QUALITY OF URBAN STORMWATER RUNOFF:

AN APPRAISAL OF THE ROLE OF GULLY POT LIQUORS

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In memory of Eric Stanley Fletcher.

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(Chapter 5 only)

A = area

B = surface breadth

c = concentration

C_{sub} = specific concentrations

C_1, C_2, C_3 = Muskingum coefficients

d = pipe diameter

g = acceleration due to gravity

i = inflow

I = rainfall intensity

K = rate of release of settled sediments

k_s = roughness coefficient

L = pipe length

M = mass

P = percentage mixed

q = outflow

Q = flow rate, discharge

r = pipe radius

R = retention time

s_o = channel slope

s_f = friction slope

S = storage

t = time

V = volume

w = wave speed

x = downstream distance

y = water depth

α = storage routing coefficient

ε = Muskingum parameter

β = Muskingum parameter

Σ = the sum of

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DECLARATION

1) While registered as a candidate for the degree for which submission is made, the author has not been a registered candidate for any other award of the CNAA or of a University.

2) The candidate has completed three postgraduate courses:-

   a) Course leading to Part 1 of the Diploma of the Institute of Water Pollution Control.

   b) Course in computing methods.

   c) Course in statistical techniques.

3) The candidate has participated in the following colloquia:-

   a) First International Conference on Urban Storm Drainage, Southampton, April 1978.

   b) Symposium of the International Workshop on Rainfall-Runoff Processes Over Urban Surfaces, Institute of Hydrology, April, 1978.

ABSTRACT

The quantity and quality of stormwater runoff from a small separately sewered residential suburban catchment has been monitored for 24 storm events over an 18 month period. An automatically operated continuous injection lithium dosing apparatus in conjunction with an automatic sampling machine was used as a means of flow determination and sampling for quality measurements. The samples were analysed for several pollutants and the results enabled an estimate of the annual pollutant loads discharged from the catchment to be calculated. Using multiple linear regression the relationship of pollutant loads and concentrations with meteorological parameters was investigated. Conclusions have been drawn on the relative importance of parameters in defining pollutant loads, the mode of removal of pollutants, pollutant interrelationships and the significance of sources of pollution.

The quality of water stored in roadside gully pots on the same catchment was investigated over a two year period. This study and additional laboratory investigations have enabled detailed conclusions to be drawn on the impact of sources of pollution on the chemistry of the stored water and the effect of rainfall, dry periods, seasonal variations and human activity upon the quality of the stored water.

The removal of dissolved material and settled sediments from gully pots for different flow rates was investigated in the laboratory using purpose-built apparatus. The results obtained were used to develop and calibrate mathematical expressions describing the pollutant transport processes. In order that the equations could be applied to real catchments and storm events, it was necessary to develop a mathematical simulation of the rainfall-runoff process. The model developed employs a single linear reservoir for the prediction of an inlet hydrograph to the sewer system from a net rainfall hyetograph and the fixed parameter Muskingum-Cunge technique for routing the inlet hydrographs through a pipe network to form the outlet hydrographs. Inclusion in this model of the equations, describing the removal of water stored in roadside gully pots prior to the rainfall event, enabled the contribution of gully liquors to storm flow to be calculated.

Contemporaneous monitoring of rainfall and runoff and contemporaneous examination of the quality of stormwater runoff and the quality of water stored in gully pots provided the data necessary for utilising the model to determine the pollutant loads in stormwater runoff that are attributable to pollutants stored in gully pots.

1. INTRODUCTION

Only within the last decade has urban stormwater run-off been identified as an important source of pollution of natural water courses. All waste water was originally conveyed to sewage treatment works through what has been termed the combined sewerage system, that is, domestic waste, industrial effluent and stormwater run-off are transported through the same pipe network. However, during periods of heavy rainfall, when flows exceeded the capacity of the treatment works, sewage was discharged without treatment into adjacent water courses and resulted in cases of severe river pollution. To alleviate this pollution the adoption of separate sewer systems for new urban developments was advocated. In a separate system stormwater run-off is carried through an independent pipe network to that used for domestic waste and is discharged without treatment into a convenient water course, thereby relieving the river of polluting discharges of storm sewage overflow. Whereas in the combined system the quality of stormwater was obscured, in the separate system the true polluting potential of this run-off was revealed.

Originally, pollution of surface waters was largely governed by the discharge of poor quality sewage and industrial effluents. The advent of secondary and even tertiary treatment of these point sources of pollution has now rendered them less significant in determining river pollution. Therefore, the assessment of the quality of non-point or diffuse polluting sources such as rural and urban stormwater run-off has become of growing importance. The need to accurately characterise the extent of pollution arising from these sources can be seen to be of particular importance when the growing number of new urban developments drained by separate systems is considered.

Additionally, the last decade has seen an increase in public awareness and concern over pollution of the environment. This concern, combined with advances in our appreciation of the deleterious effects of water pollution on the environment and on public health, has led to the recognition of water as being a national resource of great value. The result has been a trend towards an integrated approach to the management of the Nation's water resources. To assist in this approach mathematical simulation has been increasingly utilised as a management tool to predict the quantity and behaviour of pollutants in the environment. Such techniques require an in-depth quantitative knowledge of pollutant concentrations and the processes involved in their accumulation, formation and entry into water-courses. Consequently, the need for detailed information on these polluting processes is as great as ever and previously neglected sources of pollution, such as urban run-off, have assumed some considerable importance.

1.1. THE POLLUTION OF STORMWATER RUN-OFF

The pollution of stormwater results from the contamination of rainwater from the time of its origin in the atmosphere until the moment of its discharge into a receiving body of water. The variation in quality of the run-off may be brought about by such a wide variety of different events and processes that the complex changes in water chemistry that result are difficult to predict. In broad outline pollution of stormwater run-off may be attributed to the following principal sources:-

a) Open land - contributes wind blown dust and soil particles which accumulate in roadside gutters. Additionally it acts as a source of nutrients and micro-organisms. In heavy storms run-off can occur directly off open land resulting in high solids loads.

b) Natural vegetation - results in the accumulation of leaves in the Autumn and other decaying vegetable matter during the rest of the year.

c) Roof and road surfaces - are sources of inorganic solids, cement, sand, bitumen and other erroded road material. Additionally, they act as collecting areas for other pollutants.

d) Motor traffic - is a source of oil, petrol, exhaust gases, lead and other particles from car bodies and tyres.

e) Human activity - results in the accumulation of litter, detergents from car washing, garden fertilisers, grass-cuttings, herbicides, pesticides and salt used for de-icing in the winter.

f) Animal activity - leads to the deposit of faeces and urine on impervious surfaces.

g) Factories and chimneys - sources of dust and gaseous emissions in the atmosphere that subsequently settle or are washed down in rainfall.

The inter-relation of the sources and the processes at work in the accumulation of pollutants on impervious surfaces is illustrated diagrammatically in Figure 1. The relative importance of these sources at any given location is governed by the type of land use (urban, industrial, commercial) and by individual catchment characteristics such as impervious area, slope and local soil type.

For any given storm event the degree of pollution is determined by the following factors:-

a) The characteristics of the storm event, e.g. volume, intensity and duration.

b) The antecedent weather conditions. The length of the preceding dry period determines the mass of pollutants accumulated on impervious surfaces and the quality of water stored in gully pots. Temperature can affect the degree of degradation of organic matter by micro-organisms and in winter the process of road surface erosion by frost action. The wind direction can influence the degree of atmospheric pollution to be expected from adjacent industries.

c) The time of year. This defines the type of antecedent weather conditions to be expected, the type of human activity to be expected (road salting in winter, grass cutting in summer) and the type of biological activity expected (leaf fall in autumn).

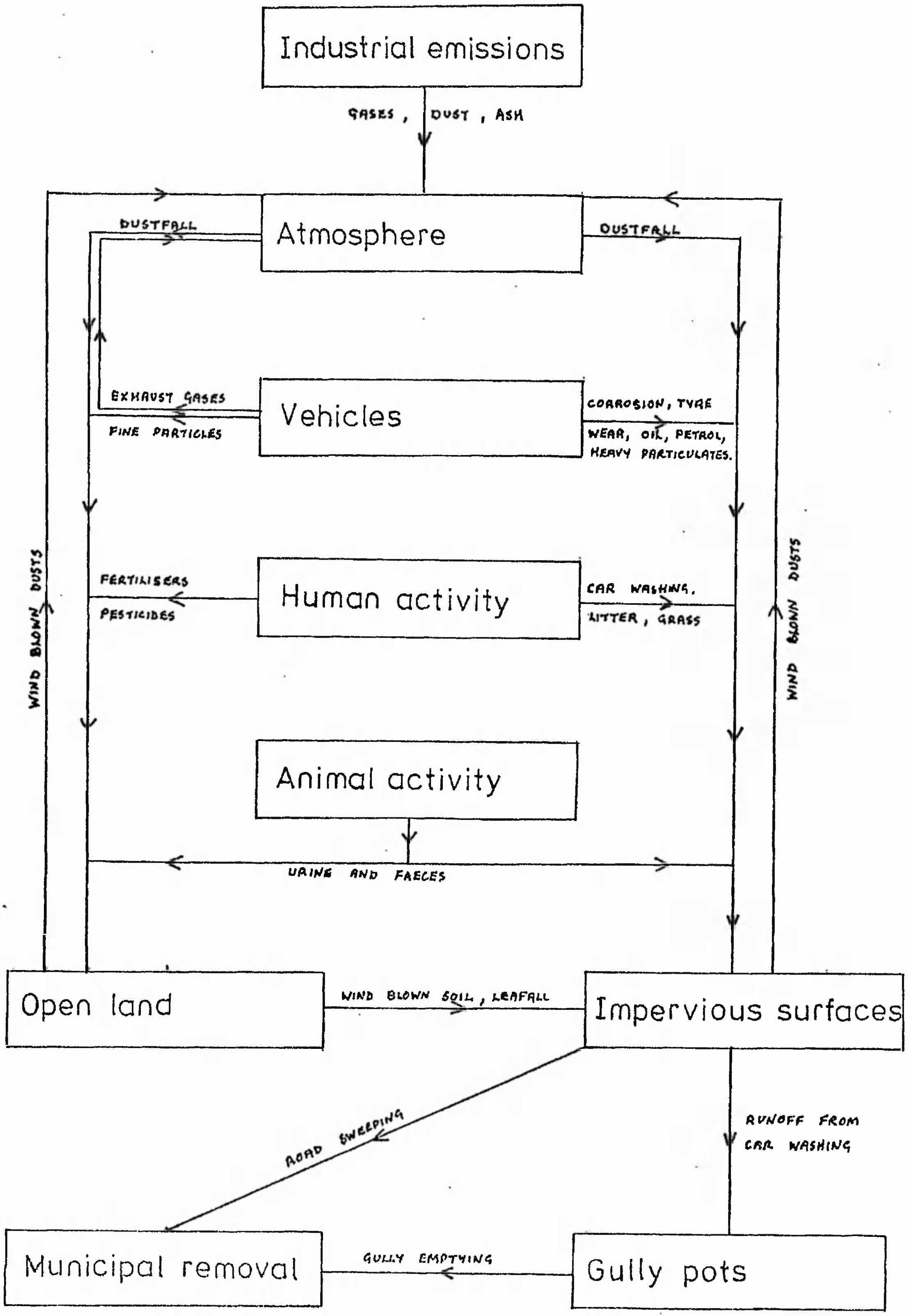
d) The effectiveness of council cleansing operations.

1.2. LITERATURE REVIEW

1.2.1. Introduction

Although, prior to 1970, considerable research effort had been expended on the efficient design of stormwater systems, little attention had been paid to the quality of stormwater run-off and the polluting impact of these discharges on water courses. However, recognition of the severe magnitude of pollution derived from combined sewer overflows and the introduction of separate stormwater systems initiated a flood of

Fig. 1 POLLUTANT ACCUMULATION AND REMOVAL PROCESSES ON URBAN SURFACES OVER A DRY PERIOD



research projects on the problems of urban stormwater pollution. By the middle of the decade several countries had identified problem areas, formulated national priorities and initiated research projects (UNESCO, 1974). Research was particularly active in the U.S.A., where, under the Environmental Protection Agency's Storm and Combined Sewer Technology program, over 90 million dollars was awarded to some 140 projects (Field and Gardner, 1978). In comparison, the research effort in the U.K. has been minimal and is considered separately in Section 1.2.2. All published work in stormwater research (system design, stormwater quality, management practices, etc.) has been reviewed annually since 1973 in the Journal of the Water Pollution Control Federation (Field et al, 1973 - 1979). In the field of stormwater quality researchers have addressed a wide variety of problem areas, these have been conveniently considered under the following headings:-

a) Pollutant concentrations and loadings.

b) Sources of pollution

c) Impact of stormwater runoff on watercourses.

d) Modelling and predicting the quality of stormwater runoff

e) Control of pollution.

1.2.2. Summary of Research into the Quality of Stormwater Runoff in the United Kingdom.

The earliest study on the quality of runoff from a separate system of drainage was conducted by Wilkinson (1956) on a small suburban housing estate at Oxhey, Hertfordshire. The problems of urban stormwater pollution uncovered by his study received no further attention until 1970 when the Technical Committee on Storm Overflows and the Disposal of Storm Sewage, whilst acknowledging that high pollutant loads could occur from industrial catchments, advocated the use of separate sewer systems for new urban developments. The magnitude of runoff pollution from industrial areas was soon confirmed by a study of the River Tame which drains a substantial portion of industrialised Birmingham (Lester et al 1971). A discrepancy between pollutant loads in the river and the loads predicted from all known sources was noted by Garland and Hart (1971), the excess load was attributed to polluted runoff from urban surfaces. Horner et al (1975) considered the problem of stormwater pollution from London. They concluded that the massive improvement in quality of the River Thames resulting from improved sewage treatment facilities left stormwater discharges as the major deleterious effect on water quality. Tucker (1975) reported results on the discharge of suspended solids from two suburban catchments in Nottingham and confirmed many of Wilkinson's earlier observations. Additionally, he presented some measurements on the quality of waters stored in roadside gully pots. The results indicated that gully pots could harbour highly polluting liquors which could be rapidly discharged at the start of a storm. These preliminary observations were further investigated by this research project which was initiated in Autumn 1975. The influence of stormwater runoff on an urban streamway in Hendon, Greater London, was investigated by Ellis (1976, 1977). He paid particular attention to the nature of particulate material and stressed its significance in determining the polluting potential of runoff. The quality of runoff from a busy urban motorway in Birmingham was the attention of a study by Hedley and Lockley (1976). They recorded extremely high pollutant loadings over the year and reported winter road salting and motor vehicles to be the most significant pollution sources. In 1977 the Working Party on Storm Sewage (Scotland) (Nicholl and McGillivray) recommended a return to the construction of combined sewer systems in Scotland. Significant financial savings and the poor quality of stormwater runoff influenced their decision. The results of a project funded by the Department of the Environment and conducted at the Water Research Centre were presented in two papers (Water Research Centre (1977)), Mance and Harman (1978)). Storm runoff from the whole of Stevenage New Town and from a purely residential sub-catchment were monitored over a period of three years. In addition to concentration and loading data, the effect of stormwater discharges on receiving streams, some approaches to the control of pollution and a comparison with a hypothetical combined system were also considered. The preliminary findings of the research presented in this thesis on the quality of water stored in roadside gully pots were published in 1978 (Fletcher et al). Also in 1978 the quality of runoff from a predominantly industrial catchment at Newcastle was the attention of short study by Adams (1978). Significant pollutant loads were recorded.

1.2.3. Pollutant Concentrations and Loads in Stormwater Runoff

The earliest studies on pollution of stormwater runoff were confined to qualitative aspects alone. Palmer (1950) gathered grab samples of runoff at catch basins in Detroit, U.S.A., and found B.O.D's up to 234 mg/l, total solids up to 914 mg/l and coliform MPN's/100 ml of 930,000. Similarly, Shigorin (1956) evaluating street runoff in Moscow and Leningrad found B.O.D's of 285 mg/l and suspended solids of 14,541 mg/l. Akerlindh (1950) looked at runoff from streets and parks in Stockholm and recorded COD's up to 3,100 mg/l, total solids of 3,000 mg/l, BOD's of 80 mg/l and coliforms up to 200,000 per 100 ml. These early studies served to indicate the possible magnitude of pollution of stormwater runoff, however, it became apparent that, to meaningfully evaluate the significance of stormwater runoff, it was necessary to monitor not only the quality of runoff, but also the quantity and, thereby, to compute the actual mass of pollutants discharged to watercourses. Wilkinson (1956) was the first to measure stormwater flow at the same time as sampling for quality determination and his studies pointed the way for future work. There is now a large bank of published work on pollutant concentrations and loadings from a variety of different catchment types and different storm events. Some of the more important studies, in chronological order, are:-
Weibel et al, (1964); Pravoshinsky and Gatillo, (1966); Burm, (1978); De Filippi and Shih, (1971); Soderlund and Lehtinen, (1972); Bryan, (1972); Waller, (1972); Whipple et al, (1974); Kluesener and Lee, (1974); Droste and Hartt, (1975); Tucker, (1975): Hedley, (1976); Holbrook et al, (1976); Whipple and Hunter, (1977); Cordery, (1977); Mills, (1977); Water Research Centre, (1977); Roberts et al, (1977); Randall et al, (1977); Malmquist and Svensson, (1977); Wanielista, (1977); Ellis, (1977); Fletcher et al, (1978); Lindholm and Balmer, (1978); Mance and Harman, (1978); Bedient et al, (1978); Rimer and Reynolds, (1978); Helsel et al, (1979).
The wide variability in concentration of pollutants that can occur is illustrated in Tables 1 and 2, where mean and maximum concentrations for selected studies have been listed. Comparison of pollutant loading rates from different studies is not straightforward and is frequently hindered by the lack of uniformity and, in some instances, the unreliability of the methods employed to obtain the data. Some authors have used an average loading rate per unit of rainfall or runoff to compute the annual pollutant load discharged from the catchments. Again, methods used to

TABLE 1 Mean and Maximum concentrations of pollutants in stormwater runoff from residential areas (in mg/l)

CONSTITUENT	OXHEY U.K. Wilkinson 1956		CINCINATTI, USA Weibel, 1964		ANN ARBOR, USA Burm, 1968		DURHAM, USA Bryan, 1972		STOCKHOLM Soderland, 1972	
	Mean	Max.	Mean	Max.	Mean	Max.	Mean	Max.	Mean	Max.
Suspended solids	376	2045	210	1200	2080	11,100	3930	13,900	122	500
Volatile solids	27%	70%	53	290	218	570	426	1,100	80	360
Dissolved solids									489	2000
COD			99	610			224	660		
BOD	20	100	19	84	28	62	31.3	232	13	25
Nitrate nitrogen			0.4	1.5	1.5	3.6				
Ammoniacal nitrogen			0.6	1.9	1.0	2.0				
Phospate			0.8	4.3	5.0	16.4	0.55	2.5	0.09	0.3
Chloride			12	35			18	390	168	320
Lead							0.67	1.85	1.0	3.0

TABLE 1 (continued)

CONSTITUENT	WINDSOR, CANADA Droste, 1975		STEVENAGE, U.K. Mance, 1978		ATLANTA, USA Holbrook, 1976	OSLO, NORWAY Lindholm, 1978	ZURICK, CHR Roberts, 1977
	Mean	Max.	Mean	Max.	Mean	Mean	Mean
Suspended solids	279	1230	112	1386	428	929	59
Volatile solids	112	392				72	
Dissolved solids			258	390			
COD					71	74	37
BOD	20.5	78.4			9		9
Nitrate Nitrogen	1.2	4.7	1.7	6.9	0.38		1.1
Ammoniacal nitrogen	0.05	0.71	0.28	6.0	0.15		0.4
Total nitrogen			2.0	7.6		2.3	1.8
Phosphate					0.35	0.3	0.22
Chloride	72	1585	49	1008			
Lead			0.205	3.7	0.13	0.07	0.14
Zinc			0.271	1.63		0.10	0.16
Copper			0.028	0.35		0.03	0.014

TABLE 2 Mean and maximum concentrations of pollutants in stormwater runoff from other catchment types (in mg/l)

CONSTITUENT	STOCKHOLM, SWEDEN Soderland, 1972		BIRMINGHAM U.K. Hedley, 1976		CRAMLINGTON, UK Adams, 1978		ATLANTA USA Holbrook, 1976	OSLO, NORWAY Lindholm, 1978
	Highway		Urban Motorway		Industrial/Res.		Industrial/Res.	Commercial
	Mean	Max.	Mean	Max.	Mean	Max.	Mean	Mean
Suspended solids	282	1000	999.5	5700	225	2070	323	1038
Volatile S. Solids	132	600	28.2%	1400				189
Dissolved Solids	855	2800			196	1630		
COD					124	1520	63	244
BOD	36	90	29.5				12	
Nitrate nitrogen							0.24	
Ammoniacal nitrogen							0.26	
Total nitrogen	2.1	4.0					0.57	4.2
Phosphate	0.08	0.3			0.53	2.5	0.35	1.2
Chloride	261	360	2592	70,000				
Lead	10	100	2.08	11.5	0.19	0.54	0.27	0.82
Zinc			3.2	14.5				1.73
Copper			0.68	2.5				0.52

TABLE 3 Estimated annual pollutant loads discharged from urban catchments calculated using impervious area and annual rainfall (kg/ha/yr)

CONSTITUENT	OXHEY. UK Wilkinson 1956	HUCKNALL UK. Tucker, 1975	RISE PARK UK. Tucker 1975	B'HAM U.K. Hedley 1976	ZURICH, CHR Roberts 1977	SHEPHALL, UK. Mance, 1978	CRAMLINGTON UK Adams 1978
	Residential	Residential	Residential	Motorway	Residential	Residential	Industrial
Suspended solids	580	342	692	6289	460	148	646
Volatile S. solids	157			1556			
Dissolved solids						168	581
BOD	23			173	71		
COD					280		451
Nitrate nitrogen					8.5	1.2	
Ammoniacal nitrogen					3.0	0.96	
Phosphate					1.7		2.1
Chloride				11611		28	
Lead				12.9	0.89	0.041	0.33
Zinc				19	1.1	0.066	
Copper				3.7	0.11	0.016	

TABLE 4 Estimated annual pollutant loads discharged from urban catchments where the method of calculation is not known (kg/ha/yr)

Constituent	WINDSOR CANADA Droste 1975	DURHAM, USA Bryan, 1972	STOCKHOLM, SWEDEN Soderlund 1972	STOCKHOLM, SWEDEN Soderlund, 1972	CINCINATTI USA Weibel, 1964	TWIN RIVERS Whipple 1978	TWIN RIVERS II USA Whipple 1978	SYDNEY AUSTRALIA Cordery, 1978
	Residential	Mixed	Highway	Residential	Residential	Residential	Residential	Residential
Suspended solids	609	18000	1185	620	803	816	1479	286.3
Volatile S. solids	198	9634	860	490	166			
Dissolved solids			2040	930				
BOD	24.1	94.1	100	43	37	90.1	32	17.2
COD		1165			264	44.2	193	
Nitrate nitrogen	1.25					6.4	1.5	
Ammoniacal "	0.67					4.4	6.2	2.29
Total nitrogen			5.1	3.45	9.8			
Phosphate		4.09	0.2	0.16	2.75	7.6	95	2.86
Chloride	75.4	81.8						
Lead		2.5				1.2	0.38	
Zinc						1.91	185	
Copper						0.58	0.38	

estimate these values have varied considerably and have not always been reported in the literature. Some of the factors which may lead to variation in the estimation of annual loading rates are:-

a) Storm sampling. For the computation of storm loads sampling should ideally be conducted at short time intervals throughout each event, however, some reported loading data has been obtained using only a few grab samples per storm.

b) The number of storms used to estimate the annual load. When only a limited number of events are available to compute the annual load, the representative nature of these events must be questioned. As an example, Tucker (1978) quotes two widely different estimated annual loads for the Rise Park catchment, 692 and 325 kg/ha/annum, the first figure includes the results of one particularly heavy thunderstorm, the second figure excludes this one storm.

c) The use of total or impervious catchment area.

d) The annual rainfall used will vary from catchment to catchment.

e) Use of discharge volume instead of rainfall to compute the average load per unit of run off.

Bearing in mind the limitations outlined above, Table 3 presents some estimated annual pollutant loads, where the impervious area was used in their calculation. Table 4 presents other figures from the literature where the method of calculation is not known. Again the figures show a wide variability in the pollutant loads discharged.

1.2.3.1. Shape of the Pollutant Runoff Curve

The initial stages of storm runoff are frequently characterised by the occurrence of high concentrations of pollutants. This effect has been termed the "first flush" and was first observed by Wilkinson (1956) and has since been confirmed by other workers. Tucker (1975) considered the first flush to be the removal, independent of rainfall intensity, of fine solids accumulated on the catchment area since previous storms. The duration of the flush and the recorded concentrations were considered to be dependent upon the flow rate, (Figure 2). Another explanation for the first flush was tentatively provided by Ellis (1976), who observed the occurrence of peak solids concentration prior to the flood peak for the Silk Stream catchment in Greater London. He explained the phenomenon firstly by the settlement of solids on the antecedent storm recession that are rapidly flushed out on the rising limb of the storm wave, and secondly, by mats of fungus and slime in the sewer that act as filters trapping large amounts of fine particulates, these mats are subsequently broken up and loosened by the initial phases of runoff (Figure 3). Another source of first flush material is roadside gully pots or catch basins (American Public Works Association, 1969). Poor quality supernatant liquors stored in the basins can be rapidly flushed out during the early stages of runoff.

The first flush is primarily a concentration effect. The actual mass of pollutant transported, in grams per second, is strongly related to flow rate. The occurrence of high pollutant concentrations at low flow rates, a situation that is typical for the first flush, can be of less significance when overall storm loads are considered. This is illustrated in Figure 4 where the removal of phosphate shows a first flush effect in concentration that is masked when the mass transported is considered (Cordery, 1977).

The first flush is not a constant feature of all storm events and its duration or occurrence has not been defined quantitatively. Wilkinson (1956) empirically considered it to be the first 30 minutes of runoff, however, he noted the variability of the effect:-

> "in many storms runoff water remained fairly dirty for a considerable time and water discharged throughout the storm was stronger than the first flush of other storms"

Mance and Harman (1978) similarly defined the first flush as being the occurrence of the peak concentration within the first 40 minutes of runoff and observed this to occur for 80% of the events monitored. A dimensionless cumulative plot has been employed by Bedient et al (1978) to give a representation of the first flush effect (Figure 5). A steeply rising curve at the start of an event with a slope greater than 1 is indicative of a first flush.

In subsequent runoff, solids concentrations are normally related to discharge, occurring, either coincident or more typically, lagging just

Fig. 2 THE FIRST FLUSH, FLOW INDEPENDENT, REMOVAL OF SUSPENDED SOLIDS (SS) FOR A STORM AT RISE PARK, NOTTINGHAM (AFTER TUCKER, 1975)

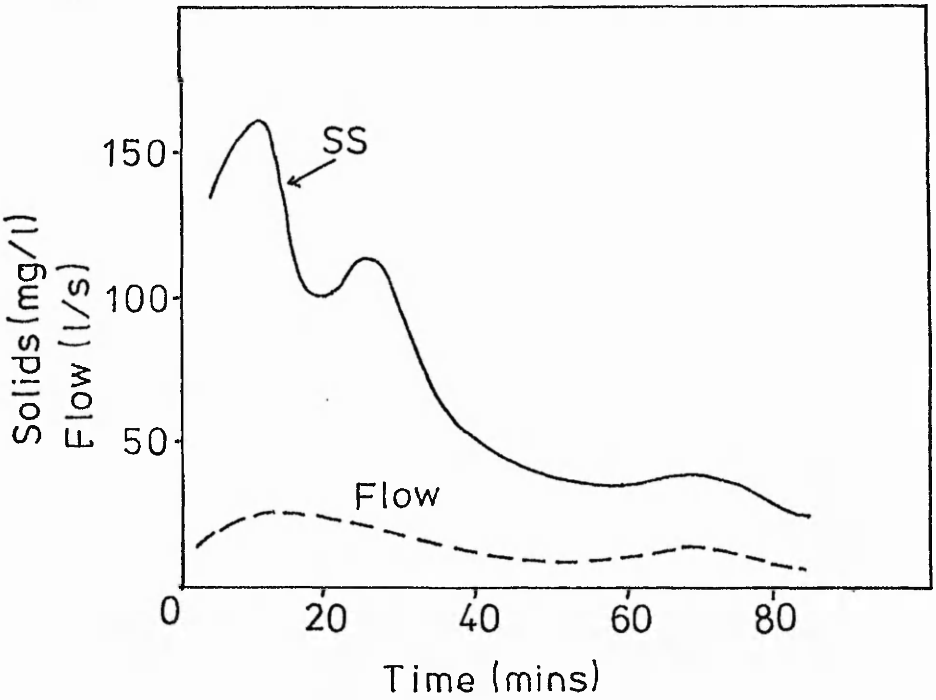


Fig. 3 COMPARISON OF THE REMOVAL OF PHOSPHATE IN TERMS OF CONCENTRATION AND INSTANTANEOUS STORM LOAD (AFTER CORDERY 1976)

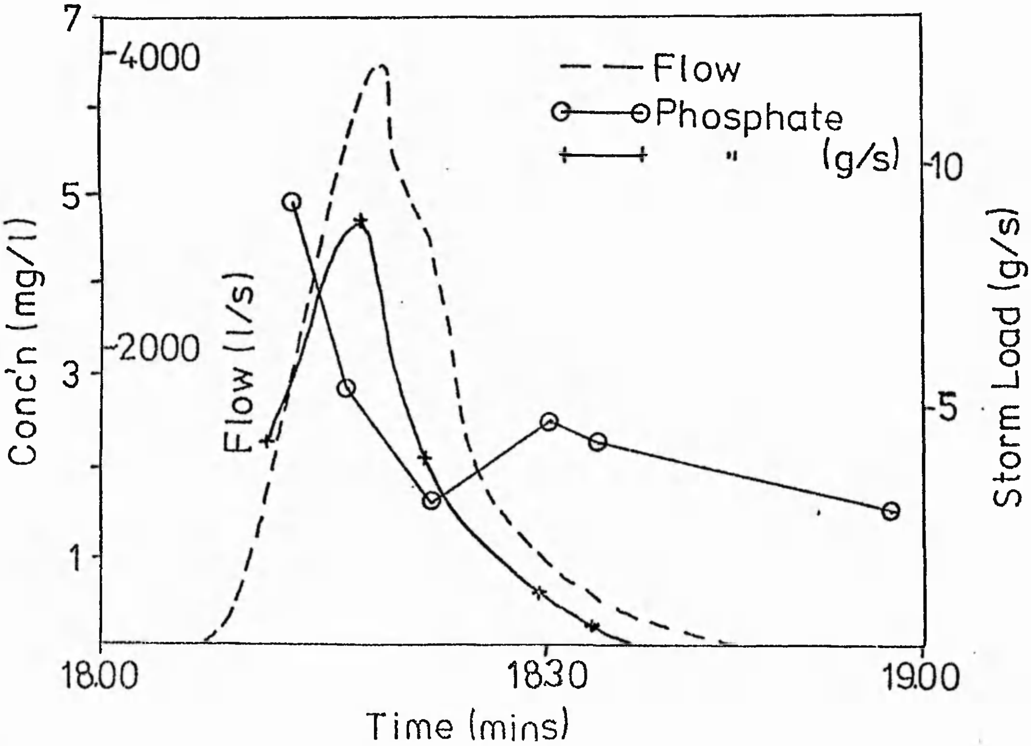


Fig. 4 FIRST FLUSH AND FLOW RELATED REMOVAL OF SUSPENDED SOLIDS (AFTER ELLIS, 1976)

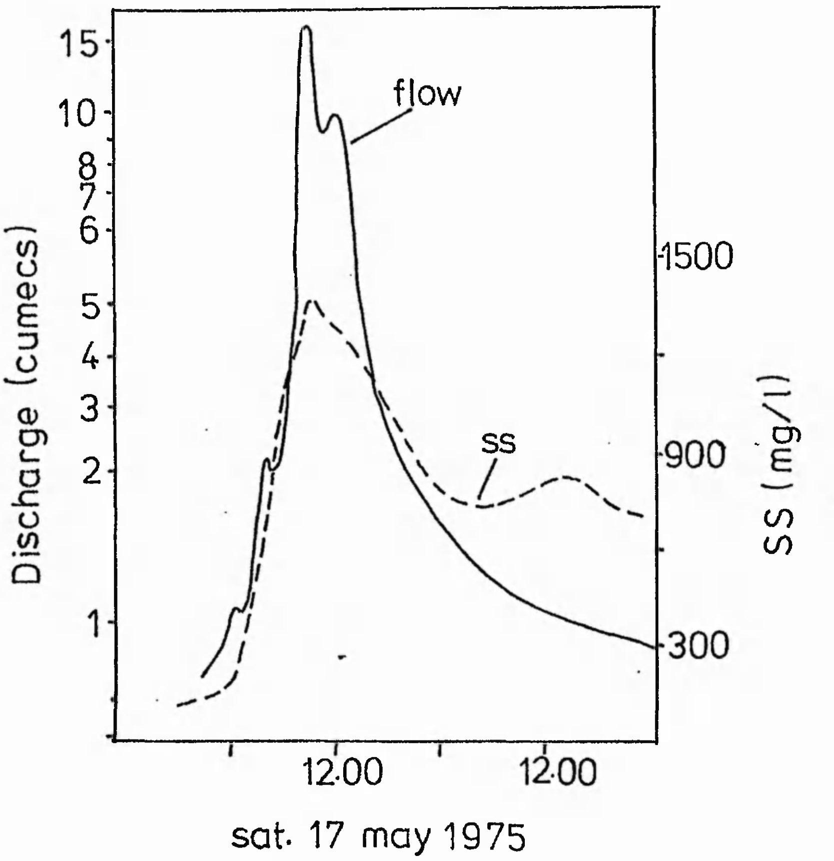
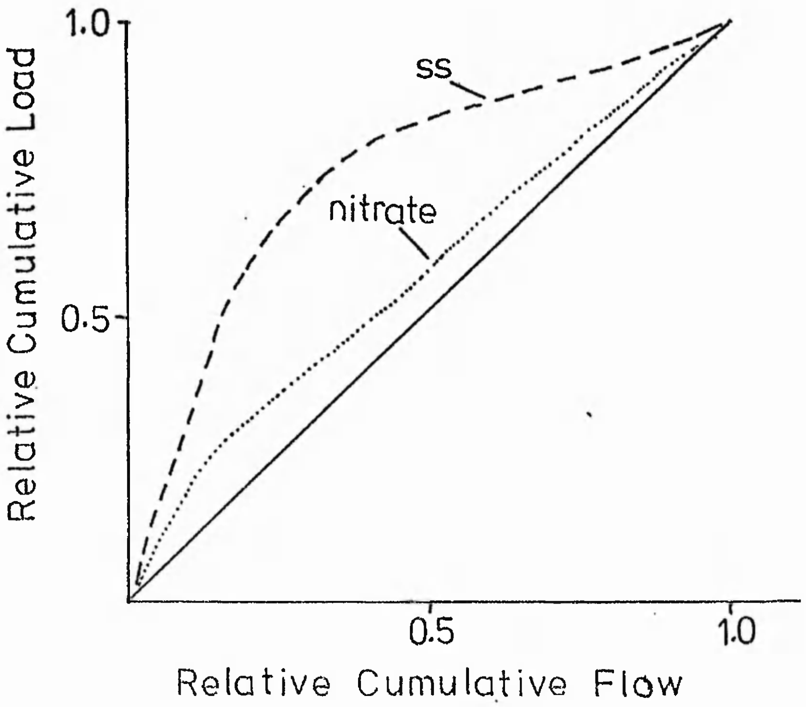


Fig. 5 DIMENSIONLESS CUMULATIVE LOAD PLOT ILLUSTRATING A STRONG FIRST FLUSH OF SUSPENDED SOLIDS



behind the flow peaks. This effect has been tentatively explained by different vertical velocity and concentration profiles that are developed in the sewer. The position of mean solids concentration in a cross-section may be below the position of mean flow velocity and as a result the velocity of solids transport is less than that of the fluid. This results in a lag between flow and concentration peaks. In storms of long duration or of high rainfall intensity, the catchment may be stripped of all particulate material that is available for release. This exhaustion of material results in low solids concentrations in the latter stages of a storm that are unrelated to flow rate. Other parameters that are usually associated with solids, such as BOD, COD, heavy metals and phosphates, have been shown to follow a similar pattern of runoff to that outlined above (Cordery, 1977). However, there is a tendancy for the ratio of oxygen demand to solids concentration to decrease during a storm. This can be ascribed to the removal of the lighter organic fractions that exert a greater oxygen demand in the earlier phases of runoff.

The concentration of dissolved solids and other soluble species in runoff, such as nitrates, ammonia, etc., show little relationship with flow rate. Their concentrations tend to steadily decrease throughout a storm event with the highest concentrations occurring in the first flush phase (Figure 6).

No hard and fast rules can be applied to the shape of a pollutant runoff curve in relation to the discharge hydrograph. Although regression analysis has demonstrated that the concentration of parameters can be linearly related to the rate of discharge, a wide variability exists between storm events (Mance and Harman, 1978). The prediction of pollutant concentrations from hydrological data is therefore unreliable.

1.2.3.2. Relationship of Pollutant Loads with Meteorological Parameters

Recent studies employing multiple regression analysis have demonstrated that the characteristics of the current rainfall-runoff event are the dominant factors determining the pollutant loads discharged from a given catchment. The results of Mance and Harman (1978) indicate that, with the exception of chloride and ammonia, 60% to 90% of the variance is explained by the total volume discharged, the length of the antecedent dry period and the magnitude of the previous runoff event: the antecedent dry period and the magnitude of the previous event

Fig. 6 THE REMOVAL OF NITRATE (NO3) AND AMMONIUM (NH4) SHOWING NO RELATIONSHIP TO DISCHARGE (FLETCHER, 1981)

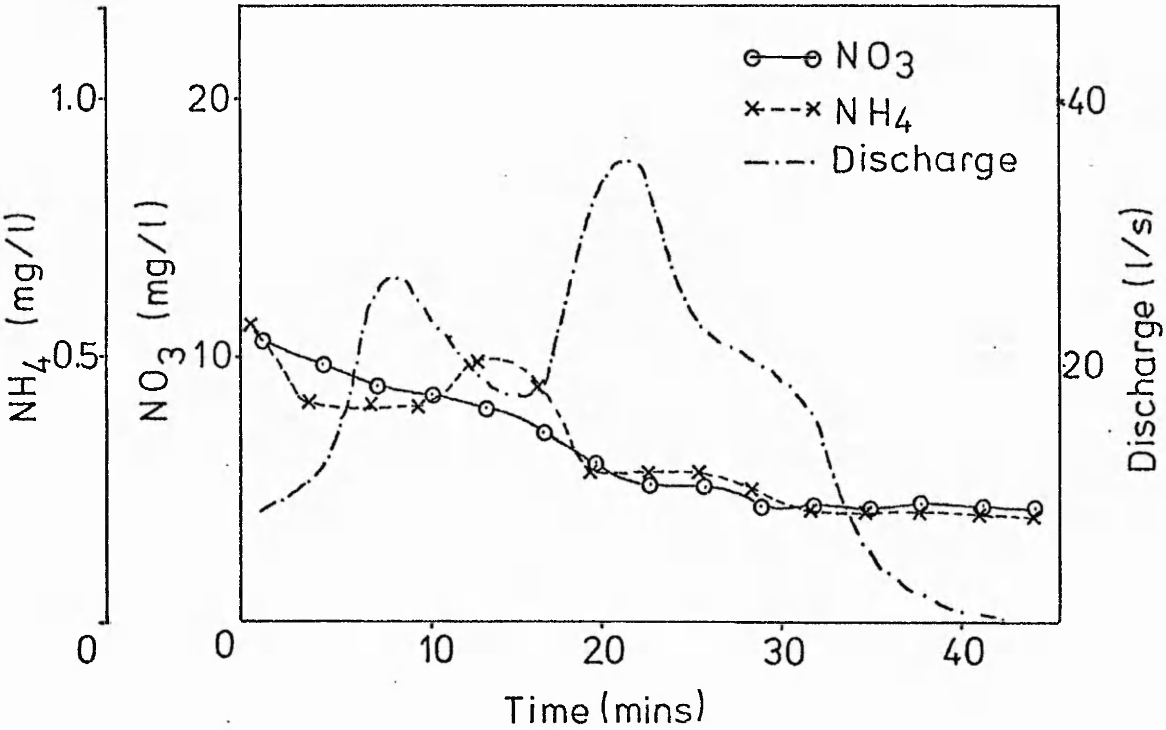


Fig. 7 RELATIONSHIP BETWEEN TOTAL RAINFALL AND SUSPENDED SOLIDS LOAD (AFTER WEIBEL, 1964)

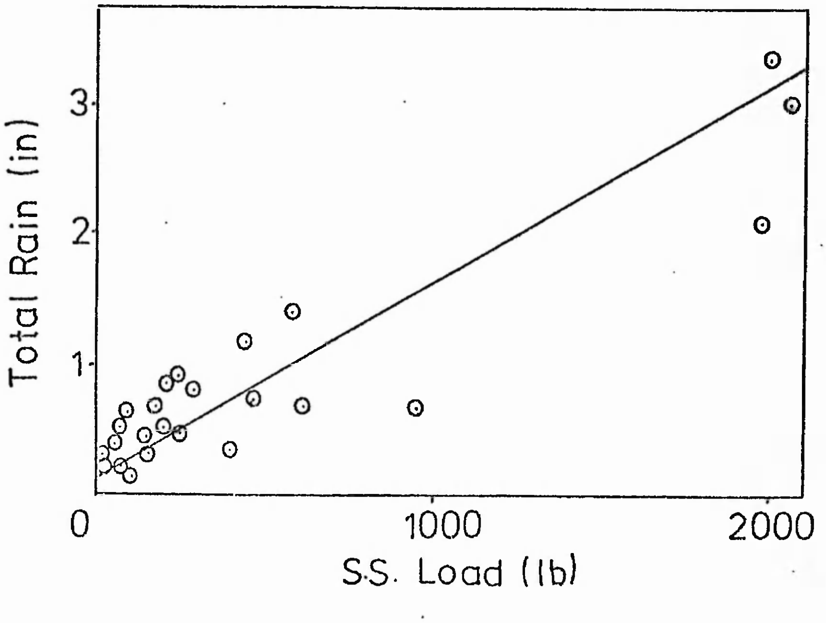


Fig. 8 RELATIONSHIP BETWEEN THE ANTECEDENT DRY PERIOD AND THE AVERAGE BOD CONCENTRATION FOR THE FIRST FLUSH (AFTER WILKINSON, 1956)

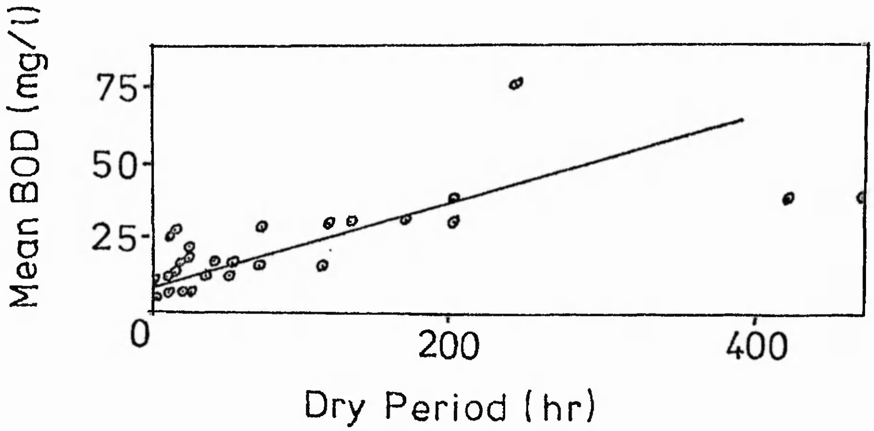
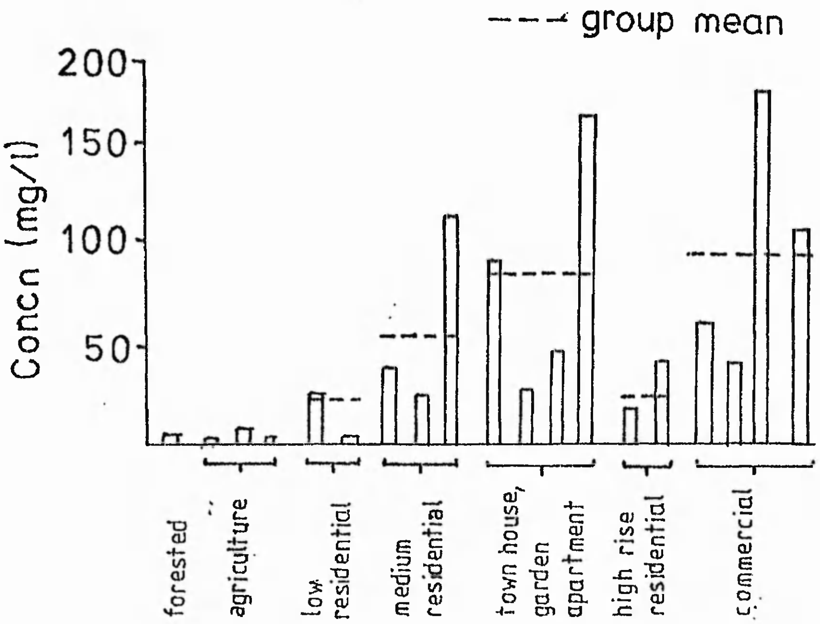


Fig. 9 MEAN EXTRACTABLE LEAD CONCENTRATIONS FOR DIFFERENT LAND USES (AFTER HELSEL, 1979)



accounting for a maximum of only 6%. A similar analysis by Adams (1978) showed that the amount of rainfall and its average intensity were the most significant paramters in determining the pollutant load. The duration of the rainfall event and the antecedent dry period were of less significance. A strong correlation between pollutant load and total runoff volume was also noted by Bedient et al (1978) for suspended solids, COD, soluble organic carbon, Kjeldahl nitrogen and phosphorus. They used the derived relationship to predict loads from other storms with some degree of success. Similarly, Weibel et al (1964) demonstrated a good correlation between total rainfall and solids and BOD load (Figure 7).

The significance of the antecedent dry period has been a matter of conjecture. Wilkinson (1956) observed that the concentration of BOD in the first flush increased with an increase in the period of drought, approximately 3 mg/l for every 24 hours (Figure 8). However, he acknowledged that the curves were ill defined, due to wide variations that occurred for short dry periods and the limited number of results that were available for longer periods of drought. A tentative linear relationship between the first flush solids load and the preceding dry period was indicated by the results of Tucker (1975). However, other workers (Weibel et al, (1964); Bryan, (1972); and Waller, (1972)), could find no statistical relationship between the two. Although, logically the antecedent dry period will influence the amount of material available for transport, in reality the characteristics of the current event are of more significance in determining the actual pollutant load discharged.

1.2.3.3. Relationship of Pollutant Loads with Catchment Characteristics

It is to be expected that the physical characteristics of a catchment, e.g. impervious area, slope, land usage (urban, industrial, commercial), will strongly influence the amount of pollutant available and load discharged from the sewer. Bradford (1977) collated all available data on pollutant loadings from published work in the U.S.A. up to 1972 and attempted to relate loading rates with a variety of catchment characteristics including land use, population density, impervious area and road surface type. However, multiple regression analysis yielded only limited success and that with data from one area only. A relationship between land use and pollution loading could not be demonstrated. Other workers have reached similar conclusions, pollutant loading rates are dependent upon so many variables that are specific to single catchments only, that the prediction of pollutant loads by the simplistic approach of 'labelling' by catchment type and utilising generalised statistical expressions is unsatisfactory.

It has been generally stated that pollutant loads tend to increase with increased urbanization of a catchment and are usually highest for industrial areas, however, there is much conflicting evidence. Holbrook et al (1976) monitored runoff from four small suburban watersheds and a central business area in Atlanta, U.S.A. They noted, with the exception of suspended solids, that all concentrations for the business area were higher than the mean concentration for the suburban area. However, Rimer and Reynolds (1978), characterising runoff from a number of different land uses found that levels of suspended solids, COD, phosphorus amd lead were a function of the degree of development and the percentage of area impervious of the catchment with theexception of the central business area (Table 5). Suspended solids levels for the business area were approximately half those observed at the 'high activity' residential areas. This was explained by the lesser degree of land disturbing activity and more regular municipal street sweeping. Bradford (1977) also noted, with the exception of BOD, organic nitrogen and lead, that loading rates for commercial areas were generally below average. Similar results were obtained for a study of four catchments of differing land uses in Houston (Bedient et al, 1978). Nutrient loadings, in particular phosphorus, were found to be greater at the two urban catchments than the two background forested watersheds, with higher loads being recorded on the catchment containing some industrial development. Suspended solids followed a similar pattern, but no differences were observed for total COD, due probably to the leaching of organic material at the forested sites. Helsel et al (1979) concentrated their attention on the influence of land use on the quality of runoff for seven metals (lead, zinc, copper, chromium, iron, manganese and cadmium). Their study was conducted using 19 small sub-basins of seven different land use categories in Washington, D.C. Although significant differences in runoff quality occurred between sub-catchments for all of the metals, they concluded that valid comparisons between broad land use categories could not be made, because of large observed variations between stations within the same category. They considered individual land use characteristics, such as traffic and ground slope

TABLE 5 Comparison of the quality of urban runoff for different land users (after Rimer and Reynolds 1978)

Land Use	Percentage Impervious	Number of storms	Average Peak Concentration			
			S. Solids	COD	Phosphate	Lead
Rural (low activity)	2.7	5	284	41	1.40	0.1
Rural (high activity)	5.1	5	416	58	0.76	0.1
Commercial (low activity)	12	9	575	87	0.83	0.2
Residential (low activity)	16	9	664	166	0.84	0.6
Residential (high activity)	32	8	1199	194	1.03	2.1
Commercial (high activity)	35	8	1082	320	1.08	1.7
Central Business District	80	11	528	336	0.66	0.9

to be better indicators of stormwater quality. Urban catchments were found to give significantly higher levels of lead, zinc and copper and good non-linear correlations for these metals were found against traffic and percentage impervious cover. The results were interpreted as suggesting that motor vehicles were a major source of these metals and that impervious surfaces delivered them more efficiently to storm drainage systems. The importance of the percentage of impervious cover was also noted by Lindholm and Balmer (1978). They found good correlations with COD, total phosphorus, total nitrogen, lead and suspended solids for seven urban catchments in Norway. With the exception of one catchment where land development gave rise to larger solids loads, there was a tendency for loadings from the city centre, commercial catchment to be greater than those from the residential catchments.

1.2.3.4 Comparison of Combined and Separate Sewerage Systems

Several workers have attempted to compare the advantages and the disadvantages of the two types of system in terms of pollutant loads that might be discharged to watercourses. Unfortunately, a direct comparison is hampered by the obvious fact that no catchment has been served by both systems! Additionally, there are other problems of comparison, for example, should loading rates be compared for the time period of a runoff event or over a whole year; should stormwater loads be compared against raw sewage, primary sewage effluent, secondary sewage effluent, secondary sewage effluent or combined sewage overflow; and should loads or concentrations be compared? Different criteria will apply to each catchment and, as a result, there is much conflicting opinion in the literature. However, the fundamental pros and cons can be simply listed as follows:-
Combined system advantages:-

a) reduced cost of a single pipe network.

b) when no overflow occurs all sewage is treated at the treatment works.

c) some measure of protection against pollution by accidental spillage of toxic chemicals, e.g. road tanker accidents.

Disadvantages:-

a) in storm conditions, when the system overflow limit is exceeded, storm sewage is discharged directly into a watercourse.

b) the whole polluting load is discharged at one point.

Separate system advantages:-

a) alleviates storm sewage overflow.

b) the river receives its due flow from the natural catchment.

c) enables more efficient design of sewage treatment plants by eliminating wide volume and quality variations and eliminating the need for storm tanks.

Disadvantages:-

a) Stormwater is discharged untreated and may also be polluting.

b) the impervious nature of urban areas produces runoff more quickly than natural catchments resulting in rapid river flow variations with the possible disruption of stream ecology.

c) accidental spillages pass directly into the river without treatment.

d) increased capital costs of installing two pipe networks.

Wilkinson (1956) compared the quality of storm runoff from a residential catchment with that of a typical secondary sewage effluent. He concluded that the separate system reduced polluting loads when judged by BOD, but increased them in terms of suspended matter by 6 to 7 times. However, he noted that even in the first flush, BOD values rarely exceeded the 20 mg/l value proposed by the Royal Commission on Sewage Disposal and that the percentage of organic matter in the suspended solids was substantially less than that in sewage effluent. Weibel et al (1964) compared annual storm runoff loads for a residential catchment in Cincinatti to annual raw domestic sewage loads calculated from average sewage concentrations and typical sewage flow rates for a population of 9 persons/acre (Table 6). Suspended solids were again found to be greater than those in domestic sewage, even on an annual basis. During storm runoff events, greater loads of all paramters were considered to be discharged than in raw sewage over a similar time period. Similar

TABLE 6 Comparison of stormwater runoff loads and domestic sewage loads over one year (after Weibel et al, 1964)

Constituent	Storm Runoff Load (lbs/acre/yr)	Domestic Sewage (lbs/acre/yr)	Percentage
Suspended Solids	730	540	140
Volatile S. Solids	160	360	44
COD	240	960	25
BOD	33	540	6
Phosphate	2.5	27	9
Total Nitrogen	8.9	81	11

TABLE 7 Comparison of combined sewer overflow and storm runoff loads over one year (after Burm et al., 1968)

Constituent	Detroit, Combined sewer overflow (lb/acre/yr)	Ann Arbor, Storm Runoff load (lb/acre/yr)	Percentage
Suspended solids	200	1010	505
Volatile S. Solids	93	185	199
Settled solids	185	780	421
Volatile settled solids	83	137	165
BOD	90	31	34
Soluble Phosphate	5.6	0.9	16
Total Phosphate	11.0	2.8	25
Ammoniacal - Nitrogen	6.2	0.7	11
Nitrate - Nitrogen	0.15	0.8	534
Organic - Nitrogen	1.6	0.4	25

conclusions were reached by Bryan (1972) when comparing runoff from a residential estate in Durham with raw domestic sewage. Pollutant loads from a combined system in Detroit were compared to those from a separate system in Ann Arbor by Burm et al (1968). Their results showed that for all parameters, except solids, the normalised load discharged was greater from the combined sewer overflow than from the storm sewer (Table 7). The solids load was about 5 times greater than the storm sewer, however, the organic (volatile) portion of this load was only 2 times greater. A comparison of the bacteriological quality of runoff discharged from the two systems was also conducted (Burm and Vaughan, 1966). Total coliforms in combined sewer overflow were found to approach those in raw sewage and were 10 times greater than levels found in both types of runoff. Soderlund and Lehtinen (1972) compared the quality of urban runoff, combined sewer overflow and treated sewage for catchments in Stockholm, and concluded that the level of contamination of storm runoff was similar to that of combined sewer overflow. The Water Research Centre (1977) compared polluting loads released from a storm sewer serving a small residential catchment in Stevenage to loads that might have been discharged from a combined system draining the same catchment. The comparison was achieved through the real time combination of flow and quality data for the existing foul and storm sewer systems at a variety of overflow settings for the hypothetical combined system. At a setting of 6 times D.W.F. (dry weather flow), a value commonly employed in combined system design, the predicted mass discharged for all determinands, with the exception of ammoniacal nitrogen, was marginally less than that observed to be discharged from the storm sewer. However, the mean concentrations of storm sewer discharges were lower than those from the combined system overflow. To achieve a significant reduction in the mass of ammoniacal nitrogen discharged, it was estimated that an overflow setting of 20 D.W.F. was necessary. It was concluded that the choice of system for individual locations would largely be governed by local circumstances, such as the presence of an existing system, distance to the point of discharge, the condition of the river and the acceptability of any discharge of urban runoff.

1.2.4. Sources of Pollution

1.2.4.1 Impervious Surfaces

The natural decay and erosion of roads, roofs, footpaths and driveways is a source of significant quanitities of particulate matter in

Fig.10(a) ACCUMULATION OF SOLIDS ON ROAD SURFACES FOR DIFFERENT LAND USE CATEGORIES

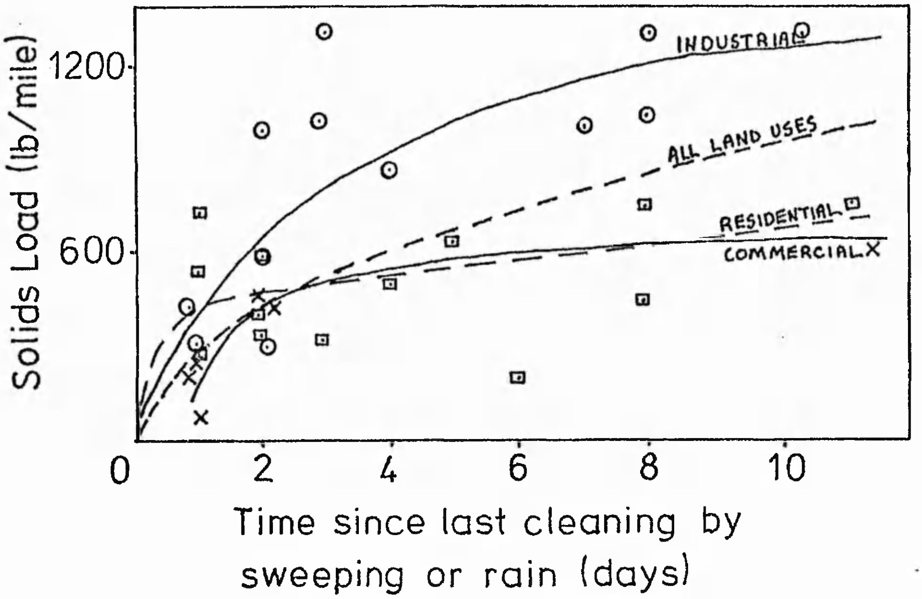


Fig. 10(b) DISTRIBUTION OF CONTAMINANTS ON ROAD SURFACES (AFTER SARTOR ET AL., 1974)

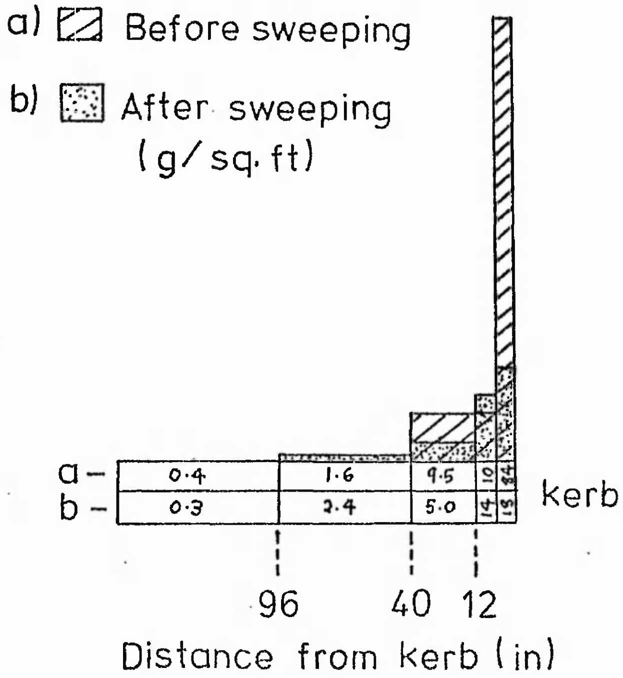


TABLE 8 Quantity and characteristics of contaminants found on street surfaces (after Sartor et al., 1974)

Constituent	Mass (kg per km of road)
Total Solids	397
Oxygen demand.	
BOD	3.8
COD	27
Volatile Solids	28.3
Nutrients.	
Phosphates	0.31
Nitrates	0.027
Kjeldahl Nitrogen	0.63
Heavy Metals.	
Zinc	0.18
Copper	0.057
Lead	0.16
Nickel	0.014
Mercury	0.021
Chromium	0.031
Pesticides	
P.p DDD	19×10^{-6}
P.p DDT	17×10^{-6}
Dieldrin	6.8×10^{-6}
PCB	310×10^{-6}
Bacteriological	
Total Coliform	28×10^{9}
Fecal Coliform	1.6×10^{9}

TABLE 9 Pollutant fractions associated with particle sizes (after Sartor et al. 1974)

Contaminant	FRACTION OF TOTAL MASS (%)		
	43m	43-246	246m
Total solids	5.9	37.5	56.5
BOD	24.3	32.5	43.2
COD	22.7	57.4	19.9
Volatile Solids	25.6	34.0	40.4
Phosphates	56.2	36.0	7.8
Nitrates	31.9	45.1	23.0
Kjeldahl Nitrogen	18.7	39.8	41.5
Heavy Metals	52		48.7
Pesticides	73		27
PCB	34		66

TABLE 10 Loading of solid material on street surfaces for different land uses (after Sartor et al., 1974)

Land Use	Loading (kg/km)	
Residential:-	240)	
	252)	
	122)	270
	340)	
	397)	
Industrial:- Light	735)	
Medium	252)	659
Heavy	990)	
Commercial:-	82	82

storm runoff: additionally, and more importantly, these impervious surfaces act as collecting areas for pollutants from other sources, (atmospheric dustfall, wind blown material), that can then be rapidly and easily transported by overland flow to the sewer system. The accumulation and composition of contaminants on street surfaces has been the attention of studies by Sartor, Boyd and Agardy (1974) and Pitt and Amy (1974), after an initial survey by the American Public Works Association (1969) had shown the accumulation of appreciable quantities of street litter at 18 test sites.

A study of 12 U.S. cities, Sartor et al (1974), showed the major constituent of street surface contaminants was consistently inorganic, mineral-like matter similar to common sand and silt. This finding has been confirmed in the U.K. by Ellis (1976), who estimated that street surface sediments consisted of an inorganic mineral fraction of 50% - 80% of the total, being composed of substantial amounts of brick, glass and concrete. He found that organic materials, which usually comprised only a small fraction of the total, but could contribute up to 30%, were comprised primarily of rubber and bitumen fractions, with lesser amounts of humic materials, plant debris and other complex organics associated with vehicular pollution. Average values for the accumulation of pollutants per kilometre of roadway are shown in Table 8.

The largest proportion of the polluting potential of street sediments has been shown to be associated with the fine, primarily organic, solids fraction. Sartor et al found that material below 43 microns, although comprising only 6% of the total solids accounted for 25% of the oxygen demand, up to 50% of the nutrients and heavy metals and 75% of the pesticides (Table 9). The mass of material that accumulates on a given street surface shows great variability from site to site but is generally dependent upon four factors:-

a) Type of land use (Table 10). Industrial locations usually have higher loading rates than urban sites. Commercial sites probably have high loading rates, however, they are also swept more frequently and therefore the net recorded loading rates are lower.

b) Surface type. Asphalt surfaces have been shown to result in 80% heavier loads than concrete surfaces.

c) Age of the surfaces. The rate of decay of old surfaces can be up to 2 times greater than a new surface in good condition.

d) Time elapsed since the surface was last cleaned, either by municipal sweeping or by rainfall. There is a tendency for a maximum loading to be reached after approximately 10 days, when natural accumulating and removal processes are balanced, (Figure 10).

Roadside channels and kerbs form barriers in and against which contaminants accumulate. Sartor et al recorded that some 80% of the material on the road surface was located within 15 cm of the kerb, (Figure 10).

Decay of roofed surfaces will also contribute to pollutant loadings in runoff, however, this source is less significant than material derived from road surfaces. The contribution from surface decay was quantified by the Water Research Centre (1977) at approximately 3% of the total mass discharged as compared to a contribution of 72% from roads and pavements.

1.2.4.2 Aerial Deposition

Aerial deposition results in the accumulation of pollutant material on urban surfaces by three processes:-

a) Settlement of particulate matter over dry periods, commonly known as dustfall or dry deposition.

b) Rainout. The removal of particles by condensation processes in clouds (Rasool, 1973).

c) Washout. The removal of particles by falling raindrops.

Several workers whilst investigating the quality of storm runoff have also made measurements of aerial deposition rates. However, the methods of measurement used have often differed, some workers considering just dustfall, others measuring total aerial deposition. Partly as a result of this variability in measurement technique, evidence on the significance of insoluble (particulate) aerial deposition in determining

TABLE 11 Insoluble (particulate) deposition rates for several studies

Catchment	Reference	Deposition Rate (kg/ha/annum)
Hamilton, Canada	Waller, 1972	169 - 300
Cincinatti, USA	Weibel, 1964	570
Stevenage, UK	Mance, 1978	95
Birmingham, UK	Hedley, 1976	1160
Styrrup, UK	Cawse, 1972	28 - 250
Blyth, UK	Warren Spring Lab. 1971	370 - 890
Chicago, USA	U.S. Dept. of Interior 1969	1560 - 2320

TABLE 12 Rates of aerial deposition and the percentage mass of pollutants discharged that is derived from aerial deposition (after Mance and Harman, 1978)

Constituent	Rate of Deposition ($mg/m^2/day$)	Percentage Contribution to runoff
Suspended solids	26.1	23
Soluble solids	77.1	30
Chloride	14.6	28
Nitrate - N	1.2	68
Ammoniacal - N	1.2	417
Nitrite - N	0.026	50
Copper	0.051	96
Manganese	0.051	49
Lead	0.128	54
Zinc	0.160	38

the quality of storm runoff is conflicting. A large variance in insoluble deposition rates for different catchments has been recorded (Table 11). In a Chicago study, Heaney and Sullivan (1971) estimated that approximately 70% of material on street surfaces was attributable to dustfall whereas Hedley and Lockley (1976) found that only 3 tonnes per annum (1160 kg/ha/annum), or 1.2% of the total of 250 tonnes input to an urban motorway catchment in Birmingham, U.K., could be ascribed to aerial deposition. Even this figure is higher than that obtained for a survey of six U.K. sites (Cause, 1974) where a variation in insoluble deposition rates between 28 and 250 kg/ha/annum was noted, the maximum occurring for the one urban catchment monitored at Styrrup, Notts.

Other workers have attempted to assess the contribution of aerial deposition to the mass of solids discharged in runoff. Waller (1972) considered that dustfall accounted for all of the solids in roof runoff for a number of small urban catchments in Hamilton, Canada. His findings were in agreement with those of Weibel et al (1964) who calculated that a dustfall rate of 570 kg/ha/annum accounted for some 70% of the 820 kg/ha/annum of solids discharged from an urban catchment in Cincinatti, U.S.A. However, for a residential catchment in the U.K. Mance and Harman (1978) estimated that total aerial deposition accounted for only 25% of the mass exported from the catchment. Their measurements of total aerial deposition also enabled them to estimate the contribution to runoff from other constituents (Table 12). Aerial deposition was found to be the principal source of inorganic nitrogen and a major contributor of heavy metals. These findings were in agreement with those of Kluesener and Lee (1974), who found that nitrate in rainfall accounted for 20 - 90% of the nitrate loadings in runoff and Fisher (1968) who noted that nitrate input in rainfall exceeded the output in stream flow. The discrepancy in ammonia input and output recorded by Mance and Harman were also observed by Cause (1974) and Kluesener and Lee (1974), and have been tentatively explained by undetected contamination from bird faeces. Work by Barkdoll et al (1977) indicated that dustfall was the major source of COD, chloride, mercury, arsenic and phosphate in stormwater runoff.

The U.K. Atomic Energy Authority conducted a comprehensive two year study of trace element concentrations in air and rainfall and trace element deposition and washout rates at seven sites in the U.K. (Cause, 1974). Additionally, element ratios in the atmosphere were compared to those occurring naturally in the earth's crust and conclusions were drawn on the causes of variability. A 10 to 40 fold increase in the concentrations was noted for areas influenced by population and industry. These increases were primarily ascribed to the following sources:-

a) combustion of coal, oil and petrol with the release of fly ash.

b) smelting of metals with the production of 'fume', e.g. Zn^O

c) mining and crushing of minerals.

d) land cultivation, earth moving and building operation.

Evidence for the importance of fossil fuel combustion in influencing atmospheric pollution was manifold. The ratio of lead to bromide was near to the ratio found in ethyl fluid added to petrol and the ratio of nickel to vanadium agreed with the ratio of particulate emission from coal combustion. Local industry and domestic coal burning was considered to contribute sulphur, ammonia and the oxides of nitrogen in addition to releasing fly ash. The internal combustion engine was also considered to be an important source of the oxides of nitrogen. Hallsworth and Adams (1973) have also recorded the contribution of significant quantities of fly ash to the atmosphere, often associated with high lead levels, from combustion at power stations in the East Midlands.

Pronounced seasonal changes were noted for the majority of elements with higher values occurring in the winter rather than the summer months. This has been explained by reduced atmospheric dispersion under conditions of persistent low inversion layers and the combustion of additional fuels for heating purposes. Johnson et al (1966) also observed a seasonal variation for dustfall composition at Seattle, U.S.A. with maximum values occurring over March, April and May. concentrations remaining approximately constant for the remainder of the year. Johnson also recorded the significance of industrial contamination of the atmosphere, with the exception of lead and phosphate, greater accumulations of all constituents were found near industrialised areas. Lead was found to correlate well with traffic flow and phosphates were greatest in residential and suburban areas.

Huff (1976) investigated the effect of atmospheric effluents from a large urban - industrial area at St. Louis, U.S.A. on water quality in two small basins that were downwind of the city. In spite of considerable atmospheric contamination by industry he concluded that no strong relationship between streamwater quality and weather conditions could be found. With the exception of nitrate and zinc which were believed to be derived from an industrial source, total atmospheric deposition accounted for only a small fraction of the total stream load.

1.2.4.3 Motor Vehicles

That vehicles are a major contributor to the accumulation of pollutants on roadways is hardly surprising. Vehicle contamination of the environment arises from the following sources:-

a) expelation of exhaust gases and particulates.

b) oil and petrol leaks and spillages.

c) tyre wear

d) bodywork corrosion.

There is little doubt that vehicle exhaust is the most significant source of lead in the environment. The resultant levels of lead in runoff have been the attention of several workers, Newton et al (1974), Oliver et al (1974), Solomon (1977). The sources of lead and the literature pertaining to the complex processes involved in its transportation and physiochemical interactions in the environment have been reviewed by Laxen and Harrison (1977).

Lead is added to petrol as an anti-knock agent in the form of tetra alkyl lead compounds at a concentration of between 0.45 and 0.55 g/l. However, the largest proportion of lead in exhaust is emitted as particulate halides and oxyhalides due to reaction with other petrol additives such as ethylene dibromide and chloride. The quantity of lead emitted has been shown to be dependant upon engine speed and driving mode (Ter Haar et al, 1972) varying from 5% of the mass added up to 2000% during rapid acceleration. This results in an average lead emission rate of between 0.06 and 0.2 g/km (Solomon, 1977). The subsequent deposition of the lead is largely determined by the size of the particulates with which it is associated. Fine particulates may be swept into the atmosphere and deposited many miles from their point of emission, but the majority of lead is deposited in a strip approximately 30 metres on either side of the highway. Lead falling on open land is considered to be effectively immobilised in the surface soil layer and causes an insignificant contribution to water pollution. On the road surface lead is almost exclusively insoluble and is associated, primarily by adsorption, with particulates. Levels of lead ranging from 1000 to 2000 mg/l have been recorded for urban street dusts (Day et al, 1975; Turner, 1971) that are substantially higher than background levels for rural soils of 50 to 100 mg/l. The speciation of lead in water is the subject of some debate, however, the majority of research indicates that the metal remains closely associated with suspended solids resulting in total concentrations in water of the order of 0.01 to 10 mg/l. Levels of lead in road runoff are usually considerably higher than background levels and are considered to pose a significant threat to receiving water ecosystems depending upon its speciation.

The presence of black stains on roadways due to oil spillages and leaks is a common occurrence and many investigators have observed oil in stormwater discharges as a blue/green sheen present on the surface of the water. However, little quantitative information is available on the mass of oil reaching surface waters due to technical problems involved in obtaining representative samples, nevertheless, the problem is clearly one of some magnitude. In addition to the oxygen demand that oils and petrols exert on surface waters the occurrence of complex and toxic trace organic compounds in runoff that are associated with oils and petrols, including known carcinogens such as polycyclic aromatic hydrocarbons, may present further problems.

Tyre wear has been observed by Hedley and Lockley (1976) to result in the accumulation of particulate rubber in sedimentation chambers that collected drainage from an urban motorway. They estimated that approximately 1.5 kg/ha/annum were discharged from the catchment. Additionally tyres contain significant quantities of zinc (circa 1% of the total mass) and may be the cause of the high levels of this metal observed in runoff. Bourcier and Hindu (1979) recorded an average zinc level of 19.1 mg/l in runoff from a highway viaduct in Washington, D.C. where vehicles were virtually the only possible source of pollution. Hedley and Lockley's study found values ranging from 0.6 to 8.0 mg/l for their similar catchment.

TABLE 13 Chloride levels in runoff after application of rock salt as a deicer.

Catchment	Reference	Maximum Chloride Concentration (mg/l)
Motorway, Birmingham UK	Hedley (1975)	70,000
Housing Est. Stevenage UK	Mance (1978)	2,724
Expressway, Chicago USA	Amercian Public Works Association (1969)	25,100
Highway, Wisconsin, USA	Schraufnagel (1967)	10,250
Street " "	"	3,275
Snow pile " "	"	1,130

TABLE 14 The composition of a typical rock salt used for deicing (after Hedley, 1975)

Constituent	Concentration (mg/ kg)
Sodium Chloride	906,000
Solids	92,000
Iron	1,550
Nickel	12
Lead	8.7
Zinc	6
Chromium	4.7
Cyanide	5.7

Corrosion of car bodywork gives rise to the accumulation of metal, paint, glass and mud on road surfaces. Bishop (1968) noted that these processes were accelerated in periods of winter road salting and were responsible for a considerable loss of metal from vehicles. He found this salt induced corrosion to be particularly active over concentration ranges of 0.05% to 10%, levels that are typically encountered during winter road salting.

1.2.4.4 Winter Road Salting

The use of rock salt as a deicer for roadways in winter is now common practice. In the U.K. the Department of the Environment have recommended that salt is applied at rates of 14 to 56 g/m^2 depending upon conditions at the time of application. In America application rates of 110 to 330 kg/km have been reported (Field et al, 1974). During periods of snow melt and subsequent runoff events the majority of this salt is rapidly washed off the roads and results in extreme high concentrations of chloride and other associated parameters in streams draining urban areas (Table 13). Not only may runoff of such large quantities of salt adversely affect river ecosystems but also trace elements and other additives in the rock salt may present a more serious threat to the environment. Ferric, sodium and potassium ferrocyanides are often added to prevent caking of salt stocks. The sodium form has been shown to generate cyanide in the presence of sunlight, a concentration of 3.8 mg/l cyanide have been produced from an initial 15.5 mg/l of the sodium salt (Hanes et al, 1970). Chromate and phosphate are sometimes added to salt stocks as corrosion inhibitors and levels of 24 mg/l sodium chromate, 1.7 mg/l hexavalent chromium and 3.9 mg/l total chromium have been reported in Minneapolis, U.S.A. (Field et al, 1974). Analysis of a typical rock salt applied in Birmingham, U.K. (Hedley and Lockley, 1975) revealed the presence of substantial amounts of the heavy metals, nickel, lead, zinc and chromium (Table 14). The application of this salt was shown to be the major source of chloride, nickel and chromium in runoff when the annual total loadings were considered.

The environmental implications of the large scale application of salt are further considered in Section 1.2.5.

1.2.4.5 Human and Animal Activity

The important influence of human and animal behaviour in polluting the urban environment has been noted by many workers. However, there is little quantitative information available on the masses of pollutants involved and their significance compared to pollutants derived from other sources. The main activities which can influence the polluting potential of runoff and have not been previously considered in other categories include the following:-

a) the use of garden fertilisers, pesticides and herbicides.

b) grass cutting

c) littering, careless disposal of paper, cigarette ends, metal cans and bottles.

d) car washing.

e) urination and defaecation by dogs and birds.

The relative importance of these activities will vary considerably from catchment to catchment. For example in commercial areas littering may be the most significant activity but in residential housing estates car washing and grass cutting are likely to be of more importance.

The American Public Works Association (1969) collected information on the accumulation of street litter and the use of pesticides, herbicides and fertilisers at a number of cities. Contributions of paper, metal and glass ranging from 0 to 40% of the total mass of material on the impervious surface was noted and the use of pesticides, etc. was reported at 90% of the cities. The presence of pesticides in runoff has been monitored by Weibel et al (1964), Bryan (1972) and Murphy and Carleo (1978). Murphy and Carleo recorded a significant loading of chlorinated organics in runoff from a predominantly residential area of 0.034 kg/ha/annum, concentrations were found to be higher for the summer months presumably due to the increased application of insecticides and herbicides.

The accumulation of dog faeces on a residential housing estate has been conservatively estimated by the Water Research Centre (1977) to be about 17 g/m^2/year. The faeces were reported as being a potential source of harmful pathogens, viable ova of which have been isolated from areas inundated by stormwater.

1.2.4.6 Roadside Gully Pots

Gully pots or catch basins are small chambers located beneath roadside channels to act as an inlet point for overland runoff to the sewer system. The purpose of their location at this point is two-fold. Firstly, they remove particulate material transported by runoff that may subsequently cause sewer blockage, and secondly, in combined systems they serve as a water seal to prevent the release of bad odours from the sewer.

The accumulation and subsequent putrefaction of organic matter washed into gully pots was first noted as early as 1900 by Folwell, additionally, he drew attention to the irregularity and inefficiency of cleaning procedures employed at the time. The role of gully pots as a source of pollution of stormwater received no further attention until 1969 when the American Public Works Association measured BOD's of the stored liquors. Concentrations between 35 and 225 mg/l were recorded after a period of several days without rainfall and they concluded for an average BOD of 60 mg/l the loading possible from gully pot liquors was 7½ times that contained in runoff water due to street liquor contact. Their observations indicated that between runoff events the supernatant liquors tended to become septic and the trapped solids took on the general characteristics of an anaerobic sludge, this resulted in the degradation of water quality and the release of foul odours. Sartor and Boyd (1974) also noted that the decomposition of accumulated litter, leaves and engine oil in gully pots presented a threat to receiving water quality. They considered that whilst gully pots were effective in removing coarse inorganic solids, they were ineffective in trapping the more polluting fine solids and organic matter. Tucker (1975) collected 55 samples from 10 pairs of gully pots at different locations in the city of Nottingham. His results (Table 15) showed great variability between pots at the same and at different locations which he ascribed to the influence of human activity. He also noted the anaerobic decomposition of organic matter and stressed the poor quality of water that could be encountered when pots became clogged with fallen leaves in autumn. Mance and Harman (1978) recorded that even after flushing by heavy rain, pots became anoxic within 24 hours. They observed the formation of thick

TABLE 15 The quality of water stored in roadside gully posts

Catchment	STEVENAGE, U.K.		CHICAGO, U.S.A.	NOTTINGHAM U.K.
Reference	MANCE (1978)		Amer. Public W'ks Ann.(1969)	Tucker (1975)
	Mean	Max.	Range	Range
Suspended solids	90.7	1032		0 - 4031
Dissolved solids	282	5860		
BOD			35 - 225	2.3 - 350
COD				422 - 965
Soluble organic carbon	28.9	255		
Ammoniacal - N	0.7	4.5		
Nitrite - N	0.08	0.34		
Nitrate - N	0.8	3.0		
Copper	0.02	0.04		
Manganese	0.2	0.62		
Lead	0.17	0.60		
Zinc	0.11	0.25		
Chloride	76.4	1829.0		6.4 - 31525.0

bacterial scums that were considered to possibly represent a significant portion of the first flush of BOD and suspended solids. Dry periods were noted to result in a slow deterioration in quality of the stored water with increasing concentrations of soluble compounds including chloride, soluble metals and ammoniacal nitrogen. Increases in ammoniacal nitrogen were ascribed to the action of denitrifying bacteria reducing nitrate nitrogen. They concluded that gully pots contributed significantly to the pollutant load of runoff.

1.2.5 The Polluting Impact of Stormwater Discharges on Watercourses

The polluting potential of stormwater discharges on watercourses is dependent not only upon the quality of the runoff but also upon the size of the discharge and the diluting capacity of the watercourse into which runoff occurs. The manner in which stormwater discharges occurs, that is, short duration but rapidly flowing slugs of polluted water, is also important in defining the polluting potential of runoff. Therefore, to survive in this environment, a species must be able to withstand the toxic properties of the runoff, the hydraulic force of the discharge and an environment where thick sediments and organic rich sludges are common. The result is a decrease in the diversity of species in streams receiving runoff from developed areas. In Greenfield, Massachusetts (Whipple et al, 1978) the benthic macroinvertebrate community was shown to progressively decrease in species diversity as the stream passed through an urban setting. The bottom sediments and the bodies of these species were found to contain large quantities of heavy metals, far above concentrations that are normally considered toxic. High concentrations of heavy metals have also been recorded in sediments of the R. Beane, downstream of the storm sewer outfall draining Stevenage New Town (Water Research Centre, 1977): the levels of metals decreasing the greater the distance from the outfall (Figure 11). The fauna and flora of the river were found to be contaminated with heavy metals and limited to a few species only. The diversity of biota recovered only after the river had passed over two weirs. Data from Maryland, U.S.A. (Whipple et al, 1976) indicated that there was a general reduction in fish species diversity as watersheds are developed. In the R. Beane, caged trout were found to be able to survive exposure to short summer storm discharges.

One of the principal reasons for the decrease in species diversity is the considerable oxygen demand, primarily from the organic solids load, that urban runoff exerts upon the receiving water. This can result in the depletion of dissolved oxygen to levels where fish life is threatened. An example of how serious this effect can be is the R. Tame, Staffordshire, which drains a substantial area of the industrialised West Midlands (Lester et al, 1971; Garland and Hart, 1971). In storm conditions the river may rise four-fold in a short space of time, the resuspension of river bed sediments and the scouring of sediments from urban surfaces creates a demand for oxygen that has resulted in the river becoming anoxic and devoid of fish life. Horner et al (1977) monitored dissolved oxygen depletion due to stormwater runoff in the R. Thames. They noted that the impact of runoff on oxygen levels was dependent not only on the volume of discharge, its quality and the point of discharge, but also on the antecedent conditions in the main river. When oxygen levels were high, very large discharges could be absorbed with little harmful effect, when oxygen levels are low small discharges could have a considerable impact. Ellis (1976) recorded dissolved oxygen sag curves for the Silk Stream in North London (Figure 12), a catchment that is heavily urbanised and receives large discharges of urban runoff. He noted the accumulation of large quantities of sediment and decomposing benthal sludges in the stream. The resuspension of these fine sludges during turbulent storm surges was considered to bring the deeper anaerobic layers up towards the surface aerobic zone and thus create a high demand for additional oxygen for oxidation. In addition to organic rich sediments, oil in runoff can also exert a considerable oxygen demand. Oil has the additional deleterious property of spreading out as a thin film across the surface of receiving waters. This can, particularly in still waters, effectively hamper the natural process of dissolved oxygen exchange with the atmosphere and so further the creation of anoxic conditions. Oils can also affect river species directly by smearing their surfaces and clogging their respiratory organs.

Ellis (1976) has stressed the importance of stormwater solids as a sink for heavy metals. Cadmium and lead extracts up to 10 mg/l were recorded for particles below 50 microns diameter in the Silk Stream sludges. Although toxic metals show a preference for association with particulate matter and are therefore rendered less harmful (levels in solids may be up to 10^5 times higher than in solution), in certain circumstances their release may be affected. One such circumstance is winter road salting. The input of high concentrations of the alkali metals, sodium and calcium, can effect the release of significant concentrations of toxic metals through ion exchange processes or complexation with chloride ions and so suddenly render the stream toxic for many forms of life.

Fig. 11 CONTAMINATION OF THE SEDIMENTS OF THE R. BEANE BY MANGANESE, COPPER, LEAD AND ZINC (AFTER W.R.C., 1977)

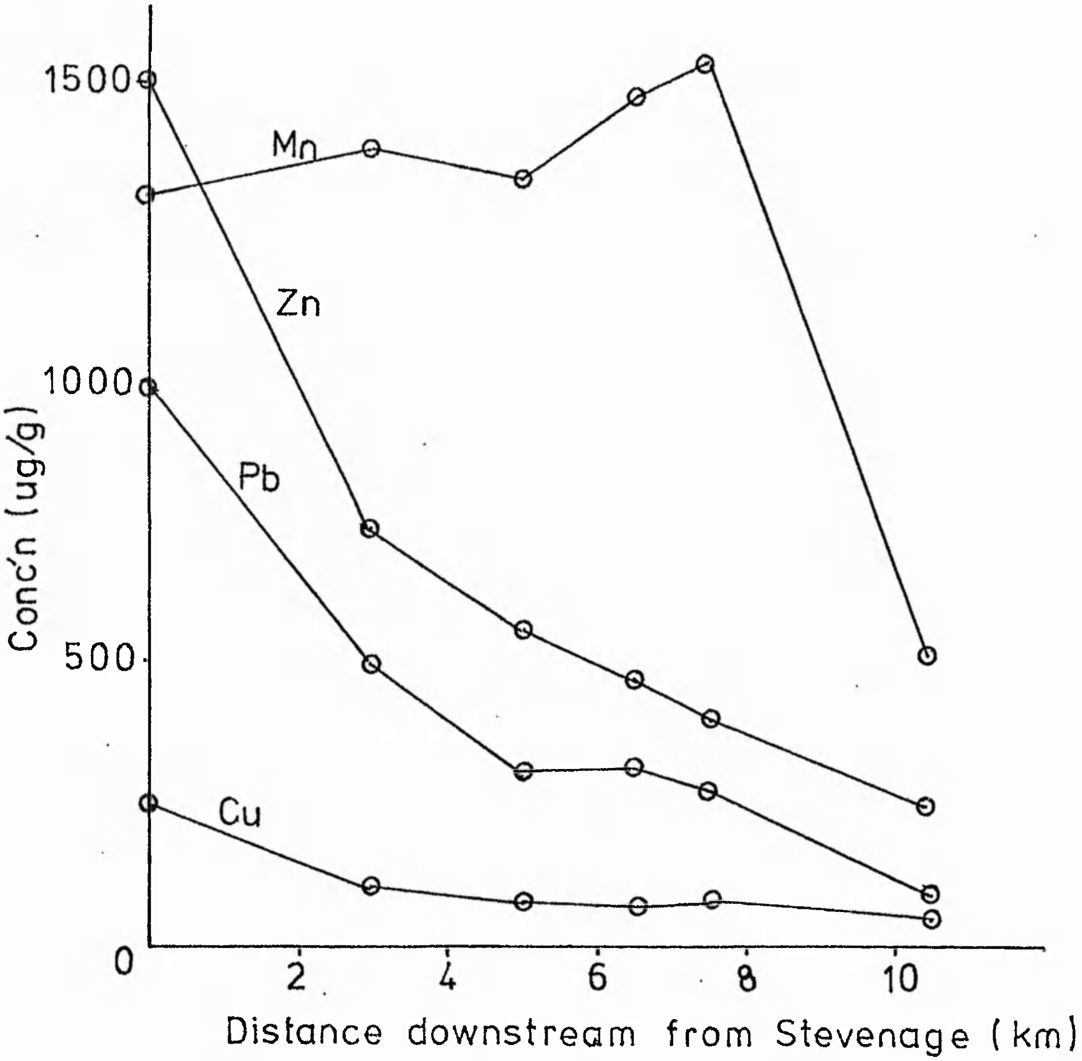
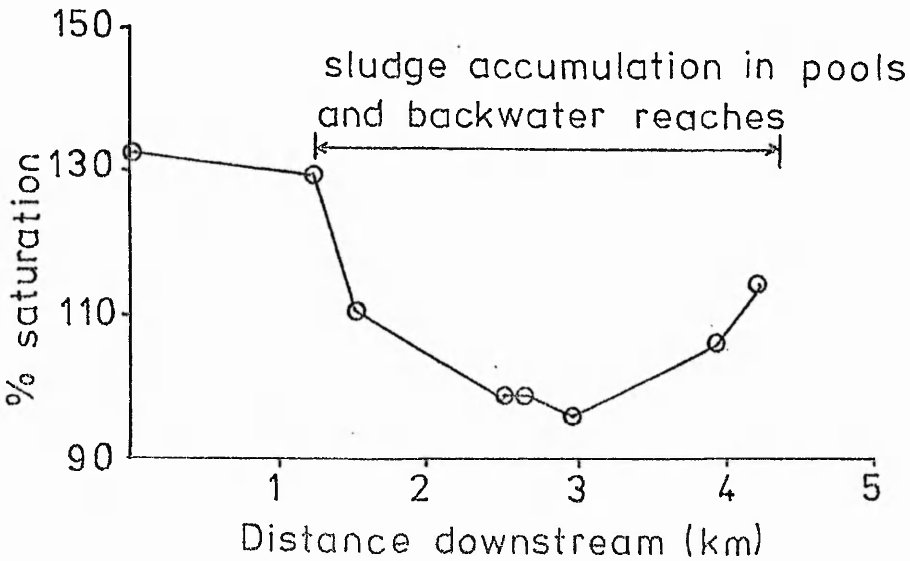


Fig. 12 DISSOLVED OXYGEN SAG CURVE FOR THE SILK STREAM, LONDON (AFTER ELLIS, 1976)



Winter road salting can result in other deleterious effects upon water bodies. In the U.S.A., salt concentrations in lakes and waterways have been observed to increase five-fold over the last 20 years and to show a strong seasonal dependency (Field et al, 1974). Runoff of salt into Irondequo t Bay, Rocester, U.S.A. (Bubeck et al, 1971) created a density stratification of chlorides in the lake that was sufficient to prevent complete vertical mixing of the bay during the spring and therefore, the transfer of oxygen to the bottom sediments. The same effect was reported for a small lake receiving urban runoff at Ann Arbor, U.S.A. (Judd, 1970). The storage of salt for deicing has been reported as resulting in the contamination of ground water drinking supplies to levels well in excess of the recommended limits (Stevens, 1973; Hawkins, 1976). In Connecticut, U.S.A., tastes and odours in water supplies were ascribed to contamination from chloride and sodium ferrocyanide from a nearby salt storage area (Scheidt, 1967).

Nutrients in storm runoff may present a further threat to lake and river water quality, namely eutrophication. Kluesener and Lee (1974) monitored the nutrient loading from a separate storm sewer in Madison, Wisconsin. Their results indicated that approximately 80% of the total nitrogen influent to Lake Wingra arose from urban runoff. Phosphorus was considered to be primarily derived from accumulated litter and car exhaust, whilst rainfall was found to be the major source of inorganic nitrogen in runoff. The availability of the nutrients nitrogen and phosphorus to algae was investigated by Cowen and Lee (1976) and Cowen, Sirisinha and Lee (1976). Bacterial activity was found to increase the algal available nitrogen by approximately ten-fold in runoff. However, physico chemical processes were considered to be more important in the release of particulate inorganic phosphorus to solution. Ellis (1976) monitored a large build up of nutrients in the Silk Stream with the consequent growth of algae and waterblooms during low flow summer periods. Break up of these growths by autumn rains, followed by their settlement and decomposition with the release of mineral and organic nutrients, was seen as a secondary source of stream pollution and a means by which eutrophication was enhanced at the commencement of the next growing season.

1.2.6 Control of Pollution from Urban Runoff

The previous sections have illustrated that non-point pollution, in particular runoff from urban areas, has become recognised as a major contributor to water quality degradation. Previous efforts to improve river water quality have concentrated upon the treatment of point sources of pollution, such as sewage and industrial effluents. The reduction of pollution from these sources through the introduction of improved treatment methods has revealed the need to control pollution from non-point sources in order that current river quality objectives may be achieved. The approaches available to control pollution from urban runoff fall into three principal categories:-

a) Control at source

b) Control within the sewer system

c) Treatment at the sewer outfall.

It is beyond the scope of this project to conduct a detailed review of all the literature available on this broad subject area but to indicate, within each category, the more important alternatives that are available. A review has been published by Field and Lager (1975).

1.2.6.1 Source Control

The theory behind source control of pollution is the limitation of the supply of contaminants and their accumulation on urban surfaces. Examples of this type of approach include municipal street sweeping, and gully emptying, restrictions on the use of chemicals (deicing compounds, pesticides, etc.) and public environmental education. The efficiency of current street sweeping methods has been questioned by Sartor and Boyd (1974). They found the removal of the more polluting dust and dirt fraction to be typically only 50%, whereas the removal of litter and other debris was 95% efficient. The effort required to achieve a greater removal effectiveness of this fraction was considered to be several times the effort normally expended. The American Public Works Association (1969) recommended that greater effort be devoted to public education programs to stem the careless scattering of litter and other polluting practices by the public. They proposed not only regulatory measures and anti-littering campaigns, but also government action in the form of purchase and placement of convenient litter containers with prompt collection of their contents.

1.2.6.2 Sewer System Controls

Examples of this type of control include sewer flushing, the use of regulator/concentrator devices, inflow/infiltration control and in-system storage.

When the possible importance of solid material deposited in sewers in influencing the quality of the first flush is considered it is surprising that little research has been conducted on sewer flushing as an effective means of removing these solids. An alternative approach has been conceived in the use of regulator/concentrator devices, such as the swirl regulator (Field, 1974; American Public Works Association, 1972), for the effective separation of solids over wide ranges of storm flow. The separated solids can then be diverted to a convenient combined system, when this is not feasible the ultimate disposal of the solids could present problems. The Water Research Centre (1977) have tentatively proposed the use of porous gully pots, these would serve the dual purpose of eliminating the storage of anoxic polluting waters and providing a large volume for the storing of the first flush of runoff. The use of porous pavements as a means of reducing the volume and rapidity of runoff is another possibility that has been investigated (Field, 1974).

1.2.6.3 Treatment of Storm Runoff

Many of the conventional treatment processes currently employed for the treatment of sewage may be applied to storm runoff discharges. However, two principal criteria must be satisfied, firstly, the process must be amenable to the rapid and variable flow rates associated with storm runoff and, secondly, for economic reasons treatment should be simple. Since the most significant pollutant in urban runoff is suspended solids and many other pollutants are also solid related, the removal of solids is of prime importance. Simple, physical treatment through sedimentation satisfies all these criteria and thus lends itself to the treatment of storm runoff and has been investigated by several workers. Weibel et al (1966) looked at the settling characteristics of storm runoff samples and found that settling periods of one hour or more were necessary for the removal of over 50% of the suspended solids. Shorter settlement times of 10 or 20 minutes did not remove suspended solids and BOD effectively. However, Cordery (1977) performing similar jar tests found a rapid sedimentation of suspended solids with

80% removal being effected in the first 4 minutes. Wanielista (1978) investigated the use of a percolation pond for capturing and treating the first flush of storm runoff. The pollutant load was substantially reduced over the year, however, percolation resulted in some groundwater contamination. Nightingale (1975) investigating the use of urban storm runoff detention basins found levels of heavy metal contamination of soil in the basin that could present health problems.

1.2.7. Modelling and Predicting the Quality of Stormwater Runoff

Methods for predicting the quality of stormwater runoff have arisen as tools for objective guidance in decision making for water resources management. Through prediction of pollutant loads from non-point sources, these models allow comparison with other sources of pollution in order that the best, cost-effective decision for the reduction of river pollution can be reached. Such models may also be used for assessment of the effectiveness of different forms of treatment and control of urban runoff, the relative merits of combined or separate systems for a given circumstance and for the day-to-day, year-to-year prediction of pollutant loading from urban areas. The accuracy and reliability of such models is hindered by the great variability and complexity of the contributing processes and the shortage of good quality data for model calibration. Ideally any process or factor that influences the accumulation and generation of pollutant loads on urban surfaces and their subsequent transport to a receiving water should be taken into account when modelling. Inevitably a large number of factors may be significant in defining the pollutant loading rate including land usage, catchment characteristics, meteorological characteristics, municipal street cleaning practices, etc. Consequently, models of widely differing complexity have been conceived, ranging from simple linear regression to highly complex deterministic models. Litwin and Donigian (1978) have catalogued the types of model available under four headings:-

a) Non-Analytical methods
The non-analytical approach, typically, utilised local data and land use inventories to formulate pollutant load/runoff rates for various pollutants to the areas of various land uses, e.g. Singh (1975). When calibrated from good local data the method can yield satisfactory results, however, when there is no data available tables for similar land used must be applied and the technique cannot be considered as reliable.

b) Statistical Techniques

Linear, multiple linear and non-linear regression have all been employed to relate pollutant loadings to selected variables such as meteorological characteristics, topographical characteristics, etc. The resultant equations have often been applied with some success to single catchments from which the data for the regression has been gathered, e.g. Bedient et al (1978). However, the derivation of a generalised equation for application to any catchment has met with little success (Bradford, 1977). Statistical models fall short of the requirements since they do not account directly for the processes involved. The models represent average conditions and characteristics which are not applicable to the wide variability of situations that can occur.

c) Simulation Models

Simulation models were originally conceived for the prediction of stormwater flows for the more efficient design of sewer systems. Such models were based on mathematical algorithms representing individual hydrological and hydraulic processes which were then linked together in a logical fashion to produce the desired output. Subsequently these models were extended to include expressions for pollutant accumulation and washoff processes, the hydrological and hydraulic portions of the model being used as 'vehicles' for calculating pollutant transport, loads and stormwater quality. A wide variety of design and simulation methods are available for evaluating stormwater flows and it is not proposed to mention them here. The state of the art has been comprehensively reviewed by Colyer and Pethick (1976) and Brandstetter (1976). Of the simulation models that can also be used for the prediction of stormwater quality, two have been most widely employed, the Storm Water Managment Model (SWMM) Metcalf and Eddy Inc. 1971) and the Storage Treatment and Overflow Model (STORM), (U.S. Army Corps of Engineers, 1975). Other models have also been proposed, notably the Hydrocomp Simulation Program (HSP) (Hydrocomp International Inc., 1975) and two models for the prediction of suspended solids (Price and Mance, 1978; Tucker and Mortimer, 1978). Simulation models fall into two main categories, models that deal with single storm events, of which SWMM is an example and models that perform continuous simulation of which STORM is an example.

The methodology available for the simulation of pollutant accumulation and removal is still in its infancy and this is reflected by the empirical nature of the mathematical expressions that are utilised. In both SWMM and STORM the expressions employed are nearly identical, for the calculation of the accumulation of dust and dirt between storm events this is:-

$$P_1 = DDFACT \times QFACT \times ADD$$

P_1 = mass of pollutant
DDFACT = dust and dirt accumulation rate
QFACT = fraction of dust and dirt that is pollutant
ADD = number of antecedent dry days.

The daily accumulation rate, DDFACT, is variable and is a function of land use, street cleaning activities and the season of the year. Having accumulated the pollutants they are then washed off by simulated runoff using an expression first proposed by Sartor and Boyd (1974):-

$$P_2 = M\,(1 - e^{-KR\Delta t})$$

P_2 = mass of pollutant washed off in time increment Δt
M = mass of pollutant available for washoff
K = decay coefficient
R = runoff rate

The parameters DDFACT, QFACT and K are all optimised using local data, however, when no such data is available the program reverts to preset default values. The use of the uncalibrated version of the model has been shown to result in gross errors in pollutant prediction (Jewell, 1978). Jewell has questioned both the pollutant accumulation and washoff functions, calibration for a catchment in Greenfield, Massachusetts, indicated that pollutant accumulation rates were not linear as the model purports but were in fact non-linear and reached a maximum value after about 10 days. In spite of these deficiencies both models have now seen several applications, Rimer and Reynolds (1978) used SWMM for seven different land use types and Hajas et al (1978) and Holbrook et al (1976) employed STORM for the prediction of pollutant loads for large catchments comprising a variety of land use types. All authors indicated the need to calibrate the models with good quality local data.

Both SWMM and STORM use, what have been termed 'black box' or 'lumped parameter' expressions for the washoff of pollutants, that is, the functions utilised do not mathematically describe the actual processes involved in soil erosion and pollutant transport. A more deterministic approach to the problem has been presented by Price and Mance (1978). They derived mathematical expressions for the removal of particulate material from impermeable surfaces where the rate of removal was considered to be dependent upon two factors: firstly, the disturbance of particles by the impact of raindrops and, secondly, the entrainment of particles by the flow of water over the surface. In the first instance, removal was considered to be directly proportional to some power of the rainfall intensity and in the second instance removal was proportional to the excess of the shear stress generated by the flowing water over some critical stress. Due to the lack of laboratory studies on these phenomena a number of parameters had to be calibrated from field data. The model yielded promising results for the one residential catchment studied but, to date, has received no further application.

It can be seen that the chief weakness of the simulation models mentioned is the complex data requirements and the need for careful calibration to achieve reliable results.

d) Intermediate Methods

These methods provide a compromise between the simplicity of the non-analytical techniques and the complexity of the linked process simulation models. The models are based, as before, on empirical mathematical representation of pollutant accumulation and washoff and the simpler versions commonly employ a design hydrograph as a means of representing the surface runoff (Singh, 1975). One weakness of the simpler models of this nature is that the continuous dynamic nature of the polluting processes is ignored. This situation has been rectified by the introduction of continuous non-point pollution simulation models that can provide for daily, monthly and yearly statistical summaries of polluting loading data in addition to single event simulation. Examples of this type of model include the Nonpoint Source model (NPS) (Litwin and Donigian, 1978), the Management of Urban Nonpoint Pollution model (MUNP) (Sutherland and McCuen, 1978) and the Quality/Quantity Simulation (QQS) (Geiger, 1975). The NPS model computes sediment accumulation rates for different land uses on a daily basis and rainfall events are simulated in 15 minute

loading rates of other pollutants are defined by what have been termed "pollutant potency factors", in reality this means that the pollutant load is considered to be a fixed percentage of the solids load. The MUNP model similarly uses pollutant potency factors to estimate the accumulation and removal of eight pollutants on urban streets. The model is capable of reflecting variation in a number of factors including the physical and chemical characteristics of accumulated pollutants, land use characteristics, rainfall characteristics, street sweeper characteristics, roadway characteristics and traffic conditions. The model employs data at hourly intervals to continuously simulate the accumulation and removal of sediment. Removal is calculated over 6 particle size ranges using the modified Yalin equation where sediment motion is effected when the lift force of flow exceeds a critical lift force. The QQS model calculated runoff and its pollution from different land use types using the unit hydrograph method modified for the calculation of water quality. The program provides for both statistical analysis at monthly and yearly intervals as well as single event simulation over 5 minute increments.

1.3. PROJECT INTRODUCTION

1.3.1. Aims

Previous work at Trent Polytechnic (Tucker, 1975) and other studies (see Section 1.2.4.6.) had indicated that roadside gully pots acted as a reservoir for poor quality water that was rapidly flushed out in the early phases of a storm event. Several researchers concluded that this stored water was highly significant in influencing the quality of stormwater runoff. However, a detailed examination of the quality of water stored in gully pots and the role of gully pots in removing sediment and concentrating polluting matter had not formed the core of any major study.

Due to the sparsity of information on this important aspect of urban stormwater pollution the broad emphasis in this project was on classifying the pollutants in gully pot liquors and their significance in determining the quality of urban stormwater runoff. To achieve these ends the following approach was adopted:-

a) Assessment of the quality of stored liquors over a period of one year for selected gully pots to establish the influence of seasonal effects, the importance of different sources of pollution and inter-relationships between pollution parameters.

b) Assessment of the changes in quality of gully pot liquors occurring over dry periods and during storm events.

c) Assessment of the variance of stored water quality across the catchment for any one day, in order to test the relevance of small sets of samples in representing the mean quality of the stored water.

d) Assessment of the quality of stormwater runoff and the pollutant loads discharged from the whole catchment in order that comparisons with gully pot liquor quality may be drawn.

e) Mathematical modelling of the removal of polluting material from gully pots under runoff conditions.

f) Integration of the gully pot pollutant removal model into a rainfall/runoff model for the whole catchment in order that the quantity of stored water and the mass of pollutants contributed from gully pots at the sewer system outfall can be predicted.

