.s
13
15
17
19
21
23
1
3
5
7
9
TIME

STORM WATER CHARACTERISTICS

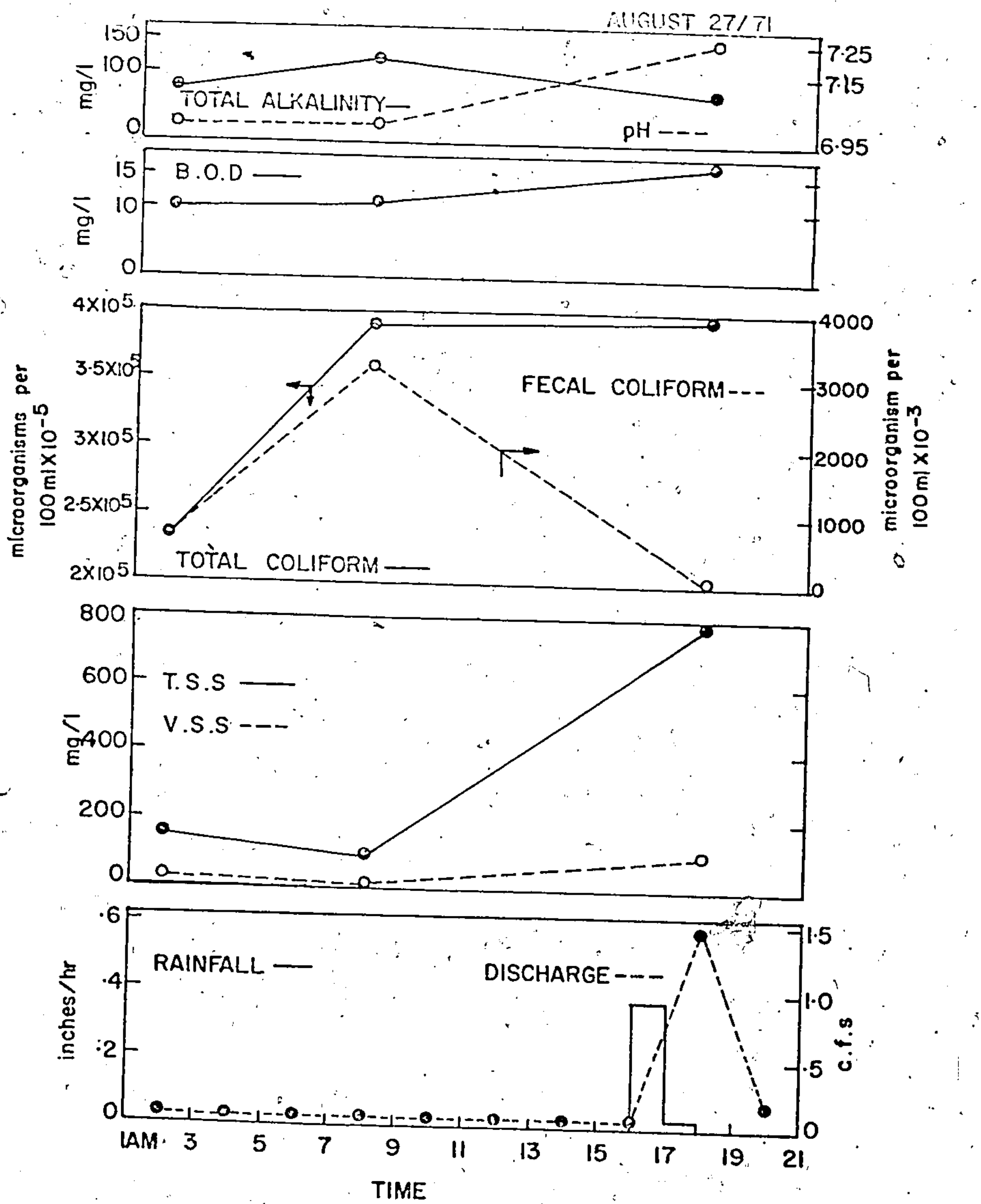



STORM WATER CHARACTERISTICS
AUGUST 10-11/71
150
100
0
mg/l
TOTAL ALKALINITY
pH
7.8
7.6
7.2
30
20
10
B.O.D
FECAL COLIFORM
2.0
1.0
microorganisms per 100ml X10^-3
1750
1500
1000
500
T.S.S
V.S.S
.8
.6
.4
.2
inches/hr
RAINFALL
DISCHARGE
8
6
4
2
c.f.s
9AM 11 1 3 5 7 9 11 1 3 5
TIME