1.3.2. Selection of a Catchment

The selection of a suitable catchment for study was dictated by two factors: firstly, the aims of the project and, secondly, practical considerations of monitoring and installing instrumentation. Apart from the obvious criterion that the catchment should have a separate sewer system, there is a choice of four principal land use types, that is, urban, industrial, commercial and rural. The quality of runoff at industrial locations is likely to be strongly influenced by the specific nature of

MAP OF NOTTINGHAM SHOWING LAND USE

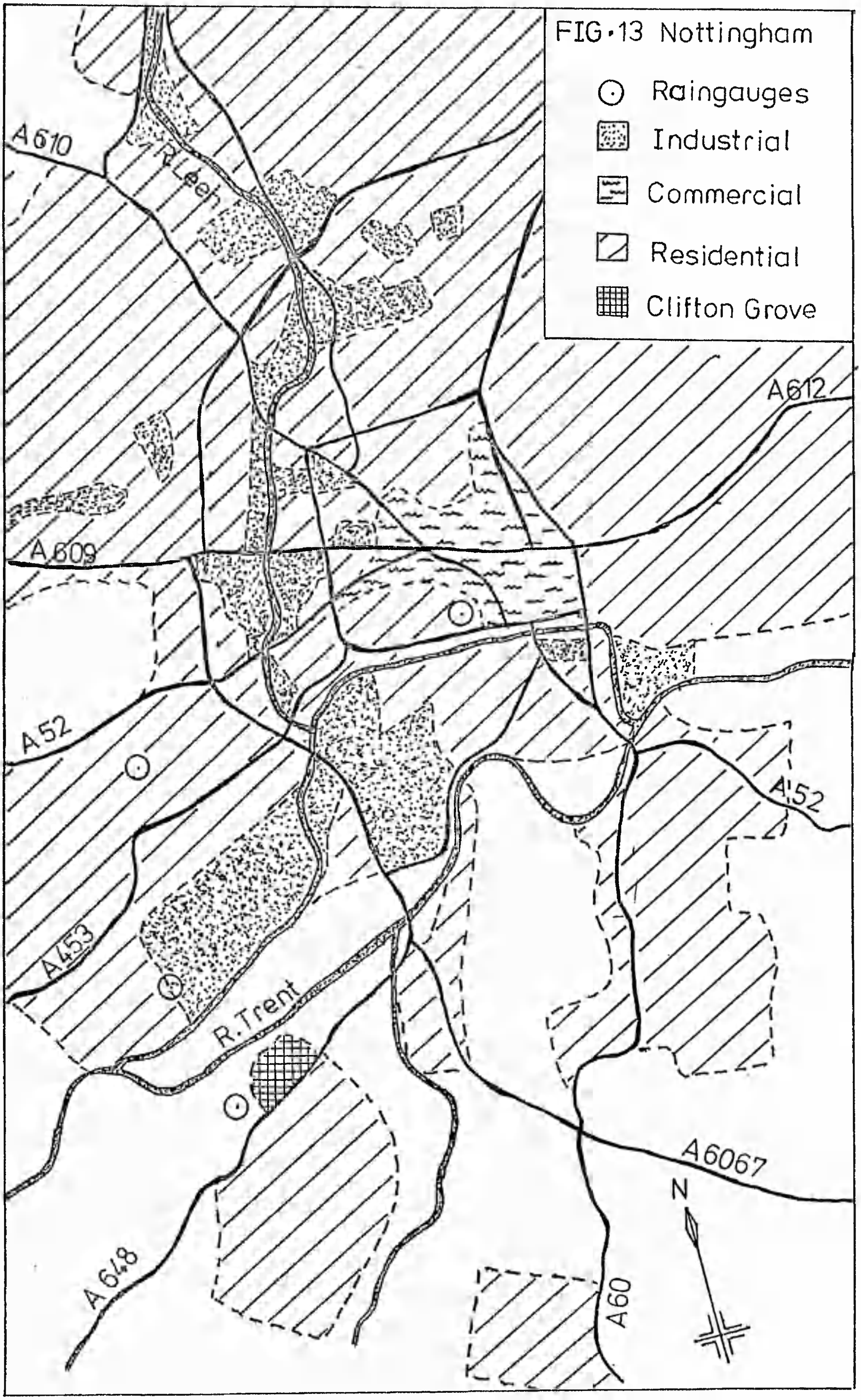


Fig. 14 MAP OF CLIFTON GROVE ESTATE, SHOWING THE STORM SEWER SYSTEM, GULLY POT SAMPLING POINTS AND STORM RUNOFF SAMPLING POINT

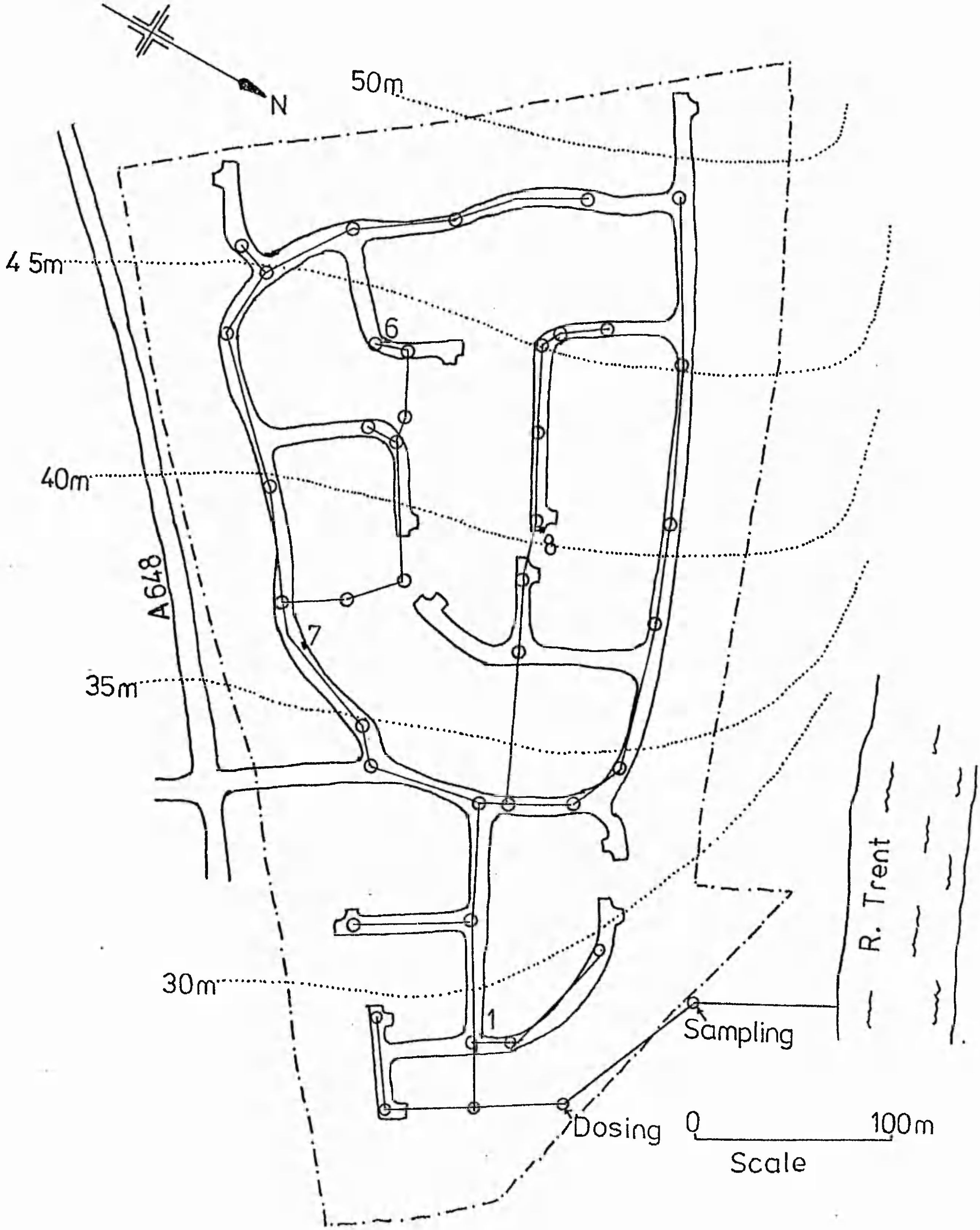


TABLE 16 Characteristics of the Clifton Grove Catchment.

Roofed Area	1.78 hectares
Roads and Footpaths	1.93 hectares
Impervious Area	3.71 hectares
Pervious Area	6.9 hectares
Total Area	10.61 hectares
Average catchment slope	4% - 5%
No. of houses	265
Housing density	25 houses per hectare
Population density	75 - 100 persons per hectare
Traffic density	Low

the industries located on the catchment. Hence, results obtained would only be of limited application to other industrial catchments in the U.K. Commercial locations would present problems with the installation of equipment and, due to their age, are rarely served by separate sewer systems. Rural locations are usually less prone to pollution and are, therefore, of less interest. The majority of catchments served by separate systems in the U.K. are residential urban developments built within the last 10 to 20 years. Such catchments are often of similar construction, polluting activities and sources are of a similar nature and, therefore, results obtained would be more applicable to other urban developments in the U.K. on similar soil and environment.

Runoff from two residential catchments in the Nottingham region had previously been monitored for suspended solids concentrations (Tucker, 1975). In order that results could be compared it was desirous that a new catchment be found. Only the Clifton Grove estate was found to fit all the criteria mentioned and it was therefore adopted as the study site.

Clifton Grove is a small suburban housing estate covering an area of some 10.6 hectares of which 3.7 hectares are impervious roof and road surfaces. The estate is comprised entirely of modern "detached" private housing being built between 1973 and 1976. The development is arranged with areas of grassed open land, designated "amenity areas", separating areas of housing arranged around culs-de-sac. In accordance with modern practice the estate is sewered on a separate system with stormwater runoff draining directly into the R. Trent (Figure 14). The principal characteristics of the catchment are listed in Table 16.

1.3.3. Selection of Gully Pots for Prolonged Study

The following subcatchment characteristics were taken into consideration in the selection of gully pots:-

a) Impervious area.

b) Subcatchment slope.

c) Number of houses in the subcatchment, possibly of importance in defining the extent of human activity within the subcatchment.

TABLE 17 Characteristics of gully pots selected for study.

Gully Pot	Slope	Imp. Area	No. of Houses	Open Land	Situation
1	.044	140 m^2	0	No	Susidiary Road.
6	.038	680 m^2	4	Yes	Cul-de-sac
7	.040	513 m^2	2.5	Possible	Feeder Road
8	.047	270 m^2	2	Little	Cul-de-sac

Fig.15 SUBCATCHMENT MAP - GULLY POT 6

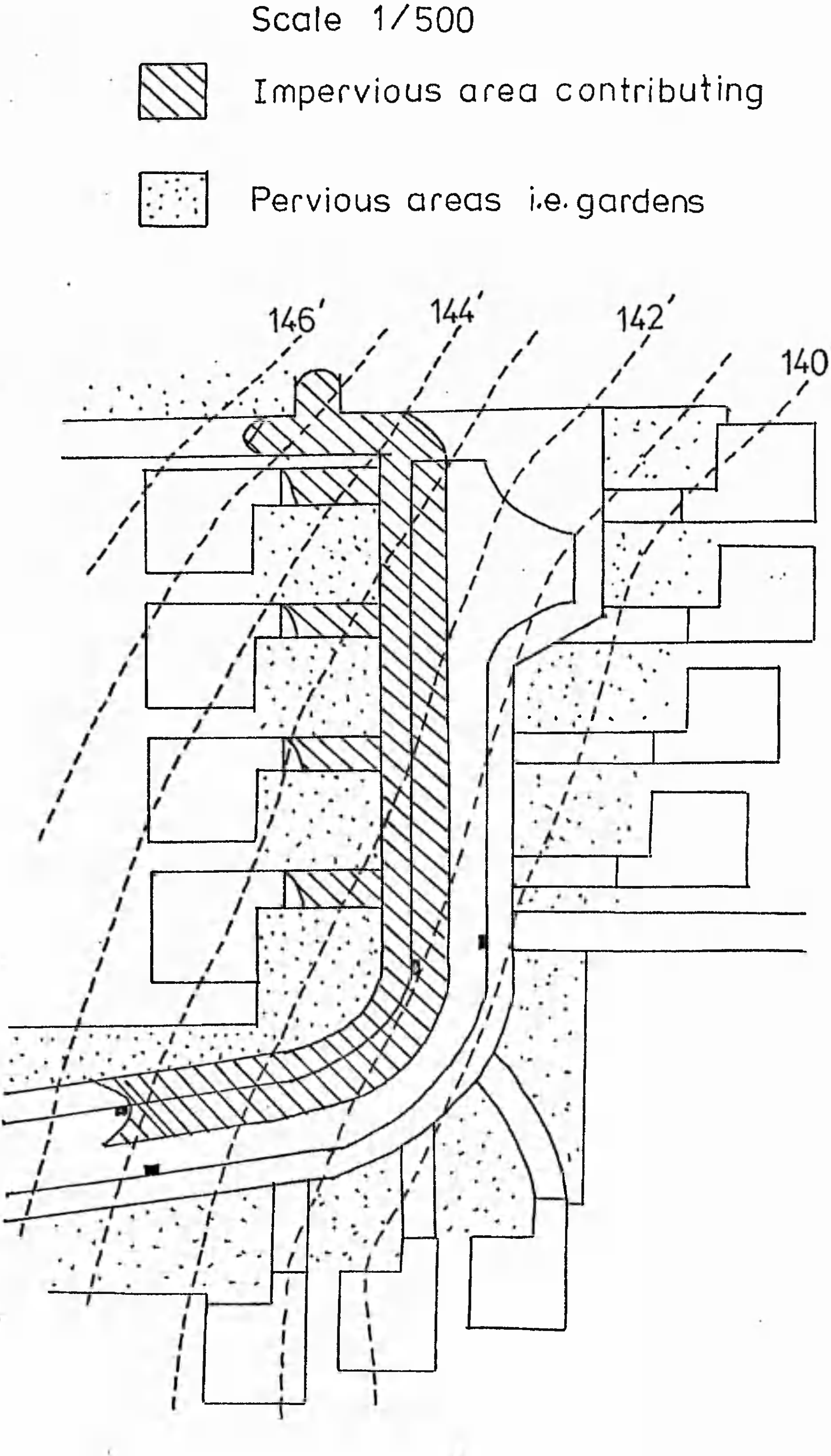


Fig. 16 SUBCATCHMENT MAP - GULLY POT 1

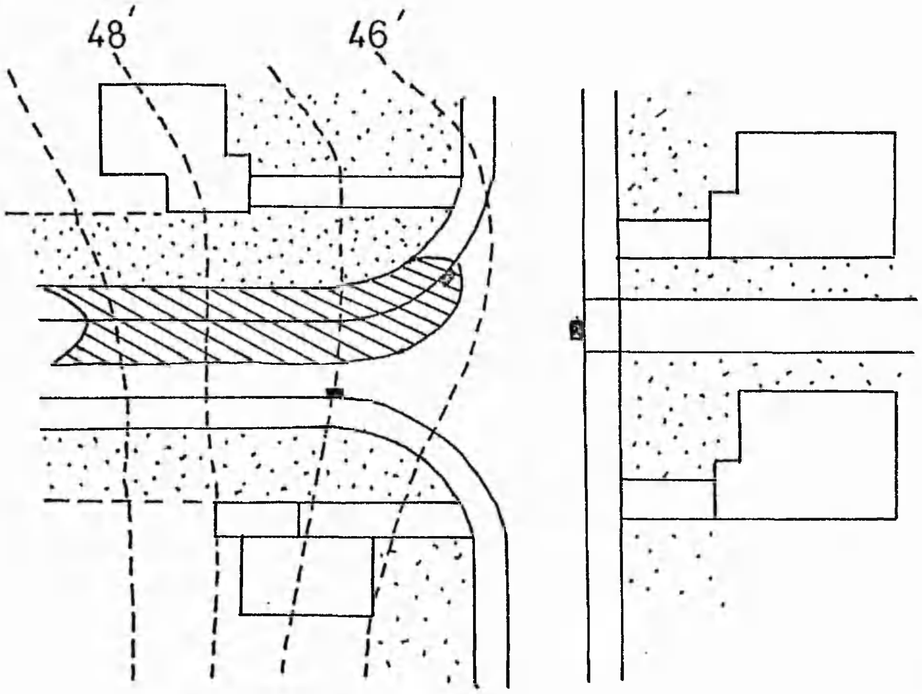


Fig.17 SUBCATCHMENT MAP - GULLY POT 8

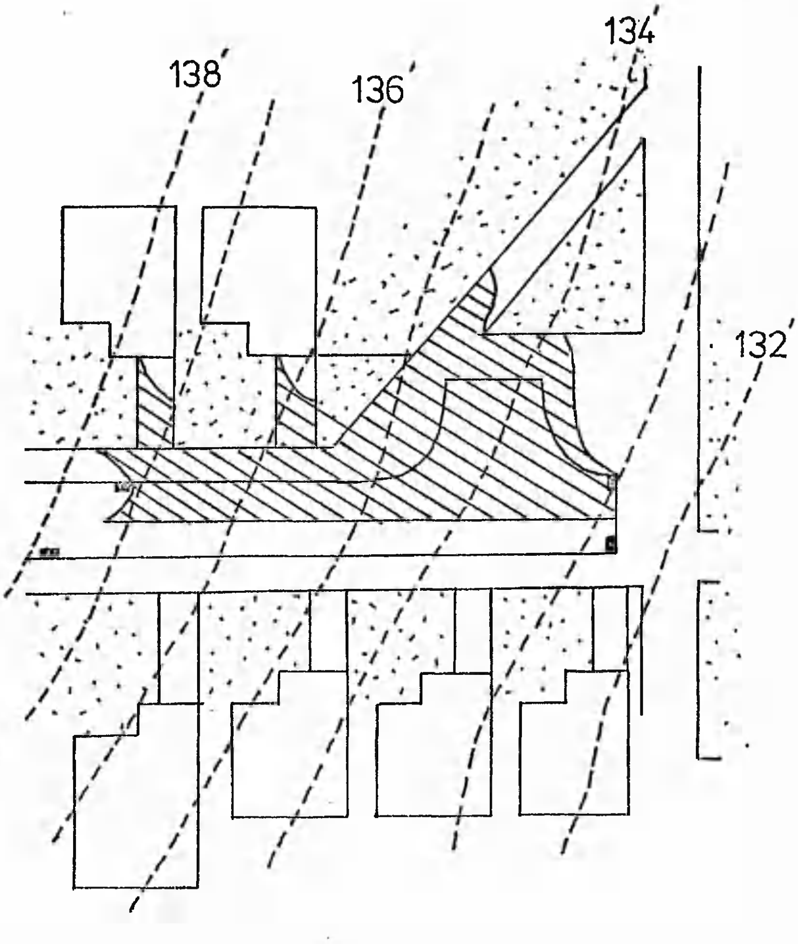
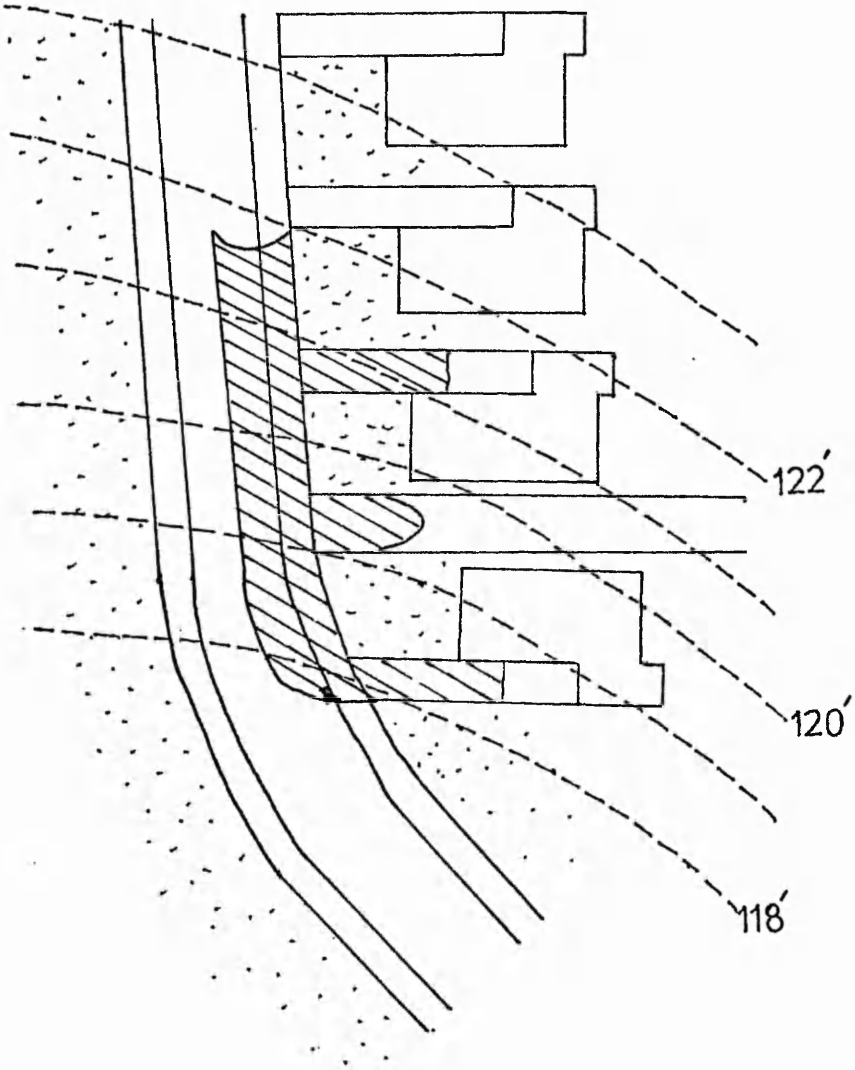


Fig. 18 SUBCATCHMENT MAP - GULLY POT 7



d) Presence of open land which might contribute to the runoff entering the pot.

e) Situation on the estate, e.g. cul-de-sac, main feeder road.

The Clifton Grove sewer system contains 108 gully pots. Each pot normally holds about 95 litres of water, resulting in a total volume of stored water of some 10,200 litres of water, there being no other storage of water in the system. Four gully pots were selected for detailed examination of pollution parameters over an extended period according to the physical criteria listed above, their subcatchment characteristics are listed in Table 17. Figures 15, 16, 17 and 18 are catchment maps for each of the gully pots. These pots were selected to represent the diverse situations that could be encountered on the estate: the occasional sampling of other gully pots was based on random selection using random number tables.

1.3.4. Selection of Pollution Parameters for Analysis

The main parameters of importance in characterising the polluting nature of a water include the following:-

a)	Solids content:-	settleable solids, suspended solids (SS), volatile suspended solids (VSS), dissolved solids (DS).
b)	Oxygen demand:-	biochemical oxygen demand (BOD), chemical oxygen demand (COD),total organic carbon (TOC).
c)	Dissolved oxygen (DO)	
d)	pH	
e)	Nutrients:-	nitrogen species (ammonia, nitrite, nitrate) phosphorus species (phosphate).
f)	Anions:-	chloride, sulphate, etc.
g)	Heavy metals:-	lead, zinc, cadmium, mercury

h) Toxic organics:- herbicides, pesticides, etc.

i) Oil and other hydrocarbons.

The relative importance of these parameters in characterising the polluting nature of a water is dependent upon the origin of the water and the polluting processes with which it comes in contact. Selection of parameters was a compromise between aiming for as wide a coverage as possible and the limited time available for analytical procedures. The parameters that were analysed on a regular basis were SS, VSS, DS, BOD, COD, DO, pH, ammonium, nitrate, chloride, sodium and calcium. The heavy metals lead, zinc, copper and cadmium were analysed less regularly. The presence of oil and detergents was noted but quantitative determination was not undertaken.

2. INSTRUMENTATION, SAMPLING AND DATA COLLECTION

For a project of this nature the data requirements and instrumentation needed for its collection are necessarily diverse and can be seen primarily as four fold:-

a) Water quality sampling from gully pots and sewers

b) Flow determination in sewers

c) Meteorological measurements

d) Other pollutant input and output measurements, i.e. rainfall quality, atmospheric dustfall, council cleaning practices, human/animal behaviour, factory emissions, etc.

2.1. WATER QUALITY SAMPLING

Sampling is a frequently disregarded aspect of water quality determinations, whereas errors in analytical methods can be reported accurately, the nature and relevance of errors from sampling techniques is rarely considered. Two principal criteria should be applied in sampling waters. Firstly, the samples should be collected in such a manner as to be representative of the mean quality of the water body under consideration and secondly, sampling should be reproducible. Both criteria are hard to satisfy and difficult to verify. The procedure adopted in this research was to perform sampling in a standardised manner and in that way results within the project were directly comparable.

2.1.1. Sampling from Gully Pots

Sampling of gully pot waters was performed using a purpose built 'S' stick (Figure 19). This arrangement allowed bottles of either 1 litre or 500 ml capacity to be immersed to a known depth, determined by a mark on the support rod and for samples to be taken without preferential inclusion of surface film. The procedure ensured that the samples collected from different gully pots or the same gully pot over time were similarly obtained and, therefore, comparable.

2.1.2 Sampling from the Sewer

Sampling was achieved using a Rock and Taylor multipurpose automatic sampling machine (Figure 20), which could receive up to a maximum of 48 samples in 500 ml plastic bottles. The machine was housed on a specially constructed wooden platform in the final manhole before the sewer outfall and was powered by a 12 volt battery.

Sampling was initiated by a Flygt ENHIO mercury float switch when flow rate in the sewer rose to approximately 8 litres/second. Pumping was performed by a twin channel peristaltic pump with a 3-stage adjustment for varying sample line velocities, i.e. sample volume. The cycle for each sample was comprised of forward pumping for sample collection and reverse pumping for emptying the inlet tube prior to the next sample. The duration of both pumping modes was controlled by adjustable timers. With the peristaltic pump adjusted to maximum pumping rate a line velocity greater than 50 mm/second was recorded which was sufficient to gain a representative suspended solids sample (Wood and Stanbridge, 1968).

The sampling arrangement on the bed of the sewer is illustrated in Figure 21. A metal 'T' piece was employed to secure the sampling tube and protect it from buffeting by objects washed down the sewer. The 'T' piece was constructed from 90° angled iron with the angle being pointed into the flow to minimise disturbance to the hydraulic regime. However, for low flow situations a minor 'stilling' effect could be observed at the sampling orifice. The orifice itself was 15 mm above the bed of the sewer and was protected from blocking by leaves or cellophane with a wire guard. Colston (1975) has reported a vertical variation in suspended solids dispersion in storm sewers, however, for this study the position of the sampling orifice was constant for all storms. This was believed to result in minimal errors since, for many of the low intensity storms monitored at Clifton Grove, the depth of flow at the sampling point rarely exceeded 200 mm, for such low depths of flow vertical variation was considered to be insignificant. The sampling arrangement described above was constant throughout the period of monitoring and was considered to represent the best compromise between effectiveness of operation and reproducibility of sampling.

Fig. 19 SAMPLING FROM A GULLY POT

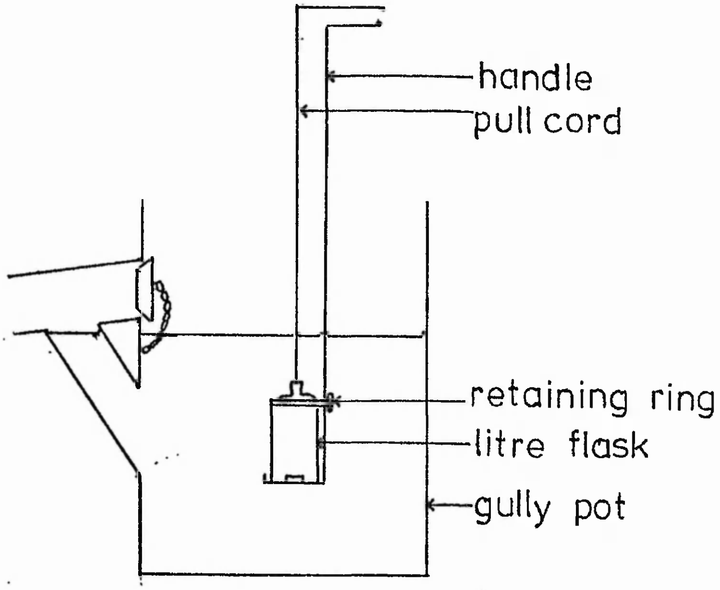


Fig.20 LAYOUT OF THE SAMPLING MACHINE IN A MANHOLE

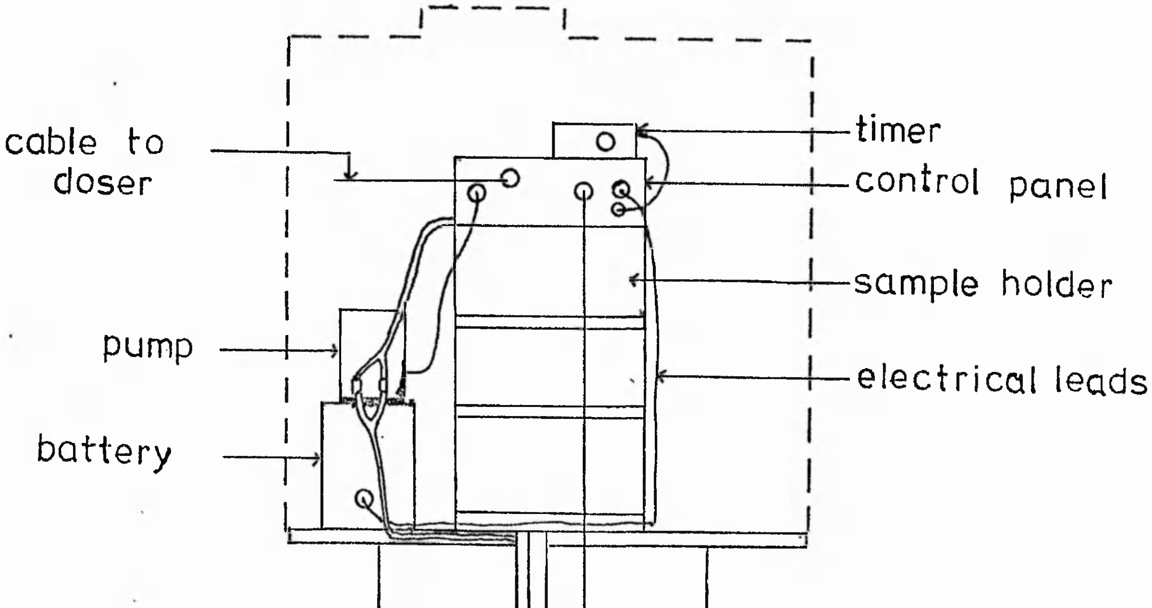
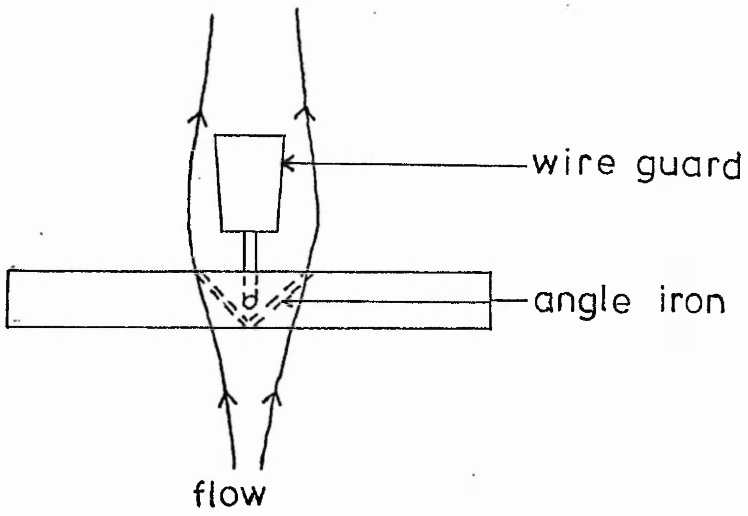
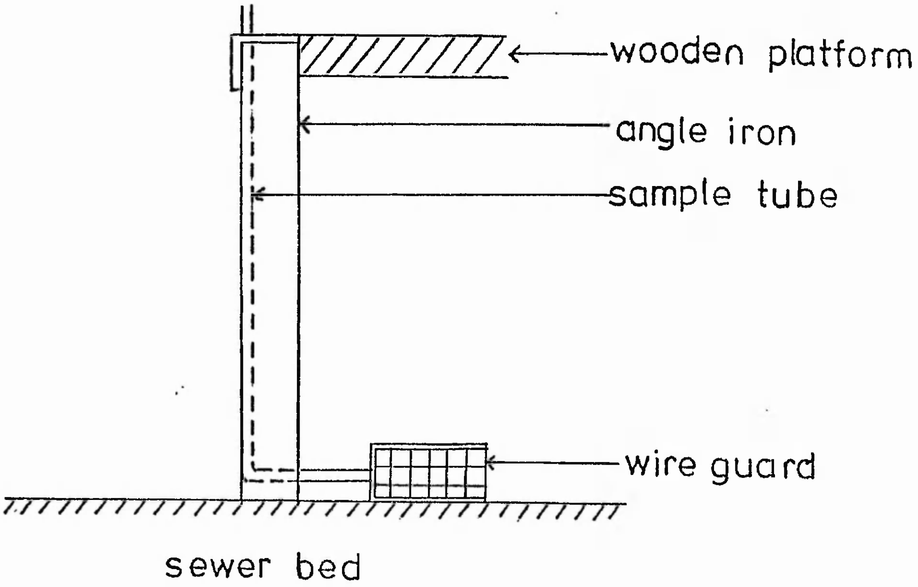


Fig. 21 DETAILS OF SAMPLING ARRANGEMENT IN THE SEWER

a) top view



b) side view



2.2. FLOW DETERMINATION

Flow in sewers is conventionally determined either by the use of a calibrated section with a known depth to discharge relationship or by chemical tracer dilution (dilution gauging). The latter method had been employed in previous studies at Trent Polytechnic and, because of the availability of instrumentation was selected for this study.

Dilution gauging is normally performed by one of two methods:-

a) Constant rate tracer injection

b) Gulp tracer injection

Both methods rely upon the same principle, a known mass of tracer in solution is added to the flow and its concentration is subsequently determined downstream after cross-sectional mixing is complete. In gulp injection a fixed volume of solution containing a known mass of tracer is introducted to the flow. Downstream the complete passage of this pulse of tracer is sampled continuously, the pipe flow is then calculated from the equation:-

$$Q = \frac{M}{(M_s - M_o)} \quad q_s$$

where
Q = flow
q_s = flow sampled
M = mass of tracer added
M_s = mass of tracer sampled
M_o = mass attributable to background levels.

This technique was used by Tucker (1975) forstudies on two residential estates in Nottingham, but was found to be unfeasible for the Clifton Grove catchment due to the low pipe gradient (1 in 300) in the dilution reach. Complete sampling of the tracer pulse in this situation would require inordinately long sampling times and result in unrepresentative sampling of suspended solids due to the low sampling line velocities required. Additionally, the long sampling times would result in poor resolution of the runoff hydrograph.

The constant rate injection method does not suffer from these limitations, is considered to be superior and was adopted in this study. A tracer solution of known concentration (C_1) is injected into the flow (Q) using a constant head apparatus to achieve a constant rate of dosage (q). A concentration of the tracer (C_2) will result downstream and, assuming background tracer levels to be negligible, then:-

$$Q = \frac{C_1}{C_2} q$$

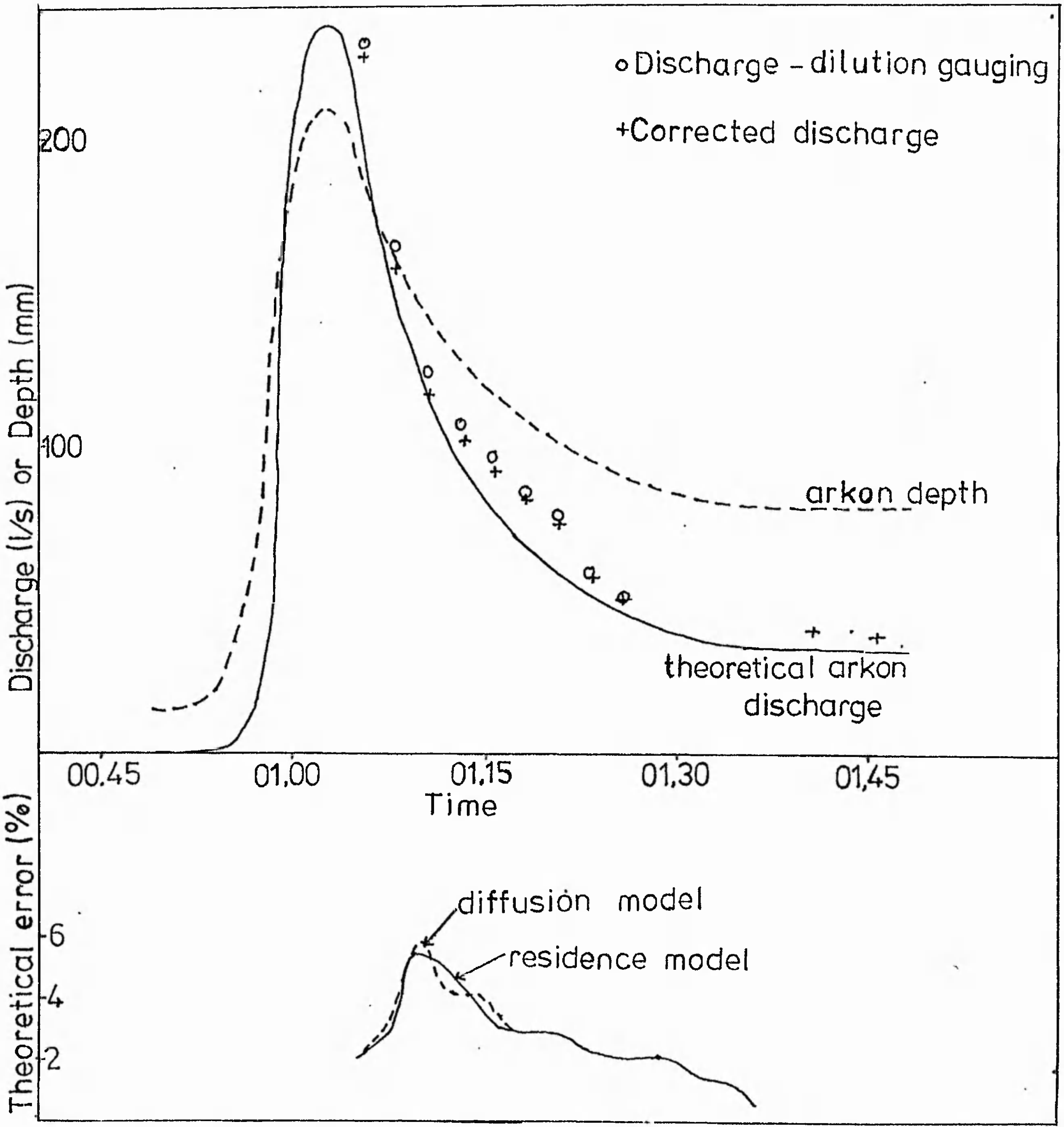
This equation is only truly valid for steady state conditions, if flow rates are rapidly varying then a systematic error will be caused by the change in discharge with time. Gilman (1975,1977) has proposed a residence-time model which can be used to estimate errors occurring in dilution gauging throughout a storm hydrograph. The model relies upon the determination of a residence-time distribution from the response noted for an instantaneous input of tracer and the manner in which this distribution varies with flow rate. Similarly Price (1976) has proposed a diffusion model based on dispersion theory which can also be used to estimate errors in discharge calculations. Both models rely on the changes in flow rate being smooth and 'slowly varying'. The models have been utilised by Harvey et al (1977) in the assessment of prototype dilution gauging instrumentation, an example of their findings are shown in Figure 22, where errors of up to 5% are indicated.

2.2.1 Practical Criteria of Dilution Gauging

Before dilution gauging can be successfully implemented certain practical criteria must also be satisfied.

Between the point of tracer injection and the sampling point downstream, it is necessary for the tracer to undergo complete cross-sectional mixing. Fortunately, the turbulent nature of flow in storm sewers provides very good mixing. In foul sewers an elementary rule has been established that the length of pipe needed to achieve cross-sectional mixing should be 100 times its diameter. For the Clifton Grove catchment for the reach of sewer under consideration, the pipe diameter was 0.45 metre and its length was 100 metres, clearly satisfying this condition.

Fig.22 DILUTION GAUGING RESULTS (AFTER HARVEY ET AL, 1977) ILLUSTRATING THE THEORETICAL ERROR IN DISCHARGE MEASUREMENT ESTIMATED BY THE DIFFUSION MODEL (PRICE, 1976) AND THE RESIDENCE MODEL (GILMAN, 1976)



There should be no additional input or abstraction from the flow between the injection and sampling points. To achieve this situation it was found necessary to divert a roof runoff input pipe at the sampling manhole to a point one metre downstream of the sampling position, where it was considered to satisfactorily bypass the sampling head and have no influence upon the sampling regime.

There should be no occurrence of still water at the sampling point as this will result in erroneous flow measurements. This problem arose on a few occasions when the River Trent in flood conditions 'backed up' from the sewer outfall and no flow measurements were possible.

2.2.2 Application of Dilution Gauging

2.2.2.1 Instrumentation

The instrumentation developed at Trent Polytechnic for constant rate tracer injection is illustrated diagrammatically in Figure 23; the general layout of the apparatus in the sewer system is shown in Figure 24. Dosing of tracer solution was initiated by adaptation of the Rock and Taylor sampling machine to send an impulse upstream by cable at the same instant that the float switch activated sampling. The impulse was used to trigger a relay which brought into operation a peristaltic pump. The pump, powered from a separate 12 volt battery, transferred tracer solution from a 25 litre container to a constant head vessel which discharged the solution through a calibrated glass capillary tube into the flow. The capillary tube was calibrated in the laboratory to a dose rate of 1.025 ml/second (averaged over 50 observations). The injection rate allowed up to 3½ hours dosing and was consistent with the amount of sampling time available on the sampling machine. Dosing rates were verified regularly during routine maintenance in the field when the capillary tube was flushed clean with distilled water and, whenever possible, prior to storm events.

The doser required approximately 6½ minutes before an equilibrium dose rate was achieved (Figure 25). This delay was created by the time needed for the constant head to reach equilibrium behind the discharge capillary tube. As a result of this delay it was necessary to apply a

Fig. 23 SCHEMATIC DIAGRAM OF THE CONSTANT HEAD CONTINUOUS INJECTION LITHIUM DOSING APPARATUS

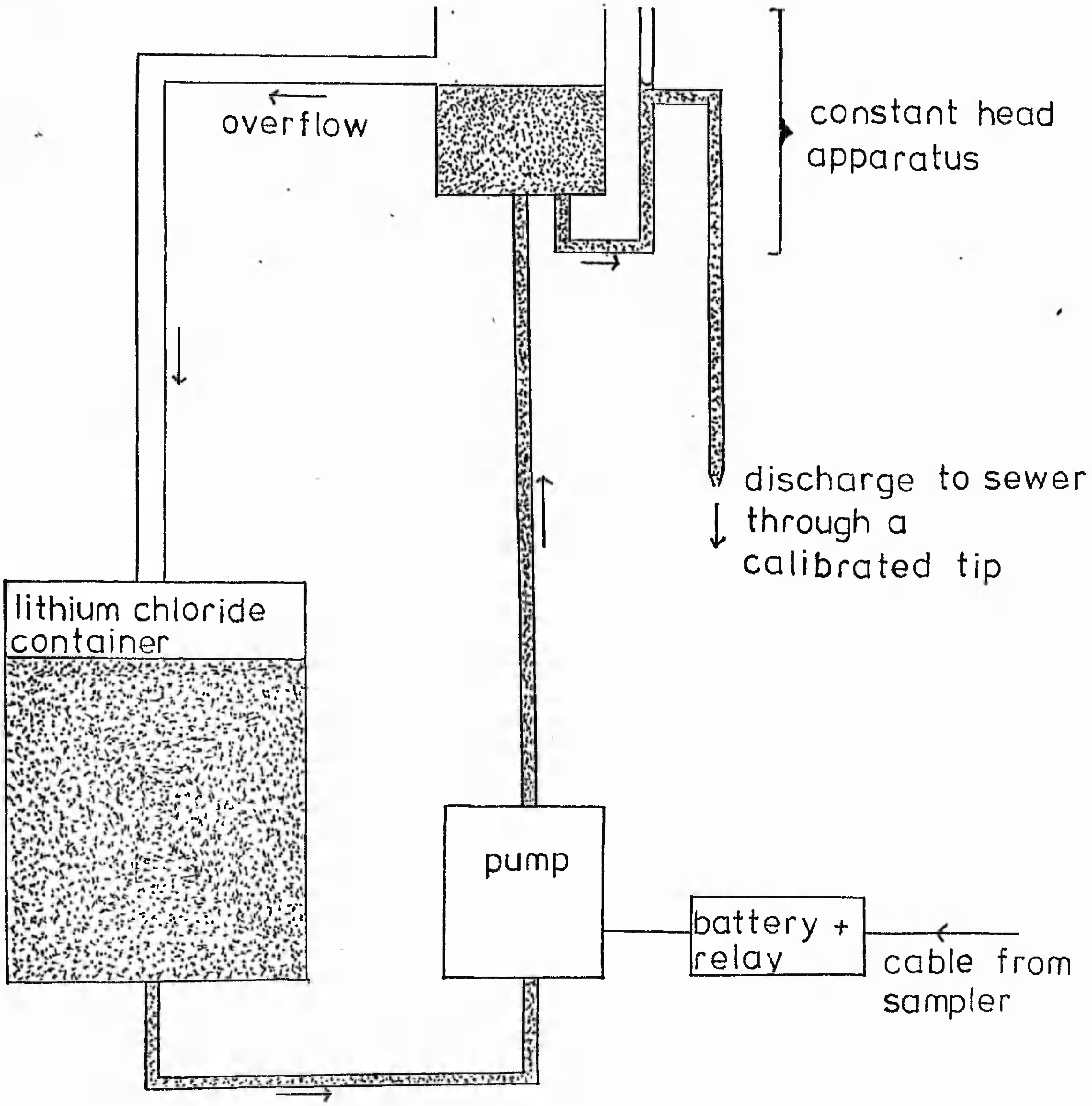


Fig. 24 LAYOUT OF INSTRUMENTATION IN THE SEWER SYSTEM

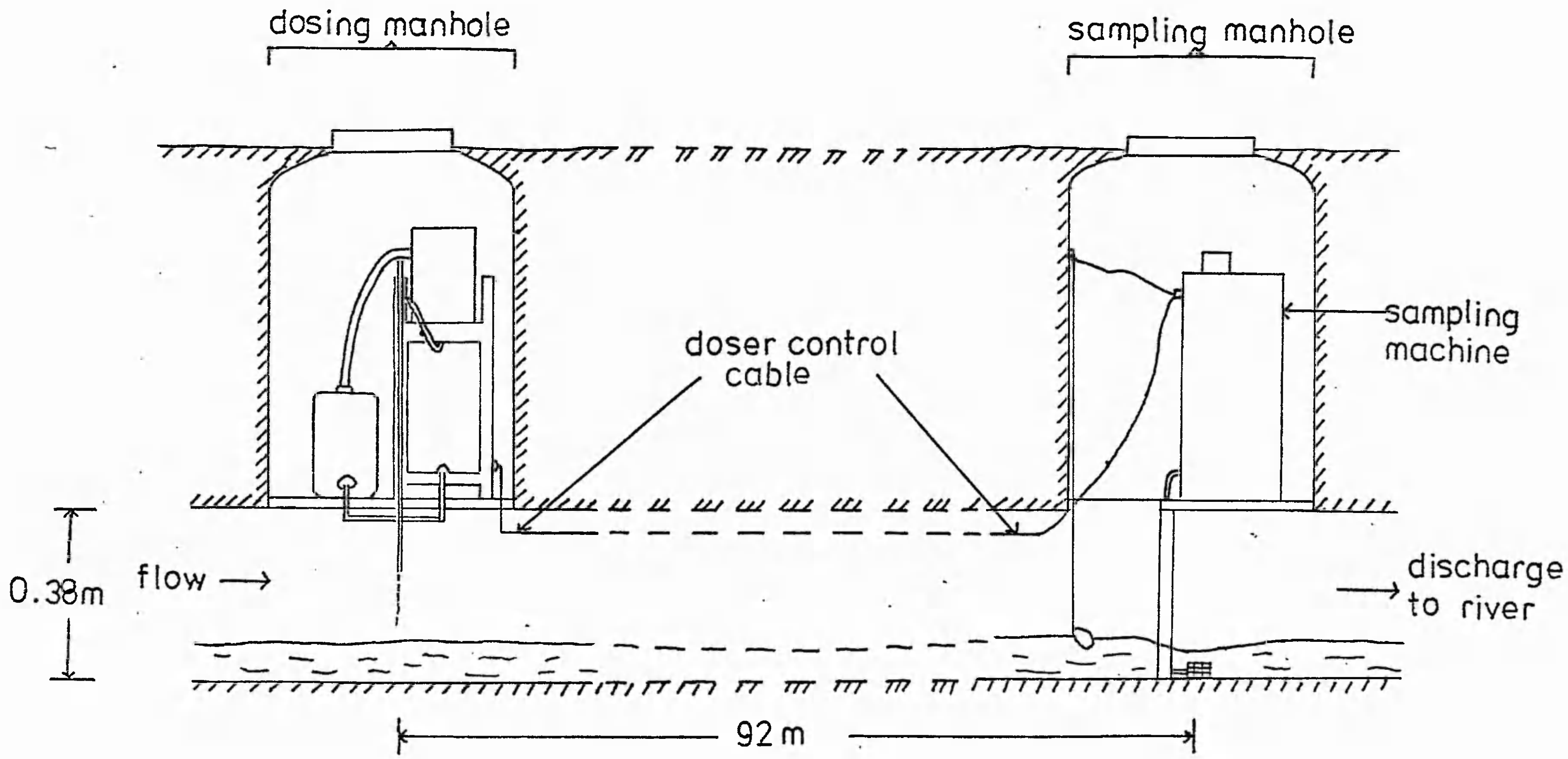
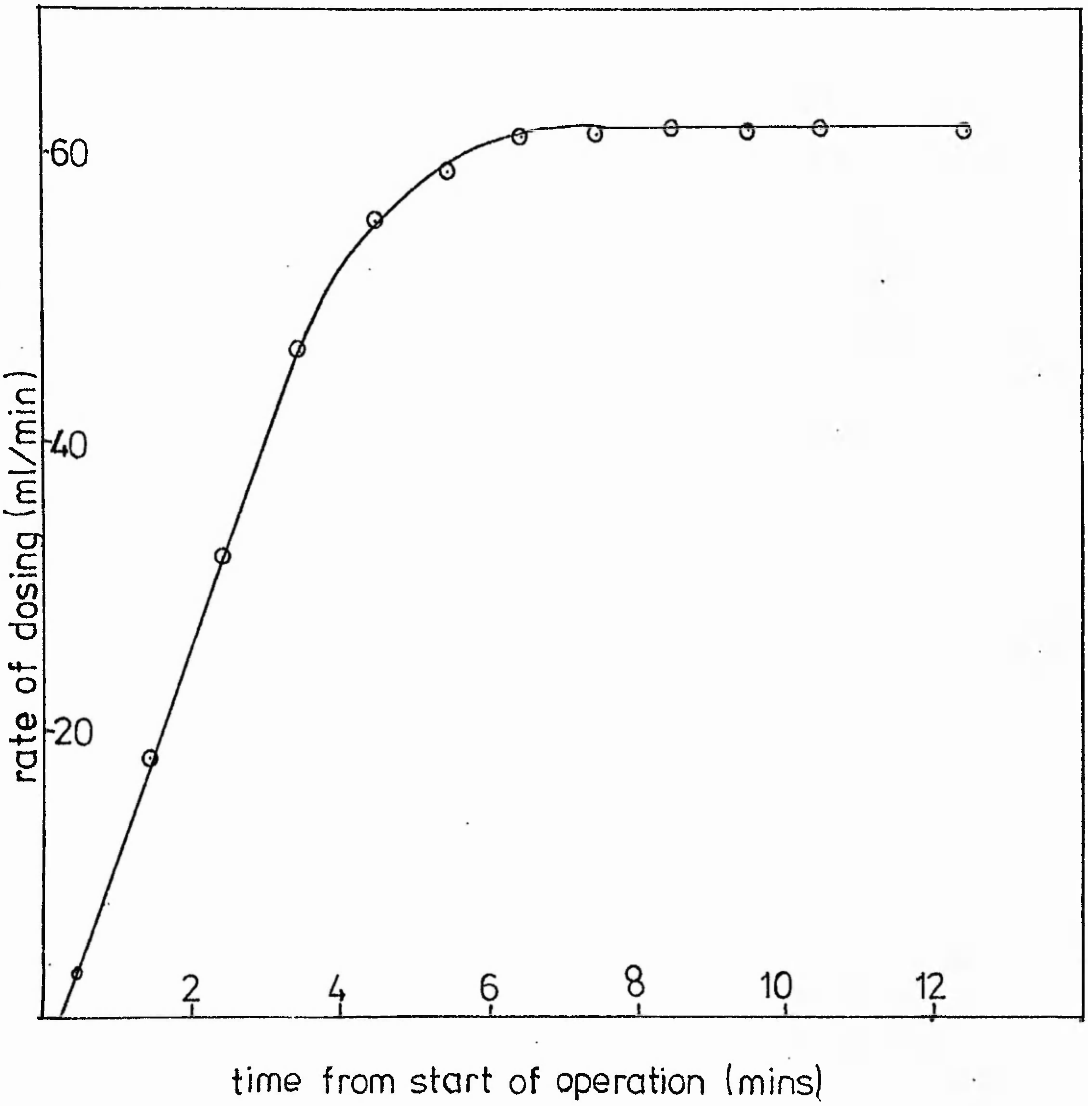


Fig. 25 CALIBRATION FOR THE RATE OF DOSING OF LITHIUM CHLORIDE FROM THE DOSER



correction factor for the determination of flow in the second and third samples (Section 4.2.1.). Theoretically the problem could have been alleviated by the use of a two way valve located in the discharge line. However, preliminary investigations with such a valve were not successful. Some leakage occurred continuously when the machine was not in operation and inconsistent operation resulted in variations in dose rate and consequently unreliable flow determination.

2.2.2.2 Selection of Tracer

For a chemical tracer to be suitable for the determination of flow in storm sewers it must satisfy three criteria. Firstly, its background concentration in the flow must be negligible, secondly, it should not be significantly adsorbed from solution onto particulate matter and, lastly, it is preferable that the tracer is environmentally safe. Lithium fulfills all these requirements and has been successfully employed for several years, (Blakey, 1969; Gizzard and Harms, 1974). Neal and Jordan (1978), examining the use of iodide and lithium as tracers, concluded that whilst lithium was satisfactory, iodide had considerable limitations because of significant adsorption onto particulate matter. Lithium, as the chloride salt, had been used previously at Trent Polytechnic (Tucker, 1975) and was employed in this work.

2.2.2.3 Tracer Preparation

A suitable concentration for the lithium chloride tracer solution was determined by consideration of the postulated maximum flow rate and the detection limits of the analytical technique used. Using the EEL 240 atomic adsorption spectrometer lithium values in the range 0.01 to 8.0 mg/l can be readily determined. With an assumed maximum flow rate of 300 litres/second, a desired lithium concentration in the flow rate of 0.1 mg/litre and a doser injection rate of 1.0 ml/second, then from the equation:-

$$\begin{aligned} \text{Concentration in tracer} &= \frac{C_2\,Q}{q} \\ &= \frac{0.1 \times 300}{1} \quad \text{mg/ml} \\ &= 30 \text{ g/l} \end{aligned}$$

In practice a tracer concentration of 40 - 45 g/l lithium was used and with measured flow rates rarely exceeding 100 l/s, the concentration of lithium in the flow (circa 0.4 mg/l) was sufficient to make background concentrations insignificant.

3.5 kg of lithium chloride were used to prepare 15 l of tracer in the laboratory. The solution was then transported in bulk and emptied into the container in the field, care being taken to ensure that no spillages occurred that would subsequently adversely affect flow determination.

2.2.2.4 Sampling Duration

In gulp injection dilution gauging the sampling duration is fixed by the time necessary to sample the whole of the tracer pulse under minimum flow conditions. With constant rate injection no such constraints on sampling times exist. Sampling times were minimised as much as possible in order that:-

a) the velocity in the sampling line was sufficient to gain a representative sample of suspended solids;

b) a close approximation to an instantaneous flow measurement was made; and

c) a better resolution of the storm hydrograph was achieved.

In practice the minimum sampling time was limited by the need to obtain a sample volume large enough for analysis. This was in turn dependent upon the maximum pumping capacity of the peristaltic pump. For the majority of events a sampling interval of 3 minutes was selected, this included a sampling period of 2 minutes and one minute of reverse pumping between samples. However, the pumping times were not accurate and these settings resulted in a mean sampling period of 2.06 minutes and an interval of 3.04 minutes between samples, with an average volume of 400 ml collected. Sampling times for the first pumping cycle were found to be slightly longer than the subsequent sampling times above and this had to be taken into account in calculations. A sampling interval of 3.37 minutes with a sampling period of 2.39 minutes were recorded for the first cycle.

2.2.2.5 Timing of Events

The commencement of sampling was recorded through the further adaptation of the Rock and Taylor sampling machine to switch off a purpose built 12V. quartz clock. The clock, powered by the 12V. battery, was set to Standard Time when the apparatus was commissioned in preparation for a storm event. When the float switch initiated sampling an impulse from the machine was used to operate a solenoid and so break the clock circuit. The clock was found to be accurate to a few seconds over several days.

2.3. METEOROLOGICAL MEASUREMENTS

Rainfall intensities for individual storm events were measured by an 8" Rimco tipping bucket raingauge. The gauge has an operating range of zero to 400 mm of rainfall per hour with an accuracy of ± 1% with 0.5 mm per bucket tip. The raingauge was calibrated in the laboratory using measured flow rates and recording the number of tips per second to obtain the true rainfall volume per bucket tip, this was found to be 0.432 mm. The sensitivity of the gauge was increased for use in the field to 0.113 mm per bucket tip by the use of four funnels to increase the collecting surface.

The accurate timing of storm events and raingauge tips was achieved using a battery operated data logging system (Microdata Ltd.). The data being recorded on standard tape cassettes which were subsequently translated at the Institute of Hydrology. Tapes and batteries were normally replaced at 3 to 4 day intervals. The raingauge was positioned on the flat roof of Clifton College, approximately 10 metres above ground level and 100 metres from the Clifton Grove catchment. Although not fulfilling all the standard conditions for siting raingauges, the placement was advantageous in that no buildings or trees overshadowed the site and vandalism of the equipment was avoided.

Daily meteorological data, including total rainfall, maximum and minimum temperatures, wind direction and speed, were available from Meteorological Office raingauge 116959 sited at Beeston sewage works approximately 1 mile to the north west of the catchment. If this station was inoperative data was also available from stations at Nottingham University or Nottingham Castle. Additionally, hourly weather data could be obtained from the regional weather centre at Watnall, approximately

7 miles to the north of the catchment.

2.4. OTHER MEASUREMENTS

A large variety of other measurements for classifying and quantifying pollutant inputs and outputs are possible. Some important aspects of the urban pollutant generation system such as human and animal behaviour defy quantification. Although door to door surveys could yield useful information on car washing frequency, application of garden fertilisers and dog ownership, etc., a study of this kind was deemed to be outside the scope of the project and visual observations were considered to be sufficient.

Information on land use, sewerage systems and council cleaning practices was available, courtesy of Nottingham City Council. Although the dates of council gully emptying on the catchment were available, it was found impractical to estimate the actual mass of material removed.

Atmospheric dustfall measurements were made using three large plastic funnels which were exposed to the atmosphere for periods of one, two and three weeks. The particulate matter and rainfall falling on the funnels was collected in a litre flask, the mass of solids collected was then determined by filtration, care being taken to ensure that all solids adhering to the funnel were washed into the flask prior to analysis. The apparatus was positioned on Clifton College roof. Measurements were hampered by flies and insects that found their way into the containers, and had to be removed during filtation. Consequently, it was found necessary to ignore some 50% of the samples and only reliable data has been presented.

Rainfall for quality determinations was collected as runoff from a greenhouse roof, located at Clifton College. Difficulties were again encountered with flies and insects being present in the sample. However, lichen washed off wooden greenhouse supports, sediments accumulating in gutters and bird droppings presented additional more serious problems. These factors may have resulted in some high values of COD and ammonia (similar observations have been reported by Mance (1977)).

3. CHEMICAL ANALYSIS

With the generation of large numbers of samples for analysis of most importance in the selection of analytical techniques, after accuracy, was simplicity and rapidity. To this end it was necessary to employ methods that involved the minimum of sample preparation in preference to techniques that, although more accurate, were also more time consuming. As an example, selective ion electrodes were used in the analysis of nitrate and ammonia in place of the lengthier colorimetric procedures that are normally recommended. This approach may have been beneficial since sample deterioration and chemical changes induced in natural waters by, for example, bacterial activity makes it essential that samples are analysed within 24 hours of collection. For analyses where degradation was not a problem, samples were stored in a fridge at 4°C with the addition of relevant preserving agents when necessary, e.g. concentrated nitric acid for heavy metals.

Of prime importance in all analytical work is the thorough cleaning of glassware prior to use. A routine of scrubbing, soaking in dilute hydrochloric acid and rinsing several times with distilled water was rigidly followed to avoid sample contamination. For the analysis of heavy metals stricter routines were employed involving the soaking of glassware in concentrated nitric acid, washing with Decon 90 and rinsing with distilled water.

All the chemical analytical methods employed routinely in the research are outlined in this chapter. Theoretical considerations are included where this is applicable in explaining the choice of technique and the problems encountered. The performance of the methods and the specific problems of relevance in the analysis of stormwater samples are discussed.

As a check on the precision of the methods employed a four litre sample, separated into eight equal portions, was analysed for each of the parameters in turn. The mean value, standard deviation and coefficient of variation were calculated and are presented in Table 18.

3.1. SOLIDS

The classification of solids in urban stormwater runoff is of particular importance in characterising the polluting nature of the waste. High levels of suspended solids have been reported in all urban runoff studies and have been shown to be related to high levels of several other pollutants, either by adsorption or by the nature of the solid itself, e.g. BOD, COD, heavy metals.

The methods used in the determination of solids are necessarily empirical, the constituents being largely defined by the procedures employed. For example, the recorded value of suspended solids is dependent upon the porosity of the filter paper, loss of volatile compounds on evaporation and the drying rate of oils. As a consequence of these errors 'Standard Methods' (American Public Health Association, 1976) recommends the use of the terms non-filterable residue for dissolved solids and filterable residue for suspended solids. In this research the classical terminology has been retained owing to its common usage. Although the measure obtained may not be the definitive solids value, the use of standardised procedures ensures that results within this study are comparable and also comparable to other studies.

Analyses were performed routinely for suspended solids (SS) and dissolved solids (DS) and occasionally for volatile suspended solids (VSS) and turbidity. Originally turbidities were determined to assess the viability of a SS/turbidity relationship for the estimation of SS concentration. Turbidity being advantageous in that it is simply and rapidly determined. Although a fair correlation was found to exist, (Figure 26), the variance was too great for a useful estimation of SS to be possible. For example, at a turbidity of 30 f.t.u. (formazin turbidity units) the recorded SS concentrations lay between 50 mg/l and 150 mg/l. Nonetheless, turbidity was usefully employed as an aid to the interpolation of SS values between known concentrations in storm hydrographs.

The specific methods employed are outlined below:-

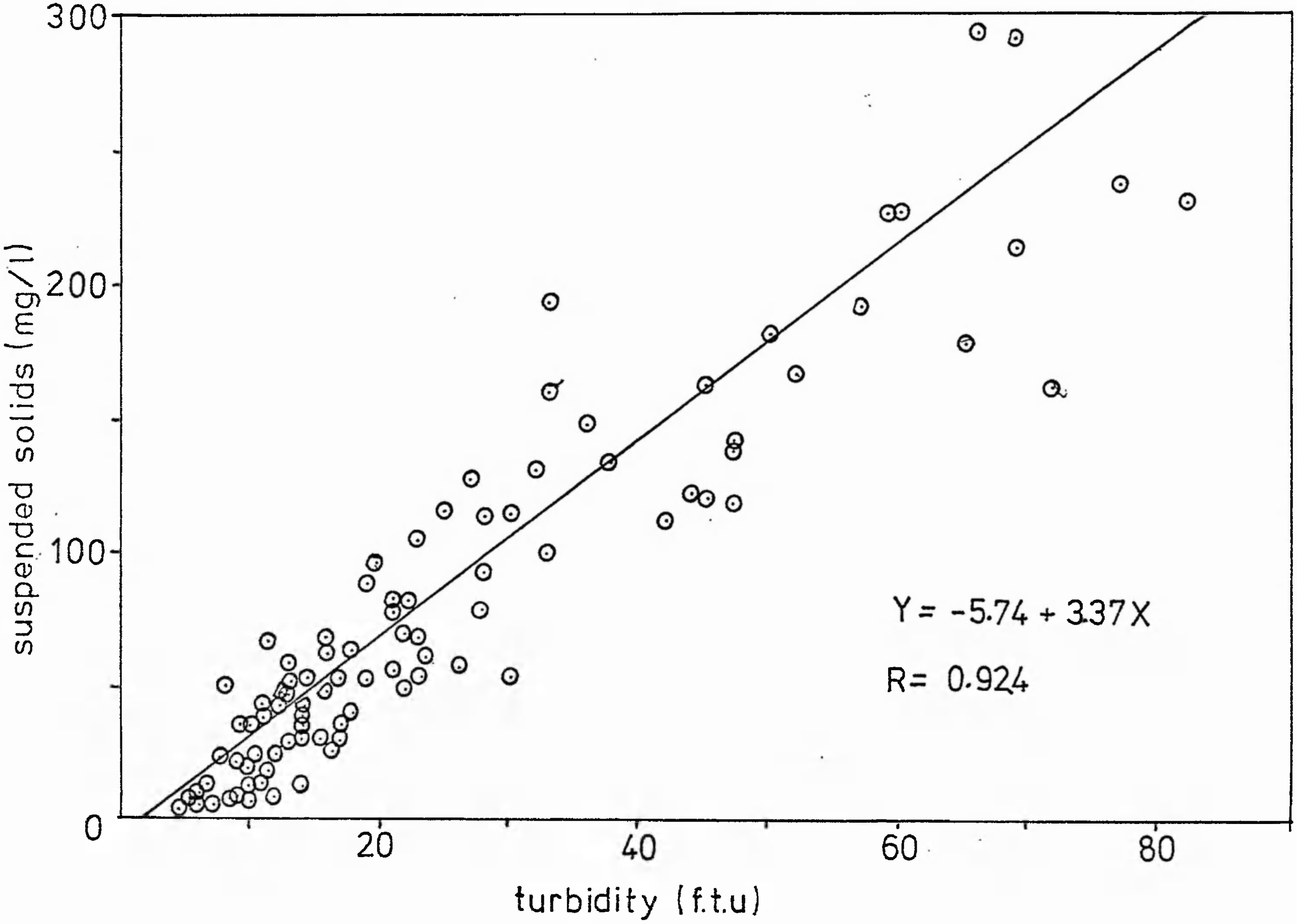
3.1.1 Suspended Solids and Volatile Suspended Solids

A glass fibre filter paper (Whatman GF/C) previously washed with distilled water was dried in an oven at 105°C for 1 hour. If volatile

TABLE 18 Precision of Analysis

Parameter	Mean	Standard Deviation	Coefficient of Variation (%)
Suspended Solids	26.5	1.9	7.2
Dissolved Solids	18.3	1.7	9.3
COD	24.4	1.2	4.9
BOD	6.75	0.52	7.7
pH	7.16	0.025	0.35
Nitrate	24.5	1.06	4.3
Ammonium	0.19	0.014	7.4
Chloride	29.2	1.95	6.7
Zinc	0.623	0.052	8.4
Lead	0.133	0.026	19.6
Copper	0.032	0.009	28
Lithium	0.8	0.02	2.5
Sodium	2.4	0.01	0.41
Calcium	17.9	0.84	4.7
Potassium	0.95	0.032	3.4

Fig. 26 CORRELATION BETWEEN SUSPENDED SOLIDS AND TURBIDITY



matter was to be determined the paper was transferred to a muffle furnace and heated to 550°C for 15 minutes. The paper was allowed to cool to room temperature in a dessicator and weighed (W_1).

100 mls of shaken sample were measured in a graduated cylinder and filtered through the paper using vacuum on a Hartley filter/Buchner flask apparatus. The cylinder was washed out with 3 x 10 mls of distilled water. The filter paper was now dried at 105°C for 1 hour, cooled to room temperature in a dessicator and weighed (W_2). If volatiles were to be determined the paper was ignited in a muffle furnace for 15 mins at 550°C, transferred to a dessicator, cooled and weighed (W_3).

$$SS = \frac{(W_2 - W_1)}{V} \times 1000 \text{ mg/l}$$

$$VSS = \frac{(W_2 - W_3)}{V} \times 1000 \text{ mg/l}$$

where V = Volume of sample

The coefficient of variation of 7.2% reported in this study agree favourably with a precision of ± 5.2 mg/l (33%) at 15 mg/l quoted in 'Standard Methods'.

3.1.2 Dissolved Solids

A porcelain evaporating dish was heated in an oven for 1 hour at 105°C, allowed to cool to room temperature in a dessicator and weighed (W_1). 50 mls of filtered sample were added to the dish, evaporated in an oven at 105°C for 1 hour, cooled and weighed (W_2).

$$DS = \frac{(W_2 - W_1)}{V} \times 1000 \text{ mg/l}$$

V = Volume of sample

Reported precisions of ± 5% compare to a coefficient of variation of 9.3% for this study. The discrepancy is ascribed to the lower sample volume used in determinations.

3.1.3 Turbidity

Measurements were made on a Hach Model 2100 Turbidimeter calibrated with standards of 10 f.t.u. (formazin turbidity units) and 100 f.t.u.

3.2. OXYGEN DEMAND

Oxygen demand tests were originally conceived as a means of quantitatively representing the polluting effect of a complex mixture of pollutants in waste waters, upon a receiving watercourse. Usually the tests make some assessment of the amount of oxygen required to oxidise, either biologically or chemically, the organic matter in a sample. As such, they give a measure of the presence of organic matter which is assumed to be a reasonable indication of the polluting capacity of the water. Many tests are available, the ones most commonly employed are:-

a) Permanganate value (PV)

b) Biochemical Oxygen Demand (BOD)

c) Chemical Oxygen Demand (COD)

d) Total Oxygen Demand (TOD)

e) Total Organic Carbon (TOC)

BOD and COD are the parameters used most frequently and were deemed to be the most suitable determination for this research.

Although the BOD test has recently been criticised for its variability and unreliability it still remains widely used and is one of the more important pollution parameters in use today. The test measures the quantity of dissolved oxygen (DO) consumed by aerobic bacterial oxidation of a water sample under specified conditions. It therefore provides an assessment of the likely impact of an effluent on stream dissolved oxygen levels, bearing in mind that the conditions under which the test is made are very different to those in the streamway.

DO is determined either chemically by the Winkler titration or by the use of a dissolved oxygen sensing probe. The DO probe was used in this study and has the advantage of simplifying the procedure. The difficulty in obtaining reproducible results is due principally to the biochemical nature of the test. Reproducibility is dependant upon the type of bacteria present, acclimatization time, the biodegradability of the sample and the presence of toxic substances. Relative standard deviations between 5% and 15% are normal (Water Research Centre, 1978), a value of 7.7% being recorded in this study.

The test is made more precise by the measurement of the BOD attributable to carbonaceous material only. The degradation of carbonaceous matter normally precedes the nitrification of any ammonia in the sample. If this is not the case and a significant amount of ammonia is contained in the sample, greatly inflated BOD values can occur. Nitrification can be suppressed and the reproducibility consequently improved by the addition of allyl thiourea. The BOD test is normally performed over a period of 5 days, however, in this research an interval of 7 days was found to be more convenient, making the suppression of nitrification even more important.

The COD test uses an acid dichromate oxidising solution which ensures almost complete oxidation of the majority of organic matter present. The technique is faster and more quantitative than the BOD determination and is a better measure of the total organic load. In the absence of interferences it gives the value to which BOD would approach, if incubation was continued until all organic material had been degraded.

Interference can occur in the presence of chloride ions and when oxidation of amino-type compounds to nitrogen occurs. Chloride interference is minimised by the addition of mercuric sulphate, but when concentrations exceed 20,000 mg/l, as was evident in a few samples affected by winter road salting, interference can be excessive and precipitation with subsequent removal is the best solution. Silver sulphate must be employed as a catalyst to ensure complete oxidation of straight chain aliphatics and certain aromatic hydrocarbons, although this can inhibit the effectiveness of mercuric sulphate.

A standard method now exists and was used in this study. The method is applicable for COD values in the range 100 to 1000 mg/l, for samples containing less than 100 mg/l COD a similar procedure was followed but using reagents with revised concentrations. In later determinations (1978 onwards) use was made of the block digester sealed tube technique (Hach Chemical Co.), based on work by Jurka and Carter (1975). Loss of volatiles is claimed to be overcome by the use of the sealed tube and the method has the advantage of being simpler and much more rapid for large numbers of samples. Guarded approval for the technique has been given by the Water Research Centre (1978) provided the usual 1 : 1 acid to dichromate reagent was used.

3.2.1 Dissolved Oxygen

A Delta Model 2110 meter complete with a dissolved oxygen sensing probe and automatic stirrer was used for all DO determinations. The meter was air calibrated before use for both field and laboratory measurements.

3.2.2 B.O.D.

Reagents:-

Phosphate buffer solution:

8.5g potassium dihydrogen phosphate $KH_2 PO_4$

21.75g dipotassium hydrogen phosphate $K_2 HPO_4$

33.4g disodium hydrogen phosphate $Na_2 HPO_4 \; 7H_2O$

1.7g ammonium chloride NH_4CL

1 litre distilled water

Magnesium sulphate solution	22.5g $MgSO_4 \; 7H_2O$/litre
Calcium chloride solution	27.5g $CaC1_2$/litre
Ferric chloride solution	0.25g $FeC1_3 \; 6H_2O$/litre
Allyl thiourea	0.5 g/l

Procedure:-

The dilution water was prepared by the addition of 1 ml of each of the above reagents to each litre of distilled water. 50 ml of sample were added to a graduated cylinder and made up to 250 ml with dilution water (a 1.5 dilution was found to be adequate for most determinations, if higher BOD's were anticipated a 1.25 dilution was also prepared). The sample and dilution water were mixed well and added to a BOD bottle. The initial dissolved oxygen (DO_1) was determined using the DO probe and the bottle was topped up with dilution water. Any remaining air bubbles were shaken out by placing the bottle in an ultrasonic bath for 5 minutes. The bottle was stoppered tightly avoiding entrainment of air and incubated for 7 days at 20°C. The same procedure was repeated for a blank of dilution water (DO_{1B}). After incubation the final dissolved oxygen of the sample (DO_2) and the blank (DO_{2B}) were determined using the DO probe.

$$BOD = \frac{(DO_1 - DO_2) - (DO_{1B} - DO_{2B}) \times V_2 \text{ mg/l}}{V_1}$$

where V_1 = volume of sample

V_2 = volume of BOD bottle

3.2.3. C.O.D.

3.2.3.1. C.O.D. Concentrations 100 to 1000 mg/l

Reagents:-

Potassium dichromate solution (0.042M) (PD)
- 12.259 g/l $K_2 Cr_2 O_7$

Silver sulphate solution - 22g $Ag_2 SO_4$ in 1 litre of H_2SO_4 (conc)

Ferrous ammonium sulphate (0.25M) - (FAS)
- 98g $Fe(NH_4)_2(SO_4)_2$, 20 mls H_2SO_4 in 1 litre of distilled water

Ferroin indicator

Mercuric sulphate

Standardisation of ferrous ammonium sulphate:-

10 ml of potassium dichromate were added to a beaker and made up to 100 ml with distilled water. 30 ml of sulphuric acid were added and the solution was allowed to cool. The mixture was titrated against ferrous ammonium sulphate using ferroin as an indicator and the volume required to change the colour from violet to red was noted:-

$$T = \frac{\text{Volume of PD}}{\text{Volume of FAS}} \times 0.25$$

Procedure:-

20 ml of sample, 0.4g mercuric sulphate, 5 ml of silver sulphate solution and several glass beads were added to a 250 ml reflux flask and mixed thoroughly. 10 ml of potassium dichromate and 25 ml of silver sulphate/sulphuric acid were introduced to the flask, the mixture was refluxed for 2 hours and then allowed to cool to room temperature. The mixture was diluted to 140 ml and titrated against ferrous ammonium sulphate using ferroin as an indicator. The operation was repeated for a blank of distilled water.

$$\text{COD} = \frac{8000\ (V_2 - V_1)\ T}{V}\ \text{mg.l}$$

V_1 = Volume of FAS in titration

V_2 = Volume of blank in titration

T = titre of FAS

V_g = Volume of sample

3.2.3.2. C.O.D. Concentrations 0 to 200 mg/1

The same procedure as for the determination of concentrated COD values was followed except a 10-fold dilution of potassium dichromate (0.0042M) was used for the reflux and titration was against a 5 fold dilution of ferrous ammonium sulphate (0.01M).

3.2.3.3. C.O.D. by Hach Procedure

Reagents:-

Dilute Reagent (0 - 200 mg/l C.O.D.)

1 part $K_2Cr_2O_7$ (0.0084M, 2.452 g/l)

2 part conc. H_2SO_4

Concentrated reagent (100 - 1000 mg/l COD)

1 part $K_2Cr_2O_7$ (0.042 M, 12.26 g/l)

2 part conc. H_2SO_4

Mixed Catalyst

1 part mercuric sulphate

1 part silver sulphate

Mixed and ground in a mortar and pestle.

Dilute ferrous ammonium sulphate (0.0025M, 0.98 g/l)
Concentrated ferrous ammonium sulphate (0.0125M, 4.9 g/l)
Ferroin indicator.

Procedure:-

3 ml of reagent, 2 ml of sample and 0.05g of catalyst were added to a glass vial. The tube was sealed, inverted until mixed, placed in the heater block and left for 2 hours at 150°C. After cooling, the contents of the vial were washed out into a conical flask with 4 x 5 ml of distilled water and the mixture was titrated against ferrous ammonium sulphate, 0.0025M or 0.0125M, dependent upon whether the concentrated or the dilute reagent was used for digestion. The operation was repeated for a blank of distilled water. The standardization of ferrous ammonium sulphate was checked for each set of samples.

3.3. SELECTIVE ION ELECTRODES

The use of selective ion electrodes is a relatively recent development in the field of water analysis. Electrodes do not measure the concentration of an ion but rather the activity of the ion in solution, that is the effective chemical reactivity of the ion. The potential of the electrode varies with the concentration of the ion and is determined by the Nernst equation:-

$$E = Ea + 2.3 \frac{RT}{F} \log A_{ion}$$

E = Measured potential

Ea = portion of the potential due to the choice of reference electrode

$2.3RT/F$ = Nernst factor

A_{ion} = activity of the ion being measured.

The relationship of activity and concentration to potential for the nitrate probe employed in this study is shown in Figure 27. The activity of an ion is also a function of the total ionic strength of the solution. Thus, samples that vary widely in total ionic strength need the addition of an ionic strength adjustor to both samples and standards.

Fig 27 RELATIONSHIP BETWEEN ELECTRODE POTENTIAL, ACTIVITY AND CONCENTRATION FOR THE DETERMINATION OF NITRATE BY SELECTIVE ION ELECTRODE

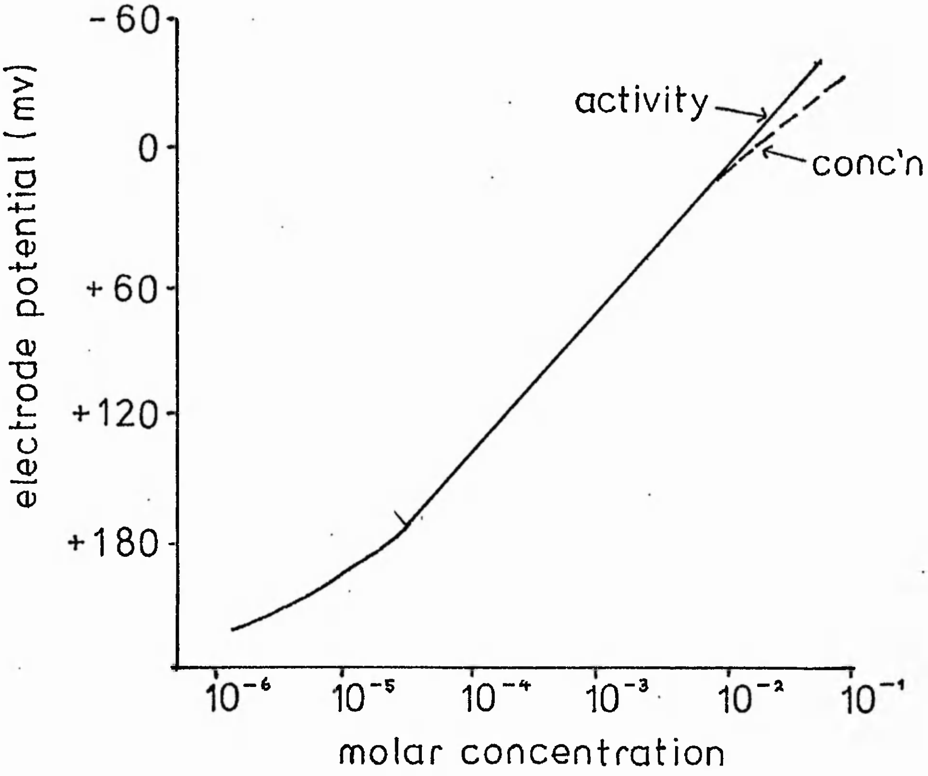
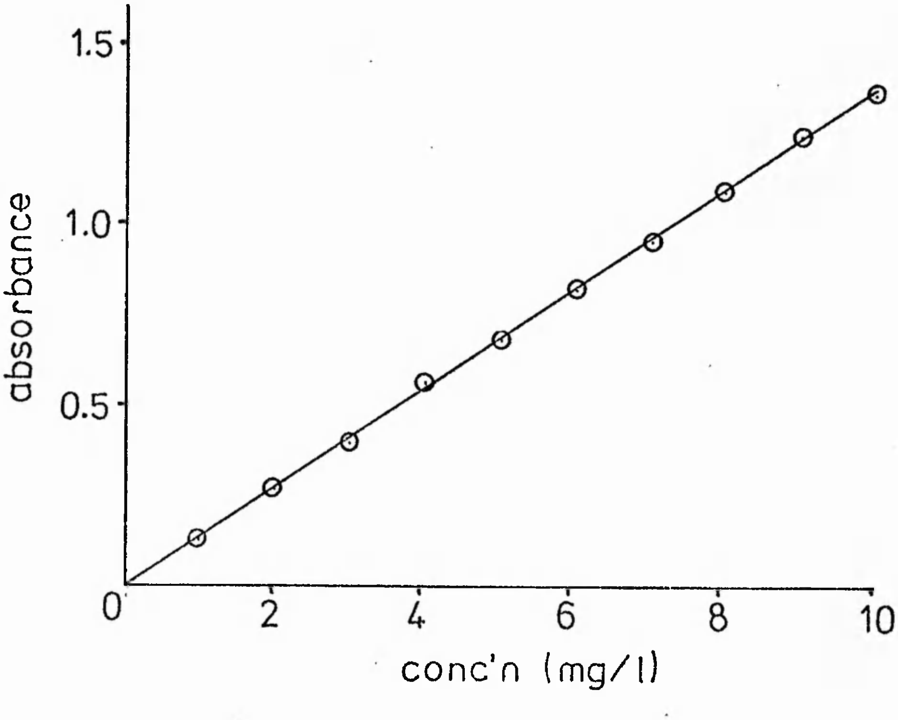


Fig.28 NITRATE CALIBRATION FOR DETERMINATION BY U.V. ABSORPTION AT 203 nm



Electrodes are subject to interferences when they are unable to distinguish between the desired ion and another ion or ions in solution. In this situation, which occurs to a greater or lesser degree for all electrodes, the potential developed is a function of the activity of the ion being measured and the activity of other interfering ions, and the Nernst equation can be written as:-

$$E = Ea + 2.3 \frac{RT}{F} \log (A_{ion} + K_{int} (A_{int})^{1/n})$$

A_{int} = activity of the interfering ion

K_{int} = selectivity constant for the interfering ion

n = charge

Electrode manufacturers supply values for the selectivity constants of interfering ions enabling the user to calculate when levels of interfering ions will significantly affect a determination.

The main advantages of selective ion electrodes is that their response is usually very rapid, unless interferences are present samples need little or no pre-treatment and they give a linear response over a wide concentration range. Sommerfeldt et al (1971), using the nitrate probe for natural waters, reported that the range of detection without dilution was considerably greater than the phenoldisulphonic acid method and sample colouration and soluble salts did not interfere with the determination. They concluded that the accuracy of the electrode technique was sufficient but not as good as the more rigorous methods. Similar conclusions were reached in this study but substantial interference by high chloride concentrations was found difficult to remove. Bremner et al (1972) using the ammonia probe for Kjeldahl nitrogen determination in place of the customary distillation and titration found close agreement between the methods. He commented that the probe was rapid, simple and precise. Thomas and Booth (1973) compared the ammonia probe to the indophenol blue method for natural waters and found results differed by 1.2% and concluded that the accuracy was comparable to accepted methods.

The use of selective ion electrodes for the analysis of inorganic water pollutants has been generally reviewed by Riseman (1969) and Weber (1971).

3.3.1. Nitrate

An Orion nitrate probe, Model 92-07, was used in conjunction with a 1M sodium sulphate/calomel reference electrode and an E.I.L. 7050 meter. Between usage the electrode was stored upright in air, the membrane and filling solution being replaced on average every 6 months. Standard nitrate solutions of 2 mg/l and 20 mg/l, prepared freshly by dilution from a 1000 mg/l stock solution were used to calibrate the meter in the concentration mode. The stock solution had 1 ml of 10 mg/l pheny mercuric acetate added as a preservative but was replaced on a regular basis. During a measurement the samples were stirred magnetically, calibration was checked after every 3 or 4 samples.

During operation the probe was found to respond rapidly but was subject to some drift and noise, this was particularly evident as the membrane became due for replacement and hence there was a need for regular calibration. High chloride levels in samples affected by winter road salting were found to interfere. Chloride interference can be prevented by precipitation with silver sulphate and removal or by mixing the sample with beads of silver ion exchange resin. The subsequent values were still subject to some doubt and a spectrometric technique was usually employed in preference. Relevant selectivity constants are presented below:-

HS^- - 4×10^{-2} HCO_3^- - 9×10^{-3} CO_3^{2-} - 2×10^{-4}
F^- - 6×10^{-5} NO_2^- - 4×10^{-2} Cl^- - 4×10^{-3}
PO_4^{3-} - 1×10^{-4} SO_4^{2-} - 3×10^{-5}

3.3.2. Ammonium

Measurements were taken with an E.I.L. ammonia probe, model 8002-8, using an E.I.L. 7050 meter. Between usage the electrode was stored in a 0.1M ammonium chloride solution and rinsed thoroughly with distilled water prior to use; the electrode was renovated at 6 monthly intervals. Ammonium standards of 0.2 mg/l and 2 mg/l were used to standardise the meter and were prepared freshly by dilution from a 1000 mg/l stock solution. The ammonium ions were converted to free ammonia before measurement with the probe by the addition of 1M sodium hydroxide solution (5 mls to 50 mls of sample). During operation samples and standards were stirred magnetically and the calibration was checked after every 3 or 4 samples. Solution carryover was avoided by blotting the electrode with absorbent tissue.

The response time for the probe was between 3 and 5 minutes for the range 0.2 - 2 mg/l. Below 0.2 mg/l response times considerably lengthened, up to 20 minutes, causing the accuracy of the determination to be lessened. The probe was free of interferences for the waters examined.

3.3.3 Chloride

An Activion type 003- 15 - 001 electrode was used in conjunction with a 1M sodium sulphate reference electrode and an E.I.L. 7050 meter. Chloride standards of 10 mg/l and 100 mg.l were prepared freshly by dilution from a 1000 mg/l stock solution and were used to standardise the meter. During operation samples and standards were stirred magnetically and the calibration checked after every 3 or 4 samples.

The probe was found to respond rapidly and, although noisy at low concentrations, no significant drift was noted. The probe gave comparable results to those obtained by the mercuric nitrate and silver nitrate titrimetric procedures. Relevant selectivity constants for the probes are:-

OH^- - 1.25×10^{-2} Br^- - 3×10^2 1^- - 2×10^6

NH_4^+ - 8.3 S^2 - may be present only in traces.

3.3.4 pH

Measurements were taken with an Orion pH combination electrode using the expanded pH scale on the E.I.L. 7050 meter. Buffers of pH7 and pH9 were used to calibrate the meter, calibration usually remaining constant throughout a series of determinations. A response time of 1 to 2 minutes was noted.

3.4. HEAVY METALS

Two types of instrumentation were evaluated for the determination of heavy metals at trace levels:-

a) atomic absorption spectrometry (AAS)

b) anodic stripping voltammetry (ASV)

3.4.1 Atomic Absorption Spectrometry

The use of AAS has become recognised as a standard procedure for the determination of low levels of heavy metals in water analysis. The technique has the advantage of speed and specificity over other analytical methods but since only one element can be determined at a time the method is not suitable for scanning simultaneously for a range of metals.

Sample Pre-treatment:-

Prior to analysis samples need some form of pre-treatment. For the determination of soluble metals filtration and acidification, as soon as possible after sample collection, is essential. If metals are only present at low levels a concentration step may be necessary either by evaporation or by chelation and extraction into an organic solvent. Evaporation is the most commonly employed method but chelation using ammonium pyrolidene dithiocarbamate (APDC) with subsequent extraction into methyl isobutyl ketone (MIBK) has gained favour (Brooks, 1967). One of the benefits of this procedure is the use of an organic solvent which has been reported as increasing the signal by 3 - 5 times depending upon the solvent used (Mulford, 1966). However, potential interferences of a chemical nature have been reported in the extraction stage (Lloyd, 1974) which can cause a lowering of extraction efficiency by the chelating agent. The use of evaporation as a concentration procedure can lead to problems of matrix interference or viscosity effects by the creation of high levels of dissolved solids. Hemsley (1971) recorded the interference of chromium on lead and recommended the use of lanthanum chloride as a releasing agent, however, he concluded that the technique was more accurate than colorimetry. For the determination of total metal concentrations digestion with some mix of inorganic acids (nitric, sulphuric, hydrochloric or perchloric acids) prior to concentration is the normal procedure. A number of different recipes have been documented depending upon the nature of the material to be analysed.

A number of sample preparation procedures were evaluated. These were:-

1. Digestion with 2M nitric acid: 5 ml of nitric acid were added to 200 ml of sample, heated and evaporated down to a desired volume (usually 20 ml).

2. Digestion with concentrated sulphuric acid and potassium permanganate: 6 ml of 5% potassium permanganate, 1 ml of sulphuric acid were added to 200 ml of sample. The mixture was heated for 3½ hours, filtered and made up to the required volume.

3. Mixed acid digestion: 1 ml of 60% perchloric acid, 5 ml of conc. nitric acid and 0.5 ml of conc. sulphuric acid were added to 200 ml of sample. The mixture was digested slowly for 30 minutes (until the appearance of white fumes), filtered and made up to the required volume.

4. Ultraviolet irradiation in the presence of hydrogen peroxide: 1 ml of 20 vol. hydrogen peroxide was added to 30 ml of sample and the mixture was irradiated overnight with UV.

5. APDC/MIBK concentration/extraction: 200 ml ofdigested sample were titrated to pH3 with sodium hydroxide and poured into a 500 ml stoppered separating flask. 5 ml of freshly prepared 5% APDC and 10 ml of redistilled MIBK were added to the flask and the mixture was shaken vigorously for 2 minutes. The layers were allowed to separate for 10 - 20 minutes and the bottom (water) layer was run off into a second separating flask, the MIBK layer being collected in a stoppered tube. The procedure was repeated for the water layer with a further 10 ml of MIBK.

Of all the procedures examined digestion with 2M nitric acid followed by a 10 fold increase in concentration by evaporation was found to be the simplest most reliable method and gave the best reproducibility. Chromium interference on lead was eliminated by the use of a 1% solution of lanthanum chloride. The other digestion procedures were found to yield high and variable blank values with similar variation being found in sample concentrations. Extraction with APDC/MIBK proved to be too time consuming for the effective analysis of large numbers of samples.

Procedure:-

An EEL 240 spectrometer was used for the majority of analyses. An air/acetylene flame was utilised with the appropriate instrument settings (wavelength, lamp current, slit width etc.) for the metal being determined as recommended. It was usually found necessary to use the instrument in the integrating mode which gave an average value for absorption over 15 seconds. The spectrometer is a single beam instrument and, at full scale expansion, top standard drift was considerable and re-calibration between every sample was found to be necessary.

3.4.2 Anodic Stripping Voltammetry (ASV)

In recent years ASV has received widespread attention as a convenient technique for the determination of certain heavy metals at trace concentrations (Gardiner, 1974; Allen, 1970; Sinko, 1970). The main advantages of the technique are that high sensitivity is easily obtained making sample pre-concentration unnecessary and certain metals can be determined simultaneously, (principally lead, zinc, cadmium and copper).

Sample Pre-treatment:-

For the determination of total metals some digestion procedure is needed. The methods outlined for AAS were all evaluated and again digestion with nitric acid was found to give the best results. For ASV determinations a constant pH is necessary so digestion was followed by titration to pH 6.5 - 7.0 and addition of 1 ml of acetate buffer solution.

Procedure:-

A Princeton Applied Research 17A polarographic analyser was used in conjunction with a hanging mercury drop electrode. Work by Chau and Chan (1974) had shown that for stripping the differential pulse mode gave great sensitivity for minimum plating times, 3 to 5 minutes compared to 40 - 70 minutes for other procedures, and was adopted for this research. To avoid contamination at the trace levels encountered a rigorous cleaning procedure was essential. The voltammetric cell was washed with nitric acid and several times with distilled water prior to analysis and between samples. When not in use the cell was filled with distilled water.

For determinations, 50 ml of sample were introduced into the cell and nitrogen was bubbled through for a period of 15 minutes. This was essential to completely deoxygenate the sample, the presence of oxygen giving rise to a sloping base line and additional current peaks at -0.8v

Fig.29 CADMIUM CALIBRATION CURVE FOR DETERMINATION BY ANODIC STRIPPING VOLTAMMETRY

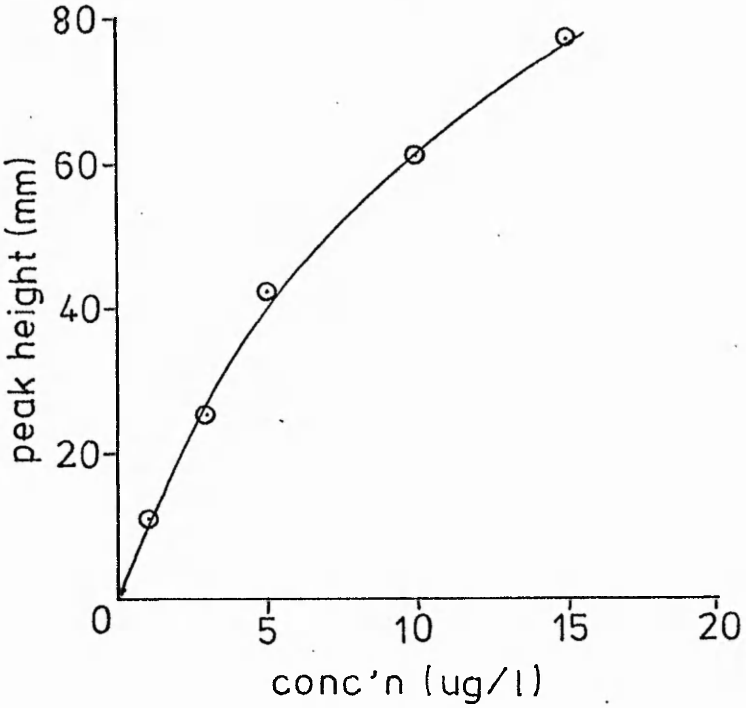


Fig.30 LEAD CALIBRATION CURVE FOR DETERMINATION BY ANODIC STRIPPING VOLTAMMETRY

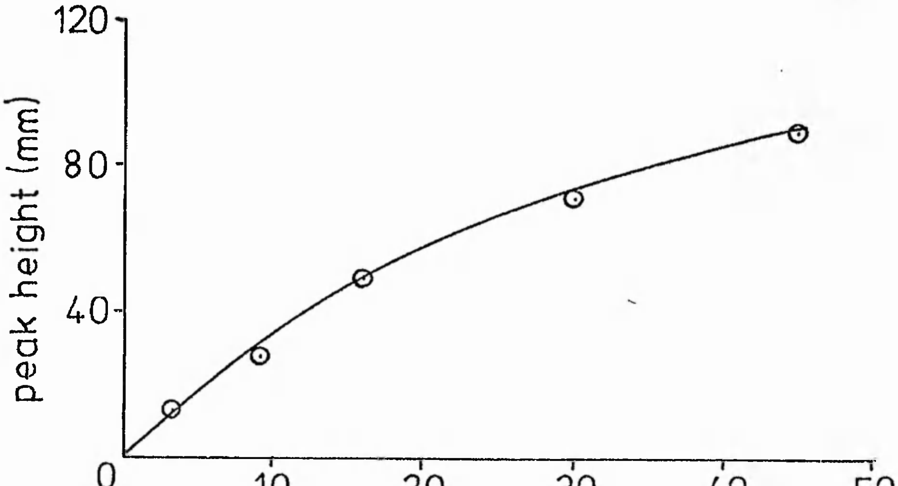
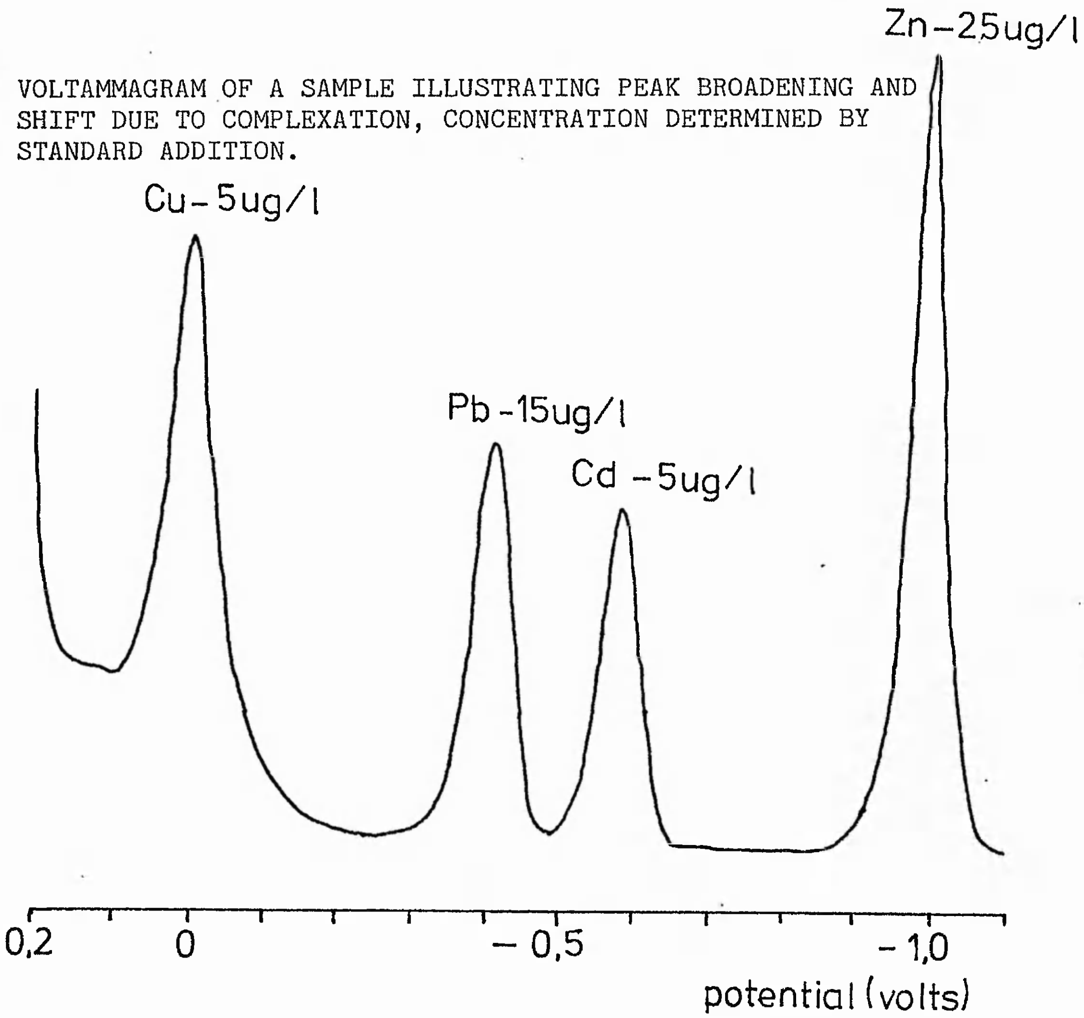
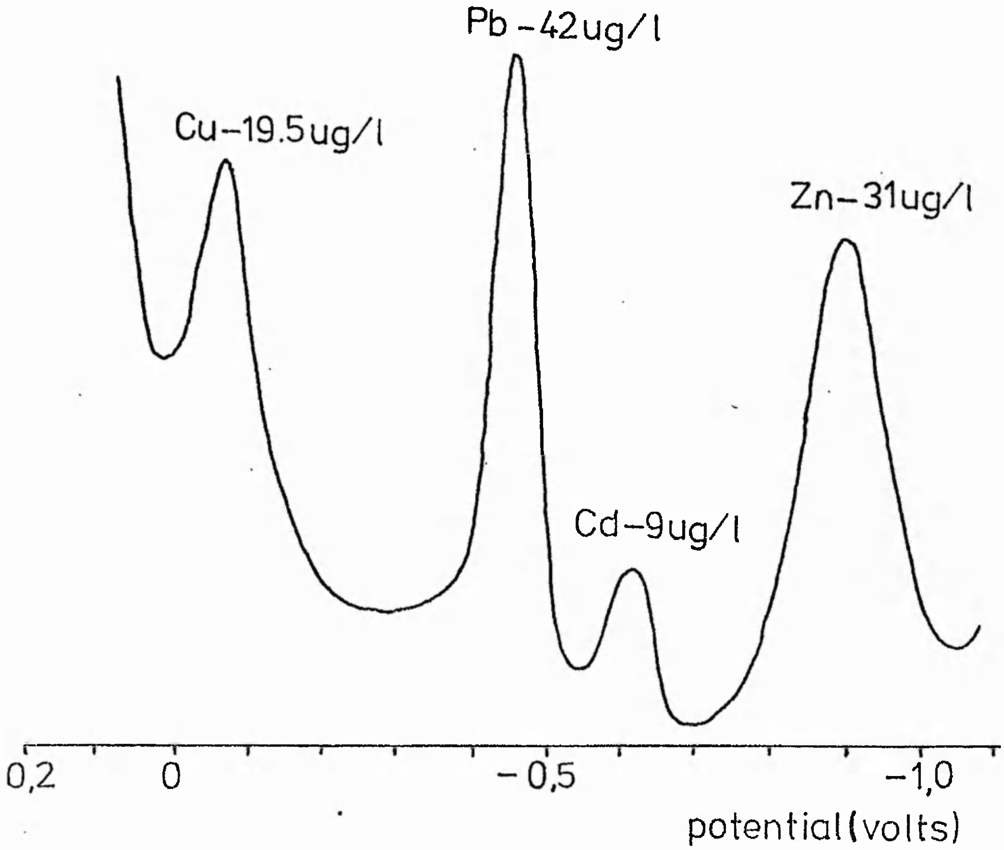


Fig.31 DIFFERENTIAL PULSE VOLTAMMAGRAM OF A STANDARD METAL SOLUTION.

Fig.32 VOLTAMMAGRAM OF A SAMPLE ILLUSTRATING PEAK BROADENING AND SHIFT DUE TO COMPLEXATION, CONCENTRATION DETERMINED BY STANDARD ADDITION.





and -0.05v. A mercury drop was prepared by turning the micrometer through 5 divisions and the metals were plated onto the electrode for 3 minutes at a constant voltage of -1100 mv, stirring being kept steady throughout deposition. The stirrer was then switched off and the metals were stripped from the electrode using a voltage scan of 5mv per second. When the potential reached a value at which the metal was electro-oxidised to its ion and returned into solution an electric current flowed which was proportional to the concentration of the metal plated. Current ranges of 2, 5 and 10 ua were used, dependent upon the concentration of metal present.

Sample concentrations were determined either from calibration curves prepared using standard solutions or by 'spiking' the sample with known concentrations of the metals to be determined. Figures 29 and 30 illustrate typical calibration curves for lead and cadmium, Figure 31 is a typical voltammagram for a standard solution.

Interferences:-

The presence of complexing agents has been reported as leading to low estimates of total trace metals concentration by preventing complete reduction of the metal ion during the plating step (Gardiner, 1974). This factor was found to be one of the major complications in the analysis of gully pot waters where the presence of complex organic material was believed to be the offender. Complex formation resulted in peak shifts and peak broadening (Figure 32) sometimes to the extent of near obliteration, none of the digestion procedures employed were completely successful in eliminating this interference. The addition of small quantities of Teepol to standard solutions was found to produce a similar masking and obliteration of peaks. Thus surfactant material from car wash runoff present in the gully pot may have been responsible for interference in the samples. The presence of this complication, with no easy solution, resulted in AAS being the preferred technique.

3.5. THE ALKALI METALS

The metals sodium, calcium and potassium were measured rapidly and easily using an EEL flame photometer. Calibration curves were prepared for the three metals and standards of 5 mg/l for sodium, 5 mg/l for potassium and 50 mg/l for calcium were used to standardise the photometer.

Samples lying outside these ranges were diluted with distilled water. High levels of calcium can interfere with potassium determinations and were suppressed using aluminium nitrate.

3.6. LITHIUM

Lithium determinations were performed on an EEL 240 atomic absorption spectrometer at a wavelength of 670.8 nm. Instrument settings used were lamp current 7.5 mA, slit width 2 or 3 and fuel air/acetylene ratio 3.7.

Sample preparation for analysis was minimal since filtration was found to be unnecessary. Careful decantation of the supernatant liquid from a settled sample made no significant difference to the results when compared to the normal procedure of analysis of the filtrate (Standard Error = 0.077). Although lithium sorption experiments have indicated that no significant uptake by sediments occurred within 7 days of addition for storm sewer waters (Neal and Jordan, 1977) samples stored for periods longer than 2 days were treated with 1 ml of conc. nitric acid.

For each run calibration standards from 0.25 mg/l to 8 mg/l were prepared from a stock solution of 1000 mg/l and a calibration curve was plotted (Figure 33) for the normal absorption mode operation. Samples were analysed 3 times in any one run, those with a concentration less than 2 mg/l were re-analysed on an expanded scale (2 mg/l equivalent to full scale deflection) using the integrating mode which gave a mean value over 15 seconds (Figure 34). Calibration was checked after every 4 or 5 samples.

Calcium has been reported as an interferent in lithium determination by A.A.S. (Water Pollution Research Laboratory, 1969) but at the levels found in stormwater samples no such interference was observed. Neal and Jordan (1977) found that matrix effects for two separate storm sewer systems were significantly different but were not significantly different for individual localities over a single storm event. They reported background response to be up to 6% at 1 mg/l and concluded that, in general, a bulked background water may be taken for use in calibration of storm sewer waters and to minimise any matrix effects. In this study it was found impracticable to gain a background sample for each event, however, isolated background samples taken during the course of the study

Fig. 33 LITHIUM CALIBRATION FOR DETERMINATION BY ATOMIC ABSORPTION (ABSORBANCE MODE)

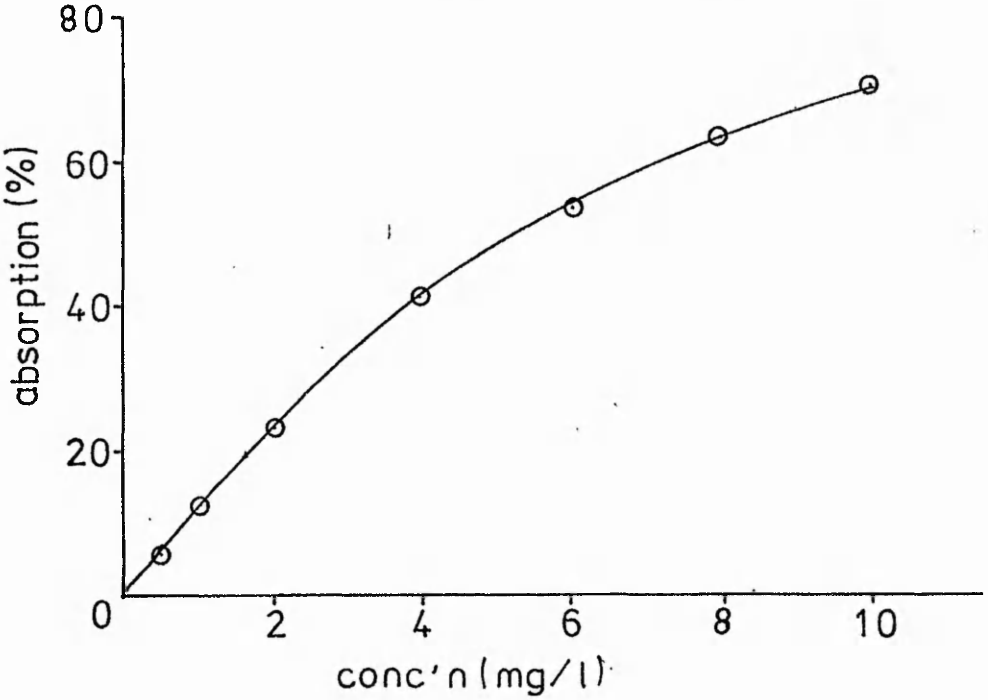
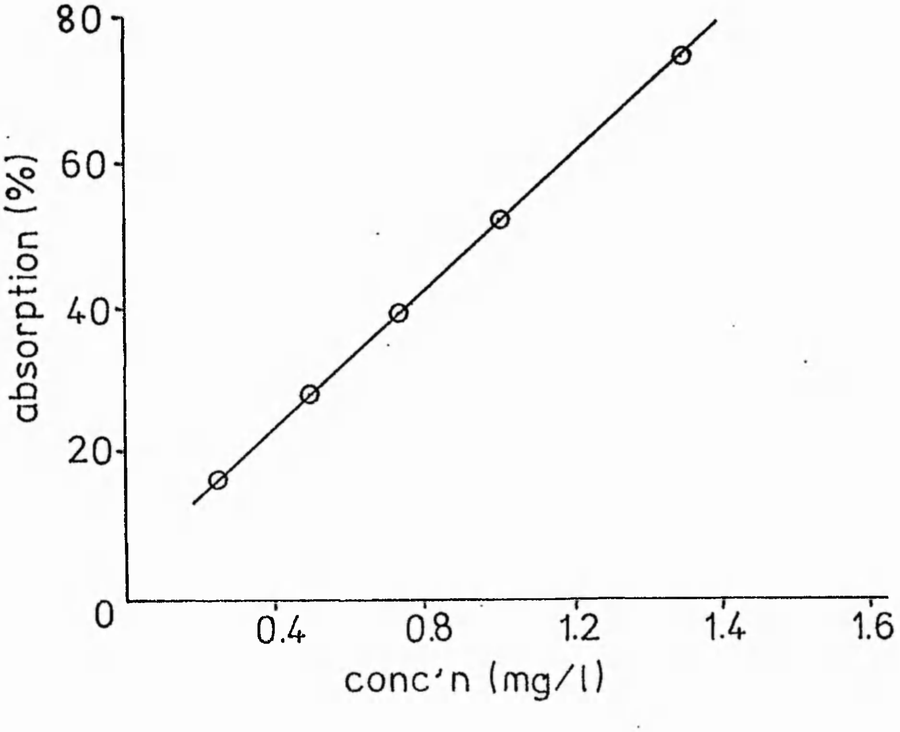


Fig. 34 LITHIUM CALIBRATION FOR DETERMINATION BY ATOMIC ABSORPTION (EXPANDED SCALE)



showed lithium background concentration to be insignificant ($<1\%$) when compared to concentrations attributable to dosing.

3.7. OTHER PROCEDURES

3.7.1. Chloride

Initial chloride determinations were made using the mercuric nitrate method. The method was subsequently used as a check on the reliability of the chloride probe and on occasions when the probe did not function.

Reagents:-

Standard sodium chloride solution - 1.648 g/l (1.0 ml = 1 mgCl^-)

Nitric acid - 0.1M

Mercuric nitrate solution - 5.04g $Hg(NO_3)_2$ H_2O in 50 ml of distilled water containing 0.5 ml nitric acid and diluted to 1 litre.

Indicator - 0.5 g diphenylcarbazone and 0.05g bromophenol blue in 100 ml alchohol.

Procedure:-

100 ml of sample were placed in a conical flask, 1 ml of indicator was added and the mixture was titrated against mercuric nitrate until the green/blue to purple colour change was noted. The procedure was repeated for a blank.

$$Cl = \frac{(V_s - V_b)}{V} \times 1000 \text{ mg/l}$$

where V = volume of sample

V_s = volume used in titration of sample

V_b = volume used in titration of blank

3.7.2 Nitrate

Nitrates were determined directly without any sample treatment using a UV spectrometer at 203 nm. A linear calibration between 0 and 10 mg/l was recorded (Figure 28). The presence of dissolved organics has been reported as an interference for this determination, in this study, the levels encountered in stormwater samples were not found to cause any significant interference. If high dissolved organics were anticipated samples were digested with hydrogen peroxide prior to analysis.

4. DATA PROCESSING

A water quality monitoring programme of the type conducted in this research results in the generation of large quantities of data. The subsequent use and interpretation of this data is dependent upon the application of accurate and relevant data processing methods. The procedures utilised in this research fall into the following categories:-

a) Calculation of elementary statistics, e.g. mean, standard deviation, range, etc.

b) Investigation of correlations.

c) Calculation of storm flow.

d) Calculation of pollutant loadings

e) Mathematical modelling.

The results collected were stored on computer in one of four data file configurations dependent upon the type of data and the manner in which it was to be analysed. All computation was conducted in FORTRAN V using an interactive DEC 20 computer; graph plotting was performed using CALCOMP graph plotting software and the majority of statistics were generated using subroutines from the NAG (numerical algorithms group) library.

Mathematical modelling is considered separately in Chapter 5. The other data processing procedures may be conveniently considered in two sections:-

a) gully pot liquor quality data

b) storm runoff event data.

4.1. GULLY POT LIQUOR QUALITY DATA

The quality of gully pot liquor was monitored in three distinct manners:-

a) Weekly/fortnightly analyses of four fixed pots. In this instance the gully pots were selected to represent widely varying situations and microcatchment characteristics.

b) One day analysis of up to 25 randomly selected pots to assess catchment wide quality variation.

c) Other miscellaneous analyses, e.g. sampling prior to storm runoff events, daily sampling during dry periods and other grab samples.

Data collected under a) and b) above were treated using the programme, Stats Package for Variation and Weekly Gully Analyses (STAT.FOR). The programme is presented in Appendix 1.1. it performed the following functions:-

a) Calculation of basic statistics.

b) Calculation of a correlation matrix for catchment wide variation analyses.

c) A4 tabulation of data and statistics.

For the periodic weekly/fortnightly analyses of the four selected gully pots the following statistics were generated, for each pollution parameter, where the input data consists of N observations for each of M gully pots as an array (x_{ij}), $i = 1$ to N and $_j = 1$ to M.

a) Annual maximum values for each gully pot.

b) Annual minimum values for each gully pot.

c) Annual range. Range = Max. - Min.

d) Interquartile range (IQR) $Q1 = \frac{N}{4}$, $Q3 = \frac{3N}{4}$, $1QR = Q3 - Q1$

e) Annual mean values for each gully pot $\bar{x}_j = \frac{1}{N} \sum_{i=1}^{N} x_{ij}$

f) Weekly mean values $\bar{x}_i = \frac{1}{N} \sum_{j=1}^{M} x_{ji}$

g) Annual standard deviation for each gully pot studied and for weekly mean values

$$S_j = \sqrt{\frac{1}{(N-1)} \sum_{i=1}^{N} (x_{ij} - \bar{x}_j)^2}$$

h) The coefficient of skewness

$$S3_j = \frac{1}{(N-1)\, S_j^3} \sum_{i=1}^{N} (x_{ij} - \bar{x}_j)^3$$

i) The coefficient of kurtosis

$$S4_j = \left[\frac{1}{(N-1)\, S_j^4} \sum_{i=1}^{N} (x_{ij} - \bar{x}_j)^4 \right] - 3$$

The application of the mean and standard deviation as reliable descriptive statistics of a sampled population is dependent upon the results being normally distributed. This may not be the case for limited numbers of water quality measurements and the assumption is made that the sample has been drawn from a whole population that is normally distributed.

Plotting the frequency distributions for each set of results (Chapter 6) shows that the majority of data sets are not normally distributed and the calculated standard deviations are commonly very high. This is due either to the presence of extreme high values that introduce a positive skew to the distribution or a preponderance of values approaching zero. A solution often employed to normalise distributions of this nature is to take logs of the individual results. However, this technique was also unsuccessful in creating a normal distribution because of the very wide spread of results, e.g. chloride, or the number of values close to zero where the limit of detection of the analytical method was the limiting factor. For these reasons the standard deviation cannot always be considered as a satisfactory measure of the dispersion of distribution. The interquartile range is presented as an alternative and was often 5 to 10 times less than the total range due to the elimination of extreme values. The coefficients of skewness and kurtosis were also presented to give some impression of the shape of the distribution. Skewness is a measure of the degree of asymmetry of the distribution. The coefficient has a value of zero for a normal distribution and takes a positive value when the distribution has a longer 'tail' to the right (positive skewness) or a negative value when the distribution is skewed to the left. Kurtosis is a measure of the degree of peakedness of the distribution and is zero for a normal distribution. Values greater than zero result from a peaked (leptokurtic) distribution and values less than zero for a flat (platykurtic) distribution.

One-day catchment-wide sampling was performed not only to examine the dispersion of values for individual pots on the same day but also to test the significance of small sets of samples (3, 4 or 5) in representing the mean value of the population. Therefore, in addition to the statistics presented above, 95% confidence limits for the estimate of the population mean based on the sampled distribution were calculated using 'Students' t- distribution:-

$$\text{Confidence limits:} \quad \bar{x}_j \pm t_{0.95} \frac{s_j}{N - 1}$$

The confidence limits were also expressed as a percentage of the mean.

Like the standard deviations, the confidence limits were often found to be very high (greater than 100% of the mean in some instances) this can again be ascribed to the presence of extreme values and serves to indicate the general unreliability of estimating the population mean from small sets of samples.

Investigation of inter-parameter correlations was not performed routinely for the periodic weekly analyses. Possible relationships were assessed individually. However, correlation analyses for the variation studies were performed routinely, the results being output as a matrix of correlation coefficients. The Pearson product - moment correlation coefficient was calculated:-

$$R_{jk} = \frac{S_{jk}}{\sqrt{S_{jj} \times S_{kk}}}$$

where

$$S_{jk} = \sum_{i=1}^{N} (x_{ij} - \bar{x}_j)(x_{ik} - \bar{x}_k)$$

$$S_{jj} = \sum_{i=1}^{N} (x_{ij} - \bar{x}_j)^2$$

Other miscellaneous gully pot quality data was not subjected to the statistical treatment outlined above but, where appropriate, weekly mean values were calculated.

4.2. STORM RUNOFF DATA

Storm runoff data was processed using the Urban Runoff Pollutant Loading programme (STQUAL.FOR). The programme is listed and its operation and parameters explained in Appendix 1.2. The programme performed the following functions:-

a) calculation of flow rate from lithium concentrations.

b) calculation of cumulative pollutant loads, total pollutant loads and mean storm concentrations.

c) tabulation of observed concentrations and cumulative loads in A4 format.

d) graphical plots of observed concentrations and percentage cumulative loads against time from start of sampling.

4.2.1. Calculation of Flow Rate

Flow rates for the 4th sample and onwards were computed from the mass balance equation for dilution gauging previously derived in Chapter 2. Assuming an insignificant background concentration, then:-

$$Q = \frac{C_1}{C_2} q \times 10^{-3} \quad \text{l/s}$$

C_1 = concn of lithium in dosing solution (mg/l)

C_2 = concentration of lithium in the sewer (mg/l)

q = rate of dosage of lithium (ml/s)

No flow rate could be calculated for the first sample collected since the sample was collected at the same moment as dosing was initiated. However, since this first sample often contained high concentrations of solids and could contribute significantly to total pollutant load for the storm event an assumed value of 8 l/s was used. This value represented the average flow rate at which the float switch started operation. Since the doser required 5½ minutes to reach an equilibrium dose rate, then, flow rates for the second and third samples had to be calculated using the doser calibration curve (Figure 35) and an estimated low flow time of travel between the dosing and sampling locations of 3.2 minutes. Given that the mid-point time of the sampling interval corresponded to the effective average dosing rate over the whole sampling interval then the dosing rates applicable to samples 2 and 3 were 0.225 ml/s and 0.883 ml/s respectively (see Figure 35).

4.2.2. Artificial Recession Curves

Towards the end of a storm event when flow rates dropped below 8 l/s the float switch acted as a circuit breaker preventing further sampling. On some occasions sampling was recorded as stopping at flow rates much higher than 8 l/s and as a result a significant portion of the storm recession was missed. On a small catchment such as Clifton Grove where runoff response is rapid and flow rates are low in comparison to larger urban areas the loss of this portion of the storm could introduce significant errors into the determination of cumulative discharge and cumulative pollutant loads. To overcome this problem a typical recession curve was artificially generated in the programme STQUAL.FOR to describe the decay in the flow rate that was missed by the field measurements. The equation was calibrated empirically to give a smooth decay consistent with available observations:=

$$Q_{t+1} = Q_t e^{-0.33T}$$

where T = sampling interval in minutes.

The equation operated until Q_{t+1} became less than 0.5 l/s when the storm was assumed to have ended.

Fig. 35 DOSING CALIBRATION CURVE ILLUSTRATING THE CALCULATION OF THE AVERAGE DOSING RATES APPLICABLE TO SAMPLES 2 AND 3

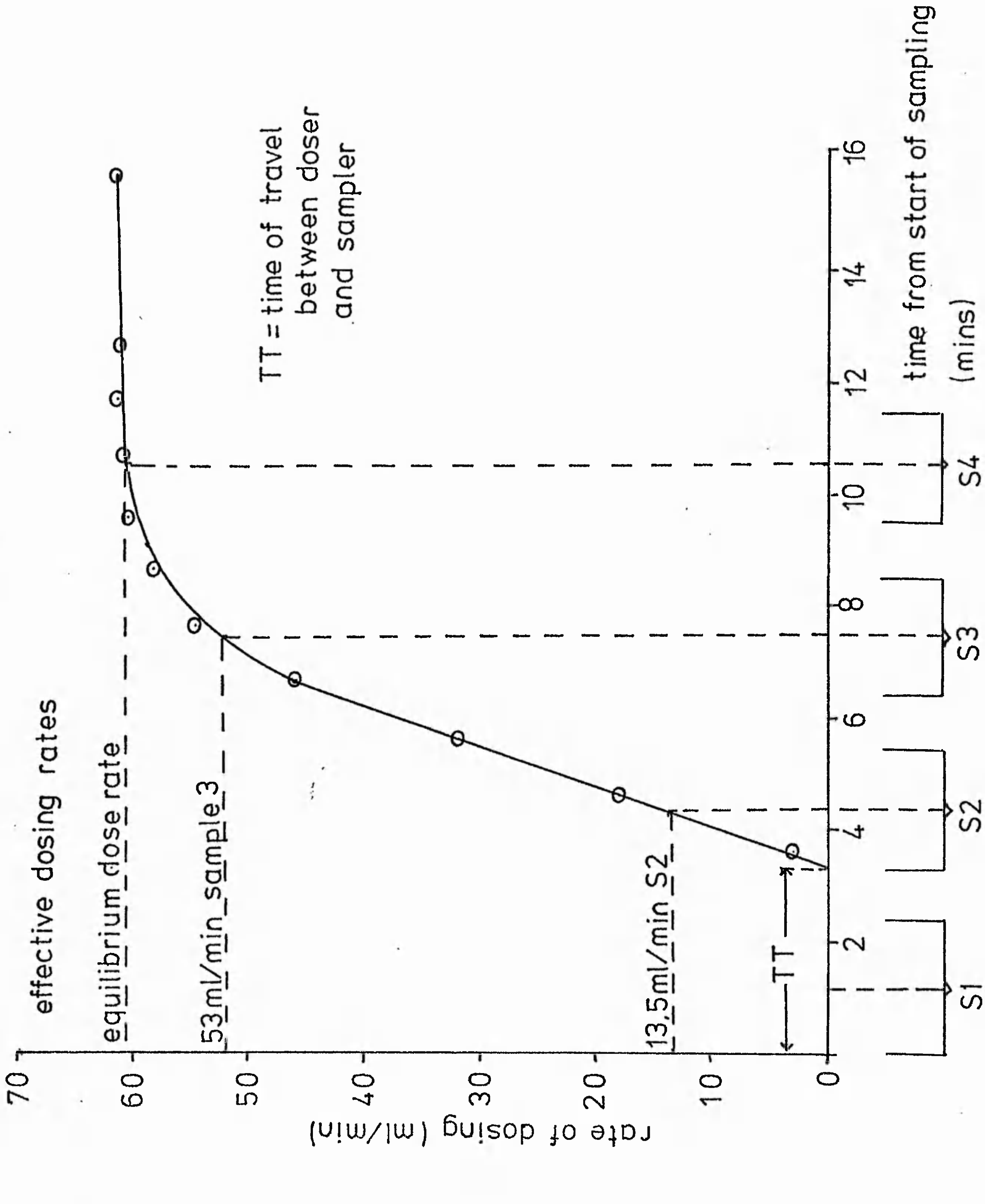


Fig. 36 EXAMPLE OF A CALCULATED FLOW RECESSION CURVE FOR THE STORM OF THE 24TH MAY, 1978

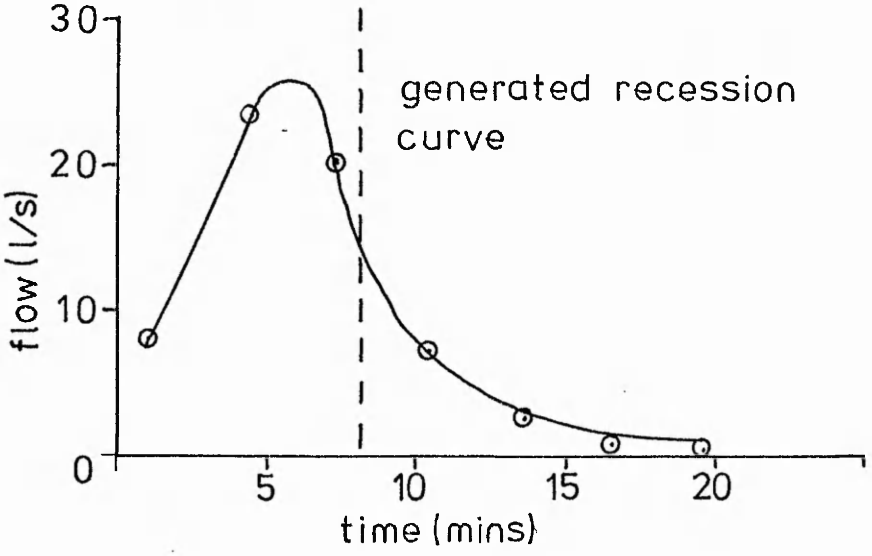
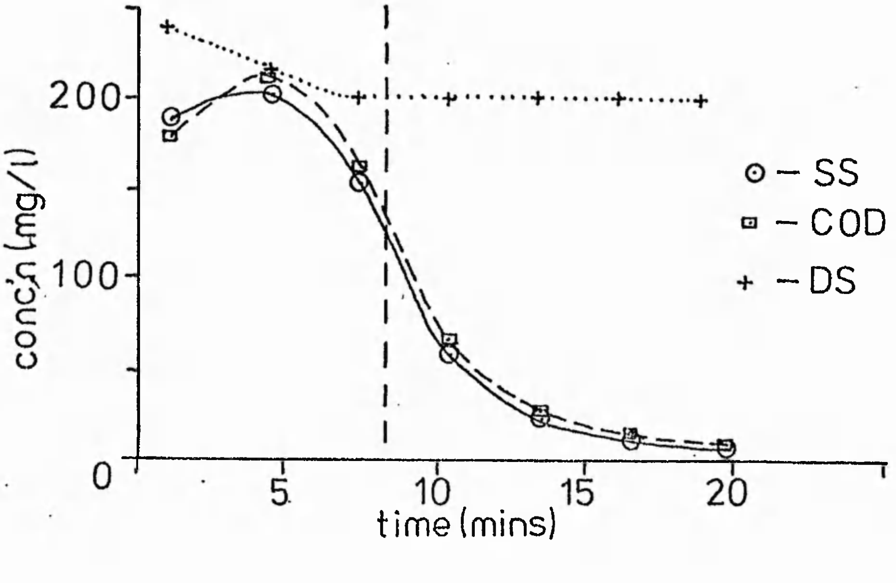


Fig. 37 EXAMPLE OF CALCULATED RECESSION CURVES FOR SUSPENDED SOLIDS (SS), CHEMICAL OXYGEN DEMAND (COD) AND DISSOLVED SOLIDS (DS) FOR THE STORM OF THE 24TH MAY, 1978



It was also necessary to apply a similar recession curve to suspended solids values since these were observed to decay at the end of a storm in a similar fashion. Their concentration was recessed down to a minimum of 3.0 mg/l, a value that was typical of the minimum concentrations observed in runoff.

$$SS_{t+1} = 3.0 + (SS_t - 3.0)\, e^{-0.33\, T}$$

Other solids related pollution paramters, such as COD and BOD, were also recessed down to minimum concentrations of 5.0 and 0.3 mg/l respectively. However, soluble materials that were not generally observed to decay towards the end of a storm, but approached a constant value, were allowed to remain at their final observed value, e.g. nitrate, ammonium, dissolved solids:-

$$DS_{t+1} = DS_t$$

Figurs 36 and 37 illustrate the use and significance of the artificial recession curves for Storm 10, a small event of only 3 samples duration.

4.2.3. Calculation of Pollutant Loads

Pollutant loadings are expressed in three ways:-

a) Instantaneous storm loads (g/s) at time t.

$$IL_t = C_t\, Q_t \times 10^{-3}$$

where C_t = concentration in mg/l at time t

Q_t = flow rate in l/s at time t

b) Pollutant load (kg) over time interval T, (minutes)

$$L_t = C_t\, Q_t\, T \times 60 \times 10^{-6}$$

where C_t and Q_t represent average values over the time interval T.

c) Cumulative pollutant loads (kg) at time t

$$\mathrm{CUML}_t = \sum_{t=1}^{t} C_t\, Q_t\, T \times 60 \times 10^{-6}$$

For the purposes of this research sampling was not discrete but continuous over a period of approximately 2 minutes with a pause of approximately 1 minute between samples for reverse pumping. The times against which concentrations and flow rates were recorded were the mid point time of the sampling interval and it was desirable that cumulative loads should be reported for these times. The rationale behind the calculation of cumulative loads for these times is illustrated in Figure 38. The situation was further complicated, since initial and subsequent sampling and reverse pumping times were different. For the cumulative load at time t = 1 only the first half of the initial sampling time is included in calculations. For the calculations of subsequent cumulative loadings (t = N) the pollutant load corresponding to the second half of the previous sampling period is calculated, the pollutant load corresponding to the first half of the present sampling period is calculated and average flow and concentration values are used to compute the pollutant load for the intermediate period of reverse pumping, the three factors are then summed and added to the cumulative load for t = N - 1 to give the cumulative load at time t = N. This approach minimised errors created by using discrete as opposed to continuous integration. Mathematically the calculation of cumulative loads can be expressed as follows:-

If:- S1 = initial sampling time
S2 = subsequent sampling time
T1 = initial sampling interval
T2 = subsequent sampling interval

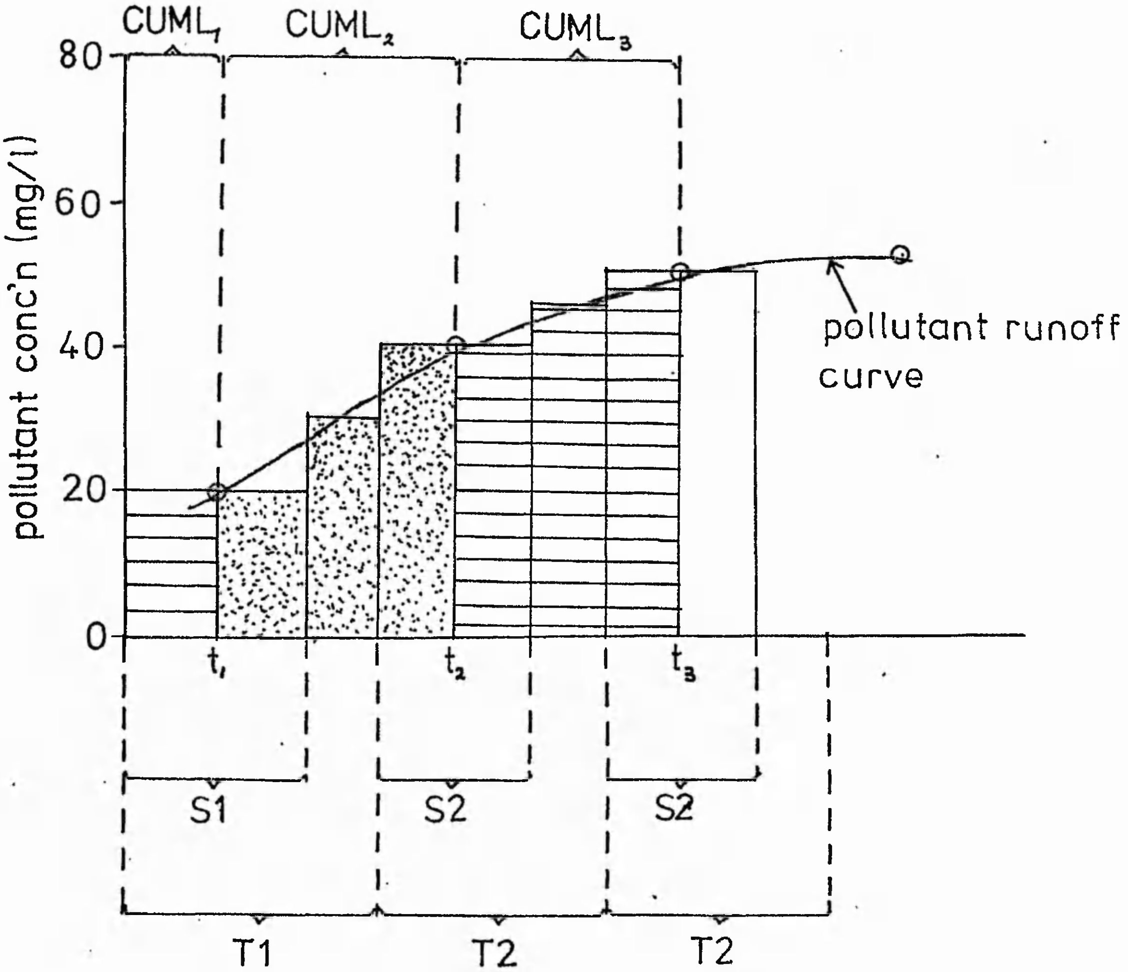
Then:-

$$\mathrm{CUML}_1 = \frac{S1}{2}\; Q_1\; C_1$$

$$\mathrm{CUML}_2 = \mathrm{CUML}_1 + \left(\frac{S1}{2}\, Q_1\, C_1\right) + \left(\frac{S2}{2}\;\; Q_2\, C_2\right)$$

$$+ \;\frac{(T1 - S1)}{4}\; (Q_1 + Q_2)\;\; (C_1 + C_2)$$

Fig. 38 GRAPH ILLUSTRATING THE METHOD OF CALCULATION OF THE CUMULATIVE LOADS



$$CUML_N = CUML_{N-1} + \frac{S2}{2} (Q_n C_n + Q_{n-1} C_{n-1}$$

$$+ \frac{(T2 - S2)}{4} (Q_{n-1} + Q_n) (C_{n-1} + C_n)$$

4.2.4. Multiple Regression Analysis

The combined data for all storm events monitored was used to investigate the relationship between pollutant loads and mean storm concentrations with meteorological parameters such as storm duration and average intensity using multiple linear regression analysis. The technique assesses the relationship between a dependent variable (Y) and a set of independent variables (x_1, x_2 --- x_n) and was of particular use in identifying the meteorological parameters of most significance in determining the generation of pollutant loadings. It was also used to formulate simple predictive models for determining pollutant loads when only basic meteorological data is available. The data was treated using a computer programme, MULREG FOR (Appendix 1.3) which made use of two subroutines for multiple regression analysis from the NAG Library, G02BGF and G02CGF. The subroutines fit a curve to the data points of the form:-

$$Y = a + b_1 X1 + b_2 X2 + b_3 X3 \ldots\ldots + b_r XN$$

where $X1 \rightarrow XN$ = variables, i.e. meteorological parameters

$X1_1 \rightarrow X1_i$ = observations on each variable (i.e. No. of storms in analysis)

Y = pollutant loading under consideration

a = regression constant

$b_1 \rightarrow b_r$ = regression coefficients.

The regression coefficients are calculated in such a way that the sum of the squared residuals is minimised. The accuracy of the resultant equation is indicated by the coefficient of determination (R^2), the proportion of variance that is explained by the variables included in the analysis.

5. MATHEMATICAL MODELLING OF URBAN RUNOFF PROCESSES AND POLLUTANT REMOVAL FROM GULLY POTS.

The development of mathematical simulation as an important aid for the management of urban stormwater has been discussed previously. A wide variety of models now exists, each comprising of differing functions and capabilities geared to the needs of various potential users. The models available range from empirical design techniques, such as the Rational method, to highly complex and versatile computer packages, of which the Stormwater Management Model, (SWMM), is an example.

Although significant progress has been made in recent years in the simulation of hydrological and hydraulic processes occurring in urban runoff, the prediction of urban runoff quality and the modelling of pollutant accumulation and removal processes is still in its infancy. The complexity of the physical and chemical processes involved in determining runoff quality defies accurate mathematical description. In the models that have been proposed the role of roadside gully pots as sediment traps or pollutant generators has not been considered. Their effect has either been ignored, with the assumption that the pollutant accumulation function generally encompasses their contribution (Sartor and Boyd, 1972) or considered to be negligible (Price and Mance, 1978).

One of the main objectives of this research was an assessment of the significance of gully pots in determining the quality of stormwater runoff. Therefore, it was considered necessary not only to quantify the nature and amount of pollutant in the gully pot, but also the mode of removal of these pollutants during a storm event and their subsequent contribution to runoff quality at the sewer outfall. Thus, the criteria for the development of an urban runoff mathematical model from this research are two-fold, as:-

a) A preliminary research tool for further catchment studies at Clifton Grove;

b) A vehicle for the prediction of pollutant contributions from gully pots in urban runoff.

To achieve these aims the following approach was adopted:-

a) A laboratory study of the removal of material from gully pots;

b) Derivation of functions describing these processes;

c) Selection of an appropriate rainfall-runoff model;

d) Development of the computer program and application of the model to the Clifton Grove catchment;

e) Integration of the gully pot pollutant contribution functions into the rainfall-runoff model.

f) Verification and calibration of the model with field measurements.

5.1. THE REMOVAL OF MATERIAL FROM GULLY POTS

Two alternative approaches may be adopted for assessing pollutant contributions to urban runoff from gully pots, that is, measurements may be conducted either in the field or the laboratory. Field measurements may actually monitor the real situation but meaningful interpretation of the data is hampered, in fact, by the large number of unknown variables, the complexity of the processes involved and logistical problems of monitoring and installation of instrumentation. Problems of data interpretation can be ascribed to the following phenomena:-

a) Unknown and variable flow rates into the pot;

b) Unknown and variable solids contribution to the pot from urban surfaces;

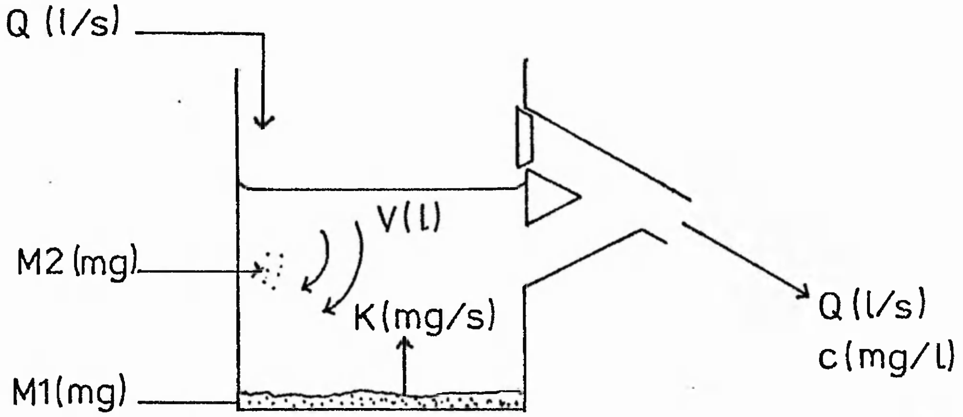
c) Unknown mass of stored sediment;

d) Unknown quality of stored sediment.

The introduction of instrumentation for the elimination of some of these unknowns such as flow measuring devices or solid filtration systems will disturb the hydraulic stirring action of flow entering the pot and also render subsequent studies valueless by altering the usual properties of the stored sediment. In a laboratory study many of these unknowns may be eliminated or made constant and, therefore, this approach was adopted.

5.1.1 Theory of the Removal of Pollutants from Gully Pots

The physical parameters governing the amount of material contributed from a gully pot are illustrated below:-



M1 = total mass of material available for release from the settled solids.

M2 = mass of material initially in suspension

K = rate of release of settled material

Q = flow through the gully pot

V = volume of fluid in the gully pot

c = concentration of material in the outflow

R = theoretical retention time of fluid in the pot = V/Q

The mass of material available for release from the settled solids (M1) is not readily defined even in a laboratory situation. M1 will be dependent upon the particle size of the sediments which is dependent in turn upon the soil types and other materials available for input in the immediate catchment locality. The degree of biological degradation of the sediments will also influence M1, however, the flow rate (Q) is likely to be the parameter of most influence in determining the size of M1. In the laboratory where the material is of constant composition and sediment input is either negligible or constant and temporarily ignoring material already in suspension then the change of concentration of material in the gully pot fluid can be expressed as:-

$$dc = \frac{K}{V}\,dt - \frac{Q}{V}\,dt\,c \qquad \ldots (1)$$

This equation is applicable from $t = o$ to $t = M1/K$ i.e. when all available material has been released.

Since $R = V/Q$

$$\frac{dc}{dt} = \frac{K}{V} - \frac{c}{R}$$

Using the integration factor:-

$$e^{\int 1/_R\,dt} = e^{t/R}$$

Then:-

$$e^{t/R}\frac{dc}{dt} + e^{t/R}\frac{c}{R} = e^{t/R}\frac{K}{V}$$

$$\frac{d}{dt}\left(e^{t/R}c\right) = e^{t/R}\frac{K}{V}$$

$$e^{t/R}c = \frac{K}{V}\int_o^t e^{t/R}\,dt$$

$$e^{t/R} = \frac{K}{V}\left[-R\,e^{t/R}\right]_o^t + A$$

$$e^{t/R}c = \frac{K}{Q}\left(e^{t/R} - 1\right) + A$$

when $t = o, \quad c = o \quad \therefore \quad A = 0$

for $o \leqslant t \leqslant M1/K$

$$c = \frac{K}{Q}\left(1 - e^{-t/R}\right) \qquad \ldots (2)$$

When all the mass available for release is in suspension, i.e. $M1/K \leqslant t \leqslant \infty$

$$\frac{dc}{dt} = \frac{-Q}{V}c \;, \quad = -\frac{c}{R}$$

$$\frac{dc}{c} = \frac{-1}{R} \int_{M1/K}^{t} dt$$

$$\left[\log_e c\right]_{c_1}^{c} = \frac{-1}{R} \left[t \right]_{M1/K}^{t}$$

$$\log_e \frac{c}{c_1} = \frac{-1}{R} \left(t - \frac{M1}{K}\right) + A$$

when $t = M1/K$, $c = c_1$, $\therefore \; A = 0$

$$\therefore \; \log_e \frac{c}{c_1} = \frac{-1}{R} (t - M1/K)$$

$$\frac{c}{c_1} = e^{(-t/r + M1/KR)}$$

since $c_1 = \frac{K}{Q} (1 - e^{-M1/KR})$

$$c = \frac{K}{Q} (1 - e^{-M1/KR}) \; e^{(-t/R + M1/KR)} \qquad \ldots (3)$$

The same theory applies for dissolved material with an initial concentration of c_o or for material initially in suspension, where $c_o = M2/V$. In this case:-

$$\left[\log_e c\right]_{c}^{c_o} = \frac{-1}{R} \left[t \right]_{o}^{t}$$

$$\log_e \frac{c_o}{c} = \frac{-t}{R} + A$$

when $t = 0$, $c = c_o$ $\therefore \; A = 0$

$$c = c_o \; e^{-t/R} \qquad \ldots (4)$$

The concentration of suspended material in the outflow derived from settled material and material in suspension in the gully pot is then described by the summation of the relevant equations:-

for $0 \leqslant t \leqslant M1/K$

$$c = \frac{K}{Q} (1 - e^{-t/R}) + c_o \, e^{-t/R} \qquad \ldots (5)$$

for $M1/K \leqslant t \leqslant \infty$

$$c = \frac{K}{Q} \quad (1 - e^{-M1/KR}) \quad e^{(-t/R + M1/KR)} \quad + \quad c_o \, e^{-t/R} \qquad \ldots (6)$$

If the inflow to the gully pot has a concentration of material itself (c_2) then Eq (1) can be modified to:-

$$dc = \frac{K}{V} dt - \frac{Qdtc}{V} + \frac{Qdtc_2}{V} \qquad \ldots (7)$$

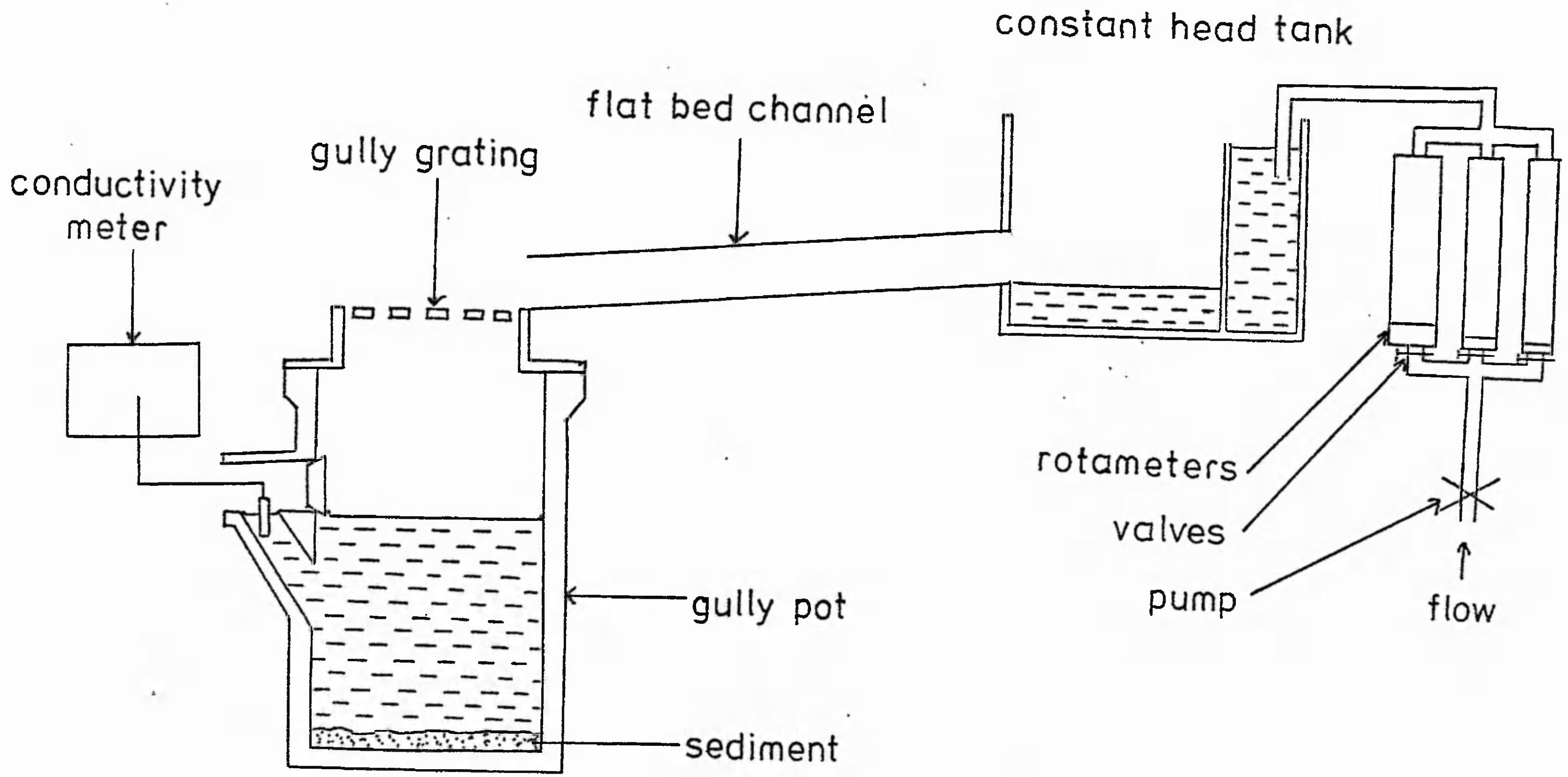
Preliminary laboratory results from a study using sediment derived from road surfaces at a city centre site (Wilson, 1978) indicated the general validity of the proposed model and a full laboratory study was initiated.

5.1.2 Experimental

The apparatus assembled for the investigation is illustrated in Figure 39. The gully pot was of the type employed in the Clifton Grove sewerage system and contained a volume of 92.8 litres of water. A pumped flow of water was available from a main supply tank that fed three rotameters. The rotameters were arranged in parallel covering a range of differing flow rates. The fluid output from this arrangement was stilled by passage through a constant head tank. A rectangular, steel bed channel was used to simulate kerbside channel flow and was arranged with a gentle slope typical of that encountered at the Clifton Grove estate. The water entered the gully pot through a standard gully grating.

Since the proposed model assumes a state of complete mixing in the gully pot it was necessary to evaluate in the first instance whether this assumption was valid. This was achieved simultaneously with the investigation of the removal of dissolved material by monitoring the changes in concentration of a solution of sodium chloride added to the pot. An initial concentration of 1.5 to 2.5 g/l sodium chloride was prepared in-situ and the removal of this solution for flow rates between 0.03 and 1.0 l/s was monitored using a conductivity probe at the outflow point of the pot. A maximum inlet flow rate of 1.0 l/s was adopted, which was consistent with expected maximum flow rates in the field. A direct correlation between salt concentration and conductivity allowed the concentration of salt in the outflow to be determined.

Fig.39 LABORATORY APPARATUS FOR INVESTIGATING THE REMOVAL OF MATERIAL FROM GULLY POTS FOR DIFFERENT INLET FLOW RATES



Sediment for the solid removal tests was obtained from municipal gully emptying tankers that serviced the Clifton area. Prior to use, the material was sterilised, dried and sieved free of large twigs, paper, cigarette ends, etc. For each test 2 kg of the dry sediment were added to the base of the pot in the absence of water. This resulted in a depth of material of approximately 15 mm. Water was carefully added to the pot until the first overflow occurred and was then left for 2 to 3 days to allow the solid to settle and saturate with water.

Tests were performed for flow rates ranging between 0.1 and 1.0 l/s. A sample of water was taken prior to each test to determine the initial suspended solids content. Samples at time intervals of 0, 0.25, 0.5, 0.75, 1.0, 1.5, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0 and 8.0 minutes were taken during each run. Samples of the inflow were also collected and the resultant background solids concentration was subtracted from the observed concentrations.

5.1.3 Interpretation of Results

For high flow rates the removal of soluble material was observed to follow the proposed exponential decay curve (Figure 40), where, for a completely mixed state, the curve is described by Equation 4. For the completely mixed state a plot of $\log_e (c_1/c_o)$ against -t/R should yield yield a straight line with a gradient of one (Figure 41): gradients greater than one are indicative of incomplete mixing. The results obtained (Table 19) show that down to approximately 0.12 l/s complete mixing normally prevails in a gully pot. However, below this flow rate, although normal exponential decay curves were recorded, gradient values were greater than one, indicating that effective retention times were much greater than would be expected if complete mixing occurred. Stirring of the pot contents after the completion of tests revealed unmixed pockets of salt solution were still present. These observations are consistent with the occurrence of 'short circuiting', that is, some zones of the gully pot were being completely mixed while others remained unstirred. The effective retention was used to calculate the volume of the gully pot in a completely mixed state, the results being illustrated graphically in Figure 42.

Fig. 40 TYPICAL CURVE ILLUSTRATING THE MODE OF REMOVAL OF SOLUBLE MATERIAL (SALT) FROM A GULLY POT UNDER STEADY FLOW CONDITIONS (1 LITRE PER SECOND)

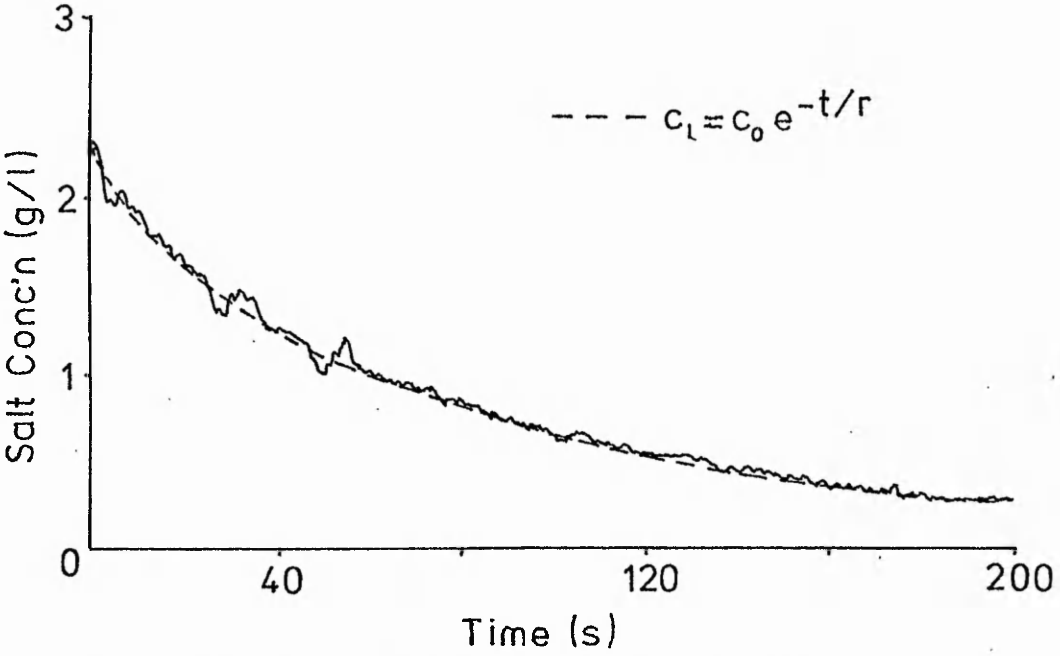


Fig. 41 PLOT OF LOGe (C1/Co) AGAINST -t/R ILLUSTRATING COMPLETE MIXING FOR A FLOW RATE OF 0.5 l/s

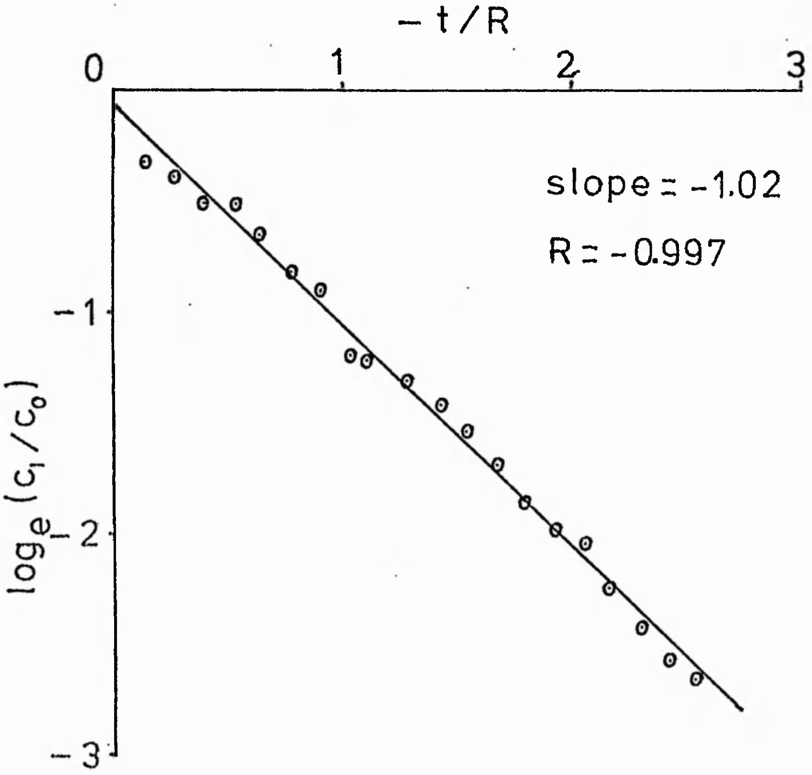


Fig. 42 RELATIONSHIP BETWEEN THE APPARENT PERCENTAGE OF A GULLY POT IN A MIXED STATE AND THE INLET FLOW RATE.

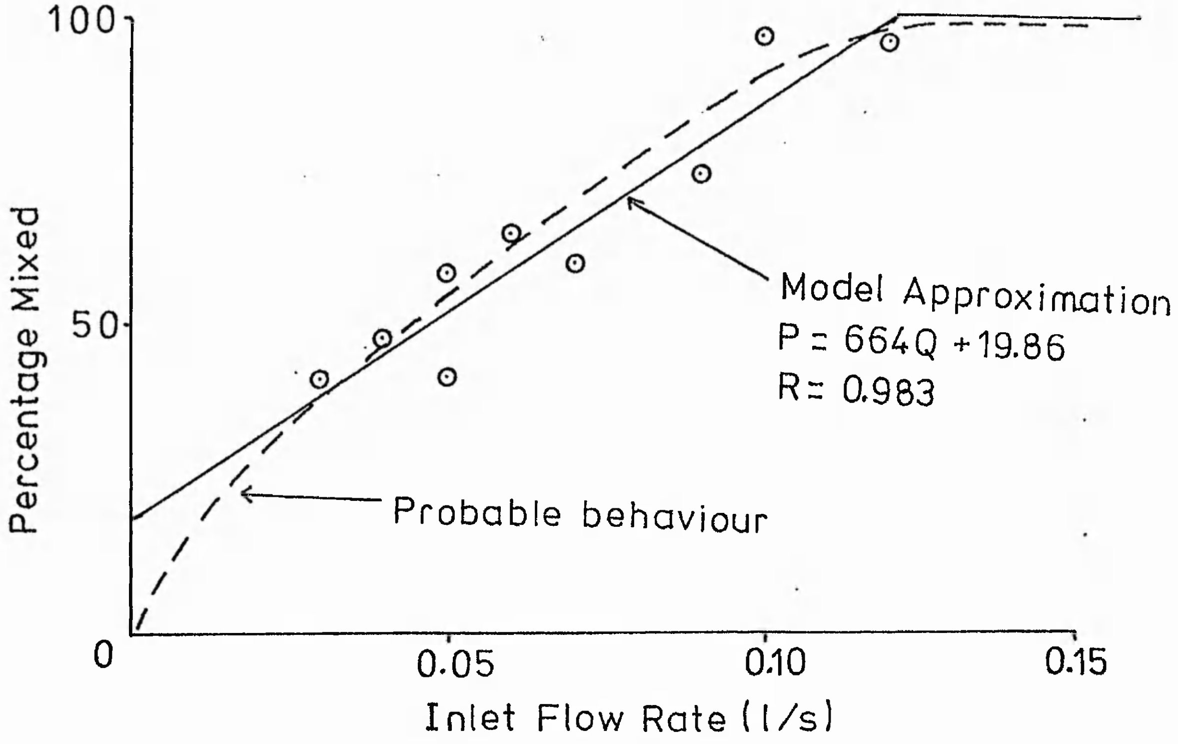


Fig. 43 TYPICAL CURVES ILLUSTRATING THE MODE OF REMOVAL OF SOLID MATERIAL FROM GULLY POTS FOR FLOW RATES OF 0.4 AND 0.5 l/s

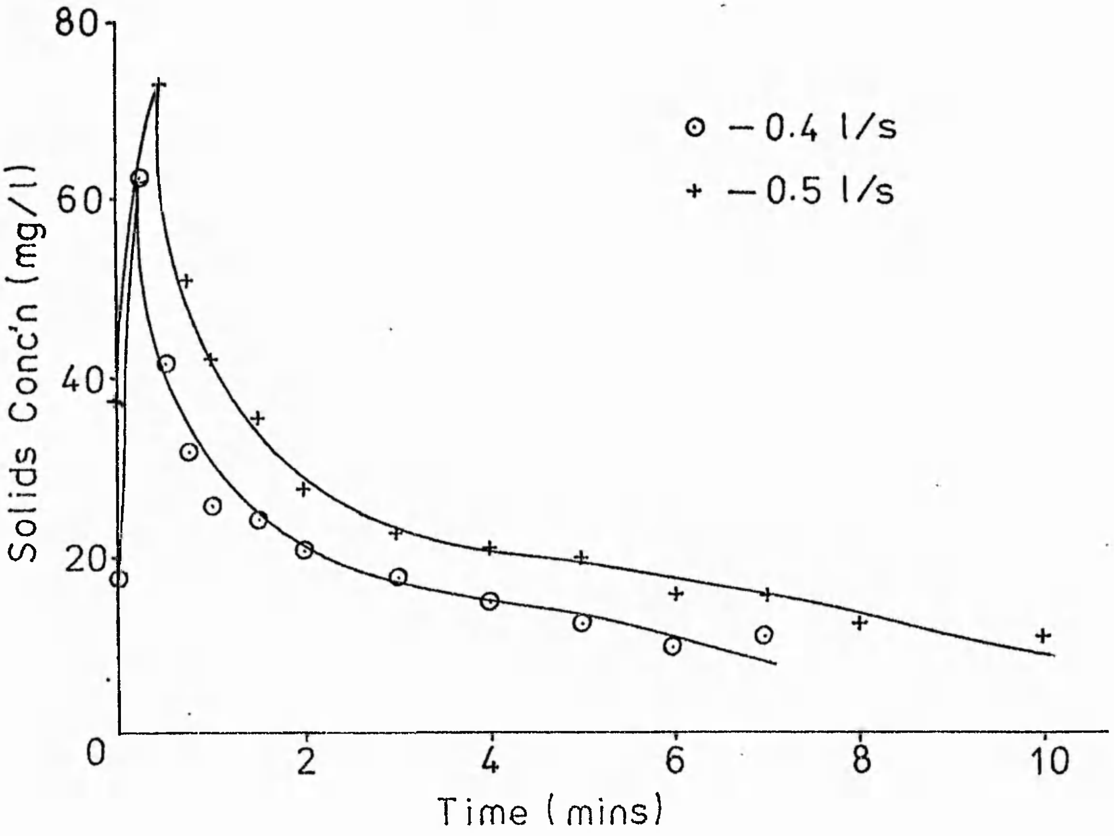


TABLE 19 Laboratory results for the removal of dissolved material from gully pots for different inlet flow rates

Flow Rate	Slope	Retention Time (S)	Theoretical Retention Time	% Volume Mixed
0.03	- 2.45	1289	3093	41.7
0.04	- 2.12	1116	2320	48.2
0.05	- 1.75	1086	1856	58.5
0.05	- 2.44	777	1856	41.8
0.06	- 1.57	1006	1547	64.9
0.07	- 1.70	798	1326	60.2
0.09	- 1.35	778	1031	75.4
0.10	- 1.05	901	928	97.0
0.12	- 1.06	743	773	96.1
0.25	- 0.89	424	371	106.1
0.50	- 1.02	185	186	99.8
1.00	- 1.02	93	93	100.0

TABLE 20 Laboratory results for the removal of particulate material from gully pots for different inlet flow rates.

Inlet Flow (L/S)	R (s)	Co (mg/l)	Cpo (mg/l)	Cps (mg/l)	tp (s)	K (mg/s)	M (mg)	M (Total)
0.1	928	27.2	27.4	0.6	15	3.7	56.2	706.8
0.2	464	18.0	49.4	32.5	30	103.8	3114.5	1673.6
0.4	232	31.6	69.0	41.2	30	135.9	4075.9	3604.8
0.5	186	17.2	57.0	41.1	15	264.7	3970.3	2799.0
0.6	155	22.4	52.2	31.8	15	206.5	3097.1	3999.6
0.7	133	27.6	49.4	24.8	15	162.3	2434.6	2902.2
0.8	116	19.6	66.6	51.4	30	180.4	5413.4	8112.0
0.9	103	44.8	85.4	46.7	15	310.4	4656.2	4719.6
1.0	92.8	52	90.6	46.4	15	310.9	4663.3	8442.0

Where R = retention time, Co = concentration of material in suspension at the start of the test, Cpo = observed peak concentrations, Cps = peak concentration attributable to resuspension of material (defined by Eqn. 9) tp = time to peak concentration, K = rate of resuspension of material (defined by Eq. 8) M txk = the mass available for release M(Total) = total measured mass removed after 8 minutes monitoring.

The results for the removal of solid material from the pot are presented in Table 20. The rate of release of available material was normally very rapid with peak concentrations being reached within 30 seconds, after which the expected decay curve was followed, (Figure 43). The rate of release for each test, K (mg/s), was calculated from the equation:-

$$K = \frac{C_{ps} Q}{(1 - e^{-t_p/R})} \qquad \ldots (8)$$

where $C_{ps} = C_{po} - C_o e^{-t_p/R}$ ... (9)

C_{ps} = peak concentration attributable to the release of bottom sediments.

C_{po} = observed peak concentration minus the background concentration.

C_o = initial suspended solids concentration

Q = flow rate

t_p = time to peak concentration (15 or 30 seconds)

R = Retention time

The total mass of material available for release could then be calculated from:- $M = t_p K$ (Table 20)

The major difficulty in the analysis of the results was the rapid depletion of material available for release. The sampling interval of 15 seconds was the fastest practical sampling rate but remained too insensitive for the accurate determination of tp, the time to peak concentration. The value obtained for t_p in turn influenced the accuracy of the determination of M and K. A linear regression of K against flow rate was employed to reduce errors through unreliable t values and gave a good correlation ($R = 0.85$, Figure 45). Similarly, a plot of M against flow rate (Figure 44) gave a reasonable correlation ($R = 0.75$) but visually the points showed a much wider scatter and with the limited data available linear regression may not be a valid method of calibration for M. It

Fig. 44 RELATIONSHIP BETWEEN THE MASS AVAILABLE FOR RELEASE, M, AND THE INLET FLOW RATE

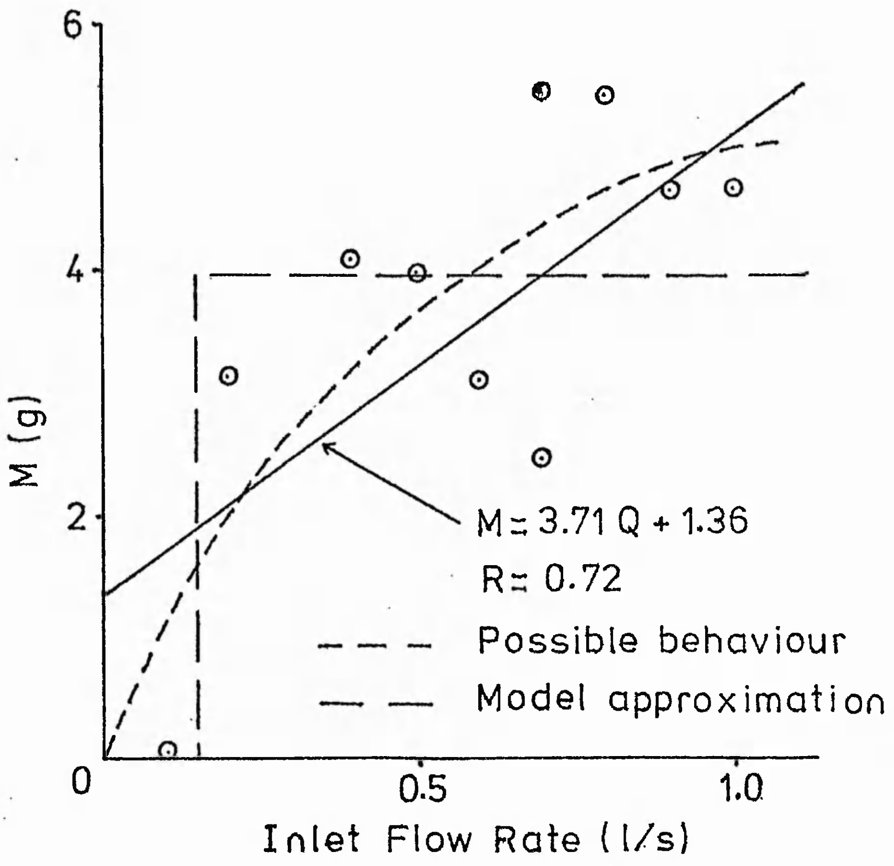
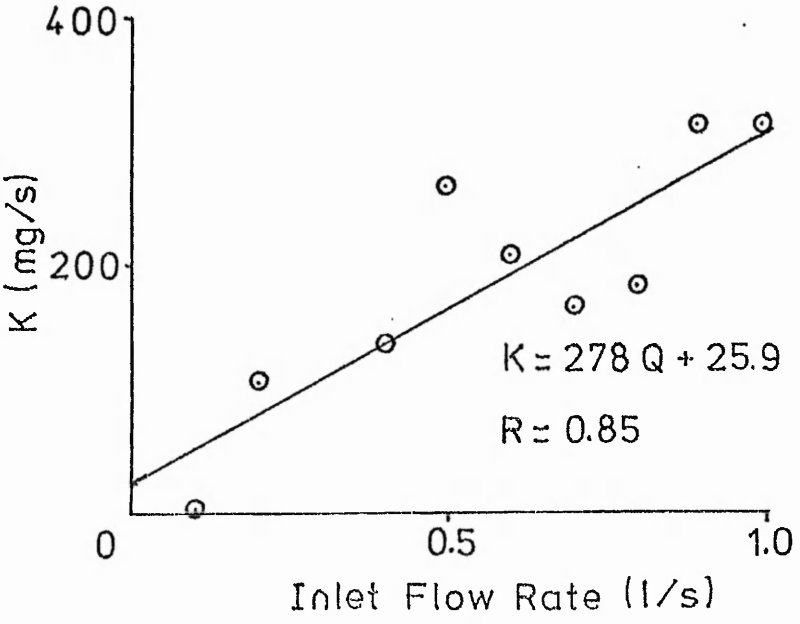


Fig. 45 RELATIONSHIP BETWEEN THE RATE OF RELEASE OF MATERIAL, K, AND THE INLET FLOW RATE.



is possible, for the low flow rates investigated, that there ia a maximum mass of solids available for release, i.e. only easily resuspended fine material and surface dusts are removed from the pot. Above 0.2 l/s the results could be interpreted in this manner with a mean mass available of approximately 4,000 mg, however, another plausible relationship is indicated by the dotted line in Figure 44. The rate of release, K, would not logically be expected to reach a plateau level but to be more rapid the faster the flow rate, and the regression equation was considered to be valid.

5.1.4 Conclusions on the Removal of Material from Gully Pots

For the removal of dissolved solids the laboratory tests probably give a reliable simulation of conditions that may occur in the field. The same may not be true for the sediment removal tests where a number of limitations inhibit the applicability of the results to field situations. Firstly, the material itself, although originally obtained from gully pots will have had its properties altered through the processes of sterilising, drying and sieving. Secondly bacterial degradation of solids creating fine solids and bacterial scums, a process that occurs continuously in the field, could not be taken into consideration. Thirdly, the depth of sediment used for all the tests was low and constant. Bearing in mind the limitations listed above the conclusion must still be that gully pots are effective in trapping coarse sediments that are not subsequently released by stirring of the pot under higher flow rates. A maximum mass released of only 0.2% of the original material input was recorded. In the field, material that is released from a gully pot probably represents wind blown dusts that settle on the surface of the liquor and fine sediments input and not removed on the recession limb of the previous storm event. The laboratory experiments are likely to represent the least polluting conditions that may occur in the field. Bacterial scums and greater depths of sediments could result in significantly larger sediment loads. Even with the low depth of solid used in the tests concentrations of up to 90 mg/l were recorded in the outflow, indicating that the resuspension of solids in gully pots may be of significance in the first flush of intense storms exhibiting high inlet flow rates.

The results indicate that the removal of dissolved material from gully pots may present a greater threat to storm water quality than the removal of sediment. Greater loads are available for release and since gully liquors may contribute up to 20% of the total storm runoff volume their discharge could result in high dissolved pollutant concentrations. Again the adverse effect is likely to be of greater significance in the first flush.

5.1.5 Application of Results to Mathematical Modelling

Since the laboratory results were of limited scope, the calibration of the theoretically derived equations from this data and the application of these equations in modelling gully pollutant contributions to urban runoff may only be considered as tentative.

Considering first the removal of dissolved solids, one of two situations may be proposed. Firstly, above a flow rate of 0.12 l/s complete mixing occurs and, secondly, below this flow rate the percentage mixed is dependent upon flow rate and is defined by linear regression. The model approximation and likely relationship are shown in Figure 42. Now for the purpose of modelling, calculations have to be performed over a finite time element of normally one minute for the solution of equations. In the proposed model the volume of total outflow derived from original gully liquors (the fluid in the gully pot prior to commencement of the storm) was computed. Hence, the concentration of dissolved material derived from gully pots may be calculated as follows:-

Equation 4 becomes:-

$$V_t = V_{t-1} \; e^{-Q_t P/V_o} \qquad \ldots (10)$$

V_t = Volume of original gully liquor remaining in the pot at time t (litres)

Q_t = flow at time t (litres/min)

V_o = volume of gully pot, = 92.8 litres
at $t = 1$, $V_t-1 = V_o$

P = percentage mixed

for $0 \leqslant Q \leqslant 0.12$

$P = 0.1107\, Q_t + 0.1986$

for $0.12 < Q < \infty$

$$P = 1.0$$

The flow attributable to original gully liquors (Q_g) is then:-

$$Q_{gt} = V_{t-1} - V_t \qquad \ldots (11)$$

and the concentration of dissolved solids attributable to original gully liquors is:-

$$c_t = \frac{Q_g t}{Q_t} \times C_o \qquad \ldots (12)$$

where C_o = the initial concentration of dissolved solids.
When another source of the pollutant occurs then the total concentration in runoff is:-

$$\text{Total } c_t = \frac{Q_g t}{Q_t} \times C_o + \frac{(Q_t - Q_g t)}{Q_t} \times F(C_p)$$

where $F(C_p)$ is either a constant pollutant background concentration, e.g. rainfall, or a function describing other processes at work in generating and transporting the pollutant.

It has been mentioned that pollutant contributions from gully pots are likely to be of greater significance during the first flush portion of a storm event. In the literature the term 'first-flush' has generally been loosely used to describe the initial pollutant rich phase of runoff. Having mathematically described the contribution of gully pot liquors to runoff allows us, for the purposes of this research, to make a quantitative definition of first-flush based upon their discharge. Thus, the first-flush is here defined as "that portion of a storm event during which 90% of the total discharge of original gully liquors has occurred". The definition is so phrased for two reasons; firstly, the gully liquors that are present at the start of storm will never be totally removed, therefore, only those that are actually discharged may be considered and, secondly, a value of 90% is necessary since some gully liquor discharge will occur throughout the storm, the use of a 100% definition would result in the first-flush always composing the whole storm. Mathematically the first-flush is defined as being complete when:-

$$\frac{\sum_{o}^{t} Q_g t}{TQG} = 0.1$$

where TQG = total volume of gully liquors discharged.

Using this definition for short low intensity storms the first-flush will comprise nearly the whole storm but for longer storm events it will consist of only the initial phases of runoff. The definition is therefore of more use than a fixed time definition (e.g. first 15 minutes) when the polluting potential of gully liquors is being considered.

The equations outlined above are the basis of a subroutine (GULLYS) for computing the contribution made by original gully liquors to flow at the storm sewer outfall. The subroutine was incorporated into the general urban runoff model and is further explained later in the chapter.

In computing the sediment contribution from gully pots both material in suspension prior to the storm event and material released from the bottom sediments have to be considered. Equation (12) can be used to describe the concentration of material from original suspended sediment (C_s). The mass available for release is defined according to the model approximation illustrated in Figures 44 and 45, and thus Equations (5) and (6) can be rewritten as:-

$$\text{for} \quad 0 < (C_t - C_{st})\, Q_t < M_t$$

$$C_t = \frac{K_q}{Q_t} \left(1 - e^{-Q_t/V_o}\right) + C_{st} \qquad \ldots (13)$$

$$\text{for} \quad M_t < (C_t - C_{st})\, Q_t < \infty$$

(that is when all the available mass has been released, then the remaining concentration C_t can be decreased exponentially)

$$C_t = C_{t-1}\, e^{-Q_t/V_o} \qquad \ldots (14)$$

where

$$M_t = M_o - \sum_{t=o}^{t} (C_t - C_{st})\, Q_t$$

$$M_o = 0 \qquad \text{for} \qquad 0 < Q_t < 0.15$$

M_o = 3928 mg for $0.15 < Q_t < \infty$

K_q(regression) = $(25.88 + 278.02\ Q_t) \times 60$

Q_t = flow in litres/minute at time t

V_o = volume of gully pot

K_q = rate of release in mg/minute for flow q

M_o = total mass available for release

C_t = total concentration in suspension at time t

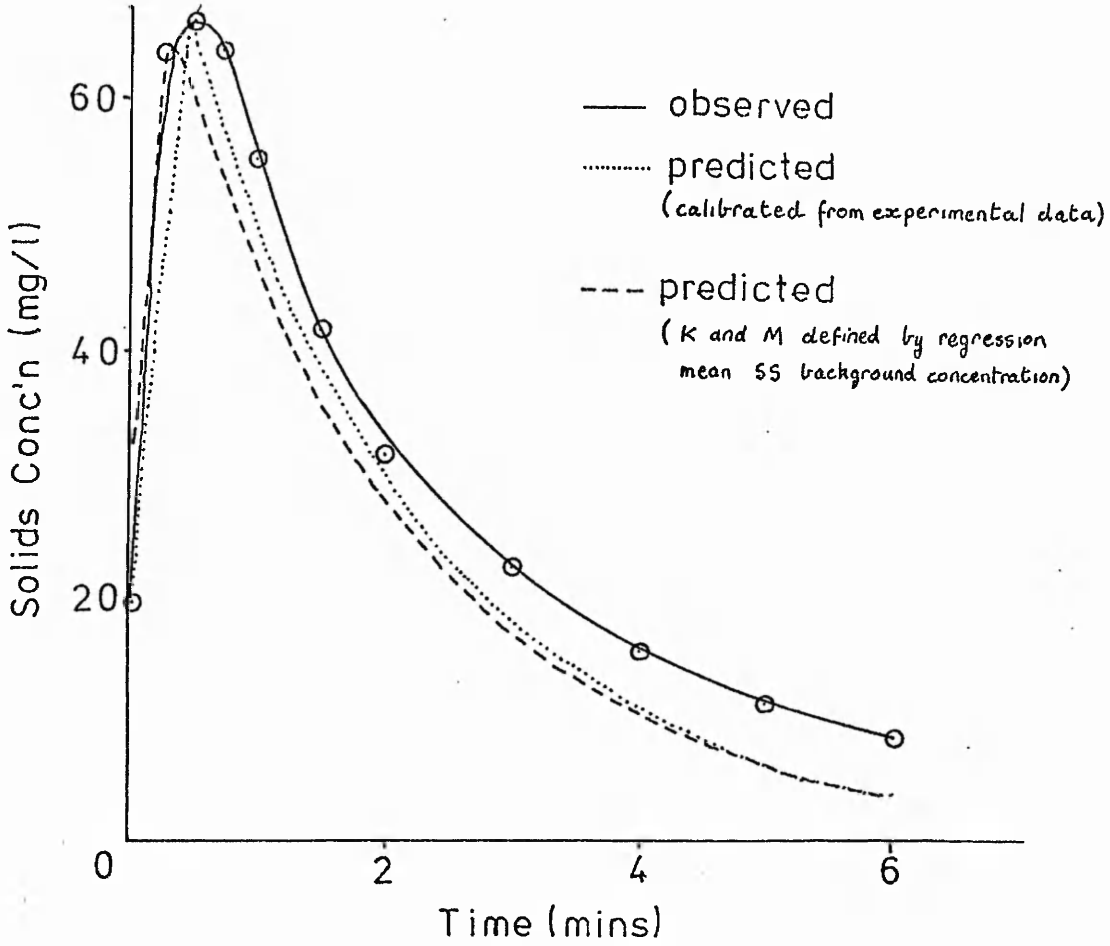
C_{st} = concentration in suspension attributable to original suspended matter.

The performance of this model cannot be verified in the field because of the impossibility of accounting for the solids input to the pot. However, the results of modelling for a constant flow rate and using the continuous expressions, i.e. not discrete minute interval calculations, are shown for one set of laboratory results in Figure 46. The observed results have been compared to the calculated curve for the model calibrated from the experimental data for that test alone and the general calibrated model, where K and M are defined by regression analysis and a mean initial suspended solids concentration was assumed.

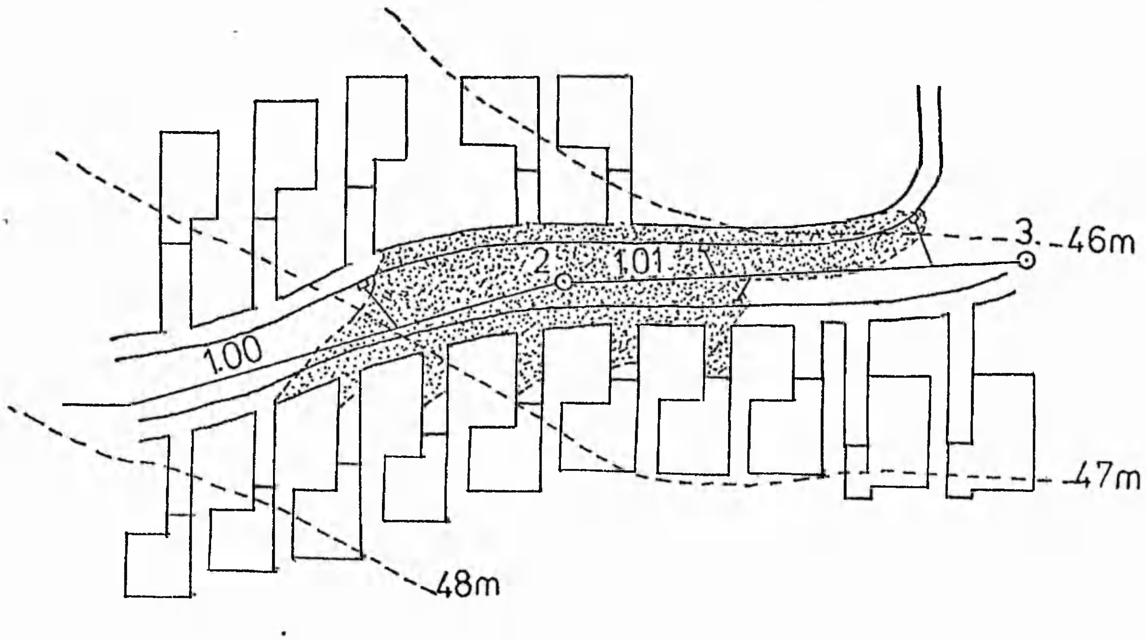
5.2. MODELLING URBAN RUNOFF

The rainfall-runoff process in a sewered urban catchment is comprised of several linked complex physical phenomena, but may be conveniently divided into two principal phases. The overland or above ground phase (i.e. the conversion of a rainfall hyetograph to an inlet hydrograph to the sewer system), consisting primarily of hydrological processes. The pipe routing or below ground phase (i.e. the formation of the outlet hydrographs by routing the inlet hydrographs through the sewer system) consisting of mainly hydraulic processes. Both aspects have been the concern of a major research effort in the U.K. at the Institute of Hydrology and the Hydraulics Research Station for the development of new and efficient design techniques for the provision

Fig. 46 OBSERVED AND PREDICTED CURVES FOR THE REMOVAL OF SOLID MATERIAL FOR AN INLET FLOW RATE OF 0.8 l/s



Fig, 47 EXAMPLE OF THE CALCULATION OF THE PAVED SUBCATCHMENT AREA CONTRIBUTING TO PIPE 1.01 AT MANHOLE 3



of storm drainage in urban areas. The results of this work have been published in several papers and reports (Institute of Hydrology (1978), Price and Kidd (1978), Kidd (1978), Helliwell et al (1976), Kidd (1976) and have formed the core of the mathematical model employed in this research.

5.2.1 The Overland Flow Model

The hydrological processes involved in the generation of the above ground runoff hydrograph from a measured rainfall input may be considered in three parts:-

a) the determination of the percentage runoff, or the evaluation of the losses in runoff volume which may occur for any given rainfall volume.

b) the distribution of these losses in time through the storm.

c) the distribution of the runoff volume in time over the urban surface.

In the proposed model the Clifton Grove catchment has been divided into a number of sub-catchments that are defined to extend between the manhole points in the storm drainage system. Since any number of gully pots may exist in one sub-catchment, the above ground phase effectively comprises not only the processes of overland flow but also the routing of the flows generated through the gully pots and along the connecting pipework to the relevant manhole junction.

The assumption was made that runoff would only occur off impervious surfaces. Roofed and road surfaces were considered separately and assumed to totally contribute to runoff. However, footpaths and driveways were examined for each sub-catchment and were excluded from area calculations when their contribution to runoff was likely to be negligible e.g. footpaths in grassed areas, driveways sloping away from the road. Figure 47 illustrates the general methodology employed in defining a typical sub-catchment paved area. The assumption that runoff will only occur from impervious areas with no contribution occurring from pervious areas is an acknowledged simplification. In high rainfall intensity storms runoff may occur directly off pervious surfaces, however, some impervious areas may drain into pervious land and the errors are assumed to cancel one another out. For the U.K., the Road Research Laboratory data (Watkins, 1962) showed percentage runoff from impervious surfaces to be consistently less than 100%. Kidd (1976) felt that pervious area contribution, whilst affecting the volume of runoff had little effect on the mechanics of the conversion from rainfall hyetograph to inlet hydrograph. However, it is clear that however the areas are defined as contributing, or not contributing, to runoff, they must have a significant effect upon the total predicted discharge.

Having acknowledged some of the assumptions necessary for the practical implementation of the above ground model the mechanics of the model is as follows. The calculation of the inlet hydrograph from the measured rainfall was achieved through the use of the three submodels:-

a) Percentage runoff submodel

b) Depression storage submodel

c) Surface routing submodel.

5.2.1.1 Percentage Runoff Submodel

The variation of percentage runoff with several catchment characteristics has been investigated by Stoneham & Kidd (1977) using data from 368 storms and 14 catchments. Their research led to the proposal of a regression equation for general application in the estimation of percentage runoff:-

$$PRO = 0.92\ PIMP + 53\ SOIL + 0.65\ UCWI - 33.6$$

where PRO = percentage runoff
PIMP = percentage impervious area
SOIL = a soil index
UCWI = urban catchment wetness index

The equation evaluates in an empirical fashion all likely losses that may occur over a catchment from processes such as surface infiltration, depression storage, infiltration and exfiltration from pipes, reduced catch by roofs and evaporation. A statistical treatment of the data was adopted due to the random and unquantifiable nature of losses making the catchment averaged approach more appropriate than a deterministic solution of all the contributing processes.

For the purposes of this study the measured total storm discharge was used to compute the percentage runoff. This procedure has been termed as forcing the predicted discharge. Although unsatisfactory for use in 'free' simulation or design procedures, the technique was consistent with the aims of this research, i.e. examination of pollutant loadings from gully pots. 'Forcing' the percentage runoff in this manner increased the reliability of the pollutant runoff prediction and is thought to be valid.

Having ascertained the value of the percentage runoff it remains to subtract the resultant loss from the rainfall hyetograph to create a net effective rainfall hyetograph. A number of options are available, of which there are 3 main categories:-

a) The constant proportion loss model (CPL). Losses are distributed as a fixed proportion of the rainfall intensity (Figure 48).

b) The Phi-index model. Losses take place at a constant rate.

c) The variable proportional loss model (VPL). This employs a Horton type equation to allow for a higher proportion of loss at the beginning of a storm than at the end.

The various loss models have been documented and evaluated in an International Workshop on Rainfall-Runoff Processes over Urban Surfaces (Institute of Hydrology, 1978) using data from the Netherlands, Sweden and the U.K. for 20 catchments. They concluded that the CPL and VPL models performed significantly better than the Phi-index model. The CPL model has been commonly employed, is simpler than the VPL model and was adopted for this research.

5.2.1.2 The Depression Storage Submodel

Depression storage is comprised of the rainfall that falls on impervious surfaces but never enters the sewer system. It can be considered as a combination of water held on the surface by surface

Fig. 48 EXAMPLE OF THE APPLICATION OF THE CONSTANT PROPORTIONAL LOSS MODEL TO A RAINFALL HYETOGRAPH

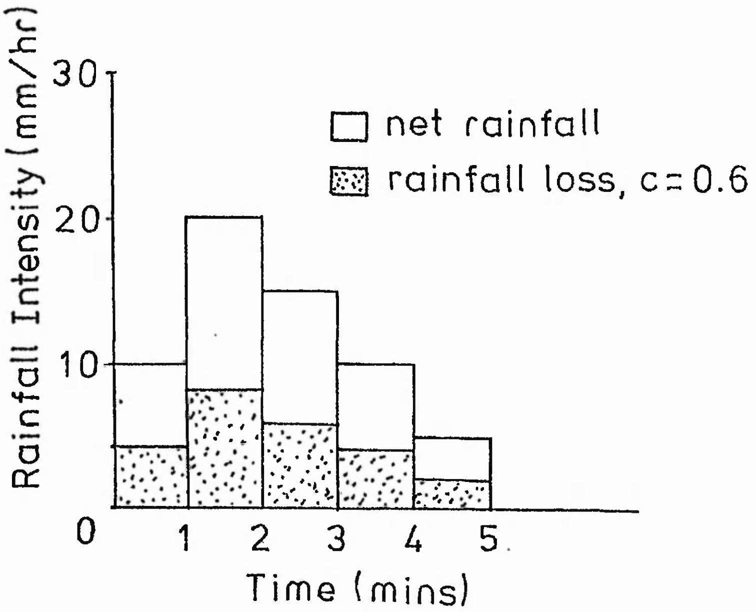
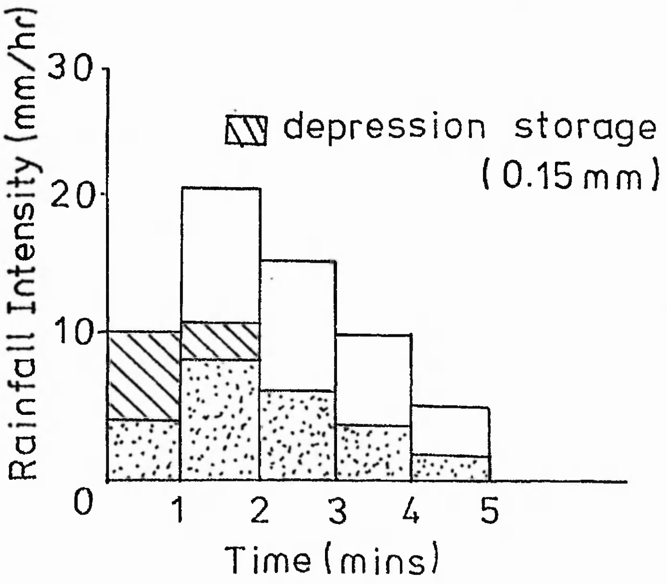


Fig. 49 EXAMPLE OF THE APPLICATION OF THE TOTAL LOSS MODEL TO A RAINFALL HYETOGRAPH



tension forces, as in initial wetting, and water contained in surface hollows as puddles. These two factors may be lumped together and treated as an even depth of water over the subcatchment. Runoff is assumed to occur only after the depression storage has been satisfied and as such the depression storage assigned in millimetres is subtracted from the initial portion of the hyetograph (Figure 49). This assumption is clearly not an altogether realistic appraisal of what can occur in practice since runoff may occur before storage has been satisfied in more remote areas of the catchment. However, the complexity of describing such a situation which could vary greatly from one subcatchment to another, justifies its use.

The analysis of data from the International Workshop led to the development of a relationship between depression storage and catchment slope (Figure 50) and a generally applicable regression equation for the evaluation of depression storage:-

$$\mathrm{DEPSTO} = 0.77\ \mathrm{SLOPE}^{-0.49} \qquad (R = 0.85)$$

The equation was employed in this study for the calculation of paved area storage values. No such equation exists for assigning a depression storage value to roofed areas but logically it is likely to be very small. Kidd (1976) had assumed a value of 0.1 mm, to cover surface wetting of roofs and this was adopted.

Depression storage was deducted from the net hyetograph after the application of the constant proportional loss model. This approach was considered to be more consistent with reality than the procedure of first deducting storage before applying the loss model, since infiltration losses will occur contemporaneously with the filling of depression storage.

5.2.1.3 Surface Routing Submodel

Surface routing is the process by which the effective hyetograph after the subtraction of losses is attenuated over the urban surface to form the inlet hydrograph at a manhole point. A wide variety of models have been used for the description of the surface routing process, these divide into two fundamental philosophies, the deterministic approach and the conceptual approach.

Fig. 50 RELATIONSHIP BETWEEN CATCHMENT SLOPE AND DEPRESSION STORAGE (KIDD, 1978)

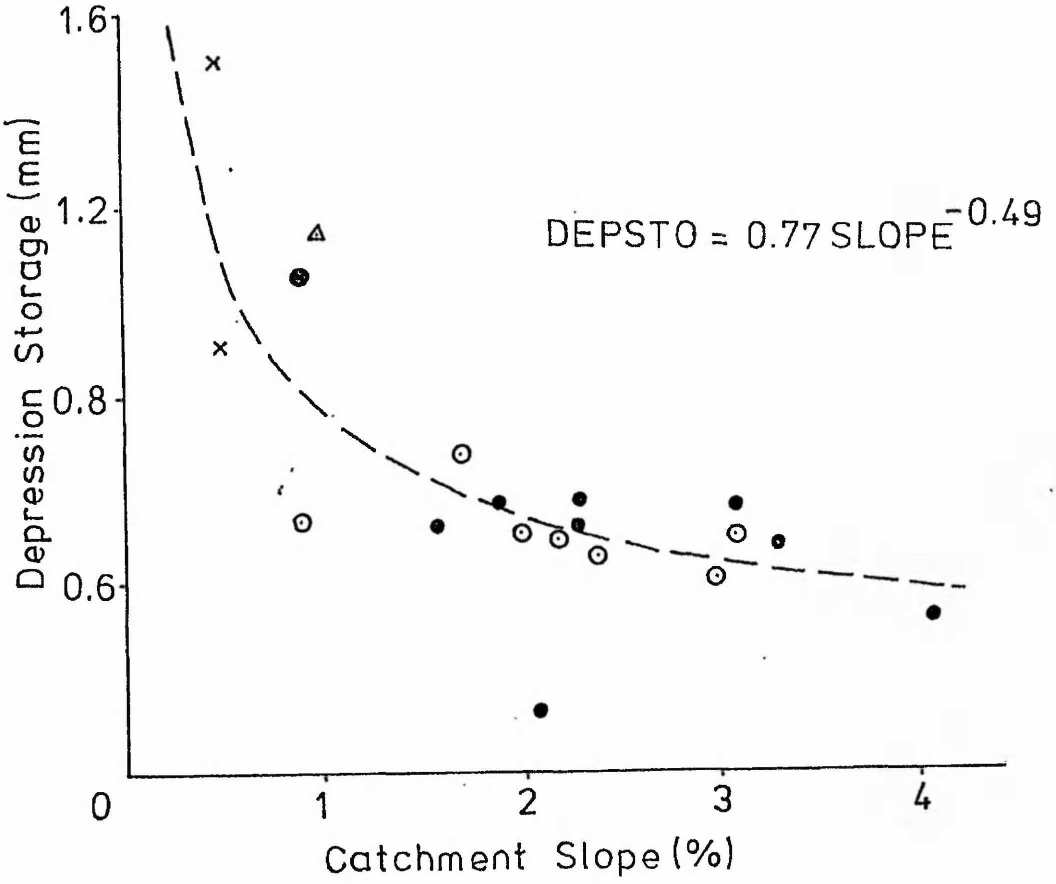


Fig. 51 FORMATION OF A HYDROGRAPH FROM A ONE MINUTE RAINFALL INTENSITY USING THE LINEAR RESERVOIR MODEL.

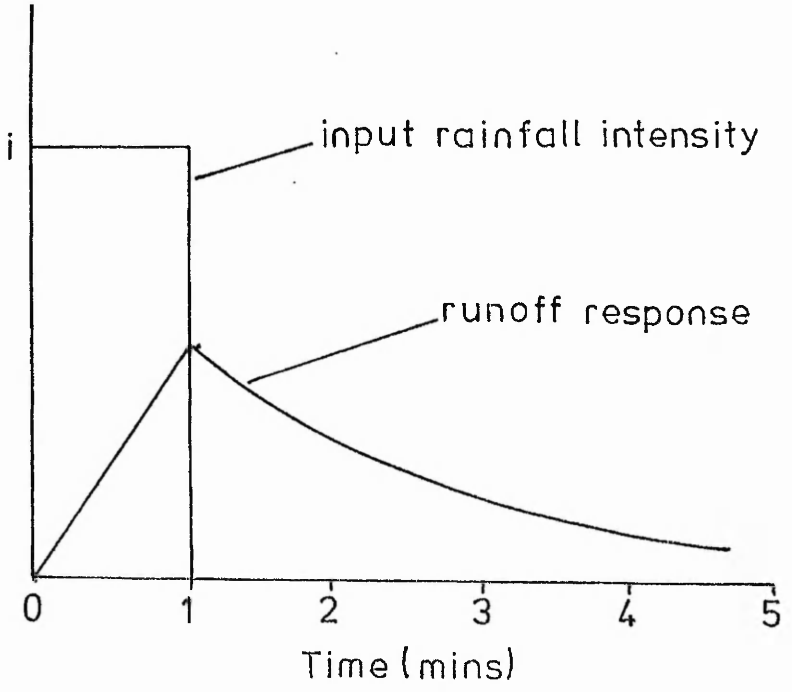
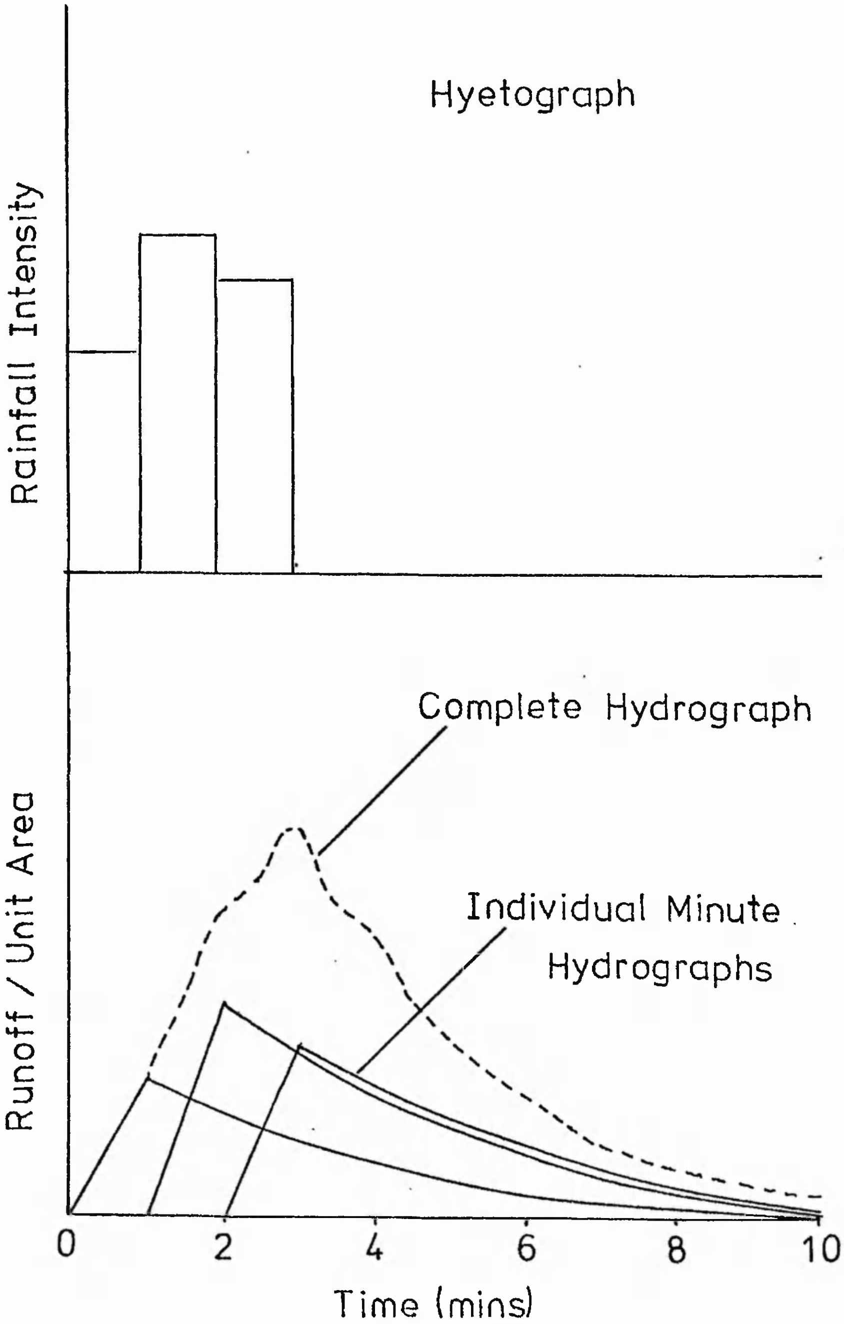


Fig. 52 ILLUSTRATION OF THE CALCULATION OF A COMPLETE HYDROGRAPH FROM A SERIES OF ONE MINUTE HYDROGRAPHS



The deterministic approach to the problem attempts to mathematically simulate all of the specific processes involved, whilst making the minimum of simplifying assumptions to obtain a working model. The main objections to the use of deterministic modelling are the large data requirements for the accurate description of a subcatchment surface, which is generally not feasible (particularly in the consideration of design methods) and the corresponding lengthy computing times needed.

The conceptual approach may be considered as employing simplified descriptions of the actual physical processes involved. Conceptual models attempt to describe a system in terms of a reduced number of parameters that can be calibrated from easily determinable system characteristics. The resultant equations have been loosely termed as 'lumped parameter' models. The general method adopted for the simulation of the overland flow is known as storage routing, where storage is considered as the lumped parameter.

A number of such conceptual models were examined by the International Workshop (Institute of Hydrology, 1978) and their performance compared over 188 rainfall-runoff events on 16 urban catchments. The models examined were:-

a) Linear reservoir

b) Non-linear reservoir

c) Non-linear reservoir with time-lag

d) Nash cascade

e) Muskingum

f) Time of Entry

Regression equations were developed for the variable parameters (after optimisation) against catchment characteristics (slope and overland flow length). All the relationships showed a marked similarity and explained between 40% and 55% of the variance in the optimised parameter. An analysis of variance for all of the models, calibrated from the derived regression equations showed that in terms of overall fit the linear reservoir, non-linear reservoir and Muskingum models were superior to the others. In terms of peak estimation there was little to chose between any of the models. The Workshop concluded that the choice of surface routing model was less critical than the manner in which it was utilised, however a non-linear model could be expected to perform marginally better than a linear one.

Of all the conceptual models the single linear reservoir is one of the simplest in terms of both application and computing, whilst retaining a high degree of accuracy. It has been used by a number of researchers for the simulation of surface runoff, Viessman (1966), Watt and Kidd (1975) and Newmann & Marr (1976).

The basic equations that describe the storage routing relationship are:-

$$\frac{dS}{dt} = i - q \qquad \ldots (15)$$

$$S = \alpha q^h \qquad \ldots (16)$$

S = storage
q = outflow
i = inflow
t = time

Differentiating equation (16) and substituting in (15)

$$n \alpha q^{n-1} \frac{dq}{dt} = i - q \qquad \ldots (17)$$

The linear reservoir is a specific solution of the above equation when n = 1, leaving α (the storage coefficient) as the only parameter to be determined. The storage coefficient has a fixed value for any one rainfall event on a given catchment. In respect of the non-linearity of the process, the International Workshop defined α as a function of the rainfall intensity making the model pseudo linear.

$$\alpha = \alpha_2 I^{-0.4} \qquad \ldots (18)$$

where I is defined as the average rainfall intensity for the most intense 10 minutes of the storm. Regression analysis for optimized α_2 values led to the proposal of the following equation for determining α_2 from the subcatchment slope and overland flow length.

$$\alpha_2 = 1.43 \text{ SLOPE}^{-0.4} \text{ LENGTH}^{0.22} \qquad \ldots (19)$$

These equations are applicable only to paved areas. For roofed areas no generally applicable regression equations have been developed for defining routing constants. The technique commonly employed is the optimization of the parameters for a given event to produce the 'best fit' hydrograph. For a catchment, such as Clifton Grove, containing some 40 subcatchments optimization for each constant would prove to be a lengthy procedure. Alternative approaches to the problem are the assignation of a single averaged routing constant for all the subcatchments and to use this in optimization procedures, or the assignation of empirical routing constants for each subcatchment. The latter course was selected to facilitate the rapid application of the model. Values assigned for the roof routing constant, were 1.0, 1.5, 2.0 and 2.5 minutes, the values chosen being dependent upon the length of flow to the manhole point of interest. Future research may improve the models performance by rationalisation of the roof routing constants.

To determine the runoff hydrograph Equation 17 is applied over specified time intervals (usually one minute) and assumes that the runoff response for the rainfall intensity over this time increment is a function only of that particular rainfall intensity and not adjacent intensities. Thus a one-minute hydrograph is generated from the one minute rainfall intensity (Figure 51). The complete runoff hydrograph is obtained by addition of the individual one-minute hydrographs (Figure 52). The runoff decay curve is obtained from Equation 17 by considering the case when $t > $ one minute, i is then equal to zero and for the linear reservoir $n = 1$.

$$\int_1^t \frac{dt}{\alpha} = \int_{qo}^{q} \frac{dq}{q} \qquad \ldots (20)$$

After integration and simplification this yields:-

$$q = q_o e^{-(t-1)/\alpha} \qquad \ldots (21)$$

q_o is obtained by equating the area under the input intensity to the area under the response curve.

$$q_o = \frac{i}{(\alpha + 0.5)} \qquad \ldots (22)$$

where i = rainfall intensity in mm/min.
and q_o = runoff per unit area in litres/M^2

Thus for a storm event the hydrograph is defined as follows:-

$$q(0) = 0$$

$$q(1) = i(1) / (\alpha + 0.5)$$

$$q(2) = i(2) / (\alpha + 0.5) + i(1) / (\alpha + 0.5)\ e^{-1/\alpha}$$

$$q(3) = i(3) / (\alpha + 0.5) + i(2) / (\alpha + 0.5) e^{-1/\alpha} + i(1) / (\alpha + 0.5)\ e^{-2}$$

$$q(n) = i(n) / (\alpha + 0.5) + i(n-1) / (\alpha + 0.5) e^{-1/\alpha} ... + i(1) / (\alpha + 0.5)\ e^{-n}$$

It can be seen that the decay curve continues for an infinite time and in practice a cutoff point is necessary when the response may be effectively ignored. This has been selected as being the point when 99% of the total area has been included in calculations. Since the area under the curve from time T to infinity is equal to $\alpha q_o e^{-T/\alpha}$ and the total area is equal to αq_o, then the cutoff time T can be determined from:-

$$\frac{\alpha q_o e^{-T/\alpha}}{\alpha q_o} = 0.01$$

thus $T = 4.6\ \alpha$

From this expression the cutoff time for the response curve for each minute increment may be determined.

The complete hydrograph per unit area derived as above is converted to the inlet hydrograph by multiplying by the subcatchment area.

5.2.2 The Pipe Routing Model

The pipe routing, or below ground, phase of urban runoff consists of combining the inlet hydrographs to each pipe at each time interval and routing the summed inlet hydrograph through the pipe to the next downstream junction. The procedure is then repeated for the following pipe in the network and so on through the system to the outfall. The modelling of this process is much more amenable to a deterministic approach than the above ground phase due to the simpler geometry involved.

The differential equations that describe gradually varied, unsteady flow in uniform channels are derived from consideration of the conservation of energy and the conservation of mass of an element of water moving in a downstream direction. The equations have been presented in many different forms and are known as the St. Venant equations, they may be written as:-

a) The dynamic equation:-

$$s_o - s_f = \frac{\delta y}{\delta x} + \frac{v}{g}\frac{\delta v}{\delta x} + \frac{1}{g}\frac{\delta v}{\delta t} \qquad \ldots (23)$$

b) The continuity equation:-

$$0 = y_m \frac{\delta v}{\delta x} + v\frac{\delta y}{\delta x} + \frac{\delta y}{\delta t}$$

where y = water depth

y_m = mean water depth

x = distance in a downstream direction

t = time

s_o = channel slope

s_f = friction slope

The equations involve two simplifying assumptions:-

a) that the flow is so gradually varied that the vertical acceleration of the water particles may be neglected,

and

b) that the resistance coefficient is the same for the given depth and mean velocity regardless of whether the flow is uniform or non-uniform.

Many methods of solving the St. Venant equations have been proposed involving varying degrees of approximation or assumption. The interrelationship of many of these solutions has been reviewed by Weinmann and Laurenson (1979). Numerical methods of solution for both equations have been termed 'complete dynamic models' and involve the conversion of Equations (23) and (24) into algebraic expressions that can be solved for y and v at finite increments of x and t. Although solutions of this type give the most complete description of flow in channels accuracy cannot be guaranteed since they remain based on the underlying assumptions in the formulation of the St. Venant equations. While all flood routing models use the equation of continuity in a similar manner further groups of models exist that can be distinguished according to the number of terms retained in the dynamic equation (Equation (25)).

$$s_o = \underbrace{\underbrace{\underbrace{\underbrace{s_f}_{\text{Kinematic wave}} + \frac{\delta y}{\delta x}}_{\text{Diffusion analogy}} + \frac{v}{g}\frac{\delta v}{\delta x}}_{\text{Approximate dynamic wave}} + \frac{1}{g}\frac{\delta v}{\delta t}}_{\text{Complete dynamic wave}} \quad \ldots (25)$$

Models that neglect the acceleration term have been called 'approximate dynamic models' whilst models that assume that the flow is at normal depth and thereby reduce the dynamic equation to $s_f = s_o$ are known as 'kinematic wave models'. Such approximations of the full St. Venant equations are of interest since,not only are they simpler, but also solutions may be computed more easily than for the full equations. Several schemes that have been utilised in the solution of the full and approximated equations are documented in the Flood Studies Report (NERC, 1975). Bettess and Price (1976) reviewed a number of the schemes for the solution of the St. Venant equations with particular reference to their accuracy and precision in routing flow along a pipe. Of the 'approximate models' tested they concluded that the Muskingum-Cunge method, a non-linear kinematic wave model, was comparable in accuracy with the approximate dynamic model but was computationally considerably faster. They recommended that the method be utilised for the design of storm-sewer systems or the simulation of flows in such systems where the speed of computation is an important factor. However, a scheme for the solution of the full equations was still considered to give the highest accuracy.

Subsequently the Muskingum-Cunge method was employed by Price and Kidd (1978) in a new urban storm sewer design and flow simulation package aimed at improving upon and superseding the conventional TRRL method (Watkins, 1962). The Muskingum-Cunge method, as developed by Price and

Kidd, was utilised in this research.

5.2.2.1 Derivation of the Muskingum-Cunge Method.

The storage of water within a pipe length is defined by the difference between the average value of the inflow (Q_{inp}) and the outflow (Q_{out}) during the time interval Δt, known as the routing period, i.e.

$$\frac{\Delta S}{\Delta t} = Q_{inp} - Q_{out} \qquad \ldots (26)$$

If Q^{t}_{inp} and Q^{t+1}_{inp} are the rates of inflow at the start and end of the routing period and Q^{t}_{out} and Q^{t+1}_{out} are the respective rates of outflow then the change in storage is given by:-

$$S_2 - S_1 = \left[\frac{(Q^{t}_{inp} + Q^{t+1}_{inp})}{2} - \frac{(Q^{t}_{out} + Q^{t+1}_{out})}{2} \right] \Delta t \qquad \ldots (27)$$

The storage at any given time may also be expressed in terms of the relative significance given to outflow and inflow by use of a weighting parameter, ε :-

$$S = \beta \, (\, \varepsilon \, Q_{inp} + (1 - \varepsilon) \, Q_{out}) \qquad \ldots (28)$$

where β is a further model parameter.