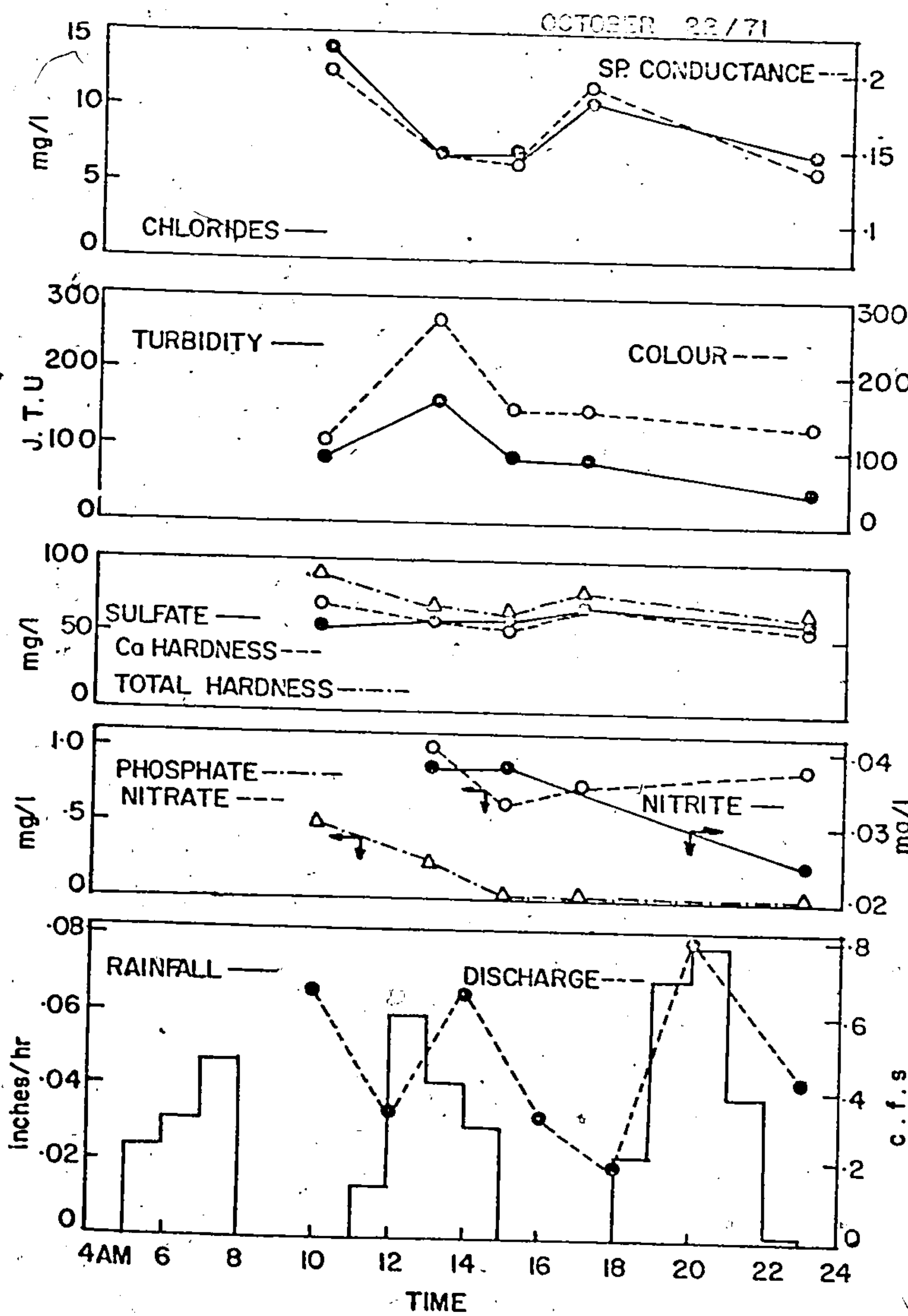
STORM WATER CHARACTERISTICS



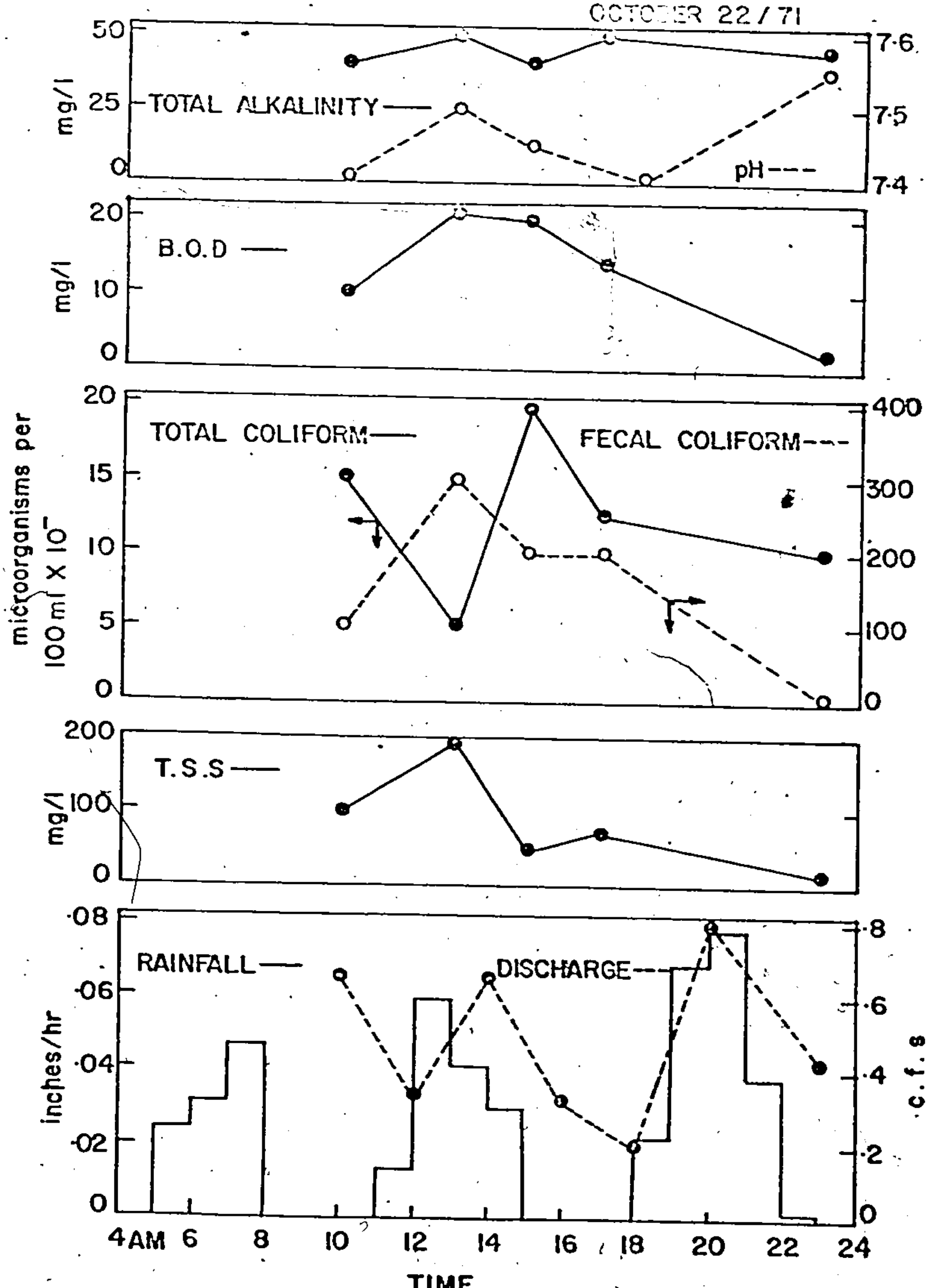
STORM WATER CHARACTERISTICS

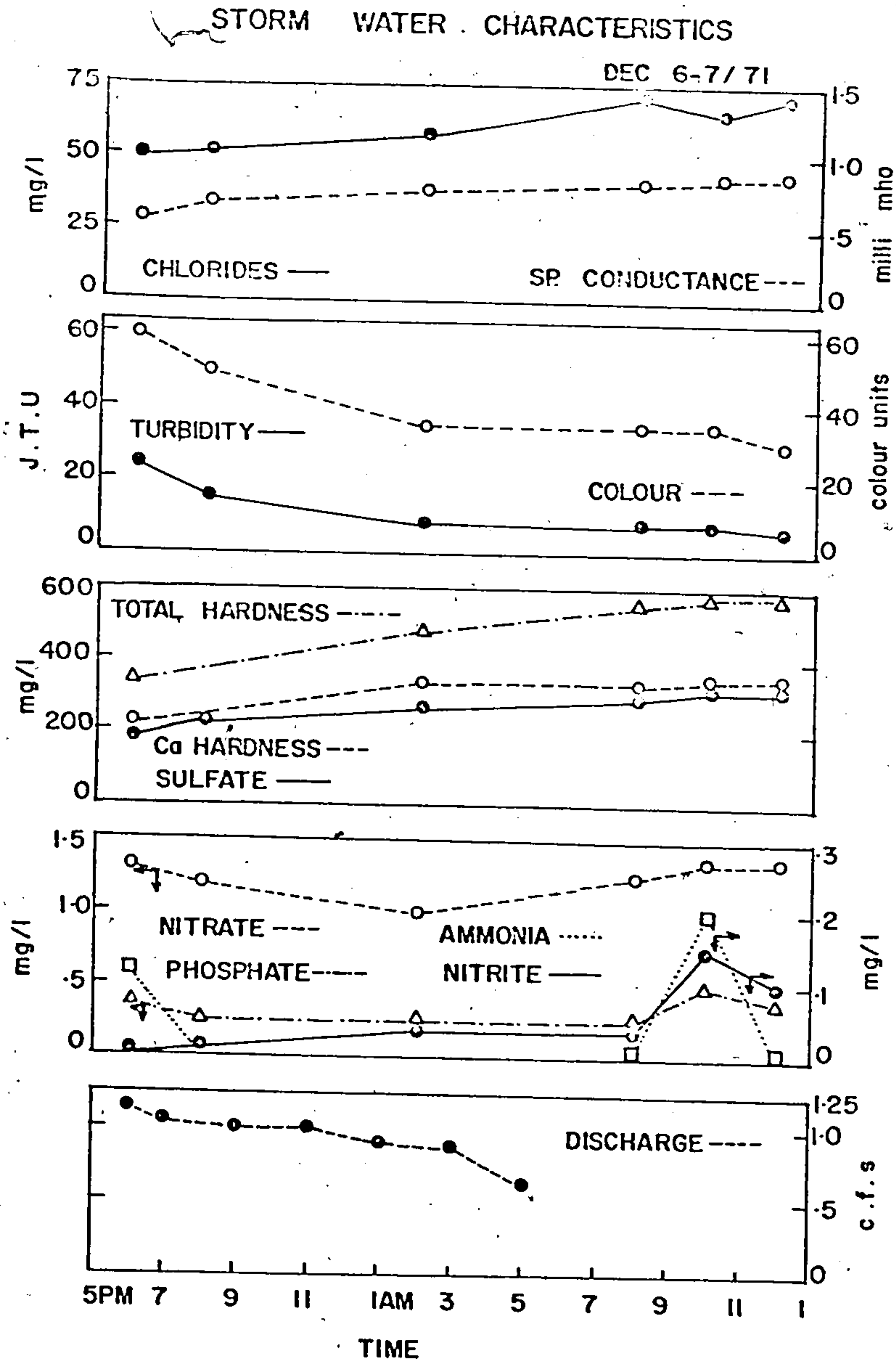


STORM WATER CHARACTERISTICS

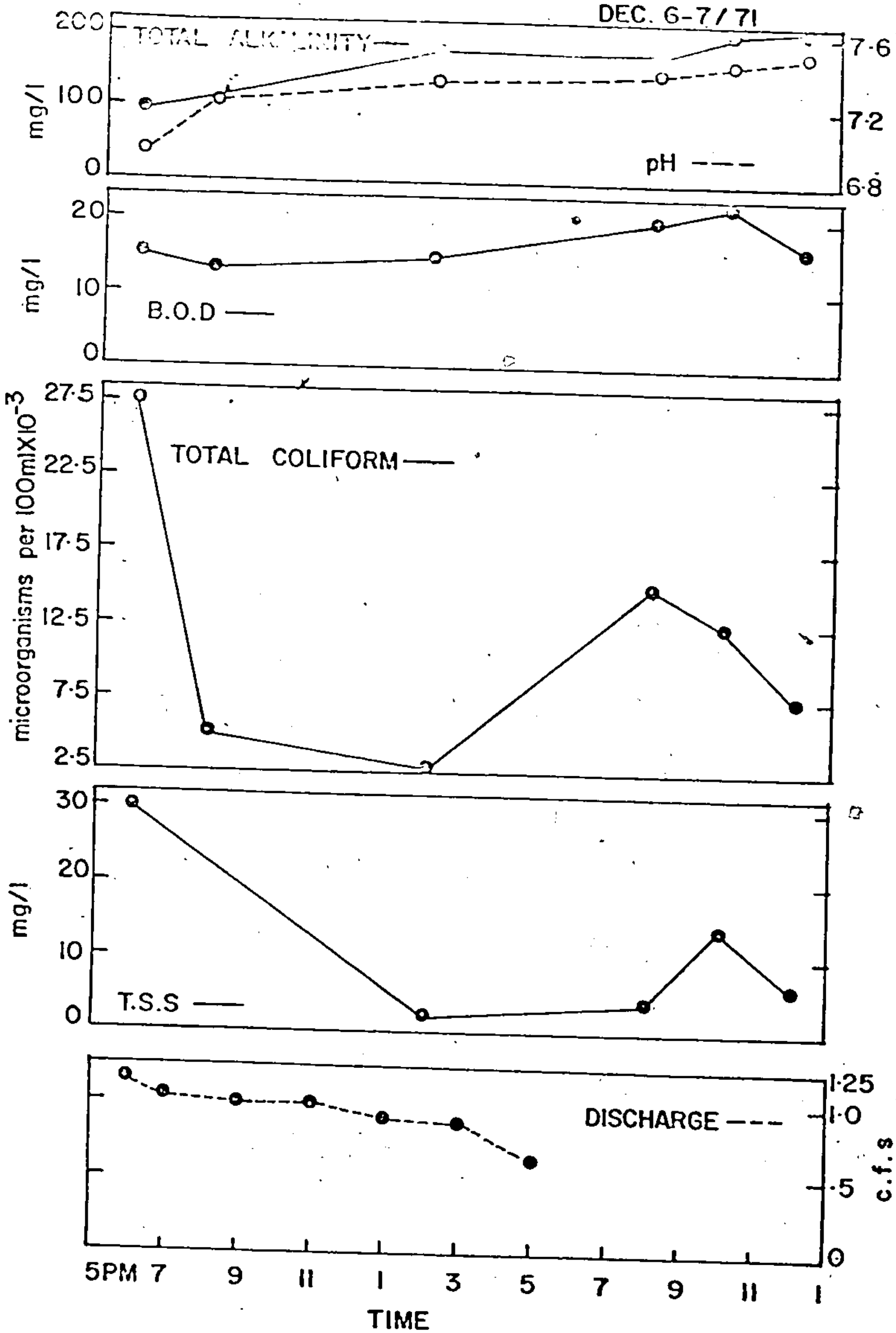


STORM WATER CHARACTERISTICS




STORM WATER CHARACTERISTICS
DEC 6-7/71