Substituting this expression for S in Equation (27) and rearranging:-

$$Q^{t+1}_{out} \, (\beta - \beta\varepsilon + \tfrac{1}{2} \Delta t) = Q^{t}_{inp} \, (\beta\varepsilon + \tfrac{1}{2} \Delta t) - Q^{t+1}_{inp} \, (\beta\varepsilon - \tfrac{1}{2} \Delta t)$$
$$+ \; Q^{t}_{out} \, (\beta - \beta\varepsilon - \tfrac{1}{2} \Delta t)$$

$$\therefore \; Q^{t+1}_{out} = C_1 Q^{t}_{inp} + C_2 Q^{t+1}_{inp} + C_3 Q^{t}_{out} \qquad \ldots (29)$$

where $C_1 = \dfrac{(\beta\varepsilon + 1/2 \Delta t)}{(\beta - \beta\varepsilon + 1/2 \Delta t)}$

$C_2 = \dfrac{-(\beta\varepsilon - 1/2 \Delta t)}{(\beta - \beta\varepsilon + 1/2 \Delta t)}$

$C_3 = \dfrac{(\beta - \beta\varepsilon - 1/2 \Delta t)}{(\beta - \beta\varepsilon + 1/2 \Delta t)}$

Equation (29) is known as the Muskingum equation and is the finite difference scheme whereby given an input hydrograph at the top end of a pipe and initial conditions down the pipe it is possible to calculate the discharge hydrograph at the bottom end of the pipe.

It now remains to define the model parameters β and ε. Although the Muskingum method outlined as above was originally believed to be purely empirical, Cunge (1969), studying the finite difference scheme used in the computation of the outflow hydrograph, found that it approximated the 'diffusion analogy' equation. This enabled the parameters β and ε to be related to the geometry and hydraulic characteristics of the pipe reach under consideration. Cunge (1969) derived the following equations for the two parameters which have subsequently been utilised for the routing of flow in pipes (Price and Kidd, 1978):-

$$\beta = \frac{L}{w} \qquad \ldots (30)$$

where L = length of the pipe

w = wave speed

Hence β can be interpreted as the time of travel of the flood peak down the pipe

and $$\varepsilon = \tfrac{1}{2}\left(1 - \frac{\overline{Q}}{\overline{B}\, s_o L\, \overline{w}}\right) \qquad \ldots (31)$$

where s_o = pipe slope

$\overline{Q}$ = mean discharge

$\overline{B}$ = mean surface breadth

$\overline{w}$ = mean wave speed

A value for the mean wave speed $(\overline{w})$ can be found from the equation

$$\overline{w} = \frac{1}{Q_{fb}} \int_0^{Q_{fb}} \frac{dQ}{dA} \, dQ \qquad \ldots (32)$$

$$\overline{w} = \frac{1}{Q_{fb}} \int_0^{d} \frac{1}{B} \left(\frac{dQ}{dy}\right)^2 dy \qquad \ldots (33)$$

with Q defined by the normal depth relationship of the Colebrook-White equation:-

$$Q = A\ (32g\ r\ S_o)\ \log_{10}\ (14.8r/k_s) \qquad \ldots\ (34)$$

where g = acceleration due to gravity

d = pipe diameter

k_s = roughness coefficient

Q_{fb} = full bore discharge

For typical values of k_s and for a water depth of 0.3d, then $\overline{w} = dQ/dA$, this value for $\overline{w}$ is used in Equation (30). However, to give an appropriate mean vlaue for ε , $\overline{w}$, $\overline{Q}$ and $\overline{B}$ in Equation (31) are evaluated for a water depth of 0.5d.

The coefficients, C_1, C_2, C_3, have now been defined purely in terms of the pipe geometry and other fixed coefficients, therefore, the method has become known as the 'fixed parameter' Muskingum-Cunge method. In reality the wave speed and the amount of storage will vary with the discharge and it is possible to devise a scheme whereby the parameters β and ε are dependent upon the discharge. Such an improvement has been examined (Price and Mance, 1978), however, despite the marginal improvement in accuracy the method was judged to be unjustified because of the larger computing costs.

5.3. APPLICATION OF THE MODELS. THE COMPUTER PROGRAMME

The sub-models and pollutant removal expressions introduced in Sections 5.1 and 5.2 form the basis of the Trent Urban Runoff Simulation (T.U.R.S.). The computer programme is written in FORTRAN V language and was executed on a DEC 20/PDP 11 computer at Trent Polytechnic, Nottingham. The programme is currently limited to a sewer system containing up to 50 manhole points and rainfall events up to 200 minutes. These values are convenient for the Clifton Grove catchment and for the data available, but could be easily changed by re-diminishing the matrix storage allocations for application to larger catchments or events. In this format the programme required 9 pages of computer storage and took 10 to 15 seconds of CPU time to execute for the storm events encountered. The programme itself is presented in Appendix 1.4. In its present form T.U.R.S. is strictly a simulation technique, its principal functions can be summarised as the computation of input hydrographs, output hydrographs and original gully liquor contribution to these hydrographs at any manhole point in the sewer system. In addition the dissolved pollutant concentrations derived from the discharge of original gully liquors can be computed. Any pollutant may be considered whose concentration in gully liquors prior to the storm event was known or was predictable. The programme comprises the following divisions and subroutines as illustrated in the flow chart. (Figure 53).

a) MAIN PROGRAMME:- performs data input and output operations, programme management and the calculation of relevant statistics;

b) HYETO SUBROUTINE:- formulates a hyetograph from raw rain-gauge data, calculates the average intensity for the most intense 10 minutes and applies the constant proportional loss model;

c) DEPSTO SUBROUTINE:- calculates the depression storage values for each paved sub-catchment. Derives the hyetographs applicable to each paved sub-catchment and to roofed areas.

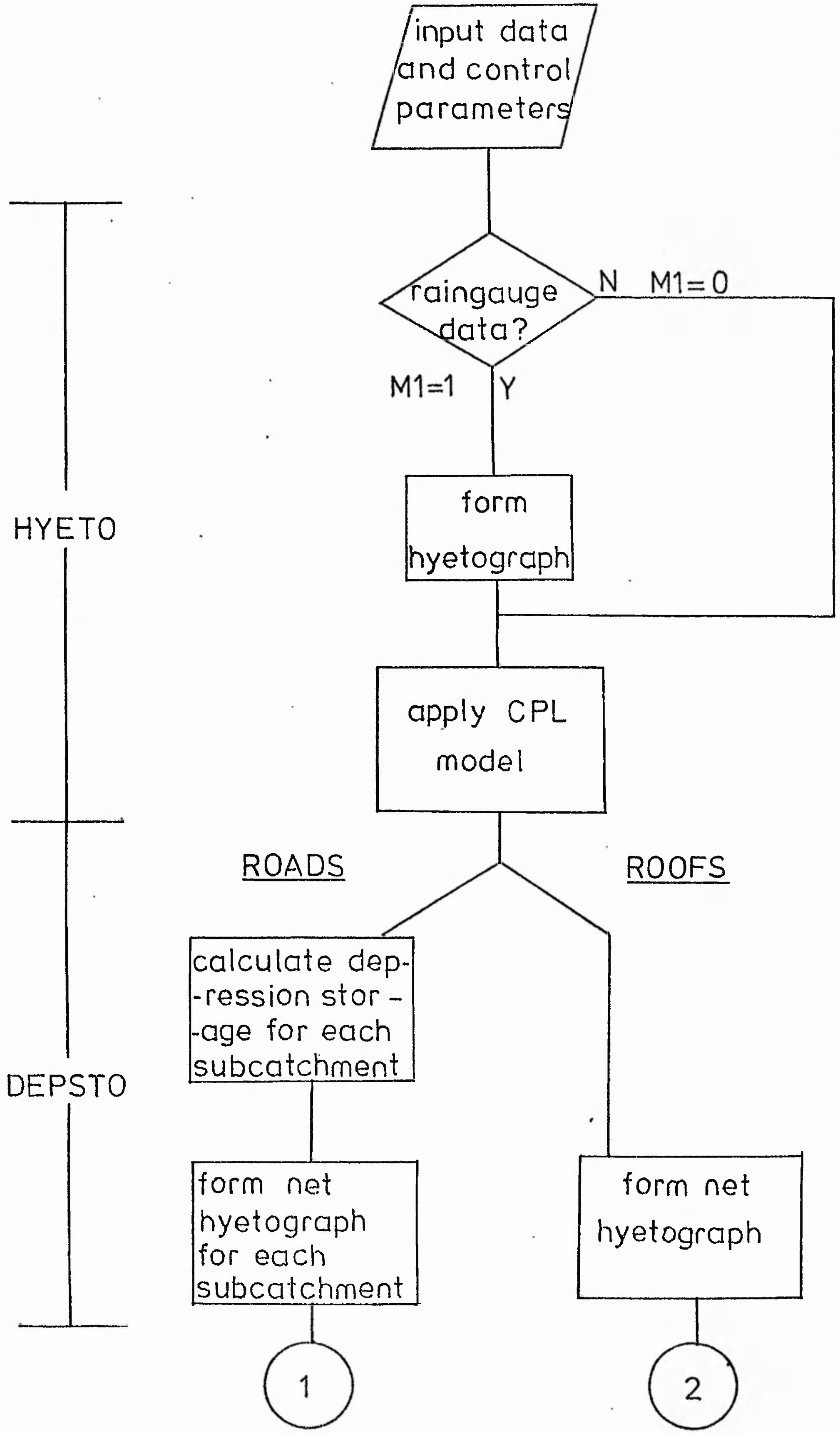
d) LINRES SUBROUTINE:- calculates the storage routing coefficient for each paved sub-catchment. Computes the inlet hydrograph for paved and roofed sub-areas from each sub-catchment. Sums the two inlet hydrographs to form a total inlet hydrograph for each sub-catchment.

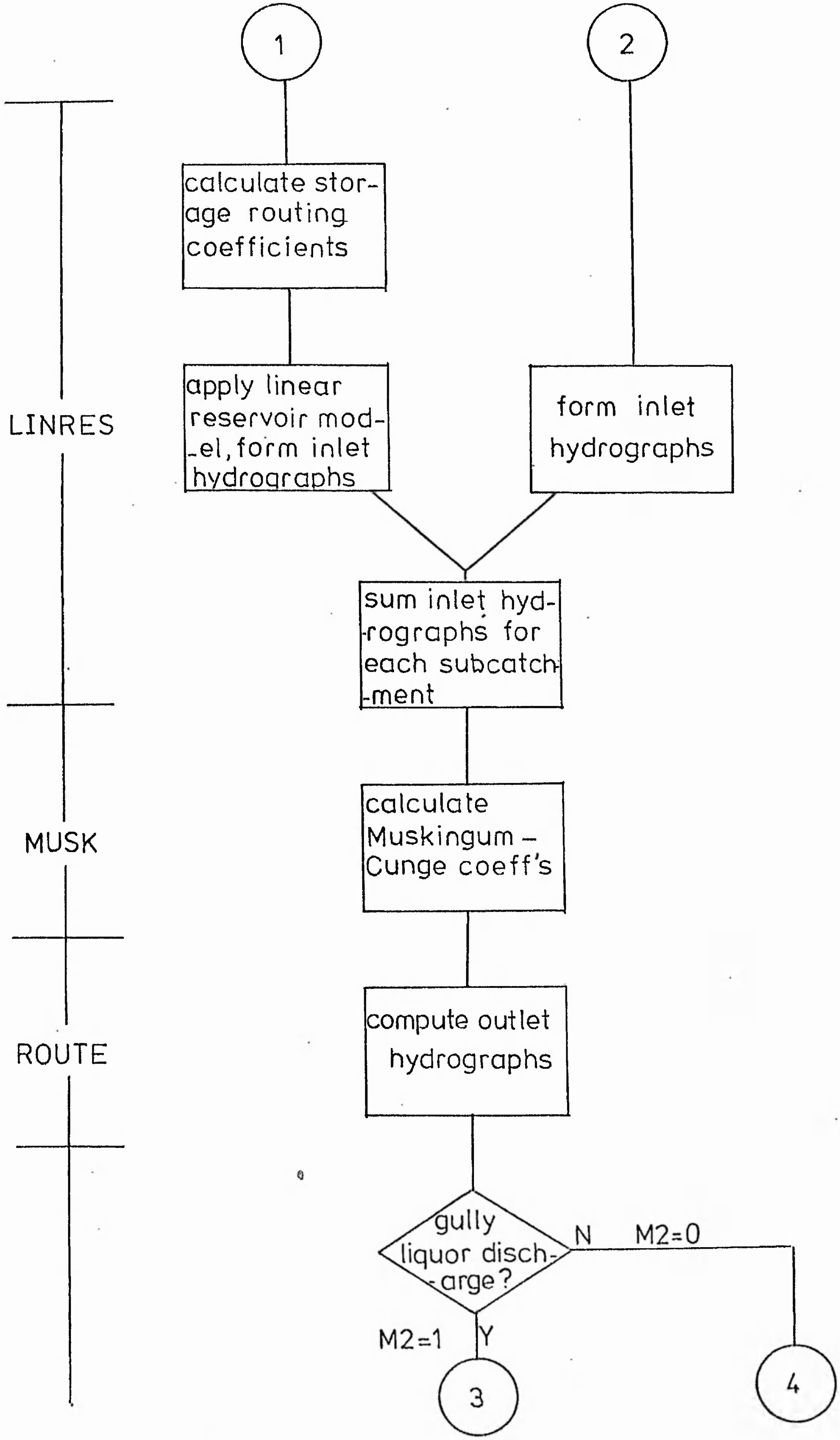
e) MUSK SUBROUTINE (supplied by courtesy of the Institute of Hydrology and the Hydraulics Research Station):- calculates the Muskingum pipe routing coefficients from pipe geometry.

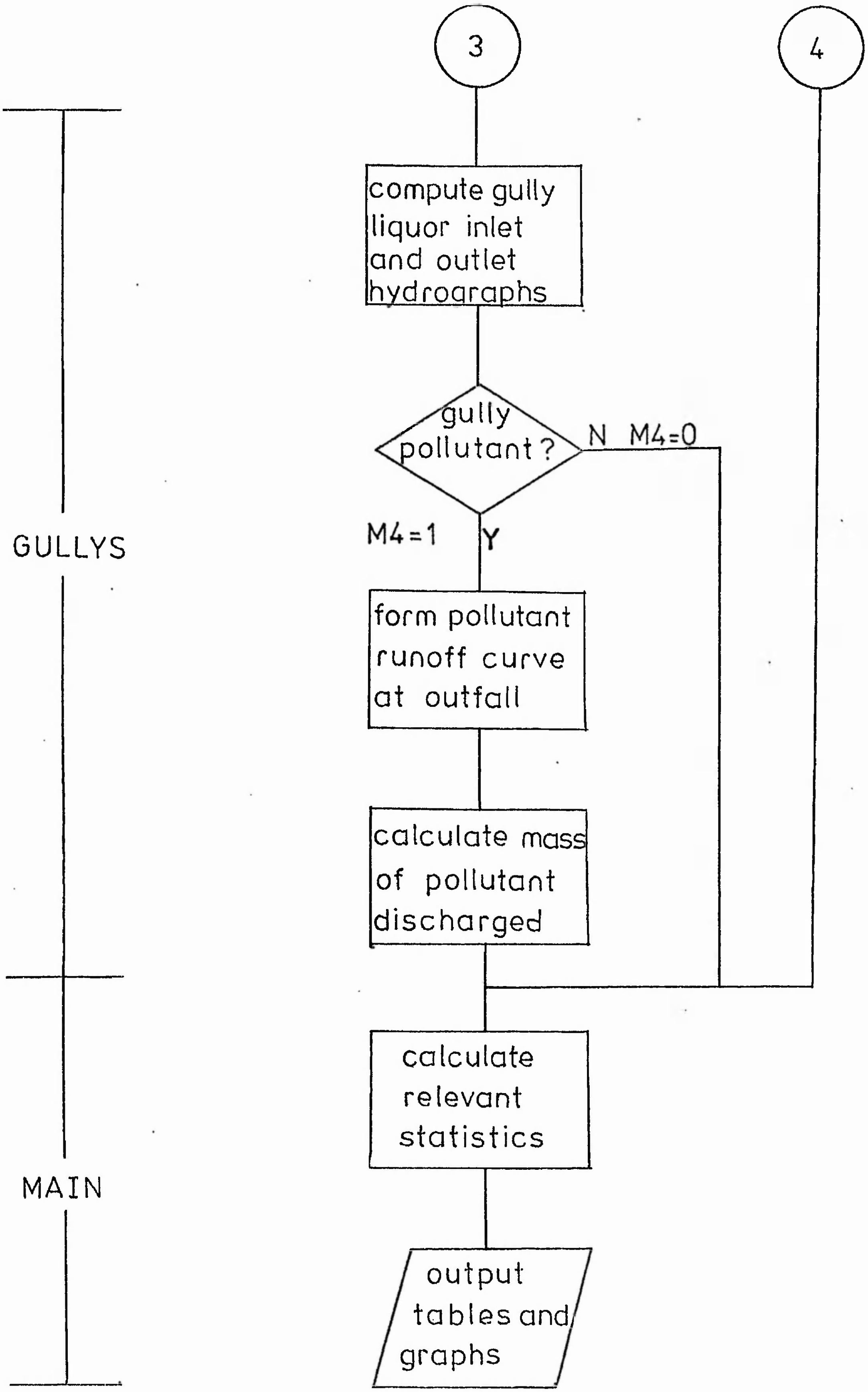
f) ROUTE SUBROUTINE:- routes the input hydrographs through the pipe network to form the output hydrographs at each manhole point.

g) GULLYS SUBROUTINE:- computes the contribution to flow attributable to the input of original gully liquors at each manhole point. Calls ROUTE to form the output hydrographs attributable to original gully liquors at each manhole point. Calculates the concentration of pollutants at the outfall derived from original gully liquors.

Fig. 53 SIMPLIFIED FLOW CHART FOR THE TRENT URBAN RUNOFF SIMULATION.




1
2
calculate storage routing coefficients
apply linear reservoir model, form inlet hydrographs
form inlet hydrographs
LINRES
sum inlet hydrographs for each subcatchment
calculate Muskingum – Cunge coeff's
MUSK
compute outlet hydrographs
ROUTE
gully liquor discharge?
N
M2=0
M2=1
Y
3
4


3
4
compute gully liquor inlet and outlet hydrographs
gully pollutant ?
N M4=0
M4=1
Y
form pollutant runoff curve at outfall
calculate mass of pollutant discharged
calculate relevant statistics
output tables and graphs
GULLYS
MAIN

5.3.1. Data Preparation and Input

The data input requirements of the programme are four fold:-

a) Fixed catchment data, i.e. pipe system data and sub-catchment characteristics.

b) Rainfall event data

c) Observed event data, i.e. measured flows, pollutant concentrations.

d) Programme control parameters.

The catchment data was derived from a combination of field measurements and the use of a site map supplied by Nottingham City Council. Initially the total catchment was divided into a number of sub-catchments defined by the number of manhole points in the pipe system (Figure 54). The paved and roofed areas contributing to each sub-catchment were determined by planimeter off the site map. The average overland flow length and the number of gully pots draining each sub-catchment were also determined from the map. The mean sub-catchment slope expressed as a percentage was determined from field measurements. The pipe system was numbered according to the branch nomenclature employed in the TRRL method (Figure 54). Correct numbering is of some importance since the addition and routing of hydrographs through the system is dependent upon it. The sub-catchments were numbered according to the pipe length to which they contributed. The pipe dimensions, length, slope and radius were determined from field measurements. The roof area storage routing coefficients which were assigned empirically (see 5.2.1.3.) were also input with this data. Tables 21 and 22 are a summary of the sub-catchment and sewer system data for the Clifton Grove catchment.

Storm event data may be input in one of two possible formats, either as a rainfall hyetograph or as raw rain-gauge data available from the translation of rain-gauge logger tapes, i.e. time/number of tilts per minute. In the latter case the dynamic calibration for the rain-gauge employed, the intensity applicable to each tilt, must also be input. It is necessary to make some assumptions in formulating the hyetograph from rain-gauge data in order that a situation of least error applies to all storms, these are:-

Fig.54 STORM SEWER PIPE NUMBERING FOR THE CLIFTON GROVE ESTATE.

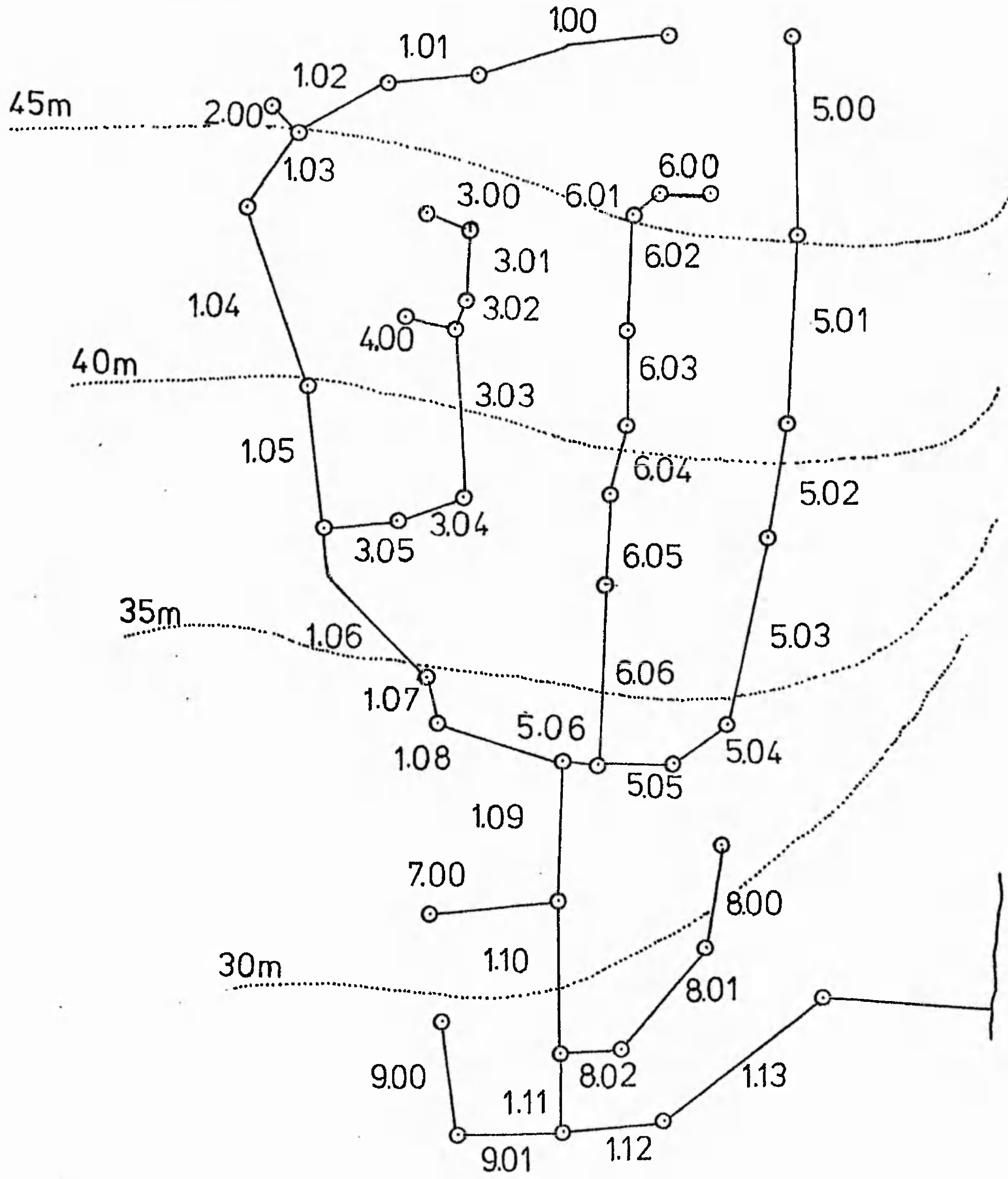


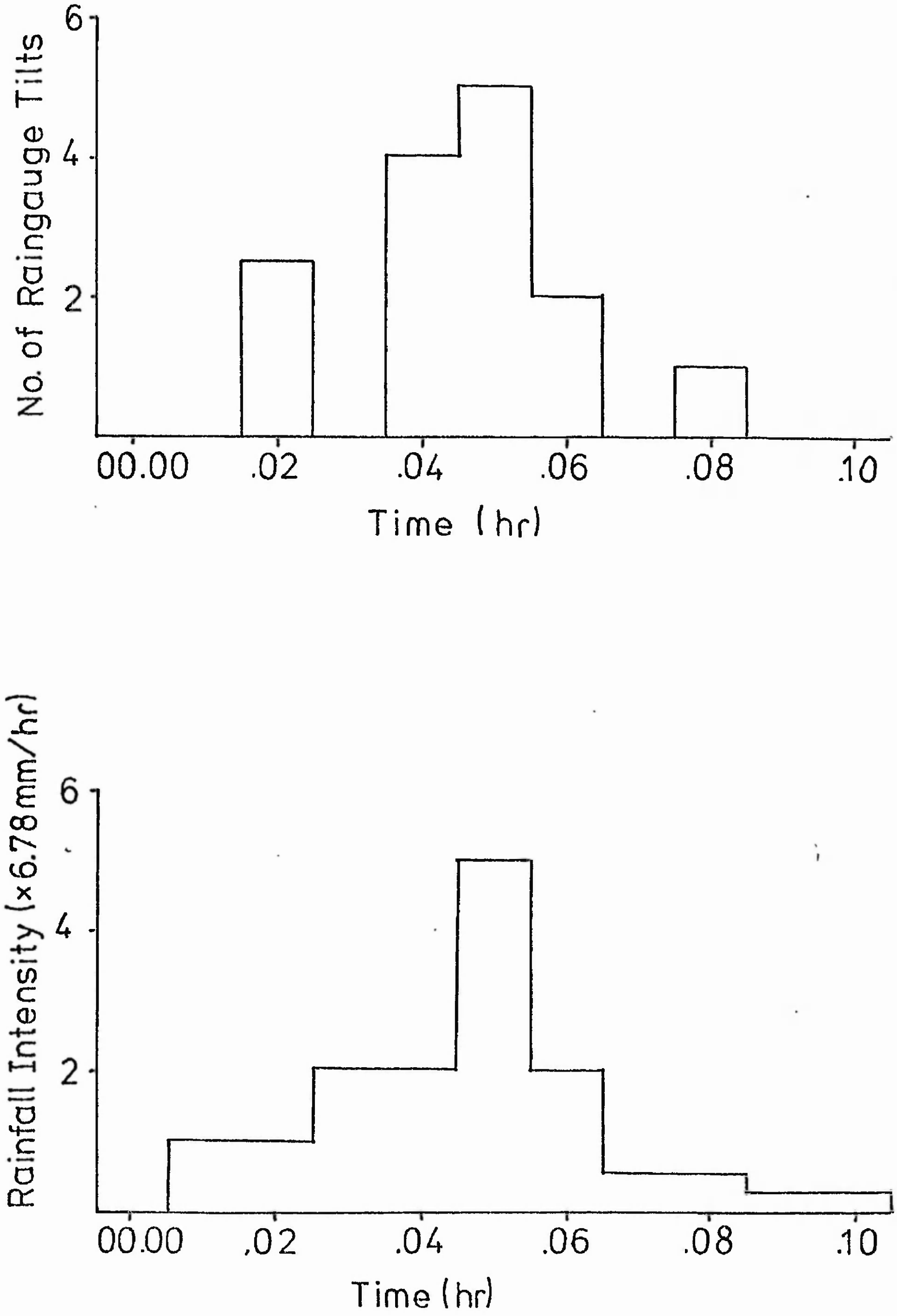
TABLE 21 Sub-catchment data

Pipe No	Slope (%)	Paved Area (m^2)	Roof Area (m^2)	Length (m)
1.00	2.734	960.00	616.25	70.0
1.01	1.813	620.00	430.75	90.0
1.02	2.164	520.00	631.25	65.0
2.00	3.813	320.00	0.00	90.0
1.03	2.910	410.00	419.75	60.0
1.04	2.995	760.00	385.00	70.0
1.05	4.300	755.00	0.00	100.0
3.00	1.500	1200.00	0.00	90.0
3.01	-	0.00	1504.25	0.0
3.02	-	0.00	0.00	0.0
4.00	.254	550.00	0.00	60.0
3.03	2.987	570.00	747.50	70.0
3.04	-	0.00	0.00	0.0
3.05	-	0.00	686.50	0.0
1.06	3.366	740.00	0.00	90.0
1.07	2.000	220.00	521.25	70.0
1.08	.500	420.00	0.00	60.0
5.00	5.102	1597.00	916.00	95.0
5.01	4.320	688.00	0.00	85.0
5.02	4.000	324.00	1136.25	80.0
5.03	3.699	940.00	0.00	95.0
5.04	3.903	350.00	0.00	70.0
5.05	.711	260.00	0.00	70.0
6.00	2.000	210.00	0.00	45.0
6.01	2.000	100.00	922.25	30.0
6.02	4.065	264.00	385.00	70.0
6.03	4.640	270.00	1255.75	90.0
6.04	4.120	280.00	0.00	85.0
6.05	3.336	1310.00	603.50	85.0
6.06	-	0.00	552.25	0.0
5.06	.315	340.00	735.00	55.0
1.09	4.672	620.00	317.50	80.0
7.00	.440	560.00	860.75	65.0
1.10	3.800	560.00	612.00	80.0
8.00	4.400	540.00	1221.75	90.0
8.01	1.226	700.00	154.00	65.0
8.02	1.200	70.00	338.50	25.0
1.11	2.000	540.00	0.00	55.0
9.00	2.482	100.00	1065.27	70.0
9.01	2.838	560.00	793.00	95.0
1.12	-	0.00	0.00	0.0
1.13	-	0.00	0.00	0.0

TABLE 22 Sewer System Data

Pipe No	Length (m)	Slope (%)	Diameter (m)	Gully Pots
1.00	79.6	3.636	.2286	6
1.01	47.0	1.504	.2286	3
1.02	49.9	3.175	.2286	4
2.00	10.7	4.484	.2286	2
1.03	35.0	3.226	.2286	2
1.04	86.5	3.759	.2286	6
1.05	70.7	4.739	.2286	4
3.00	13.1	2.092	.2286	4
3.01	35.6	4.717	.2286	0
3.02	95.0	.440	.2286	0
4.00	19.1	.429	.2286	3
3.03	76.0	3.968	.2286	4
3.04	34.0	2.667	.2286	0
3.05	32.4	1.866	.2286	0
1.06	75.5	2.364	.3048	3
1.07	15.5	2.558	.3048	1
1.08	58.9	.639	.3810	3
5.00	96.0	5.051	.2286	7
5.01	71.0	5.051	.2286	5
5.02	48.4	4.854	.2286	2
5.03	87.0	4.115	.2286	6
5.04	30.0	1.186	.2286	2
5.05	25.3	1.799	.2286	2
6.00	27.0	2.646	.2286	3
6.01	8.2	7.752	.2286	1
6.02	54.0	4.405	.2286	2
6.03	47.5	4.854	.2286	2
6.04	29.7	2.342	.2286	2
6.05	36.0	3.650	.2286	5
6.06	78.6	4.525	.2286	0
5.06	20.0	2.041	.3048	3
1.09	61.5	5.882	.3810	4
7.00	57.5	1.972	.2286	4
1.10	66.0	2.786	.3810	4
8.00	43.0	4.016	.2286	2
8.01	59.4	.485	.2286	5
8.02	26.7	.100	.2286	1
1.11	44.2	4.386	.3810	1
9.00	58.0	2.288	.2286	2
9.01	45.2	4.405	.2286	2
1.12	35.5	5.102	.3810	0
1.13	92.0	.484	.3810	0

Fig. 55 EXAMPLE OF THE FORMATION OF A HYETOGRAPH FROM RAINGAUGE DATA



a) the tipping bucket is half full at the beginning and end of a storm.

b) the storm commenced at a time prior to the first tilt that is equal to the time gap (in minutes) between the first and second tilt.

c) the storm ended at a time after the final tilt that is equal to the time gap between the final and penultimate tilts.

An example of the transformation of raingauge data to form a storm hyetograph is shown in Figure 55.

The programme operation is determined by the input of five programme control parameters (M1 - M5). The parameters determine the type of data input, the passage followed through the simulation subroutines and the nature of the output. The following alternatives are available:-

M1	= 1	Raw raingauge data to be input
M1	= 0	Storm hyetograph to be input
M2	= 1	Contributions from original gully liquors wanted
M3	= 1	Observed flow data to be input
M4	= 1	Observed gully pollutant concentrations to be input
M5	= 1	Graphical output

In addition it is necessary to input the desired output device number (IWRI) either a terminal or line printer and the constant proportional loss (CPL) coefficient. The latter is normally set to 1.0 for an initial run with a data set. For subsequent runs the predicted and observed discharges can be equated to determine the CPL coefficient and, therefore, 'force' the predicted discharge. Provision is also made for the input of observed flow data and observed gully pollutant concentrations, when these are available, for the calculation of relevant statistics and graph plotting.

5.3.2 Output

Output may be obtained in two forms, A4 tabulated data and graph plots. Specifically these are as follows:-

a) Tabulation of calculated data:-

Time (Hours)
Rainfall Intensity (mm/hour)
Flow at outfall (l/s)
M2 = 1 Gully liquor contribution to flow at outfall (l/s)
M4 = 1 Gully pollutant concentration at outfall (mg/l)

It is a simple task to adjust the programme in order that the parameters may be output for other points in the system.

b) Tabulation of observed data:-

M3 = 1 Observed times
M3 = 1 Observed flows
M4 = 1 Observed gully pollutant concentrations

c) Graphical output (M5 = 1). Up to three plots are available in any execution:-

1. Predicted runoff, Observed runoff, Hyetograph
1a. Predicted runoff, hyetograph
2. Predicted runoff, predicted gully liquor contribution, hyetograph
3. Predicted runoff, predicted pollutant concentration, observed pollutant concentration

d) Tabulation of storm statistics. A variety of statistics are available for output again, dependent upon the programme control parameters:-

1) Storm duration (hours)
2) Total rainfall (mm)
3) Total rainfall volume on impervious area (litres)
4) Depression storage loss (litres)
5) Other losses, e.g. infiltration (litres)
6) Average intensity (mm/hour)

7) Average intensity for the most intense ten minutes (mm/hour)
8) Total predicted discharge (litres)
M3 = 1 (9) Total observed discharge (litres)
(10) Percentage runoff from impervious areas
(11) Total original gully liquor discharge (litres)
(12) Percentage gully liquor contribution to total runoff (litres)
(13) First flush time (hours)
M2 = 1 (14) First flush volume (litres)
(15) Percentage gully liquor contribution to the first flush
(16) Percentage original gully liquor discharged to the total original gully liquor volume
(17) Total predicted pollutant mass (g)
M4 = 1 (18) Total observed pollutant mass (g)

5.3.3 Application of the Model. Results and Conclusions.

The accurate calibration of the model was restricted by two factors, firstly the limitations of the model itself and secondly the small size and the limitations of the available data set. The limitations of the model have been discussed previously and could be minimised with calibration from a good set of data. The principal problems of calibration and therefore verification of the model's performance arise from restrictions imposed by the accuracy and reliability of the observed data. These in turn may be primarily ascribed to the use of lithium dilution for the determination of flow. Firstly, sampling and hence flow determination commenced only when discharge exceeded about 8 l/s. Many of the storms monitored were of low rainfall intensity and for the small Clifton Grove catchment resulted in long periods when discharge at the outfall was less than 8 l/s. As a consequence of this, for long periods of some storms no samples were collected and, therefore, no flow data was available, e.g. Storm 21 (Figure 56). Therefore, the total observed discharge could not be determined accurately and 'forcing' the predicted hydrograph by equating the observed and predicted total discharges to determine the CPL coefficient was impractical. The alternative approach that was adopted for the majority of storms lay in forcing the peak heights of the predicted hydrograph to be of the same magnitude as the observed hydrograph.

Figure 56

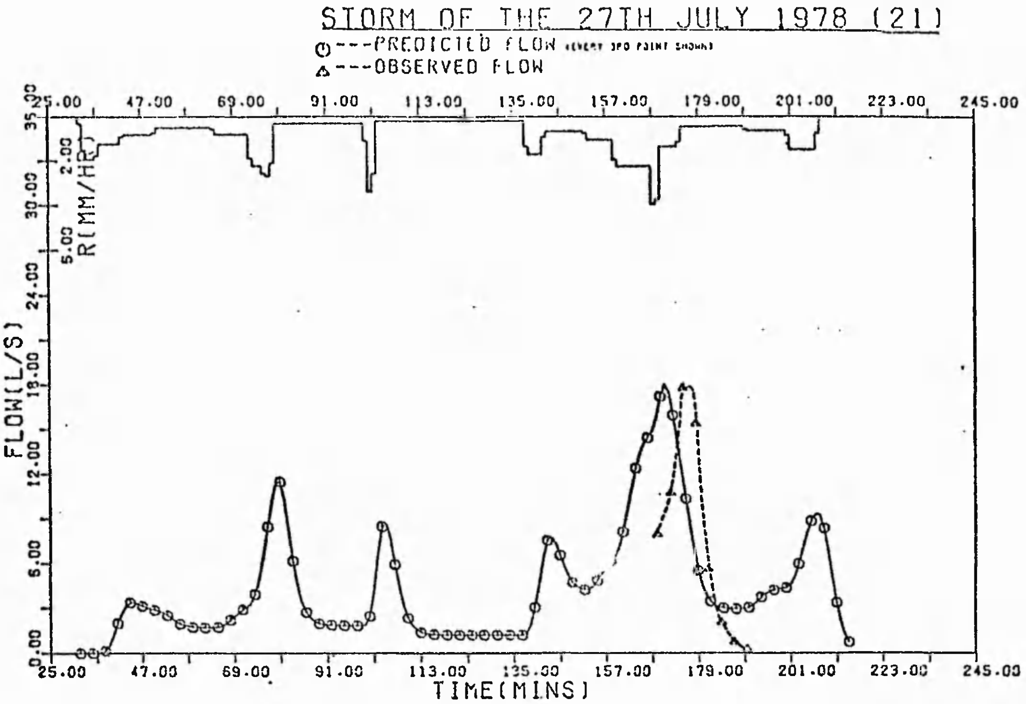


Figure 57

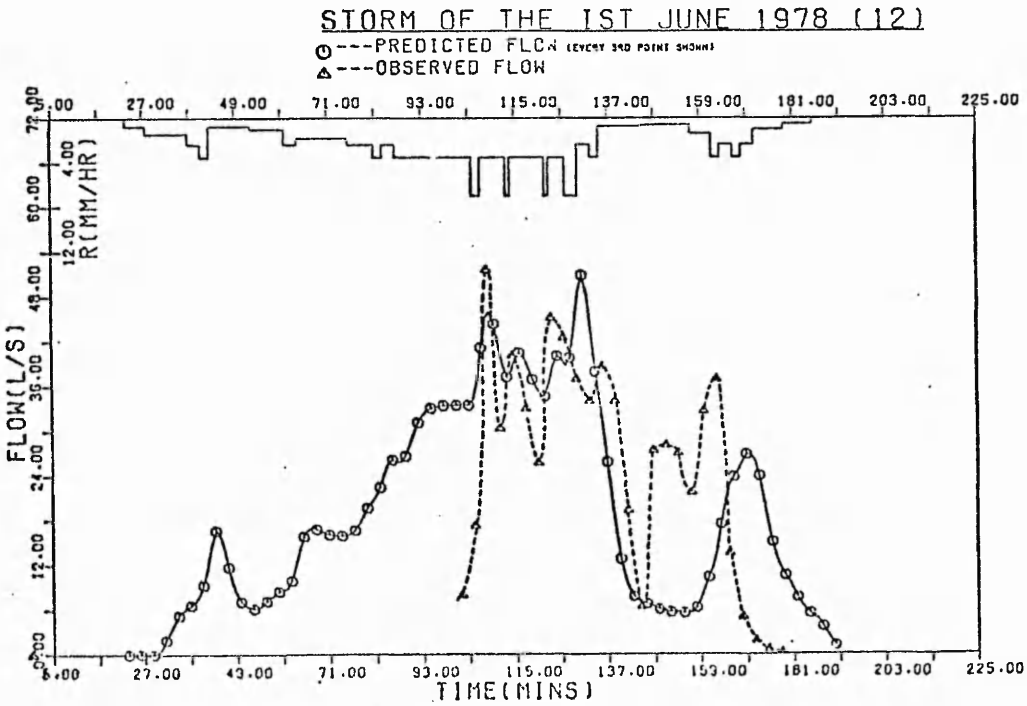


Figure 58

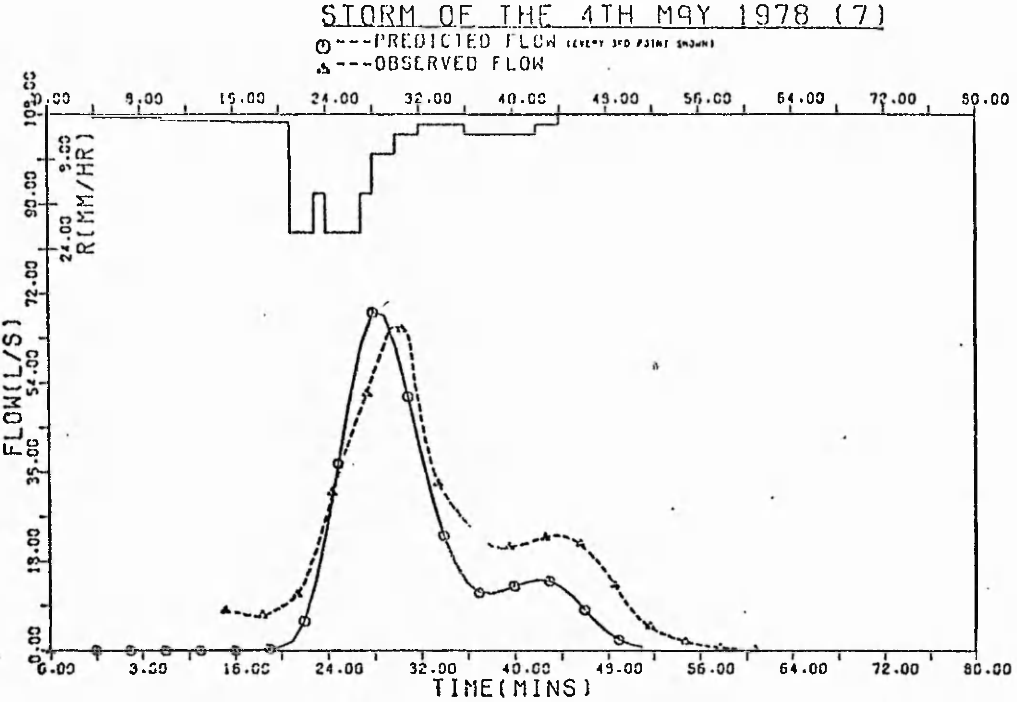
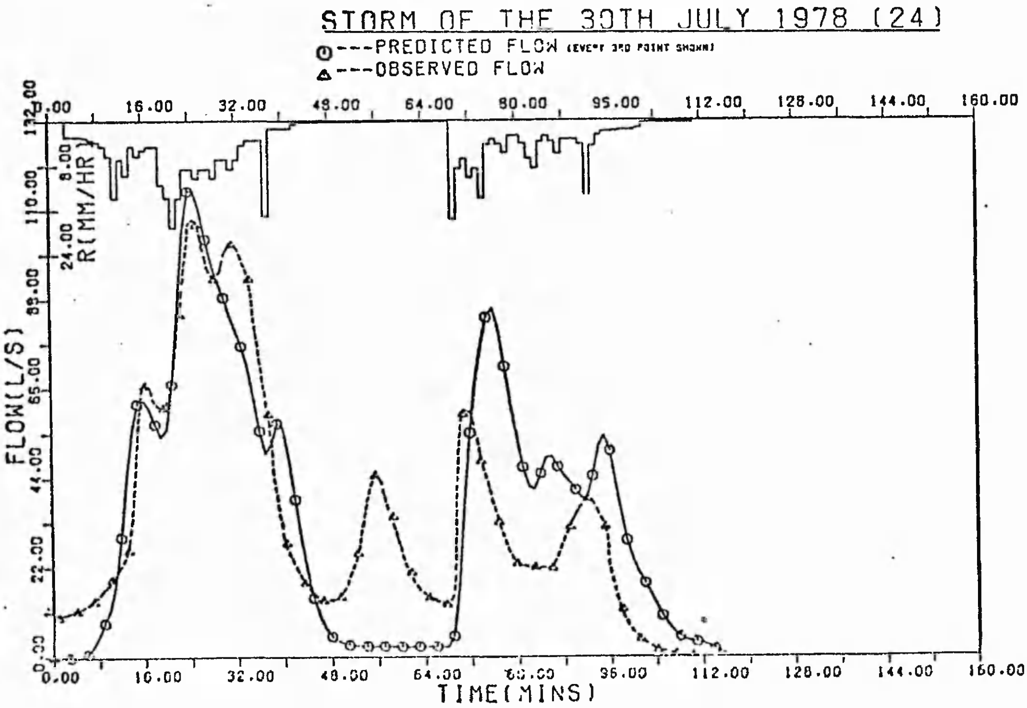


Figure 59



Although it has been assumed above that the first sample was collected at a flow rate of about 8 l/s this may not have always been the case. Prevention of triggering, either by obstructing objects such as twigs washed down the sewer, or just unreliable action of the float switch was observed to result in portions of some large storms being missed, e.g. Storms 12 (Figure 57) and 17. Again this rendered the discharge based calculation of the CPL coefficient impractical.

The reliable use of smaller storm events for evaluating the model was restricted by two other factors in addition to those outlined above. Firstly sampling was conducted over a minimum time period of 2 minutes, therefore, observed flow rates represent an average value over the sampling time period. This results in a lack of resolution in the observed hydrograph. A second restriction for small events, where only 3 or 4 samples were collected, was the length of time required for dosing to reach equilibrium. Due to these two restrictions observed flow rates for small events of 10 to 15 minutes duration may only be considered as approximate.

Another problem with flow determination was the occurrence of spuriously low lithium concentrations for the occasional sample in an otherwise reliable set of data. This is probably attributable to fluctuations in the lithium dose rate and may be due to temporary partial blocking of the dosing orifice by small dust particles. When this occurred an estimated flow value was obtained by interpolation from adjacent flow values and consideration of the shape of the predicted hydrograph.

The timing of raingauge tilts and the commencement of sampling was achieved through the use of two separate clocks. Although these were both set to standard time when the instrumentation was prepared in readiness for a storm event, timing may not have been exactly synchronous when batteries started to run down. For some storms one clock or the other did not function and when this occurred observed and predicted peak flow rates were arranged to occur at the same time, e.g. Storms 7 (Figure 58) and 24.

When observed flow values for storm events where rainfall had been recorded were either absent or poor (Storms 6, 9, 10 and 11) then the predicted hydrograph was used as an estimation of flow for the purpose of calculating pollutant loadings, the first flush and gully liquor contributions. In this situation the CPL coefficient was estimated from knowing the number of samples taken and assuming that sampling commenced at 8 l/s. The coefficient being determined by the reduction of the predicted hydrograph necessary to be consistent with the number of samples collected.

As a result of the limitations of the data outlined above no monitored storm was accurate in all facets to enable a reliable calibration of the model to be conducted. How the model was applied and the restrictions applicable to each storm are listed in Table 23. The lithium dilution method of flow determination is concluded as being unreliable and not of sufficent accuracy for model calibration on the Clifton Grove catchment. Accurate calibration will be possible when some alternative continuous flow measurement system is installed. Since it was impractical to perform a statistical error analysis on the performance of the model, conclusions can only be of a general nature and are presented after due consideration of the limitations applicable to each storm event.

Firstly, the overall shape of the predicted hydrographs would appear to be in broad agreement with that observed. This is more evident for the longer storms of greater intensity, e.g. Storms 7 and 24 (Figures 58 and 59) where a larger number of observed flow values were available. When the timing of rainfall and runoff was considered to be synchronous, then the time to peak flow for predicted and observed hydrographs was in reasonable agreement, e.g. Storms 9 (Figure 60), 10, 11 and 21 (Figure 56). However, for other events there was some tendency for the predicted peak to occur prior to the observed peak, as in Storms 19 and 20 (Figure 61. It is possible that the effect can be ascribed to the non-optimization of the roof storage routing constants. α values assigned are possibly too low and result in a rapid runoff response from roofs. The early contribution from roofed areas to runoff at the outfall would logically be expected but is possibly not as rapid as the model currently predicts. For low intensity storms the initial periods of runoff, up to 30 minutes, can be attributed solely to roof runoff, e.g. Storm 15. For Storm 11 (Figure 62), which consisted of a total rainfall of only 0.234 mm, the predicted hydrograph was comprised only of roof runoff. Few conclusions can be made on the effectiveness of the model in determining peak flow rate since this parameter was most frequently used to determine the CPL coefficient and optimise the predicted hydrograph. However, for situations where no adjustment of the CPL coefficient was necessary, i.e. CPL = 1.0,

TABLE 23 Data availability, application and limitations.

Storm	Quality Data	Flow Data	Rainfall Data	Model used to Predict Flow	Flow Data Questionable	Timing Inconsistent or Missing	Model Application	Peak height 'forced'	Peak times 'forced'	Gully Liquor Discharge Predicted	Gully Liquor Pollutant loads predicted	Gully Liquor Pollutant loads estim.	
1	*	/	/	/	/	/	/	/	/	/	/	/	
2	*	/	/	/	/	/	/	/	/	/	/	/	
3	*	*	/	/	/	/	/	/	/	/	/	/	
4	*	*	/	/	/	/	/	/	/	/	/	/	
5	*	*	/	/	/	/	/	/	/	/	/	/	
6	*	/	*	*	/	*	*	*	*	*	*	/	
7	*	*	*	/	/	*	*	*	*	*	*	/	
8	*	*	/	/	/	/	/	/	/	/	/	/	
9	*	/	*	*	/	/	*	*	/	*	*	/	
10	*	/	*	*	/	/	*	*	/	*	*	/	
11	*	/	*	*	/	/	*	/	/	/	/	/	
12	*	*	*	/	*	*	*	/	*	*	*	/	
13	*	*	/	/	/	/	/	/	/	/	/	*	
14	/	/	*	/	/	/	*	/	/	/	/	/	
15	*	*	*	/	/	*	*	/	*	*	*	/	
16	*	*	*	/	*	*	*	/	*	*	/	/	
17	*	*	*	/	/	*	*	*	*	*	/	/	
18	*	*	/	/	/	/	/	/	/	/	/	*	
19	*	*	*	/	/	/	*	*	/	*	*	/	
20	*	*	*	/	/	/	*	/	/	*	*	/	
21	*	*	*	/	/	/	*	*	/	*	/	/	
22	*	*	/	/	/	/	/	/	/	/	/	/	
23	*	*	*	/	/	/	*	/	/	*	/	/	
24	*	*	*	/	/	*	*	/	/	*	*	/	

Figure 60

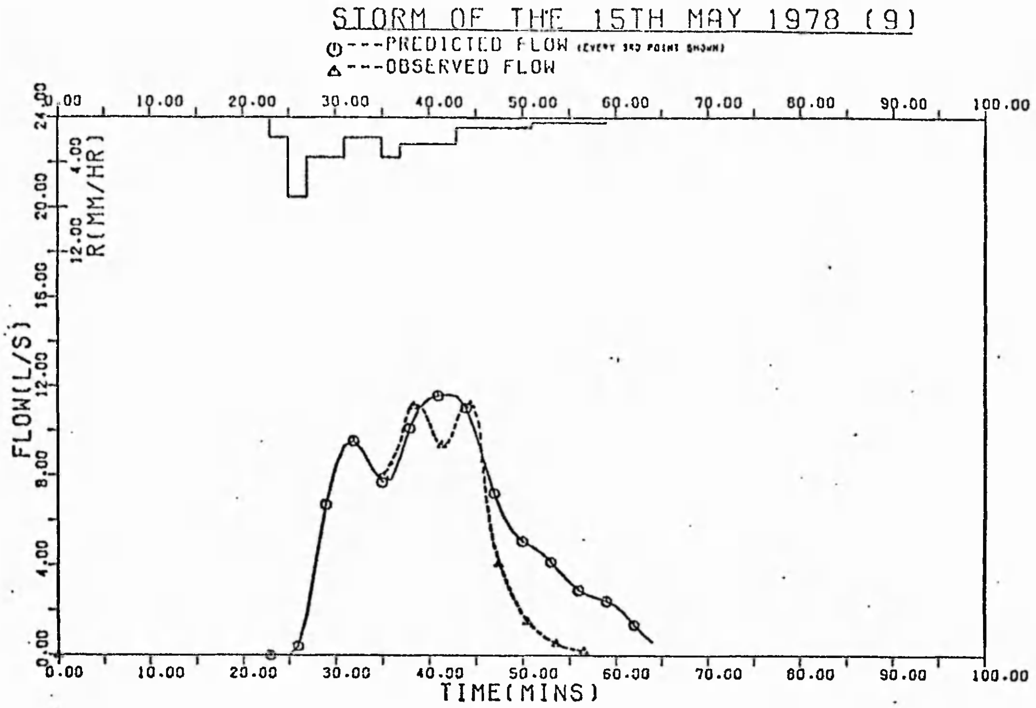


Figure 61

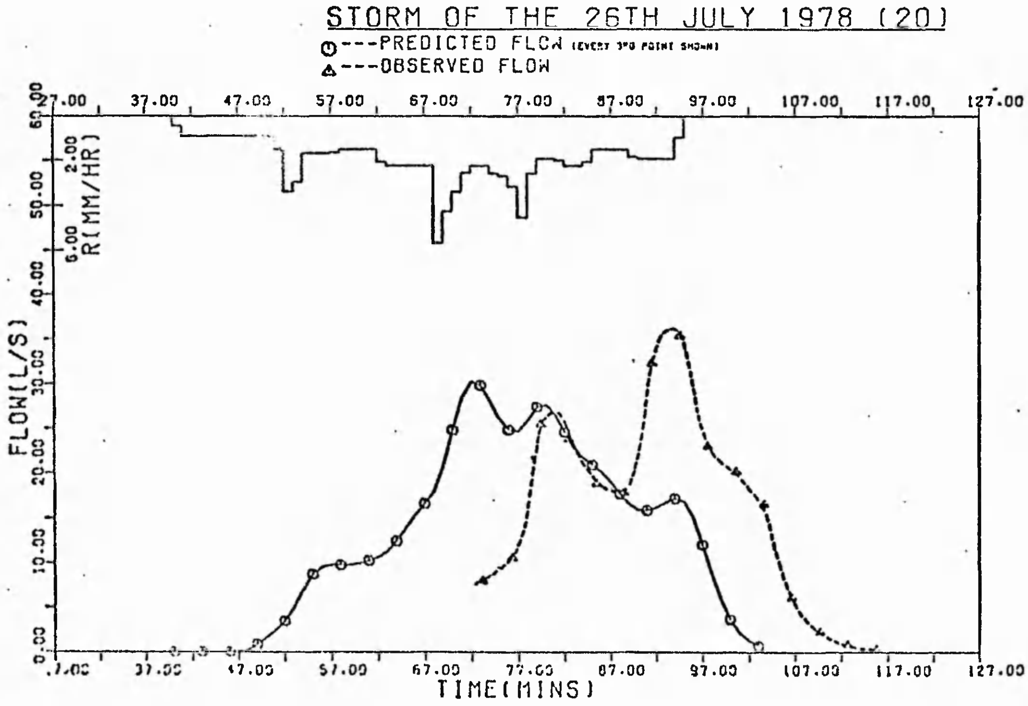


Figure 62

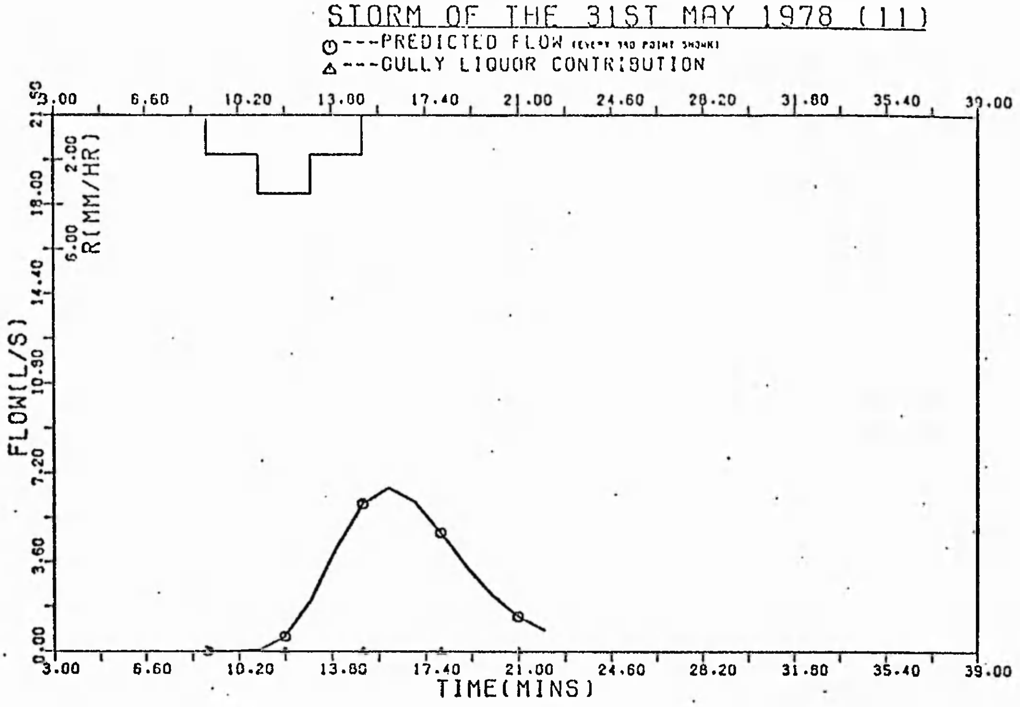


Figure 63

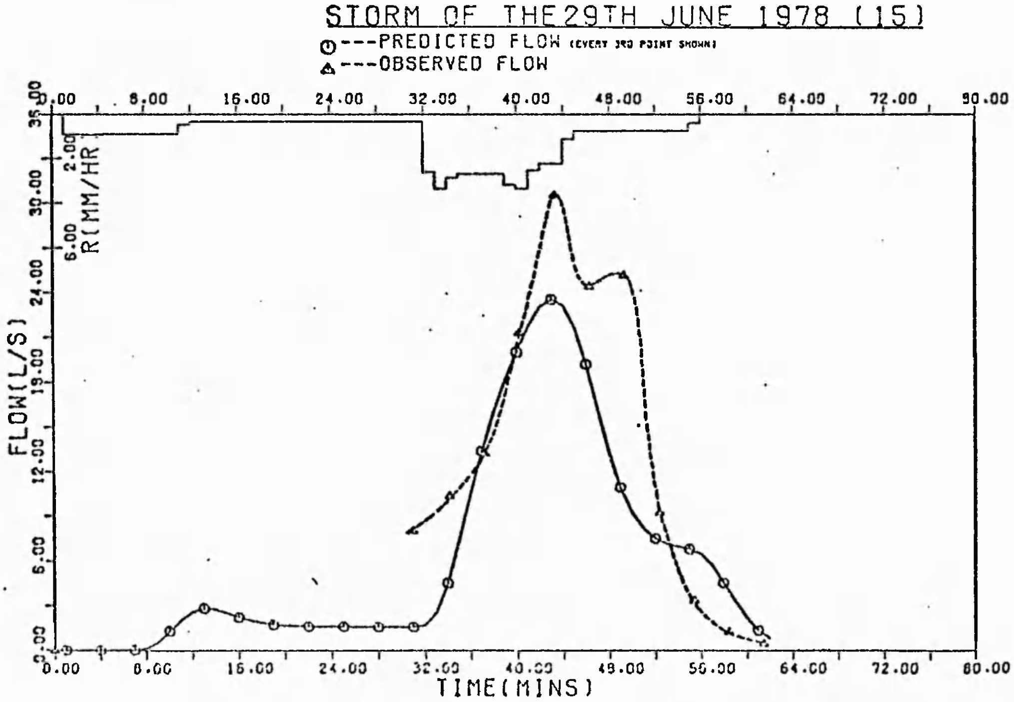


Figure 64

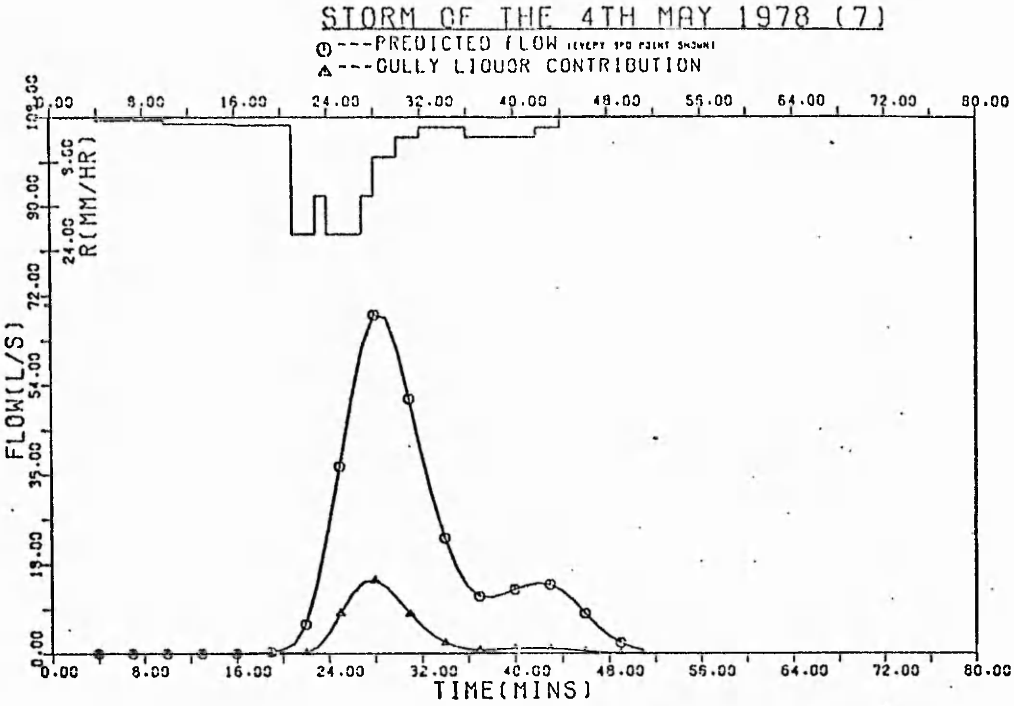


Figure 65

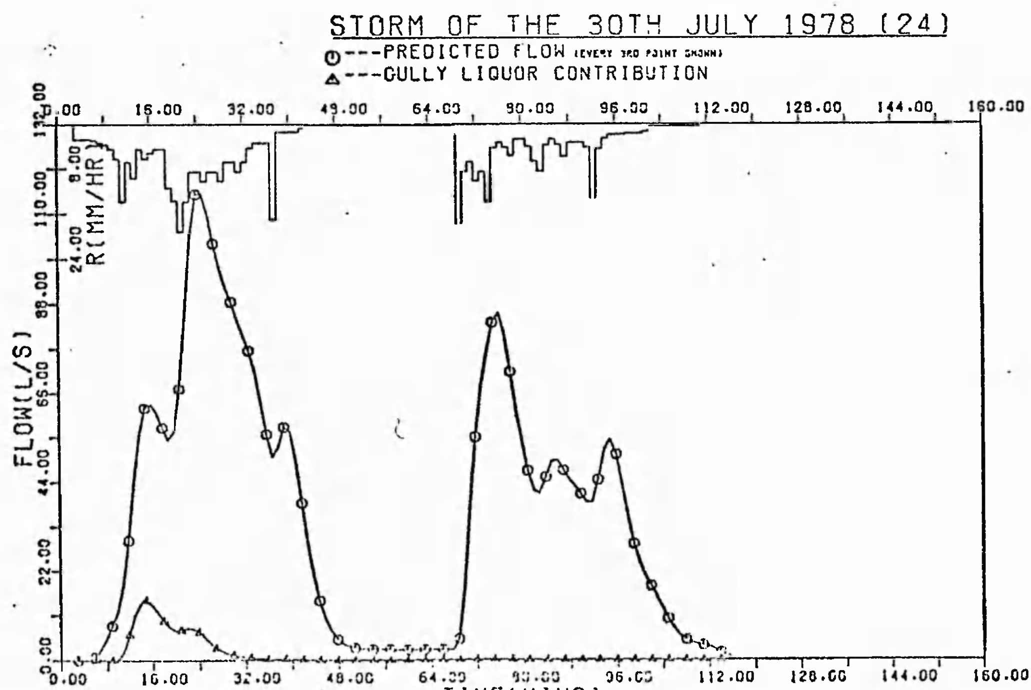
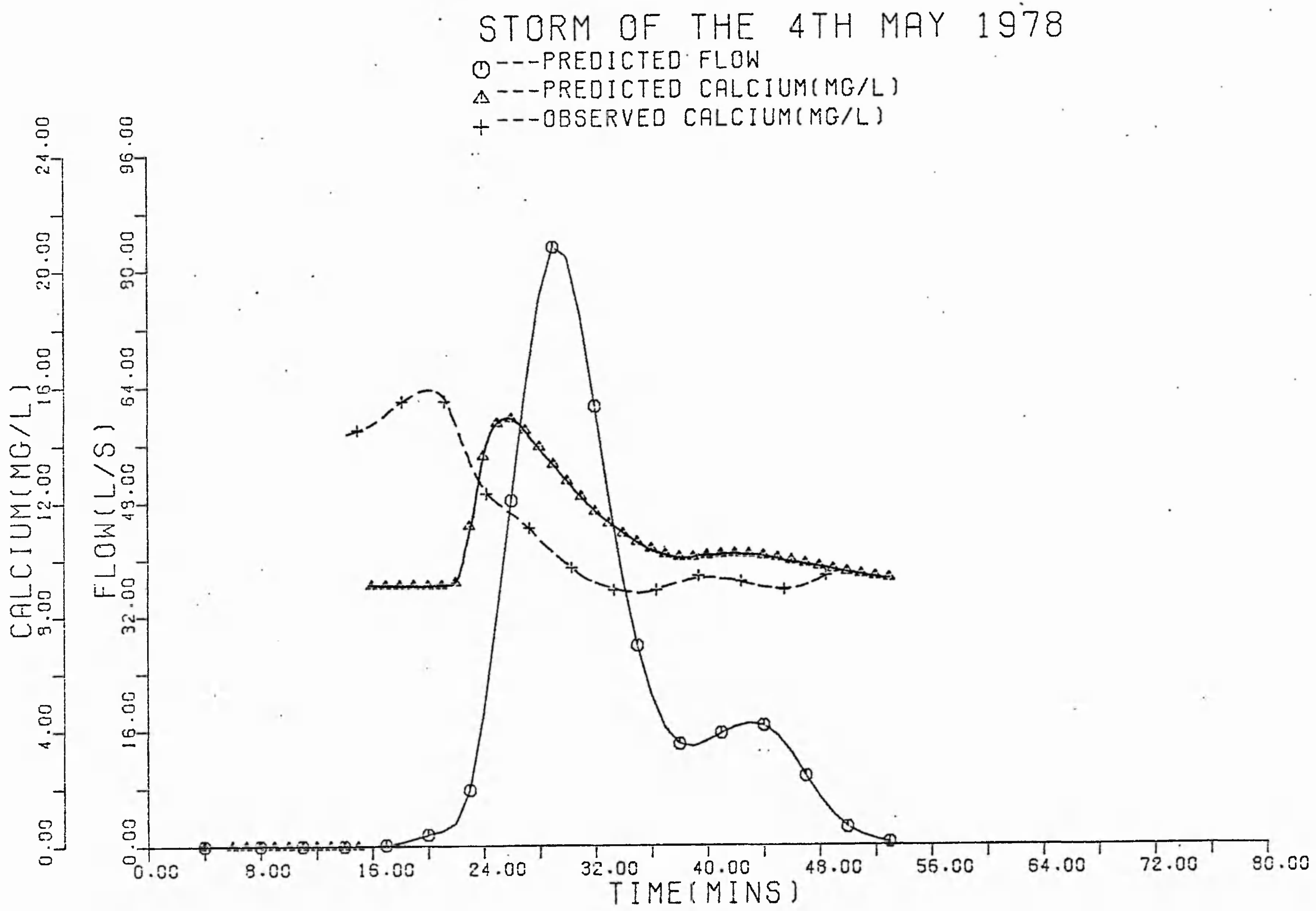


Figure 66


STORM OF THE 4TH MAY 1978
---PREDICTED FLOW
---PREDICTED CALCIUM(MG/L)
---OBSERVED CALCIUM(MG/L)
CALCIUM(MG/L)
0.00
4.00
8.00
12.00
16.00
20.00
24.00
FLOW(L/S)
0.00
16.00
32.00
48.00
64.00
80.00
96.00
TIME(MINS)
0.00
8.00
16.00
24.00
32.00
40.00
48.00
56.00
64.00
72.00
80.00

then for a multipeaked storm a fair agreement was obtained, e.g. Storm 24 (Figure 59). Adjustment of the CPL coefficient to a value greater than one was not found to be necessary, only Storm 15 (Figure 63) showed predicted peak runoff to be significantly lower than the observed peak runoff for a CPL coefficient of 1.0.

The verification of the gully liquor contribution model requires that each gully pot on the catchment is dosed with a similar concentration of some tracer and the concentration of that tracer is subsequently determined in storm runoff at the outfall. It is also important that the tracer used should not be available from any other source in the catchment. When the unreliability of sampling and storm flow determination are considered along with the practical difficulties associated with a task of this size the above approach can be discounted. However, gully pot liquors were considered for a naturally occurring parameter that could be used in a similar fashion. Calcium and ammonium were both observed to have high values over dry periods when gully pot liquors are likely to be the prime source of the parameter. However, for the period of study mean values of any parameters from five gully pot samples were never sufficiently high in respect to other possible sources to be used in this manner. Some limited results for calcium in Storm 7 were obtained and are presented in Figure 66, they indicate a reasonable agreement.

A full interpretation of the use of the model for predicting gully liquor pollutant concentrations at the outfall and defining the first flush is covered in Chapter 6. Figures 64 and 65 illustrate the gully liquor contributions to a runoff hydrograph for Storms 7 and 24.

In the light of the limitations of the currently available data set and bearing in mind the objectives of this research, then the following general conclusions may be drawn. Firstly, although verification can only be considered as tentative until reliable data is available the model would appear to give a good estimation of the storm runoff hydrograph and, as such, provides a useful tool for further catchment research. Future research aimed at optimizing the roof storage routing coefficients should improve the model's performance. The gully liquor contribution model, although not verified for the whole catchment, is based on simple mathematics and the laboratory results indicate that the model should provide a reliable estimation of original gully liquor contributions at the outfall. The removal of these liquors can be used as a quantitative assessment of the duration of the first flush and for the purpose of this research it has been used to estimate the mass of pollutants derived from original gully liquors and, therefore, their significance in determining the overall quality of storm water runoff.

6. RESULTS

6.1. THE QUALITY OF WATER STORED IN ROADSIDE GULLY POTS.

The quality of water stored in roadside gully pots was examined in three ways:-

a) Weekly and subsequently fortnightly sampling of four gully pots with differing catchment characteristics, (see Section 1.3.3), for a period of one year, to assess the magnitude of temporal and seasonal fluctuations of pollutant concentrations and the impact of sources of pollution on stored water quality.

b) Sampling on one day of up to 25 gully pots to assess the variability of water quality between pots, and to test the significance of small sets of samples in representing the mean quality of water stored in the drainage system.

c) Other miscellaneous samples collected prior to rainfall events and over dry periods.

The mean and maximum results for all samples are shown in Table 24. The results are broadly comparable to those obtained for a similar catchment at Stevenage, U.K. (Water Research Centre, 1977, Table 15). Figure 67 illustrates the frequency distributions of the parameters where sufficient sample numbers were available. The majority of the distributions are leptokurtic and exhibit a strong positive skew. Whilst most pollutant concentrations were at low and reasonably steady values, occasional extreme values, which were attributed to the occurrence of a polluting event, resulted in this skewness. It is important to note that due to the skewness of the distributions, the arithmetic mean, as indicated on the diagrams, is no longer a strict representation of the central tendency of the distribution and is invariably greater than the modal value. Similarly, the standard deviation alone is not an adequate measurement of the variance of the distributions due to the occurrence of extreme values. This is indicated by the interquartile ranges (see results Appendix 2) which can be as low as one-fifth of the total range.

6.1.1 Temporal and Seasonal Variations

All of the results for the weekly/fortnightly analysis of the four gully pots are tabulated in Appendix 2.1. The annual mean values have been summarized in Table 25. Temporal variation is illustrated graphically for

TABLE 24 Mean quality of water stored in roadside gully pots: summary of all results (concentration in mg/l)

Constituent	Number of Samples	Mean	Max.
Suspended solids	243	31.2	455
Dissolved solids	261	335	17,475
COD	176	63	935
BOD	195	7.6	135
Dissolved oxygen	63	6.0	0 - 11.2
Ammoniacal nitrogen	266	1.0	8.9
Nitrate nitrogen	263	2.0	29.8
Chloride	220	268	9800
pH	201	8.0	6.3 - 12.9
Calcium	246	31	272
Sodium	221	125	5560
Potassium	221	3.8	28
Lead (total)	31	0.058	1.36
Lead (soluble)	11	0.032	0.10
Zinc (total)	74	0.65	3.5
Zinc (soluble)	29	0.10	0.56
Copper (total)	28	0.012	0.32
Copper (soluble)	7	0.05	0.09
Cadmium	26	0.058	0.07
Manganese	19	0.21	0.74
Nickel	19	0.07	0.42
Iron	19	1.08	7.00
Chromium	19	0.05	0.48

TABLE 25 Annual mean concentrations of parameters for individual gully pots (in mg/l)

Constituent	GP 1	GP 6	GP 7	GP 8
Suspended solids	15	27	29	15
Dissolved solids	197	343	231	818
COD	24.5	56.2	36.5	30.3
BOD	7.1	7.1	6.5	6.5
Ammonium	1.2	0.8	1.1	0.8
Nitrate	4.2	12.4	6.6	7.9
Dissolved oxygen	3.6	8.5	6.2	6.0
pH	7.5	10.5	7.5	7.9
Calcium	23	49	21	30
Sodium	28	9.7	34	232
Potassium	2.0	4.8	1.8	3.0
Chloride	44.7	26.4	71.9	426

Fig. 67 - Frequency distributions for the concentration of pollutants in gully pot liquors.

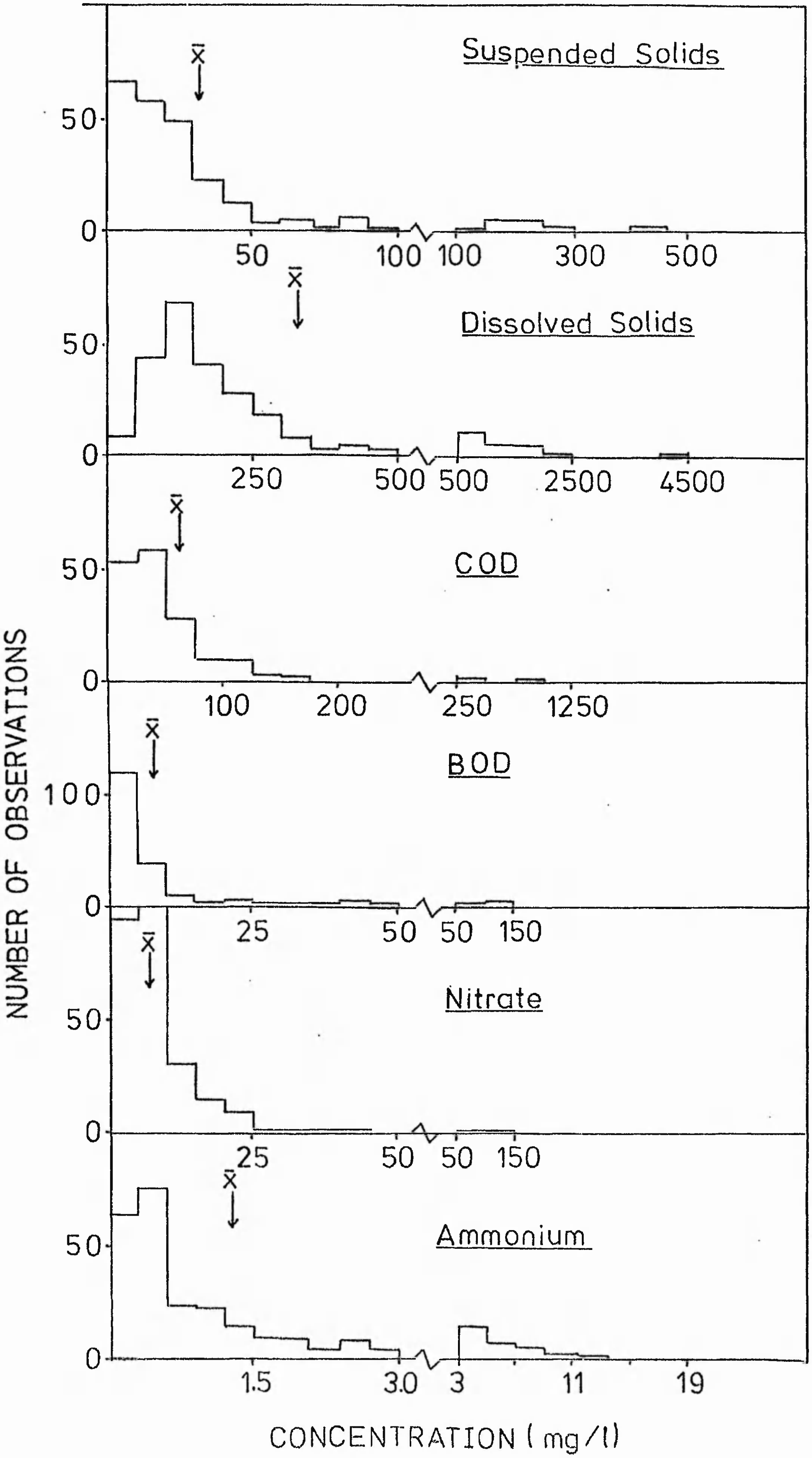
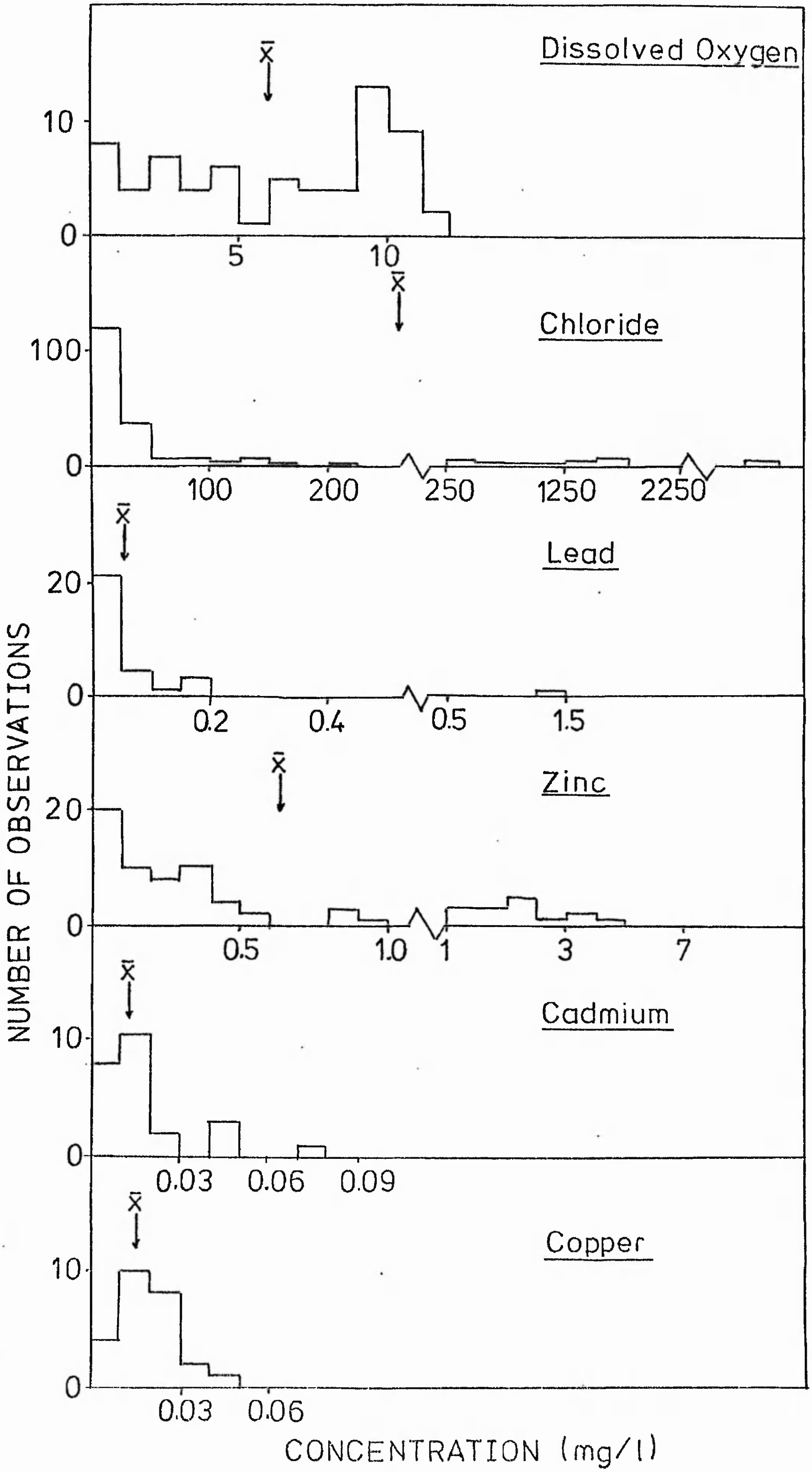


Fig. 67 (b) continued



some of the parameters in Figures 68 to 78, either as weekly mean values or values for individual gully pots.

A degree of temporal variation is exhibited in all of the results, but, changes in concentration may not be simply ascribed to seasonal fluctuations but are a result of numerous interactions, some of which are seasonally dependent.

Of all the parameters investigated ammonium concentrations behaved in the most predictable fashion (Figure 68). It retained consistently low values during the winter months and high values were closely associated with summer dry periods. Weeks 1, 2, 36, 42 and 46 all show peaks in ammonium concentrations and are all coincident with periods of dry weather in excess of 5 days. Figure 69 illustrates ammonium concentrations for gully pots 1, 6 and 7, the similarity in profile shown by these 3 pots indicated that the generation of ammonium is reasonably consistent across the catchment and has little dependency upon subcatchment differences. Mechanisms for the formation of ammonium over dry periods are discussed further in Section 6.1.3.

Nitrate concentrations were less consistent in their behaviour with peak values occurring in both winter and summer months, (Figure 70). Rainfall is an important source of nitrate and would be expected to result in complimentary increases for all gully pots indicating that pollution within the subcatchment was of more importance in defining the concentration. Possible sources of nitrate that could account for such differences include the application of garden fertilisers that was blown onto impervious surfaces and washed off during rainfall, or runoff of car wash liquors. There is some evidence in favour of the latter when the results for the summers of 1976 and 1977 are compared. During the summer of 1976 a long period of drought resulted in a public ban on car washing and Figure 70 shows that only low nitrate values were recorded. In the summer of 1977 nitrate values were high and variable, they showed no obvious relationship with either rainfall or dry periods, but may be explained by the regular input from some polluting activity within the gully pot subcatchment, i.e. car washing. Since sampling for the duration of the whole survey was always conducted on a Monday and car washing is a common activity on Sunday in urban areas, then it is hardly surprising that the concentrations recorded will show some dependency upon car wash liquor composition.

High nitrate concentrations resulting from the runoff of car wash liquors may be due to the following:-

Fig. 68 - Temporal variation of weekly mean ammonium concentrations (for key to week numbers see Appendix 2)

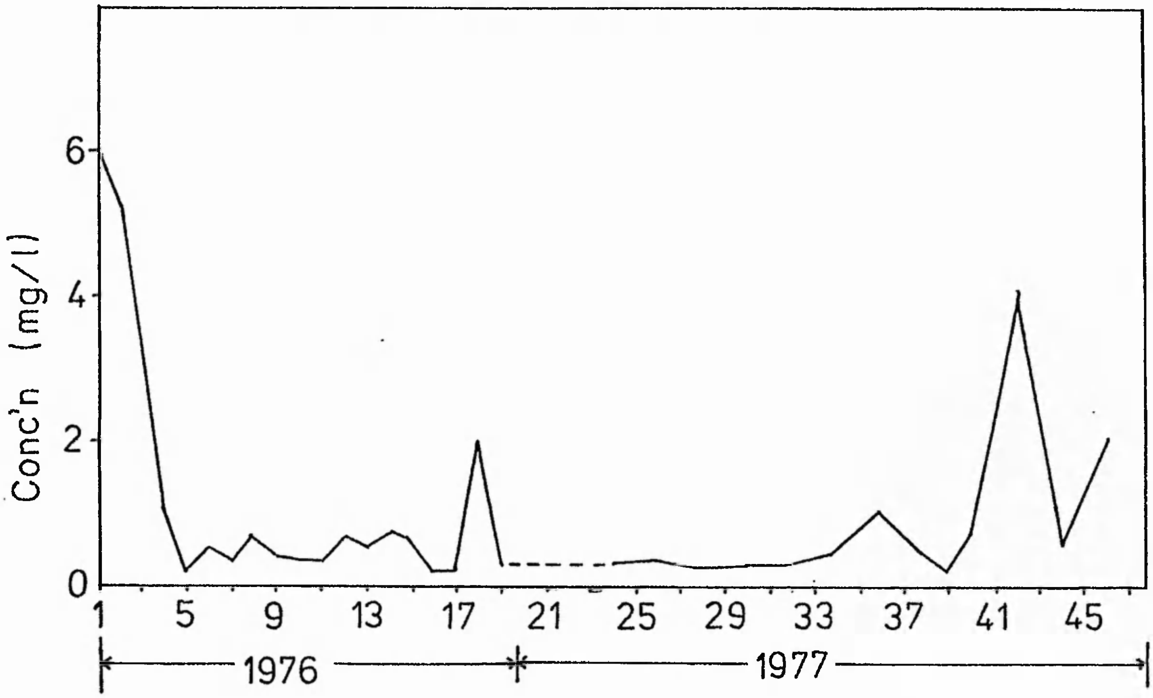


Fig. 69 - Temporal variation of ammonium concentration in gully pots 1, 6 and 7.

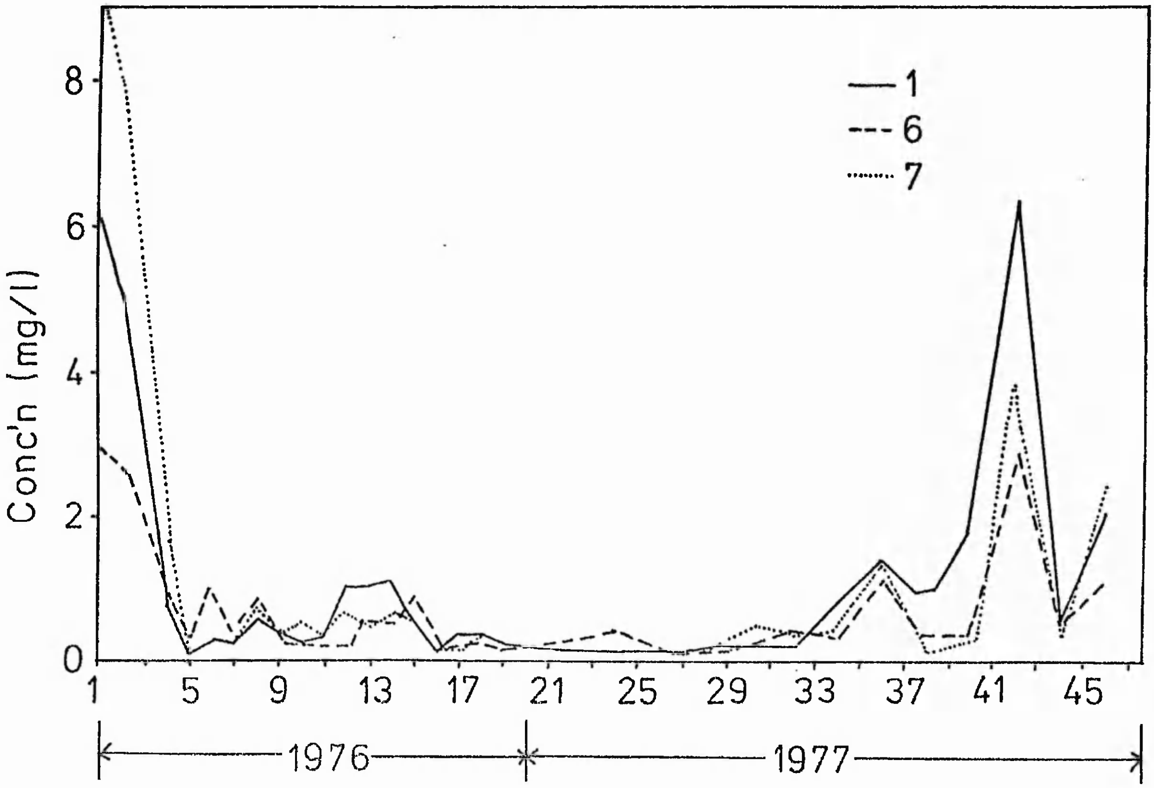


Fig. 70 - Temporal variation of nitrate concentration in gully pots 1, 6 and 8.

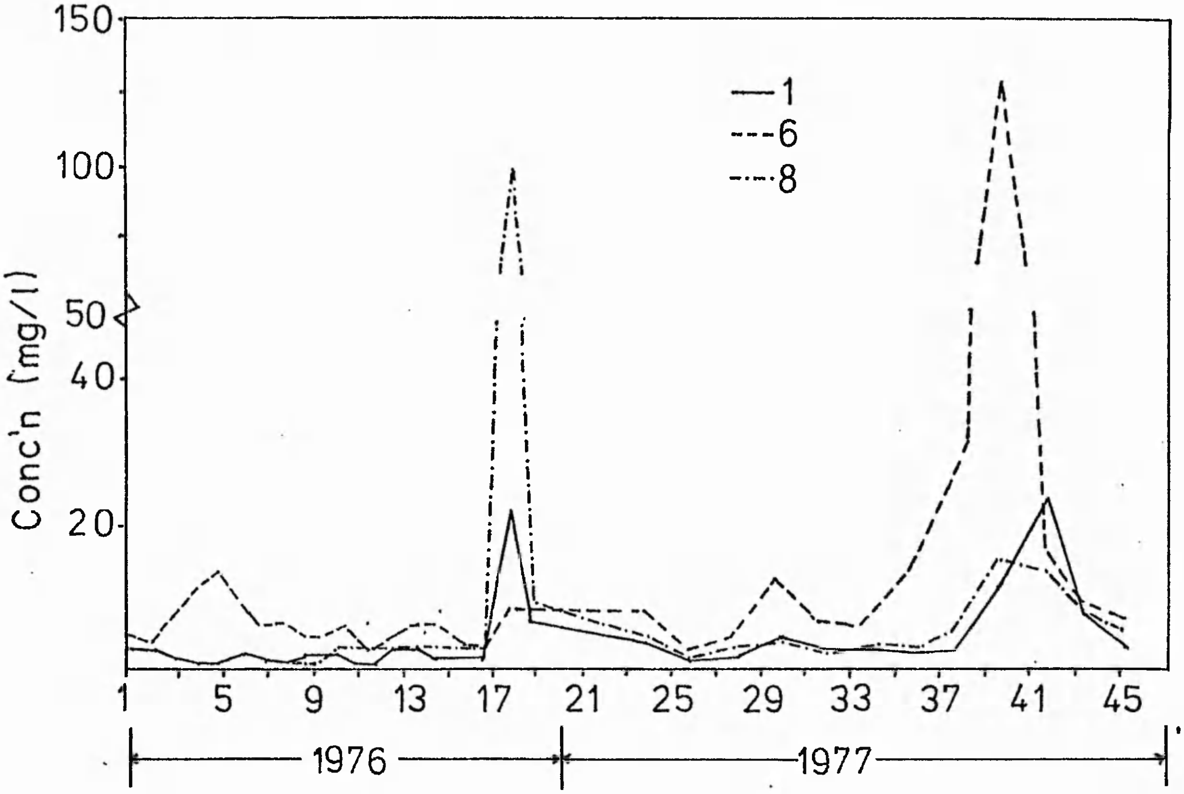


Fig. 71 - Temporal variation of weekly mean concentration of BOD and COD

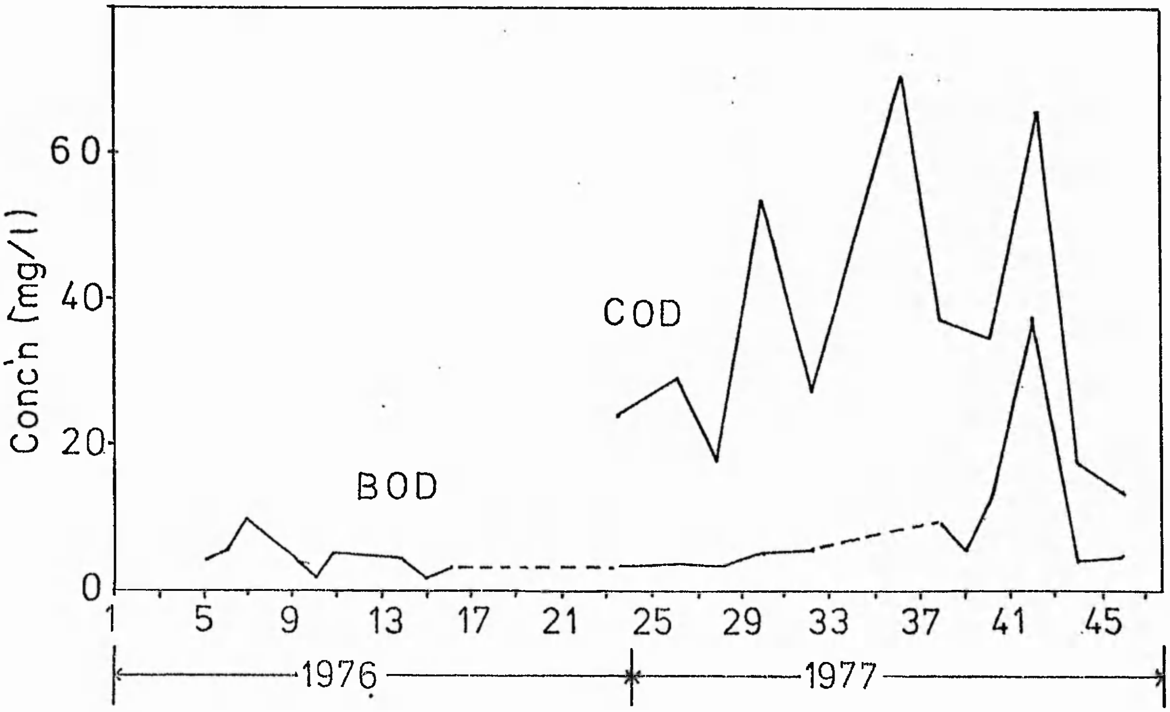


Fig. 72 - Maximum and minimum temperatures, antecedent dry period and total weekly rainfall for the duration of the study.

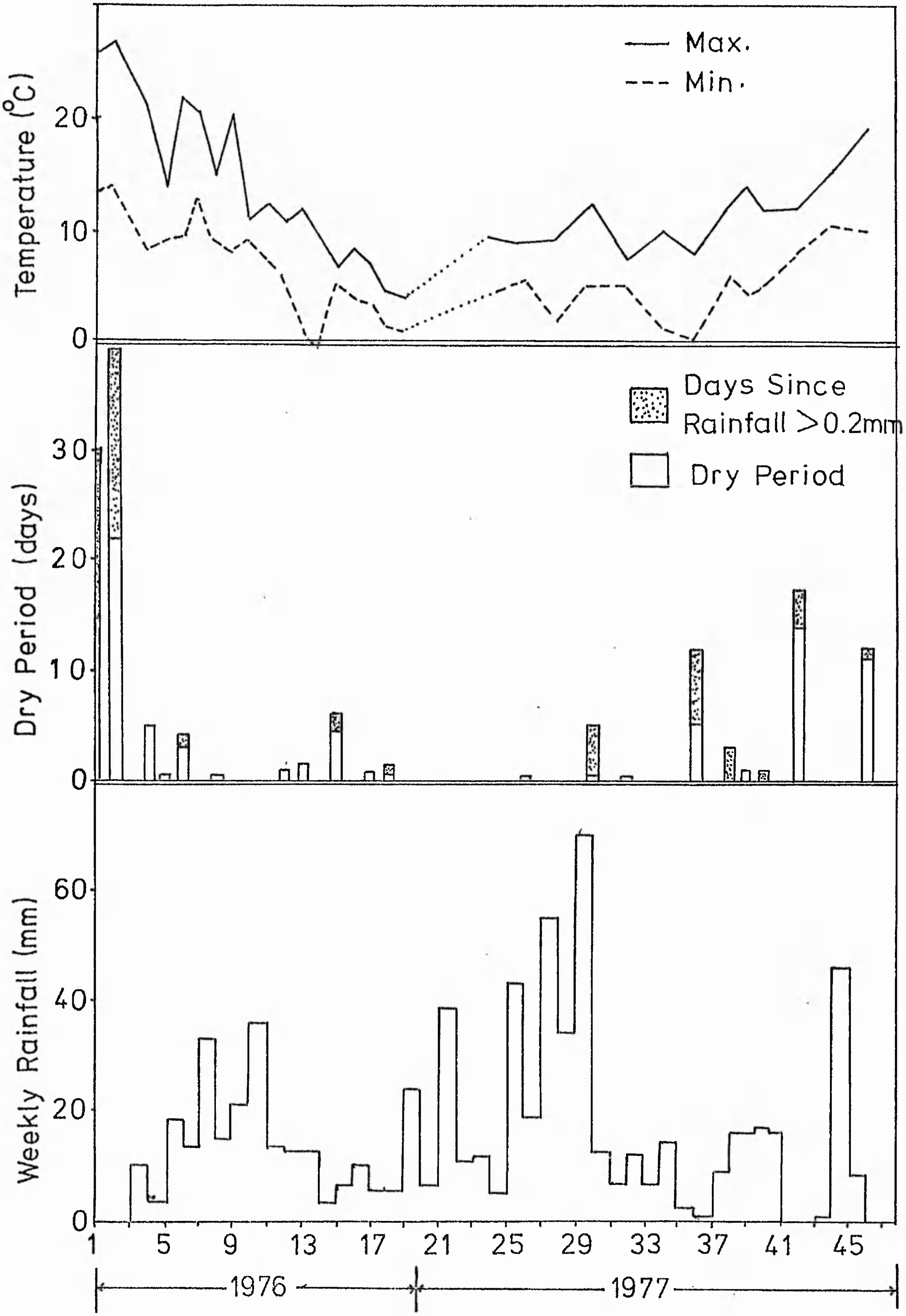


Fig. 73 - Temporal variation of BOD concentration in gully pots 1, 6 and 7.

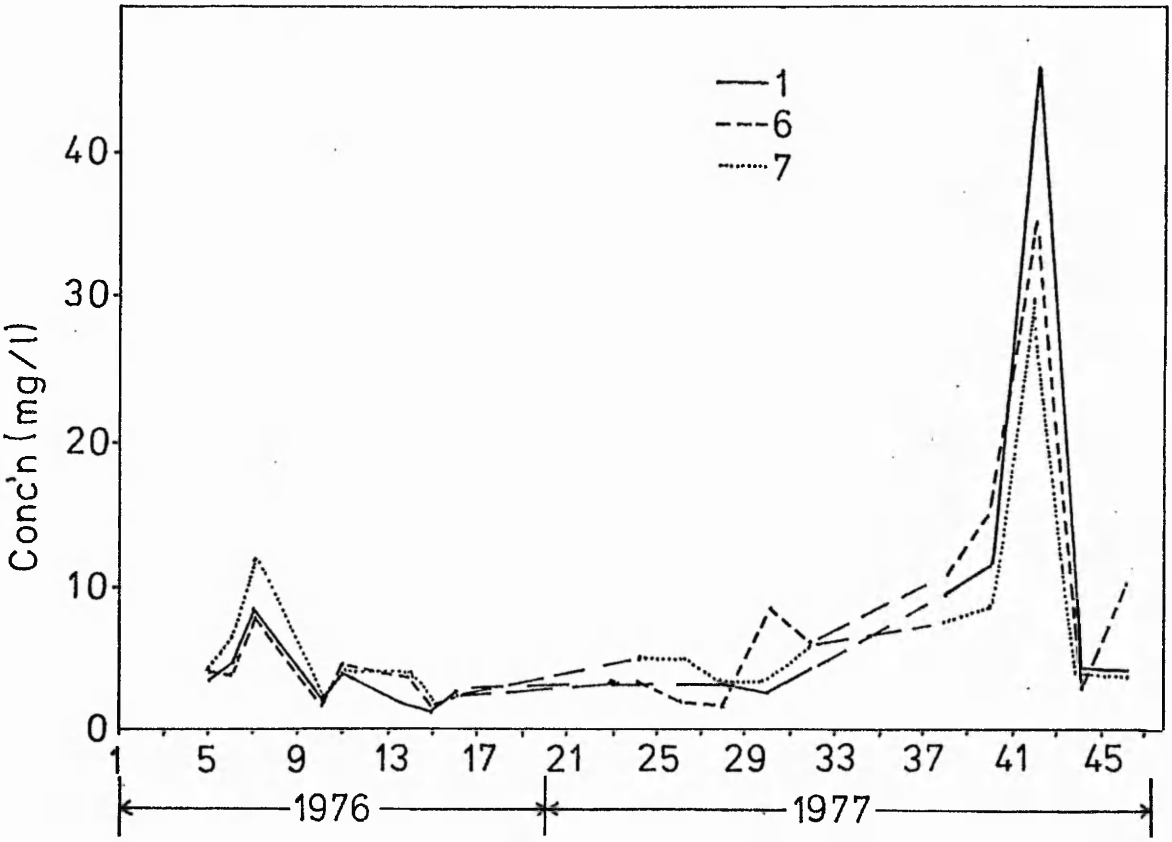
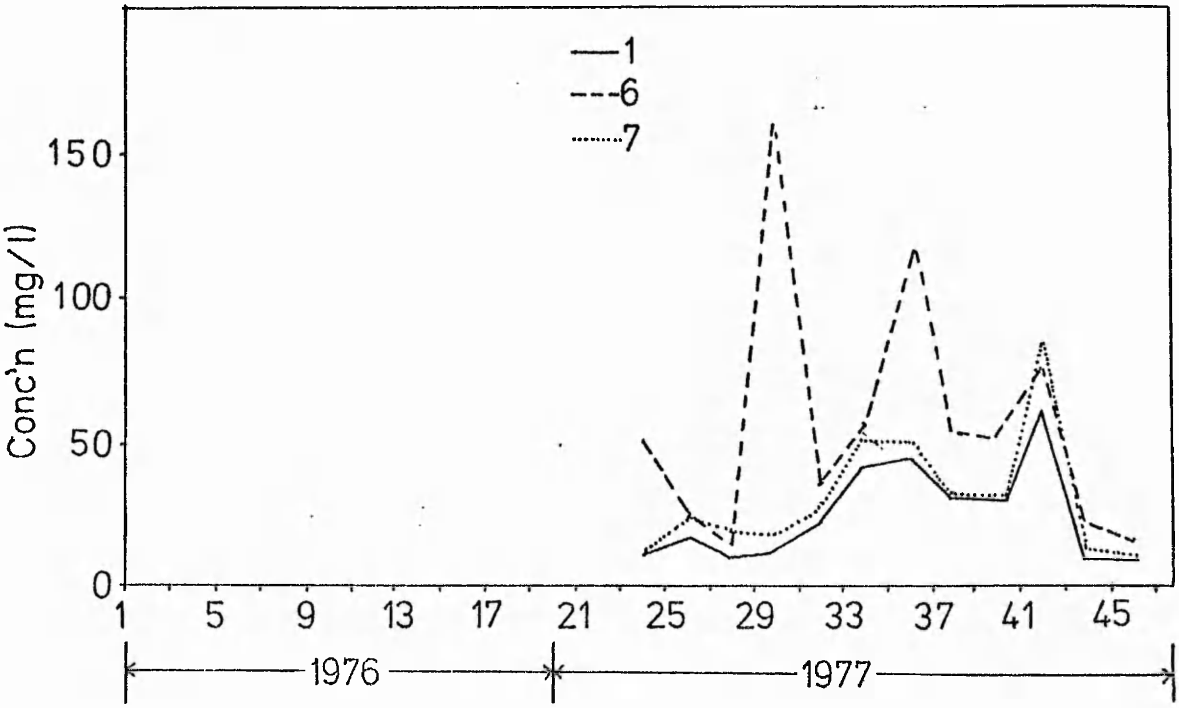


Fig. 74 - Temporal variation of COD concentration in gully pots 1, 6 and 7.



a) Nitrate present in the washing liquid used (see 6.1.3.1).

b) Higher nitrate levels in the local tap water. Typical concentrations in Clifton tap water of 8.0 to 9.6 mg/l (Severn-Trent Water Authority) are higher than the average nitrate concentrations recorded for gully pots 1, 7 and 8.

c) Ammonium present in the washing liquid used which, in the aerated liquor, undergoes nitrification to form nitrate. Analysis of a commercial washing up liquid and a commercial car wash preparation has shown them to contain 6.5 and 0.6 mg/g of ammonium. The use of such liquids can result in ammonium concentrations in the region of 0.5 to 10.0 mg/l in the car wash liquor. Laboratory experiments indicate that, under aerobic conditions, such concentrations can undergo nitrification with the production of nitrite and nitrate over a period of 24 to 28 hours. The actual impact that this may have upon concentrations in gully pots is unpredictable being dependent upon the amount of washing liquid used and the volume of runoff reaching the pot.

Other peak nitrate concentrations were recorded in the winter during periods of road salting, the input of nitrate is thought to be attributable to the impure rock salt employed. Nitrate rarely maintains a constant concentration in a body of water, but, under anaerobic conditions may undergo bacterial reduction to ammonium; this is one plausible explanation for increases in ammonium over dry periods (see Section 6.1.3). Other evidence in favour of this conversion mechanism was recorded for a sample collected in week 18 from gully pot 8. Although the low temperatures prevalent at this time of year will normally inhibit such processes, exceptionally high concentrations of nitrate associated with street salting resulted in a small peak in ammonium concentration that was not mirrored in the other gully pots.

The oxygen demand (COD and BOD) of the gully pot liquors showed a similar but slightly more variable pattern to that observed for ammonium (Figure 72). Peak BOD concentrations were related to dry periods and were reflected in all gully pots, e.g. week 42, Figure 73. Such increases may be explained by the anaerobic bacterial degradation of trapped, settled sediments and other matter, with the release of soluble organic compounds resulting in rises in both the BOD and COD of the supernatant water. In the winter months BOD values remained consistently low reflecting both the rarity of dry periods and the lack of bacterial degradation due to the low temperatures. COD also exhibited peak concentrations coincident with summer dry periods (Figure 74), but other peaks were also recorded which were probably attributable to the input of oxidizable, but not readily biodegradable compounds, from polluting activities within the subcatchment. Neither BOD nor COD showd any relationship with suspended solids concentration, further indicating that the bulk of the oxygen demand of the supernatant liquors was derived from soluble organic compounds created by degradation of bottom sediments or other organic compounds, such as oil, input from activity in the subcatchment. Maximum values of BOD and COD were both associated with the presence of large quantities of engine oil, presumably from the draining of car sumps - an activity, which though illegal, is still widely practised. Autumn leaf fall which has been reported as giving rise to a high oxygen demand through the accumulation and putrefaction of leaves in gully pots (Tucker, 1975), had no significant effect upon the quality of stored water in the Clifton Grove system. This can be explained by the fact that the catchment, only recently developed, has few deciduous trees of any size.

The concentration of dissolved solids in gully pot liquors mirror, in a general manner, the polluting events and seasonal changes already mentioned for specific parameters. Again the two events to have the greatest impact on dissolved solids concentrations were winter road salting and summer dry periods. Obviously, road salting was the cause of rapid and large increases in dissolved solids, as the applied salt melted ice and runoff occurred into gully pots. Values recorded in different gully pots during this period were highly variable, reflecting both the uneven application of the salt, but in particular, localized heavy application of salt by residents on drives and footpaths, which resulted in concentrations up to 17,000 mg/l. Road salting, not only resulted in increases in dissolved solids (Figure 75) chloride and sodium (Figure 76) but also caused increases in nitrate, potassium and calcium (Figure 77). These parallel increases were attributed to the impure rock salt employed. In the long dry period of the 1976 summer, coincident increases in dissolved solids concentration, up to 2000 mg/l, were recorded, but in the wetter summer of 1977 the increases, although remaining coincident with dry periods, were smaller and a maximum of 284 mg/l was recorded after 14 days dry weather. The increases that occur over dry periods are due to the following:-

a) Anaerobic degradation of organic matter to soluble compounds by bacterial action.

b) Input of soluble material from human activity, e.g. car washing.

Fig. 75 - Temporal variation of dissolved solids concentration in gully pots 1, 6 and 7.

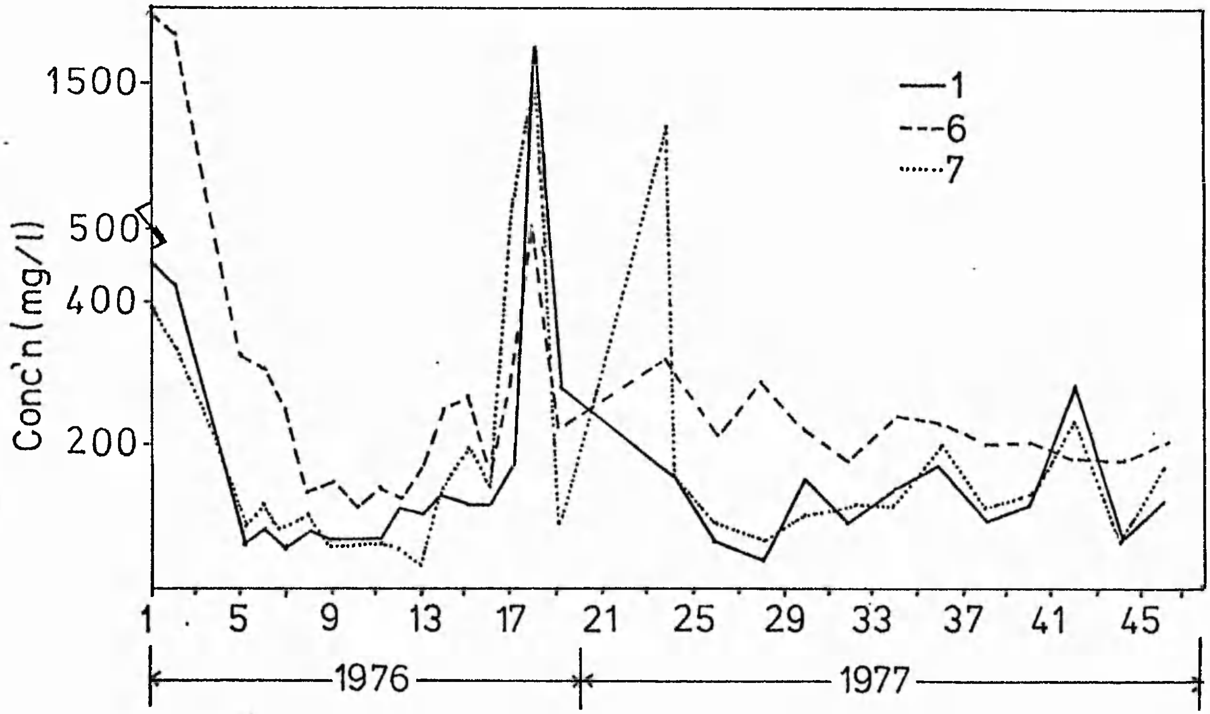


Fig. 76 - Temporal variation of weekly mean chloride and sodium concentrations.

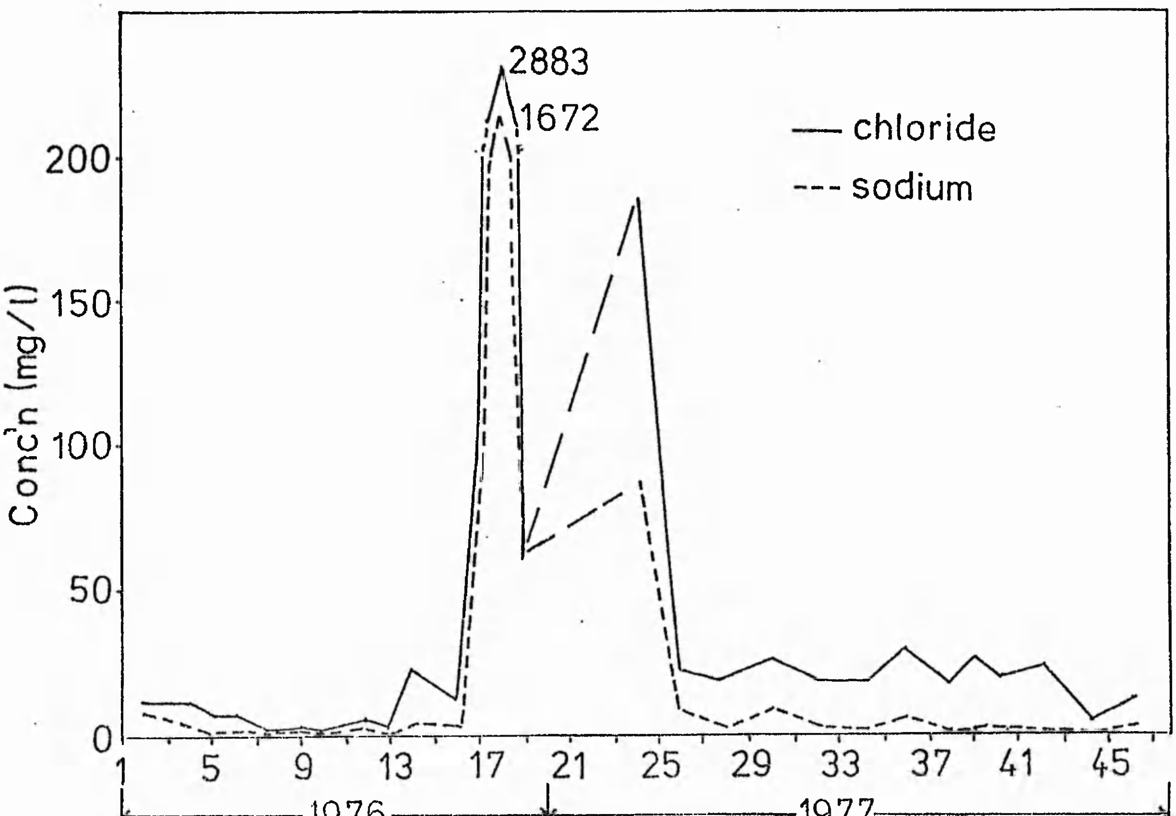


Fig. 77 - Temporal variation of weekly mean calcium concentration.

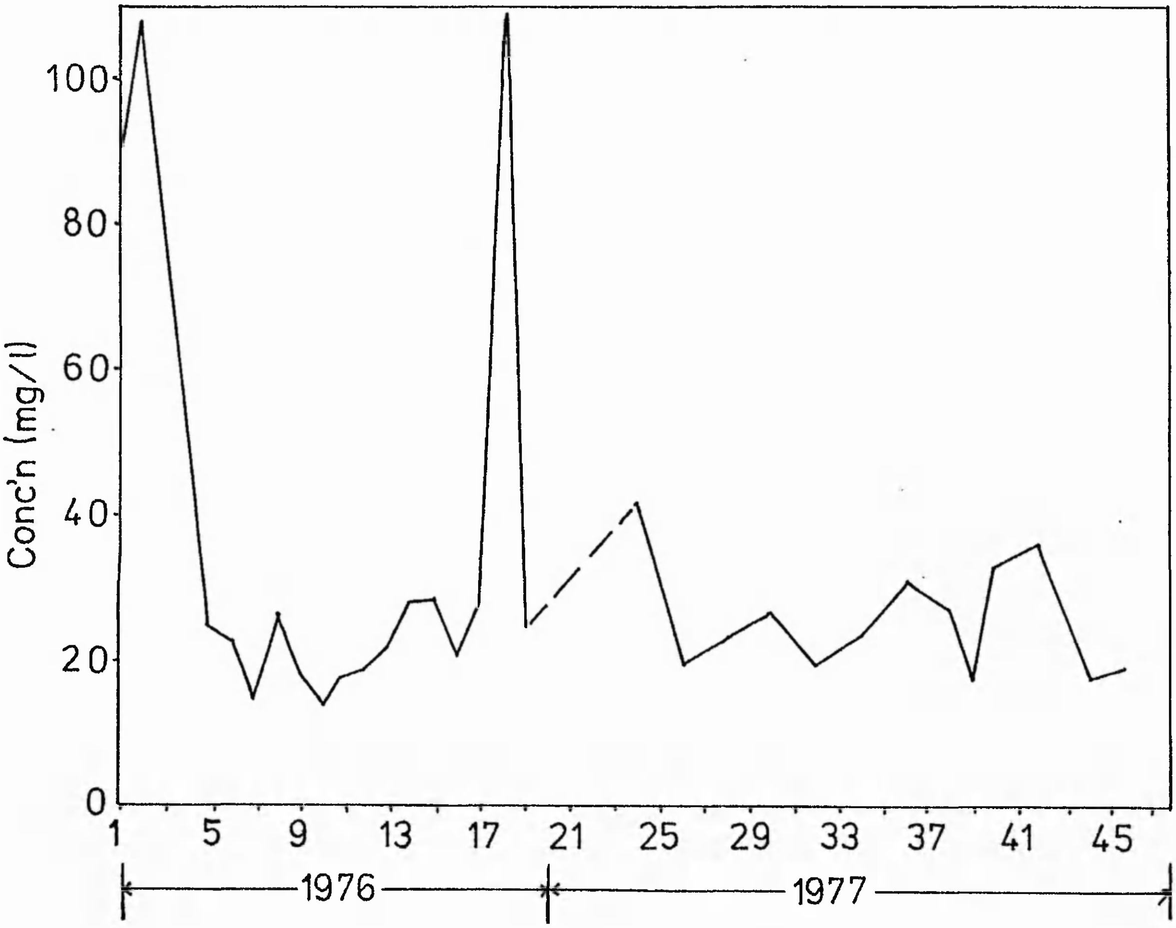
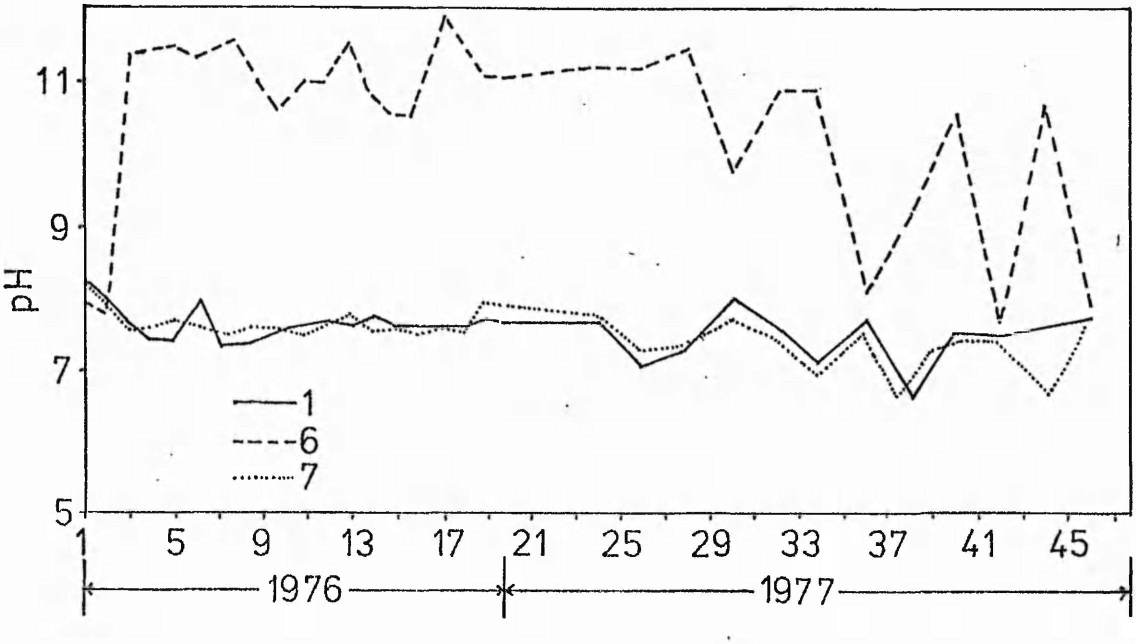


Fig. 78 - Temporal variation in pH for gully pots 1, 6 and 7.



c) Input from road sweepings and wind blown material, e.g. grass-cuttings and organic debris, which provide fresh material for a).

d) Evaporation which increases the effective concentration.

The pH of gully pot liquors, with the exception of gully pot 6, exhibited a degree of variability, but showed little temporal variation. In gully pot 6 exceptionally high pH levels were recorded (Figure 78), which were believed to be due to the leaching of lime since higher levels of calcium were also recorded for this pot. During dry periods the pH fell quite rapidly from 11.0 to a more typical pH value of 7 to 8. This drop is explained by the buffering capacity of natural water; at this pH an imbalance in the carbonate/bicarbonate equilibria can result in neutralization and precipitation reactions taking place (see Section 6.1.3). A similar, but less marked behaviour was observed for gully pot 8.

Suspended solids and dissolved oxygen concentrations, as expected, showed no temporal variation. However, dissolved oxygen is an important parameter in defining the nature of reactions that will occur during other polluting events (see Section 6.1.3), for instance, anaerobic degradation and putrescence of solid matter occurs when dissolved oxygen falls to zero. The results indicate that this happens after a period of 1 to 7 days dry weather. Both suspended solids and dissolved oxygen concentrations are dependent upon the time elapsed since the preceding storm event. For dissolved oxygen the concentration will also be dependent upon the catchment area of the gully pot, since the greater the volume of runoff through the pot the greater will be the degree of aeration of the stored Water. Plotting dissolved oxygen against the total volume of runoff for the week prior to analysis (estimated from the total rainfall and the impervious catchment area) indicates that for the Clifton Grove catchment, to keep the stored water fully aerated a runoff volume of approximately 6 cubic metres per week is necessary. (Figure 79). In order to keep the dissolved oxygen at a reasonable concentration and assuming a typical weekly summer rainfall of 6 mm, a catchment area of some 500 m^2 would be needed. The majority of gully pot catchment areas at Clifton Grove are smaller than this, for example, gully pot 1 has an area of only 140 m^2 and can be seen from the graph to be rarely fully aerated. It would seem that one means of reducing the pollution threat due to the putrescence of organic matter is to increase the spacing between gully gratings and thereby increase their catchment area. This would have the additional advantage of reducing the number of gully pots and thereby reducing the cost of installation, the time required for cleansing a given area and the volume of poor quality stored water, however, each gully pot would be subject to greater loads of solid material.

6.1.2 Influence of Sources of Pollution on the Quality of Stored Water.

a) Impervious Surfaces

The impervious surfaces were of a consistent type across the catchment. Roadways and pavements were of bitumen or tarmacadam and driveways were typically constructed of concrete strips separated by gravel. Erosion of these surfaces would typically produce large inorganic mineral particulates that are unlikely to undergo chemical change or decomposition, and so influence the quality of the stored water, but which would remain trapped in the bottom sediments until removed during council gully cleansing. An exception to this is the possibility of leaching of complex organic compounds from bitumen or tar coatings which may occur at low concentrations. Other particulate matter that gathers upon impervious surfaces, such as aerial dustfall, wind blown and rainfall eroded soils and vegetation, is likely to be of more significance. Fine particulates from dustfall are rapidly and easily removed by overland runoff and will normally be washed through gully pots into the sewer system. However, fine particulates reaching a gully pot on the recession limb of a storm, or during short low intensity storms where little runoff occurs, can influence gully pot chemistry. The slow settlement of such particles means that they will exert some oxygen demand on the stored waters over a period of a few days after the storm and probably comprise the bulk of the recorded suspended solids. Dustfall is likely to be of constant composition across the catchment and will not explain variation in quality between gully pots. Wind blown and eroded soils and vegetable matter consist of a variety of particle sizes and composition and are consequently of the most importance in influencing the chemistry of gully pots. The vegetable and organic components of this material will undergo decomposition over dry periods exerting an oxygen demand and subsequently, when anaerobic conditions prevail, releasing soluble organic compounds to the supernatant liquors.
The degree of influence of soils on the quality of stored water will vary according to the presence or absence of soil and vegetation in a gully pot subcatchment, the amount of exposed soil and its

availability for removal. With the exception of treatment of soils by residents and the introduction of builders' sand during land developments, local soils should be of reasonably constant composition across a catchment, the size of Clifton Grove. Between catchments substantial variation in the nature of solids trapped in gully pots was recorded. Table 26 shows the results of an analysis of material retrieved from municipal gully emptying vehicles for the Clifton residential area and for Basford, a light industrial/old residential area of Nottingham.

b) Vehicles

The presence of oil was commonly observed in gully pots as a blue/green sheen covering the water surface. In some cases large quantities of oil were observed, which were attributed to the now illegal practice of emptying car sump oil into the drains. The presence of such large quantities of oil had a significant impact on the BOD and COD of stored waters. Tyre rubber and small rust fragments were observed in gully pot sediments and supernatant liquors had high concentrations of iron. Lead, of which the primary source in the environment is vehicle exhaust emission, was not found to be present in as high concentrations in the stored water as has been recorded in urban runoff in some studies. Levels were typically in the range of 0.025 to 0.200 mg/l compared to concentrations of 0.5 to 5.0 mg/l recorded by Hedley (1976) in motorway runoff. This is probably a reflection of the low traffic density on the catchment. However, the levels were higher than those expected for a typical surface water, where lead concentrations of less than 0.05 mg/l would be expected. High zinc concentrations of 0.2 to 1.0 mg/l, presumably derived from tyre rubber and vehicle corrosion, were also recorded.

c) Road Salting

Road salting was the most discrete polluting event monitored. Since the Clifton Grove estate contained no trunk roads, it was of low priority for municipal salting and, in most instances of snowfall, only the circular feeder road, Fabis Drive, was gritted and salted by the Council. Therefore, the high dissolved solids concentrations recorded over such periods and the large variations in concentrations between gully pots indicates the importance of localised salting of driveways and footpaths by residents. Salt application rates by residents were in excess of those of the Council and in excess of the quantities needed to effect melting. The maximum dissolved solids concentration was recorded for gully pot 8 located at the bottom of a cul-de-sac, which was not salted by the council. Salting by residents was not restricted to periods of snowfall alone. In the storm of the 6th December, 1976, high salt levels were recorded following a period of frosty weather, no council salt application had taken place and the high chloride levels could only be ascribed to salting by residents. The use of impure rock salt also results in increases in other substances, including nitrate, potassium, calcium, (see Section 6.1.1), nickel, lead zinc and chromium (Hedley, 1976). Additionally, the high concentrations of alkali metals in solution can upset water sediment equilibria and effect the release of further heavy metals, through ion exchange processes or complexation with chloride.

d) Human and animal activity

The nature and degree of human activity within a gully pot sub-catchment is believed to be one of the most important factors determining the variation in composition of gully pot liquors. The variable and unpredictable nature of human activity leads to differences in stored water composition across a catchment. The occurrence of exceptional concentrations of parameters that are not mirrored in measurements from other gully pots may often be ascribed to human activity in the subcatchment. Some of the activities that lead to the pollution of pot liquors are:-

a) Car maintenance and servicing results in oil, petrol, rust, paint, hydraulic fluid, antifreezes, etc., accumulating on roads and driveways. Such debris is commonly washed off or swept into kerbside channels after the completion of a job.

b) Car washing is a widely practiced activity on residential estates and was considered to account for the frothiness of many of the samples collected from gully pots. Car wash liquids may have been an additional source of nitrate; samples exhibiting frothiness were commonly associated with high nitrate concentrations.

c) Grass cutting. In the summer months grass cuttings were found in abundance in gully pots and at the roadside, providing further organic material for subsequent degradation over dry periods.

Fig. 79 - Variation of dissolved oxygen (DO) concentration with estimated runoff through gully pots 1, 6, 7 and 8 for week prior to analysis.

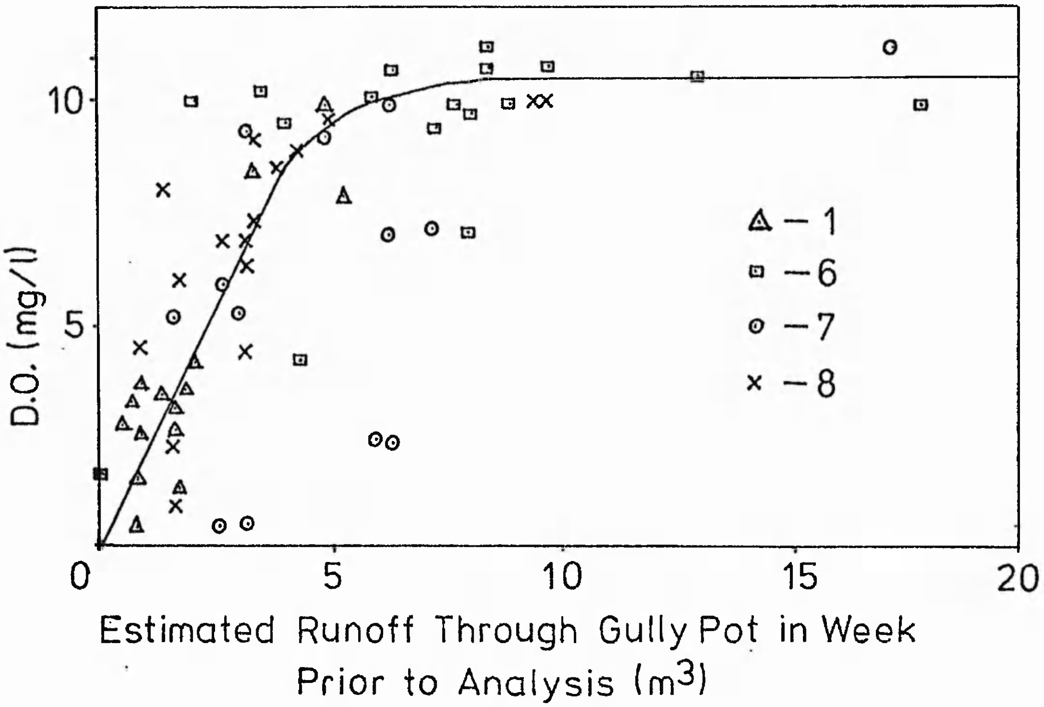


Fig. 80 - Relationship of annual mean BOD and COD concentrations with impervious subcatchment area.

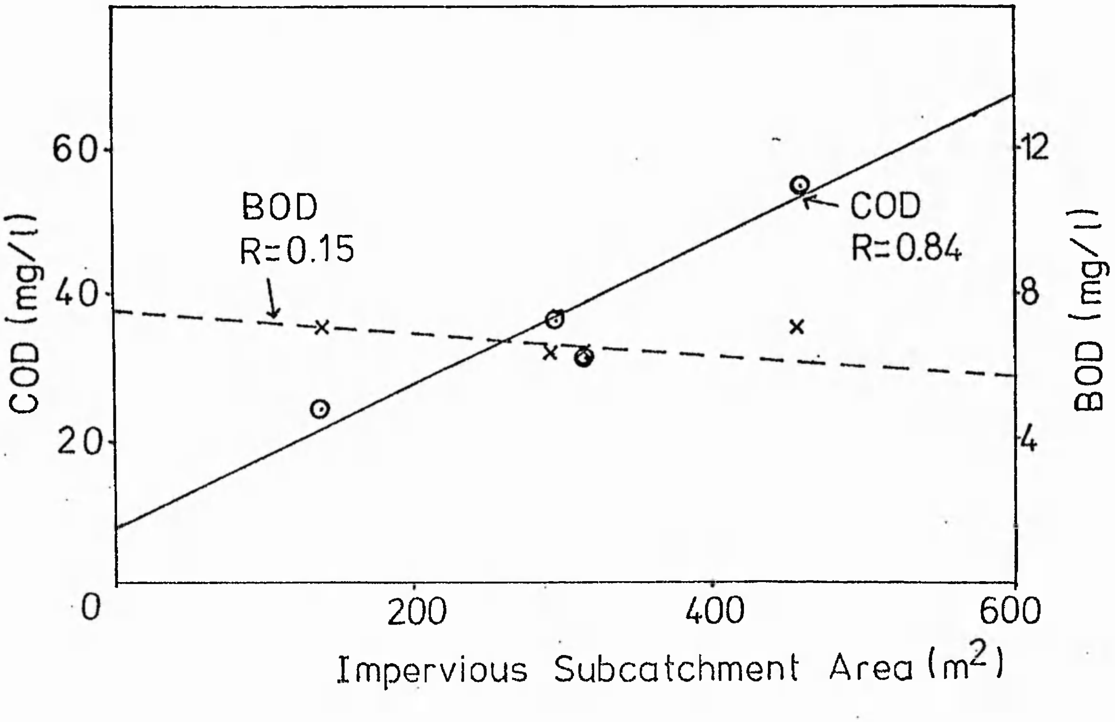


Fig. 81 - Relationship of annual mean nitrate concentration with impervious subcatchment area.

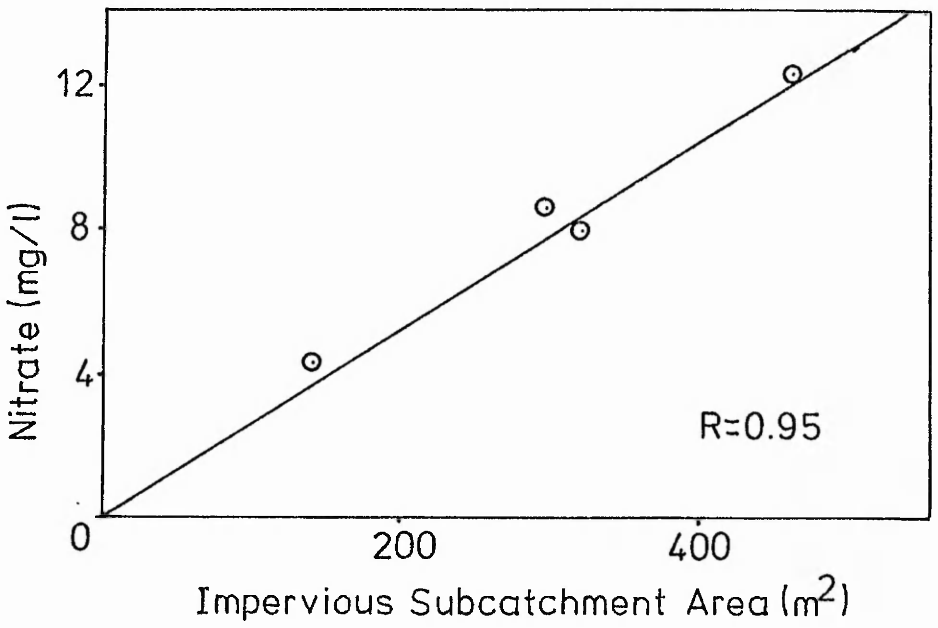


Fig. 82 - Relationship of annual mean dissolved oxygen concentration with impervious subcatchment area.

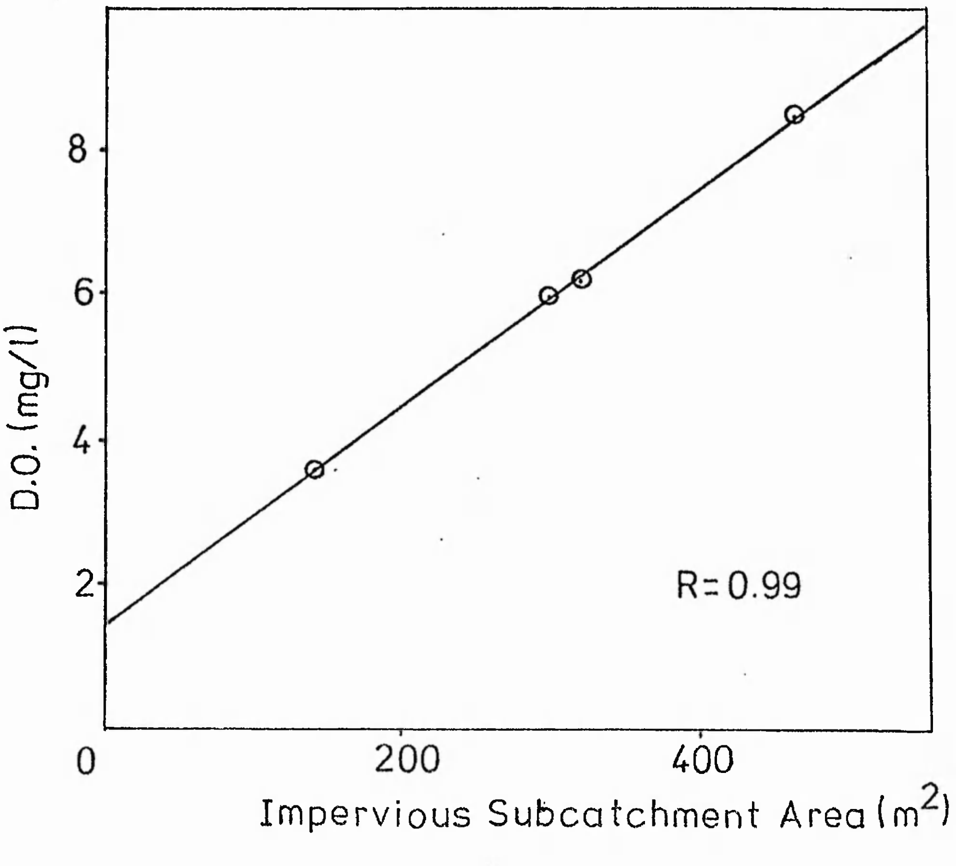


TABLE 26 Composition of gully pot sediments
for two urban areas

	Clifton	Basford
BOD (MG/G)	43.8	9.1
COD (MG/G)	34711.0	8462.0
Volatiles (%)	21.0	7.6
Zinc (MG/G)	0.69	0.22
Soluble Components:-		
Dissolvable Solids (MG/G)	4.0	4.5
NO3 (MG/G)	0.165	0.185
NH4 (MG/G)	0.037	0.035
CL (MG/G)	0.75	1.25
COD (MG/G)	3.2	2.7

d) Garden treatment. The application of manure, peat, fertilisers, pesticides and herbicides provide additional sources of pollutants which may accumulate in gully pots. Fertilisers can contribute nutrients and alkali metals to overland runoff, the use of lime may have been responsible for high pH values recorded in gully pots 8 and 6.

e) Winter salting of driveways and footpaths to melt snow and ice.

f) Litter dropping. Paper, cigarette ends and other garbage were observed at the roadside and in gully pots.

g) Urination and defecation by dogs and birds. Dog faeces were observed on footpaths, gutters and wedged in gully grates. In addition to contributing degradable organic matter, they are a source of bacteria and even virus.

The influence of human activity on the quality of the water stored in gully pots might be expected to relate to the subcatchment area, i.e. the larger the subcatchment area, the greater the number of dwellings and the greater the likelihood of human influence. Figure 80, a plot of annual mean values of COD and BOD for the four pots investigated on a weekly basis against the contributing impervious subcatchment area, indicates (for the limited data available) that COD correlates well with subcatchment area, i.e. the degree of human influence, whilst BOD shows no dependency upon subcatchment area. This indicates that whilst the polluting input from human activity contributes a significant oxygen demand the materials are not readily biodegradable. This concurs with the analysis of oxygen demand of gully pot sediments from two areas of Nottingham (Table 26) where the BOD of the sediment is only 0.1 to 0.2% of the COD. A similar correlation exists for annual mean nitrate concentration against impervious subcatchment area (Figure 81). The use of garden fertilisers and car washing are believed to account for the difference in nitrate concentration between gully pot 1 containing no houses in its subcatchment and gully pot 6 draining 4 houses.

6.1.3 The Chemistry of Gully Pot Liquors

The changes in composition and chemical reactions occurring in gully pot liquors can be conveniently considered in two parts:-

a) during dry periods
b) during rainfall

6.1.3.1 Changes in Water Quality over a dry period

Changes in composition of the supernatant liquors over dry periods were evaluated in three ways:-

a) Consideration of the antecedent dry period relevant to each weekly sampling date;

b) Samples collected over a dry period in the field; and,

c) A laboratory study using sediment collected from gully pots during municipal cleansing.

The results of the temporal variation study had indicated that gully pot liquors were at their most polluting state during long summer dry periods. A laboratory study was undertaken to investigate the chemical changes that migh occur over a dry period in a controlled environment where no unknown pollutant input could occur. A gully pot, of the same dimensions as those in the Clifton Grove sewer system, was filled to a depth of 30 mm with sediment obtained from municipal gully emptying vehicles. Distilled water was then added to the point of overflow and the contents were stirred to simulate the effect of a passing storm. Samples for analysis were drawn initially on a daily basis, but as changes in parameters became less marked, this interval was extended to every 2 or 3 days. The duration of the test was 36 days during which time the average temperature was 25°C.

Many chemical changes in natural waters can be related to the growth and decay of bacterial populations as they utilise material for energy and respiration. The type of bacteria present in a water, and consequently the nature of chemical changes, is largely determined by the dissolved oxygen level. When dissolved oxygen is present aerobic bacteria will predominate, that is, bacteria that utilise the oxygen for respiration. However, when dissolved oxygen is depleted, bacteria turn to other sources of oxygen, such as nitrate and sulphate, and anaerobic bacteria predominate. In water stored in gully pots both states occur. In the field, dissolved oxygen levels were monitored as falling to zero over a dry period of 1 to 7 days. The length of the period during which the stored waters remain aerobic is dependent upon the initial dissolved oxygen concentration and the degree of organic pollution. The greater the concentration of organic material the greater will be the demand for oxygen by bacteria, utilising the material as a source of energy. The initial dissolved oxygen concentration is related to the antecedent weather conditions (e.g. size of the rainfall event) and the subcatchment area drained by the gully pot, i.e. the the greater the volume of runoff the greater the reaeration of the pot liquors (Figure 82). In the laboratory study, the dissolved oxygen decay over a dry period was monitored continuously using a probe and chart recorder (Figure 83). From a fully aerated condition the dissolved oxygen concentration fell rapidly to about 4 mg/l, when demand began to ease off. A point of inflexion was reached after which the dissolved oxygen demand accelerated resulting in a sharp cutoff, when oxygen became depleted, after a period of only 7 hours. This rapid utilisation of the dissolved oxygen was a result of the high oxygen demand of the sediment employed in the test. The different phases of dissolved oxygen consumption are believed to represent different phases in the growth of the two principal bacterial types. The initial, rapid consumption of oxygen corresponds to its utilisation by aerobic bacteria. The rate of consumption gradually declines as conditions becomes less hospitable for their development and the final accelerating stage of consumption corresponds to the gradual increase in population of bacteria capable of surviving under conditions of little or no dissolved oxygen.

Nitrogen containing species, that is, nitrate, nitrite, ammonia and organically bound nitrogen, can undergo a range of reactions that are bacteriologically and biologically dependent. In a water-sediment system a wide variety of transformations are possible, the situation is complex and, to date, poorly understood. The major transformations may be listed as follows:-

a) Nitrification. This is the two stage oxidation of ammonia to nitrate as a result of the activity of autotrophic bacteria Nitrosomas and Nitrobacter:-

$$NH_4^+ \xrightarrow[\text{NITROSOMAS}]{} NO_2^- \xrightarrow[\text{NITROBACTER}]{} NO_3^-$$

Nitrification is believed to be one of the most important nitrogen transformations in both polluted,and unpolluted,river water (Curti et al, 1975). It is of particular significance in polluted waters

Fig. 83 - Laboratory simulation of the reduction in dissolved oxygen concentration in a gully pot liquor over a dry period.

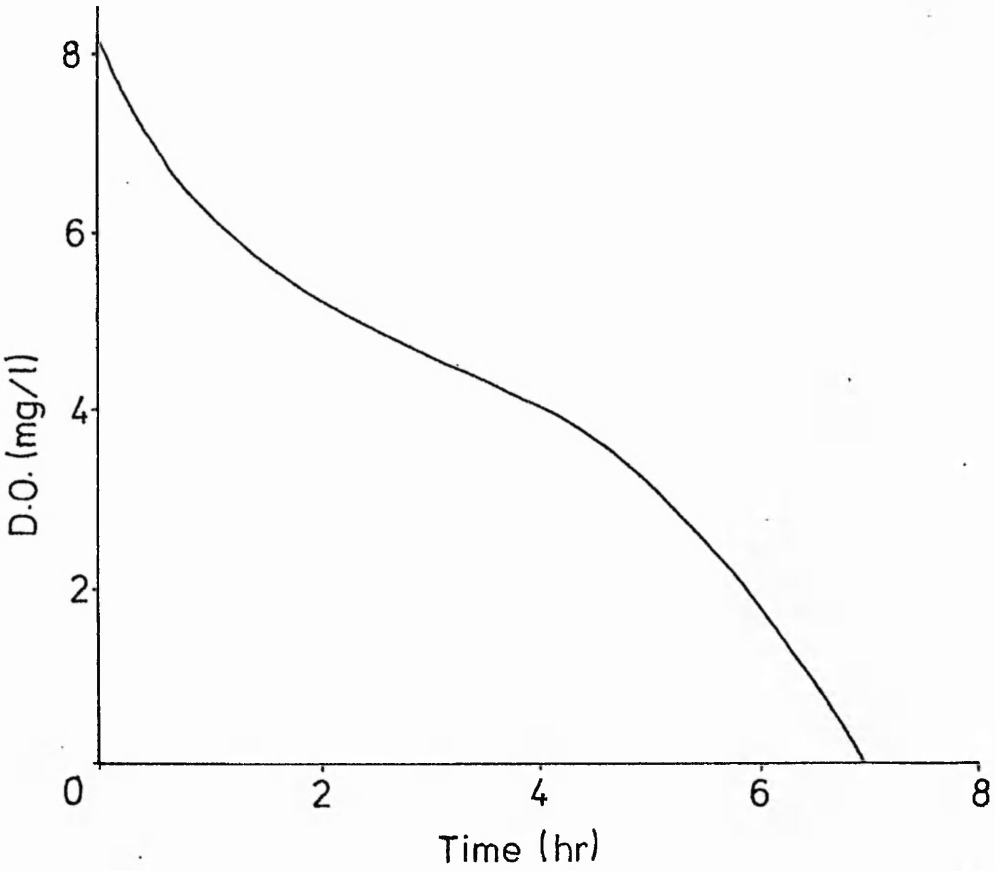


Fig. 84 - Major transformations of nitrogen in a water sediment system (after Van-Kessel (1977)). The thickness of the lines gives an impression of the relative importance of the processes.

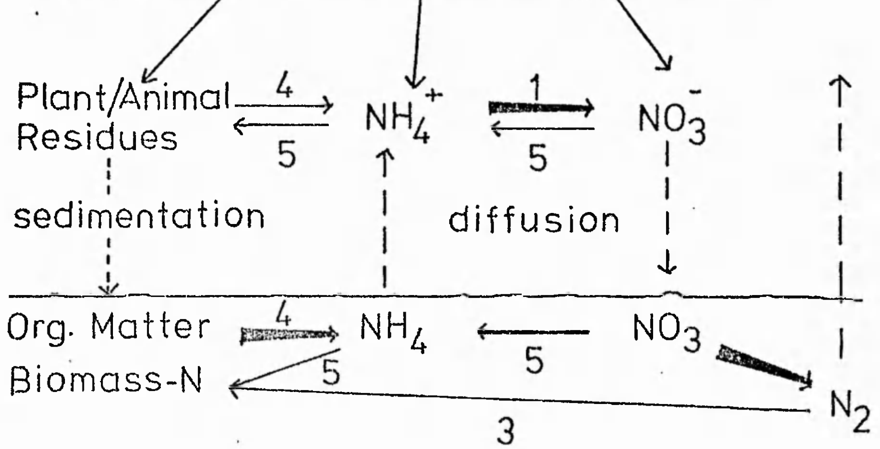


Fig. 85 - Relationship of weekly mean ammonium concentration in gully pot liquors with the antecedent dry period.

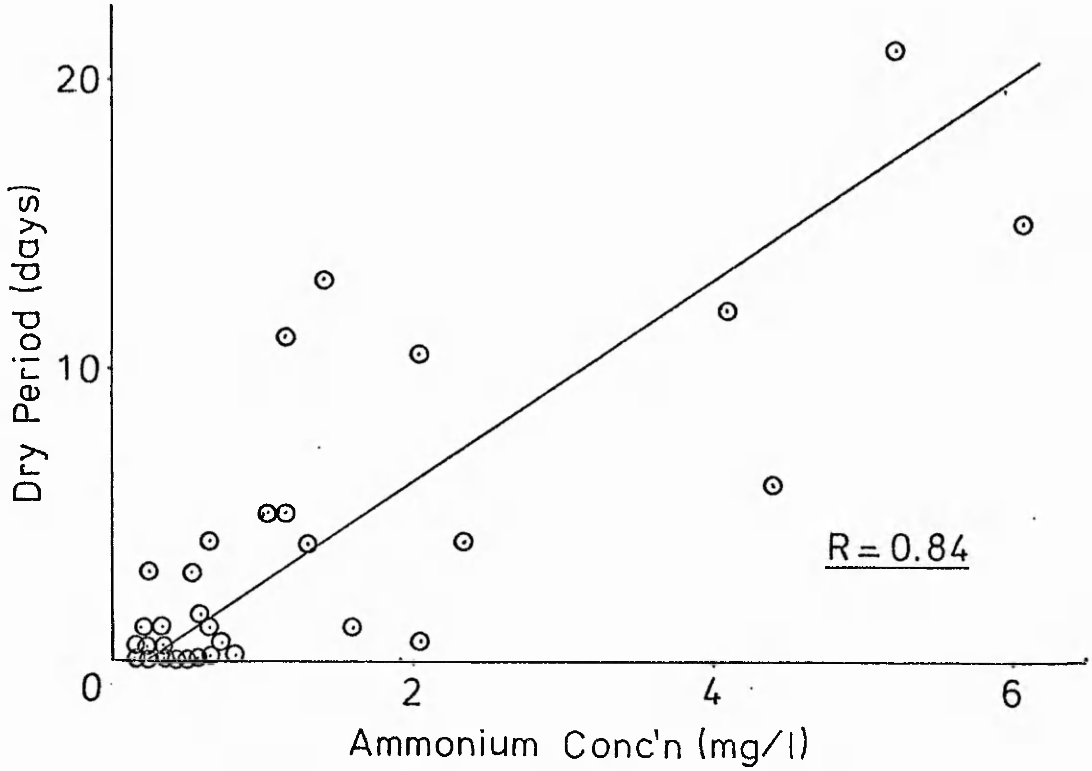
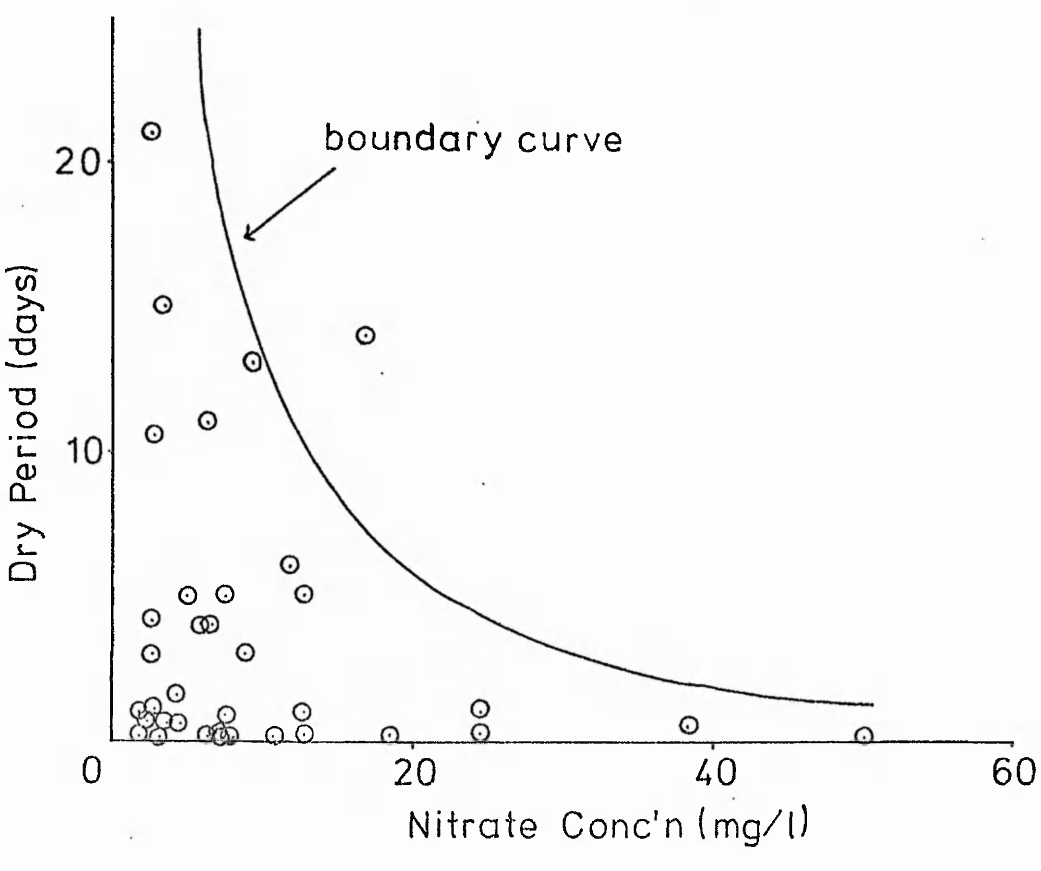


Fig. 86 - Relationship of weekly mean nitrate concentration in gully pot liquors with the antecedent dry period.



where ammonia discharge in sewage effluents can constitute, by its bacterial oxidation, a significant proportion of the biochemical oxygen demand of the water.

b) Denitrification. This is the reduction of nitrate or nitrite to gaseous nitrogen, the process is impaired in waters that contain dissolved oxygen. However, bottom sediments are typically highly reduced and rich in organic matter making conditions for denitrification favourable.

c) Nitrogen fixation. This is the uptake of gaseous nitrogen by algae and bacteria.

d) Ammonification. The production of ammonia through the deamination of cell organic nitrogen, an important process in anaerobic sediments.

e) Immobilisation. This, along with denitrification, is another process whereby aerobic heterotrophic bacteria can utilise nitrate under anaerobic conditions. Nitrate is thus reduced to ammonia.

These processe are illustrated diagrammatically in Figure 84 (van Kessel, 1977). In gully pot liquors the most significant change in nitrogen speciation over dry periods was the increase in ammonium concentrations. The temporal variation study had shown that high ammonium concentrations were invariably coincident with periods of dry weather and a linear correlation between the two could be obtained (Figure 85). Two mechanisms are available for the production of ammonium under anaerobic conditions: firstly, the breakdown of organic matter in sediments yielding ammonia as a by-product and, secondly,the reduction of nitrate by bacteria utilising it as a source of oxygen. There was some evidence for the occurrence of both reactions. Firstly, weekly mean nitrate values bore a loose inverse relationship with the antecedent dry period, (Figure 86), that is, high nitrate values were not coincident with dry periods. Secondly, for gully pot 8, week 18, high nitrate concentrations from road salting had resulted in the production of ammonium. Both observations indicate the occurrence of nitrate reduction. However, in the laboratory, whilst significant rises in ammonium concentration were recorded nitrate concentrations remained reasonably constant (Figure 87), indicating that ammonification was the prime source of ammonium production in gully pot liquors over dry periods. In the laboratory test it is interesting to note that an initial decrease in ammonium concentrations occurred even though anaerobic conditions existed, additionally, gradual increases were observed in nitrate values contemporaneous with ammonium increases up to 24 days into the test. These observations may be tentatively explained by the following stages:

a) Initial nitrification, before the commencement of anaerobic digestion, results in a decrease in ammonium concentration.

b) Ammonium concentrations start to climb as breakdown of organic nitrogen commences.

c) Nitrification of ammonium continues in surface layers where oxygen diffusion can take place resulting in contemporaneous increases in both nitrate and ammonium.

d) Nitrate concentrations eventually start to fall as denitrification and immobilisation reactions assume greatest importance.

Over a dry period the reactions occurring in gully pot liquors may be compared to those that take place in anaerobic digestors for the treatment of sewage sludges. Anaerobic digestion is employed as a process for the reduction of the quantity of sewage sludge through conversion into gases or liquids:-

$$\text{Organic material} \longrightarrow CO_2 + CH_4 + NH_4^+ + H_2S$$

Digestion can be considered as occurring in two separate stages:-

a) An acid fermentation by acid forming bacteria (pH4 → 6.5) comprising breakdown of organic matter to give simple organic compounds and organic acids resulting in a fall in pH and the sludge becoming slimey and foul smelling.

b) An alkaline fermentation by methane forming bacteria (pH7 → 7.8) comprising breakdown of the simpler organic compounds into methane and carbon dioxide accompanied by a rise in pH.

At ordinary temperatures complete digestion is a slow process and may take between 3 to 6 months.

In a sludge digestion plant process a) takes hours to develop, whereas process b) may take many weeks. However, the sludge obtained in b) contains the bacteria and enzymes necessary to break down the simple organic compounds almost as quickly as they are formed, giving rise to a continuous breakdown of organic materials, via simple organic compounds, to carbon dioxide and methane. However, when digestion has become unstable or "gone sour" the production of hydrogen sulphide and other odourous compounds may occur. Additionally, the process is susceptible to inhibition by toxic substances, such as heavy metals, in the sludge.

The laboratory study confirmed the development of anaerobic digestion in gully pot liquors. After stirring of the pot contents (simulated storm) there was an initial period of settlement of suspended solids with closely correlating falls in COD and BOD (Figure 88). On day 4 the development of a thick surface bacterial scum was noted and, by day 8, the release of methane from the bottom sediments was confirmed by odour and ignition. It was about this time that the production of ammonium commenced. By day 23 the surface film had started to break up, bubbles of methane had become less frequent and suspended solids, BOD and COD had all attained reasonably constant levels. Over the duration of the test, a gradual rise in pH was recorded from 7.8 up to a peak value of 8.4 for day 35. There was a steady rise in dissolved solids (Figure 87) indicating that the breakdown of solid material to soluble compounds had occurred. However, no significant rises in soluble COD were recorded suggesting that process b) had been attained and the breakdown of organic material in the sediment to simpler soluble organic compounds was rapidly succeeded by complete breakdown to gases and simple inorganic compounds.

The development of anaerobic digestion was also noted in the field. The occurrence of surface bacterial scums over dry periods was common and the release of methane and hydrogen sulphide was recorded. Increases in dissolved solids, ammonium and oxygen demand were all noted and the liquors often turned a yellow colour, presumably through the release of soluble organic compounds. These last observations contradict the findings of the laboratory study, where no rises in oxygen demand were recorded and indicate that, in the field, the second stage of digestion was rarely achieved and anaerobic breakdown of solid organic matter results in a degradation of the quality of the stored water, through the

Fig. 87 - Laboratory simulation of the variation in gully liquor chemistry over a dry period - changes in dissolved solids (DS), nitrate (NO_3) and ammonium (NH_4) concentrations.

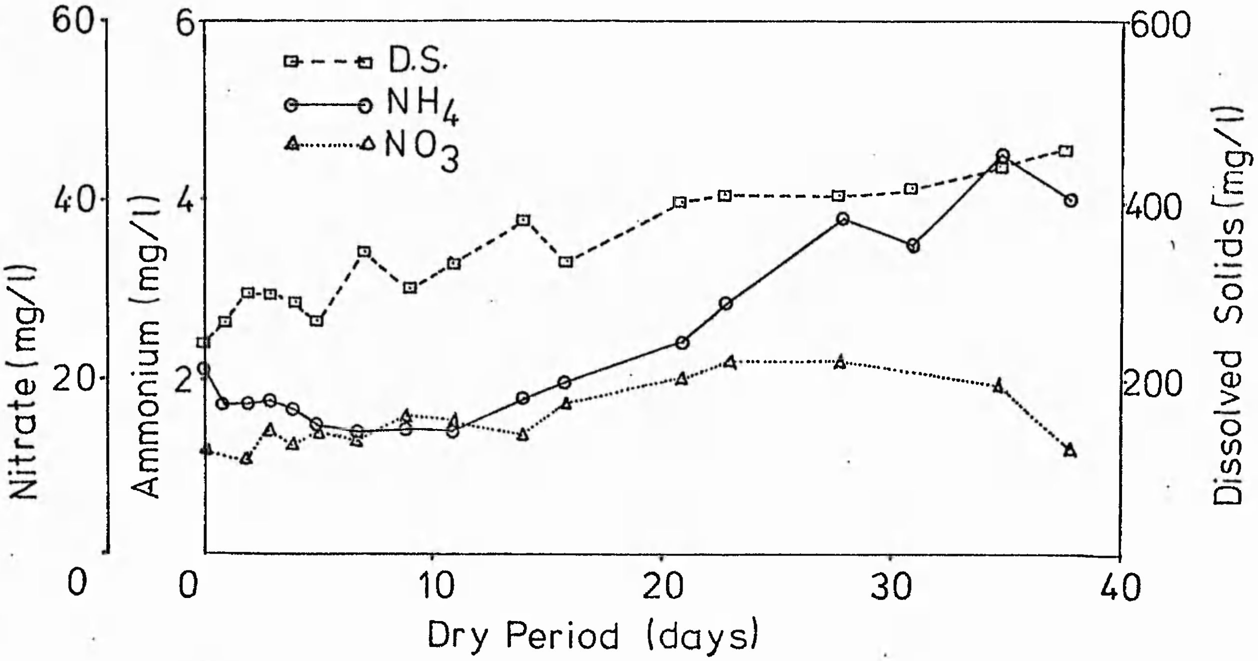


Fig. 88 - Laboratory simulation of the variation in gully liquor chemistry over a dry period - changes in suspended solids (SS), COD and BOD concentrations.

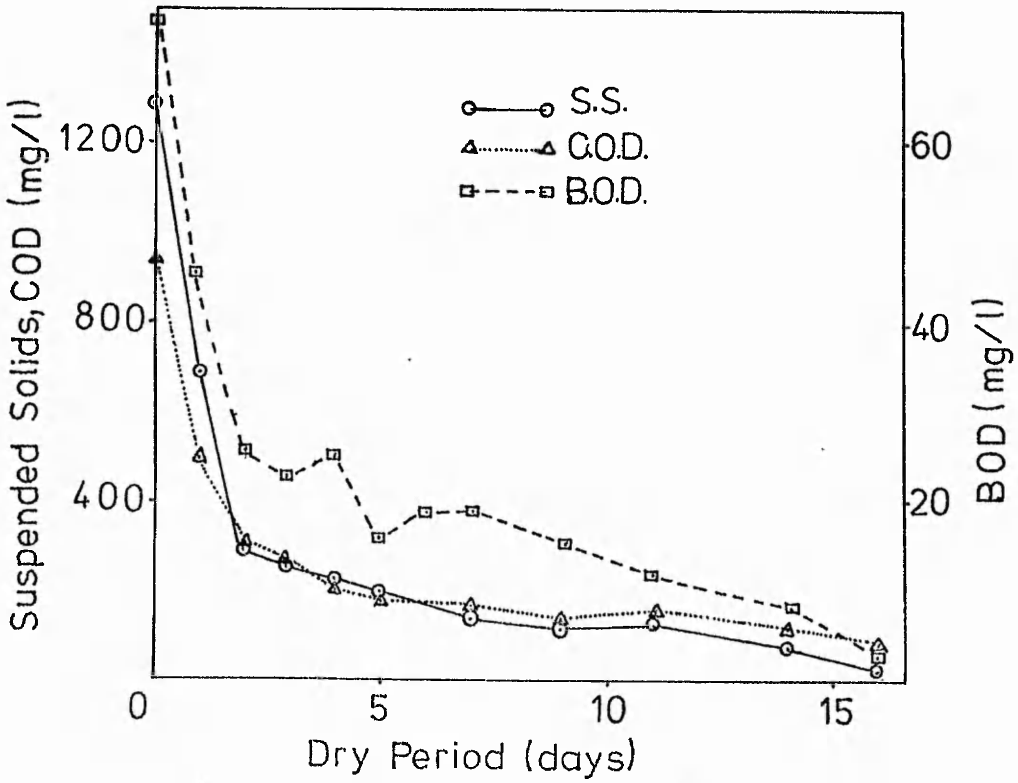


Fig. 89 - Laboratory simulation of the influence of car wash liquor runoff on COD, BOD and nitrate concentrations in an anaerobic gully pot liquor.

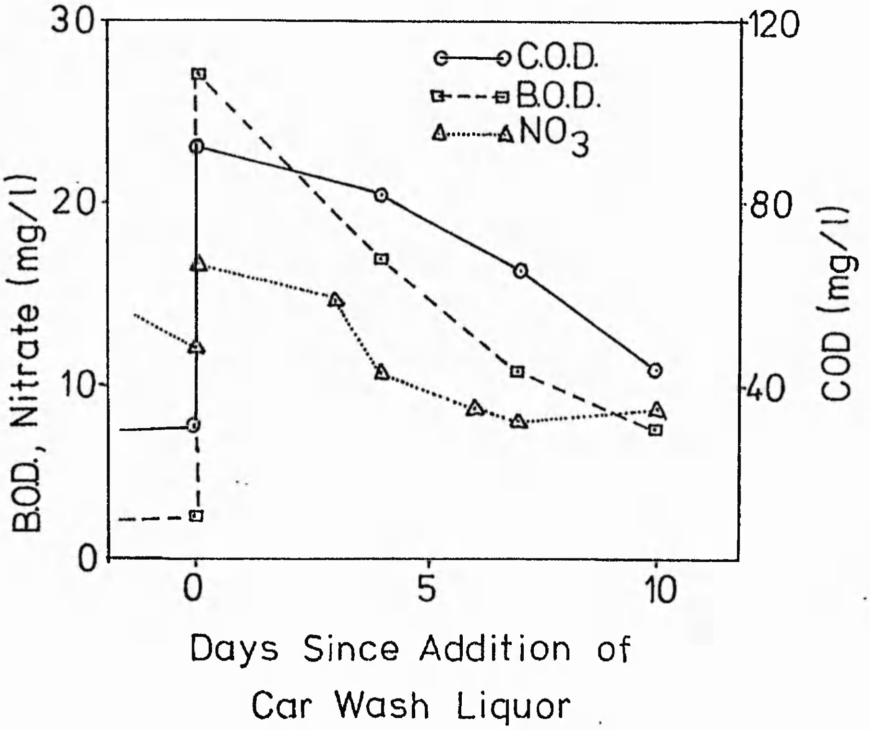


Fig. 90 - Relationship between annual mean values of pH and calcium.

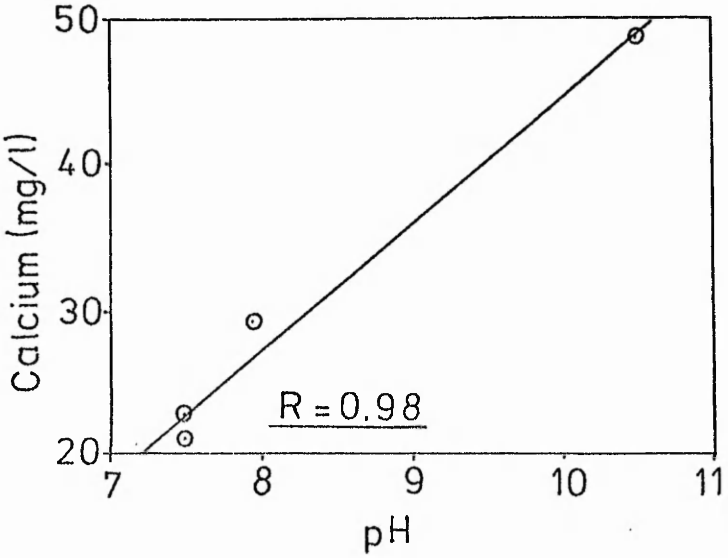


Fig. 91 - Influence of lime on the pH of distilled water, gully pot liquor and tap water.

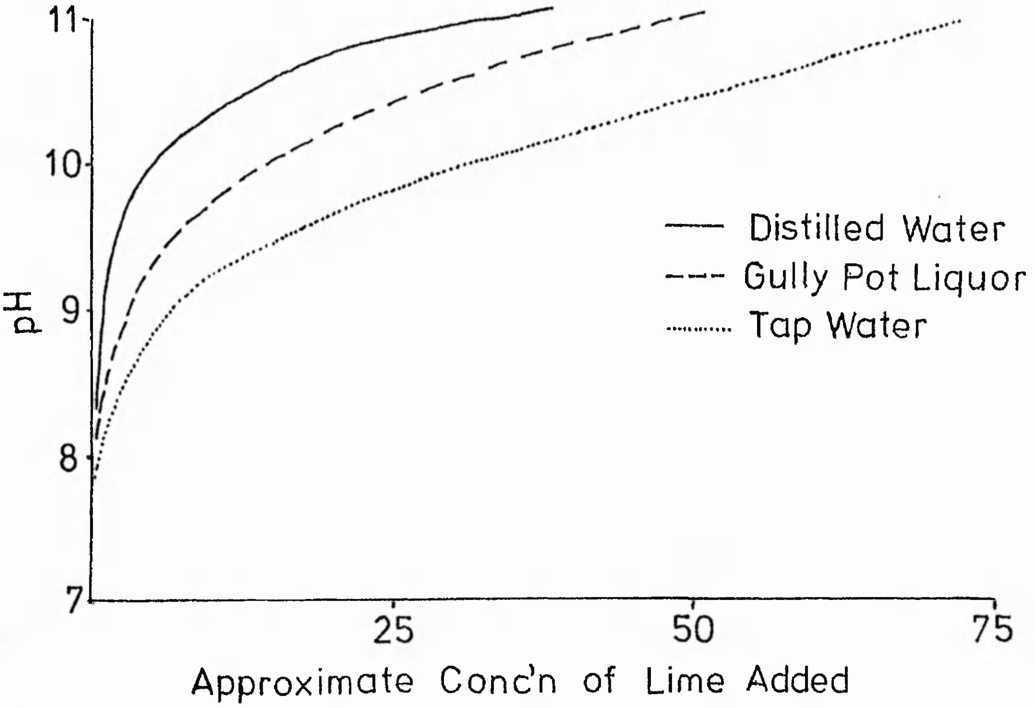
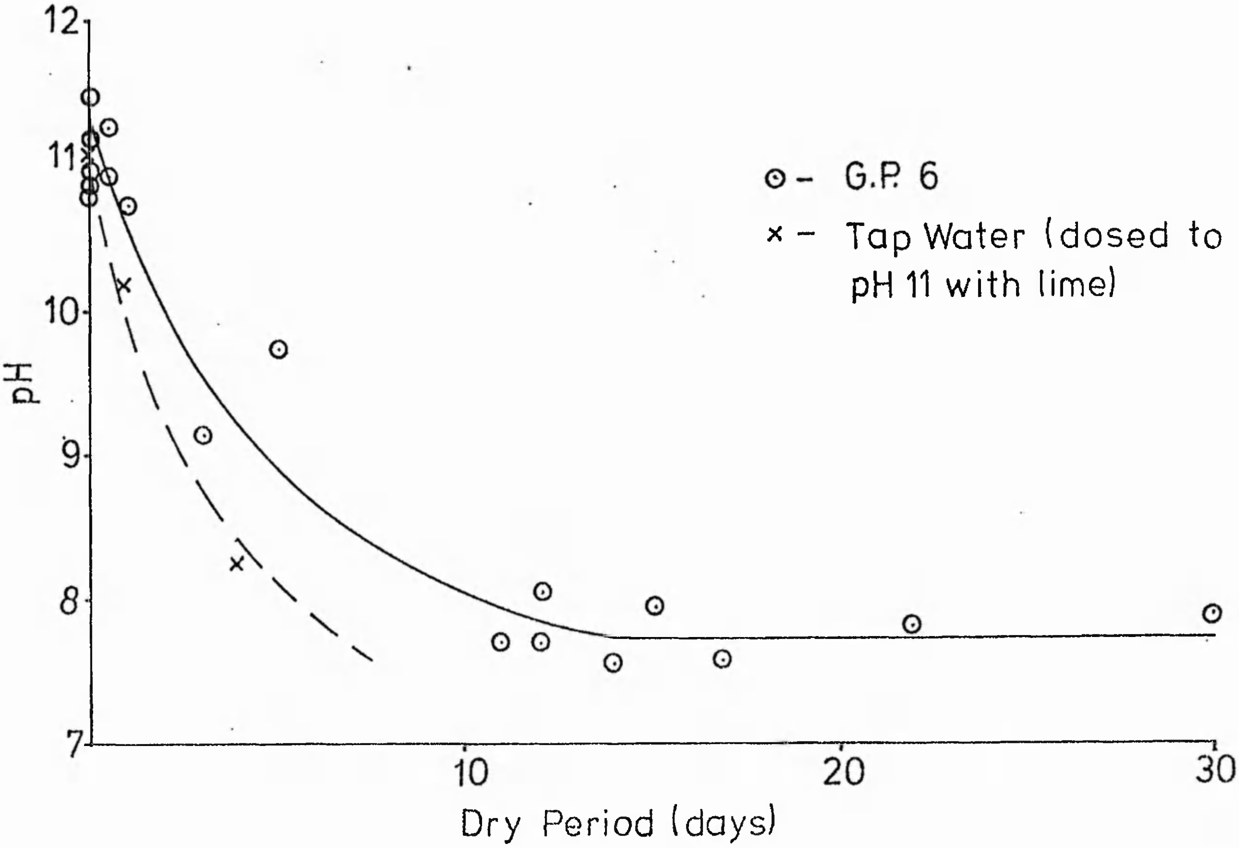


Fig. 92 - Relationship of pH with antecedent dry period for gully pot 6.



release of soluble organic compounds. The bacterial scum and the growth of suspended biomass (recorded in gully pot 8 over a dry period) may all contribute to the increases in oxygen demand recorded.

Thus the occurrence and development of anaerobic digestion in gully pots appears to be less predictable than during its controlled use for the treatment of sewage sludge. In gully pots digestion is unlikely to be efficient and does not result in the complete breakdown of organics to carbon dioxide and methane. Digestions may go 'sour', as indicated by the release of hydrogen sulphide in some gully pots. Conversely, in some circumstances digestion may not develop or may be inhibited by the input or presence of toxic substances.

Breakdown of solid organic material in gully pots may also have the undesirable effect of releasing loosely bound or chelated toxic heavy metals into solution; evidence for this effect has been recorded by Mance and Harman (1978). In the field additional pollutant input may occur, over a dry period, through human activity in the gully pot subcatchment. This can be a source of fresh material for degradation and also result in further increases in the oxygen demand of the liquors. The effect of car wash runoff on the quality of gully pot liquors was investigated in the laboratory through the addition of a dilute solution of a commercially available washing liquid on day 38 of the dry period investigation (Figure 89). Immediate increases in concentration were recorded for BOD, COD and nitrate, but, over the succeeding five days a steady decrease in all parameters was recorded. The steady reduction in oxygen demand may be explained by the fact that the second stage of digestion had been attained resulting in rapid breakdown of organic material.

Other changes in the concentration of species in gully pot liquors can result from natural buffering and precipitation reactions. Evidence of such reactions was recorded for gully pot 6 and to a lesser degree for gully pot 8. During wet weather gully pot 6 exhibited consistently high pH values, this was ascribed, either to the runoff of lime applied to local soils, or to the leaching of unfixed lime in cement and indeed a correlation between annual mean values of calcium and pH was indicated (Figure 90). Laboratory experiments showed that between 25 and 75 mg/l of lime were necessary to produce a pH in the region of 11 (Figure 91), corresponding to the runoff of between 2g and 7g of lime into the gully pot. The average difference in calcium concentration between gully pots 1 and 7 and gully pot 6 of about 30 mg/l is equivalent to 50 mg/l of lime and corresponds to the runoff of about 5g of lime into the gully pot and may account totally for the difference in pH observed between these pots. Over dry periods the pH of gully pot 6 was observed to fall gradully to an equilibrium value of between 7.4 and 7.8 (Figure 92). This pH drop is attributed to a number of possible reactions; added lime may react with dissolved carbon dioxide to form calcium bicarbonate:-

$$\mathrm{Ca\ (OH)_2 + CO_{2\ (aq)} \longrightarrow CaHCO_3 + H_2O}$$

Additionally at high pH values the formation of carbonate anions from bicarbonate is preferred resulting in the release of hydrogen ions and a decrease in pH:-

$$\mathrm{HCO_3^- + H_2O \rightleftharpoons CO_3^{2-} + H_3O^+}$$

In the presence of excess calcium it is also possible that the precipitation of calcium carbonate would occur. This would result in a drop in calcium in solution over dry periods for which there is little evidence, therefore, the reaction is likely to be of only minor significance:-

$$\mathrm{Ca^{2+} + CO_3^{2-} \longrightarrow CaCO_3 \downarrow}$$

At high pH similar precipitation reactions may occur for other species with the precipitation of either carbonate or hydroxide compounds:-

$$\mathrm{Cd^{2+} + 2H_2O \xrightarrow{pH\ 9.3} Cd\ (OH)_2 + 2H^+}$$

$$\mathrm{Fe^{3+} + 3H_2O \longrightarrow Fe\ (OH)_3 + 3H^+}$$

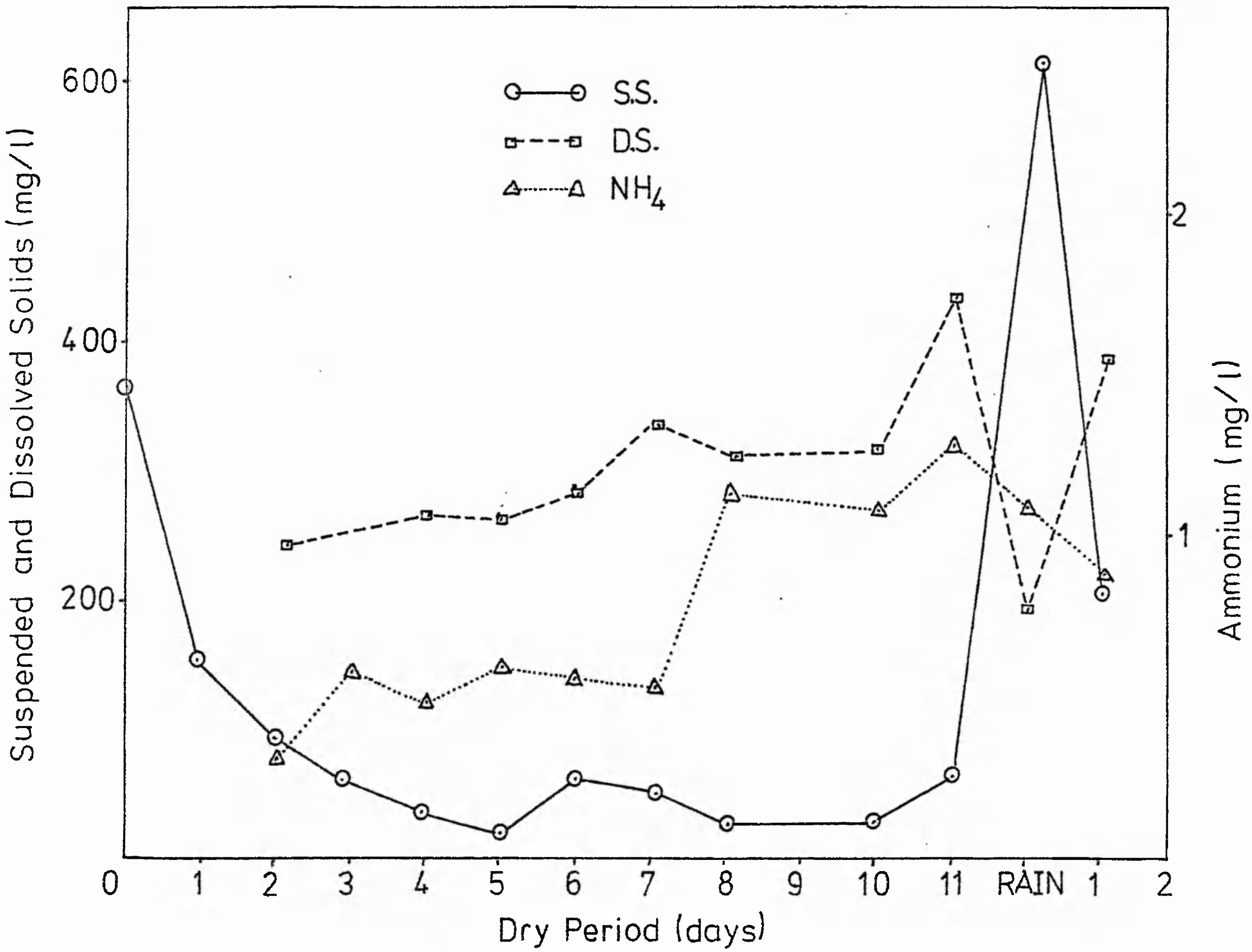
In conclusion it is evident that changes in the chemistry of gully pot liquors over dry periods are complex and highly variable. In terms of mathematical modelling, this variability makes the prediction of concentration changes by simple conceptual methods, such as linear regression, unreliable.

6.1.3.2 Changes in Water Quality during Rainfall.

Changes in the concentration of parameters during a rainfall event are largely determined by three factors: the composition of the liquors prior to the event, the composition of the incoming runoff and the characteristics of the storm event.

The initial phases of overland runoff readily transports in suspension dustfall and other fine material that has accumulated on the

Fig. 93 - Variation over a dry period of suspended solids, dissolved solids and ammonium concentrations in gully pot 4.



impervious surfaces over dry periods. The removal of these fine solids is more or less independent of flow rate, but, the subsequent erosion and transport of heavy particulates is determined by both the rainfall intensity and the flow rate. The first runoff entering the gully pot causes a rapid rise in suspended solids concentration, (Figure 91), due to the solids carried in the runoff, the resuspension of fine material settled in the pot and the mixing up of surface dusts and bacterial scums. Solid material in suspension is now flushed out of the pot in a similar manner to the removal of soluble components and constitutes the poor quality first flush of storm runoff. However, heavy particulates entering the pot will generally remain trapped in spite of the stirring action of runoff. Towards the end of a storm fine material carried in suspension may also be trapped in the gully pot as the rate of runoff recedes.

Soluble material is transported by runoff rapidly and more easily than solid material. The rate of flushing out of dissolved solids from gully pots is dependent upon the degree of mixing of the incoming runoff with the original gully liquors, which is determined by the rate of inflow (see Section 5.1.3). After a storm the concentration of dissolved components in the liquor will depend upon the volume of original gully liquors removed and the concentration of the components in the incoming runoff, which is, in turn, dependent upon the concentration in the rainfall and the amount of material dissolved or adsorbed during overland runoff.

The stirring action of incoming runoff also has the effect of increasing the dissolved oxygen concentration. The increase is strongly dependent upon the rate and volume of runoff.

To summarise, after a storm a completely new set of conditions prevail in a gully pot. The stored water is well aerated, different concentrations of dissolved parameters exist and fresh, undegraded solid material has been input.

6.1.4 Variation in the Quality of Water Stored in Gully Pots across the Catchment.

Variation in the quality of stored water across the whole catchment was evaluated by collecting, in one day, up to 25 samples from randomly selected gully pots. Five such sets of samples were collected at different times of the year, namely, 3rd September, 1977,

Table 27 Coefficients of Variation ($\sigma/\bar{x}$.100%) for the catchment - wide variation analyses

Constituent	Sept.	Feb.	March	May	July
Suspended solids	177%	91%	89%	174%	48%
Dissolved solids	37.7	134	117	93	33.5
COD	171	171	61	124	66.3
BOD	89.6	221	108	188	159
Nitrate	71.3	56.3	25.7	44.5	25.6
Ammonium	75	165	80.3	105	88
Chloride	36.4	129	185	206	116
pH	2.54	2.65	3.66	14.7	-
Calcium	14.8	72	71.4	31	18.3
Sodium	149	155	180	314	160
Potassium	300	51	92	56	77

TABLE 28 95% confidence limits (expressed as a percentage of the mean value) for the catchment - wide variation analyses

Constituent	Sept.	Feb.	March	May	July
Suspended solids	64.4%	33.3%	33.3%	67.3%	18.7%
Dissolved solids	13.5	49.1	44.1	35.9	12.9
COD	61.4	62.4	22.9	48.0	25.7
BOD	32.1	80.8	40.6	12.6	61.8
Nitrate	26.6	20.6	9.7	17.3	10.0
Ammonium	27.0	60.2	30.2	40.4	34.0
Chloride	13.0	47.0	69.6	79.6	44.9
pH	0.9	1.0	1.4	5.7	-
Calcium	5.3	26.4	26.9	12.0	7.1
Sodium	54.2	56.7	67.9	120.0	62.2
Potassium	48.9	18.5	34.5	21.9	29.6

TABLE 29 95% Confidence limits for estimating the mean quality of water stored in gully pots during the summer months with five random samples.

Confidence limits - $\bar{X} \pm 2.776\bar{\sigma}/\sqrt{5}$

where $\bar{\sigma}$ = average standard deviation calculated from variation analyses not affected by winter road salting.

Constituent	Confidence Limits ($\bar{X} \pm$)
Suspended solids	62 mg/l
Dissolved solids	66 mg/l
COD	76 mg/l
BOD	17 mg/l
Nitrate	4.6 mg/l
Ammonium	2.0 mg/l
Chloride	19.2 mg/l
pH	0.54
Calcium	8.3 mg/l
Sodium	11.1 mg/l
Potassium	4.2 mg/l

23rd February 1978, 20th March 1978, 15th May 1978, and the 17th July 1978. In all cases a wide variation in the concentration of parameters was exhibited, as shown by Table 27, the coefficients of variation (relative standard deviation) and Table 28, the 95% confidence limits (expressed as a percentage of the mean) for an estimate of the population mean based on the samples collected. The results indicate that the highest variations occur in the winter (February samples), presumably through the influence of road salting, and the lowest variations occur in the summer (July samples). As for the weekly analyses, the inter-quartile ranges were substantially less than would be expected from a normal distribution, indicating that occasional extreme values were the major cause of the high variability in quality.

In spite of the high variability in parameter concentrations it has been necessary, for the purpose of practicality, to assume that five randomly selected samples will provide some estimation of the mean quality of water stored in gully pots throughout the catchment. Taking an average standard deviation, calculated for each parameter from all of the tests, then the percentage range within which the population mean would be expected to fall is shown in Table 29. High deviations for chloride and other parameters similarly affected by road salting have been ignored since such variance is not applicable to the period when stormwater sampling was undertaken.

6.2. THE QUALITY OF STORMWATER RUNOFF

The quality of stormwater runoff from the Clifton Grove catchment was monitored for 24 storm events over a period of 2 years. The majority of events monitored occurred in May, June and July, 1978. Two events were monitored in June and July, 1977 and three in November and December, 1976. The results for each storm event were processed using a computer programme, STQUAL-FOR (see Section 4.2.). Tabulated pollutant concentrations, loads and graph plots formed the output of this programme and are presented in Appendix 2.3. Where reliable rainfall, runoff and quality measurements were available for an event, the mathematical model described in Chapter 5 was utilised to predict the mode of discharge of gully pot liquors and, thereby, to calculate the storm load attributable to their discharge. Graph plots of rainfall intensity, predicted and measured storm flows and predicted gully liquor discharge for storms analysed by this programme are presented in Appendix 2.4.

6.2.1 Pollutant Loads and Concentrations in Runoff

The mean and maximum concentrations for all storm events are summarised in Table 30, and for individual events in Tables 31 and 32. The figures are broadly comparable with results obtained from other developed residential catchments reported in Tables 1 and 2, for example, Zurich (Roberts et al, 1977) and Stevenage (Mance and Harman,1978). However, residential catchments, where building operations were still in progress, gave higher values of suspended solids and related pollutants, e.g. Oxhey (Wilkinson, 1956) and Rise Park (Tucker, 1975). Mixed, industrial, commercial and motorway catchments also yielded much higher levels of pollutants, e.g. M6 Motorway (Hedley, 1976), Oslo (Lindholm, 1978).

The distribution of the data is illustrated in Figure 94. Like the gully liquor quality data a positive skew is evident making the modal value commonly less than the mean value, e.g. suspended solids modal value is 0 to 50, whereas the mean value is 95; dissolved solids modal is 50 to 100, whereas the mean is 119. Runoff was not monitored during periods of road salting, therefore, extreme concentrations of dissolved solids and other parameters which were recorded in gully pot liquors have not influenced the distributions. Since the majority of storms monitored occurred in the summer months, the distribution may be considered as most representative of summer runoff only.

Comparing the average quality of the storm runoff with what might be expected from typical combined sewer overflow or secondary sewage effluent leads to the same conclusion as other studies. Namely, suspended solids concentrations are normally higher than the 30 mg/l limit recommended by the Royal Commission on Sewage Disposal for sewage effluent, whilst, BOD concentrations rarely exceed the recommended 20 mg/l. With the exception of nitrate, the levels of other parameters are generally lower than those in sewage effluent and combined sewer overflow.

6.2.1.1 Annual Pollutant Loads Discharged

The pollutant loads expected to be discharged from the catchment over a period of one year were calculated by three methods:-

a) Pollutant loads for all storm events with known rainfall were summed, divided by the total rainfall and the impervious catchment area to give the load per unit area per mm of rainfall. The result was multiplied by a typical annual rainfall of 600 mm

TABLE 30 Mean quality of stormwater runoff: summary of all results (concentrations in mg/l)

Constituent	Mean	Maximum	No. of Samples.
Suspended solids	94.5	882	257
Volatile S. Solids	26.8	60	22
Dissolved solids	119	492	183
BOD	8.7	44.5	125
COD	63.4	600 +	147
Nitrate - N	1.8	7.3	225
Ammoniacal - N	1.3	4.1	151
Chloride	58.3	179	41
pH	7.54	8.22	21
Calcium	14.5	48.6	166
Sodium	90.7	211	52
Potassium	2.2	3.46	58
Lead	0.29	0.44	4
Zinc	0.25	0.33	4
Cadmium	0.013	0.03	4
Copper	0.05	0.10	4
Chromium	0.009	0.01	4
Iron	4.3	5	3
Nickel	0.02	0.03	4
Manganese	0.05	0.08	4

TABLE 31 Mean Pollutant Concentrations for Individual Storm Events (mg/l)

Storm	Q (L/S)	SS	DS	BOD	COD	NO_3	NH_4
4	24	114	-	-	-	-	-
5	31	148	-	7.8	-	7.3	0.63
6	11	50	153	5.7	31	10.4	1.06
7	20	172	79	7.2	100	8.3	0.88
8a	15	31	77	5.7	8.3	3.9	0.23
8b	17	30	95	-	2.7	1.2	-
8c	16	13	107	-	-	4.7	0.06
9	5.9	139	258	14.2	89	11.7	1.24
10	9.2	155	375	27.1	159	31.5	2.05
11	3.2	295	368	31.8	314	-	5.30
12	26	68	150	-	41	-	-
13	37	51	110	5.8	34	8.0	0.76
15	14	22	51	5.7	86	5.1	0.56
16	9.4	27	70	2.6	38	6.1	0.24
17	15	92	124	5.3	66	4.5	0.24
18	10	30	136	7.4	32	9.1	1.17
19	5.4	46	107	8.1	23	5.2	0.41
20	16	15	87	6.4	19	6.9	0.35
21	7.8	372	138	-	233	5.6	-
22	8.6	126	181	-	103	10.0	-
23	4.4	32	110	-	37	6.6	-
24	35	84	71	-	75	3.9	-

TABLE 32 Maximum Pollutant Concentrations for Individual Storm Events (mg/l)

Storm	Q (L/S)	SS	DS	BOD	COD	NO_3	NH_4
4	71	226	-	-	-	-	-
5	138	332	-	13.0	-	22.0	1.60
6	24	69	265	6.7	49	11.7	1.25
7	65	292	152	12.3	157	12.3	1.40
8a	21	49	136	6.7	18	5.1	0.33
8b	48	30	136	-	-	6.9	0.15
8c	41	52	126	-	-	5.4	0.07
9	11	202	320	20.2	121	12.5	1.3
10	23	205	416	36.6	214	32.4	2.1
11	8	413	368	44.5	439	-	5.3
12	52	130	300	-	109	-	-
13	85	178	224	15.5	133	32.1	1.80
15	31	40	120	9.7	107	10.0	0.70
16	29	60	88	8.4	53	7.5	0.34
17	36	201	232	8.6	102	6.7	0.36
18	51	64	170	14.2	67	11.8	2.0
19	13	68	108	11.0	29	5.8	0.44
20	66	25	120	11.8	36	10.9	0.56
21	18	882	164	-	504	6.1	-
22	20	279	200	-	147	12.5	-
23	11	42	116	-	47	6.6	-
24	106	323	140	-	254	5.5	-

Fig. 94 - Frequency distributions for the concentrations of parameters in storm water runoff.

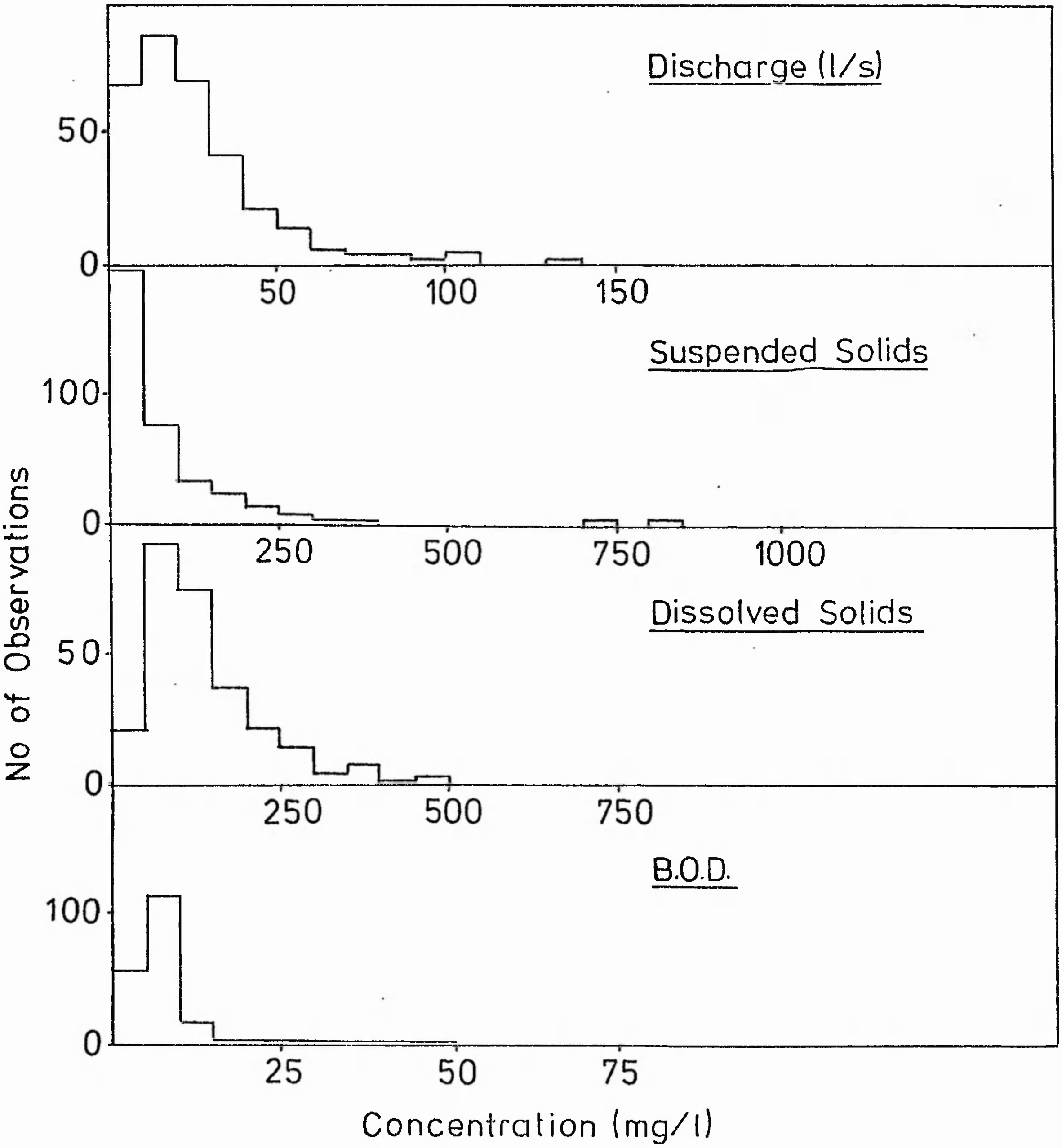


Figure 94 (continued)

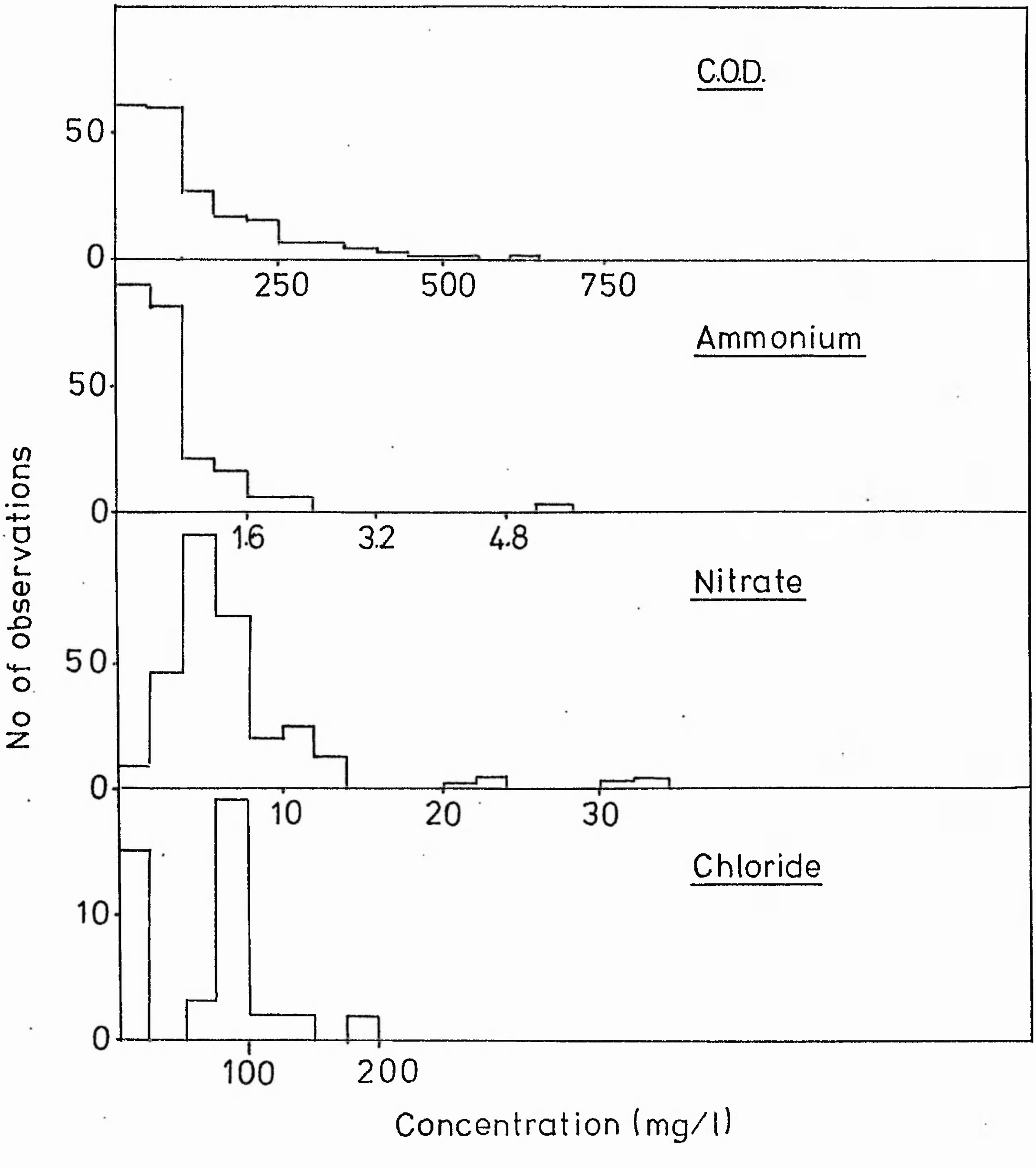


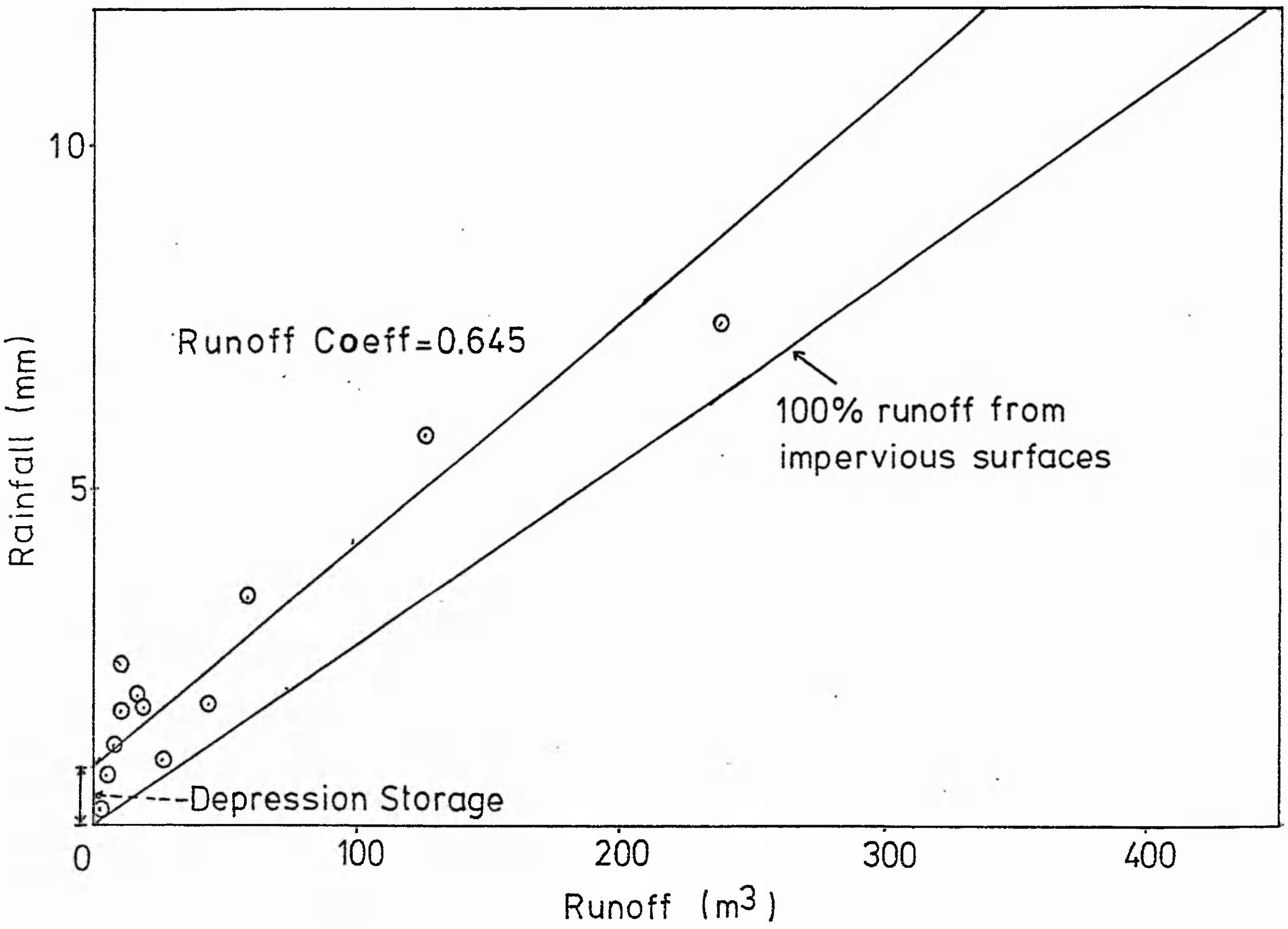
TABLE 33 Pollutant Loads for Individual Storm Events (kg)

Storm	Discharge (m^3)	SS	DS	BOD	COD	NO_3	NH_4
4	285	32.6	-	-	-	-	-
5	421	62.2	-	3.29	-	3.07	0.264
6	19.6	0.99	3.01	0.112	0.61	0.204	0.021
7	58.	10.03	4.6	0.421	5.82	0.484	0.051
8a	40	1.25	3.1	0.229	0.34	0.158	0.009
8b	43	1.28	4.03	-	0.12	0.052	-
8c	57	0.73	6.08	-	-	0.268	0.004
9	8.3	1.16	2.15	0.118	0.75	0.097	0.010
10	11.4	1.77	4.27	0.408	1.81	0.358	0.023
11	2.2	0.64	0.80	0.069	0.68	-	0.012
12	126	8.56	18.8	-	5.2	-	-
13	292	15.0	32.0	1.684	9.82	2.342	0.221
15	27	0.58	1.38	0.151	2.29	0.135	0.015
16	16.8	0.45	1.18	0.044	0.63	0.102	0.004
17	37	3.36	4.53	0.195	2.4	0.165	0.009
18	18.4	0.55	2.51	0.136	0.59	0.168	0.022
19	5.7	0.26	0.61	0.046	0.13	0.030	0.002
20	44	0.66	3.83	0.280	0.83	0.302	0.015
21	11	4.1	1.52	-	2.57	0.061	-
22	4.6	0.15	0.51	-	0.17	0.030	-
23	12.2	1.54	2.21	-	1.26	0.123	-
24	239	20.2	16.85	-	17.96	0.929	-

TABLE 34 Estimated annual pollutant loads discharged from the Clifton Grove catchment by three methods of calculation (see 6.2.1.1.) (kg/ha/annum)

	A	B	C
	Calculated for all events with known rainfall.	As 'A' but excluding storms 16,17,21	Discharge based calculation using all storms.
Suspended solids	229	295	306
Dissolved solids	276	371	417
BOD	11.9	11.9	27.7
COD	181	237	208
Ammoniacal - N	0.93	1.61	1.97
Nitrate - N	3.98	5.92	7.03

Fig. 95 - Relationship between rainfall and runoff for the storms monitored.



to give the estimated annual load:-

$$\text{Annual Load (kg/ha/annum)} = \frac{\Sigma(\text{Storm Load}) \times \text{Annual Rain}}{\Sigma(\text{Rainfall}) \times \text{Imp. Area}}$$

(13 storms were used in the calculation).

b) The same procedure was followed as above but eliminating storms 16, 17 and 21 where the entire storm may not have been sampled.

(10 storms were used in the calculation).

c) Storm loads for all events with reliable discharge measurements were summed and divided by the total discharge and impervious catchment area to give the load per unit area per cubic metre of runoff. Using a runoff coefficient of 0.645 (an average based on the events monitored, Figure 95) the annual load for 600 mm of rainfall was calculated:-

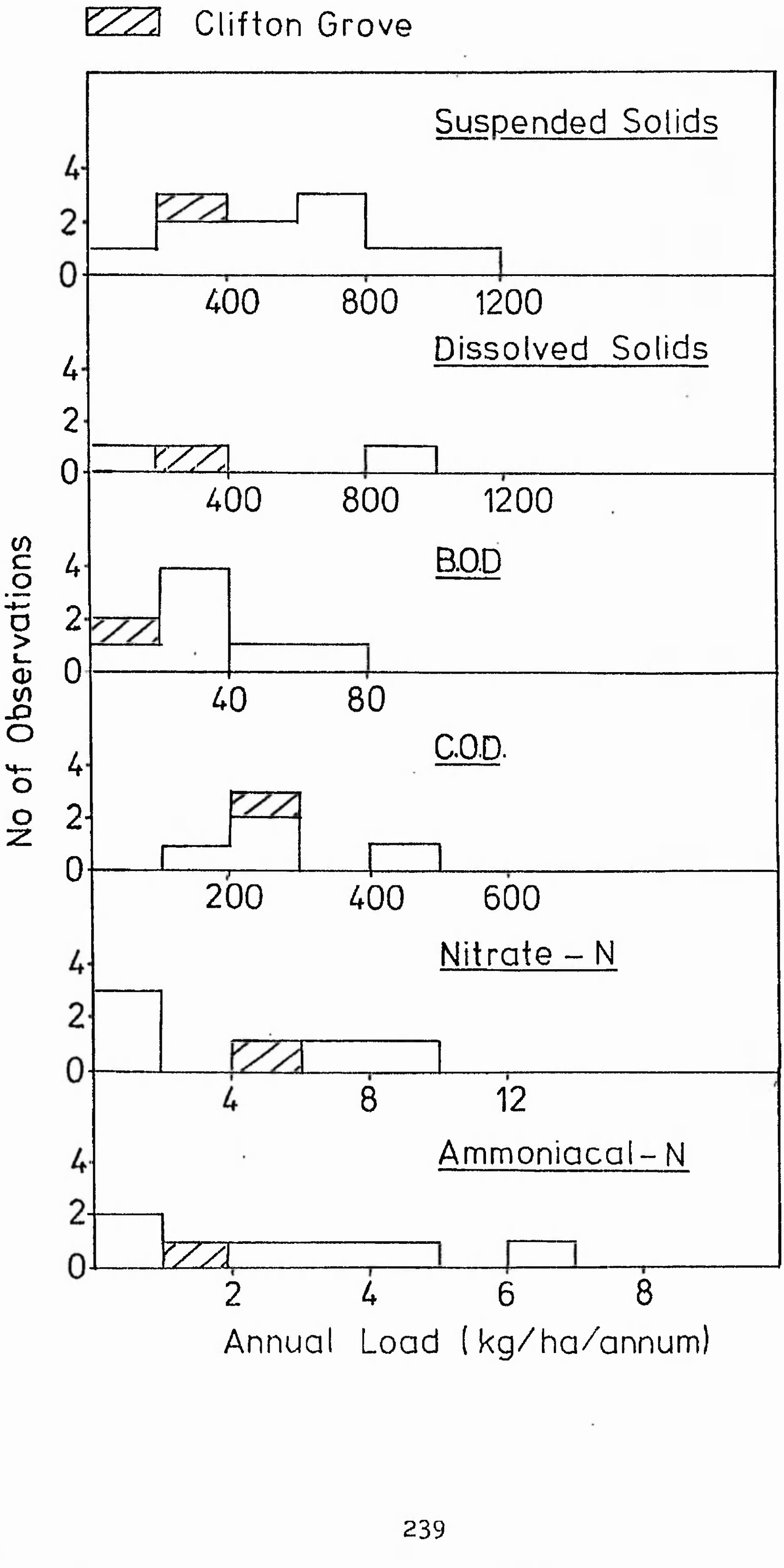
$$\text{Annual Load (kg/ha/annum)} = \frac{\Sigma(\text{Storm Load}) \times \text{Annual Rain} \times \text{Runoff Coeff.}}{\Sigma\ \text{Discharge}}$$

(20 storms were used in the calculation).

The results for the three methods are presented in Table 34. Variation between the three techniques serves to indicate how the method of calculation and the number of storms utilised may account for the wide variation in annual loads reported in the literature and further enforces the comments made in Section 1.2.3. The annual loads for the Clifton Grove catchment are broadly comparable to the values reported for other residential catchments (where a similar method of calculation was used, Table 3). The distribution of annual pollutant loads is shown in Figure 96. Difference in the annual rainfall used in the calculation may also account for some of the variation in the annual loads, for example, in the Zurich study (Roberts et al, 1977) low average concentrations were recorded, but a high annual rainfall resulted in the predicted loads being higher than average.