75
50
25
0
mg/l
1·5
1·0
·5
0
milli mho
CHLORIDES —
SP. CONDUCTANCE ---
60
40
20
0
J.T.U
60
40
20
0
colour units
TURBIDITY —
COLOUR ---
600
400
200
0
mg/l
TOTAL HARDNESS -·-·-
Ca HARDNESS ---
SULFATE —
1·5
1·0
·5
0
mg/l
·3
·2
·1
0
mg/l
NITRATE ---
AMMONIA ·····
PHOSPHATE -·-·-
NITRITE —
1·25
1·0
·5
0
c.f.s
DISCHARGE ----
5PM 7 9 11 1AM 3 5 7 9 11 1
TIME

STORM WATER CHARACTERISTICS



Mean Water Temperatures for the Storms Analyzed

No.	Date	Average Temperature in Centigrade
1	January 4-5, 1971	7
2	February 4-5, 1971	3
3	February 11-13, 1971	4
4	February 17-19, 1971	2
5	March 11, 1971	5
6	March 13-14, 1971	6
7	April 28, 1971	7
8	May 12, 1971	10
9	May 20-21, 1971	10
10	May 24-25, 1971	11
11	June 1-2, 1971	11
12	June 6, 1971	15
13	June 7, 1971	11
14	July 5, 1971	14
15	July 15, 1971	15
16	July 30-31, 1971	17
17	August 10-11, 1971	17
18	August 27, 1971	17
19	October 22, 1971	16
20	December 6-7, 1971	7

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