Since the Clifton Grove catchment is a new relatively clean and well kept residential estate, then the magnitude of the annual loads discharged serve to indicate the importance of stormwater runoff in influencing river water quality. When it is considered that a number of similar catchments and other catchments with potentially greater pollutant loads such as motorways, industrial and commercial areas may all discharge untreated runoff into one river, then the magnitude of pollution that

Fig. 96 - Distribution of annual pollutant loads for residential catchments.



may arise from this source is evident.

The relative importance of dustfall as a source of suspended solids in stormwater runoff can be estimated from the measured average dustfall deposition rate of 46.5 mg/m^2/day. Over one year this accounts for 170 kg or 55% of the 306 kg/ha of suspended solids load.

6.2.1.2 Relationships between Storm Loads, Discharge and Concentrations

It is to be expected that the greater the volume of runoff the greater will be the mass of pollutants discharged and, indeed, total storm loads show a good correlation for all parameters with total storm discharge (Figure 97). Because of the dominating influence of discharge in determining the pollutant load, relationships also exist between different pollutants, for example, suspended solids load with BOD and COD loads. Such relationships can be used with some success to predict the pollutant loads discharged on catchments where sufficient data is available to develop the regression equation, e.g. Bedient et al, (1978). These methods are advantageous in that only easily obtained data (e.g. total rainfall and the runoff coefficient) are needed for their application, however, they are limited since their use is only valid for the catchment for which the equation was developed.

To examine whether relationships exist between pollutants it is more meaningful to evaluate correlations between mean storm concentrations and thereby eliminate the dominating effect of discharge (mean storm concentration = total storm load/total storm discharge). Table 35 shows correlations between storm loads and Table 36 shows correlations between mean storm concentrations for all available data. It can be seen that, whereas strong correlations exist between many parameters when storm loads are considered, correlations between mean storm concentrations are fewer and more tenuous. For this data set the suspended solids concentration shows a good correlation with only one parameter, that is COD. This finding indicates that, although good correlations exist between suspended solids load and other pollutant loads, the technique of using suspended solids concentration as a means of predicting the concentrations of other pollutants in runoff though the application of 'pollutant potency factors' as practised in SWMM (Metcalf and Eddy, 1971) and STORM (Roesner et al, 1974), may not be valid. The use of these factors (simple ratio between pollutants) relies upon the strong correlation that exists between discharge and pollutant loads,

Fig. 97 - Correlations between pollutant loads and cumulative discharge for individual storm events.

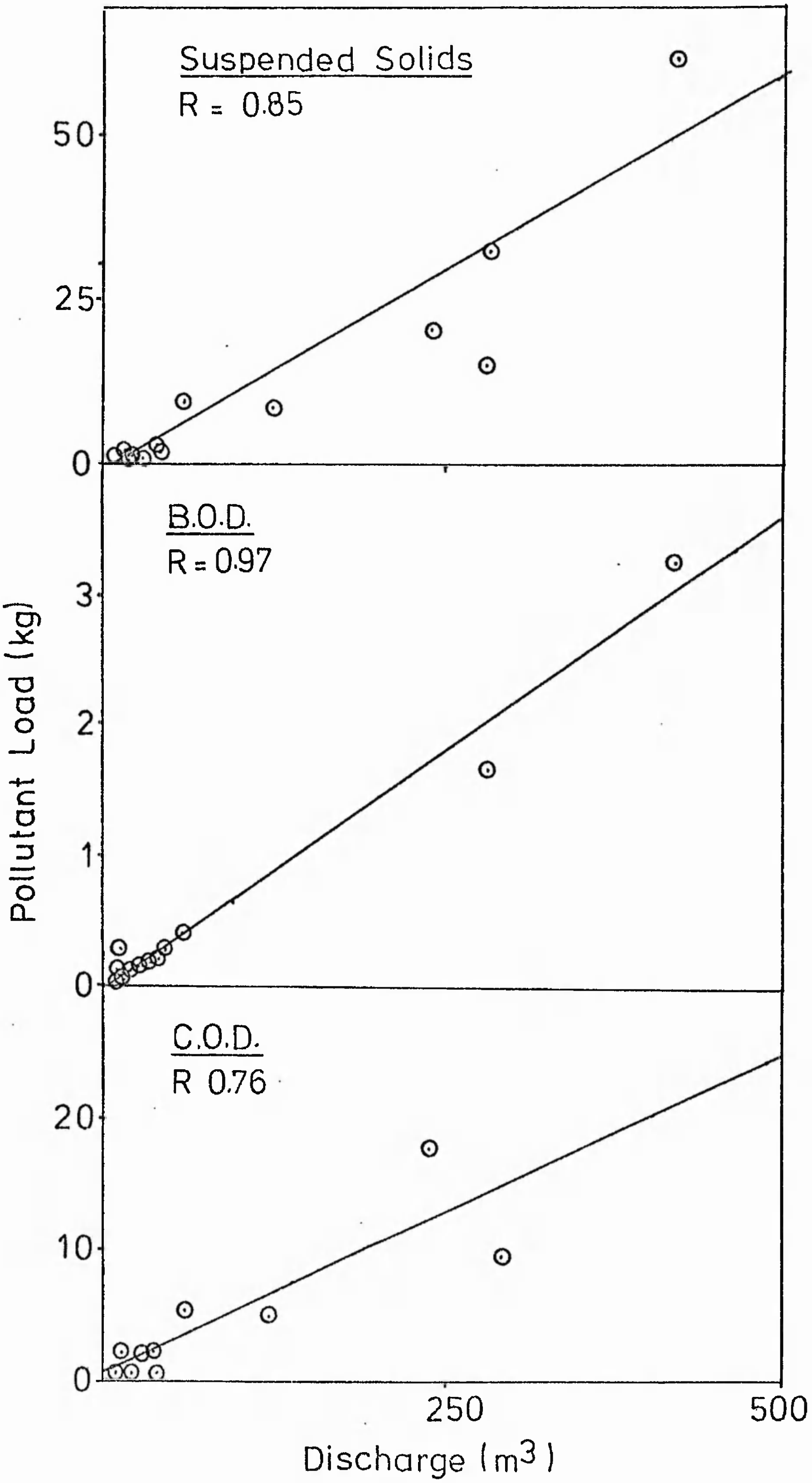


Figure 97 (continued)

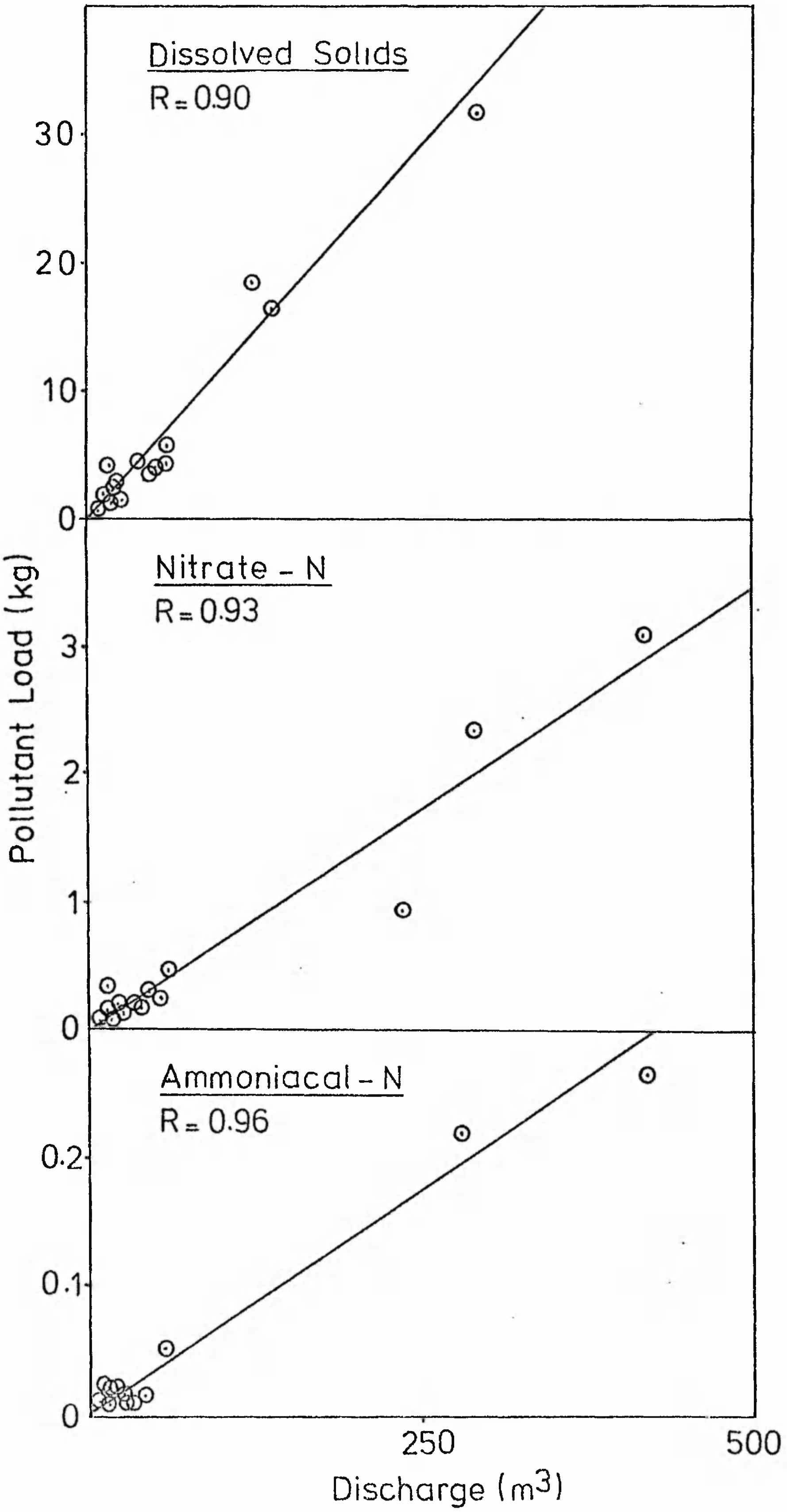


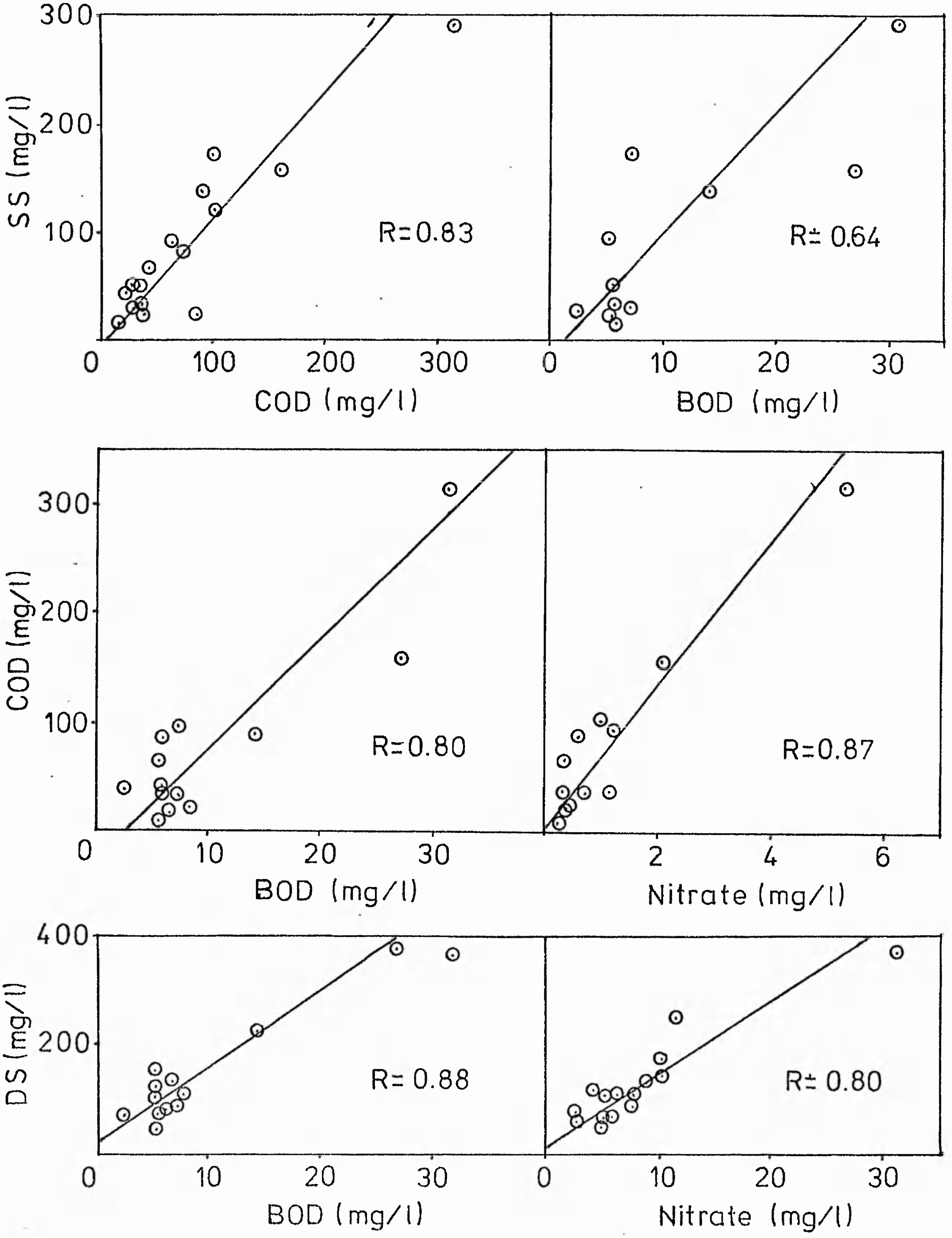
Table 35 Correlation matrix for storm loads (all available data)

	Discharge	SS	DS	BOD	COD	NO_3
SS	0.85	-	-	-	-	-
DS	0.90	0.65	-	-	-	-
BOD	0.97	0.94	0.97	-	-	-
COD	0.76	0.93	0.54	0.83	-	-
NO_3	0.93	0.80	0.96	0.96	0.47	-
NH_4	0.96	0.77	0.94	0.93	0.84	0.99

Table 36 Correlation matrix for mean storm concentrations.

	Q	SS	DS	BOD	COD	NO_3
SS	-0.32	-	-	-	-	-
DS	-0.49	0.30	-	-	-	-
BOD	-0.54	0.34	0.88	-	-	-
COD	-0.38	0.84	0.21	0.60	-	-
NO_3	-0.23	0.07	0.80	0.88	0.18	-
NH_4	-0.48	0.41	0.03	0.71	0.87	0.79

Fig. 98 - Some correlations between mean storm concentrations



the extension of this relationship to the prediction of concentrations and the pollutant runoff profile (pollutograph) will not be reliable, since discharge is no longer the determining parameter.

The strong correlations that exist, for both loads and concentrations, between COD and suspended solids indicate that the COD is largely determined by oxidizable organic material carried in suspension. However, with the exception of very high suspended solids concentrations, the results suggest that suspended solids exert less influence on BOD. Good correlations were also indicated between BOD, ammonium and dissolved solids, however, in this instance a direct relationship between the parameters is unlikely but, for example, common accumulation and removal processes or a common dependency upon some other factor is plausible.

6.2.1.3 Relationship of Pollutant Loads and Concentrations with Meteorological Parameters.

Since pollutant loads exhibit a strong correlation with storm discharge it is an attractive proposition that pollutant loads could be predicted with greater accuracy through the use of easily determined meteorological parameters such as rainfall volume and intensity. Multiple regression analysis is an ideal tool for obtaining such a relationship and also for investigating the dependency of storm loads upon a number of different factors. The analysis was undertaken using 13 storms, which satisfied the data requirements, and which were judged to be reliable. Pollutant loads for suspended solids, dissolved solids, BOD, COD, nitrate and ammonium were related to the following meteorological parameters (the data matrix used is shown in Table 37).

a) Storm duration (DUR) in minutes.
b) Runoff Volume (ROVOL) in cubic metres
c) Average rainfall intensity (AVIN) in mm/hr.
d) Average rainfall intensity for the most intense ten minutes (AV 10) - mm/hr.
e) Peak rainfall intensity (PI) mm/hr.
f) Rainfall volume (PPT) mm
g) Volume of the previous event (SPE) in mm.
h) Length of the antecedent dry period (ADP) in days.

Table 37 Meteorological parameters for storms utilised in the multiple regression analysis.

Storm No.	DUR	ROVOL	AVIN	AV10	PI	ADP	AWI	PPT	SPE
6.	107.000	60.369	0.975	3.978	7.020	0.000	46.200	1.755	1.900
7.	39.000	116.713	5.090	15.093	21.060	0.000	44.300	3.393	0.200
9.	35.000	40.246	1.950	3.510	7.020	0.000	46.300	1.170	3.300
15.	54.000	33.299	1.056	2.877	3.379	0.000	48.700	0.968	0.200
16.	111.000	64.081	0.998	2.824	3.997	0.000	45.100	1.863	1.900
19.	27.000	27.125	1.690	2.616	6.808	0.000	46.900	0.789	3.100
20.	54.000	61.901	1.963	3.325	5.657	1.000	47.700	1.800	4.500
24.	107.000	254.778	4.115	11.278	19.131	0.000	48.000	7.407	2.800
12.	151.000	197.780	2.270	4.914	7.020	0.000	49.700	5.750	0.200
10.	38.000	60.369	2.700	5.967	14.040	7.000	57.000	1.755	0.100
11.	6.000	8.049	2.340	2.340	3.510	6.000	56.000	0.234	1.200
17.	115.000	294.743	4.432	8.619	13.756	0.000	45.700	8.569	2.200
21.	175.000	83.274	0.825	2.566	3.947	0.000	45.100	2.421	0.200

i) Antecedent wetness index (AWI) defined as:-

$$AWI = 50 + ADP - (R1 + \frac{R2}{2} + \frac{R3}{3} + \frac{R4}{4} + \frac{R5}{5})$$

where R1 = rainfall on the previous day

R2 = rainfall two days prior to the event.

Not all of the parameters were used in any one analysis, parameters that reflected similar facets of a storm event were usually not paired up, e.g. runoff volume was not paired with rainfall volume. The results of some of the analyses for different combinations of parameters are presented in Appendix 2.5.

The strong relationship between pollutant load and runoff volume has been discussed previously and not surprisingly the total rainfall volume was found to be the most significant parameter for all pollutants. The measures of dry period, ADP and AWI, showed little correlation with any of the pollutants, nor was the size of the previous event of any significance. Measures of storm intensity, AVIN, AV10 and PI, were of considerable importance for suspended solids and COD, but were of less singificance for dissolved solids, where the storm duration assumed more importance. These differences may be explained by the fact that the removal of suspended solids is governed by the rainfall intensity needed to dislodge and transport particles trapped in small crevices on the road surface, whereas dissolved solids will be transported regardless of rainfall intensity.

All of the analyses gave high coefficients of determination indicating that the technique should provide a good means of predicting pollutant loads for any catchment where sufficient data is available to formulate an equation. Again, the applicability of such an equation to other catchments is likely to be limited. The results of the analysis confirm the findings of Mance and Harman (1978) that the characteristics of the current rainfall event are of the most importance in determining the magnitude of the pollutant load, the antecedent dry period and the size of the previous rainfall event are of little importance. However, the small size of the data set and the limited number of storms, with antecedent dry periods of one day or more, combine to make the results only tentative.

Since storm loads have been shown to be strongly dependent upon the total rainfall volume, it is hardly surprising that there is much conflicting evidence in the literature concerning the influence of the antecedent dry period on storm runoff quality (see Section 1.2.3.2). In a regression analysis of ADP against storm load any influence the ADP may exert on runoff quality is masked by the characteristics of the current event. It is of more use to investigate the relative significance of other meteorological parameters by examining their relationship with mean storm concentrations and thereby eliminate the influence of the rainfall volume.

Multiple regression analysis of mean storm concentrations with meteorological parameters confirmed that the total rainfall volume (PPT) and the duration of the rainfall event (DUR) became of little significance for all of the pollutants examined. The analysis for suspended solids showed the limitation of the small size of the data set. When Storm 11 was excluded from the analysis, then measurements of rainfall intensity (PI, AVIN, AV10) were of the most significance. However, when it was included in the analysis, then the antecedent dry period became the most significant parameter. This anomaly can be explained by the nature of Storm 11, the event combined a strong first flush effect, and hence high concentrations for all pollutants, with a short rainfall event of low intensity (only one sample was collected) after a period of 7 days dry weather. For dissolved solids concentrations the only meteorological parameters of any significance, both including and excluding Storm 11, were the dry period measures. None of the parameters showed any significance for COD, BOD, nitrate and ammonium except when Storm 11 was included in the analysis when the dry period measures became of the most importance.

The multiple regression analysis for all of the pollutants was characterised by weak correlations, low coefficients of determination and high standard errors (see Appendix 2.5). However, the results point to the antecedent dry period, although being of no importance in determining the total storm load, being of some significance in influencing the concentration in runoff. This is probably particularly true for the early, or first flush, phases of runoff.

6.2.2. Variations in Quality during Runoff. The Mode of Removal of Pollutants.

Observations for individual storm events on quality variations during runoff and the mode of removal of pollutants are presented below, along with possible limitations of the data. All data and graphs are presented in Appendix 2.3.

6.2.2.1 Observations for each Storm

Storm 1 - 6th November 1976
Storm 2 - 6th December 1976
Storm 3 - 17th December 1976

No flow or rainfall data was available for these three storms which were used for preliminary testing of the sampling equipment.

Storms 1 and 2 showed suspended solids rising to a peak concentration, whereas, for storm 3 suspended solids remained low and constant. With the exception of storm 2, the soluble components show a steady decline in concentration throughout the storm. Storm 2 was influenced by road salting by residents following some frosty weather. Consequently, both dissolved solids and chloride rise to peak values, which precede the suspended solids peak, indicating the relative ease of mobilisation of soluble material on road surfaces compared to solid material. The initial low values of these components is explained by earlier runoff from roofed areas not influenced by road salting.

Storm 4 - 9th June 1977
Storm 5 - 27th June 1977

Although discharge was monitored for these two storms, no rainfall intensity data was available. The storms were used for testing the operation of the lithium chloride doser.

Storm 4 shows a clear relationship between flow rate and suspended solids concentration. The two main flow peaks are followed by peaks in suspended solids concentration lagging behind by 12 and 4 minutes. In spite of its duration, this storm shows no indication of solids exhaustion, which may be explained by the stage of development of the catchment: building was still in progress in two parts of the catchment and open ungrassed areas and piles of building sand provided a supply of solid material for easy removal by runoff. The storm provides an interesting comparison with later storms when the catchment was fully developed and confirms that far greater solids loads can be expected from catchments still under development.

Storm 5 is a very long and complex event for which the flow data

Fig. 99 - Storm 4 Discharge (l/s), suspended solids concentration (mg/l)

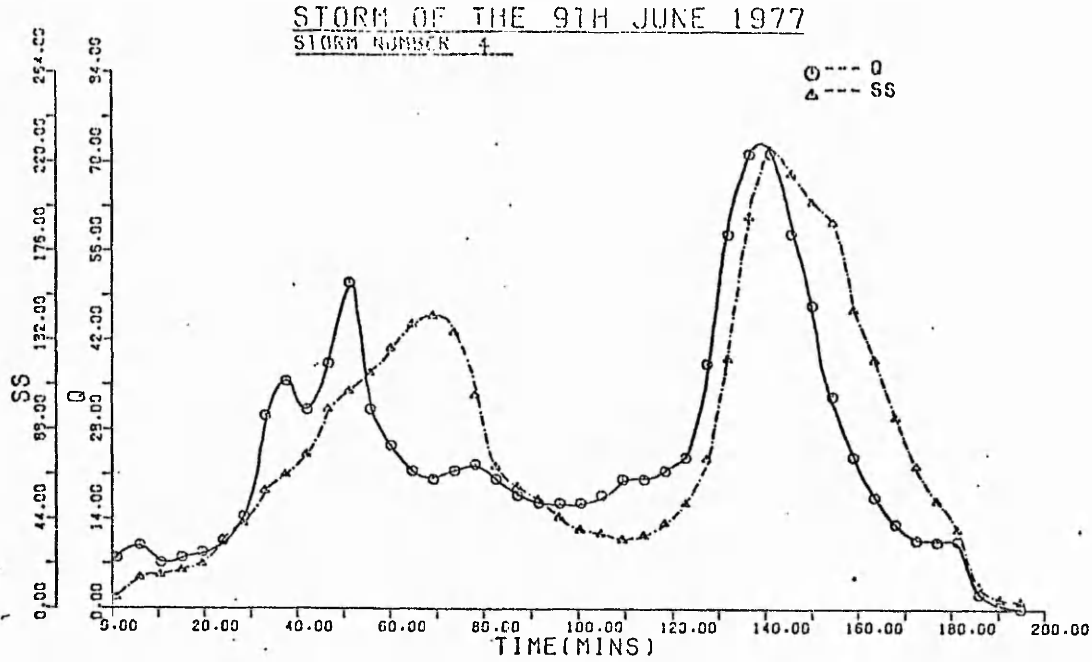


Fig. 100 - Storm 4 Percentage cumulative discharge (CQ) and suspended solids (CSS).

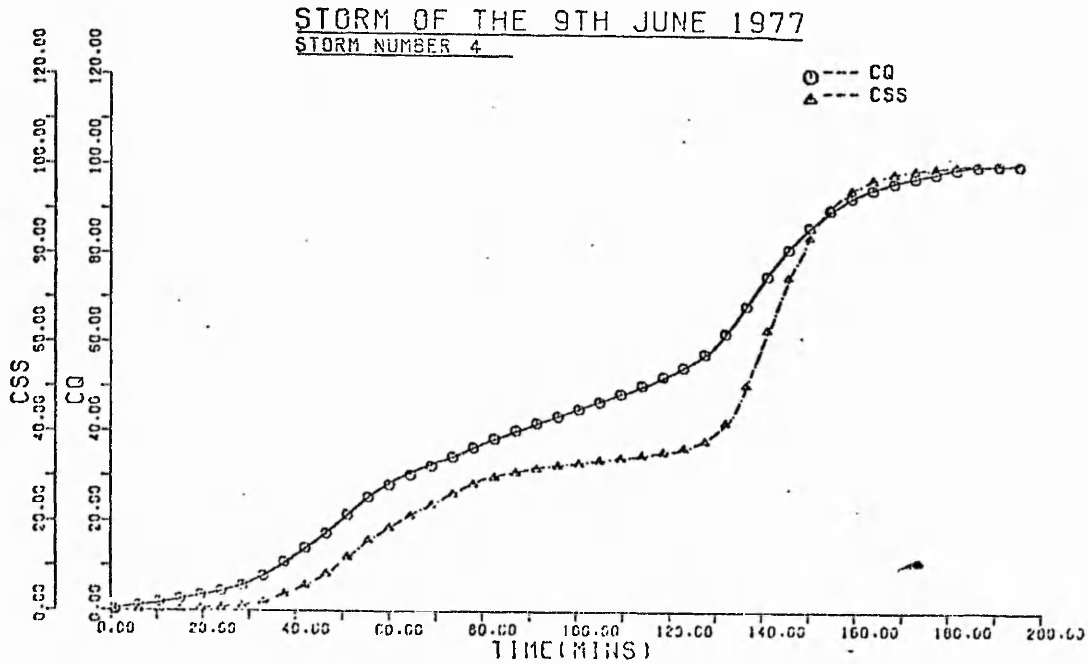


Fig. 101 - Storm 5 Percentage cumulative discharge (CQ) and suspended solids (CSS).

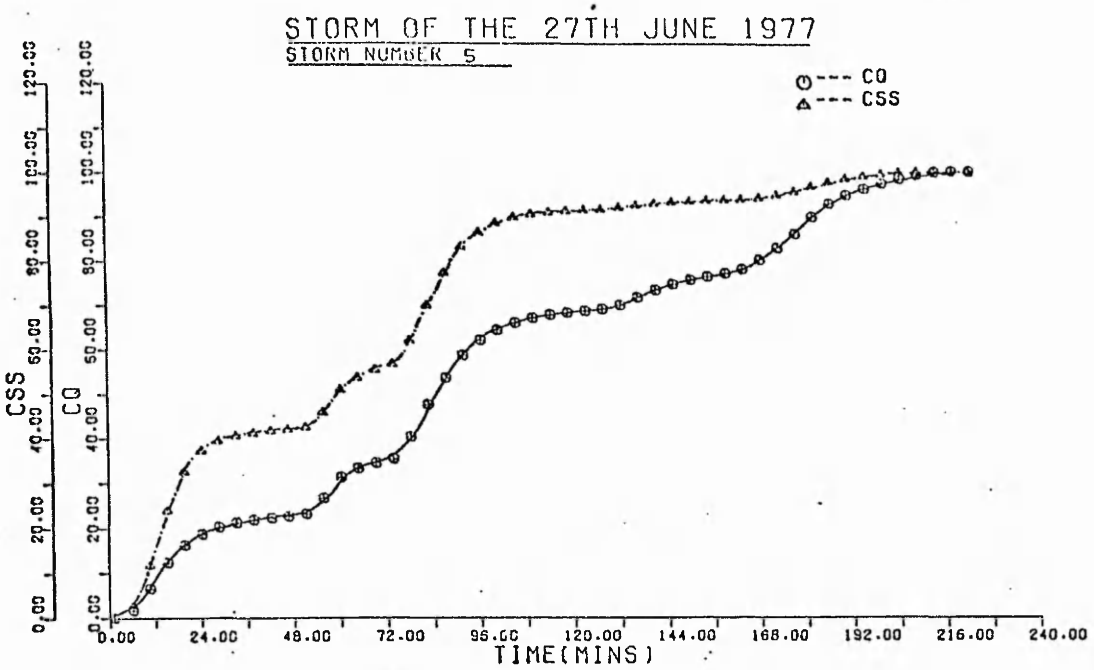


Fig. 102 - Storm 7 Discharge (l/s), suspended solids and COD concentration (mg/l)

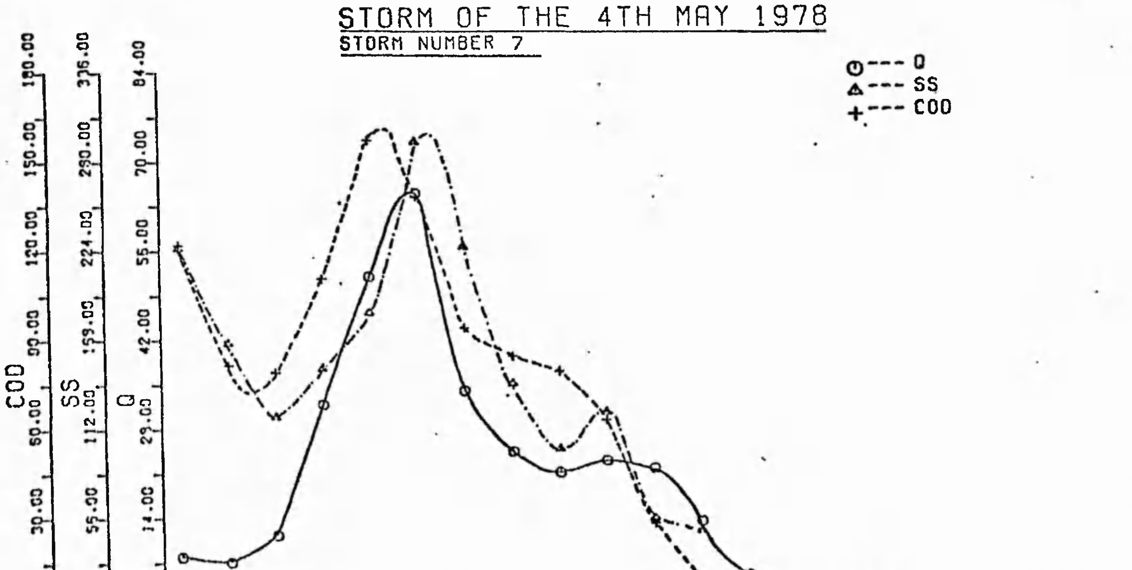


Fig. 103 - Storm 7 - Nitrate, ammonium and calcium concentration (mg/l)

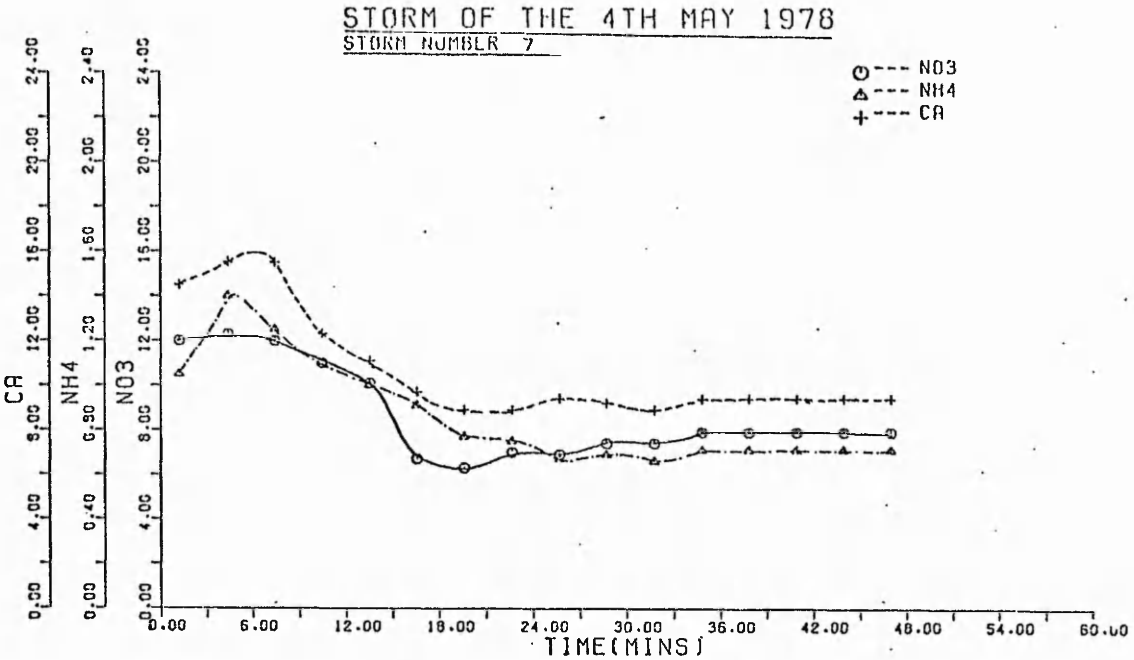
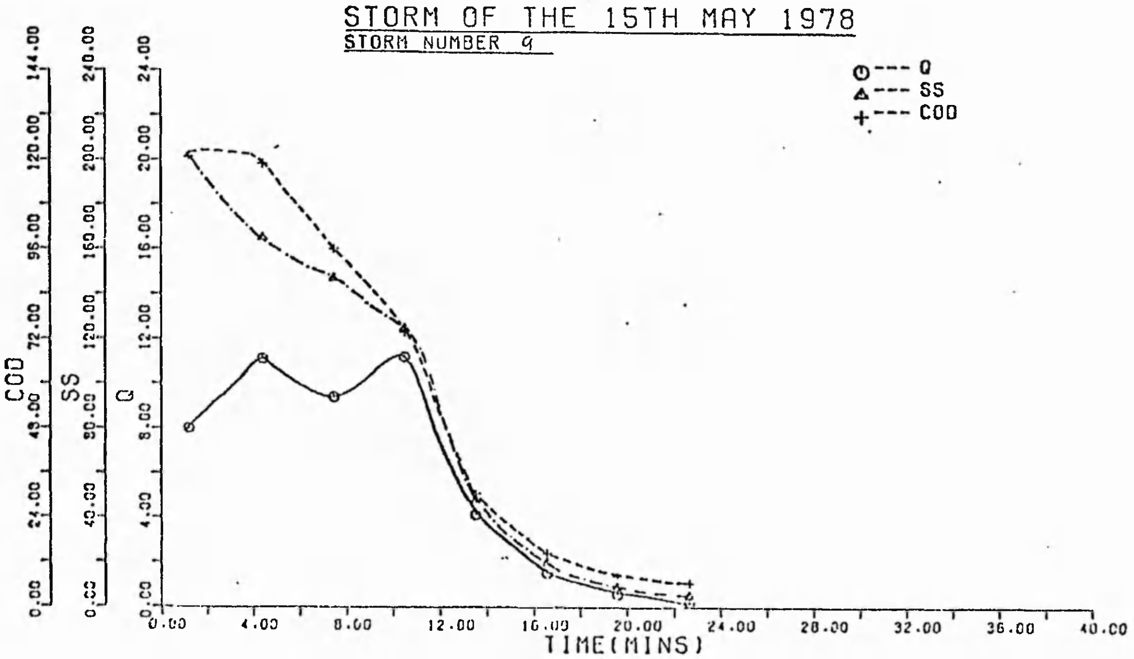


Fig. 104 - Storm 9 Discharge (l/s), suspended solids and COD concentration (mg/l)



may be available. The storm was preceded by 11 days of dry weather and, as expected, exhibited a strong first flush of suspended solids. There was also some indication of solids exhaustion as peaks in suspended solids concentration became smaller towards the end of the storm.

Storm 6 - 2nd May 1978

The lithium doser failed to operate for this storm and flow values applicable to the six samples collected were predicted using the rainfall runoff model.

Storm 7 - 4th May 1978

The storm was characterised by a single peaked hydrograph. The suspended solids and COD curves showed a similar profile, with peak concentrations being coincident with peak runoff. High initial values of both suspended solids and COD when flow rates were low indicated an initial, or first flush, phase of flow independent removal of solid material. BOD and the soluble components - nitrate, ammonium and calcium showed similar removal patterns, a steady decline from initial high values. Although all the parameters exhibited a first flush effect in terms of concentration, the cumulative load plots do not indicate a first flush in terms of pollutant load.

Storm 8 - 5th May 1978

No rainfall intensity data was available for this long duration, but low volume, storm. Outfall flow rate was low, usually less than 30 l/s, and consequently the sampler was activated on three separate occasions (8A, 8B, 8C). The heavy storm on the 4th May, which effectively washed the catchment clean and the low flow rates, resulted in low concentrations for the majority of pollutants.

Storm 9 - 15th May 1978

This was a short duration, low intensity event for which only 4 samples were collected. Suspended solids and COD concentrations both exhibited high concentrations for the first sample, followed by a decline in concentration, which was not related to flow rate.

Storm 10 - 24th May 1978

This storm was of a similar nature to Storm 9, being of short duration and low intensity, during which only 3 samples were collected. However, it was preceded by 7 days dry weather. In spite of the dry period the suspended solids concentrations were similar in both storms, which suggests that high initial values of solids in the runoff may be attributed, not to the wash-off of fine solids settled on impervious areas, but to the flow independent removal of sediments settled in the sewer from the previous storm event. The concentrations of COD, BOD, dissolved solids, and ammonium were all much higher than in storm 9 and indicate that some degradation of solids had taken place, either in the sewer or in gully pots.

Storm 11 - 31st May 1978

A very short storm of only 0.23 mm and 6 minutes duration (only one sample was collected), after a period of 6 days dry weather. The storm is of some interest, since the mathematical model predicted that the rainfall was insufficient to satisfy depression storage on the roads and runoff occurred only from roofs. In spite of probably being composed purely of roof runoff, the one sample collected was of very poor quality with a suspended solids concentration of 413 mg/l, COD of 439 mg/l and ammonium of 5.3 mg/l. Again the result is a strong indication that the degradation of sediments, settled in the pipe network after the previous storm and their subsequent resuspension by the early phases of runoff of the next storm, is of significance in determining the poor quality of the first flush. The high ammonium concentration suggest that the sediments, possibly trapped in shallow, sludge-rich pools within the pipe system, had undergone anaerobic degradation. It seems unlikely that roof deterioration could account for such high concentrations of both solids and ammonium.

Storm 12 - 1st June 1978

A long and complex storm of variable rainfall intensity which resulted in multiple flow peaks. The mathematical model indicated that sampling commenced some 30 minutes after the time expected.

Like discharge, the suspended solids concentration showed multiple peaks, but there was little relationship between the two. Some suspended solids peaks were coincident with peaks in discharge, but some apparently preceded them, whilst others lagged behind. COD concentrations exhibited a similar behaviour. Dissolved solids showed high initial values which may be due to the flushing out of gully pot liquors that were not removed during Storm 11 and had, therefore, some 7 days to degrade.

Storm 13 - 15th June 1978

No rainfall intensity data was available for this long storm which comprised four major peaks in discharge. The storm followed a period of 7 days dry weather.

Fig. 105 - Storm 10 - Discharge (l/s), suspended solids and COD concentration (mg/l)

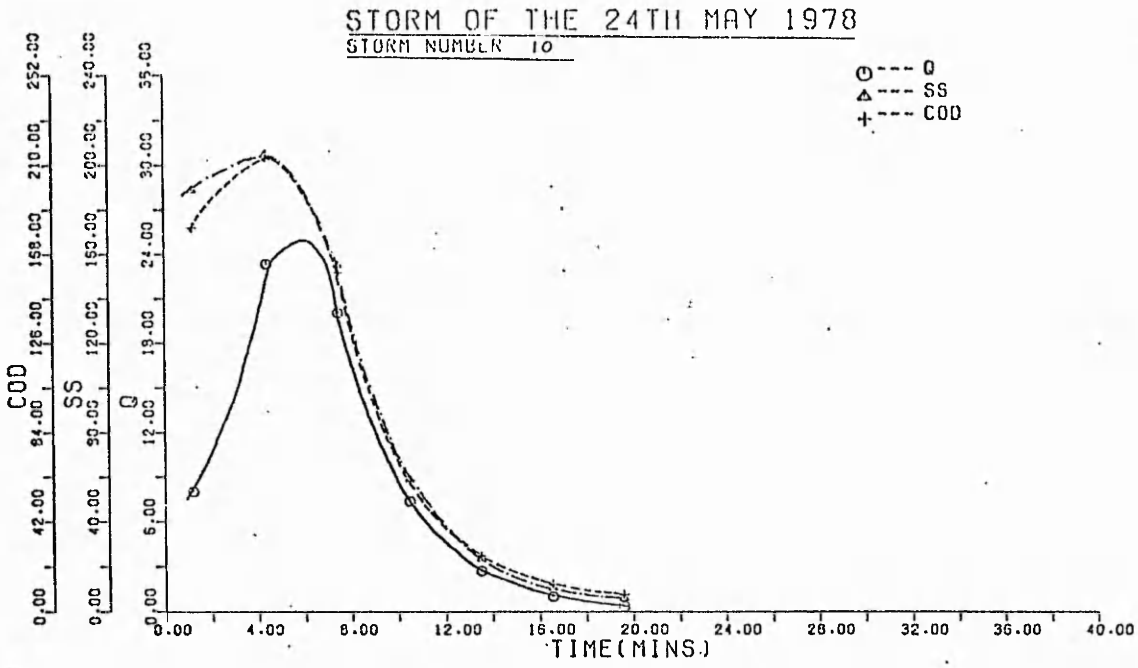


Fig. 106 - Storm 10 Nitrate, ammonium and calcium concentration (mg/l)

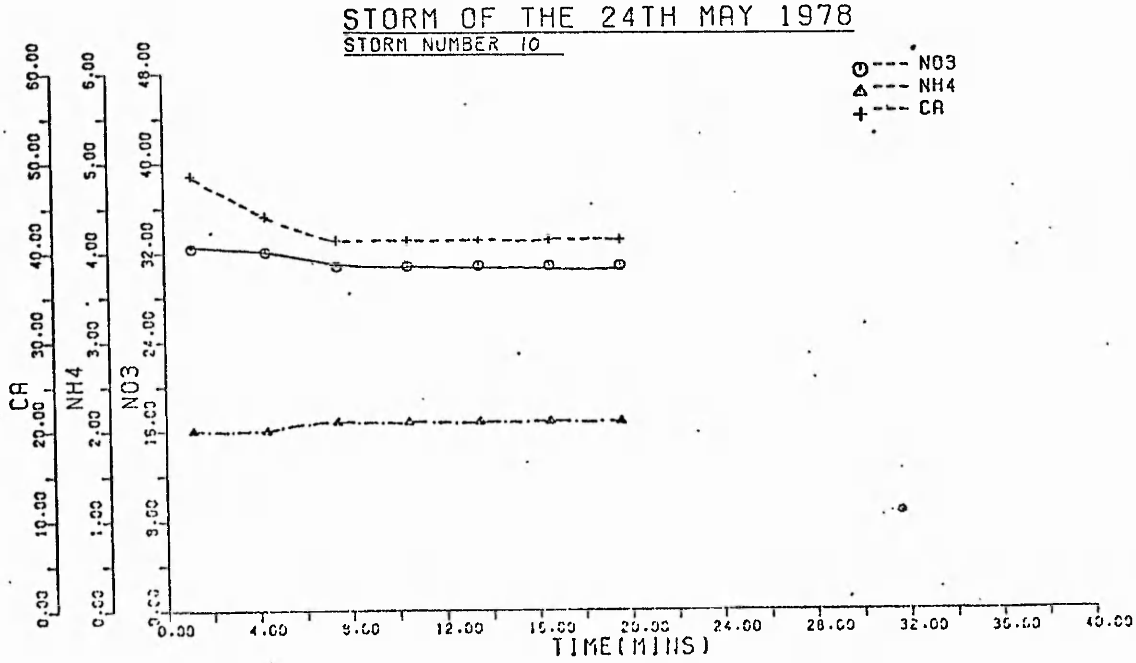


Fig. 107 - Storm 15 Discharge (l/s), suspended solids and COD concentration (mg/l)

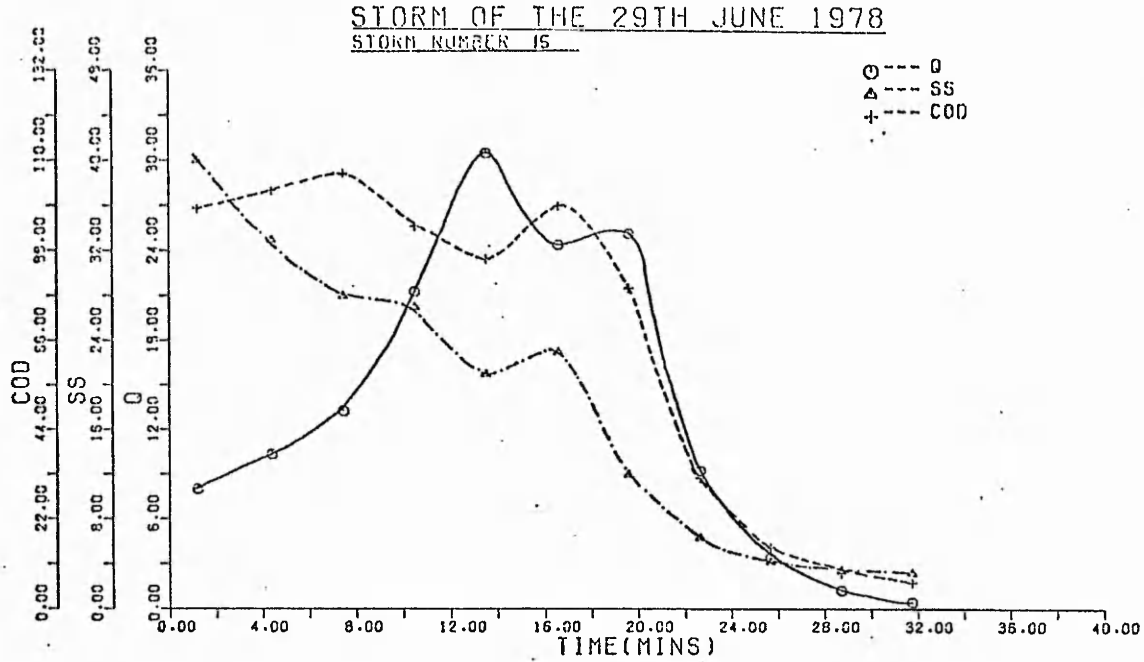
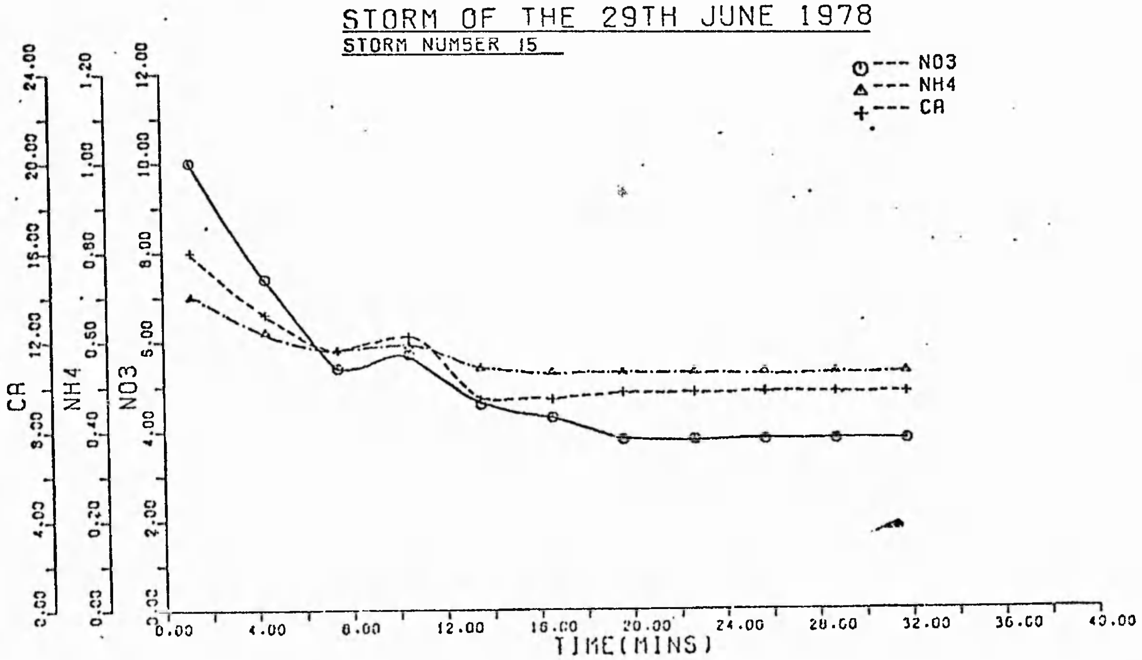


Fig. 108 - Storm 15 Nitrate, ammonium and calcium concentration (mg/l)



Moderately high ammonium concentrations in the first flush phase of runoff suggest that some degradation of gully pot liquors and sewer sediments had taken place. A first flush, flow independent, removal of suspended solids, BOD and COD was also evident. The storm was of sufficient duration to exhibit exhaustion of solids from the catchment. Both suspended solids and COD show high initial values, which fall rapidly, with no significant rises in their concentration associated with peaks in discharge.

Storm 14 - No samples collected

Storm 15 - 29th June 1978

Another short duration, low intensity storm with discharge not exceeding 31 l/s. Suspended solids and COD concentrations are also low and again show no relationship to discharge. For small storms such as this, the first flush concentration effect appears to dominate the shape of the pollutant runoff curve with the removal of solids showing little, if any, relationship to the shape of the outfall hydrograph. Soluble components again exhibited a steady decline from high initial concentrations.

Storm 16 - 1st July 1978

A short duration, low intensity storm of similar nature to storm 15 and exhibiting similar effects.

Storm 17 - 3rd July 1978

A long duration and complex event which, according to the mathematical model, was only partially sampled. All parameters again show peak concentrations for the first samples, with a general decline in concentration throughout the period of monitoring. The suspended solids curve showed only small humps that were coincident with peaks in discharge.

Storm 18 - 19th July 1978

No rainfall intensity data was available for this storm, which was another of short duration and low intensity. The storm followed a period of 10 days dry weather and, although high ammonium concentrations were recorded, the concentrations of COD and suspended solids were both low. Nevertheless, all parameters exhibited a first flush effect, with suspended solids and COD both showing the typical high initial concentrations followed by a steady decline, unrelated to changes in discharge.

Storm 19 - 23rd July 1978

A very short storm for which only 2 samples were collected. Low concentrations of all parameters were recorded.

Storm 20 - 26th July 1978

A storm of medium duration but low intensity with flow rates not exceeding 40 l/s. All parameters exhibited the typical removal patterns outlined above for this type of storm; a general decline in concentration throughout the storm, with little relationship to discharge.

Storm 21 - 27th July 1978

A long duration but low intensity storm with flow rate rarely exceeding the value necessary for sampling to commence, resulted in only 4 samples being collected approximately 2 hours after runoff had commenced. In view of these circumstances and the fact that there had been no dry weather for some weeks, it is surprising that exceptionally high suspended solids and COD concentrations were recorded for the first two samples. Dissolved solids concentrations were low and constant and, therefore, consistent with the nature of the event.

Storm 22 - 30th July 1978
Storm 23 - 30th July 1978
Storm 24 - 30th July 1978

These storms form part of a complex series of rainfall events on the 30th July which were sampled in three sections. Four samples were collected for Storm 22 and two samples for Storm 23. Storm 24 was the main runoff event and was composed of several peaks in discharge.

The first of the sampling periods, Storm 22, showed the highest dissolved solids concentrations, which probably represented the first flush of soluble material from the catchment. The storm also exhibited a first flush of solid material.

The second sampling period, Storm 23, was judged to form the initial stages of the main sampling period Storm 24. The entire storm is a good example of both a strong first flush of solids and, subsequently, of solids exhaustion. The initial phases of runoff (Storm 22) were of low flow rate and were not efficient in the removal of either solids on the impervious surfaces or of solids settled in the sewer. Sediment may have been partially transported by this event but not discharged from the catchment resulting in greater quantities of solids in the sewer than

Fig. 109 -Storm 24 Discharge (l/s), suspended solids and COD concentration (mg/l)

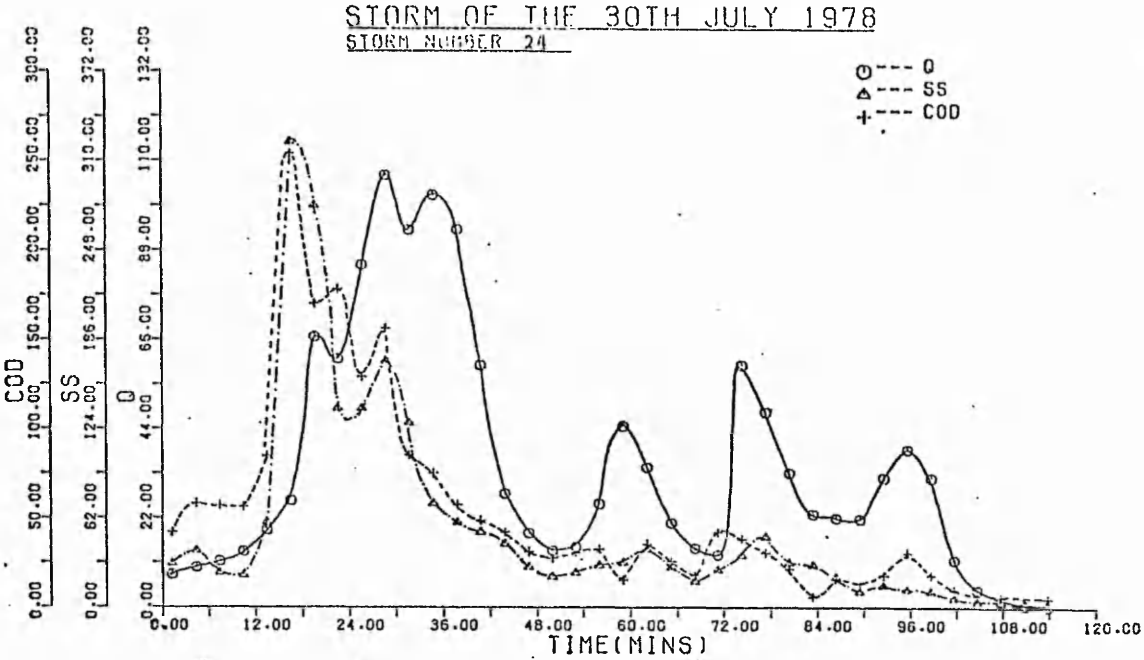
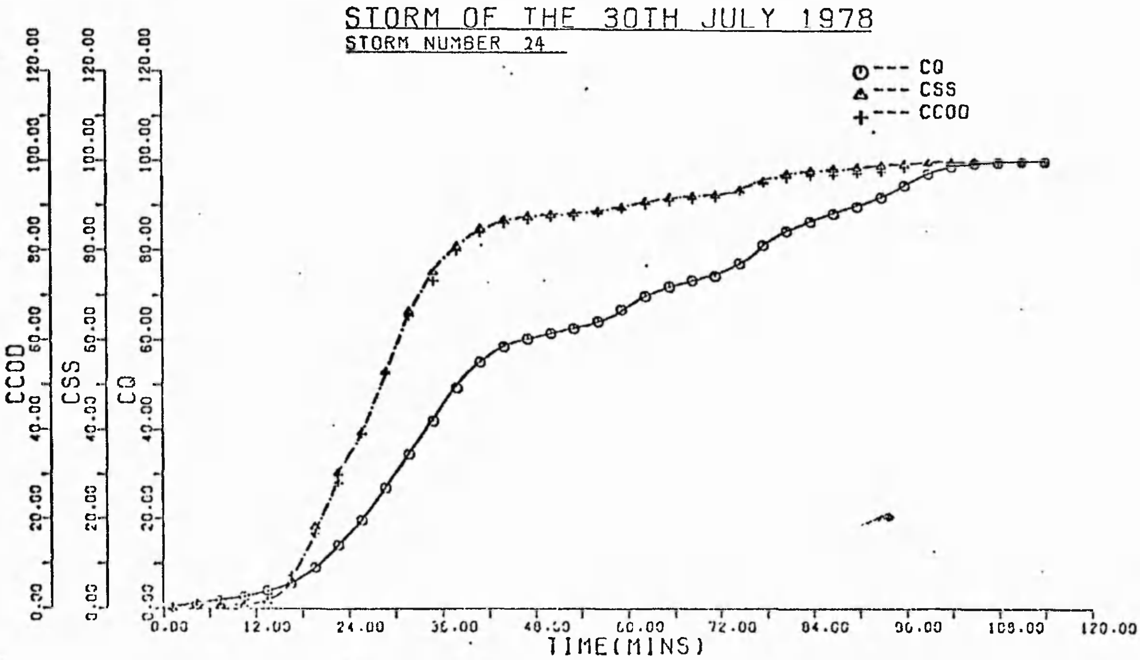


Fig. 110 - Storm 24 Percentage cumulative discharge (CQ) and suspended solids (CSS)



existed prior to Storm 24. The rapidly rising flow at the start of Storm 24 caused an equally rapid flushing out of this material and resulted in a peak in suspended solids concentration of 323 mg/l prior to any peak in discharge. The solids concentration then fell sharply, with the occurrence of only small rises in concentration related to peaks in the discharge hydrograph, indicating that the catchment had been flushed clean of the majority of solids available for transport. COD concentrations bore a close relationship to suspended solids. Dissolved solids and nitrate concentrations, although variable maintained the same concentration at the end of the storm, as at the beginning, indicating that the majority of soluble material had been removed in the first phase of runoff (Storm 22).

6.2.2.2 Conclusions on the Mode of Removal of Pollutants by Stormwater Runoff.

The removal of pollutants in stormwater runoff is most conveniently discussed in two sections: the removal of soluble species and the removal of solid and solid related components.

Soluble material on urban surfaces and in the atmosphere are rapidly and easily taken into solution by flowing or falling water, the uptake per unit volume being independent of the intensity of the rainfall or the rate of flow of the overland runoff. Consequently, the shape of the pollutant removal curve of soluble species is characterised by high initial concentrations, followed by a steady decline in concentration, until a constant value is approached at the end of a storm (e.g. Storms 7 and 10). However, the rate of decline in concentration is dependent upon the volume of runoff; for an intense storm with high flow rates, the rate of decline will be more rapid than for a milder storm. The initial concentrations in runoff may be dependent upon a number of factors, but the results indicate that the antecedent dry period is probably of the most importance. The longer the antecedent dry period the greater will be the accumulation of soluble pollutants on urban surfaces and the greater will be the degradation of sediment trapped in gully pots and in sewers resulting in the release of soluble compounds, e.g. Storm 10 exhibits high dissolved species concentrations after 7 days dry weather. Additionally, the nature of the previous storm event must be taken into consideration, if the event was of low rainfall volume then efficient cleansing of the catchment or flushing out of the gully pots may not have occurred, e.g. Storm 12 had an effective antecedent dry period of zero, however, the previous event, Storm 11, was of low volume and no road runoff occurred, resulting in high dissolved solids concentrations being recorded for Storm 12. The initial concentrations of components, whose prime source is washout from the atmosphere, will be influenced by local industrial activity, seasonal residential activity, e.g. burning of coal and the prevailing wind direction. In the winter the concentrations of particular soluble components will be largely determined by road salting.

Of the species monitored, the behaviour outlined above was typical of dissolved solids, nitrate and ammonium. Peaks in the pollutant runoff curve can occur for soluble components, but are considered to be due to the lag time between roof and road runoff and the configuration of the sewer system. For example, roofs are less susceptible to polluting activities than roads and runoff from roofs will generally have lower pollutant concentration. Since depression storage is minimal for roofed areas, the early phases of runoff will be dominated by roof runoff, which has lower dissolved pollutant concentrations. When the percentage of road runoff at the sampling point increases, this may result in a peak in concentration, e.g. dissolved solids and chloride in Storm 2. However, if high concentrations of soluble components are deposited in the sewer, then this effect may be masked.

The mode of removal of solid material is considered as occurring in two fractions:-

a) Fine sediments and particulates that are removed independent of flow rate and comprise the first flush.

b) Heavy particulates whose removal is dependent upon flow rate.

The fine dust fraction behaves similarly to soluble components and is believed to be of most importance in determining the quality of the first flush. As for soluble compounds, fine particulates are rapidly and easily transported by flowing water and their removal appears to be independent of the rate of runoff. This results in high concentrations of suspended solids occurring in the early phases of runoff, which were unrelated to peaks in discharge and were found to be characteristic of many of the events monitored, e.g. Storms, 7, 9, 10, 15, 16, 18, 22 and 24. Therefore the first flush of solid material may be ascribed to the flow independent removal of sediments from the following sources:-

a) Fine solids accumulated on roof and road surfaces from atmospheric dustfall.

b) Fine sediments deposited in sewers on the recession limb of the previous storm.

c) Fine sediments deposited in gully pots on the recession limb of the previous storm.

d) Dusts, sediments and other material (bacterial scums) in suspension and input to gully pots over dry periods.

e) Break-up of sediments in sewers and gully pots through anaerobic degradation over dry periods.

For storms of short duration with low flow rates, the first flush removal of sediments, outlined above, dominates the shape of the suspended solids runoff curve, e.g. Storms 9, 10, 15, 16, 18, 20. The results suggest that sediments deposited in the sewer are of the most importance in defining the first flush of solid material for this type of event (see Storms 9, 10 and 11, Section 6.2.2.1).

The removal and transport of heavy particulates on impervious surfaces is largely determined by the rate of overland flow and the intensity of the rainfall event. Consequently, peaks in discharge result in peaks in solids concentration. It is usual for the solids peak to lag behind the runoff peak, due to the development of different vertical velocity and concentration profiles in the sewer. The position of mean solids concentration in a cross-section would typically be below the position of mean flow velocity, as a result, the mean velocity of solids transport is less than that of the fluid, causing a lag between flow and concentration peaks, e.g. Storm 4. The results show the time lag to be variable, which may be due to different particulate distributions being available for transport for different storms and/or variation in the removal of different particle sizes in individual storm events. Sources of material removed in this manner include soil eroded from pervious areas, such as gardens, during heavy rainfall, and material from the breakup of road surfaces, sands and grits. When all solid material on urban surfaces has been removed, or when rainfall is no longer sufficiently intense to erode material from pervious areas or transport heavy particulates, then solids exhaustion occurs. This is apparent, at the end of a storm, when peaks in runoff occur that are not matched by peaks in solids concentration, e.g. Storms 5, 13 and 24. The occurrence of solids exhaustion is believed to be dependent upon the state of development of the catchment. For example, Storm 4, in June 1977, was a large event composed of two major runoff peaks and it showed no signs of solids exhaustion compared to similar storms in the summer of 1978. In June 1977, development of the catchment had not reached completion, exposed piles of builders sand and ungrassed areas provided a ready supply of erodable solids, whereas in 1978 development was complete. The result suggests that substantially higher pollutant loads can be expected from catchments under development.

The behaviour, outlined above, will also apply for other solids related parameters such as volatile suspended solids, oxygen demand and heavy metals. The ratio of COD and BOD to suspended solids for long events was commonly found to fall throughout the storm. This reflects the preferential occurrence of organic material in the fine solids fraction, heavier particulates being typically composed of the largely inorganic sand and grit fractions. COD removal was found to closely follow that of suspended solids, the ratio of COD to suspended solids tending to be greater for small storms than for large, due to the effect described above. However, BOD concentration, although influenced by high solids concentrations, did not imitate the pattern of solids removal, but tended to follow a hybrid curve between the solids and soluble behaviour. The removal of oil and organic compounds created during anaerobic degradation of sediment would typically be the same as the removal of soluble components and appears to be of equal influence as solids in determining the shape of the BOD removal curve.

6.3. THE CONTRIBUTION OF POLLUTANTS IN GULLY POTS TO STORMWATER RUNOFF

The contribution of stored water in gully pots prior to a runoff event to the total storm runoff volume was examined using the mathematical model described in Section 5.1.5. The model predicted the flow, throughout the hydrograph, attributable to the discharge of original gully liquors. A knowledge of the average concentration of pollutants in gully pots prior to the storm event enabled the pollutant load from gully pots to be calculated.

Since the discharge of gully pollutants was likely to be of more importance in the initial phases of a storm their contribution to the first flush was examined using a definition of the first flush based upon the discharge of gully liquors (Section 5.1.5). Pollutant contributions from gully pots were assessed for all storms where analyses of gully pot liquors prior to the storm event were available. The contribution for other storms, where no such information was available, was assessed using model values for the pollutants, judged from the annual survey.

6.3.1 Gully Liquor Contributions

As expected, the model indicated that, even for the heaviest storms, not all of the stored liquors were discharged. The maximum recorded discharge was 86% of the total original gully liquors for a storm of some 9 mm. Typically, between 50% and 70% were discharged for storms of 2 and 3 mm (Figure 111 Table 38). At the sewer outfall, gully pot liquors contributed up to 17% of the total runoff volume. Their contribution was of most significance for storms of 1 to 3 mm and became of less importance for high volume storms (Figure 112). For storms of less than 1 mm, roof runoff predominated and for storms greater than 5 mm gully liquors became depleted. A similar pattern of contribution was observed for the first flush with the maximum percentage contributions occurring for storms of 1 to 3 mm. However, for storms of 1 to 3 mm, the contributions were only marginally greater than to total storm runoff. For heavier storms a substantially greater contribution to the first flush occurred than to total runoff.

6.3.2 Pollutant Contributions

Tables 39 and 40 list the percentage contributions of pollutants stored in gully pots to the total storm load and to the first flush load. Again, pollutant contributions were of most significance for storms of 1 to 3 mm, percentage contributions decreasing for the larger storms, e.g. dissolved solids, Figure 113. Laboratory studies had indicated that the contribution of suspended solids through the resuspension of bottom sediments was only of significance for the more intense storms when inlet flows to gully pots exceeded 0.2 l/s. For the majority of storms this situation did not occur and the suspended solids contribution was derived only from material already in suspension in gully pots. Consequently, a low suspended solids contribution was recorded for most storms reflecting this fact and illustrating that gully pots are not an important source of solids in storm runoff. Of the other constituents investigated significant contributions were found for all of them in some events, contributions up to 49% for COD were recorded, 30% for BOD, 25% for nitrate and 40% for dissolved solids. The average percentage contribution for all constituents exceeded the average contribution of 11.3% for gully liquors to total storm runoff, showing that the liquor is relatively more polluted than some other components of storm runoff, ie. roof runoff. Ammonium showed the greatest contributions suggesting

Fig. 111 - Relationship between the percentage of gully liquor removed during a storm and the rainfall volume.

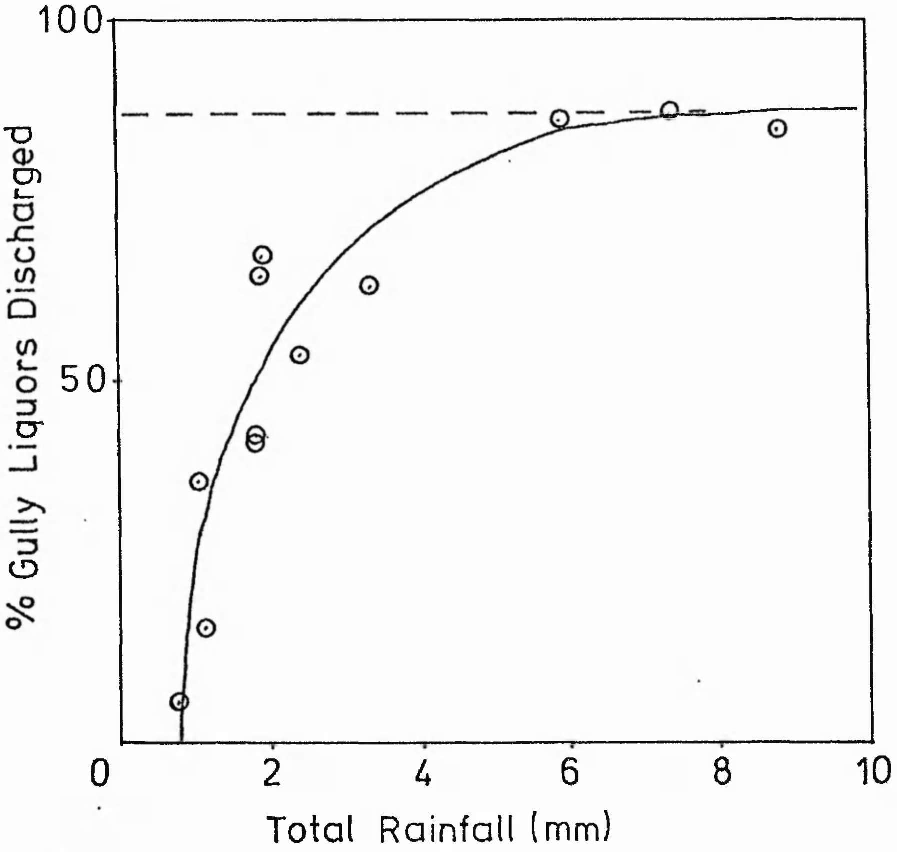


Fig. 112 - The percentage contribution of gully liquors to total runoff volume and first flush runoff volume for varying rainfall volume.

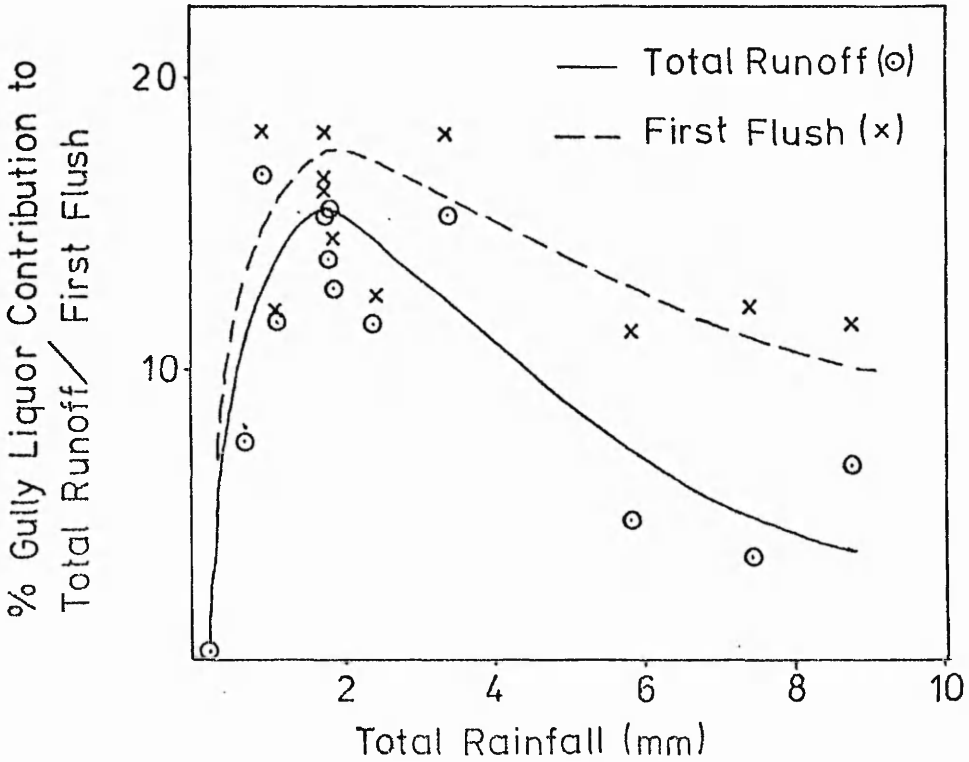


Fig. 113 - The percentage contribution of dissolved solids in gully liquors to the total storm load and to the first flush load for varying rainfall volume.

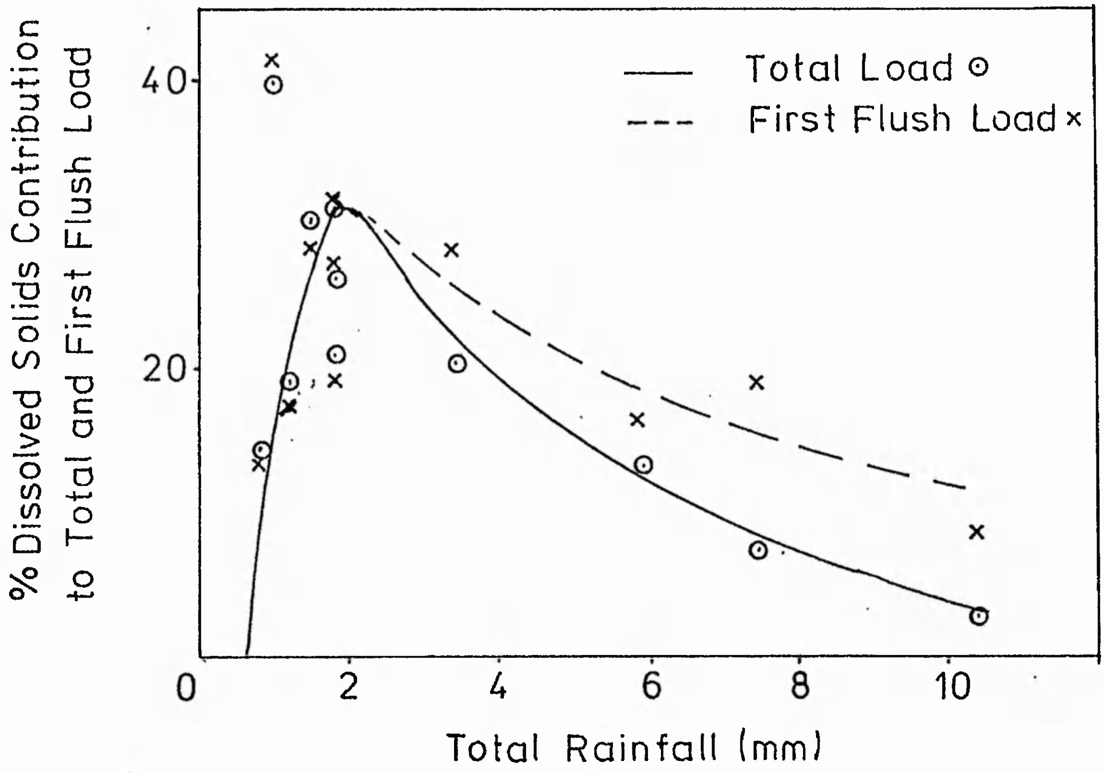


Fig. 114 - The percentage contribution of nitrate in gully liquors to the total storm load and to the first flush load for varying rainfall volumes.

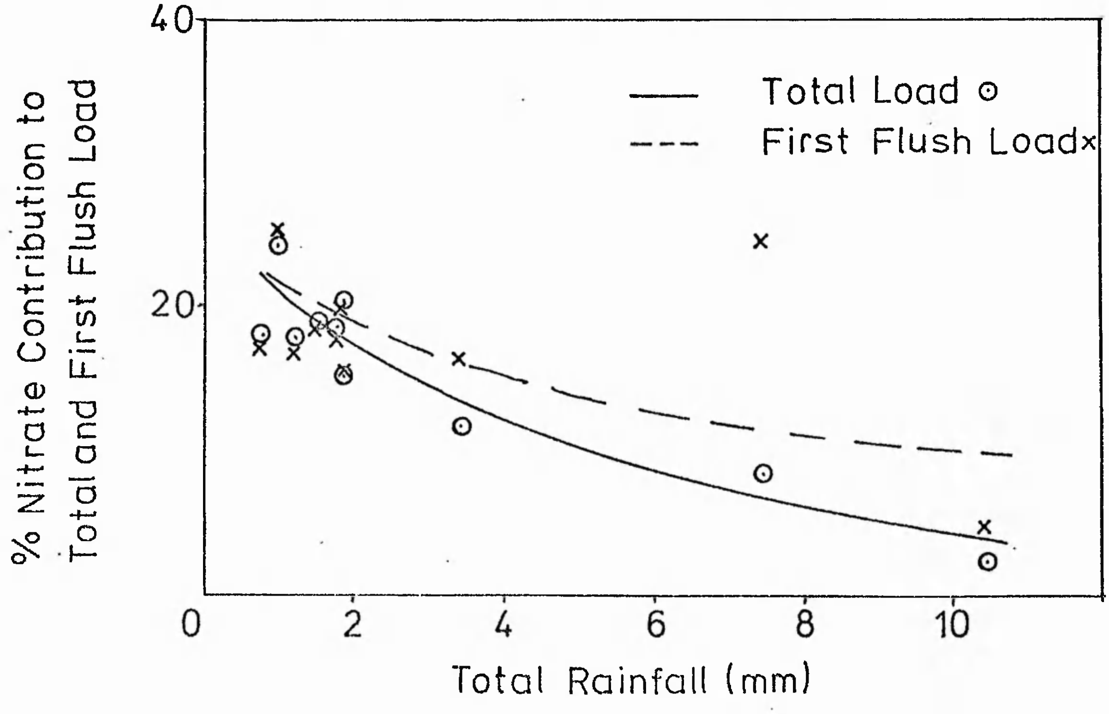


Table 38 Details of the first flush and gully liquor contributions to total runoff and the first flush (total gully liquor volume = 10.02 m^3)

Storm Number	6	7	9	10	12	15	16	17	19	20	21	24	Mean
Rainfall (mm)	1.8	3.39	1.17	1.76	5.87	0.97	1.86	8.57	0.79	1.8	2.42	2.74	-
Storm Duration (min)	86	40	40	44	153	162	105	116	33	56	178	111	94
Total runoff volume (m^3)	28.94	42.53	14.52	48.09	190.53	22.73	52.90	131.72	7.94	50.72	48.77	243.44	73.6
Volume of gully liquors dis. (m3)	4.42	6.53	1.69	4.44	8.94	3.83	6.79	8.82	0.61	7.02	5.59	8.99	5.64
Volume of first flush (m^3)	22.15	32.53	13.05	24.63	71.63	19.07	42.21	68.79	7.46	40.81	40.18	67.65	37.5
First flush duration (min)	54	22	28	34	63	44	85	69	28	41	147	23	53
% Gully liquors discharged	42.5%	62.8%	16.3%	42.7%	86%	36.8%	65.3%	84.8%	6.0%	67.5%	53.8%	86.5%	54.3
% gully liquors contribution to total runoff	15.3%	15.4%	11.6%	15.7%	4.7%	16.8%	12.8%	6.7%	7.7%	13.8%	11.5%	3.4%	11.3
% gully liquors contribution to first flush	18%	18.2%	11.8%	16.5%	11.3%	18.2%	14.6%	11.6%	7.7%	15.7%	12.5%	12.2%	14.0
% first flush volume to total runoff.	76.5%	(58.5) 76.5%	89.9%	51.2%	37.6%	83.9%	79.8%	52.2%	94.0%	80.5%	52.4%	27.8%	69.4%
% first flush duration to storm duration	62.8%	55%	70%	77%	41.2%	71%	81%	59.5%	84.8%	73.2%	82.6%	20.7%	64.9%

TABLE 39 Percentage of pollutant contributions from gully pots to the total storm load.

	SS	DS	COD	BOD	NO_3	NH_4
6	13	21.3	42.2	30.4	18.8	20.2
7	1.9	20.5	6.5	12.0	11.7	12.3
9	4.3	18.2	12.1	12.2	18.0	31.0
10	7.3	31.2	5.1	6.4	15.3	29.8
12	3.0	13.3	19.4	-	-	-
13	4.4	3.8	3.9	2.7	2.6	9.5
15	19.1	40.2	9.7	19.5	24.6	24.5
18	22.4	30.5	47	12.6	19.8	80.9
19	6.9	14.7	27.6	10.4	18	30
20	31.0	26.5	49.2	19.3	20.2	45.3
24	3.2	7.7	2.9	-	8.4	-
Mean	10.6	20.7	20.5	13.9	15.7	31.5

TABLE 40 Percentage of pollutant contributions from gully pots to the first flush load.

	SS	DS	COD	BOD	NO_3	NH_4
6	11.7	19.6	38.1	27.6	17.4	19.1
7	2.3	28.5	7.6	15.5	16.1	16.1
9	3.9	16.9	10.9	11.1	16.8	28
10	7.3	31.2	6.4	5.1	15.3	29.8
12	3.5	16.7	21.9	-	-	-
13	11.8	8.9	8.9	7.0	4.8	19.7
15	18.5	41.5	9.7	19.4	25.5	27.6
18	20.2	28.2	42.5	11.5	18.2	76.3
19	6.3	13.8	25.0	9.4	17.0	27.0
20	31.0	27.6	46.9	19.0	20.2	43.7
24	5.4	18.6	3.8	-	24.7	-
Mean	11.1	22.9	20.2	14.0	17.6	31.9

TABLE 41 Percentage of pollutant loads discharged in the first flush

	SS	DS	COD	BOD	NO_3	NH_4
6	99.7	97.6	99.7	99.1	97	95.2
7	73.6	64.9	76.9	69.6	65.3	68.6
9	99.2	96.7	99.9	100	96.9	100
10	89.6	89.8	71.3	85.3	89.9	91.3
12	77.7	71.6	79.6	-	-	-
13	36.8	40.0	39.7	35.1	48.4	43.4
15	93.3	87.2	89.6	90.7	86.6	80.0
18	99.8	97.3	99.7	99.3	97.6	95.4
19	100	95.9	99.2	100	96.7	100
20	85	86.4	99.4	91.4	89.7	93.3
24	52.7	37.3	68.6	-	30.5	-

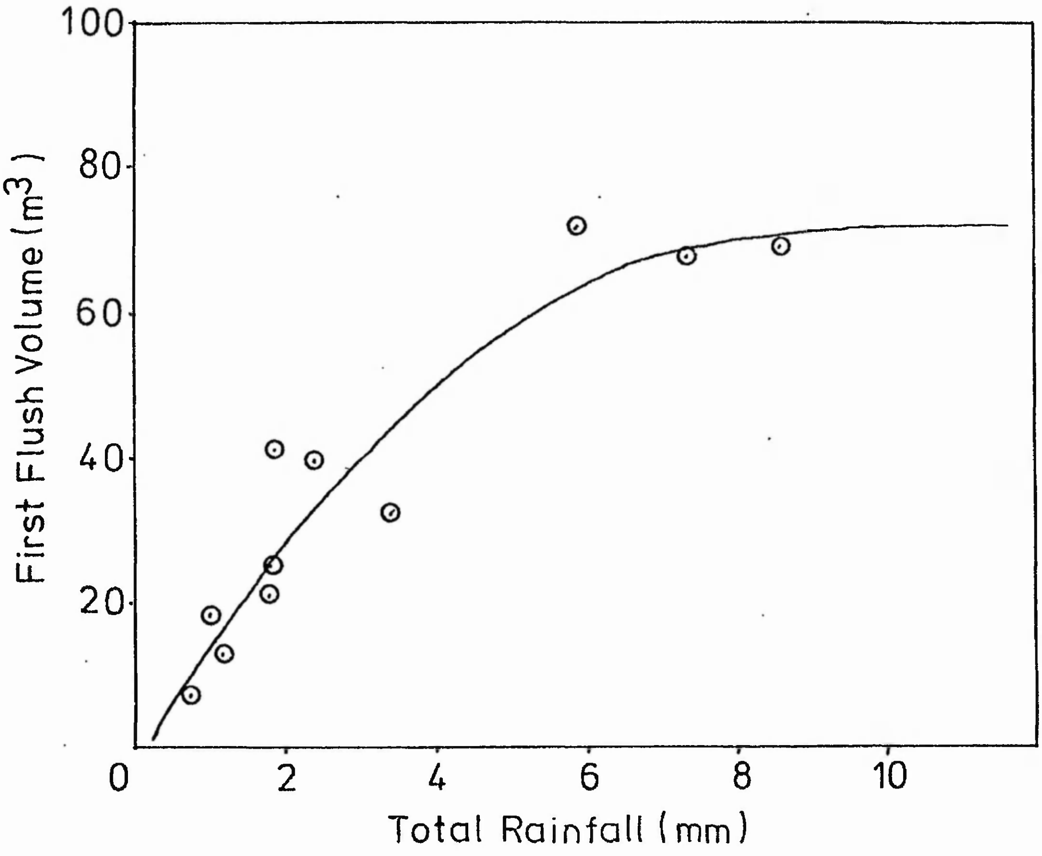
that gully pots are the most important source of this parameter, particularly for storms occurring after periods of dry weather. A contribution of 80% was recorded for Storm 18 after 10 days dry weather. Dissolved solids and COD also exhibited high contributions after 10 days dry weather: 31% for dissolved solids and 47% for COD. Since gully pots only contribute small loads of suspended solids, by inference the high COD contributions indicate that the liquors are an important source of dissolved organic compounds.

For the first flush the percentage pollutant contributions were again dependent upon the size of the rainfall event. For low volume storms, the first flush composed the majority of runoff and the percentage contributions were similar to those for the whole storm. Maximum contributions were again recorded for storms of 1 to 3 mm and were between 10% and 30% greater than for the contribution to the whole storm. For high volume storms the percentage contribution was approximately double, but still less than for storms of 1 to 3 mm (Figure 113, for dissolved solids). Therefore, whilst pollutant contributions from gully pots are greater for the first flush than for the whole storm, other pollutant sources exhibit a first flush effect of similar magnitude, which tends to make the relative contribution of gully liquors to the first flush the same as to the whole storm.

6.3.3 Alleviation of Pollution by Treatment of the First Flush

It has been proposed that treatment of the more polluting first flush phase of runoff could substantially reduce the pollution threat from stormwater runoff. This hypothesis was investigated for the storms monitored using the definition of the first flush in Section 5.1.5. For the storms monitored, the first flush consisted of between 20 and 150 minutes, that is, between 20% and 85% of the total storm duration, and the volume of the first flush comprised between 28% and 94% of the total runoff volume (Table 41). For short storms, the first flush composed virtually the whole storm, therefore, these storms were of less interest in defining the percentage of pollutant load, that can be removed by treating the first flush. For larger events, the relative pollution capacity of the first flush was revealed; for example in Storm 12, the volume of the first flush consisted of only 38% of the total runoff volume, however, this accounted for 78% of the suspended solids load, 72% of the dissolved solids load and 80% of the COD load. Similarly, for Storm 24, the first flush comprised 28% of the runoff and consisted of 53% of the

Fig. 115 - Relationship between the volume of the first flush and the rainfall volume.



suspended solids load, 38% of the dissolved solids load and 69% of the COD. For Storm 10 the first 50% of runoff carried 90% of the suspended solids and dissolved solids, 71% of the COD, 85% of the BOD and 91% of the ammonium load. These figures indicate that an effective treatment of the first flush could result in a substantial reduction in pollutant loads discharged.

If pollution from the first flush is to be eliminated it is important to know what volume of runoff needs to be treated to achieve this aim. Figure 115, a plot of the volume of the first flush against total rainfall, shows that for storms greater than 6 mm the first flush volume approached a constant value. For the Clifton Grove catchment approximately 80 cubic metres of runoff would need to be treated to ensure an adequate treatment of the first flush for the heaviest events. This volume is equivalent to approximately 22 cubic metres for each impervious hectare drained and would provide complete treatment for a high percentage of rainfall events (of the storms modelled only Storms 12, 17 and 24 exceeded this volume), with adequate treatment of the more heavily polluted phases of the larger events. It is likely that similar treatment volumes per impervious hectare would be applicable to other residential catchments.

Another approach to partially alleviate the problem of pollution from the first flush might be the use of porous gully pots (Mance and Harman, 1978). Whilst this approach has the dual advantage of eliminating polluted gully liquors and also of providing an initial storage volume for road runoff, its application may be hindered by the need to modify current methods of emptying gully pots and a more rapid accumulation of sediment necessitating more frequent emptying. In the Clifton Grove drainage system, gully pots could provide a storage volume up to 10.0 cubic metres. For rainfall events of less than 1.5 mm this volume could provide virtually complete retention of road runoff, e.g. Storms 9, 15 and 19. For events of less than 3 mm this volume could provide sufficient storage for the first flush of road runoff, e.g. Storms 6, 7 and 10. However, for larger rainfall events this storage volume would not greatly reduce the volume of road runoff and the occurrence of high inlet flow rates could result in high solids concentrations from the discharge of fine sediments that may have accumulated over a number of rainfall events.

7. SUMMARY OF CONCLUSIONS

7.1. LABORATORY STUDIES ON THE REMOVAL OF MATERIAL FROM GULLY POTS

a) The removal of dissolved material from gully pots is characterised by an exponential decay curve defined by the equation below. For inlet flow rates greater than 0.12 l/s the pot liquors are completely mixed, but, below this value 'short circuiting' occurs and the percentage of the pot liquors mixed is dependent upon the incoming flow rate:-

$$c = c_o e^{-tQP/V}$$

when $Q > 0.12 \qquad P = 1.0$

$Q < 0.12 \qquad P = 0.1107Q + 0.1986$

where c = concentration in outflow
c_o = initial concentration in the liquor
t = time
Q = inlet flow rate
V = volume of the gully pot
P = percentage mixed.

b) The removal of solid material occurs in two portions: material already in suspension, which obeys the same equations as dissolved material, and material resuspended from the bottom sediments by the hydraulic stirring action of incoming runoff. The mass of material released from the bottom sediments and the rate of uptake of this material is dependent upon the incoming flow rate:-

when $0 \leqslant t \leqslant M/K$

$$c = \frac{K}{Q} \left(1 - e^{-tQ/V}\right)$$

when $M/K \leqslant t \leqslant \infty$

$$c = \frac{K}{Q} \left(1 - e^{-MQ/KV}\right) e^{(-tQ/V + MQ/KV)}$$

c) The laboratory results show gully pots to be efficient in retaining trapped sediments, a maximum of only 0.2% of the bottom sediments were removed by the highest flow rate examined of 1.0 l/s. The solid material that was removed was taken up rapidly and recorded concentrations of 90 mg/l suggest that it may be of importance in the first flush. However, the removal of dissolved pollutants from gully pots represents a greater threat to stormwater quality than the removal of sediment.

7.2. THE RAINFALL - RUNOFF MATHEMATICAL SIMULATION

a) The rainfall-runoff model is composed of the following elements:-

i) Hyetograph. Calculation of the rainfall hyetograph from raw raingauge data and application of a constant proportional loss model.

ii) Depression storage. Calculation of the depression storage for each sub-catchment (defined by manhole points in the pipe network) and formation of the net rainfall hyetographs applicable to each sub-catchment.

iii) Linear Reservoir. Calculation of the inlet hydrograph, for each sub-catchment, from the net rainfall hyetograph using a single linear reservoir.

iv) Muskingum-Cunge method. Calculation of the fixed parameter Muskingum-Cunge coefficients for the pipe network.

v) Pipe routing. Routing of the inlet hydrographs through the pipe network, using the Muskingum-Cunge coefficients, to form the hydrographs.

Within the limitations of the available data, the model has been shown to give a reliable simulation of the storm runoff hydrograph at the sewer outfall. Further refinement of the depression storage coefficients and the storage routing coefficients should improve the model's performance.

b) Integration of the equations, developed from the laboratory study, describing the removal of material from gully pots into the rainfall-runoff model enables the model to be used to predict the contribution of gully liquors to the outlet hydrographs and the concentration of dissolved pollutants in runoff derived from gully pots. Both facets of the model have given satisfactory results, but await further verification. Application of the model predicting the contribution of solid material from gully pots to storm runoff is dependent upon further evidence that the laboratory results adequately describe the behaviour in the field.

c) Calculation of the discharge of gully liquors by the model can be used as a quantitative method of defining the duration of the first flush.

7.3. THE QUALITY OF WATER STORED IN GULLY POTS

a) The quality of water stored in gully pots is highly variable and particularly polluting after periods of dry weather and winter road salting.

b) Over dry weather periods dissolved oxygen is consumed and the subsequent anaerobic degradation of material trapped in gully pots results in a deterioration of the quality of the supernatant liquors, through the release of ammonium, hydrogen sulphide and soluble organics, which cause rises in the BOD and COD.

c) Human activity in the gully pot sub-catchment is one of the major sources of pollution of the liquors and is the principal cause of variation in quality between gully pots. The activities affecting quality are car maintenance and servicing, car washing, grass cutting, garden treatment, salting of driveways and footpaths, litter dropping and urination and defecation by animals. COD concentrations in the pot liquors showed a dependency upon the degree of human activity in the sub-catchment (sub-catchment area), however, BOD showed no such dependency.

d) Road salting is responsible for very high concentration of dissolved solids, salt and other species that are present as impurities in the salt. Localised heavy application by residents was the cause of extremely high concentrations.

e) Dissolved oxygen concentrations in pot liquors were related to the sub-catchment area and the volume of runoff through the gully pot.

f) Wide variation in the quality of stored water exists between gully pots across a catchment. The highest variation occurring during winter road salting.

7.4. THE QUALITY OF STORMWATER RUNOFF

a) The concentration and annual loads of pollutants from the Clifton Grove catchment are comparable to other studies of suburban residential catchments. Average suspended solids concentration exceeded the Royal Commission standard of 30 mg/l, whereas, BOD concentration was substantially less than the 20 mg/l limit. The method of calculation of the annual pollutant loads was shown to be critical and may account for some of the variance reported in the literature.

b) Pollutant loads are strongly related to the total storm discharge and are largely determined by the characteristics of the current rainfall event. The total rainfall volume and the rainfall intensity were of the most importance for all pollutants. The antecedent dry period was of little significance in influencing the pollutant load but was of importance in determining the pollutant concentrations in the early, or first flush, phases of runoff.

c) Multiple regression equations can be developed for the prediction of pollutant loads from easily obtainable meteorological data. The reliable performance of such an equation is limited to the catchment from which the data was derived.

d) The majority of events monitored exhibited a pronounced first flush effect, that is, the occurrence of high concentrations of pollutants in the initial phases of runoff that are unrelated to changes in discharge. For larger storms the first flush, although comprising only 30% to 50% of the total storm runoff, has been shown to carry the bulk of the pollutant load (between 60% and 90%).

e) Soluble pollutants are easily transported by storm runoff and their removal is characterised by high initial concentrations followed by a steady decline until a constant value is approached at the end of a storm. Dilution by the less polluted roof runoff may result in peaks in their concentration when road runoff reaches the outfall.

f) The removal of solid material occurs in two principal fractions, firstly the removal of fine particulates that compose the first flush, and secondly, the flow dependent removal of heavier particulates. The fine particulate fraction is composed of sediments deposited in sewers and gully pots on the recession limb of the previous storm event, dustfall accumulated on roof and road surfaces and sediments broken up in gully pots and sewers through anaerobic degradation over dry periods. This fraction appears to be removed independent of flow rate and dominates the first flush portion of a storm. The results indicate, particularly for short storms, that solids deposited in sewers are the chief explanation of this phenomenon. The transport of heavy particulates on road surfaces is dependent upon the rate of runoff and results in peaks in solids concentration related to peaks in discharge.

g) Solids exhaustion is a phenomenon that occurs when all solid material available for transport for a given rainfall event has been removed. It is characterised by peaks in discharge that do not result in peaks in solids concentration and was observed for larger rainfall events when the catchment was completely developed. Solids exhaustion may not occur while a catchment is still under development, when piles of builders sand and ungrassed surfaces provide a supply of easily transportable material and much greater pollutant loads can be expected.

h) The removal of solid material is also characteristic of the removal of COD and strong correlations exist between the two. However, the removal of BOD has characteristics of both solid and soluble pollutant removal. This is ascribed to the joint influence of oil and suspended solids on BOD concentration.

i) Provision of treatment for the first 22 cubic metres of runoff per impervious hectare would provide complete treatment for a high percentage of storms, ensure adequate treatment of the first flush for larger events, and substantially reduce the pollutant loads discharged.

7.5. CONTRIBUTION OF POLLUTANTS IN GULLY POTS TO STORMWATER RUNOFF

a) Original gully liquors (water stored prior to a runoff event) are rarely, if ever, completely discharged. A maximum of 86% removal was recorded.

b) Original gully liquors show the highest percentage contribution to total storm discharge (up to 17%) for storms of 1 mm to 3 mm. For heavier storms their contribution to the first flush is approximately twice their contribution to total runoff.

c) Pollutant contributions from gully pots are also of most significance for storms of 1 mm to 3 mm. The contribution of suspended solids is not of importance compared to other sources, but significant contributions of other pollutants were recorded, up to 80% for ammonium, 49% for COD, 40% for dissolved solids, 30% for BOD and 25% for nitrate. Gully pots are the most important source of ammonium in storm runoff occurring after a dry period.

d) In the first flush the percentage of pollutant contribution to runoff from gully pots is similar to their contribution to the whole storm. This indicates that other pollutant sources exhibit a first flush effect of similar magnitude to that from gully pots.

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QUALITY OF URBAN STORMWATER RUNOFF:

AN APPRAISAL OF THE ROLE OF GULLY POT LIQUORS

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Vol II

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APPENDICES

Appendix 1	-	Computer Programmes
Appendix 2	-	Results
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APPENDIX 1

COMPUTER PROGRAMMES

1. STATS PACKAGE FOR VARIATION AND WEEKLY GULLY ANALYSIS

LIST OF SYMBOLS

a) INPUT (in order of occurrence)

NC = No. of rows

NV = No. of columns

NV2 = No. of titled columns

K = Output device number (5 or 3)

M1 = Program control parameter

M2 = " " "

M1 = 0 - No correlation

M1 = 1 - Correlation

M2 = 0 - Weekly Gully Analysis

M2 = 1 - Variation Analysis

NAME(J) = Title of run (for labelling output)

KVAR(J) = Column numbers

TITLE(J) = Column names, e.g. GP1, GP6.

X(I,J) = Data array

T = t- value for 95% confidence limits

SEQR(J) = Interquartile Range

b) OUTPUT (excluding above)

XMIN(J) = minimum

XMAX(J) = maximum

RANGE(J) = range

XBAR(J) = mean

STD(J) = standard deviation

CSK(J) = coefficient of skewness

CKU(J) = coefficient of kurtosis

C95(J) = 95% confidence limits

PC95(J) = Percent 95% confidence limits

WMEAN(I) = weekly mean

R(I,J) = matrix of correlation coefficients

```
C
C     *********************************************************
C    *STATS PACKAGE FOR VARIATION AND WEEKLY GULLY ANALYSIS*'STS*
C    ******************************************************  ****
C
C         PROGRAMME NAME- STAT.FOR
C
C         PROGRAMME USES TWO SUBROUTINES FROM THE NAG LIBRARY
C         G01AAF, G02BGF
C         THREE OPTIONS ARE AVAILABLE :-
C           A) M1=0 ,M2=0  BASIC STATS FOR WEEKLY ANALYSIS
C              (INCOMPLETE ARRAYS MAY BE USED)
C           B) M1=0 ,M2=1  BASIC STATS FOR VARIATION ANALYSIS
C              (INCOMPLETE ARRAYS MAY BE USED)
C           C) M1=1  CORRELATION ANALYSIS (ONLY COMPLETE ARRAYS)
C
      DIMENSION X(100,100),SSP(100,100),STD(100),XBAR(100),XMAX(100)
      DIMENSION XMIN(100),RANGE(100),SEQR(100),KVAR(100)
      DIMENSION R(100,100),TITLE(100),NAME(50),X2(100),CSK(100)
      DIMENSION CKU(100),ESTD(100),C95(100),PC95(100),XAV(100)
      DIMENSION DEV(100),WMEAN(100)
      OPEN(UNIT=1,FILE='G.DAT',ACCESS='SEQIN')
      READ(1,991) NC,NV,NV2,K,M1,M2
      READ(1,992) (NAME(J),J=1,10)
      READ(1,993) (KVAR(J),TITLE(J),J=1,NV2)
      READ(1,994) ((X(I,J),J=1,NV),I=1,NC)
      READ(1,995) T,(SEQR(J),J=2,NV)
 991  FORMAT(6I3)
 992  FORMAT(10A5)
 993  FORMAT(10(I2,A5))
 994  FORMAT(5F10.4)
 995  FORMAT(F8.4,7(F7.4))
      IFAIL=0
      IF(M1.EQ.1) GOTO70
C
C         BASIC STATS
C
      DO 10 J=2,NV
      N=0
      DO 20 I=1,NC
      IF(X(I,J).EQ.-1) GOTO20
      N=N+1
      X2(N)=X(I,J)
  20  CONTINUE
      CALL G01AAF(N,X2,0,WT,XMEAN,S2,S3,S4,XL,XG,WTSUM,IFAIL)
      IF(IFAIL) 25,35,25
  25  WRITE(5,996) IFAIL
 996  FORMAT(I3)
      GOTO100
  35  CONTINUE
      XBAR(J)=XMEAN
      STD(J)=S2
      CSK(J)=S3
      CKU(J)=S4
      XMIN(J)=XL
      XMAX(J)=XG
      RANGE(J)=XG-XL
      ESTD(J)=SQRT((N/(N-1))*(S2**2))
      RN=N
      C95(J)=T*ESTD(J)/SQRT(RN)
```

```
      PC95(J)=(C95(J)/XBAR(J))*100
   10 CONTINUE
C
C        WEEKLY MEAN CALCULATION
C
      N1=0
      DO 22 I=1,NC
      SUMW=0
      N=0
      DO 21 J=2,NV
      IF(X(I,J).EQ.-1) GOTO21
      N=N+1
      SUMW=SUMW+X(I,J)
   21 CONTINUE
      SUMW=SUMW+X(I,J)
      WMEAN(I)=SUMW/N
      IF(SUMW.EQ.0) WMEAN(I)=-1
      IF(WMEAN(I).EQ.-1) GOTO22
      N1=N1+1
      X2(N1)=WMEAN(I)
   22 CONTINUE
      CALL G01AAF(N1,X2,0,WT,XMEAN,S2,S3,S4,XL,XG,WTSUM,IFAIL)
      IF(IFAIL) 25,75,25
   75 CONTINUE
      XBAR(NV+1)=XMEAN
      STD(NV+1)=S2
      CSK(NV+1)=S3
      CKU(NV+1)=S4
      XMIN(NV+1)=XL
      XMAX(NV+1)=XG
      RANGE(NV+1)=XG-XL
   70 IF(M1.EQ.0) GOTO80
C
C        CORRELATION
C
      CALL G02BGF(NC,NV,X,50,NV2,KVAR,XAV,DEV,SSP,50,R,50,IFAIL)
      IF(IFAIL) 45,55,45
   45 WRITE(5,996) IFAIL
      GOTO100
   55 CONTINUE
      GOTO90
C
C        OUTPUT
C
   80 WRITE(K,895)(NAME(J),J=1,10)
      IF(M2.EQ.0) GOTO82
      L1=2
      L2=6
      N10=INT(((NV)/3)+0.5)
      DO 84 L=1,N10
      WRITE(K,891)(TITLE(1),(TITLE(J),J=L1,L2),(X(I,1),(X(I,J)
     1,J=L1,L2),I=1,NC))
      WRITE(K,893)((XMIN(J),J=L1,L2),(XMAX(J),J=L1,L2),(RANGE(J),
     1J=L1,L2),(SEQR(J),J=L1,L2),(XBAR(J),J=L1,L2),(STD(J),J=L1,L2),
     1(CSK(J),J=L1,L2),(CKU(J),J=L1,L2))
      WRITE(K,894)((C95(J),J=L1,L2),(PC95(J),J=L1,L2))
      WRITE(K,897)
      L1=L1+5
      L2=L2+5
      IF(L2.GT.NV) L2=NV
```

```
 84     CONTINUE
        GOTO83
 82     WRITE(K,892)((TITLE(J),J=1,NV),((X(I,J),J=1,NV),XMEAN(I),
    1   I=1,NC))
        IF(M2.EQ.0) NV=NV+1
        WRITE(K,893)((XMIN(J),J=2,NV),(XMAX(J),J=2,NV),(RANGE(J),
    1   J=2,NV),(SEQR(J),J=2,NV),(XBAR(J),J=2,NV),(STD(J),J=2,NV),
    1   (CSK(J),J=2,NV),(CKU(J),J=2,NV))
 83     GOTO100
 90     WRITE(K,895)(NAME(J),J=1,10)
        WRITE(K,896)((TITLE(I),I=1,NV),(TITLE(I),(R(I,J),
    1   J=1,NV),I=1,NV))
100     CONTINUE
        STOP
890     FORMAT('1'/////////15X,10A5/15X,'-------------------------',
    1   '---------------------------------')
891     FORMAT('0'/15X,6(3X,A5,2X)//(16X,F3.0,6X,5(F8.2,2X)))
892     FORMAT('0'/15X,5(3X,A5,2X),3X,'MEAN'//(18X,F3.0,4X,5(F8.2,2X)))
893     FORMAT('0',14X,'MINIMUM',3X,5(F8.2,2X)/15X,'MAXIMUM',3X,
    1   5(F8.2,2X)/15X,'RANGE',5X,5(F8.2,2X)/15X,'I.Q RANGE',1X,
    1   5(F8.2,2X)/15X,'MEAN',6X,5(F8.2,2X)/15X,'STD DEV',3X,
    1   5(F8.2,2X)/15X,'SKEWNESS',2X,5(F8.2,2X)/15X,'KURTOSIS',
    1   2X,5(F8.2,2X))
894     FORMAT('0',14X,'C95 LMT',3X,5(F8.2,2X)/15X,'C95 (%)',3X,
    1   5(F8.2,2X))
895     FORMAT('1'///15X,10A5/15X,'------------------------------',
    1   '--------------------------')
896     FORMAT('0'/15X,14(A5,5X)//(15X,A5,5X,14(F7.4,3X)))
897     FORMAT('1'////15X,'CONTINUED'/15X,'---------')
        END
```

2. URBAN RUNOFF POLLUTANT LOADING PROGRAMME

LIST OF SYMBOLS

a) INPUT (in order of occurrence)

K5 = Output device number (5 or 3)

NS

M1 = program control parameters

M2 = " " "

M1 = 0 → Recession curve

M1 = 1 → No recesssion curve

M2 = 0 - Graphical output

M2 = 1 - No graphical output

T1 = Sampling interval (first sample)

S1 = Sampling duration (first sample)

T2 = Sampling interval (remaining samples)

S2 = Sampling duration (remaining samples)

NAME(I) = title of run for labelling output

TIM = time sampling commenced

N = No. of samples

DOSEC = concentration of dosing solution

DOSER = rate of dosing

DATE = date of storm

RLI(I) = lithium concentration

SS(I) = suspended solids concentration

DS(I) = dissolved solids concentration

BOD(I) = BOD concentration

COD(I) = COD concentration

RNO3(I) = nitrate concentration

RNH4(I) = ammonium concentration

CA(I) = calcium concentration

b) OUTPUT (excluding above)

DUR = sampling duration

TIME(I) = time of each sample

FLOW(I) = flow rate

QM = mean flow rate

SSM = mean, flow weighted, suspended solids concentration
DSM = " " " dissolved solids concentration
CAM = " " " calcium concentration
BODM = " " " BOD concentration
CODM = " " " COD concentration
RNO3M = " " " nitrate concentration
RNH4M = " " " ammonium concentration
CUMQ(I) = cumulative discharge
CUMSS(I) = " suspended solids load
CUMDS(I) = " dissolved solids load
CUMCA(I) = " calcium load
CUMBOD(I) = " BOD load
CUMCOD(I) = " COD load
CUMNO3(I) = " nitrate load
CUMNH4(I) = " ammonium load
TQ = total discharge
TSSL = " suspended solids load
TDSL = " dissolved solids load
TCAL = " calcium load
TBODL = " BOD load
TCODL = " COD load
TNO3L = " nitrate load
TNH4L = " ammonium load

```
C
C         ****************************************
C         *URBAN RUNOFF POLLUTANT LOADING PROGRAMME*
C         ****************************************
C
C          PROGRAMME NAME 'STQUAL'      LANGUAGE FORTRAN V
C          ======================
C
C               PROGRAMME CALCULATES FLOW VALUES FROM LITHIUM
C           CONCENTRATIONS, CUMULATIVE POLLUTANT LOADS, TOTAL
C           POLLUTANT LOADS AND MEAN FLOW WEIGHTED VALUES FOR
C           OBSERVED PARAMETERS IN ANY ONE STORM. OUTPUT
C           TABLES AND GRAPHS ARE IN A4 FORMAT.
C
      DIMENSION YAXIS(20,100),NAME(20),Y1(100)
      DIMENSION RLI(100),FLOW(100),SS(100),DS(100),BOD(100),COD(100)
      DIMENSION RNO3(100),RNH4(100),TIME(100),DATE(4),CUMSS(100)
      DIMENSION CUMQ(100),CUMBOD(100),CUMCOD(100),CUMNO3(100)
      DIMENSION CUMNH4(100),CUMDS(100),CA(100),CUMCA(100)
      DIMENSION Y2(100)
      OPEN(UNIT=1,FILE='S.DAT',ACCESS='SEQIN')
      READ(1,34) K5,NS,M1,M2
   34 FORMAT(I2,I3,I2,I2)
      READ(1,32) T1,S1,T2,S2
   32 FORMAT(4F5.2)
      READ(1,1)(NAME(I),I=1,18)
    1 FORMAT(9A4)
   20 READ(1,2)TIM,N,DOSEC,DOSER
    2 FORMAT(F6.2,I2,2F6.3)
      READ(1,33) DATE
   33 FORMAT(4A5)
      READ(1,3) (RLI(I),SS(I),DS(I),BOD(I),COD(I),RNO3(I),RNH4(I),
     C CA(I),I=1,N)
    3 FORMAT(8F10.3)
C
C          CALCULATION OF FLOW AND TIME ARRAYS
C
      FLOW(1)=8
      IF(RLI(2).EQ.0.0) FLOW(1)=0.0
      FLOW(2)=(DOSEC/RLI(2))*DOSER*.2196
      FLOW(3)=(DOSEC/RLI(3))*DOSER*.8615
      DO4I=4,N
    4 FLOW(I)=(DOSEC/RLI(I))*DOSER
      TIME(1)=S1/2
     TIME(2)=T1+(S2/2)
      DO5I=3,N+10
    5 TIME(I)=TIME(2)+((I-2)*T2)
      IF(FLOW(1).EQ.0.0) GOTO7
C
C          CUMULATIVE LOADS FOR THE FIRST TWO SAMPLES
C
      X=0
      Y=0
      Z=0
      X=TIME(1)*FLOW(1)*0.06
      CUMQ(1)=X
      CUMSS(1)=X*SS(1)/1000
      CUMDS(1)=X*DS(1)/1000
      CUMBOD(1)=X*BOD(1)/1000
      CUMCOD(1)=X*COD(1)/1000
```

```
      CUMNO3(1)=X*RNO3(1)/1000
      CUMNH4(1)=X*RNH4(1)/1000
      CUMCA(1)=X*CA(1)/1000
      X=X/1000
      Y=(S2/2)*FLOW(2)*0.06/1000
      Z=(T1-S1)*(FLOW(1)+FLOW(2))/2*0.06/1000
      CUMQ(2)=CUMQ(1)+((X+Y+Z)*1000)
      CUMSS(2)=CUMSS(1)+(Y*SS(2))+(X*SS(1))+(Z*(SS(1)+SS(2))/2)
      CUMDS(2)=CUMDS(1)+(Y*DS(2))+(X*DS(1))+(Z*(DS(1)+DS(2))/2)
      CUMBOD(2)=CUMBOD(1)+(Y*BOD(2))+(X*BOD(1))+(Z*(BOD(1)+BOD(2))/2
      CUMCOD(2)=CUMCOD(1)+(Y*COD(2))+(X*COD(1))+(Z*(COD(1)+COD(2))/2
      CUMNO3(2)=CUMNO3(1)+(Y*RNO3(2))+(X*RNO3(1))
     1+(Z*(RNO3(1)+RNO3(2))/2)
      CUMNH4(2)=CUMNH4(1)+(Y*RNH4(2))+(X*RNH4(1))
     1+(Z*(RNH4(1)+RNH4(2))/2)
      CUMCA(2)=CUMCA(1)+(Y*CA(2))+(X*CA(1))+(Z*(CA(1)+CA(2))/2)
C
C          ADDITION OF RECESSION CURVE
C
      IF(M1.EQ.1) GOTO50
      DO 40 I=N,N+10
      M=M+1
      FLOW(I+1)=FLOW(I)*EXP(-0.33*T2)
      IF(SS(I).EQ.0.0) GOTO41
      SS(I+1)=((SS(I)-3.0)*EXP(-0.33*T2))+3.0
   41 IF(BOD(I).EQ.0.0) GOTO42
      BOD(I+1)=((BOD(I)-0.3)*EXP(-0.33*T2))+0.3
   42 IF(COD(I).EQ.0.0) GOTO43
      COD(I+1)=((COD(I)-5.0)*EXP(-0.33*T2))+5.0
   43 DS(I+1)=DS(I)
      RNO3(I+1)=RNO3(I)
      RNH4(I+1)=RNH4(I)
      CA(I+1)=CA(I)
      IF(FLOW(I+1).LT.0.5) GOTO50
   40 CONTINUE
   50 N=N+M
C
C          CUMULATIVE LOADS FOR REMAINING SAMPLES
C
      DO6I=3,N
      X =0
      Y=0
      Z=0
      X=(S2/2)*FLOW(I)*0.06/1000
      Y=(S2/2)*FLOW(I-1)*0.06/1000
      Z=(T2-S2)*(FLOW(I)+FLOW(I-1))/2*0.06/1000
      CUMQ(I)=CUMQ(I-1)+((X+Y+Z)*1000)
      CUMSS(I)=CUMSS(I-1)+(X*SS(I))+(Y*SS(I-1))
     1+(Z*(SS(I)+SS(I-1))/2)
      CUMDS(I)=CUMDS(I-1)+(X*DS(I))+(Y*DS(I-1))
     1+(Z*(DS(I)+DS(I-1))/2)
      CUMBOD(I)=CUMBOD(I-1)+(X*BOD(I))+(Y*BOD(I-1))
     1+(Z*(BOD(I)+BOD(I-1))/2)
      CUMCOD(I)=CUMCOD(I-1)+(X*COD(I))+(Y*COD(I-1))
     1+(Z*(COD(I)+COD(I-1))/2)
      CUMNO3(I)=CUMNO3(I-1)+(X*RNO3(I))+(Y*RNO3(I-1))
     1+(Z*(RNO3(I)+RNO3(I-1))/2)
      CUMNH4(I)=CUMNH4(I-1)+(X*RNH4(I))+(Y*RNH4(I-1))
     1+(Z*(RNH4(I)+RNH4(I-1))/2)
    6 CUMCA(I)=CUMCA(I-1)+(X*CA(I))+(Y*CA(I-1))
```

```
     1 +(Z*(CA(I)+CA(I-1))/2)
C
C        CALCULATION OF MEAN VALUES AND TOTAL LOADS
C
    7 Z=(S2/2)*FLOW(N)*0.06/1000
      TQ=CUMQ(N)+(Z*1000)
      TSSL=CUMSS(N)+(Z*SS(N))
      TDSL=CUMDS(N)+(Z*DS(N))
      TBODL=CUMBOD(N)+(Z*BOD(N))
      TCODL=CUMCOD(N)+(Z*COD(N))
      TNO3L=CUMNO3(N)+(Z*RNO3(N))
      TNH4L=CUMNH4(N)+(Z*RNH4(N))
      TCAL=CUMCA(N)+(Z*CA(N))
      DUR=TIME(N)+(S2/2)
      DURS=DUR*60
      QM=TQ*1000/DURS
      SSM=TSSL*1000/TQ
      DSM=TDSL*1000/TQ
      BODM=TBODL*1000/TQ
      CODM=TCODL*1000/TQ
      RNO3M=TNO3L*1000/TQ
      RNH4M=TNH4L*1000/TQ
      CAM=TCAL*1000/TQ
C
C        OUTPUT
C
      L=0
      CALL WRITE(DATE,L,K5)
      L=L+1
      WRITE(K5,102)TIM
  102 FORMAT(/23X,'TIME SAMPLING COMMENCED   ',F5.2)
      WRITE(K5,130)DUR
  130 FORMAT(23X,'SAMPLING DURATION(MINS) ',F6.2)
      WRITE(K5,131)DOSEC
  131 FORMAT(23X,'DOSER CONCENTRATION(G/L)   ',F5.2)
      WRITE(K5,132)DOSER
  132 FORMAT(23X,'DOSE RATE(ML/MIN)   ',F5.2//)
      WRITE(K5,103)
  103 FORMAT(' ',15X,'MEASURED PARAMETER CONCENTRATIONS'/16X,
     C'---------------------------------'/)
      WRITE(K5,104)
  104 FORMAT(23X,'T(MINS)    Q(L/S)     SS(MG/L)  DS(MG/L)  CA(MG/L)'/)
      LN=18
      DO9I=1,N
      IF(LN.LE.50)GOTO8
      CALL WRITE(DATE,L,K5)
      WRITE(K5,104)
      LN=8
    8 WRITE(K5,106)TIME(I),FLOW(I),SS(I),DS(I),CA(I)
  106 FORMAT(19X,5F10.2)
      LN=LN+1
    9 CONTINUE
      IF(FLOW(1).EQ.0.0) GOTO152
      WRITE(K5,107)QM,SSM,DSM,CAM
  107 FORMAT(/' ',15X,'MEAN VALUES'/' ',15X,'FLOW WEIGHTED',
     C4F10.2//)
      LN=LN+3
  152 IF(LN.LT.46)GOTO10
      CALL WRITE(DATE,L,K5)
      LN=8
```

```
 10     WRITE(K5,109)
109     FORMAT(/' '23X,'T(MINS)    BOD(MG/L) COD(MG/L) NO3(MG/L)
   1    NH4(MG/L)'/)
        LN=LN+3
        DO11I=1,N
        IF(LN.LE.50)GOTO15
        CALL WRITE(DATE,L,K5)
        WRITE(K5,109)
        LN=10
 15     WRITE(K5,110)TIME(I),BOD(I),COD(I),RNO3(I),RNH4(I)
110     FORMAT(19X,5F10.2)
        LN=LN+1
 11     CONTINUE
        IF(FLOW(1).EQ.0.0) GOTO151
        WRITE(K5,111)BODM,CODM,RNO3M,RNH4M
111     FORMAT(/' ',15X,'MEAN VALUES'/' ',15X,'FLOW WEIGHTED',
   C    4F10.2//)
        LN=LN+3
        IF(LN.LT.45)GOTO12
        CALL WRITE(DATE,L,K5)
        LN=7
 12     WRITE(K5,112)
112     FORMAT(' ',15X,'CUMULATIVE PARAMETER LOADINGS'/16X,
   C    '============================='/)
        WRITE(K5,113)
113     FORMAT(23X,'T(MINS)    Q(CU.M)    SS(KG)     DS(KG)    CA(KG)'/)
        LN=LN+5
        DO13I=1,N
        IF(LN.LF.50)GOTO14
        CALL WRITE(DATE,L,K5)
        WRITE(K5,113)
        LN=9
 14     WRITE(K5,114)TIME(I),CUMQ(I),CUMSS(I),CUMDS(I),CUMCA(I)
114     FORMAT(19X,5F10.3)
        LN=LN+1
 13     CONTINUE
        WRITE(K5,115)TQ,TSSL,TDSL,TCAL
115     FORMAT(/'0',15X,'TOTAL LOADINGS',F9.3,3F10.3//)
        LN=LN+2
        IF(LN.LT.45)GOTO16
        CALL WRITE(DATE,L,K5)
        LN=7
 16     WRITE(K5,117)
117     FORMAT(23X,'T(MINS)    BOD(KG)    COD(KG)    NO3(KG)    NH4(KG)'/)
        LN=LN+3
        DO17I=1,N
        IF(LN.LT.50)GOTO18
        CALL WRITE(DATE,L,K5)
        WRITE(K5,117)
        LN=9
 18     WRITE(K5,118)TIME(I),CUMBOD(I),CUMCOD(I),CUMNO3(I),CUMNH4(I)
118     FORMAT(19X,5F10.3)
        LN=LN+1
 17     CONTINUE
        WRITE(K5,119)TBODL,TCODL,TNO3L,TNH4L
119     FORMAT(/'0',15X,'TOTAL LOADINGS',F9.3,3F10.3//)
151     DO19I=1,N
        YAXIS(1,I)=FLOW(I)
        YAXIS(2,I)=SS(I)
        YAXIS(3,I)=COD(I)
```

```
      YAXIS(4,I)=FLOW(I)
      YAXIS(5,I)=BOD(I)
      YAXIS(6,I)=DS(I)
      YAXIS(7,I)=RNO3(I)
      YAXIS(8,I)=RNH4(I)
      YAXIS(9,I)=CA(I)
      YAXIS(10,I)=(CUMQ(I)/TQ)*100
      YAXIS(11,I)=(CUMSS(I)/TSSL)*100
      IF(TSSL.EQ.0.0) YAXIS(11,I)=0.0
      YAXIS(12,I)=(CUMCOD(I)/TCODL)*100
      IF(TCODL.EQ.0.0) YAXIS(12,I)=0.0
      YAXIS(13,I)=(CUMQ(I)/TQ)*100
      YAXIS(14,I)=(CUMBOD(I)/TBODL)*100
      IF(TBODL.EQ.0.0) YAXIS(14,I)=0.0
      YAXIS(15,I)=(CUMDS(I)/TDSL)*100
      IF(TDSL.EQ.0.0) YAXIS(15,I)=0.0
      YAXIS(16,I)=(CUMNO3(I)/TNO3L)*100
      IF(TNO3L.EQ.0.0) YAXIS(16,I)=0.0
      YAXIS(17,I)=(CUMNH4(I)/TNH4L)*100
      IF(TNH4L.EQ.0.0) YAXIS(17,I)=0.0
      YAXIS(18,I)=(CUMCA(I)/TCAL)*100
      IF(TCAL.EQ.0.0) YAXIS(18,I)=0.0
   19 CONTINUE
C
C          GRAPHICAL OUTPUT
C
      IF(M2.EQ.1) GOTO21
      A=20.0
      B=12.0
      C=0.0
   22 CONTINUE
      CALL PLOTS(0,0,18)
      CALL PLOT(5.0,5.0,-3)
      DO204I=1,18
      IF(YAXIS(I,1).EQ.0.0) GOTO61
      IF(C.NE.0.0)GOTO202
      TIME(N+1)=0.0
      TIME(N+2)=INT((DUR/20.0)+1.0)
      CALL AXIS(0.0,0.0,'TIME(MINS)',-10,A,0,TIME(N+1),TIME(N+2))
  202 YMAX=0.0
      DO 25 K=1,N
      Y2(K)=YAXIS(I,K)
      IF(Y2(K).GT.YMAX) YMAX=Y2(K)
   25 CONTINUE
      IF(Y2(1).EQ.0.0) GOTO204
      NAM=NAME(I)
      Y2(N+1)=0.0
      Y2(N+2)=INT((YMAX/10.5)+1.0)
      IF(YMAX.LT.5.0) Y2(N+2)=0.5
      IF(YMAX.LT.2.0) Y2(N+2)=0.2
      IF(YMAX.LT.1.3) Y2(N+2)=0.1
      CALL AXIS(-C-(C*0.2),0.0,NAM,8,B,90.,Y2(N+1),Y2(N+2))
      C2=C+1.0
      C3=(C*0.5)-0.5
      M5=INT(C2)
      CALL LINE(TIME,Y2,N,1,-1,M5)
      CALL SYMBOL((3*A/4),B-0.5-C3,0.28,M5,0.0,-1)
      CALL SYMBOL((3*A/4)+0.3,B-0.5-C3,0.28,'***',0.0,4)
      CALL SYMBOL((3*A/4)+1.3,B-0.5-C3,0.28,NAM,0.0,4)
      IF(C.NE.0.0)GOTO203
```

```
      CALL SYMBOL((2*A/10),B+1,0.42,'STORM OF THE ',0.0,13)
      CALL SYMBOL((2*A/10)+5.1,B+1,0.42,DATE,0.0,20)
      CALL SYMBOL((2*A/10),B+0.5,0.28,'STORM NUMBER ',0.0,13)
      CALL SYMBOL((2*A/10)+3.7,B+0.5,0.28,NS,0.0,3)
  203 C=C+1.0
      IF(C.GT.2)GOTO60
   61 IF(I.EQ.9.0) GOTO60
      CALL PLOT(0.0,0.0,3)
      GOTO65
   60 C=0.0
      CALL PLOT(-6.3,-3.5,3)
      CALL PLOT(-6.3,17.3,2)
      CALL PLOT(23.4,17.3,2)
      CALL PLOT(23.4,-3.5,2)
      CALL PLOT(-6.3,-3.5,2)
      CALL PLOT(0.0,0.0,3)
      CALL PLOT(A+20.0,0.0,-3)
   65 DO70K=1,N
   70 Y2(K)=0
      NAM=0
  204 CONTINUE
      CALL PLOT(40.0,0.0,-3)
      CALL PLOT(0.0,0.0,999)
      DO80I=1,18
      DO90K=1,N
   90 YAXIS(I,K)=0
   80 NAME(I)=0
   21 CONTINUE
      STOP
      END
C
C            ****************
C            SUBROUTINE WRITE
C            ****************
C
      SUBROUTINE WRITE(DATE,L,K5)
      DIMENSION DATE(4)
      WRITE(K5,100)
      WRITE(K5,101)(DATE(I),I=1,4)
      IF(L.EQ.0)GOTO20
      WRITE(K5,105)
  100 FORMAT('1'/////' ',35X,'STORM RUNOFF DATA'/35X,
     C'-----------------')
  101 FORMAT(/'0',15X,'STORM OF THE '4A5/15X,
     C'---------------------------------')
  105 FORMAT('+',51X,'(CONTINUED)'//)
   20 RETURN
      END
```

3. MULTIPLE REGRESSION PROGRAMME

LIST OF SYMBOLS

a) INPUT (in order of occurrence)

NC = No. of rows

NV = No. of columns

NV2 = dependent variable column number

K = output device number)5 or 3)

NAME(J) = title of run for labelling output

KVAR(J) = column numbers

TITLE(J) = column titles

X (I,J) = data array

b) OUTPUT (excluding above)

R(I,J) = matrix of correlation coefficients

COEFF(I,J) = matrix of multiple regression coefficients, standard error and t - values

CONST(I) = array of multiple regression constant, standard error and t - value.

RESULT(I) = array of multiple regression correlation coefficient, determination coefficient and corrected determination coefficient.

```
C
C        *******************************
C        *MULTIPLE REGRESSION PROGRAMME*
C        *******************************
C
C         PROGRAMME NAME- MULREG.FOR
C
C         PROGRAMME USES TWO SUBROUTINES FROM THE
C         NAG LIBRARY,G02CGF,G02BGF.
C
      DIMENSION X(50,200),SSP(50,50),STD(50),XBAR(50),KVAR(50)
      DIMENSION R(50,50),RESULT(20),COEFF(50,10),CONST(10)
      DIMENSION RINV(50,50),C(50,50),WKZ(500,50),TITLE(50),NAME(50)
      OPEN(UNIT=1,FILE='M.DAT',ACCESS='SEQIN')
      READ(1,991) NC,NV,NV2,K
991   FORMAT(4I3)
      READ(1,990)(NAME(J),J=1,10)
990   FORMAT(10A5)
      READ(1,993)(KVAR(J),TITLE(J),J=1,NV2)
993   FORMAT(10(I2,A5))
      READ(1,992)((X(I,J),J=1,NV),I=1,NC)
992   FORMAT(6F10.4)
      IFAIL=0
      NI=NV2-1
      NE=KVAR(NV2)
      CALL G02BGF(NC,NV,X,50,NV2,KVAR,XBAR,STD,SSP,50,R,50,IFAIL)
      IF(IFAIL)20,40,20
 20   WRITE(K,995) IFAIL
995   FORMAT(I3)
      GOTO60
 40   CONTINUE
      CALL G02CGF(NC,NV2,NI,XBAR,SSP,50,R,50,RESULT,COEFF,50,CONST
    1 ,RINV,50,C,50,WKZ,500,IFAIL)
      IF(IFAIL)80,100,80
 80   WRITE(K,996)IFAIL
996   FORMAT(I3)
      GOTO60
100   CONTINUE
      WRITE(K,890)(NAME(J),J=1,10)
      WRITE(K,891)(TITLE(NV2),(TITLE(I),R(I,NV2),I=1,NI))
      WRITE(K,896)
      WRITE(K,892)(TITLE(I),(COEFF(I,J),J=1,3),I=1,NI)
      WRITE(K,893)(CONST(I),I=1,3)
      WRITE(K,895)(RESULT(I),I=10,13)
890   FORMAT('1'///15X,10A5/15X,'----------------------------',
    1 '------------------------'//15X,'CORRELATION COEFFICTENTS'
    1 /15X,'---------------------------')
891   FORMAT('0'/25X,A5//(15X,A5,4X,F7.4/))
892   FORMAT('0',15X,'PARAMETER',5X,'COEFF',11X,'STD ERR',8X,
    1 'T-VALUE'//,(16X,A5,8X,3(F9.4,6X)))
893   FORMAT(15X,'CONSTANT',6X,3(F9.4,6X))
895   FORMAT('0'/15X,'STANDARD ERROR OF ESTIMATE =',F8.4
    1 //15X,'MULTIPLE CORRELATION (R)    =',F8.4
    2 //15X,'DETERMINATION (R SQUARED)   =',F8.4
    3 //15X,'CORRECTED R SQUARED         =',F8.4///////)
896   FORMAT('0'/15X,'ANALYSIS OF REGRESSION'/15X,'---------',
    1 '--------------')
 60   STOP
      END
```

4. TRENT URBAN RUNOFF SIMULATION

LIST OF SYMBOLS

a) INPUT (in order of occurrence)

IWRI = Output device number (5 or 3)
M1,M2,M3, M4,M5. = program control parameters
NA = No. of subcatchments
PIPE(I) = pipe numbers
PLENGT(I) = pipe length
PSLOPE(I) = pipe slope
RADIUS(I) = pipe radius
GULLY(I) = No. of gully draining each subcatchment
SLOPE(I) = subcatchment slope
PAVEA(I) = impervious paved area
ROOFA(I) = roof area
LENGTH(I) = overland flow length
CR(I) = roof storage routing coefficients
N = No. of raingauge data observations
TI(I) = time of raingauge data
TILT(I) = No. of raingauge tilts
K = dynamic calibration coefficient i.e. intensity/tilt
PERCEN = constant proportional loss coefficient
DATE = date of storm
NR = No. of rainfall intensities
AVIN = average intensity for the most intense 10 minutes
RAIN(I) = rainfall hyetograph
TIME(I) = minute increments over hyetograph
NO = No. of samples
QOBS(I) = observed flow rates
TOBS(I) = times corresponding to observed flows
MCA = mean pollutant concentration in gully pots
FCA = final pollutant concentration in storm runoff
CAOBS(I) = observed pollutant concentrations

b) OUTPUT (excluding above)

HYETO:-
CRAIN(I) = hyetograph adjusted for constant proportional loss

b) OUTPUT, Contd...

DEPSTO:-

SRAIN(I,J) = hyetograph for each paved subcatchment after depression storage

RRAIN(I) = hyetograph for roofed area

DEP(I) = depression storage for each subcatchment

DEPSTR = roof depression storage

LINRES:-

NQ = No. of runoff data points

CP(I) = paved area storage routing coefficients

QR(I,J) = roofed area hydrographs (as intensities)

QP(I,J) = paved area hydrographs (as intensities)

QRL(I,J) = subcatchment input hydrographs (roofed areas)

QPL(I,J) = subcatchment input hydrographs (paved areas)

QINP(I,J) = subcatchment total input hydrographs

MUSK:-

C1,C2,C3 = Muskingum coefficients

ROUTE:-

Q(I,J) = output hydrographs for each pipe

GULLYS:-

GVOL = volume of gully pot

VOL(I) = volume of original gully liquors in gully pot (VOL(I) = GVOL)

PM = fraction of gully liquor mixed

QG(I,J) = input gully liquor hydrographs for each subcatchment

QGO(I,J) = output gully liquor hydrographs

CA(I) = predicted pollutant concentrations

MAIN (Storm Statistics):-

DUR = Storm duration

TR = total rainfall

TRV = total rainfall

DSL = depression storage volume

b) OUTPUT, Contd...

PIL = other losses (e.g. infiltration)

TQ2 = total predicted discharge

AVIN = average rainfall intensity for the most intense 10 minutes

AVINT = average rainfall intensity

TOQ = total observed discharge

PR2 = percentage runoff from impervious areas

TQG = total volume of gully liquors discharged

PGT = percentage gully liquor contribution to total runoff volume.

PG99 = percentage gully liquor contribution to first flush volume

TIME 1 = end time of first flush

TQ1 = first flush volume

PGD = percentage gully liquors discharged of the total gully liquor volume

TCA = total predicted pollutant load

TOCA = total observed pollutant load

```
C
C       **************************************
C       *TRENT URBAN RUNOFF DATA SIMULATION*
C       **************************************
C
C       VERSION ONE        NOVEMBER 1978
C       ***********        *************
C
C       AUTHOR I.J.FLETCHER
C       *******************
C
C       PROGRAMME NAME 'STMOD'.   LANGUAGE FORTRAN V
C       ======================
C
C            THE PROGRAMME CALCULATES THE STORM RUNOFF HYDRO-
C         GRAPHS, INPUT HYDROGRAPHS AND THE CONTRIBUTION TO
C         THE RUNOFF MADE BY ORIGINAL GULLY LIQUORS AT ANY
C         MANHOLE POINT IN AN URBAN STORMWATER SEWERAGE SYSTEM.
C            THE OPERATION OF THE PROGRAMME IS DETERMINED
C         BY THE PROGRAMME CONTROL PARAMETERS (M1,M2,M3,M4)
C         THEY DECIDE THE AMOUNT AND TYPE OF DATA INPUT, THE
C         PASSAGE FOLLOWED THROUGH THE SIMULATION SUBROUTINES
C         AND THE NATURE OF THE OUTPUT. THE PROGRAMME MAY BE
C         SUBDIVIDED INTO THE FOLLOWING PRINCIPAL SECTIONS :-
C            A) DATA INPUT
C            B) STORM RUNOFF MODEL
C               1. HYETO - FORMS HYETOGRAPH FROM RAINGAUGE INPUT
C               2. DEPSTO - SUBTRACTS DEPRESSION STORAGE
C               3. LINRES - FORMS INPUT HYDROGRAPHS BY PASSING
C                    HYETOGRAPHS THROUGH A LINEAR RESERVOIR
C               4. MUSK - CALCULATES MUSKINGUM PIPE ROUTING
C                    COEFFICIENTS
C               5. ROUTE - ROUTES THE INPUT HYDROGRAPHS THROUGH
C                    THE PIPE SYSTEM TO FORM THE OUTPUT HYDRO-
C                    GRAPHS
C               6. GULLYS - CALCULATES THE CONTRIBUTION MADE BY
C                    ORIGINAL GULLY LIQUORS TO OUTPUT HYDROGRAPH
C            C) CALCULATION OF RELEVANT STORM STATISTICS
C            D) DATA OUTPUT FORMAT, A4 TABLES AND GRAPHS
C
C            **************
C            MAIN PROGRAMME
C            **************
C
        DIMENSION QPL(50,200),QINP(50,200),QGO(50,200),QOUT1(50,200)
        DIMENSION DATE(4),QOBS(200),TOBS(200),CAOBS(200)
        DIMENSION Q(200),Q2(200),C(200),T(200)
        COMMON/ONE/TI(100),TILT(100)
        COMMON/ONEA/RAIN(200),TIME(200)
        COMMON/ONEB/CRAIN(200)
        COMMON/TWO/SLOPE(50),SRAIN(50,200),RRAIN(200)
        COMMON/THREE/LENGTH(50),CR(50),PAVEA(50),ROOFA(50)
        COMMON/FOUR/ PLENGT(50),PSLOPE(50),RADIUS(50)
        COMMON/FOURA/ C1(50),C2(50),C3(50)
        COMMON/SIX/GULLY(50),CA(200)
        COMMON/FIVE/PIPE(50)
        REAL K,LENGTH,MCA
        OPEN(UNIT=1,FILE='R.DAT',ACCESS='SEQIN')
C
C            DATA INPUT
```

```
C
      READ(1,4) IWRI
    4 FORMAT(I2)
      READ(1,10) M1,M2,M3,M4,M5,M6
   10 FORMAT(6I2)
      READ(1,30)NA
   30 FORMAT(I2)
      READ(1,35)(PIPE(I),PLENGT(T),PSLOPE(I),RADIUS(I),GULLY(I),
     1 SLOPE(I),PAVEA(I),ROOFA(I),LENGTH(I),CR(I),I=1,NA)
   35 FORMAT(3F7.3,F7.5,F5.1,F6.3,3F8.3,F7.3)
      IF(M1.EQ.0) GOTO40
      READ(1,60) N,K,PERCEN,DATE,(TI(I),TILT(I),I=1,N)
   60 FORMAT(I3,F8.5,F5.3,4A5/(F6.3,F3.0))
      GOTO70
   40 READ(1,80) NR,AVIN,PERCEN,DATE,(RAIN(I),TIME(I),I=1,NR)
   80 FORMAT(I3,F7.4,F6.4,4A5/(F7.4,F6.2))
      DO 45 K=1,NR
      RAIN(K)=RAIN(K)/60
   45 CONTINUE
   70 IF(M3.EQ.0) GOTO90
      READ(1,100) NO,(QOBS(I),TOBS(I),I=1,NO)
  100 FORMAT(I3/(F7.2,F8.4))
   90 IF(M4.EQ.0) GOTO110
      READ(1,120) MCA,FCA,(CAOBS(I),I=1,NO)
  120 FORMAT(2F8.3/(F7.3))
  110 CONTINUE
      GOTO124
      WRITE(IWRI,999)(PIPE(I),PLENGT(I),PSLOPE(I),RADIUS(I),
     1 GULLY(I),I=1,NA)
  999 FORMAT('1'//15X,'SEWER SYSTEM DATA'/15X,'================='
     1 //15X,'PIPE NO',5X,'LENGTH(M)',3X,'SLOPE(%)',4X,'RADIUS(M)',
     2 3X,'GULLY POTS'//(17X,F5.2,7X,F5.1,7X,F5.3,7X,F6.4,6X,F4.1))
      WRITE(IWRI,998)(PIPE(I),SLOPE(I),PAVEA(I),ROOFA(I),LENGTH(I)
     1 ,I=1,NA)
  998 FORMAT('1',//15X,'SUB CATCHMENT DATA'/15X,'=================='
     1 //15X,'PIPE NO',5X,'SLOPE(%)',4X,'PAVED AREA',2X,
     2 'ROOF AREA',3X,'LENGTH(M)'//(17X,F5.2,7X,F5.3,7X,F7.2,5X,
     3 F7.2,5X,F5.1))
C
C           STORM RUNOFF MODEL
C
  124 CONTINUE
      CALL HYETO(K,M1,N,NR,AVIN,IWRI,PERCEN)
      CALL DEPSTO(NR,NA,IWRI)
      CALL LINRES(NA,NR,NQ,AVIN,IWRI,QPL,QINP)
      CALL MUSK(NA,IWRI)
      CALL ROUTE(NQ,NA,IWRI,QINP,QOUT1)
      IF(M2.EQ.0) GOTO140
      CALL GULLYS(NQ,NA,IWRI,QPL,QGO,QOUT1,MCA,FCA,M4)
  140 CONTINUE
C
C           CALCULATION OF STORM STATISTICS
C
      DO 145 K=2,NQ
      L1=L1+1
      IF(QOUT1(NA,K).GE.QOUT1(NA,K-1)) GOTO145
      IF(QOUT1(NA,K).GE.0.5) GOTO145
      NQ=L1
      GOTO146
  145 CONTINUE
```

```
 146    CONTINUE
        DO 150 I=1,NQ
        TR=RAIN(I)+TR
        TQ=(QOUT1(NA,I)*60/PERCEN)+TQ
        TQ2=(QOUT1(NA,I)*60)+TQ2
        IF(M2.EQ.0) GOTO150
        TQG=(QGO(NA,I)*60)+TQG
        IF(M4.EQ.0) GOTO150
        TCA=((CA(I)*QOUT1(NA,I)*60)/1000)+TCA
 150    CONTINUE
        TPV=TR*34398.27
        AVINT=TR*60/NR
        AVIN=AVIN*60
        DSL=TRV-TQ
        IF(M3.EQ.0) GOTO170
        DO 160 I=1,NO
        Z=3.03
        IF(I.EQ.1) Z=1.2
        IF(I.EQ.2) Z=3.2
        TOQ=TOQ+(QOBS(I)*60*Z)
        IF(M4.EQ.0) GOTO160
        TOCA=TOCA+((CAOBS(I)*QOBS(I)*60*Z)/1000)
 160    CONTINUE
        PR=(TOQ/TQ2)*100
        PERCEN=PR/100
        PIL=TQ-TQ2
        PR2=TQ2/TRV*100
 170    CONTINUE
        IF(M2.EQ.0) GOTO195
        DO 180 I=1,NQ
        TQG1=(QGO(NA,I)*60)+TQG1
        TQ1=(QOUT1(NA,I)*60)+TQ1
        TIMF1=TIME(I)
        IF(TQG1/TQG.GE.0.9) GOTO190
 180    CONTINUE
 190    PG99=(TQG1/TQ1)*100
        PGT=(TQG/TQ2)*100
        PGD=(TQG/(112*92.8))*100
 195    ITN=INT(TIME(NR))
        IT1=INT(TIME(1))
        DUR=((ITN-IT1)*60)+((TIME(NR)-ITN)-(TIME(1)-IT1))*100
        DUR=INT(DUR/60)+(DUR-(INT(DUR/60)*60))/100
        DO 197 I=1,NR
 197    RAIN(I)=RAIN(I)*60
C
C               OUTPUT FORMAT
C
        WRITE(IWRI,200) DATE
 200    FORMAT('1'//,30X,'STORM RUNOFF MODEL OUTPUT'/
     1  30X,'-------------------------'//,15X,'STORM OF THE '
     2  ,4A5/15X,'---------------------------------'
     3  //,15X,'PREDICTED DATA'/15X,'--------------')
        IF(M2.EQ.1) GOTO220
        WRITE(IWRI,230) (TIME(I),RAIN(I),QOUT1(NA,I),I=1,NQ)
 230    FORMAT(//,15X,'TIME(HRS)',9X,'RAIN(MM/HR) ',6X
     1  ,'FLOW(L/S)'//(17X,F5.2,13X,F6.3,12X,F7.3))
        GOTO300
 220    IF(M4.EQ.1) GOTO240
        WRITE(IWRI,250) (TIME(I),RAIN(I),QOUT1(NA,I),QGO(NA,I),
     1  I=1,NQ)
```

```
250    FORMAT(//,15X,'TIME(HRS)',5X,'RAIN(MM/HR) ',2X,
   1   'FLOW(L/S)',5X,'GULLY FLOW(L/S)'//(17X,F5.2,9X,F6.3,
   2   8X,F7.3,7X,F7.3))
       GOTO300
240    CONTINUE
       WRITE(IWRI,260) (TIME(I),RAIN(I),QOUT1(NA,I),QGO(NA,I),
   1   CA(I),I=1,NQ)
260    FORMAT(//15X,'TIME(HRS)',3X,'RAIN(MM/HR)',1X,'FLOW(L/S)',
   1   3X,'G.FLOW(L/S)',1X,'CA(MG/L)'//(17X,F5.2,7X,F6.3,6X,
   2   F7.3,5X,F7.3,4X,F7.2))
300    CONTINUE
       IF(M3.EQ.0) GOTO400
       WRITE(IWRI,310) DATE
310    FORMAT('1'//15X,'STORM OF THE ',4A5,2X,'(CONTINUED)'
   1   /15X,'========================================'//15X,
   2   'OBSERVED DATA'/15X,'=============')
       WRITE(IWRI,320) (TOBS(I),QOBS(I),CAOBS(I),I=1,NO)
320    FORMAT(//,15X,'TIME(HRS)',9X,'FLOW(L/S)',11X,
   1   'CA(MG/L)'//(16X,F6.3,12X,F7.2,12X,F7.2))
400    CONTINUE
       WRITE(IWRI,405) DATE
405    FORMAT('1'//,15X,'STORM OF THE ',4A5,2X,'(CONTINUED)'
   1   /15X,'========================================'//15X,
   2   'STORM STATISTICS'/15X,'================')
       WRITE(IWRI,410) DUR,TR,TRV,DSL,PIL,TQ2,AVIN,AVINT
410    FORMAT(//15X,'STORM DURATION (HRS) ',14X,'= ',F5.2
   1   //15X,'TOTAL RAINFALL (MM) ',15X,'= ',F7.3
   2   //15X,'TOTAL RAINFALL VOLUME (LITRES) ',4X,'= ',F9.1
   3   //15X,'DEPRESSION STORAGE LOSS (LITRES)',3X,'= ',F8.1
   4   //15X,'INFILTRATION LOSS (LITRES)',9X,'= ',F8.1
   5   //15X,'TOTAL PREDICTED DISCHARGE (LITRES) = ',F9.1
   6   //15X,'MAX INTENSITY FOR 10 MINS (MM/HR)  = ',F7.4
   7   //15X,'AVERAGE INTENSITY (MM/HR)',10X,'= ',F7.4)
       IF((TQ-TQ2).GT.500) GOTO416
       WRITE(IWRI,415) PERCEN
415    FORMAT(/15X,'PERCEN',29X,'= ',F7.5)
416    IF(M3.EQ.0) GOTO425
       WRITE(IWRI,420) TOQ,PR2
420    FORMAT(/15X,'TOTAL OBSERVED DISCHARGE (LITRES)  = ',F9.1
   1   //15X,'PERCENTAGE RUNOFF',18X,'= ',F6.2)
425    IF(M2.EQ.0) GOTO445
       WRITE(IWRI,430) TQG,PGT,PG19,TIME1,TQ1,PGD
430    FORMAT(/15X,'TOTAL GULLY DISCHARGE (LITRES) ',4X,'= '
   1   ,F7.1//15X,'% GULLY RUNOFF/TOTAL RUNOFF',8X,'= ',F6.2//15X
   2   '% GULLY/TOTAL FOR THE FIRST FLUSH',2X,'= ',F6.2//15X
   3   'FIRST FLUSH TIME',19X,'= ',F6.2//15X,
   4   'FIRST FLUSH VOLUME (LITRES)',8X,'= ',F8.1//15X,
   5   '% GULLY RUNOFF/TOTAL GULLY VOLUME',2X,'= ',F6.2)
       IF(M4.EQ.0) GOTO445
       WRITE(IWRI,440) TCA,TOCA
440    FORMAT(/15X,'TOTAL PREDICTED CALCIUM (GRAMS)     = '
   1   ,F8.2//15X,'TOTAL OBSERVED CALCIUM (GRAMS)     = ',F8.2)
445    CONTINUE
C
C             GRAPHICAL OUTPUT
C
       IF(M5.EQ.0) GOTO1000
       A=20
       B=12
       L2=0
```

```
      TIME(1)=(TIME(1)-INT(TIME(1)))*100
      DO 520 K=2,NQ
520   TIME(K)=TIME(1)+K-1
      TOBS(1)=(TOBS(1)-INT(TOBS(1)))*100
      IF(M6.GT.0) TOBS(1)=TOBS(1)+(M6*60)
      TOBS(2)=TOBS(1)+3.2
      DO 530 K=3,NQ
530   TOBS(K)=TOBS(2)+((K-2)*3.03)
      CALL PLOTS(0,0,18)
      CALL PLOT(3.0,3.0,-3)
550   DO 535 K=1,NQ
      T(K)=TIME(K)
535   CONTINUE
      CALL SCALE(T(1),A,NQ,1)
      T(NQ+1)=T(NQ+1)-5.0
      IF(T(NQ+1).LT.0.0) T(NQ+1)=0.0
      IF(T(NQ).GT.(T(NQ+2)*20)-T(1)) T(NQ+2)=T(NQ+2)+1.0
      L2=L2+1
      CALL AXIS(0.0,0.0,'TIME(MINS)',-10,A,0,T(NQ+1),T(NQ+2))
      DO 500 K=1,NQ
      Q(K)=QOUT1(NA,K)
500   CONTINUE
      CALL SCALE(Q(1),B,NQ,1)
      Q(NQ+2)=Q(NQ+2)+1.0
      CALL AXIS(0.0,0.0,'FLOW(L/S)',9,B,90.,Q(NQ+1),Q(NQ+2))
      CALL LINE(T,Q,NQ,1,3,1)
      CALL SYMBOL(6.0,14.0,0.42,'STORM OF THE',0.0,13)
      CALL SYMBOL(11.1,14.0,0.42,DATE,0.0,20)
      CALL SYMBOL(6.0,13.5,0.28,1,0.0,-1)
      CALL SYMBOL(6.3,13.5,0.28,'---PREDICTED FLOW',0.0,18)
      CALL SYMBOL(11.2,13.5,0.14,'(EVERY 3RD POINT SHOWN)',0.0,23)
      IF(M3.EQ.0) GOTO600
      IF(L2.EQ.2) GOTO650
      IF(L2.EQ.3) GOTO750
      DO 540 K=1,NQ
      T(K)=TOBS(K)
      Q(K)=QOBS(K)
540   CONTINUE
      CALL LINE(T,Q,NQ,1,-1,2)
      CALL SYMBOL(6.0,13.0,0.28,2,0.0,-1)
      CALL SYMBOL(6.3,13.0,0.28,'---OBSERVED FLOW',0.0,17)
560   CONTINUE
600   CALL G2(RAIN,TIME,NQ,A)
      IF(M2.EQ.0) GOTO699
      CALL PLOT(0.0,25.0,-3)
      GOTO550
650   CONTINUE
      DO 660 K=1,NQ
      Q2(K)=QGO(NA,K)
660   CONTINUE
      DO 640 K=1,NQ
      Q(NQ+K+2)=Q(K)
      Q(K)=Q2(K)
640   CONTINUE
      CALL LINE(T,Q,NQ,1,3,2)
      CALL SYMBOL(6.0,13.0,0.28,2,0.0,-1)
      CALL SYMBOL(6.3,13.0,0.28,'---GULLY LIQUOR CONTRIBUTION',
     1 0.0,29)
      DO 670 K=1,NQ
      Q(K)=Q(NQ+K+2)
```

```
  670 Q(NQ+K+2)=0
      CALL G2(RAIN,TIME,NQ,A)
      GOTO700
  699 L2=L2+1
  700 CONTINUE
      IF(M4.EQ.0) GOTO900
      CALL PLOT(0.0,25.0,-3)
      GOTO550
  750 CONTINUE
      DO 755 K=1,NQ
  755 C(K)=CA(K)
      CALL SCALE(C(1),B,NQ,1)
      CALL AXIS(-1.5,0.0,'CALCIUM(MG/L)',13,B,90.,C(NQ+1),C(NQ+2))
      CALL LINE(T,C,NQ,1,-1,2)
      CALL SYMBOL(6.0,13.0,0.28,2,0.0,-1)
      CALL SYMBOL(6.3,13.0,0.28,'---PREDICTED CALCIUM(MG/L)'
     1 ,0.0,26)
      DO 760 K=1,NQ
      T(K)=TOBS(K)
  760 C(K)=CAOBS(K)
      CALL LINE(T,C,NQ,1,-1,3)
      CALL SYMBOL(6.0,12.5,0.28,3,0.0,-1)
      CALL SYMBOL(6.3,12.5,0.28,'---OBSERVED CALCIUM(MG/L)'
     1 ,0.0,25)
  900 CALL PLOT(0,0,0.0,999)
 1000 STOP
      END
C
C           *************
C           SUBROUTINE G2
C           *************
C
C           PROGRAMME PLOTS HYETOGRAPH
C
      SUBROUTINE G2(RAIN,TIME,NQ,A)
      DIMENSION RAIN(200),TIME(200)
      DIMENSION TIM2(200),RAIN2(200)
      CALL PLOT(0.0,0.0,3)
      CALL PLOT(0.0,12.0,-3)
      CALL SCALE(TIME(1),A,NQ,1)
      TIME(NQ+1)=TIME(NQ+1)-5.0
      IF(TIME(NQ+1).LT.0.0) TIME(NQ+1)=0.0
      IF(TIME(NQ).GT.(TIME(NQ+2)*20)-TIME(1)) TIME(NQ+2)=TIME(NQ+2)+1.0
      CALL AXIS(0.0,0.0,' ',1,A,0,TIME(NQ+1),TIME(NQ+2))
      CALL SCALE(RAIN(1),3.0,NQ,-1)
      CALL AXIS(0.0,-3.0,'R(MM/HR) ',-9,3.0,90.,RAIN(NQ+1),RAIN(NQ+2))
      DO 5 K=1,NQ
      TIM2(K)=(TIME(K)-TIME(NQ+1))/TIME(NQ+2)
      RAIN2(K)=RAIN(K)/RAIN(NQ+2)
    5 CONTINUE
      CALL PLOT(TIM2(1),0.0,3)
      DO 10 K=1,NQ
      CALL PLOT(TIM2(K),RAIN2(K),2)
      CALL PLOT(TIM2(K+1),RAIN2(K),2)
   10 CONTINUE
      CALL PLOT(A,0.0,3)
      CALL PLOT(A,-12.0,2)
      CALL PLOT(0.0,-12.0,-3)
      RETURN
      END
```

```
C
C           ****************
C           SUBROUTINE HYETO
C           ****************
C
C           PROGRAMME FORMULATES A HYETOGRAPH (RAIN(T)) FROM
C           RAINGAUGE INPUT, APPLIES A CONSTANT PROPORTIONAL
C           LOSS MODEL TO FORM A NEW HYETOGRAPH (CRAIN(I))
C           AND DETERMINES THE MEAN INTENSITY FOR THE MOST
C           INTENSE TEN MINUTES (AVIN).
C
      SUBROUTINE HYETO(K,M1,N,NR,AVIN,IWRI,PERCEN)
      COMMON/ONE/TI(100),TILT(100)
      COMMON/ONEA/RAIN(200),TIME(200)
      COMMON/ONEB/CRAIN(200)
      DIMENSION AVI(200)
      REAL K
C
C           CALCULATION OF HYETOGRAPH FOR ONE MINUTE
C           INCREMENTS, ASSUMING BUCKET TO BE HALF FULL
C           AT THE BEGINNING AND END OF THE STORM
C
      IF(M1.EQ.0.0) GOTO62
      W=TI(2)
      IF(INT(TI(2))-INT(TI(1)).EQ.0) GOTO5
      W=W-0.4
    5 START=(2*TI(1)-W)+0.01
      S1=(START-INT(START))*100
      IF(S1.GE.60) START=START-0.4
      W2=START
      IX=INT(START)
      IY=INT(TI(1))
      IF(IY-IX.EQ.0)GOTO10
      W2=W2+0.4
   10 R=((TI(1)-W2)*100)+1.0
      NR=INT(R+.5)
      Z=((TILT(1)-0.5)*K)/NR
      DO20J=1,NR
      RAIN(J)=Z
   20 CONTINUE
      NR=NR+1
      DO30I=2,N
      NR1=0
      W1=0
      IY1=0
      IX1=0
      W1=TI(I-1)
      IX1=INT(TI(I))
      IY1=INT(TI(I-1))
      IF(IX1-IY1.EQ.0)GOTO50
      W1=W1+0.4
   50 R1=((TI(I)-W1)*100)
      NR1=INT(R1+0.5)
      DO40J=NR,NR+NR1-1
      RAIN(J)=TILT(I)*K/NR1
   40 CONTINUE
      NR=NR+NR1
   30 CONTINUE
      DO60J=NR,NR+NR1-1
      RAIN(J)=((TILT(N)-0.5)*K)/NR1
```

```
 60   CONTINUE
      NR=NR+NR1-1
C
C             CALCULATION OF TIME ARRAY
C
      TIME(1)=START
 62   IF (M1.EQ.1.0) GOTO63
      START =TIME(1)
      IX=INT(START)
 63   CONTINUE
      C=INT(START*100)-(IX*100)
      DO15I=2,200
      TIME(I)=TIME(I-1)+0.01
      C=C+1
      IF(C.LT.60)GOTO15
      TIME(I)=TIME(I)+0.40
      C=0
 15   CONTINUE
C
C             PROPORTIONAL LOSS MODEL
C
      DO75J=1,NR
 75   CRAIN(J)=RAIN(J)*PERCEN
C
C             DETERMINATION OF MEAN INTENSITY
C
      DO70I=1,NR-9
      AVI(I)=0
      DO80J=I,I+9
      AVI(I)=AVI(I)+RAIN(J)
 80   CONTINUE
      AVI(I)=AVI(I)/10
 70   CONTINUE
      AVIN=0
      DO90I=1,NR
      IF(AVI(I).LT.AVIN)GOTO90
      AVIN=AVI(I)
 90   CONTINUE
      RETURN
      END
C
C             *****************
C             SUBROUTINE DEPSTO
C             *****************
C
C             PROGRAMME CALCULATES THE HYETOGRAPHS APPLICABLE
C             TO EACH SUB AREA AFTER DEPRESSION STORAGE HAS
C             BEEN SUBTRACTED. (SRAIN(J,I) FOR PAVED AREAS,
C             RRAIN(I) FOR ROOFED AREAS)
C
      SUBROUTINE DEPSTO(NR,NA,IWRI)
      DIMENSION DEP(50)
      COMMON/ONEB/CRAIN(200)
      COMMON/TWO/SLOPE(50),SRAIN(50,200),RRAIN(200)
C
C              HYETOGRAPHS FOR PAVED AREAS
C
      DO 10 J=1,NA
      IF(SLOPE(J).EQ.-1.0) GOTO5
      DEP(J)=0.77*(SLOPE(J)**-0.49)
```

```
      GOTO8
    5 DEP(J)=-1.0
    8 DO 20 I=1,NR
      IF(DEP(J).EQ.-1.0) GOTO15
      IF(CRAIN(I).LE.DEP(J)) GOTO60
      SRAIN(J,I)=CRAIN(I)-DEP(J)
      DEP(J)=0.0
      GOTO20
   60 DEP(J)=DEP(J)-CRAIN(I)
   15 SRAIN(J,I)=0.0
   20 CONTINUE
   10 CONTINUE
C
C            HYETOGRAPH FOR ROOFED AREAS
C
      DEPSTR=0.1
      DO 30 I=1,NR
      IF(CRAIN(I).LE.DEPSTR) GOTO40
      RRAIN(I)=CRAIN(I)-DEPSTR
      DEPSTR=0.0
      GOTO30
   40 DEPSTR=DEPSTR-CRAIN(I)
      RRAIN(I)=0.0
   30 CONTINUE
      RETURN
      END
C
C            ******************
C            SUBROUTINE LINRES
C            ******************
C
C            PROGRAMME DERIVES THE INPUT HYDROGRAPHS (QINP(J,K))
C            TO THE SEWER SYSTEM FOR EACH SUB AREA (PAVED
C            AND ROOF). INPUT HYETOGRAPHS FOR EACH AREA
C            ARE ROUTED THROUGH A LINEAR RESERVOIR WHERE
C            THE ROUTING CONSTANT(CP) IS DETERMINED FROM
C            THE SUB AREA CHARACTERISTICS(LENGTH,SLOPE)
C
      SUBROUTINE LINRES(NA,NR,NQ,AVIN,IWRI,QPL,QINP)
      DIMENSION CP(50),QR(50,200),QP(50,200),QRL(50,200)
      DIMENSION MAX(50),QPL(50,200),QINP(50,200)
      COMMON/TWO/SLOPE(50),SRAIN(50,200),RRAIN(200)
      COMMON/THREE/LENGTH(50),CR(50),PAVEA(50),ROOFA(50)
      COMMON/FIVE/ PIPE(50)
      REAL LENGTH
C
C            CALCULATION OF PAVED AREA ROUTING CONSTANTS
C
      DO 10 J=1,NA
      IF(SLOPE(J).EQ.-1.0) GOTO15
      C=1.43*(SLOPE(J)**-0.4)*(LENGTH(J)**-0.22)
      CP(J)=C*(AVIN**-0.4)
      GOTO18
   15 CP(J)=-1.0
C
C            CALCULATION OF INPUT HYDROGRAPH FOR EACH
C            SUB AREA (PAVED AND ROOF)
C
   18 DO 20 K=1,NR
      QP(J,K)=SRAIN(J,K)/(CP(J)+0.5)
```

```
      QR(J,K)=RRAIN(K)/(CR(J)+0.5)
      IF(CP(J).EQ.-1.0) QP(J,K)=0.0
      IF(CR(J).EQ.-1.0) QR(J,K)=0.0
  20  CONTINUE
   7  CONTINUE
      NITP=INT((4.6*CP(J))+0.5)
      NITR=INT((4.6*CR(J))+0.5)
      IF(NITP.LT.1) GOTO50
      DO 30 K=1,NR+NITP
      X=0.0
      Z=0.0
      DO 40 L=1,NITP
      IF(K-L.EQ.0) GOTO45
      IF((1-L).NE.0) GOTO64
      ZA=QP(J,K-L)*CP(J)
      GOTO63
  64  ZA=QP(J,K-L)*CP(J)*EXP((-L+1)/CP(J))
  63  ZB=QP(J,K-L)*CP(J)*EXP(-L/CP(J))
      X=X+ZA-ZB
  40  CONTINUE
  45  QPL(J,K)=(X+(QP(J,K)/2))*PAVEA(J)
      IF(INT(PIPE(J)).EQ.6) QPL(J,K)=0.0
  30  CONTINUE
  50  IF(NITR.LT.1.0) GOTO65
      DO 60 K=1,NR+NITR
      X1=0.0
      Z1=0.0
      DO 70 L=1,NITR
      IF(K-L.EQ.0) GOTO75
      IF((1-L).NE.0) GOTO66
      Z1A=QR(J,K-L)*CR(J)
      GOTO67
  66  Z1A=QR(J,K-L)*CR(J)*EXP((-L+1)/CR(J))
  67  Z1B=QR(J,K-L)*CR(J)*EXP(-L/CR(J))
      X1=X1+Z1A-Z1B
  70  CONTINUE
  75  QRL(J,K)=(X1+(QR(J,K)/2))*ROOFA(J)
  60  CONTINUE
  65  IF(NITP.LT.NITR) GOTO80
      MAX(J)=NITP
      GOTO90
  80  MAX(J)=NITR
  90  DO 100 K=1,NR+MAX(J)
      QINP(J,K)=QPL(J,K)+QRL(J,K)
      GOTO100
 100  CONTINUE
  10  CONTINUE
      NMAX=0
      DO 110 J=1,NA
      IF(NMAX.LT.MAX(J)) NMAX=MAX(J)
 110  CONTINUE
      NO=NR+NMAX
      RETURN
      END
C
C             ***************
C             SUBROUTINE MUSK
C             ***************
C
C     PROGRAMME EVALUATES THE MUSKINGUM COEFFTS(C1,C2,C3)
```

```
C       FOR NA PIPES OF GIVEN LENGTH (METRES), SLOPE (%) AND
C       RADIUS (METRES) FOR A TIME INCREMENT OF ONE MINUTE
C
        SUBROUTINE MUSK(NA,IWRI)
        COMMON/FOUR/ PLENGT(50),PSLOPE(50),RADIUS(50)
        COMMON/FOURA/ C1(50),C2(50),C3(50)
        REAL KSD14,LN10D2
        TINC=60
        DATA G32,KSD14,X0,X1/313.92,0.00002027,1.159279,0.916515/
        DATA X2,DRDY,LN10D2/0.792673,0.468818,1.151295/
C
C       CALCULATION OF COEFFICIENTS
C
        IF(NA.GT.50) GOTO900
        DO 200 I=1,NA
        PSLOPE(I)=PSLOPE(I)/100
        FLAREA=X2*RADIUS(I)**2
        WP=2.0*RADIUS(I)*X0
        W=2.0*RADIUS(I)*X1
        HR=FLAREA/WP
        FF=-1.0/ALOG10(KSD14/HR)
        QP=FLAREA/FF*SQRT(G32*HR*PSLOPE(I))
        WS=0.5*QP*((W+W)/FLAREA+DRDY*(1.0+FF/LN10D2))/W
        AM=QP/(PSLOPE(I)*(W+W))
        GAM=0.0
        VPL=WS*TINC
        PVPL=1.0
        IF(VPL.LT.PLENGT(I)) GOTO100
        PVPL=PLENGT(I)/VPL
        GAM=PVPL-1.0
  100   EPS=0.5-(AM*PVPL)/(WS*PLENGT(I))
        CNU=2.0*PLENGT(I)/(PVPL*TINC*WS)
        X3=1.0/(1.0+CNU*(1.0-EPS))
        C1(I)=(1.0+CNU*(EPS+GAM))*X3
        C2(I)=(1.0-CNU*(EPS+GAM))*X3
        C3(I)=((1.0-EPS)*CNU-1.0)*X3
  200   CONTINUE
        RETURN
  900   WRITE(IWRI,600)
  600   FORMAT('1TOO MANY PIPES - EXECUTION HALTED')
        END
C
C               ****************
C               SUBROUTINE ROUTE
C               ****************
C
C               PROGRAMME EVALUATES THE OUTPUT HYDROGRAPH FOR
C               EACH PIPE (QOUT(J,K)) USING THE INPUT HYDROGRAPH
C               (QINP(J,K)) AND THE MUSKINGUM PIPE ROUTING COEFFTS
C               (C1,C2,C3)
C
        SUBROUTINE ROUTE(NQ,NA,IWRI,QINP,QOUT)
        DIMENSION NJ(20),QINP(50,200),QOUT(50,200)
        COMMON/FOURA/C1(50),C2(50),C3(50)
        COMMON/FIVE/PIPE(50)
C
C               CALCULATION OF OUTPUT HYDROGRAPHS
C
        I=0
        DO 101 J=1,NA
```

```
    6 CONTINUE
      IF(J.EQ.1) GOTO30
      IF(INT(PIPE(J))-INT(PIPE(J-1)).GE.1.0) GOTO10
      IF(INT(PIPE(J))-INT(PIPE(J-1)).LE.-1.0) GOTO20
      DO 102 K=1,NQ
      QINP(J,K)=QINP(J,K)+QOUT(J-1,K)
  102 CONTINUE
      GOTO30
   10 I=I+1
      NJ(I)=J-1
      GOTO30
   20 DO 103 K=1,NQ
      QINP(J,K)=QINP(J,K)+QOUT(J-1,K)+QOUT(NJ(I),K)
  103 CONTINUE
      I=I-1
   30 DO 104 K=1,NQ
      IF(K.NE.1) GOTO40
      QOUT(J,1)=0
      GOTO104
   40 QOUT(J,K+1)=(C1(J)*QINP(J,K))+(C2(J)*QINP(J,K+1))
     1+(C3(J)*QOUT(J,K))
      GOTO104
  104 CONTINUE
  101 CONTINUE
      DO 106 J=1,NA
      DO 107 K=1,NQ
      QOUT(J,K)=QOUT(J,K)/60
  107 CONTINUE
  106 CONTINUE
      RETURN
      END
C
C                *****************
C                SUBROUTINE GULLY
C                *****************
C
C                PROGRAMME COMPUTES THE CONTRIBUTION TO THE
C                OUTPUT HYDROGRAPHS MADE BY ORIGINAL GULLY LIQUORS
C                (QGO(J,K))
C
      SUBROUTINE GULLYS(NQ,NA,IWRI,QPL,QGO,QOUT,MCA,FCA,M4)
      DIMENSION QG(50,200),QGO(50,200),VOL(200),QPL(50,200)
      DIMENSION QOUT(50,200)
      COMMON/SIX/GULLY(50),CA(200)
      REAL MCA
      GVOL=92.8
      DO 100 J=1,NA
      DO 200 K=1,NQ
      IF(GULLY(J).EQ.0) GOTO20
      QPL(J,K)=QPL(J,K)/GULLY(J)
      PM=1.0
      IF(K.EQ.1) GOTO10
      IF(QPL(J,K).EQ.0.0) GOTO40
      IF(QPL(J,K).GT.7.241) GOTO40
      PM=(0.1107*QPL(J,K))+0.198618
   40 VOL(K)=VOL(K-1)*EXP((-QPL(J,K)*PM)/GVOL)
      QG(J,K)=(VOL(K-1)-VOL(K))*GULLY(J)
      GOTO200
   10 VOL(1)=GVOL
      QG(J,1)=0
```

```
      GOTO200
 20   QG(J,K)=0
200   CONTINUE
100   CONTINUE
      CALL ROUTE(NQ,NA,IWRI,QG,QGO)
      IF(M4.EQ.0) GOTO50
      DO 150 K=1,NQ
      IF(QOUT(NA,K).EQ.0.0) GOTO125
      CA1=(QGO(NA,K)*MCA)/QOUT(NA,K)
      CA2=(QOUT(NA,K)-QGO(NA,K))*FCA
      CA(K)=CA1+(CA2/QOUT(NA,K))
      GOTO150
125   CA(K)=0.0
150   CONTINUE
 50   CONTINUE
      RETURN
      END
```

APPENDIX 2

RESULTS

1. GULLY LIQUOR QUALITY DATA

LIST OF SYMBOLS (in order of occurrence)

R = total rainfall (mm) for week prior to sampling
ADP = antecedent dry period days
ADP>2 = days since rainfall greater than 0.2
T. MAX = maximum temperature on day prior to sampling
T. MIN = minimum temperature on day prior to sampling
GP = gully pot
C95 LMT = 95% confidence limits
C95 (%) = 95% confidence limits expressed as a percentage of the mean
SS = suspended solids
DS = dissolved solids
COD = chemical oxygen demand
BOD = biochemical oxygen demand
CL = chloride
NO2 = nitrate
NH4 = ammonium
CA = calcium
NA = sodium
K = potassium
ZN = zinc
TOC = total organic carbon
PB = lead
CD = cadmium
MN = manganese
NI = nickel
CR = chromium
FE = iron
CU = copper

(all concentrations are expressed in mg/l)

Key to Week Numbers

Number	Date
1	16/ 8/76
2	23/ 8/76
4	6/ 9/76
5	13/ 9/76
6	20/ 9/76
7	27/ 9/76
8	4/10/76
9	11/10/76
10	18/10/76
11	25/10/76
12	1/11/76
13	8/11/76
14	15/11/76
15	22/11/76
16	29/11/76
17	6/12/76
18	13/12/76
19	20/12/76
24	24/ 1/77
26	7/ 2/77
28	21/ 2/77
30	8/ 3/77
32	21/ 3/77
34	4/ 4/77
36	18/ 4/77
38	2/ 5/77
39	9/ 5/77
40	16/ 5/77
41	20/ 5/77
44	13/ 6/77
46	27/ 6/77

WEATHER DATA FOR WEEKLY GULLY ANALYSIS

WEEK	R(MM)	ADP	ADP>2	T.MAX	T.MIN
1.	0.00	15.00	32.00	26.00	11.50
2.	0.00	22.00	39.00	27.00	14.00
4.	3.80	5.00	5.00	21.00	8.00
5.	18.40	0.50	0.50	13.50	9.00
6.	13.40	3.00	4.00	22.00	9.50
7.	33.40	0.00	0.00	21.00	13.00
8.	15.30	0.50	0.50	15.00	9.00
9.	21.20	0.00	0.00	20.00	8.00
10.	35.80	0.00	0.00	11.00	9.00
11.	12.60	0.00	0.00	12.50	7.50
12.	11.70	1.00	1.00	11.00	5.50
13.	11.80	1.50	1.50	12.00	1.00
14.	3.20	0.50	0.50	9.00	-1.00
15.	6.30	4.00	6.00	7.00	5.00
16.	9.90	0.00	1.00	8.50	4.00
17.	6.40	0.50	0.50	7.00	3.50
18.	6.10	0.50	1.50	4.50	1.00
19.	24.00	0.00	0.00	4.00	1.00
24.	5.30	0.00	0.00	9.50	4.50
26.	19.40	0.50	0.50	9.00	5.50
28.	33.70	0.00	0.00	9.50	2.00
30.	12.00	0.50	5.00	12.50	5.00
32.	12.50	0.50	0.50	7.50	5.00
34.	14.40	0.00	0.00	10.00	1.50
36.	1.20	5.00	12.00	8.00	0.00
38.	16.20	0.00	3.00	12.00	6.00
39.	16.50	1.00	1.00	14.00	4.50
40.	15.60	0.00	1.00	12.00	5.00
42.	0.00	14.00	17.00	12.50	8.00
44.	46.40	0.00	0.00	15.50	10.50
46.	0.00	11.00	12.00	19.50	10.00

SUSPENDED SOLIDS (MG/L); WEEKLY ANALYSES (1976-77)

WEEK	GP 1	GP 6	GP 7	GP 8	MEAN
1.	7.400	12.400	12.200	-1.000	10.667
2.	11.800	21.200	8.600	-1.000	13.867
4.	9.000	16.600	8.800	-1.000	11.467
5.	5.400	13.200	1.800	-1.000	6.800
6.	6.600	13.600	7.200	-1.000	9.133
7.	0.200	38.400	2.400	4.000	11.250
8.	13.600	16.400	10.800	18.800	14.900
9.	5.800	21.800	17.600	10.400	13.900
10.	26.600	88.500	28.600	15.400	39.775
11.	7.000	27.200	15.600	10.200	15.000
12.	22.600	44.100	30.500	7.800	26.250
13.	-1.000	3.000	5.600	0.400	3.000
14.	5.200	34.800	26.300	4.600	17.725
15.	1.600	16.600	34.600	4.000	14.200
16.	7.600	38.000	12.800	8.400	16.700
17.	39.200	35.000	62.600	16.000	38.200
18.	71.400	25.200	88.200	46.800	57.900
19.	13.200	5.500	20.300	7.500	11.625
24.	2.800	24.200	57.800	2.800	21.900
26.	17.600	14.400	213.600	36.800	70.600
28.	12.600	17.000	31.400	20.000	20.250
30.	33.200	26.200	13.600	17.800	22.700
32.	13.600	32.000	39.800	9.400	23.700
34.	4.400	11.500	10.000	15.300	10.300
36.	15.000	8.400	8.000	45.400	19.200
38.	4.800	24.400	12.800	6.800	12.200
39.	-1.000	-1.000	25.000	-1.000	25.000
40.	22.400	25.200	14.800	4.000	16.600
41.	25.000	49.600	21.700	24.600	30.225
44.	10.400	36.800	21.600	14.800	20.900
46.	18.800	58.000	29.600	30.800	34.300
MINIMUM	0.200	3.000	1.800	0.400	3.000
MAXIMUM	71.400	88.500	213.600	46.800	70.600
RANGE	71.200	85.500	211.800	46.400	67.600
I.Q RANGE	17.000	23.200	22.600	15.400	3.000
MEAN	14.993	26.640	28.845	15.312	21.298
STD DEV	14.430	17.535	39.109	12.790	14.487
SKEWNESS	2.241	1.564	3.598	1.193	1.799
KURTOSIS	5.879	3.157	13.845	0.479	3.199

DISSOLVED SOLIDS (MG/L); WEEKLY ANALYSES (1976-77)

WEEK	GP 1	GP 6	GP 7	GP 8	MEAN
1.	464.00	1920.00	398.00	-1.00	927.33
2.	420.00	1795.00	350.00	-1.00	855.00
4.	205.00	415.00	218.00	-1.00	279.33
5.	60.00	328.00	73.00	-1.00	153.67
6.	93.00	303.00	125.00	-1.00	173.67
7.	55.00	245.00	53.00	50.00	100.75
8.	85.00	135.00	103.00	85.00	102.00
9.	68.00	158.00	60.00	60.00	86.50
10.	75.00	115.00	60.00	63.00	78.25
11.	78.00	145.00	75.00	78.00	94.00
12.	108.00	130.00	63.00	95.00	99.00
13.	103.00	180.00	35.00	83.00	100.25
14.	128.00	248.00	143.00	83.00	150.50
15.	120.00	268.00	198.00	140.00	181.50
16.	120.00	165.00	138.00	95.00	129.50
17.	175.00	295.00	705.00	168.00	335.75
18.	1753.00	530.00	1552.00	17475.00	5327.50
19.	275.00	218.00	68.00	345.00	226.50
24.	158.00	328.00	1285.00	208.00	494.75
26.	65.00	210.00	83.00	98.00	114.00
28.	45.00	288.00	70.00	85.00	122.00
30.	160.00	223.00	100.00	158.00	160.25
32.	94.00	181.00	115.00	83.00	118.25
34.	143.00	243.00	115.00	123.00	156.00
36.	170.00	233.00	200.00	135.00	184.50
38.	98.00	213.00	110.00	108.00	132.25
39.	-1.00	-1.00	123.00	-1.00	123.00
40.	125.00	208.00	120.00	148.00	150.25
42.	284.00	182.00	222.00	232.00	230.00
44.	66.00	184.00	64.00	84.00	99.50
46.	124.00	210.00	150.00	162.00	161.50
MINIMUM	45.00	115.00	35.00	50.00	78.25
MAXIMUM	1753.00	1920.00	1552.00	17475.00	5327.50
RANGE	1708.00	1805.00	1517.00	17425.00	5249.25
I.Q RANGE	150.00	119.00	127.00	57.00	0.00
MEAN	197.23	343.20	231.42	817.76	375.72
STD DEV	310.33	420.98	344.80	3470.86	940.62
SKEWNESS	4.35	3.19	2.86	4.60	4.86
KURTOSIS	18.82	8.68	7.22	19.10	22.61

BIOCHEMICAL OXYGEN DEMAND (MG/L): WEEKLY ANALYSES

WEEK	GP 1	GP 6	GP 7	GP 8	MEAN
5.	3.70	4.00	4.10	-1.00	3.93
6.	4.80	4.10	7.00	-1.00	5.30
7.	8.50	7.90	12.30	10.30	9.75
10.	1.50	1.90	2.40	0.90	1.67
11.	4.00	4.90	4.50	4.60	4.53
14.	2.90	3.70	4.00	3.60	3.55
15.	1.40	1.80	1.60	1.60	1.60
16.	3.00	2.70	3.00	3.15	2.96
24.	-1.00	3.60	5.10	1.60	3.43
26.	3.50	2.20	5.10	3.20	3.50
28.	3.40	1.90	3.30	3.50	3.03
30.	2.80	8.90	3.60	3.70	4.75
32.	4.60	6.20	6.00	3.30	5.03
38.	9.60	11.00	7.70	5.70	8.50
39.	-1.00	-1.00	5.50	-1.00	5.50
40.	11.60	15.30	8.80	11.50	11.80
42.	46.00	35.00	31.00	40.00	38.00
44.	4.50	2.90	4.10	4.10	3.90
46.	4.10	10.40	4.00	2.40	5.23
MINIMUM	1.40	1.80	1.60	0.90	1.60
MAXIMUM	46.00	35.00	31.00	40.00	38.00
RANGE	44.60	33.20	29.40	39.10	36.40
I.Q RANGE	3.50	7.10	3.70	3.30	0.00
MEAN	7.05	7.13	6.48	6.45	6.63
STD DEV	10.41	7.92	6.44	9.40	8.03
SKEWNESS	3.24	2.53	3.04	2.99	3.28
KURTOSIS	9.27	6.14	8.78	7.85	9.99

```
CHEMICAL OXYGEN DEMAND (MG/L); WEEKLY ANALYSES
----------------------------------------------------


   WEEK         GP 1        GP 6        GP 7        GP 8        MEAN

   24.         10.30       49.90       -1.00       11.00       23.73
   26.         16.50       23.80       50.00       24.50       28.70
   28.          8.80       15.00       28.60       18.40       17.70
   30.         13.00      163.00       20.00       17.00       53.25
   32.         22.40       33.90       -1.00       23.70       26.67
   34.         42.50       54.50       44.60       51.00       48.15
   36.         44.70      118.40       68.40       49.10       70.15
   38.         28.30       52.00       37.60       30.30       37.05
   39.         -1.00       -1.00       -1.00       -1.00       -1.00
   40.         29.70       51.00       31.00       28.30       35.00
   42.         60.20       75.40       39.80       85.60       65.25
   44.          8.70       21.10       28.50       13.40       17.92
   46.          9.20       16.30       16.30       11.30       13.28

MINIMUM         8.70       15.00       16.30       11.00       13.29
MAXIMUM        60.20      163.00       68.40       85.60       70.15
RANGE          51.50      148.00       52.10       74.60       56.87
I.Q RANGE      33.30       54.30       23.00       35.70        0.00
MEAN           24.53       56.19       36.48       30.30       36.40
STD DEV        17.00       44.52       15.33       21.86       18.92
SKEWNESS        0.80        1.28        0.67        1.40        0.54
KURTOSIS       -0.68        0.55       -0.33        1.00       -1.12
```

DISSOLVED OXYGEN (MG/L); WEEKLY ANALYSES (1976-77)

WEEK	GP 1	GP 6	GP 7	GP 8	MEAN
10.	9.90	9.80	9.80	10.00	9.88
11.	2.90	10.70	9.90	7.30	7.70
12.	2.60	9.90	10.00	6.40	7.23
13.	0.80	6.60	2.20	4.40	3.50
14.	2.80	10.00	4.60	4.50	5.48
15.	0.50	4.10	0.60	0.85	1.51
16.	3.50	9.40	9.20	6.90	7.25
17.	2.30	8.90	9.30	6.00	6.63
18.	3.70	9.50	4.60	2.20	5.00
19.	-1.00	-1.00	-1.00	-1.00	-1.00
24.	3.40	10.20	5.80	8.00	6.85
26.	8.20	10.50	10.80	9.60	9.77
28.	7.90	10.60	11.20	9.90	9.90
30.	1.40	9.70	2.30	6.30	4.93
32.	3.60	11.20	7.00	9.20	7.75
34.	4.10	10.00	7.10	8.50	7.43
36.	0.50	1.20	0.40	1.60	0.92
46.	-1.00	1.70	0.00	0.00	0.57
MINIMUM	0.50	1.20	0.00	0.00	0.57
MAXIMUM	9.90	11.20	11.20	10.00	9.90
RANGE	9.40	10.00	11.20	10.00	9.33
I.Q RANGE	2.70	3.90	7.70	7.00	0.00
MEAN	3.63	8.47	6.16	5.98	6.02
STD DEV	2.77	3.14	3.93	3.25	2.97
SKEWNESS	1.00	-1.44	-0.29	-0.48	-0.52
KURTOSIS	-0.07	0.50	-1.47	-1.09	-0.83

NITRATE (MG/L); WEEKLY ANALYSES (1976-77)

WEEK	GP 1	GP 6	GP 7	GP 8	MEAN
1.	3.20	4.70	2.20	-1.00	3.37
2.	3.00	3.50	2.40	-1.00	2.97
4.	1.37	10.80	1.80	-1.00	4.66
5.	1.40	14.00	1.28	-1.00	5.56
6.	2.00	10.50	1.70	-1.00	4.73
7.	1.20	6.40	0.85	1.20	2.41
8.	0.96	6.00	1.10	1.30	2.34
9.	1.90	4.80	1.10	1.70	2.38
10.	2.00	5.00	1.70	2.50	2.80
11.	1.30	7.10	2.60	2.60	3.40
12.	1.20	2.90	0.80	2.30	1.80
13.	3.00	5.00	1.70	2.70	3.10
14.	2.60	6.50	5.40	2.60	4.27
15.	1.50	6.20	2.30	2.80	3.20
16.	1.80	3.60	2.80	1.80	2.50
17.	1.90	3.70	8.30	2.00	3.97
18.	24.00	8.30	20.00	101.00	38.33
19.	7.50	8.60	3.20	10.00	7.33
24.	3.90	8.70	16.20	4.90	8.43
26.	0.80	3.50	1.30	1.40	1.75
28.	1.80	4.20	2.60	2.60	2.80
30.	4.20	13.00	2.80	3.80	5.95
32.	2.60	7.10	5.80	2.15	4.41
34.	2.90	6.00	3.70	3.00	3.90
36.	2.60	14.00	11.00	3.60	7.80
38.	3.30	32.00	10.50	5.00	12.70
39.	-1.00	-1.00	24.50	-1.00	24.50
40.	11.50	132.00	42.00	14.50	50.00
42.	23.00	17.00	15.00	13.00	17.00
44.	6.40	9.00	7.40	7.00	7.45
46.	1.60	7.30	1.50	1.60	3.00
MINIMUM	0.80	2.90	0.80	1.20	1.75
MAXIMUM	24.00	132.00	42.00	101.00	50.00
RANGE	23.20	129.10	41.20	99.80	48.25
I.Q RANGE	2.10	5.00	7.15	3.20	2.24
MEAN	4.21	12.38	6.63	7.88	8.03
STD DEV	5.69	23.30	8.94	19.72	10.88
SKEWNESS	2.71	4.66	2.42	4.37	2.71
KURTOSIS	6.27	20.97	6.00	17.73	6.63

AMMONIUM (MG/L); WEEKLY ANALYSES (1976-77)

WEEK	GP 1	GP 6	GP 7	GP 8	MEAN
1.	6.05	2.97	9.13	-1.00	6.05
2.	5.30	2.64	7.80	-1.00	5.25
4.	0.75	1.10	1.54	-1.00	1.13
5.	0.10	0.31	0.13	-1.00	0.18
6.	0.34	1.00	0.21	-1.00	0.52
7.	0.35	0.39	0.35	0.42	0.38
8.	0.65	0.93	0.77	0.57	0.73
9.	0.42	0.39	0.36	0.44	0.40
10.	0.29	0.32	0.53	0.30	0.36
11.	0.45	0.32	0.34	0.37	0.37
12.	1.14	0.32	0.66	0.48	0.65
13.	1.11	0.55	0.44	0.17	0.57
14.	1.17	0.51	0.70	0.50	0.72
15.	0.55	0.94	0.57	0.41	0.62
16.	0.24	0.20	0.18	0.28	0.23
17.	0.41	0.22	0.18	0.12	0.23
18.	0.42	0.31	0.28	7.04	2.01
19.	0.30	0.24	0.33	0.35	0.30
24.	0.15	0.49	0.25	0.25	0.29
26.	0.14	0.21	0.20	0.13	0.17
28.	0.12	0.13	0.13	0.08	0.12
30.	0.19	0.39	0.25	0.24	0.27
32.	0.25	0.48	0.57	0.07	0.34
34.	0.83	0.45	0.45	0.18	0.48
36.	1.43	1.17	1.37	0.14	1.03
38.	0.86	0.52	0.19	0.20	0.44
39.	-1.00	-1.00	0.19	-1.00	0.19
40.	1.90	0.62	0.35	0.31	0.80
42.	6.40	3.00	3.90	3.10	4.10
44.	0.64	0.57	0.41	0.54	0.54
46.	2.10	1.34	2.42	2.32	2.05
MINIMUM	0.10	0.13	0.13	0.07	0.12
MAXIMUM	6.40	3.00	9.13	7.04	6.05
RANGE	6.30	2.87	9.00	6.97	5.94
I.Q RANGE	0.89	0.65	0.51	0.30	0.00
MEAN	1.17	0.77	1.13	0.76	1.02
STD DEV	1.69	0.78	2.11	1.48	1.47
SKEWNESS	2.27	1.97	2.90	3.36	2.41
KURTOSIS	3.80	2.76	7.30	10.84	4.66

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CHLORIDE (MG/L); WEEKLY ANALYSES (1976-77)
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       WEEK          GP 1         GP 6         GP 7         GP 8         MEAN

         1.          9.00        16.00        12.00        -1.00        12.33
         2.         12.00        18.00        -1.00        -1.00        15.00
         4.         12.00        15.00        16.00        -1.00        14.33
         5.          2.50        18.00         2.00        -1.00         7.50
         6.          3.00        14.00         7.00        -1.00         8.00
         7.          3.00         8.00         3.10         3.80         4.40
         8.          1.80         2.40         1.90         2.30         2.10
         9.          2.40         5.40         2.50         2.70         3.25
        10.          2.60         3.00         2.40         2.00         2.50
        11.         -1.00        -1.00        -1.00        -1.00        -1.00
        12.          7.70         7.50         5.80         8.30         7.32
        13.          4.00         4.30         2.40         2.70         3.35
        14.         31.00        29.60        28.50         7.60        24.18
        15.          3.00        24.50        29.40        15.70        18.15
        16.          6.50        14.70        20.80         6.00        12.00
        17.         37.00        27.80       327.00        17.20       102.25
        18.        875.00       160.00       700.00      9800.00      2883.75
        19.         85.00        16.00        16.00       126.00        60.75
        24.         23.00        81.80       610.00        36.00       187.70
        26.         12.50        31.00        28.50        23.00        23.75
        28.         13.00        21.50        27.00        20.00        20.38
        30.         24.00        31.00        26.00        29.00        27.50
        32.         14.50        27.00        25.00        14.00        20.13
        34.         18.00        30.00        19.50        16.50        21.00
        36.         23.50        35.50        46.00        16.50        30.38
        38.         11.50        31.00        21.00        12.50        19.00
        39.         -1.00        -1.00        29.20        -1.00        29.20
        40.         18.00        33.00        22.00        18.00        22.75
        42.         23.00        27.00        29.50        35.50        28.75
        44.          4.10        10.50         6.50         6.50         6.90
        46.         12.50        21.00        17.50        10.50        15.38

MINIMUM              1.80         2.40         1.90         2.00         2.10
MAXIMUM            875.00       160.00       700.00      9800.00      2883.75
RANGE              873.20       157.60       698.10      9798.00      2881.65
I.Q RANGE           18.90        20.50        22.30        17.00         0.00
MEAN                44.66        26.36        71.88       426.35       121.13
STD DEV            160.53        29.86       172.21      1996.73       523.03
SKEWNESS             4.93         3.33         2.90         4.49         5.07
KURTOSIS            22.57        11.81         6.91        18.12        23.84
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PH; WEEKLY ANALYSES (1976-77)

WEEK	GP 1	GP 6	GP 7	GP 8	MEAN
1.	8.23	7.92	8.13	-1.00	8.09
2.	8.03	7.84	7.95	-1.00	7.94
4.	7.63	11.39	7.63	-1.00	8.88
5.	7.50	11.44	7.69	-1.00	8.88
6.	7.99	11.34	7.59	-1.00	8.97
7.	7.29	11.40	7.58	8.11	8.60
8.	7.34	11.58	7.46	7.88	8.57
9.	7.37	10.94	7.54	7.55	8.35
10.	7.48	10.58	7.58	9.22	8.72
11.	7.48	10.95	7.47	7.41	8.33
12.	7.53	11.00	7.54	7.55	8.40
13.	7.51	11.50	7.63	7.61	8.56
14.	7.70	10.88	7.42	7.64	8.41
15.	7.57	10.53	7.51	7.40	8.25
16.	6.54	10.50	7.42	7.70	8.04
17.	7.54	12.94	7.50	10.28	9.57
18.	7.52	11.48	7.50	7.64	8.53
19.	7.64	11.00	7.92	9.65	9.05
24.	7.63	11.23	7.74	9.74	9.09
26.	7.00	11.26	7.31	8.63	8.55
28.	7.32	11.45	7.36	7.45	8.39
30.	7.89	9.74	7.70	7.96	8.32
32.	7.59	10.92	7.49	7.47	8.37
34.	7.09	10.95	6.96	7.28	8.07
36.	7.68	8.03	7.63	7.64	7.75
38.	6.57	9.14	6.35	6.30	7.09
39.	-1.00	-1.00	7.16	-1.00	7.16
40.	7.48	10.68	7.41	7.32	8.22
42.	7.48	7.56	7.54	6.95	7.38
44.	7.01	10.77	6.71	7.91	8.10
46.	7.69	7.67	7.81	7.66	7.71
MINIMUM	6.54	7.56	6.35	6.30	7.09
MAXIMUM	8.23	12.94	8.13	10.28	9.57
RANGE	1.69	5.38	1.78	3.98	2.48
I.Q RANGE	0.33	1.27	0.21	0.70	0.00
MEAN	7.48	10.49	7.49	7.92	8.33
STD DEV	0.37	1.37	0.34	0.92	0.55
SKEWNESS	-0.70	-1.02	-1.37	1.12	-0.33
KURTOSIS	0.93	0.03	2.90	0.71	0.19

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SODIUM (MG/L); WEEKLY ANALYSES (1976-77)
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   WEEK        GP 1       GP 6       GP 7       GP 8       MEAN

    1.         3.30      19.30       5.70      -1.00       9.43
    2.         3.80      13.50       4.50      -1.00       7.27
    4.         2.10       6.30       3.60      -1.00       4.00
    5.         0.40       4.30       0.64      -1.00       1.78
    6.         0.55       3.78       1.26      -1.00       1.86
    7.         0.30       1.20       0.44       0.82       0.69
    8.         0.40       2.05       0.57       1.12       1.04
    9.         0.78       1.57       1.38       1.50       1.31
   10.         1.36       1.62       1.42       1.36       1.44
   11.         1.45       1.78       1.57       1.67       1.62
   12.         1.82       1.42       1.37       1.77       1.59
   13.         2.10       1.83       1.36       1.70       1.75
   14.         4.85      11.25       8.35       2.57       6.76
   15.         3.28       6.46      10.52       3.54       5.95
   16.         2.63       6.21       8.46       2.65       4.99
   17.        22.30      18.70     212.00       7.00      65.00
   18.       630.00      83.00     414.00    5560.00    1671.75
   19.        94.80      17.20      20.72     140.02      68.18
   24.        31.30      38.80     267.00      22.30      89.85
   26.         3.28       5.74      18.80       8.24       9.01
   28.         2.12       6.14       6.56       3.98       4.70
   30.         8.40      10.40      13.50      14.60      11.73
   32.         2.83       4.00       7.90       4.15       4.72
   34.         3.60       2.73       5.64       3.36       3.83
   36.         5.00       7.10      13.40       5.60       7.78
   38.         2.82       3.14       2.87       2.77       2.90
   39.        -1.00      -1.00       2.44      -1.00       2.44
   40.         3.60       2.47       6.40       3.74       4.05
   42.         3.08       3.38       7.76       5.14       4.84
   44.         0.80       1.72       2.48       1.05       1.51
   46.         1.12       2.43       2.57       2.12       2.06

MINIMUM        0.30       1.20       0.44       0.82       0.69
MAXIMUM      630.00      83.00     414.00    5560.00    1671.75
RANGE        629.70      81.80     413.56    5559.18    1671.06
I.Q RANGE      2.85       8.86       9.84       5.33       0.02
MEAN          28.14       9.65      34.04     232.11      64.70
STD DEV      115.05      15.96      91.92    1110.32     299.03
SKEWNESS       4.93       3.52       3.11       4.60       5.17
KURTOSIS      22.83      12.80       8.59      19.09      24.81
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CALCIUM (MG/L); WEEKLY ANALYSES (1976-77)

WEEK	GP 1	GP 6	GP 7	GP 8	MEAN
1.	43.00	178.00	34.00	-1.00	85.00
2.	95.40	194.00	40.50	-1.00	109.97
4.	25.60	57.00	25.60	-1.00	36.07
5.	8.30	50.00	8.60	-1.00	22.33
6.	13.00	41.70	14.70	-1.00	23.13
7.	4.00	39.00	5.00	6.30	13.58
8.	6.00	79.80	8.00	11.20	26.25
9.	12.20	34.60	11.40	14.20	18.10
10.	8.90	26.20	8.60	10.00	13.42
11.	15.00	31.50	12.50	12.80	17.95
12.	19.50	28.50	9.50	16.50	18.50
13.	19.60	39.20	13.30	16.50	22.15
14.	26.00	40.50	20.50	26.00	28.25
15.	22.30	37.00	29.00	23.20	27.88
16.	18.60	29.00	17.60	15.80	20.25
17.	20.20	42.80	20.80	27.60	27.85
18.	53.00	44.50	63.00	272.00	108.13
19.	21.20	43.30	9.50	23.10	24.28
24.	24.00	43.40	75.00	25.00	41.85
26.	12.30	43.70	7.70	13.30	19.25
28.	10.00	54.00	10.50	14.40	22.22
30.	27.50	34.30	20.20	22.70	26.17
32.	17.50	27.00	17.50	13.80	18.95
34.	19.60	43.40	13.30	15.00	22.83
36.	21.80	37.00	35.20	28.50	30.63
38.	23.50	41.00	19.00	20.70	26.05
39.	-1.00	-1.00	17.50	-1.00	17.50
40.	28.00	42.00	21.60	42.50	33.53
42.	37.50	33.80	34.40	38.70	36.10
44.	12.80	27.00	13.00	13.90	16.67
46.	15.50	18.00	16.50	17.00	16.75
MINIMUM	4.00	18.00	5.00	6.30	13.42
MAXIMUM	95.40	194.00	75.00	272.00	109.97
RANGE	91.40	176.00	70.00	265.70	96.54
I.Q RANGE	13.70	9.90	15.90	12.20	0.00
MEAN	22.73	49.37	21.08	29.63	31.34
STD DEV	17.32	38.88	15.74	51.21	24.41
SKEWNESS	2.65	2.98	1.93	4.40	2.43
KURTOSIS	8.23	7.78	3.55	17.91	4.69

POTASSIUM (MG/L); WEEKLY ANALYSES (1976-77)

WEEK	GP 1	GP 6	GP 7	GP 8	MEAN
1.	2.20	8.80	3.00	-1.00	4.67
2.	5.73	17.40	8.30	-1.00	10.47
4.	2.68	16.70	3.40	-1.00	7.59
5.	0.57	10.20	1.03	-1.00	3.93
6.	1.00	1.80	1.32	-1.00	1.37
7.	0.53	3.10	0.45	1.75	1.46
8.	0.37	4.40	0.45	2.10	1.83
9.	1.00	2.14	0.73	2.40	1.57
10.	1.20	1.20	0.53	1.33	1.06
11.	1.17	1.80	1.07	1.25	1.32
12.	1.75	1.30	0.80	1.95	1.45
13.	1.40	2.38	0.70	1.80	1.57
14.	1.95	2.32	1.50	3.00	2.19
15.	1.60	3.36	2.37	3.20	2.63
16.	1.85	1.80	1.55	2.00	1.80
17.	1.90	2.38	1.55	3.65	2.37
18.	3.65	4.04	4.35	12.00	6.01
19.	2.00	6.60	0.70	2.43	2.93
24.	1.90	6.20	4.94	4.35	4.35
26.	0.95	3.10	0.55	1.90	1.63
28.	0.50	6.62	0.14	1.50	2.19
30.	2.23	4.20	1.05	4.60	3.02
32.	1.40	3.05	1.85	1.90	2.05
34.	1.70	2.37	0.75	1.85	1.67
36.	2.63	4.75	2.47	2.63	3.12
38.	2.42	3.20	1.25	2.38	2.31
39.	-1.00	-1.00	0.95	-1.00	0.95
40.	3.53	3.75	1.25	3.14	2.92
42.	6.72	6.50	3.60	6.20	5.75
44.	1.55	3.10	0.72	1.40	1.69
46.	2.27	5.00	2.43	3.20	3.23
MINIMUM	0.37	1.20	0.14	1.25	0.95
MAXIMUM	6.72	17.40	8.30	12.00	10.47
RANGE	6.35	16.20	8.16	10.75	9.52
I.Q RANGE	1.75	3.99	1.72	1.30	0.00
MEAN	2.01	4.79	1.80	2.96	2.94
STD DEV	1.40	3.98	1.70	2.21	2.10
SKEWNESS	1.80	2.01	2.11	2.90	1.95
KURTOSIS	3.38	3.54	4.85	8.88	3.68

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GULLY POT QUALITY VARIATION: 3RD SEPTEMBER 1977
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   GP           SS          DS           COD         BOD          PH

   2.         12.80      115.00        43.40       24.80        7.55
   4.         23.60      185.00        17.90       22.[illegible]        8.38
   7.         10.40      125.00        15.30        4.80        7.60
  19.         20.00      127.50        15.30        3.50        7.83
  95.         87.60      282.50       428.60       41.60        7.92
  32.         34.00      114.00        51.00        9.30        7.77
  33.         16.80      118.00        35.70       12.80        7.85
  35.        190.00      142.00        91.80       22.50        8.15
  39.         16.80      126.00        30.60        3.30        7.63
  46.          4.00      124.00         7.70       12.30        7.75
  45.         18.00      144.00       250.00       40.00        7.73
  47.          2.80       62.50         5.10        5.30        7.91
 1[illegible]1.          4.00       85.00         0.00        2.80        7.88
 1[illegible]5.         12.00       95.00         0.00       18.00        7.61
  97.         21.20      102.50        28.10        9.80        7.92
  68.        252.80      177.50       150.50       23.[illegible]        8.2[illegible]
  69.         -1.00      132.50       318.90        1.00        7.76
  70.          8.40      162.50         7.70        6.30        7.89
  72.         24.40      292.50         0.00       15.50        8.13
  75.          6.80      170.00        30.60       18.82        7.65
  86.         12.00      142.50         2.60        2.00        7.62
  92.          3.40      145.00         0.00       12.00        7.84
  42.          9.60      122.50         0.70        0.00        7.97

MINIMUM        2.80       62.50         0.00        0.00        7.55
MAXIMUM      252.80      292.50       428.60       41.60        8.38
RANGE        250.00      230.00       428.60       41.60        0.83
I.Q RANGE     16.50       49.00        59.20       18.20        0.17
MEAN          35.97      143.17        66.56       13.13        7.87
STD DEV       63.28       53.79       114.11       11.73        0.22
SKEWNESS       2.57        1.51         2.06        0.99        0.73
KURTOSIS       5.28        2.12         3.06        0.21        0.31

C95 LMT       23.16       19.26        40.85        4.22        0.07
C95 (%)       64.39       13.45        61.38       32.06        0.91
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CONTINUED
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  GP         CL        NO3        NH4        CA         NA

  2.        17.00      7.40      3.13      20.80      2.27
  4.        22.00     17.00      0.97      22.80     17.70
  7.        13.50      5.90      1.00      26.60      1.67
 19.        12.50     17.00      0.44      22.30      1.77
 95.        36.00     -1.00      0.21      29.00     25.80
 32.        16.50     20.50      0.97      23.20      2.05
 33.        18.00      2.50      1.21      24.80      2.33
 35.        24.50      5.30      0.73      31.00      3.27
 39.        13.00      5.80      0.82      24.80      1.47
 44.         9.50      7.70      1.15      23.64      1.47
 45.        31.00     -1.00      0.90      27.50      4.65
 47.        14.50      5.40      0.98      24.83      1.83
101.        13.50      3.60      1.04      27.50      1.72
105.        18.00     12.50      0.95      26.40      1.83
 97.        17.00     28.00      2.04      26.40      2.12
 68.        11.00      2.40      4.62      35.80      1.92
 69.        11.50      7.80      1.12      23.60      2.27
 70.        19.00      3.30      1.00      25.60      2.06
 72.        19.50     12.00      2.31      30.54      1.67
 75.        15.50      5.30      0.94      27.20      1.37
 86.        22.00      4.80      1.00      17.60      2.52
 92.        15.50     11.00      1.10      21.60      2.08
 42.        28.50     10.50      3.52      26.70      1.82

MINIMUM      9.50      2.40      0.21      17.60      1.37
MAXIMUM     36.00     28.00      4.62      35.80     25.80
RANGE       26.50     25.60      4.41      18.20     24.43
I.Q RANGE    8.50      7.20      0.47       4.40      0.85
MEAN        18.22      9.32      1.40      25.63      3.85
STD DEV      6.63      6.62      1.05       3.79      5.02
SKEWNESS     1.12      1.28      1.78       0.47      3.02
KURTOSIS     0.60      0.97      2.27       0.31      7.66

C95 LMT      2.37      2.48      0.38       1.36      2.08
C95 (%)     13.04     26.63     26.97       5.29     54.18
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CONTINUED
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       CP              K             ZN

      2.             3.86           0.01
      4.             3.47           0.02
      7.             1.44           0.00
     19.             1.70           0.00
     25.             6.55           0.57
     32.             2.00           0.12
     33.             1.90           0.04
     35.             2.78           0.28
     39.             1.83           0.02
     44.             1.71           0.14
     45.            28.20           0.00
     47.            24.30           0.22
    101.             5.00           0.21
    105.             3.54           0.12
     97.             3.10           0.05
     66.             2.88           0.20
     69.             2.52           0.01
     70.             2.27           0.00
     72.             6.00           0.00
     75.             1.65           0.04
     86.             1.90           0.04
     92.             3.00           0.01
     42.             2.84           0.21

    MINIMUM          1.44           0.00
    MAXIMUM         28.20           0.57
    RANGE           26.76           0.57
    I.Q RANGE        2.29           0.14
    MEAN             5.06           0.09
    STD DEV          6.91           0.13
    SKEWNESS         2.65           2.12
    KURTOSIS         5.50           4.56

    C95 LMT          2.47           0.05
    C95 (%)         48.87          52.73    *
```

GULLY POT QUALITY VARIATION: 23RD FEBRUARY 1978

GP	SS	DS	COD	BOD	TOC
6.	49.00	1065.00	53.90	6.80	0.00
9.	85.50	2488.00	757.00	11.50	6.75
20.	40.00	493.00	29.50	4.50	4.50
25.	257.00	275.00	611.00	20.00	41.00
28.	35.00	808.00	57.00	35.00	0.00
29.	43.50	726.00	41.00	3.50	6.50
30.	29.50	618.00	32.00	4.00	2.00
32.	19.50	17.00	29.00	6.00	3.50
33.	88.50	645.00	76.00	3.50	13.00
34.	33.50	673.00	20.00	2.00	0.00
38.	50.00	756.00	45.00	1.50	2.00
56.	8.00	70.00	9.20	0.00	0.00
58.	66.50	47.00	38.00	0.00	11.50
63.	155.00	31.00	112.00	6.00	35.00
70.	196.50	522.00	935.00	135.00	135.00
81.	35.50	172.00	29.00	0.00	0.50
86.	63.00	75.00	48.00	0.50	14.00
89.	243.00	218.00	51.00	0.50	14.00
91.	61.00	1519.00	67.00	3.80	0.00
92.	20.50	4042.00	13.20	0.50	0.00
96.	155.00	35.00	121.00	6.00	18.00
104.	30.00	209.00	154.00	42.00	0.00
MINIMUM	8.00	17.00	9.20	0.00	0.00
MAXIMUM	257.00	4042.00	935.00	135.00	135.00
RANGE	249.00	4025.00	925.80	135.00	135.00
I.Q RANGE	72.50	695.00	85.00	7.50	14.00
MEAN	80.23	704.73	151.31	13.30	13.93
STD DEV	73.05	945.49	258.36	29.35	29.27
SKEWNESS	1.31	2.32	2.15	3.42	3.37
KURTOSIS	0.36	5.10	3.01	11.15	11.00
C95 LMT	26.74	346.11	94.47	10.74	10.72
C95 (%)	33.33	49.11	62.43	80.78	76.92

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CONTINUED
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   GP            NO3          NH4          CL           NA           CA

    6.           8.80         0.77      2600.00      1135.00       123.20
    9.          33.60         6.50      6400.00      3270.00       160.00
   20.          16.60         0.31      1250.00       390.00        91.30
   25.          15.60         1.90       680.00       220.00        38.40
   28.          24.30         1.70      1700.00       535.00       163.00
   29.          23.10         0.45      1700.00       685.00       112.00
   30.          18.10         0.51      1320.00       560.00        93.00
   32.           3.70         0.00       130.00        37.00        24.00
   33.          17.70         0.28      1650.00       730.00        87.00
   34.          18.90         0.85      1530.00       730.00        80.00
   38.          27.00         0.08      1650.00       785.00        77.00
   56.           5.60         0.76        80.00        27.00        22.00
   58.           7.80         0.13        53.00        27.00        16.00
   63.           9.20         0.07        52.00        22.00         6.50
   70.          40.50         0.44      1220.00       610.00        62.00
   81.          12.30         0.09       460.00       207.00        53.00
   86.          17.40         0.86       275.00        76.00        22.00
   89.          36.30         0.28      8400.00      5200.00       216.00
   91.          36.80         2.00      3400.00      2320.00       133.00
   92.          13.80         0.00       450.00       172.00        64.00
   96.           9.00         0.00       140.00        46.00        24.00
  104.          18.00         0.69       420.00        99.00        48.00

MINIMUM          3.70         0.00        52.00        22.00         6.50
MAXIMUM         40.50         6.50      8400.00      5200.00       216.00
RANGE           36.80         6.50      8348.00      5178.00       209.50
I.Q RANGE       15.30         0.76      1459.00       676.00        90.80
MEAN            18.79         0.85      1598.18       912.41        78.97
STD DEV         10.59         1.40      2049.67      1259.22        56.91
SKEWNESS         0.62         3.14         2.11         2.36         0.82
KURTOSIS        -0.68         9.85         3.91         4.86        -0.22

C95 LMT          3.88         0.51       750.31       460.96        20.84
C95 (%)         20.64        60.24        46.95        56.74        26.43
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CONTINUED
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   GP              K             PH

   6.            10.50          8.13
   9.            15.20          7.86
  20.             8.60          8.08
  25.             7.10          8.18
  28.            14.00          8.28
  29.            14.30          7.94
  30.            11.40          7.86
  32.             2.60          7.78
  33.             9.30          8.07
  34.             9.00          7.94
  38.            13.60          7.86
  56.             4.50          8.16
  58.             4.00          7.87
  63.             2.10          7.39
  70.             6.00          7.68
  81.             6.40          8.10
  86.             5.20          7.56
  89.            13.60          7.91
  91.            17.60          7.96
  92.            12.60          7.84
  96.             3.30          7.86
 104.             6.80          8.18

MINIMUM           2.10          7.39
MAXIMUM          17.60          8.28
RANGE            15.50          0.89
I.Q RANGE         8.60          0.26
MEAN              8.99          7.93
STD DEV           4.55          0.21
SKEWNESS          0.16         -0.63
KURTOSIS         -1.23          0.16

C95 LMT           1.66          0.08
C95 (%)          18.52          0.99
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GULLY POT QUALITY VARIATION: 20TH MARCH 1978
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     GP             SS          DS          BOD         COD          NO3

      8.           3.10      184.00        5.00       40.20        6.10
     11.           3.40      164.00       11.00       25.90        6.90
     12.           1.60      140.00        1.00       32.00        6.10
     23.           1.40      108.00        2.00       19.60  [illegible]
     24.           3.10      120.00        2.00       33.00  [illegible]
     28.           1.30      252.00        1.00       28.90  [illegible]
     32.           1.70       68.00        4.00       22.70        4.30
     34.           3.00      148.00        3.00       43.30        5.40
     37.           1.70      128.00        1.25       17.50        5.20
     38.           3.53     1088.00        0.75       29.90        8.50
     39.           1.40     1360.00        1.25       36.10        9.20
     44.          13.80      404.00        6.00       68.00        8.30
     51.           1.60      228.00        3.50       35.10        4.80
     55.           5.40     1024.00        6.00      128.90        6.20
     68.           4.40      124.00        4.00       50.50        7.10
     75.           1.90      112.00        2.25       25.60  [illegible]
     87.           7.40      128.00        8.00       62.90        9.70
     95.           3.00      124.00        3.50       50.80        9.40
     98.           1.20      180.00        4.50       22.20        6.20
     99.           1.60      296.00       21.00       30.90        4.70
    105.           2.40      168.00        1.00       37.10        7.20

MINIMUM            1.20       68.00        0.50       17.50        4.00
MAXIMUM           13.80     1360.00       21.00      128.90        9.70
RANGE             12.60     1292.00       20.50      111.40        5.70
I.Q RANGE          1.90      161.00        4.50       23.10        3.30
MEAN               3.23      311.43        4.52       40.52        6.35
STD DEV            2.87      364.95        4.88       24.67  [illegible]
SKEWNESS           2.56        1.94        2.17        2.29        0.39
KURTOSIS           6.45        2.16        4.31        5.49       -1.03

C95 LMT            1.08      137.38        1.84        9.29        0.62
C95 (%)           33.45       44.11       40.63       22.92        9.72
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COMBINED
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     GP          NH4        CL          PH        NA          CA

   8.           0.56     145.00       7.12      37.[illegible]      13.[illegible]
  11.           0.57      38.00       7.38      13.8[illegible]      15.[illegible]
  12.           0.33      24.00       7.1[illegible]        5.9[illegible]      [illegible]1.[illegible]
  23.           0.30      28.00       7.02        9.6[illegible]       9.[illegible]
  24.           0.40      14.00       7.[illegible]        6.2[illegible]       [illegible].[illegible]
  28.           0.35     125.00       7.46      44.5[illegible]      1[illegible].5
  32.           0.39      23.00       7.12      11.1[illegible]       9.[illegible]
  34.           1.01      14.00       7.22      17.2[illegible]      12.[illegible]
  37.           0.38      14.50       7.16        5.4[illegible]      1[illegible].5[illegible]
  38.           0.27     945.00       7.89      68.8[illegible]      56.[illegible]
  39.           1.16    1350.00       7.85     400.00      11.5
  44.           0.53     2[illegible]5.00       7.76      83.[illegible]      26.[illegible]
  51.           0.52     115.00       7.36      5[illegible].[illegible]       9.[illegible]
  55.           2.42    13[illegible].00       7.56     334.[illegible]      22.[illegible]
  58.           1.07      23.00       7.19        6.3[illegible]      [illegible].[illegible]
  70.           0.47      19.00       7.12        7.8[illegible]       9.[illegible]
  87.           0.46      25.00       7.36      1[illegible].7[illegible]      15.5[illegible]
  95.           0.66      25.00       7.34        8.8[illegible]      13.5
  98.           0.26      75.00       7.48      32.7[illegible]       9.[illegible]
  99.           0.24     142.00       7.74      50.[illegible]      22.5[illegible]
 105.           0.37      57.00       7.55      29.7[illegible]      13.[illegible]

MINIMUM         0.24      14.00       7.02        5.4[illegible]       [illegible].[illegible]
MAXIMUM         2.42    1350.00       7.89     400.00      56.[illegible]
RANGE           2.18    1336.00       0.87     394.60      4[illegible].[illegible]
I.Q RANGE       0.30     121.00       0.44      41.9[illegible]      11.3[illegible]
MEAN            0.61     225.31       7.37      59.17      16.[illegible]
STD DEV         0.49     416.39       0.27     106.73      11.92
SKEWNESS        2.55       2.03       0.53       2.52       2.[illegible]7
KURTOSIS        6.51       2.36      -0.99       4.76       3.93

C95 LIT         0.18     156.74       0.12      40.18       4.4[illegible]
C95 (%)        30.24      69.57       1.37      67.91      26.8[illegible]
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[illegible]
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     GP          K

    8.          1.43
   11.          1.40
   12.          0.90
   23.          1.24
   24.          1.15
   28.          2.53
   32.          1.45
   34.          1.90
   37.          1.15
   38.          8.13
   39.         10.20
   44.          4.90
   51.          1.53
   55.          2.85
   58.          1.43
   70.          1.70
   87.          2.07
   95.          1.45
   98.          2.20
   99.          3.35
  135.          1.85

MINIMUM         0.90
MAXIMUM        10.20
RANGE           9.30
I.Q RANGE       1.33
MEAN            2.60
STD DEV         2.38
SKEWNESS        2.19
KURTOSIS        3.70

C95 LMT         0.90
C95 (%)        34.53
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GULLY POT QUALITY VARIATION: 15TH MAY 1978
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      GP            SS          DS          BOD         COD         NO3

      2.          30.00      268.00        8.60       32.00        7.80
      7.          20.00      352.00        3.40       48.00       15.00
      9.          42.00      148.00        9.00       62.00        6.64
     39.          10.00       76.00        0.40       11.00        3.80
     33.          22.00      204.00        0.90       38.00       10.24
     34.          16.00      276.00        5.60       33.00        8.40
     32.          12.00      212.00       25.60      315.00       19.00
     29.           3.00       88.00        1.50       46.00        8.60
     25.          20.00      164.00        7.30       25.00       10.70
     56.          11.00      176.00        0.00        9.00        6.40
     45.          40.00     1116.00       23.70       24.00        9.30
     63.          25.00      192.00        8.80       58.00       16.00
     69.          16.00      264.00        0.60       19.00       15.30
     95.          49.00      204.00        8.40       64.00       14.40
     97.           6.00      336.00        0.40       55.00       21.60
     72.           5.00       96.00        0.90       84.00        7.10
    101.          19.00      140.00        0.00        5.00        8.40
     81.           1.00       48.00        0.00        0.00        5.80
     89.          14.00      268.00        0.40       42.00       13.40
     92.         249.00      160.00       72.60      140.00        7.20

MINIMUM            1.00       48.00        0.00        0.00        3.80
MAXIMUM          249.00     1116.00       72.60      315.00       21.60
RANGE            248.00     1068.00       72.60      315.00       18.00
I.Q RANGE         20.00      128.00        8.40       43.00        7.90
MEAN              30.50      239.40        8.90       55.50       10.76
STD DEV           53.05      222.50       16.71       68.88        4.80
SKEWNESS           3.64        3.13        2.93        2.81        0.72
KURTOSIS          12.16        9.76        8.23        7.79       -0.53

C95 LMT           20.51       86.02        6.46       26.63        1.86
C95 (%)           67.25       35.93       72.55       47.98       17.26
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CONTINUED
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     GP          NH4        CL          PH        CA         NA

     2.          3.00      73.00       7.26      28.00      27.00
     7.          1.70     115.00       6.44      33.00      14.00
     9.          1.60      54.00       6.70      16.00      11.00
    39.          1.30      18.00       6.86      17.00       3.00
    33.          1.70      49.00       6.91      30.00       4.00
    34.          1.20     115.00       7.10      33.00      33.00
    32.          6.70      90.00       6.70      24.00      11.00
    29.          0.83      24.00       6.88      26.00       5.00
    25.          1.20      38.00       6.82      22.00       4.00
    56.          0.20      48.00       7.16      21.00      22.00
    45.          7.60    1150.00       6.81      34.00   / 600.00
    63.          2.40     110.00       6.42      20.00       6.00
    69.          1.30      63.00       6.74      25.00       7.00
    95.          3.40      67.00       6.70      23.00       6.00
    97.          1.60      95.00      10.72      45.00      38.00
    72.          0.22      23.00       7.38      19.00       4.00
   101.          0.83      33.00       9.78      23.00      17.00
    81.          0.18      11.50       7.56      13.00       4.00
    89.          1.20     125.00       7.40      31.00      27.00
    92.          0.11      79.00       7.18      17.00       6.00

MINIMUM          0.11      11.50       6.42      13.00       3.00
MAXIMUM          7.60    1150.00      10.72      45.00     600.00
RANGE            7.49    1138.50       4.30      32.00     597.00
I.Q RANGE        1.57      77.00       0.68      12.00      18.00
MEAN             1.91     119.02       7.28      24.95      42.45
STD DEV          2.00     245.19       1.07       7.74     131.67
SKEWNESS         1.80       3.89       2.31       0.72       3.96
KURTOSIS         2.34      13.46       4.20       0.18      13.92

C95 LMT          0.77      94.79       0.42       2.90      52.91
C95 (%)         40.37      79.64       5.70      11.99     119.92
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CONTINUED
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      GP              K            PB            ZN            CD            MN

      2.            3.00          0.00          0.09          0.01          0.74
      7.            1.40          0.18          3.50          0.04          0.39
      9.            2.30          0.00          1.30          0.02          0.63
     39.            1.40          0.00          2.00          0.01          0.28
     33.            1.90          0.45          3.40          0.07          0.39
     34.            2.30          0.05          2.40          0.02          0.12
     32.            4.00          0.00          1.80          0.01          0.11
     29.            3.40          0.03          0.80          0.01          0.05
     25.            3.90          0.00          2.40          0.01          0.34
     56.            8.90          0.00          1.40          0.00          0.04
     45.            4.50          0.01          0.80          0.01          0.42
     63.            2.70          0.01          2.70          0.01          0.17
     69.            2.30          0.01          3.20          0.01          0.07
     95.            3.10         -1.00         -1.00         -1.00         -1.00
     97.            4.00          0.00          1.20          0.01          0.04
     72.            3.40          0.00          1.80          0.00          0.01
    171.            4.70          0.00          0.50          0.00          0.00
     81.            1.70          0.00          2.20          0.00          0.01
     89.            7.90          0.09          0.19          0.00          0.01
     92.            2.40          0.02          2.00          0.00          0.19

    MINIMUM         1.40          0.00          0.09          0.00          0.00
    MAXIMUM         8.90          0.45          3.50          0.07          0.74
    RANGE           7.50          0.45          3.41          0.07          0.74
    I.Q RANGE       1.70          0.02          1.70          0.01          0.35
    MEAN            3.46          0.04          1.76          0.01          0.21
    STD DEV         1.96          0.11          1.04          0.02          0.22
    SKEWNESS        1.53          3.02          0.06          2.26          0.99
    KURTOSIS        1.76          8.24         -1.07          4.78         -0.11

    C95 LMT         0.76          0.04          0.41          0.01          0.09
    C95 (%)        21.87         96.88         23.37         53.21         41.44
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CONTINUED
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       GP             NI          CR          FE          CU

        2.           0.05        0.00        1.10        0.03
        7.           0.32        0.48        7.00        0.32
        9.           0.03        0.00        1.40        0.04
       39.           0.02        0.00        0.40        0.05
       33.           0.42        0.33        4.00        0.32
       34.           0.03        0.00        0.60        0.03
       32.           0.03        0.00        0.40        0.05
       29.           0.20        0.00        0.30        0.04
       25.           0.03        0.00        0.90        0.02
       56.           0.01        0.00        0.20        0.03
       45.           0.01        0.00        1.20        0.01
       63.           0.03        0.00        0.90        0.03
       69.           0.01        0.00        0.40        0.02
       95.          -1.00       -1.00       -1.00       -1.00
       97.           0.02        0.02        0.50        0.03
       72.           0.01        0.00        0.10        0.01
      101.           0.02        0.01        0.20        0.06
       31.           0.01        0.00        0.10        0.02
       89.           0.01        0.02        0.20        0.00
       92.           0.02        0.00        0.70        0.03

     MINIMUM         0.01        0.00        0.10        0.00
     MAXIMUM         0.42        0.48        7.00        0.32
     RANGE           0.41        0.48        6.90        0.32
     I.Q RANGE       0.02        0.01        0.90        0.03
     MEAN            0.07        0.05        1.08        0.06
     STD DEV         0.12        0.13        1.68        0.09
     SKEWNESS        2.16        2.67        2.66        2.39
     KURTOSIS        3.14        5.40        6.12        3.88

     C95 LMT         0.05        0.05        0.67        0.04
     C95 (%)        68.24      113.38       61.40       61.35
```

GULLY POT QUALITY VARIATION; 17TH JULY 1978

GP	SS	DS	COD	BOD	NO3
9.	20.00	176.00	78.90	2.60	7.3[illegible]
10.	12.00	180.00	26.30	0.00	5.6[illegible]
11.	63.00	136.00	44.40	0.00	7.7[illegible]
94.	27.00	196.00	59.20	3.40	5.3[illegible]
40.	22.00	184.00	68.50	2.40	6.6[illegible]
5.	24.00	132.00	87.30	5.80	[illegible]
83.	13.00	128.00	39.40	1.90	6.[illegible]
81.	24.00	104.00	25.40	0.90	4.1[illegible]
78.	29.00	140.00	25.40	1.90	5.3[illegible]
76.	21.00	152.00	69.50	2.40	7.9[illegible]
74.	16.00	128.00	6.60	1.90	5.1[illegible]
73.	25.00	152.00	16.20	0.00	5.4[illegible]
79.	21.00	96.00	51.60	0.90	5.6[illegible]
71.	23.00	272.00	115.50	0.60	9.[illegible]
99.	15.00	178.00	24.40	0.20	5.[illegible]
97.	26.00	168.00	164.30	2.80	9.1[illegible]
16.	18.00	108.00	38.50	5.20	[illegible].9
51.	53.00	152.00	53.20	5.80	7.7[illegible]
54.	29.00	300.00	99.50	26.20	10.6[illegible]
25.	32.00	188.00	59.20	6.50	7.12
MINIMUM	12.00	96.00	6.60	0.00	4.1[illegible]
MAXIMUM	63.00	300.00	164.30	26.20	10.6[illegible]
RANGE	51.00	204.00	157.70	26.20	6.5[illegible]
I.Q RANGE	11.00	76.00	53.50	4.60	2.7[illegible]
MEAN	25.65	159.80	57.47	3.57	6.9[illegible]
STD DEV	12.40	53.22	38.12	5.71	1.77
SKEWNESS	1.80	1.21	1.12	3.22	0.39
KURTOSIS	2.78	0.99	0.99	10.07	-0.91
C95 LMT	4.79	20.58	14.74	2.21	0.69
C95 (%)	18.69	12.94	25.65	61.80	9.95

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      GP          NH4        CL          CA          NA          K

      9.          8.10      12.50       17.60        3.50       2.30
     10.          3.60      17.50       18.10        9.80       2.10
     11.          1.40      14.00       15.50        5.00       1.20
     94.          8.10      16.00       10.60        3.00       3.50
     40.          2.90      31.00       21.20        8.70       1.40
      5.          1.50       8.70       13.80        1.60       0.80
     83.          1.60      10.80       16.50        3.40       1.50
     81.          3.60      11.90       16.50        2.80       2.20
     78.          3.30       9.60       19.70        2.10       1.70
     76.          0.40      14.00       21.70        3.00       3.10
     74.          0.62      11.50       18.10        3.00       3.30
     73.          2.60      12.60       21.30        4.10       3.40
     70.          1.50      13.00       15.50        3.40       2.30
     71.          9.70      24.00       22.80        6.80      11.50
     99.          1.80      13.50       16.50        4.00       2.10
     97.          1.40      15.00       21.20        4.60       4.70
     16.          2.40       8.20       14.40        2.20       2.10
     51.          6.40      46.00       17.70       11.70       2.80
     54.         11.50     118.00       23.60       57.00       4.00
     25.          1.40      13.00       18.20        9.80       2.60

MINIMUM           0.40       8.20       10.60        1.60       0.80
MAXIMUM          11.50     118.00       23.60       57.00      11.50
RANGE            11.10     109.80       13.00       55.40      10.70
I.Q RANGE         5.00       6.00        5.70        5.70       1.70
MEAN              3.69      21.04       18.03        7.48       2.93
STD DEV           3.25      24.46        3.30       12.02       2.24
SKEWNESS          1.14       3.30       -0.20        3.65       2.86
KURTOSIS         -0.07      10.08       -0.51       12.20       8.30

C95 LMT           1.26       9.45        1.28        4.65       0.87
C95 (%)          34.03      44.94        7.08       62.15      29.56
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MISCELLANEOUS GULLY LIQUOR ANALYSES

DATE 3RD MAY 1976

	GP 7	GP 2	GP 3	GP 4	GP 5	MEAN
SS	226.0	221.0	151.0	454.0	40.8	218.4
NH4	0.47	0.59	0.54	0.37	0.35	0.46
ZN-T	0.496	0.333	0.379	0.354	0.148	0.342
ZN-S	0.048	0.035	0.036	0.029	0.039	0.037
DS	120.0	185.0	135.0	225.0	135.0	160.0
NO3	5.4	5.6	6.2	10.25	5.3	6.55

DATE 10TH MAY 1976

	GP 1	GP 2	GP 3	GP 4	GP 5	MEAN
SS	71.6	29.2	43.6	82.4	21.6	49.7
NH4	1.6	2.04	1.49	2.4	2.97	2.1
ZN-T	0.074	0.08	0.152	0.18	0.177	0.133
ZN-S	-	-	0.063	0.015	0.085	0.054
DS	285.0	275.0	325.0	385.0	410.0	336.0

DATE 17TH MAY 1976

	GP 1	GP 2	GP 3	GP 4	GP 5	MEAN
SS	14.8	18.4	12.4	96.4	6.0	29.6
NH4	0.23	0.48	0.18	0.32	0.32	0.31
ZN-T	0.44	0.474	0.365	0.347	0.254	0.376
ZN-S	0.217	0.071	0.033	0.031	0.246	0.08
DS	185.0	195.0	200.0	340.0	160.0	336.0
NO3	1.9	1.85	2.73	2.82	2.05	2.27

DATE 12TH APRIL 1976

	GP 1	GP 2	GP 3	MEAN
SS	32.8	21.4	101.9	88.2
NH4	0.41	1.0	2.42	1.3
PB-T	0.11	0.095	0.05	0.085
PB-S	0.035	0.04	0.03	0.035
ZN-T	0.18	0.22	0.35	0.25
ZN-S	0.064	-	0.18	0.122
NO3	6.2	4.5	6.9	5.9

DATE 26TH APRIL 1976

	GP 1	GP 2	GP 3	GP 4	GP 5	MEAN
SS	20.0	4.8	38.8	23.6	20.4	21.5
NH4	0.03	0.76	0.36	0.79	3.78	1.14
ZN-T	0.481	0.364	0.352	0.37	2.08	0.509
ZN-S	0.056	0.075	0.096	0.065	0.284	0.115
DS	525.0	310.0	500.0	485.0	695.0	503.0
NO3	6.4	4.3	6.4	8.2	6.0	6.3

GULLY LIQUOR ANALYSES PRIOR TO STORM RUNOFF EVENTS

DATE 20TH APRIL 1978

	GP 8	GP 7	GP 43	GP 44	GP 11	MEAN
NO3	10.6	4.8	4.3	5.4	6.0	6.2
NH4	0.12	0.13	0.23	0.21	0.23	0.18
COD	34.0	51.1	57.9	76.0	78.3	59.5
BOD	2.5	1.8	2.5	3.4	3.6	2.8
CA	25.0	13.5	6.5	7.5	5.5	11.6

DATE 25TH APRIL 1978

	GP 8	GP 7	GP 43	GP 44	GP 11	MEAN
NO3	10.6	9.3	8.9	7.1	6.1	8.4
NH4	0.33	0.33	0.18	0.25	0.04	0.23
COD	40.9	15.7	67.9	83.0	63.5	54.2
DS	120.0	225.0	135.0	125.0	265.0	174.0
CA	17.0	16.5	25.6	14.5	12.8	17.3

DATE 23RD MAY 1978

	GP 7	GP 43	GP 89	GP 86	GP 84	MEAN
NO3	6.6	8.4	23.3	12.1	13.5	12.8
NH4	2.5	1.4	2.1	1.2	0.63	1.6
COD	4.9	0.0	34.0	23.9	44.1	21.4
BOD	7.7	1.2	8.3	4.3	1.5	4.6
DS	428.0	248.0	484.0	168.0	220.0	310.0
CA	70.8	24.9	29.1	13.8	47.1	37.1

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CONTINUED
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DATE 31ST MAY 1978
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           GP 7     GP 43     GP 84     GP 86     GP 89     MEAN

NO3        14.7       8.0      13.8      11.3      11.3     11.8
NH4         4.1       3.8       2.1       3.3       8.8      4.4
COD       124.7     121.9     123.3     104.7     109.0    116.8
BOD         5.3      11.0       0.4       2.1       5.3      4.8
DS        368.0     412.0     252.0     188.0     232.0    290.4
CA         27.0      42.0      35.0      29.0      29.0     32.4

DATE 12TH JUNE 1978
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           GP 7     GP 43     GP 44     GP 52     GP 53     MEAN

NO3         7.1       4.7       7.1       7.0       7.7      6.7
NH4         2.0       5.5       1.7       1.8       0.64     2.32
COD        17.0      14.2      22.6      37.7     122.6     42.8
BOD         1.5       1.3       0.9       5.2      16.8      5.1
DS        132.0     136.0      84.0     104.0     224.0    136.0
CA         12.8      21.2       9.4      16.0      22.4     16.4


METEOROLOGICAL DATA FOR MISCELLANEOUS GP ANALYSES
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DATE         R(MM)       ADP         ADP.2        TMAX         TMIN

12.4.76      1.0          4           4           10.5          8.5
26.4.76      0.0         12          12            9.0          5.0
 3.5.76      0.8         0           0            11.5          8.0
10.5.76      6.4         0.5         0.5          17.0         12.5
17.5.76      6.2         1           1            19.5          6.0
13.7.76      7.2         0.5         0.5          23.0         17.0
FOR GP ANALYSES DURING STORM RUNOFF ANALYSIS

20.4.78     16.2         0           0            12.7          7.5
25.4.78      9.3         3           3            12.5          4.5
23.5.78      9.5         1           1            15.0          8.0
31.5.78      1.2         6           6            14.6          7.6
12.6.78      4.8         4           4            12.0          8.5


FOR GP QUALITY VARIATION ANALYSES

23.9.77      0.0        13          13            14.6         10.5
23.2.78      5.6         0           0            10.4          4.9
20.3.78      8.0         0           0             9.6          4.3
15.5.78     14.5         0           0          14.5            7.5
17.7.78     44.8         0           0            22.9         11.2
```

HEAVY METAL ANALYSES - ZINC

DATE	METHOD	SAMPLE	TOTAL	SOLUBLE
12.4.76	AAS	GP 1	0.183	0.064
12.4.76	"	GP 2	0.220	-
12.4.76	"	GP 3	0.350	0.180
12.4.76	"	GP 3	0.810	0.100
12.4.76	"	GP 3	1.74	0.56
5.4.76	"	GP 1	0.383	0.140
26.4.76	"	GP 1	0.481	0.056
26.4.76	"	GP 2	0.364	0.075
26.4.76	"	GP 3	0.352	0.096
26.4.76	"	GP 4	0.370	0.065
26.4.76	"	GP 5	0.983	0.284
3.5.76	"	GP 1	0.496	0.048
3.5.76	"	GP 2	0.333	0.035
3.5.76	"	GP 3	0.379	0.036
3.5.76	"	GP 4	0.354	0.029
3.5.76	"	GP 5	0.148	0.039
10.5.76	"	GP 1	0.074	-
10.5.76	"	GP 2	0.088	-
10.5.76	"	GP 3	0.152	0.063
10.5.76	"	GP 4	0.180	0.015
10.5.76	"	GP 5	0.177	0.085
17.5.76	"	GP 1	0.440	0.217
17.5.76	"	GP 2	0.474	0.071
17.5.76	"	GP 3	0.365	0.033
17.5.76	"	GP 4	0.347	0.031
17.5.76	"	GP 5	0.254	0.046
13.7.76	ASV	GP 7	0.160	0.052
16.8.76	"	GP 6	0.283	0.205
16.8.76	"	GP 1	0.200	0.135
23.8.76	"	GP 6	-	0.150
6.9.76	"	GP 1	0.008	0.010
27.9.76	"	GP 6	0.022	0.110
MINIMUM			0.008	0.010
MAXIMUM			1.74	0.56
RANGE			1.732	0.550
I.Q.RANGE			0.301	0.115
MEAN			0.360	0.104
STD.DEV.			0.328	0.110

HEAVY METAL ANALYSES - LEAD

DATE	METHOD	SAMPLE	TOTAL	SOLUBLE
12.4.76	AAS	GP 1	0.11	0.035
12.4.76	"	GP 2	0.095	0.040
12.4.76	"	GP 3	0.050	0.030
12.1.76	"	GP 3	0.150	0.035
12.4.76	"	GP 3	1.360	0.100
5.4.76	"	GP 1	0.150	0.035
13.7.76	ASV	GP 7	0.062	0.012
16.8.76	"	GP 6	0.079	0.013
16.8.76	"	GP 1	-	0.012
23.8.76	"	GP 6	0.151	-
6.9.76	"	GP 1	0.024	0.004
27.9.76	"	GP 6	0.015	0.027
MINIMUM			0.015	0.004
MAXIMUM			1.36	0.100
RANGE			1.345	0.096
I.Q.RANGE			0.130	0.022
MEAN			0.093	0.032
STD.DEV.			0.048	0.025

HEAVY METAL ANALYSES - COPPER

DATE	METHOD	SAMPLE	TOTAL	SOLUBLE
26.4.76	AAS	GP 1	0.056	0.068
26.4.76	"	GP 2	0.056	0.059
26.4.76	"	GP 3	0.056	0.016
26.4.76	"	GP 4	0.058	0.088
26.4.76	"	GP 5	0.073	0.085
13.7.76	ASV	GP 7	0.011	0.003
16.8.76	"	GP 6	0.080	0.018
16.8.76	"	GP 1	0.032	-
MINIMUM			0.011	0.003
MAXIMUM			0.080	0.088
RANGE			0.069	0.085
MEAN			0.052	0.048

HEAVY METAL ANALYSES - CADMIUM

DATE	METHOD	SAMPLE	TOTAL	SOLUBLE
13.7.76	ASV	GP 7	0.010	0.006
16.8.76	"	GP 6	0.013	0.025
16.8.76	"	GP 1	0.040	0.040
23.8.76	"	GP 6	0.042	0.225
6.9.76	"	GP 1	0.004	0.001
27.9.76	"	GP 6	0.006	0.003
MINIMUM			0.004	0.001
MAXIMUM			0.042	0.040
RANGE			0.038	0.039
MEAN			0.019	0.017

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DUSTFALL MEASUREMENTS
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DATE           DURATION   MASS(MG)    MASS PER WEEK

7-14/4/77         1          9.9          9.9
7-21/4/77         2         26.0         13.0
7-28/4/77         3         33.3         11.1
18-25/4/77        1          8.8          8.8
18-2/5/77         2         28.6         14.3
9-23/5/78         2         27.1         13.55
12-19/6/78        1          9.2          9.2
26-3/7/78         1          7.3          7.3
6-20/7/78         2         15.8          7.8

MEAN MASS COLLECTED PER WEEK = 10.55 MG

DUSTFALL ACCUMULATION RATE    = 46.5 MG/SQ.M/DAY

DUSTFALL ACCUMULATION RATE    = 169.6 KG/HA/ANNUM

LOADING PER ANNUM FOR CLIFTON GROVE = 610 KG
(IMPERVIOUS AREA ONLY)
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2. LABORATORY STUDIES

LABORATORY STUDY OF THE BEHAVIOUR OF POLLUTION PARAMETERS IN GULLY POT LIQUORS OVER A DRY PERIOD

THE SEDIMENT WAS OBTAINED FROM A COUNCIL GULLY EMPTYING VEHICLE, SOURCE CLIFTON ESTATE.

THE GULLY POT WAS FILLED WITH DEIONIZED WATER, STIRRED AND AERATED TO SIMULATE THE PASSAGE OF A STORM. THE FIRST SAMPLE WAS DRAWN AFTER ONE AND HALF HOURS. THE LIQUOR TURNING ANAEROBIC AFTER SEVEN HOURS.

GULLY POT VOLUME = 93 LITRES

SEDIMENT DEPTH = 30 MM

DAYS	SS	BOD	COD	COD(SOL)
0	1297.0	72.2	929.0	-
1	688.0	45.4	494.0	-
2	283.0	26.0	296.0	-
3	245.0	22.5	253.0	-
4	223.0	25.0	204.0	73.0
5	191.0	15.5	184.0	75.6
7	128.0	18.5	158.6	53.7
9	106.0	15.0	127.9	61.4
11	110.0	11.0	148.3	98.6
14	62.0	7.5	103.8	40.3
16	13.0	2.0	59.3	16.9
21	18.0	7.0	61.9	19.0
23	16.0	2.0	51.9	39.5
28	3.0	5.0	43.5	42.5
31	13.0	0.8	30.3	30.3
35	-	1.5	26.7	26.7
38	12.0	4.3	30.0	30.0

ADDITION OF 5.2G OF CAR WASH LIQUID

DAYS	SS	BOD	COD	COD(SOL)
38	40.0	27.3	93.0	66.0
42	9.0	17.0	81.7	53.3
45	6.0	10.8	65.2	60.7
49	-	-	42.6	41.7

DRY PERIOD STUDY CONTINUED

DAYS	NO3	NH4	CL	DS	PH
0	12.0	2.1	80.0	240.0	7.84
1	11.0	1.7	95.0	265.0	7.86
2	10.7	1.7	110.0	295.0	-
3	14.0	1.75	125.0	295.0	7.85
4	12.5	1.65	128.0	285.0	-
5	13.5	1.45	96.0	265.0	7.74
7	12.8	1.35	115.0	345.0	7.82
9	15.0	1.45	110.0	300.0	-
11	14.5	1.45	-	330.0	7.83
14	13.5	1.78	155.0	380.0	-
16	17.0	1.95	120.0	330.0	8.09
21	20.0	2.4	125.0	390.0	-
23	22.0	2.8	110.0	405.0	7.94
28	22.0	3.9	125.0	400.0	7.90
31	20.0	3.5	-	410.0	8.36
35	19.0	4.5	-	-	8.41
38	12.0	4.0	175.0	455.0	8.06
ADDITION OF 5.2G OF CAR WASH LIQUID					
38	16.5	3.7	145.0	500.0	7.94
41	14.5	4.3	125.0	-	8.21
42	10.5	4.4	120.0	450.0	7.85
44	8.5	-	-	-	-
45	7.8	4.3	120.0	480.0	8.05
49	8.5	4.0	-	470.0	8.11

COMPOSITION OF GULLY POT SEDIMENT

TWO COMPOSITE SAMPLES WERE COLLECTED FROM COUNCIL GULLY EMPTYING VEHICLES :-

A) CLIFTON (RESIDENTIAL)
B) BASFORD (RESIDENTIAL/ LIGHT INDUSTRIAL)

	CLIFTON	BASFORD
BOD (MG/G)	43.8	9.1
COD (MG/G)	34711.0	8462.0
VOLATILES (%)	21.0	7.6
ZINC (MG/G)	0.69	0.22
SOLUBLE COMPONENTS:-		
DISSOLVABLE SOLIDS (MG/G)	4.0	4.5
NO3 (MG/G)	0.165	0.185
NH4 (MG/G)	0.037	0.035
CL (MG/G)	0.75	1.25
COD (MG/G)	3.2	2.7

VISUAL OBSERVATIONS

MAINLY FINE SAND ,SILT AND GRIT. LEAVES, SMALL TWIGS, SMALL STONES, PAPER, CELLOPHANE WRAPPING PAPER (SWEETS), SILVER PAPER (CIGARETTE PACKETS), CIGARETTE ENDS,BOTTLE TOPS, CAN PULL KEYS.

```
LABORATORY SIMULATION OF THE REMOVAL OF PARTICULATE
---------------------------------------------------
MATERIAL FROM GULLY POTS
------------------------

CUMULATIVE MASS OF SOLIDS REMOVED (MG) FOR VARIOUS FLOW RATES
-------------------------------------------------------------

TIME      0.1      0.2      0.4      0.5      0.6      0.7      0.8      0.9      1.0

0.25     41.1     58.8    327.6    427.6    469.8    245.7    770.4   1152.9   1359.0
0.5      72.6    291.6    741.6    699.2    831.6    764.4   1569.6   1647.0   2442.0
0.75    104.7    428.4   1014.0    895.5   1164.6   1077.3   2340.0   2222.3   3417.0
1.0     129.0    519.2   1233.6   1047.0   1458.0   1318.0   3004.8   2343.6   4362.0
1.5     184.8    678.8   1596.0   1326.0   1886.4   1671.6   3998.4   2910.6   5664.0
2.0     239.4    802.4   1857.6   1551.0   2286.0   1995.0   4152.0   3348.0   6642.0
3.0     343.8    989.6   2275.2   1917.0   2725.0   2440.2   5836.8   3898.8   7518.0
4.0     465.0   1164.8   2635.2   2187.0   3106.8   2717.4   6576.0   4298.4   8058.0
5.0     533.4   1346.0   2976.0   2385.0   3373.2   2877.0   7123.2   4525.2   8382.0
6.0     599.4   1467.0   3211.2   2511.0   3582.0   2885.4   7536.0   4622.4   8442.0
7.0     655.2   1570.4   3466.4   2673.0   3805.2   2893.8   7891.2   4687.2   8442.0
8.0     706.8   1673.6   3604.8   2799.0   3999.6   2902.2   8112.0   4719.6   8442.0

TOTAL
MASS (G) 0.71      1.67     3.60     2.80     4.0      2.9      8.1      4.8      8.44
```

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LABORATORY SIMULATION OF THE REMOVAL OF PARTICULATE
---------------------------------------------------
MATERIAL FROM GULLY POTS
------------------------

OBSERVED CONCENTRATIONS (MG/L) FOR VARIOUS FLOW RATES
-----------------------------------------------------

                        FLOW RATE (L/S)

TIME     0.1     0.2     0.4     0.5     0.6     0.7     0.8     0.9     1.0

0.25    27.4    20.2    54.6    57.0    52.2    23.4    64.2    85.4    90.6
0.5     21.0    49.4    69.0    36.2    40.2    49.4    66.6    36.6    72.2
0.75    21.4   45.0     45.4    26.2    37.0    29.8    64.2    27.8    65.0
1.0     16.2    30.2    36.6    20.2    32.6    23.0    55.4    23.8    59.0
1.5     18.6    26.6    30.2    18.6    23.8    16.8    41.4    21.0    45.4
2.0     18.2    20.6    21.8    15.0    22.2    15.4    31.4    16.2    32.6
3.0     17.4    15.0    17.4    12.2    12.2    10.6    22.6    10.2    14.6
4.0     20.2    14.6    15.0     9.0    10.6     6.6    15.4     7.4     9.0
5.0     11.4    15.4    14.2     6.6     7.4     3.8    11.4     4.2     5.4
6.0     11.0    10.2     9.8     4.2     5.8     0.2     8.6     1.8     1.0
7.0      9.3     8.6     9.8     5.4     6.2     0.2     7.4     1.2     0.0
8.0      8.6     8.6     6.6     4.2     5.4     0.2     4.6     0.6     0.0
```

```
LABORATORY SIMULATION OF THE REMOVAL OF
---------------------------------------
DISSOLVED MATERIAL FROM GULLY POTS
----------------------------------

 FLOW RATE = LITRES/SEC

 SLOPE = LOG(S/S1)/TIME(SECS)

 R,T, = RETENTION TIME CALCULATED FROM SLOPE

 %VOL,MIXED = THEORETICAL % COMPLETELY MIXED
              CALCULATED FROM RETENTIION TIME
              RATIOS


FLOW        SLOPE       R,T,(SECS)     %VOL,MIXED

 0,03        -2,45       1289,3            41,7
 0,04        -2,12       1116,9            48,2
 0,05        -1,75       1085,9            58,5
 0,05        -2,44        777,0            41,8
 0,06        -1,57       1005,7            64,9
 0,07        -1,70        798,1            60,2
 0,09        -1,35        777,9            75,4
 0,10        -1,05        901,1            97,0
 0,12        -1,06        743,2            96,1
 0,25        -0,894       424,2           106,1
 0,50        -1,02        185,3            99,8
 1,00        -1,02         92,8           100,0
```

3. STORM RUNOFF QUALITY DATA

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                          STORM RUNOFF DATA
                          =================


        STORM OF THE  6TH NOVEMBER 1976
        ===============================

             TIME SAMPLING COMMENCED   0.00
             SAMPLING DURATION(MINS) 65.42
             DOSER CONCENTRATION(G/L)   0.00
             DOSE RATE(ML/MIN)   0.00


        MEASURED PARAMETER CONCENTRATIONS
        =================================

             T(MINS)    Q(L/S)    SS(MG/L)  DS(MG/L)  CA(MG/L)

               1.03       0.00      25.00    180.00     20.10
               6.09       0.00      39.30    157.50     20.20
              10.59       0.00      59.00     72.50     19.20
              15.09       0.00      63.00     80.00     17.00
              19.59       0.00      67.50     90.00     16.50
              24.09       0.00      76.50     82.50     16.50
              28.59       0.00      80.00     75.00     16.20
              33.09       0.00      74.40     60.00     16.00
              37.59       0.00      52.50     65.00     15.60
              42.09       0.00      41.00     62.50     14.80
              46.59       0.00      34.20     57.50     14.40
              51.09       0.00      34.50     60.00     13.30
              55.59       0.00      32.30     70.00     12.80
              60.09       0.00      28.50     65.00     12.80
              64.59       0.00      31.00     65.00     12.20

              T(MINS)    BOD(MG/L)  CL(MG/L) NO3(MG/L)   NH4(MG/L)

               1.03       0.00       7.50      4.70      0.00
               6.09       0.00      22.40     12.20      0.00
              10.59       0.00       6.00      4.00      0.00
              15.09       0.00       4.70      3.50      0.00
              19.59       0.00       4.60      2.90      0.00
              24.09       0.00       3.80      2.70      0.00
              28.59       0.00       3.60      2.70      0.00
              33.09       0.00       3.60      2.60      0.00
              37.59       0.00       3.60      2.60      0.00
              42.09       0.00       3.40      2.70      0.00
              46.59       0.00       3.10      2.60      0.00
              51.09       0.00       3.00      2.40      0.00
              55.59       0.00       3.00      2.30      0.00
              60.09       0.00       2.90      2.20      0.00
              64.59       0.00       3.40      2.20      0.00
```

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                             STORM RUNOFF DATA
                            ===================


           STORM OF THE  6TH DECEMBER 1976
          ============================

                TIME SAMPLING COMMENCED    0.00
                SAMPLING DURATION(MINS) 42.92
                DOSER CONCENTRATION(G/L)    0.00
                DOSE RATE(ML/MIN)    0.00


           MEASURED PARAMETER CONCENTRATIONS
           ===========================

                T(MINS)    Q(L/S)     SS(MG/L)  DS(MG/L)  CA(MG/L)

                  1.03      0.00       96.20    396.00     37.00
                  6.09      0.00      196.20    492.00     34.30
                 10.59      0.00      271.00    452.00     28.50
                 15.09      0.00      284.00    352.00     24.40
                 19.59      0.00      270.00    304.00     22.50
                 24.09      0.00      248.00    332.00     20.20
                 28.59      0.00      196.00    352.00     19.20
                 33.09      0.00      164.00    224.00     17.80
                 37.59      0.00      159.00    204.00     17.80
                 42.09      0.00      156.00    200.00     18.10

                 T(MINS)    BOD(MG/L)   CL(MG/L)  NO3(MG/L)    NH4(MG/L)

                  1.03      0.00      117.00      5.50       0.15
                  6.09      0.00      176.00      6.80       0.15
                 10.59      0.00      179.00      6.20       0.15
                 15.09      0.00      142.00      5.40       0.12
                 19.59      0.00      133.00      5.00       0.16
                 24.09      0.00       97.00      4.50       0.10
                 28.59      0.00      103.00      4.10       0.15
                 33.09      0.00       84.00      3.70       0.11
                 37.59      0.00       82.00      3.90       0.10
                 42.09      0.00       75.00      4.10       0.19
```

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                    STORM RUNOFF DATA
                    -----------------


STORM OF THE  17TH DECEMBER 1976
--------------------------------

        TIME SAMPLING COMMENCED    0,00
        SAMPLING DURATION(MINS) 78,92
        DOSER CONCENTRATION(G/L)    0,00
        DOSE RATE(ML/MIN)    0,00


MEASURED PARAMETER CONCENTRATIONS
---------------------------------

        T(MINS)    Q(L/S)     SS(MG/L)  DS(MG/L)  CA(MG/L)

          1,03      0,00        34,40    275,00     24,70
          6,09      0,00        34,80    275,00     24,50
         10,59      0,00        39,20    265,00     23,70
         15,09      0,00        37,20    262,00     23,20
         19,59      0,00        32,00    265,00     23,20
         24,09      0,00        31,60    247,00     22,70
         28,59      0,00        35,20    257,00     22,40
         33,09      0,00        30,40    255,00     22,30
         37,59      0,00        33,60    260,00     22,30
         42,09      0,00        30,40    255,00     22,30
         46,59      0,00        30,00    244,70     22,30
         51,09      0,00        24,40    224,00     22,30
         55,59      0,00        31,60    260,00     21,70
         60,09      0,00        26,00    264,00     21,20
         64,59      0,00        24,00    200,00     20,40
         69,09      0,00        43,20    232,00     19,90
         73,59      0,00        29,60    184,00     19,60
         78,09      0,00        21,60    248,00     20,20

         T(MINS)    BOD(MG/L)  CL(MG/L) NO3(MG/L)    NH4(MG/L)

          1,03      0,00        90,00      6,80       0,20
          6,09      0,00        90,00      6,50       0,27
         10,59      0,00        90,00      6,40       0,28
         15,09      0,00        90,00      6,40       0,26
         19,59      0,00        90,00      6,30       0,25
         24,09      0,00        90,00      6,40       0,25
         28,59      0,00        90,00      6,60       0,22
         33,09      0,00        90,00      6,40       0,25
         37,59      0,00        90,00      6,60       0,22
         42,09      0,00        78,00      6,00       0,14
         46,59      0,00        78,00      6,50       0,25
         51,09      0,00        78,00      6,00       0,27
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STORM RUNOFF DATA

STORM OF THE 17TH DECEMBER 1976

(CONTINUED)

T(MINS)	BOD(MG/L)	CL(MG/L)	NO3(MG/L)	NH4(MG/L)
55.59	0.00	78.00	7.10	0.27
60.09	0.00	78.00	5.90	0.29
64.59	0.00	78.00	5.80	0.29
69.09	0.00	73.00	5.70	0.30
73.59	0.00	73.00	5.80	0.29
78.09	0.00	73.00	5.60	0.29

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                          STORM RUNOFF DATA
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      STORM OF THE  9TH JUNE 1977
      ===========================

            TIME SAMPLING COMMENCED    0.00
            SAMPLING DURATION(MINS) 195.92
            DOSER CONCENTRATION(G/L)  48.00
            DOSE RATE(ML/MIN)    1.04


      MEASURED PARAMETER CONCENTRATIONS
      =================================

            T(MINS)     Q(L/S)     SS(MG/L)    DS(MG/L)    CA(MG/L)

               1.03       8.00        5.20        0.00        0.00
               6.09       9.97       15.20        0.00        0.00
              10.59       7.23       16.40        0.00        0.00
              15.09       8.05       19.00        0.00        0.00
              19.59       8.91       22.00        0.00        0.00
              24.09      10.74       34.00        0.00        0.00
              28.59      14.47       42.00        0.00        0.00
              33.09      30.25       58.00        0.00        0.00
              37.59      35.66       66.00        0.00        0.00
              42.09      31.20       76.00        0.00        0.00
              46.59      38.40       98.00        0.00        0.00
              51.09      50.94      107.00        0.00        0.00
              55.59      31.20      116.00        0.00        0.00
              60.09      25.60      128.00        0.00        0.00
              64.59      21.70      140.00        0.00        0.00
              69.09      20.38      144.00        0.00        0.00
              73.59      21.70      136.00        0.00        0.00
              78.09      22.69      105.00        0.00        0.00
              82.59      20.38       70.00        0.00        0.00
              87.09      17.83       60.00        0.00        0.00
              91.59      16.64       54.00        0.00        0.00
              96.09      16.64       45.00        0.00        0.00
             100.59      16.64       39.00        0.00        0.00
             105.09      17.83       37.00        0.00        0.00
             109.59      20.38       34.00        0.00        0.00
             114.09      20.38       36.00        0.00        0.00
             118.59      21.70       42.00        0.00        0.00
             123.09      23.77       52.00        0.00        0.00
             127.59      38.40       74.00        0.00        0.00
             132.09      58.73      123.00        0.00        0.00
             136.59      71.31      193.00        0.00        0.00
             141.09      71.31      226.00        0.00        0.00
             145.59      58.73      214.00        0.00        0.00
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                         STORM RUNOFF DATA
                         =================


     STORM OF THE  9TH JUNE 1977
     ==============================           (CONTINUED)


           T(MINS)    Q(L/S)     SS(MG/L)   DS(MG/L)   CA(MG/L)

           150.09      47.54     200.00       0.00       0.00
           154.59      33.28     190.00       0.00       0.00
           159.09      23.77     147.00       0.00       0.00
           163.59      17.52     122.00       0.00       0.00
           168.09      13.31      94.00       0.00       0.00
           172.59      10.76      70.00       0.00       0.00
           177.09      10.51      53.00       0.00       0.00
           181.59      10.62      39.00       0.00       0.00
           186.09       2.41      11.15       0.00       0.00
           190.59       0.54       4.85       0.00       0.00
           195.09       0.12       3.42       0.00       0.00

     MEAN VALUES
     FLOW WEIGHTED     24.28     114.38       0.00       0.00



     CUMULATIVE PARAMETER LOADINGS
     =============================

           T(MINS)    Q(CU.M)    SS(KG)     DS(KG)     CA(KG)

            1.030      0.494      0.003      0.000      0.000
            6.090      3.210      0.030      0.000      0.000
           10.590      5.531      0.067      0.000      0.000
           15.090      7.594      0.103      0.000      0.000
           19.590      9.884      0.150      0.000      0.000
           24.090     12.537      0.225      0.000      0.000
           28.590     15.940      0.355      0.000      0.000
           33.090     21.977      0.663      0.000      0.000
           37.590     30.875      1.216      0.000      0.000
           42.090     39.901      1.856      0.000      0.000
           46.590     49.297      2.677      0.000      0.000
           51.090     61.358      3.916      0.000      0.000
           55.590     72.447      5.148      0.000      0.000
           60.090     80.115      6.082      0.000      0.000
           64.590     86.501      6.937      0.000      0.000
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                        STORM RUNOFF DATA
                        =================

STORM OF THE  9TH JUNE 1977
===========================                   (CONTINUED)

      T(MINS)     Q(CU.M)     SS(KG)      DS(KG)      CA(KG)

      69.090       92.181      7.743       0.000       0.000
      73.590       97.862      8.538       0.000       0.000
      78.090      103.856      9.260       0.000       0.000
      82.590      109.670      9.771       0.000       0.000
      87.090      114.827     10.106       0.000       0.000
      91.590      119.480     10.372       0.000       0.000
      96.090      123.973     10.594       0.000       0.000
     100.590      128.466     10.783       0.000       0.000
     105.090      133.119     10.960       0.000       0.000
     109.590      138.277     11.143       0.000       0.000
     114.090      143.778     11.335       0.000       0.000
     118.590      149.459     11.557       0.000       0.000
     123.090      155.598     11.846       0.000       0.000
     127.590      163.991     12.383       0.000       0.000
     132.090      177.104     13.699       0.000       0.000
     136.590      194.660     16.495       0.000       0.000
     141.090      213.914     20.529       0.000       0.000
     145.590      231.470     24.395       0.000       0.000
     150.090      245.817     27.368       0.000       0.000
     154.590      256.728     29.500       0.000       0.000
     159.090      264.430     30.808       0.000       0.000
     163.590      270.004     31.561       0.000       0.000
     168.090      274.166     32.014       0.000       0.000
     172.590      277.415     32.282       0.000       0.000
     177.090      280.286     32.458       0.000       0.000
     181.590      283.139     32.589       0.000       0.000
     186.090      284.898     32.639       0.000       0.000
     190.590      285.296     32.643       0.000       0.000
     195.090      285.386     32.643       0.000       0.000

TOTAL LOADINGS    285.392     32.643       0.000       0.000
```

STORM RUNOFF DATA

STORM OF THE 27TH JUNE 1977

TIME SAMPLING COMMENCED 0.00
SAMPLING DURATION(MINS) 222.92
DOSER CONCENTRATION(G/L) 42.40
DOSE RATE(ML/MIN) 1.04

MEASURED PARAMETER CONCENTRATIONS

T(MINS)	Q(L/S)	SS(MG/L)	VSS(MG/L)	CA(MG/L)
1.03	8.00	225.00	44.00	0.00
6.09	40.35	245.00	46.00	0.00
10.59	108.54	295.00	53.20	0.00
15.09	73.49	332.00	60.00	0.00
19.59	47.93	320.00	53.00	0.00
24.09	29.40	230.00	33.60	0.00
28.59	18.00	187.00	30.00	0.00
33.09	10.76	172.00	28.00	0.00
37.59	7.41	162.00	26.40	0.00
42.09	5.65	137.00	24.00	0.00
46.59	8.09	115.00	23.00	0.00
51.09	9.91	113.00	22.80	0.00
55.59	100.22	160.00	25.20	0.00
60.09	41.21	175.00	26.00	0.00
64.59	21.51	214.00	28.00	0.00
69.09	15.47	238.00	41.20	0.00
73.59	13.57	178.00	34.00	0.00
78.09	137.80	148.00	24.00	0.00
82.59	88.19	176.00	29.00	0.00
87.09	97.99	187.00	44.00	0.00
91.59	61.24	151.00	37.00	0.00
96.09	44.10	138.00	29.00	0.00
100.59	28.09	125.00	33.00	0.00
105.09	20.51	117.00	39.50	0.00
109.59	13.78	87.00	34.00	0.00
114.09	8.91	74.50	25.50	0.00
118.59	6.73	70.00	20.00	0.00
123.09	5.24	68.00	15.00	0.00
127.59	6.50	57.00	10.00	0.00
132.09	22.05	51.00	5.00	0.00
136.59	29.40	39.00	5.00	0.00
141.09	23.84	37.00	5.00	0.00
145.59	18.76	33.00	5.00	0.00

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                    STORM RUNOFF DATA
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   STORM OF THE  27TH JUNE 1977
   ============================        (CONTINUED)


        T(MINS)    Q(L/S)     SS(MG/L)  VSS(MG/L)  CA(MG/L)

        150.09     11.45       33.00       5.00      0.00
        154.59     11.02       25.00       5.00      0.00
        159.09     11.02       20.00       5.00      0.00
        163.59     19.17       20.00       5.00      0.00
        168.09     45.00       25.00       5.00      0.00
        172.59     37.69       32.00       5.00      0.00
        177.09     60.41       43.00       5.00      0.00
        181.59     58.02       47.00       5.00      0.00
        186.09     35.00       54.00       5.00      0.00
        190.59     24.23       60.00       5.00      0.00
        195.09     19.17       56.00       5.00      0.00
        199.59     17.78       52.00       5.00      0.00
        204.09     13.57       45.00       5.00      0.00
        208.59     15.81       28.00       5.00      0.00
        213.09      3.58        8.66       5.00      0.00
        217.59      0.81        4.28       5.00      0.00
        222.09      0.18        3.29       5.00      0.00

   MEAN VALUES
   FLOW WEIGHTED   31.42      147.94      26.75      0.00


         T(MINS)   BOD(MG/L)  CL(MG/L) NO3(MG/L)   NH4(MG/L)

          1.03      9.80       0.00     22.00      1.60
          6.09     11.50       0.00     13.00      0.90
         10.59     13.00       0.00      8.40      0.70
         15.09     10.80       0.00      6.70      0.59
         19.59      9.00       0.00      6.50      0.55
         24.09      8.50       0.00      6.40      0.51
         28.59      7.00       0.00      7.20      0.57
         33.09      6.30       0.00      7.60      0.49
         37.59      6.80       0.00      7.60      0.50
         42.09      7.80       0.00     10.20      0.40
         46.59      8.60       0.00      9.70      0.48
         51.09      9.30       0.00     10.40      0.53
         55.59      7.60       0.00      5.50      0.53
         60.09      6.30       0.00      5.60      0.56
         64.59      6.00       0.00      7.20      0.80
         69.09      6.50       0.00      9.10      1.00
         73.59      7.20       0.00     10.20      1.30
         78.09      7.60       0.00      7.70      0.78
         82.59      8.50       0.00      7.50      0.92
         87.09     10.10       0.00      7.70      0.49
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STORM RUNOFF DATA

STORM OF THE 27TH JUNE 1977

(CONTINUED)

T(MINS)	BOD(MG/L)	CL(MG/L)	NO3(MG/L)	NH4(MG/L)
91.59	9.80	0.00	6.70	0.53
96.09	12.00	0.00	6.50	0.62
100.59	9.80	0.00	6.70	0.59
105.09	8.70	0.00	7.10	0.57
109.59	8.50	0.00	7.20	0.59
114.09	7.70	0.00	7.60	0.58
118.59	7.50	0.00	8.60	0.56
123.09	6.50	0.00	9.60	0.59
127.59	6.30	0.00	8.80	0.62
132.09	6.60	0.00	7.60	0.69
136.59	6.50	0.00	7.00	0.60
141.09	6.00	0.00	6.80	0.49
145.59	6.60	0.00	8.20	0.54
150.09	6.50	0.00	9.40	1.15
154.59	6.00	0.00	9.40	0.52
159.09	6.10	0.00	9.20	0.45
163.59	5.50	0.00	7.80	0.47
168.09	4.20	0.00	6.30	0.54
172.59	5.20	0.00	5.70	0.50
177.09	5.40	0.00	5.00	0.49
181.59	4.80	0.00	4.80	0.47
186.09	3.10	0.00	4.90	0.42
190.59	3.30	0.00	5.60	0.45
195.09	4.20	0.00	6.10	0.46
199.59	2.80	0.00	6.30	0.45
204.09	3.00	0.00	6.30	0.44
208.59	3.20	0.00	6.30	0.45
213.09	0.96	0.00	6.30	0.45
217.59	0.45	0.00	6.30	0.45
222.09	0.33	0.00	6.30	0.45
MEAN VALUES FLOW WEIGHTED	7.83	0.00	7.30	0.63

CUMULATIVE PARAMETER LOADINGS

T(MINS)	Q(CU.M)	SS(KG)	VSS(KG)	CA(KG)
1.030	0.494	0.111	0.022	0.000
6.092	7.640	1.805	0.345	0.000
10.590	27.739	7.317	1.354	0.000

STORM RUNOFF DATA

STORM OF THE 27TH JUNE 1977

(CONTINUED)

T(MINS)	Q(CU.M)	SS(KG)	VSS(KG)	CA(KG)
15.090	52.314	14.989	2.739	0.000
19.590	68.706	20.341	3.670	0.000
24.090	79.145	23.253	4.131	0.000
28.590	85.544	24.599	4.335	0.000
33.090	89.425	25.299	4.448	0.000
37.590	91.878	25.709	4.515	0.000
42.090	93.641	25.974	4.559	0.000
46.590	95.497	26.206	4.603	0.000
51.090	97.927	26.483	4.659	0.000
55.590	112.794	28.618	5.021	0.000
60.090	131.887	31.794	5.508	0.000
64.590	140.354	33.422	5.736	0.000
69.090	145.347	34.547	5.907	0.000
73.590	149.268	35.365	6.054	0.000
78.090	169.702	38.603	6.616	0.000
82.590	200.211	43.511	7.418	0.000
87.090	225.346	48.076	8.340	0.000
91.590	246.843	51.742	9.217	0.000
96.090	261.064	53.802	9.689	0.000
100.590	270.808	55.089	9.990	0.000
105.090	277.369	55.884	10.226	0.000
109.590	281.998	56.361	10.397	0.000
114.090	285.061	56.610	10.490	0.000
118.590	287.172	56.763	10.538	0.000
123.090	288.788	56.874	10.566	0.000
127.590	290.373	56.973	10.586	0.000
132.090	294.228	57.179	10.613	0.000
136.590	301.173	57.489	10.648	0.000
141.090	308.359	57.763	10.684	0.000
145.590	314.110	57.964	10.712	0.000
150.090	318.190	58.099	10.733	0.000
154.590	321.224	58.187	10.748	0.000
159.090	324.201	58.254	10.763	0.000
163.590	328.277	58.336	10.783	0.000
168.090	336.940	58.534	10.827	0.000
172.590	348.102	58.851	10.882	0.000
177.090	361.345	59.353	10.949	0.000
181.590	377.333	60.073	11.029	0.000
186.090	389.890	60.703	11.091	0.000
190.590	397.885	61.157	11.131	0.000
195.090	403.744	61.497	11.161	0.000
199.590	408.733	61.767	11.186	0.000

STORM RUNOFF DATA

STORM OF THE 27TH JUNE 1977

(CONTINUED)

T(MINS)	Q(CU.M)	SS(KG)	VSS(KG)	CA(KG)
204.090	412.965	61.973	11.207	0.000
208.590	416.931	62.117	11.227	0.000
213.090	419.547	62.170	11.240	0.000
217.590	420.140	62.175	11.243	0.000
222.090	420.274	62.175	11.243	0.000
TOTAL LOADINGS	420.284	62.175	11.243	0.000

T(MINS)	BOD(KG)	COD(KG)	NO3(KG)	NH4(KG)
1.030	0.005	0.000	0.011	0.001
6.090	0.082	0.000	0.129	0.009
10.590	0.331	0.000	0.336	0.025
15.090	0.625	0.000	0.523	0.041
19.590	0.789	0.000	0.632	0.050
24.090	0.880	0.000	0.699	0.056
28.590	0.930	0.000	0.742	0.059
33.090	0.956	0.000	0.771	0.061
37.590	0.972	0.000	0.790	0.063
42.090	0.985	0.000	0.805	0.063
46.590	1.000	0.000	0.824	0.064
51.090	1.022	0.000	0.848	0.065
55.590	1.144	0.000	0.955	0.073
60.090	1.279	0.000	1.061	0.084
64.590	1.331	0.000	1.115	0.089
69.090	1.362	0.000	1.155	0.094
73.590	1.389	0.000	1.193	0.098
78.090	1.541	0.000	1.368	0.118
82.590	1.786	0.000	1.600	0.144
87.090	2.020	0.000	1.791	0.161
91.590	2.234	0.000	1.947	0.172
96.090	2.388	0.000	2.041	0.180
100.590	2.495	0.000	2.105	0.186
105.090	2.556	0.000	2.150	0.190
109.590	2.596	0.000	2.183	0.193
114.090	2.621	0.000	2.206	0.194
118.590	2.637	0.000	2.223	0.196
123.090	2.648	0.000	2.238	0.197
127.590	2.658	0.000	2.252	0.198
132.090	2.683	0.000	2.283	0.200
136.590	2.729	0.000	2.334	0.205

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                         STORM RUNOFF DATA
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     STORM OF THE  27TH JUNE 1977
     ============================          (CONTINUED)


          T(MINS)     BOD(KG)     COD(KG)     NO3(KG)     NH4(KG)

          141.090      2.774       0.000       2.383       0.209
          145.590      2.810       0.000       2.426       0.211
          150.090      2.837       0.000       2.462       0.215
          154.590      2.856       0.000       2.491       0.217
          159.090      2.874       0.000       2.518       0.219
          163.590      2.897       0.000       2.553       0.221
          168.090      2.938       0.000       2.613       0.225
          172.590      2.991       0.000       2.680       0.231
          177.090      3.061       0.000       2.750       0.237
          181.590      3.143       0.000       2.829       0.245
          186.090      3.193       0.000       2.889       0.251
          190.590      3.219       0.000       2.931       0.254
          195.090      3.241       0.000       2.965       0.257
          199.590      3.258       0.000       2.996       0.259
          204.090      3.270       0.000       3.023       0.261
          208.590      3.283       0.000       3.048       0.263
          213.090      3.289       0.000       3.065       0.264
          217.590      3.289       0.000       3.068       0.264
          222.090      3.289       0.000       3.069       0.264


     TOTAL LOADINGS    3.289       0.000       3.069       0.264
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                    STORM RUNOFF DATA
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STORM OF THE  2ND MAY 1978
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          TIME SAMPLING COMMENCED  12.45
          SAMPLING DURATION(MINS)  29.75
          DOSER CONCENTRATION(G/L)  40.00
          DOSE RATE(ML/MIN)   1.00


MEASURED PARAMETER CONCENTRATIONS
=================================

          T(MINS)    Q(L/S)     SS(MG/L)  DS(MG/L)  CA(MG/L)

            1.19      8.00       36.00     215.00     25.60
            4.40      9.55       69.00     265.00     22.70
            7.44     11.88       49.00     160.00     18.70
           10.48     19.51       62.00     155.00     16.50
           13.52     21.86       56.00     142.00     15.00
           16.56     23.67       54.00     115.00     15.50
           19.60      8.68       21.70     115.00     15.50
           22.64      3.18        9.86     115.00     15.50
           25.68      1.17        5.51     115.00     15.50
           28.72      0.43        3.92     115.00     15.50

MEAN VALUES
FLOW WEIGHTED        10.98       50.28     153.33     17.31


           T(MINS)   BOD(MG/L) COD(MG/L) NO3(MG/L)   NH4(MG/L)

            1.19      6.20       11.70      11.70      0.65
            4.40      6.70       23.20      11.20      0.67
            7.44      6.70       43.10      10.40      0.76
           10.48      6.70       49.40      10.40      1.20
           13.52      6.50       54.20      10.00      1.25
           16.56      5.50       11.40      10.20      1.15
           19.60      2.21        7.35      10.20      1.15
           22.64      1.00        5.86      10.20      1.15
           25.68      0.56        5.32      10.20      1.15
           28.72      0.39        5.12      10.20      1.15

MEAN VALUES
FLOW WEIGHTED         5.70       30.92      10.41      1.06
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STORM RUNOFF DATA

STORM OF THE 2ND MAY 1978

(CONTINUED)

CUMULATIVE PARAMETER LOADINGS

T(MINS)	Q(CU.M)	SS(KG)	DS(KG)	CA(KG)
1.195	0.574	0.021	0.123	0.015
4.400	2.253	0.109	0.527	0.055
7.440	4.208	0.223	0.935	0.095
10.480	7.071	0.385	1.384	0.145
13.520	10.844	0.607	1.944	0.205
16.560	14.996	0.835	2.476	0.268
19.600	17.946	0.962	2.815	0.314
22.640	19.028	0.981	2.939	0.330
25.680	19.425	0.984	2.985	0.337
28.720	19.570	0.985	3.002	0.339
TOTAL LOADINGS	19.596	0.985	3.005	0.339

T(MINS)	BOD(KG)	COD(KG)	NO3(KG)	NH4(KG)
1.195	0.004	0.007	0.007	0.000
4.400	0.014	0.036	0.026	0.001
7.440	0.027	0.102	0.047	0.003
10.480	0.047	0.236	0.077	0.006
13.520	0.072	0.432	0.115	0.010
16.560	0.096	0.566	0.157	0.015
19.600	0.109	0.595	0.187	0.019
22.640	0.111	0.603	0.198	0.020
25.680	0.112	0.605	0.202	0.020
28.720	0.112	0.606	0.204	0.021
TOTAL LOADINGS	0.112	0.606	0.204	0.021

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                     STORM RUNOFF DATA
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     STORM OF THE  4TH MAY 1978
     ===============================

            TIME SAMPLING COMMENCED    8.05
            SAMPLING DURATION(MINS)  47.99
            DOSER CONCENTRATION(G/L)  38.00
            DOSE RATE(ML/MIN)   1.03


     MEASURED PARAMETER CONCENTRATIONS
     =================================

            T(MINS)   Q(L/S)    SS(MG/L)  DS(MG/L)  CA(MG/L)

              1.19      8.00     226.00    124.00     14.50
              4.40      7.13     166.00    116.00     15.50
              7.44     11.37     120.00    152.00     15.50
             10.48     31.93     150.00    126.00     12.30
             13.52     51.93     185.00     90.00     11.10
             16.56     64.92     292.00     56.00      9.70
             19.60     33.87     226.00     28.00      8.90
             22.64     24.34     140.00     84.00      8.90
             25.68     21.05      99.00     88.00      9.40
             28.72     22.91     122.00     56.00      9.20
             31.76     21.64      55.00     76.00      8.90
             34.80     13.20      47.00     72.00      9.40
             37.84      4.84      19.13     72.00      9.40
             40.88      1.78       8.92     72.00      9.40
             43.92      0.65       5.17     72.00      9.40
             46.96      0.24       3.80     72.00      9.40

     MEAN VALUES
     FLOW WEIGHTED     20.23     172.20     78.88     10.39


             T(MINS)   BOD(MG/L) COD(MG/L) NO3(MG/L)   NH4(MG/L)

              1.19     12.30     122.00     12.00      1.05
              4.40      8.40      81.40     12.30      1.40
              7.44      8.80      79.10     12.00      1.25
             10.48      9.90     110.70     11.00      1.10
             13.52      8.70     157.00     10.10      1.00
             16.56      6.90     137.90      6.70      0.91
             19.60      7.70      93.80      6.30      0.77
             22.64      7.10      84.20      7.00      0.75
             25.68      4.70      79.10      6.90      0.67
             28.72      6.50      62.70      7.40      0.69
             31.76      4.90      27.70      7.40      0.66
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                    STORM RUNOFF DATA
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STORM OF THE  4TH MAY 1978
==============================              (CONTINUED)


         T(MINS)    BOD(MG/L) COD(MG/L) NO3(MG/L)    NH4(MG/L)

          34.80       3.40       9.00       7.90        0.71
          37.84       1.44       6.47       7.90        0.71
          40.88       0.72       5.54       7.90        0.71
          43.92       0.45       5.20       7.90        0.71
          46.96       0.36       5.07       7.90        0.71

MEAN VALUES
FLOW WEIGHTED         7.23      99.87       8.31        0.88


CUMULATIVE PARAMETER LOADINGS
=============================

         T(MINS)    Q(CU.M)    SS(KG)     DS(KG)    CA(KG)

          1.195      0.574      0.130      0.071     0.008
          4.400      2.032      0.420      0.247     0.030
          7.440      3.720      0.655      0.478     0.056
         10.480      7.669      1.207      1.010     0.109
         13.520     15.317      2.510      1.814     0.198
         16.560     25.974      5.094      2.578     0.308
         19.600     34.983      7.491      2.983     0.393
         22.640     40.292      8.488      3.264     0.440
         25.680     44.432      8.987      3.620     0.478
         28.720     48.442      9.431      3.907     0.515
         31.760     52.505      9.793      4.174     0.552
         34.800     55.683      9.958      4.410     0.581
         37.840     57.328     10.019      4.529     0.596
         40.880     57.932     10.029      4.572     0.602
         43.920     58.153     10.030      4.588     0.604
         46.960     58.234     10.031      4.594     0.605


TOTAL LOADINGS      58.249     10.031      4.595     0.605


         T(MINS)    BOD(KG)    COD(KG)    NO3(KG)   NH4(KG)

          1.195      0.007      0.070      0.007     0.001
          4.400      0.022      0.221      0.025     0.002
          7.440      0.037      0.356      0.045     0.005
         10.480      0.075      0.751      0.090     0.009
         13.520      0.145      1.803      0.170     0.017
         16.560      0.227      3.367      0.258     0.027
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STORM RUNOFF DATA

STORM OF THE 4TH MAY 1978

(CONTINUED)

T(MINS)	BOD(KG)	COD(KG)	NO3(KG)	NH4(KG)
19.600	0.292	4.453	0.317	0.035
22.640	0.332	4.928	0.352	0.039
25.680	0.357	5.267	0.381	0.042
28.720	0.379	5.550	0.410	0.045
31.760	0.402	5.735	0.440	0.047
34.800	0.416	5.798	0.464	0.050
37.840	0.420	5.812	0.477	0.051
40.880	0.421	5.816	0.482	0.051
43.920	0.421	5.817	0.483	0.051
46.960	0.421	5.817	0.484	0.051
TOTAL LOADINGS	0.421	5.817	0.484	0.051

STORM RUNOFF DATA

STORM OF THE 5TH MAY 1978

TIME SAMPLING COMMENCED 2.00
SAMPLING DURATION(MINS) 44.95
DOSER CONCENTRATION(G/L) 38.95
DOSE RATE(ML/MIN) 1.03

MEASURED PARAMETER CONCENTRATIONS

	T(MINS)	Q(L/S)	SS(MG/L)	DS(MG/L)	CA(MG/L)
	1.19	8.00	18.00	40.00	0.00
	4.40	2.36	21.00	40.00	0.00
	7.44	14.64	25.00	36.00	0.00
	10.48	18.15	32.00	54.00	0.00
	13.52	17.36	49.00	136.00	0.00
	16.56	15.07	45.00	100.00	0.00
	19.60	12.48	43.00	84.00	0.00
	22.64	20.47	36.00	76.00	0.00
	25.68	17.74	30.00	60.00	0.00
	28.72	21.01	28.00	68.00	0.00
	31.76	11.09	26.00	96.00	0.00
	34.80	17.36	29.00	88.00	0.00
	37.84	16.63	32.00	60.00	0.00
	40.88	15.07	20.00	82.00	0.00
	43.92	17.36	12.00	88.00	0.00
MEAN VALUES FLOW WEIGHTED		14.98	30.92	76.71	0.00

T(MINS)	BOD(MG/L)	COD(MG/L)	NO3(MG/L)	NH4(MG/L)
1.19	6.50	4.50	5.10	0.27
4.40	6.60	10.10	5.10	0.27
7.44	6.70	18.10	4.60	0.28
10.48	6.70	16.10	4.40	0.25
13.52	6.70	12.40	4.10	0.21
16.56	5.60	10.20	4.20	0.21
19.60	4.90	6.80	3.60	0.21
22.64	5.20	8.40	3.80	0.22
25.68	6.20	9.00	4.40	0.23
28.72	6.10	8.20	3.70	0.24
31.76	5.80	6.80	3.60	0.33
34.80	5.60	5.00	3.50	0.21

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                         STORM RUNOFF DATA
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    STORM OF THE  5TH MAY 1978
    ==============================               (CONTINUED)


           T(MINS)    BOD(MG/L) COD(MG/L) NO3(MG/L)    NH4(MG/L)

            37.84       4.90      2.80      3.50       0.20
            40.88       4.30      2.50      3.30       0.19
            43.92       4.10      2.30      3.20       0.19

    MEAN VALUES
    FLOW WEIGHTED       5.68      8.33      3.91       0.23


    CUMULATIVE PARAMETER LOADINGS
    =============================

          T(MINS)    Q(CU.M)    SS(KG)    DS(KG)    CA(KG)

            1.195      0.574     0.010     0.023     0.000
            4.400      1.597     0.030     0.064     0.000
            7.440      3.147     0.067     0.121     0.000
           10.480      6.137     0.153     0.258     0.000
           13.520      9.375     0.284     0.563     0.000
           16.560     12.332     0.423     0.915     0.000
           19.600     14.844     0.533     1.147     0.000
           22.640     17.849     0.650     1.386     0.000
           25.680     21.334     0.766     1.624     0.000
           28.720     24.869     0.868     1.851     0.000
           31.760     27.797     0.948     2.083     0.000
           34.800     30.391     1.020     2.320     0.000
           37.840     33.491     1.114     2.550     0.000
           40.880     36.382     1.190     2.754     0.000
           43.920     39.339     1.237     3.006     0.000


    TOTAL LOADINGS     40.412     1.250     3.100     0.000

          T(MINS)    BOD(KG)    COD(KG)   NO3(KG)   NH4(KG)

            1.195      0.004     0.003     0.003     0.000
            4.400      0.010     0.009     0.008     0.000
            7.440      0.021     0.034     0.015     0.001
           10.480      0.041     0.085     0.029     0.002
           13.520      0.062     0.131     0.043     0.002
           16.560      0.081     0.164     0.055     0.003
           19.600      0.094     0.186     0.065     0.004
           22.640      0.109     0.209     0.076     0.004
           25.680      0.129     0.240     0.090     0.005
```

STORM RUNOFF DATA

STORM OF THE 5TH MAY 1978

(CONTINUED)

T(MINS)	BOD(KG)	COD(KG)	NO3(KG)	NH4(KG)
28.720	0.151	0.270	0.104	0.006
31.760	0.168	0.292	0.115	0.007
34.800	0.183	0.307	0.124	0.007
37.840	0.199	0.319	0.135	0.008
40.880	0.213	0.327	0.145	0.008
43.920	0.225	0.334	0.155	0.009
TOTAL LOADINGS	0.229	0.337	0.158	0.009

```
                         STORM RUNOFF DATA
                         =================


 STORM OF THE  5TH MAY 1978
 ==========================

        TIME SAMPLING COMMENCED    3.00
        SAMPLING DURATION(MINS)  60.15
        DOSER CONCENTRATION(G/L)  38.95
        DOSE RATE(ML/MIN)    1.03


 MEASURED PARAMETER CONCENTRATIONS
 =================================

        T(MINS)    Q(L/S)     SS(MG/L)  DS(MG/L)  CA(MG/L)

          1.19       8.00       7.00      88.00      0.00
          4.40       3.81       8.00      96.00      0.00
          7.44      12.74      17.00      88.00      0.00
         10.48      15.84      29.00      84.00      0.00
         13.52      13.09      18.00      84.00      0.00
         16.56      15.36      10.00      88.00      0.00
         19.60      14.52      15.00      96.00      0.00
         22.64      16.99       8.00      98.00      0.00
         25.68      20.47       9.00     108.00      0.00
         28.72      47.53       8.40     115.00      0.00
         31.76      38.02       8.80     124.00      0.00
         34.80      16.23       9.00     136.00      0.00
         37.84      21.58       8.80     120.00      0.00
         40.88      21.58      19.00     116.00      0.00
         43.92      20.58      30.00     100.00      0.00
         46.96      16.99      12.00      96.00      0.00
         50.00       6.23       6.30      96.00      0.00
         53.04       2.28       4.21      96.00      0.00
         56.08       0.84       3.44      96.00      0.00
         59.12       0.31       3.16      96.00      0.00

 MEAN VALUES
 FLOW WEIGHTED      15.79      12.88     106.62      0.00


         T(MINS)    BOD(MG/L) COD(MG/L) NO3(MG/L)   NH4(MG/L)

          1.19       0.00       0.00       3.00      0.15
          4.40       0.00       0.00       2.90      0.12
          7.44       0.00       0.00       2.90      0.10
         10.48       0.00       0.00       2.90      0.07
         13.52       0.00       0.00       2.80      0.09
         16.56       0.00       0.00       2.70      0.10
         19.60       0.00       0.00       2.70      0.08
```

STORM RUNOFF DATA

STORM OF THE 5TH MAY 1978 (CONTINUED)

T(MINS)	BOD(MG/L)	COD(MG/L)	NO3(MG/L)	NH4(MG/L)
22.64	0.00	0.00	3.20	0.08
25.68	0.00	0.00	3.00	0.07
28.72	0.00	0.00	6.90	0.06
31.76	0.00	0.00	6.30	0.06
34.80	0.00	0.00	5.80	0.05
37.84	0.00	0.00	5.30	0.04
40.88	0.00	0.00	5.10	0.04
43.92	0.00	0.00	5.20	0.03
46.96	0.00	0.00	5.10	0.04
50.00	0.00	0.00	5.10	0.04
53.04	0.00	0.00	5.10	0.04
56.08	0.00	0.00	5.10	0.04
59.12	0.00	0.00	5.10	0.04
MEAN VALUES FLOW WEIGHTED	0.00	0.00	4.70	0.06

CUMULATIVE PARAMETER LOADINGS

T(MINS)	Q(CU.M)	SS(KG)	DS(KG)	CA(KG)
1.195	0.574	0.004	0.050	0.000
4.400	1.730	0.013	0.156	0.000
7.440	3.239	0.034	0.292	0.000
10.480	5.846	0.095	0.516	0.000
13.520	8.485	0.158	0.738	0.000
16.560	11.079	0.194	0.961	0.000
19.600	13.803	0.228	1.211	0.000
22.640	16.677	0.260	1.490	0.000
25.680	20.093	0.289	1.843	0.000
28.720	26.295	0.343	2.541	0.000
31.760	34.097	0.410	3.470	0.000
34.800	39.045	0.454	4.105	0.000
37.840	42.493	0.484	4.544	0.000
40.880	46.430	0.539	5.009	0.000
43.920	50.275	0.633	5.424	0.000
46.960	53.701	0.707	5.761	0.000
50.000	55.818	0.729	5.964	0.000
53.040	56.595	0.732	6.038	0.000
56.080	56.880	0.734	6.066	0.000
59.120	56.984	0.734	6.076	0.000
TOTAL LOADINGS	57.003	0.734	6.078	0.000

STORM RUNOFF DATA

STORM OF THE 5TH MAY 1978

(CONTINUED)

T(MINS)	BOD(KG)	COD(KG)	NO3(KG)	NH4(KG)
1.195	0.000	0.000	0.002	0.000
4.400	0.000	0.000	0.005	0.000
7.440	0.000	0.000	0.010	0.000
10.480	0.000	0.000	0.017	0.001
13.520	0.000	0.000	0.025	0.001
16.560	0.000	0.000	0.032	0.001
19.600	0.000	0.000	0.039	0.001
22.640	0.000	0.000	0.048	0.002
25.680	0.000	0.000	0.058	0.002
28.720	0.000	0.000	0.092	0.002
31.760	0.000	0.000	0.144	0.003
34.800	0.000	0.000	0.174	0.003
37.840	0.000	0.000	0.193	0.003
40.880	0.000	0.000	0.214	0.003
43.920	0.000	0.000	0.233	0.003
46.960	0.000	0.000	0.251	0.004
50.000	0.000	0.000	0.262	0.004
53.040	0.000	0.000	0.266	0.004
56.080	0.000	0.000	0.267	0.004
59.120	0.000	0.000	0.268	0.004
TOTAL LOADINGS	0.000	0.000	0.268	0.004

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                        STORM RUNOFF DATA
                        =================

     STORM OF THE  5TH MAY 1978
     ==========================

            TIME SAMPLING COMMENCED    4.00
            SAMPLING DURATION(MINS)   41.91
            DOSER CONCENTRATION(G/L)   38.95
            DOSE RATE(ML/MIN)    1.03


     MEASURED PARAMETER CONCENTRATIONS
     =================================

            T(MINS)    Q(L/S)     SS(MG/L)   DS(MG/L)   CA(MG/L)

              1.19       8.00       8.00     126.00       0.00
              4.40       7.31       9.00     110.00       0.00
              7.44      41.19      52.00      96.00       0.00
             10.48      31.94      46.00      92.00       0.00
             13.52      18.57      29.00      88.00       0.00
             16.56      28.12      35.00      84.00       0.00
             19.60      29.57      19.00      88.00       0.00
             22.64      24.34      24.00      96.00       0.00
             25.68      19.47      27.00     104.00       0.00
             28.72      16.23      11.00      96.00       0.00
             31.76       5.95       5.93      96.00       0.00
             34.80       2.18       4.08      96.00       0.00
             37.84       0.80       3.39      96.00       0.00
             40.88       0.29       3.14      96.00       0.00

     MEAN VALUES
     FLOW WEIGHTED      16.94      30.02      94.60       0.00


             T(MINS)   BOD(MG/L) COD(MG/L) NO3(MG/L)   NH4(MG/L)

              1.19       0.00       0.00       4.80       0.04
              4.40       0.00       0.00       4.50       0.03
              7.44       0.00       0.00       5.20       0.02
             10.48       0.00       4.90       0.04       0.00
             13.52       0.00       4.50       0.05       0.00
             16.56       0.00       3.80       0.07       0.00
             19.60       0.00       0.90       0.07       0.00
             22.64       0.00       4.50       0.06       0.00
             25.68       0.00       0.50       0.05       0.00
             28.72       0.00       5.42       0.04       0.00
             31.76       0.00       5.15       0.04       0.00
             34.80       0.00       5.05       0.04       0.00
             37.84       0.00       5.02       0.04       0.00
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                         STORM RUNOFF DATA


STORM OF THE  5TH MAY 1978
                                            (CONTINUED)


          T(MINS)    BOD(MG/L) COD(MG/L) NO3(MG/L)   NH4(MG/L)

          40.88        0.00      5.01      0.04        0.00

MEAN VALUES
FLOW WEIGHTED          0.00      2.71      1.23        0.01


CUMULATIVE PARAMETER LOADINGS


         T(MINS)     Q(CU.M)     SS(KG)     DS(KG)     CA(KG)

          1.195       0.574      0.005      0.072      0.000
          4.400       2.049      0.017      0.247      0.000
          7.440       6.472      0.197      0.688      0.000
         10.480      13.141      0.526      1.316      0.000
         13.520      17.747      0.705      1.733      0.000
         16.560      22.005      0.843      2.097      0.000
         19.600      27.266      0.985      2.550      0.000
         22.640      32.183      1.090      3.001      0.000
         25.680      36.180      1.191      3.400      0.000
         28.720      39.436      1.254      3.726      0.000
         31.760      41.459      1.273      3.920      0.000
         34.800      42.201      1.277      3.991      0.000
         37.840      42.473      1.278      4.018      0.000
         40.880      42.572      1.278      4.027      0.000


TOTAL LOADINGS       42.590      1.279      4.029      0.000


         T(MINS)     BOD(KG)    COD(KG)    NO3(KG)    NH4(KG)

          1.195       0.000      0.000      0.003      0.000
          4.400       0.000      0.000      0.010      0.000
          7.440       0.000      0.000      0.032      0.000
         10.480       0.000      0.015      0.051      0.000
         13.520       0.000      0.037      0.051      0.000
         16.560       0.000      0.054      0.051      0.000
         19.600       0.000      0.066      0.052      0.000
         22.640       0.000      0.079      0.052      0.000
         25.680       0.000      0.090      0.052      0.000
         28.720       0.000      0.099      0.052      0.000
         31.760       0.000      0.110      0.052      0.000
         34.800       0.000      0.113      0.052      0.000
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                    STORM RUNOFF DATA
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STORM OF THE  5TH MAY 1978
==============================            (CONTINUED)


          T(MINS)    BOD(KG)    COD(KG)    NO3(KG)    NH4(KG)

          37.840      0.000      0.115      0.052      0.000
          40.880      0.000      0.115      0.052      0.000


TOTAL LOADINGS        0.000      0.115      0.052      0.000
```

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                         STORM RUNOFF DATA
                         =================


     STORM OF THE  15TH MAY 1978
     ===========================

             TIME SAMPLING COMMENCED  16.34
             SAMPLING DURATION(MINS)  23.67
             DOSER CONCENTRATION(G/L)  41.50
             DOSE RATE(ML/MIN)    1.03


     MEASURED PARAMETER CONCENTRATIONS
     =================================

             T(MINS)    Q(L/S)     SS(MG/L)  DS(MG/L)  CA(MG/L)

               1.19       8.00     202.00    320.00     26.80
               4.40      11.12     165.00    272.00     24.70
               7.44       9.40     147.00    224.00     23.20
              10.48      11.19     125.00    240.00     19.60
              13.52       4.10      47.74    240.00     19.60
              16.56       1.51      19.41    240.00     19.60
              19.60       0.55       9.02    240.00     19.60
              22.64       0.20       5.21    240.00     19.60

     MEAN VALUES
     FLOW WEIGHTED        5.86     138.89    257.86     22.80


              T(MINS)    BOD(MG/L) COD(MG/L) NO3(MG/L)   NH4(MG/L)

               1.19      20.20     121.00     12.50      1.02
               4.40      12.00     119.00     12.00      1.27
               7.44      15.10      96.00     11.40      1.30
              10.48      17.20      74.00     11.30      1.30
              13.52       6.50      30.30     11.30      1.30
              16.56       2.57      14.28     11.30      1.30
              19.60       1.13       8.40     11.30      1.30
              22.64       0.61       6.25     11.30      1.30

     MEAN VALUES
     FLOW WEIGHTED       14.19      89.74     11.69      1.24


     CUMULATIVE PARAMETER LOADINGS
     =============================

             T(MINS)    Q(CU.M)    SS(KG)     DS(KG)    CA(KG)

              1.195      0.574     0.116      0.184     0.015
              4.400      2.397     0.448      0.720     0.062
              7.443      4.268     0.741      1.187     0.107
```

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                              STORM RUNOFF DATA
                              =================

     STORM OF THE  15TH MAY 1978
     ============================              (CONTINUED)


            T(MINS)    Q(CU.M)    SS(KG)     DS(KG)    CA(KG)

            10.480      6.146     0.995      1.624      0.147
            13.520      7.541     1.133      1.958      0.174
            16.560      8.053     1.152      2.081      0.184
            19.600      8.240     1.155      2.126      0.188
            22.640      8.309     1.156      2.143      0.189


     TOTAL LOADINGS     8.321     1.156      2.146      0.190


            T(MINS)    BOD(KG)    COD(KG)    NO3(KG)    NH4(KG)

             1.195      0.012     0.069      0.007      0.001
             4.400      0.040     0.288      0.029      0.003
             7.440      0.066     0.490      0.051      0.005
            10.480      0.096     0.649      0.073      0.008
            13.520      0.115     0.731      0.088      0.009
            16.560      0.118     0.744      0.094      0.010
            19.600      0.118     0.746      0.096      0.010
            22.640      0.118     0.747      0.097      0.010


     TOTAL LOADINGS     0.118     0.747      0.097      0.010
```

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                    STORM RUNOFF DATA
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STORM OF THE  24TH MAY 1978
============================

       TIME SAMPLING COMMENCED    9.41
       SAMPLING DURATION(MINS)   20.63
       DOSER CONCENTRATION(G/L)   41.50
       DOSE RATE(ML/MIN)    1.03


MEASURED PARAMETER CONCENTRATIONS
=================================

       T(MINS)    Q(L/S)     SS(MG/L)   DS(MG/L)   CA(MG/L)

         1.19       8.00     189.00     416.00      48.60
         4.40      23.35     205.00     380.00      44.10
         7.44      20.03     155.00     360.00      41.40
        10.48       7.34      58.74     360.00      41.40
        13.52       2.69      23.44     360.00      41.40
        16.56       0.99      10.50     360.00      41.40
        19.60       0.36       5.75     360.00      41.40

MEAN VALUES
FLOW WEIGHTED       9.18     155.47     374.94      43.37


        T(MINS)    BOD(MG/L) COD(MG/L) NO3(MG/L)   NH4(MG/L)

         1.19      33.70     180.60      32.40       2.00
         4.40      36.60     213.60      32.10       2.00
         7.44      26.10     159.20      30.80       2.10
        10.48       9.76      61.55      30.80       2.10
        13.52       3.77      25.74      30.80       2.10
        16.56       1.57      12.60      30.80       2.10
        19.60       0.77       7.79      30.80       2.10

MEAN VALUES
FLOW WEIGHTED      27.14     159.11      31.48       2.05

CUMULATIVE PARAMETER LOADINGS
=============================

       T(MINS)    Q(CU.M)    SS(KG)     DS(KG)    CA(KG)

        1.195      0.574      0.108      0.239     0.028
        4.400      3.512      0.694      1.393     0.162
        7.440      7.468      1.412      2.858     0.332
       10.480      9.964      1.716      3.757     0.435
       13.520     10.880      1.759      4.086     0.473
```

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                              STORM RUNOFF DATA
                              =================


STORM OF THE  24TH MAY 1978
==============================            (CONTINUED)


          T(MINS)    Q(CU.M)    SS(KG)     DS(KG)     CA(KG)

          16.560     11.215      1.765      4.207      0.487
          19.600     11.338      1.766      4.252      0.492


TOTAL LOADINGS       11.361      1.766      4.260      0.493


          T(MINS)    BOD(KG)    COD(KG)    NO3(KG)    NH4(KG)

           1.195      0.019      0.104      0.019      0.001
           4.400      0.124      0.697      0.113      0.007
           7.440      0.249      1.440      0.238      0.015
          10.480      0.300      1.754      0.315      0.020
          13.520      0.307      1.799      0.343      0.022
          16.560      0.308      1.806      0.353      0.023
          19.600      0.308      1.807      0.357      0.023


TOTAL LOADINGS        0.308      1.808      0.358      0.023
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                    STORM RUNOFF DATA
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STORM OF THE  31ST MAY 1978
============================

        TIME SAMPLING COMMENCED  17.13
        SAMPLING DURATION(MINS)  11.51
        DOSER CONCENTRATION(G/L)  41.50
        DOSE RATE(ML/MIN)    1.03

MEASURED PARAMETER CONCENTRATIONS
==================================

        T(MINS)    Q(L/S)     SS(MG/L)  DS(MG/L)  CA(MG/L)

          1.19       8.00     413.00    368.00     25.00
          4.40       2.94     151.00    368.00     25.00
          7.44       1.08      56.00    368.00     25.00
         10.48       0.40      22.44    368.00     25.00

MEAN VALUES
FLOW WEIGHTED        3.15     294.97    368.00     25.00


         T(MINS)   BOD(MG/L) COD(MG/L) NO3(MG/L)   NH4(MG/L)

          1.19      44.50     439.00      0.00      5.30
          4.40      16.30     161.00      0.00      5.30
          7.44       6.00      59.00      0.00      5.30
         10.48       2.39      24.80      0.00      5.30

MEAN VALUES
FLOW WEIGHTED       31.79     313.65      0.00      5.30

CUMULATIVE PARAMETER LOADINGS
==============================

        T(MINS)    Q(CU.M)    SS(KG)    DS(KG)   CA(KG)

         1.195      0.574      0.237     0.211     0.014
         4.400      1.650      0.592     0.607     0.041
         7.440      2.017      0.635     0.742     0.050
        10.480      2.151      0.641     0.792     0.054


TOTAL LOADINGS      2.176      0.642     0.801     0.054
```

STORM RUNOFF DATA

STORM OF THE 31ST MAY 1978 (CONTINUED)

T(MINS)	BOD(KG)	COD(KG)	NO3(KG)	NH4(KG)
1.195	0.026	0.252	0.000	0.003
4.400	0.064	0.629	0.000	0.009
7.440	0.068	0.675	0.000	0.011
10.480	0.069	0.682	0.000	0.011
TOTAL LOADINGS	0.069	0.682	0.000	0.012

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                    STORM RUNOFF DATA
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STORM OF THE  1ST JUNE 1978
---------------------------

          TIME SAMPLING COMMENCED  17.30
          SAMPLING DURATION(MINS)  81.43
          DOSER CONCENTRATION(G/L)  41.50
          DOSE RATE(ML/MIN)    1.03


MEASURED PARAMETER CONCENTRATIONS
---------------------------------

          T(MINS)    Q(L/S)     SS(MG/L)  DS(MG/L)  CA(MG/L)

             1.19      8.00      130.00    300.00     28.50
             4.40     17.30       53.00    168.00     18.00
             7.44     51.61       88.00    164.00     16.30
            10.48     30.38       68.00    152.00     15.00
            13.52     30.38       83.00    136.00     13.80
            16.56     40.13       79.00    142.00     12.80
            19.60     32.72       14.00    148.00     11.40
            22.64     25.78       40.00    152.00     10.00
            25.68     45.25       92.00    160.00      9.80
            28.72     42.54      114.00    156.00     12.50
            31.76     36.99       23.00    156.00     10.60
            34.80     34.03       48.00    136.00      8.80
            37.84     38.67      105.00    108.00      9.00
            40.88     34.03      127.00    140.00     11.60
            43.92     19.34       22.00    168.00     10.00
            46.96      6.40       78.00    164.00     11.60
            50.00     27.44       26.00    164.00     10.00
            53.04     28.17       30.00    160.00      9.90
            56.08     27.09       52.00    158.00     10.00
            59.12     21.81       39.00    152.00      9.50
            62.16     32.72       63.00    144.00      8.90
            65.20     36.99      115.00    128.00     11.00
            68.24     13.56       44.07    128.00     11.00
            71.28      4.97       18.06    128.00     11.00
            74.32      1.82        8.52    128.00     11.00
            77.36      0.67        5.03    128.00     11.00
            80.40      0.25        3.74    128.00     11.00

MEAN VALUES
FLOW WEIGHTED        25.71       68.17    149.97     11.67
```

STORM RUNOFF DATA

STORM OF THE 1ST JUNE 1978

(CONTINUED)

T(MINS)	BOD(MG/L)	COD(MG/L)	NO3(MG/L)	NH4(MG/L)
1.19	0.00	109.00	0.00	0.00
4.40	0.00	63.00	0.00	0.00
7.44	0.00	60.00	0.00	0.00
10.48	0.00	60.00	0.00	0.00
13.52	0.00	59.00	0.00	0.00
16.56	0.00	55.00	0.00	0.00
19.60	0.00	17.30	0.00	0.00
22.64	0.00	32.00	0.00	0.00
25.68	0.00	54.00	0.00	0.00
28.72	0.00	60.00	0.00	0.00
31.76	0.00	13.00	0.00	0.00
34.80	0.00	31.00	0.00	0.00
37.84	0.00	47.00	0.00	0.00
40.88	0.00	51.00	0.00	0.00
43.92	0.00	15.00	0.00	0.00
46.96	0.00	36.00	0.00	0.00
50.00	0.00	14.00	0.00	0.00
53.04	0.00	14.00	0.00	0.00
56.08	0.00	22.00	0.00	0.00
59.12	0.00	8.10	0.00	0.00
62.16	0.00	33.00	0.00	0.00
65.20	0.00	72.40	0.00	0.00
68.24	0.00	29.72	0.00	0.00
71.28	0.00	14.06	0.00	0.00
74.32	0.00	8.32	0.00	0.00
77.36	0.00	6.22	0.00	0.00
80.40	0.00	5.45	0.00	0.00
MEAN VALUES FLOW WEIGHTED	0.00	41.37	0.00	0.00

CUMULATIVE PARAMETER LOADINGS

T(MINS)	Q(CU.M)	SS(KG)	DS(KG)	CA(KG)
1.195	0.574	0.075	0.172	0.216
4.400	2.960	0.274	0.698	0.269
7.440	9.245	0.751	1.737	0.175
10.480	16.723	1.350	2.926	0.293
13.520	22.265	1.769	3.724	0.373

STORM RUNOFF DATA

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STORM OF THE  1ST JUNE 1978
                                              (CONTINUED)

           T(MINS)     Q(CU.M)     SS(KG)     DS(KG)     CA(KG)

           16.560      28.696      2.289      4.620      0.458
           19.600      35.340      2.612      5.582      0.539
           22.640      40.675      2.751      6.381      0.596
           25.680      47.154      3.210      7.397      0.660
           28.720      55.160      4.033      8.662      0.749
           31.760      62.413      4.545      9.794      0.833
           34.800      68.890      4.773     10.741      0.896
           37.840      75.520      5.288     11.546      0.955
           40.880      82.150      6.054     12.364      1.023
           43.920      87.017      6.464     13.100      1.077
           46.960      89.364      6.559     13.492      1.101
           50.000      92.450      6.686     13.998      1.134
           53.040      97.522      6.828     14.819      1.184
           56.080     102.562      7.034     15.621      1.231
           59.120     107.023      7.239     16.313      1.278
           62.160     111.996      7.501     17.046      1.323
           65.200     118.354      8.073     17.969      1.386
           68.240     122.964      8.491     18.499      1.437
           71.280     124.655      8.551     18.716      1.456
           74.320     125.275      8.560     18.795      1.462
           77.360     125.502      8.562     18.824      1.465
           80.400     125.586      8.562     18.835      1.466


TOTAL LOADINGS        125.601      8.562     18.837      1.466


           T(MINS)     BOD(KG)     COD(KG)    NO3(KG)    NH4(KG)

            1.195       0.000      0.063      0.000      0.000
            4.400       0.000      0.256      0.000      0.000
            7.440       0.000      0.642      0.000      0.000
           10.480       0.000      1.088      0.000      0.000
           13.520       0.000      1.418      0.000      0.000
           16.560       0.000      1.783      0.000      0.000
           19.600       0.000      2.031      0.000      0.000
           22.640       0.000      2.159      0.000      0.000
           25.680       0.000      2.451      0.000      0.000
           28.720       0.000      2.907      0.000      0.000
           31.760       0.000      3.179      0.000      0.000
           34.800       0.000      3.329      0.000      0.000
           37.840       0.000      3.581      0.000      0.000
           40.880       0.000      3.905      0.000      0.000
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                              STORM RUNOFF DATA
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    STORM OF THE  1ST JUNE 1978
    ===========================               (CONTINUED)

          T(MINS)     BOD(KG)     COD(KG)     NO3(KG)     NH4(KG)

          43.920      0.000       4.082       0.000       0.000
          46.960      0.000       4.134       0.000       0.000
          50.000      0.000       4.197       0.000       0.000
          53.040      0.000       4.268       0.000       0.000
          56.080      0.000       4.358       0.000       0.000
          59.120      0.000       4.427       0.000       0.000
          62.160      0.000       4.538       0.000       0.000
          65.200      0.000       4.878       0.000       0.000
          68.240      0.000       5.145       0.000       0.000
          71.280      0.000       5.186       0.000       0.000
          74.320      0.000       5.193       0.000       0.000
          77.360      0.000       5.195       0.000       0.000
          80.400      0.000       5.195       0.000       0.000


    TOTAL LOADINGS    0.000       5.196       0.000       0.000
```

STORM RUNOFF DATA

STORM OF THE 15TH JUNE 1978

TIME SAMPLING COMMENCED 10.12
SAMPLING DURATION(MINS) 130.07
DOSER CONCENTRATION(G/L) 41.50
DOSE RATE(ML/MIN) 1.03

MEASURED PARAMETER CONCENTRATIONS

T(MINS)	Q(L/S)	SS(MG/L)	DS(MG/L)	CA(MG/L)
1.19	8.00	178.00	224.00	27.00
4.40	9.16	161.00	208.00	24.00
7.44	36.28	126.00	212.00	22.40
10.48	47.26	97.00	208.00	21.00
13.52	46.74	114.00	216.00	18.00
16.56	36.99	83.00	132.00	16.00
19.60	38.67	68.00	192.00	20.40
22.64	30.38	58.00	188.00	12.00
25.68	30.38	49.00	166.00	10.00
28.72	31.51	44.00	152.00	11.20
31.76	27.80	42.00	144.00	9.40
34.80	25.63	40.00	112.00	13.80
37.84	29.54	42.00	108.00	10.00
40.88	42.97	46.00	104.00	9.10
43.92	58.27	56.00	108.00	8.00
46.96	67.52	68.00	104.00	6.80
50.00	81.80	60.00	108.00	7.00
53.04	47.26	52.00	168.00	6.50
56.08	45.25	44.00	116.00	6.20
59.12	50.04	38.00	112.00	6.20
62.16	85.08	35.00	112.00	5.90
65.20	77.34	62.00	104.00	6.50
68.24	52.52	45.00	112.00	5.90
71.28	55.97	47.00	156.00	5.90
74.32	42.54	25.00	116.00	7.40
77.36	41.70	68.00	184.00	7.70
80.40	35.45	24.00	120.00	6.50
83.44	34.03	22.00	92.00	5.90
86.48	31.51	22.00	50.00	7.70
89.52	28.94	17.00	20.00	6.20
92.56	29.54	18.00	18.00	6.50
95.60	55.97	50.00	13.00	5.90
98.64	50.64	52.00	20.00	6.20

STORM RUNOFF DATA

STORM OF THE 15TH JUNE 1978

(CONTINUED)

T(MINS)	Q(L/S)	SS(MG/L)	DS(MG/L)	CA(MG/L)
101.68	49.46	41.00	28.00	7.70
104.72	40.51	54.00	26.00	5.30
107.76	29.54	8.00	22.00	5.90
110.80	23.24	5.00	14.00	5.90
113.84	17.36	3.00	20.00	6.80
116.88	18.10	6.00	27.00	7.00
119.92	6.64	4.10	27.00	7.00
122.96	2.43	3.40	27.00	7.00
126.00	0.89	3.15	27.00	7.00
129.04	0.33	3.05	27.00	7.00
MEAN VALUES FLOW WEIGHTED	37.41	51.37	109.74	8.97

T(MINS)	BOD(MG/L)	COD(MG/L)	NO3(MG/L)	NH4(MG/L)
1.19	15.50	133.00	32.10	1.20
4.40	11.20	120.00	22.80	1.80
7.44	10.10	92.00	22.00	1.60
10.48	9.00	69.80	23.80	1.30
13.52	9.00	75.00	21.60	1.40
16.56	9.20	50.90	13.20	1.70
19.60	8.80	50.00	13.00	1.50
22.64	8.40	50.00	12.60	1.40
25.68	7.00	36.00	12.10	1.30
28.72	6.20	28.00	11.60	1.10
31.76	6.50	28.00	11.50	1.20
34.80	7.10	26.00	12.00	1.10
37.84	7.00	27.60	11.50	0.95
40.88	6.70	34.00	9.30	0.85
43.92	6.20	38.00	7.80	0.70
46.96	5.60	42.00	6.90	0.61
50.00	5.30	38.20	6.60	0.65
53.04	4.90	38.00	6.10	0.64
56.08	4.50	32.20	5.80	0.65
59.12	4.10	23.00	5.20	0.67
62.16	4.60	26.00	4.80	0.68
65.20	5.40	31.00	4.70	0.70
68.24	5.20	22.00	4.60	0.66
71.28	4.30	15.00	4.40	0.56
74.32	4.00	19.00	4.60	0.54
77.36	3.40	21.00	4.80	0.53
80.40	3.60	20.00	4.70	0.51

STORM RUNOFF DATA

STORM OF THE 15TH JUNE 1978 (CONTINUED)

T(MINS)	BOD(MG/L)	COD(MG/L)	NO3(MG/L)	NH4(MG/L)
83.44	5.80	16.00	4.60	0.49
86.48	3.80	12.00	4.60	0.53
89.52	2.60	11.00	4.40	0.57
92.56	4.30	22.00	4.40	0.46
95.60	5.60	27.00	4.50	0.31
98.64	5.00	30.00	4.40	0.36
101.68	4.70	34.00	4.30	0.37
104.72	6.50	26.00	4.80	0.37
107.76	5.40	20.00	4.60	0.36
110.80	5.20	16.00	4.10	0.34
113.84	4.80	12.00	4.60	0.30
116.88	4.30	6.00	4.80	0.28
119.92	1.77	5.37	4.80	0.28
122.96	0.84	5.13	4.80	0.28
126.00	0.50	5.05	4.80	0.28
129.04	0.37	5.02	4.80	0.28
MEAN VALUES FLOW WEIGHTED	5.77	33.65	8.02	0.76

CUMULATIVE PARAMETER LOADINGS

T(MINS)	Q(CU.M)	SS(KG)	DS(KG)	CA(KG)
1.195	0.574	0.102	0.128	0.015
4.400	2.218	0.381	0.484	0.057
7.440	6.362	0.946	1.357	0.152
10.480	13.981	1.786	2.956	0.317
13.520	22.555	2.690	4.774	0.484
16.560	30.191	3.452	6.128	0.615
19.600	37.092	3.972	7.249	0.741
22.640	43.389	4.371	8.446	0.845
25.680	48.931	4.668	9.427	0.906
28.720	54.576	4.930	10.324	0.966
31.760	59.985	5.163	11.126	1.021
34.800	64.858	5.363	11.751	1.078
37.840	69.889	5.569	12.304	1.137
40.880	76.502	5.862	13.004	1.200
43.920	85.734	6.337	13.984	1.278
46.960	97.206	7.052	15.199	1.363
50.000	110.825	7.920	16.644	1.457

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                         STORM RUNOFF DATA
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      STORM OF THE  15TH JUNE 1978
      ============================               (CONTINUED)


           T(MINS)     Q(CU.M)      SS(KG)       DS(KG)      CA(KG)

           53.040     122.596       8.588       18.205       1.537
           56.080     131.033       8.993       19.406       1.591
           59.120     139.724       9.349       20.396       1.644
           62.160     152.047       9.795       21.776       1.719
           65.200     166.859      10.507       23.378       1.810
           68.240     178.702      11.154       24.651       1.884
           71.280     188.596      11.609       25.981       1.943
           74.320     197.580      11.942       27.220       2.002
           77.360     205.263      12.298       28.371       2.060
           80.400     212.299      12.630       29.452       2.110
           83.440     218.635      12.776       30.125       2.149
           86.480     224.613      12.908       30.553       2.190
           89.520     230.125      13.015       30.748       2.228
           92.560     235.458      13.109       30.850       2.262
           95.600     243.257      13.400       30.966       2.310
           98.640     252.980      13.896       31.126       2.369
          101.680     262.109      14.320       31.344       2.432
          104.720     270.315      14.707       31.567       2.486
          107.760     276.704      14.920       31.721       2.522
          110.800     281.517      14.952       31.809       2.550
          113.840     285.221      14.967       31.871       2.573
          116.880     288.455      14.982       31.947       2.596
          119.920     290.711      14.994       32.008       2.611
          122.960     291.539      14.997       32.031       2.617
          126.000     291.842      14.998       32.039       2.619
          129.040     291.953      14.999       32.042       2.620


      TOTAL LOADINGS  291.973      14.999       32.042       2.620


           T(MINS)     BOD(KG)     COD(KG)     NO3(KG)     NH4(KG)

             1.195       0.009       0.076       0.018       0.001
             4.400       0.031       0.284       0.064       0.003
             7.440       0.074       0.700       0.156       0.010
            10.480       0.146       1.309       0.331       0.021
            13.520       0.224       1.930       0.525       0.033
            16.560       0.293       2.418       0.661       0.041
            19.600       0.355       2.766       0.751       0.055
            22.640       0.409       3.081       0.832       0.064
            25.680       0.452       3.319       0.900       0.072
            28.720       0.489       3.499       0.967       0.079
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STORM RUNOFF DATA

STORM OF THE 15TH JUNE 1978

(CONTINUED)

T(MINS)	BOD(KG)	COD(KG)	NO3(KG)	NH4(KG)
31.760	0.524	3.651	1.030	0.085
34.800	0.557	3.782	1.087	0.091
37.840	0.592	3.917	1.146	0.096
40.880	0.637	4.124	1.214	0.102
43.920	0.697	4.458	1.292	0.109
46.960	0.764	4.918	1.376	0.116
50.000	0.838	5.462	1.468	0.125
53.040	0.899	5.911	1.543	0.132
56.080	0.938	6.208	1.594	0.138
59.120	0.976	6.446	1.641	0.144
62.160	1.030	6.751	1.702	0.152
65.200	1.104	7.172	1.773	0.162
68.240	1.166	7.493	1.828	0.170
71.280	1.212	7.675	1.872	0.176
74.320	1.249	7.826	1.913	0.181
77.360	1.277	7.980	1.949	0.185
80.400	1.302	8.124	1.982	0.189
83.440	1.332	8.239	2.012	0.192
86.480	1.361	8.323	2.039	0.195
89.520	1.378	8.386	2.064	0.198
92.560	1.397	8.474	2.088	0.201
95.600	1.436	8.669	2.122	0.204
98.640	1.488	8.946	2.166	0.207
101.680	1.532	9.238	2.205	0.210
104.720	1.578	9.486	2.243	0.213
107.760	1.616	9.635	2.273	0.216
110.800	1.642	9.723	2.294	0.217
113.840	1.660	9.775	2.310	0.219
116.880	1.675	9.804	2.325	0.220
119.920	1.683	9.817	2.336	0.220
122.960	1.684	9.822	2.340	0.220
126.000	1.684	9.823	2.341	0.221
129.040	1.684	9.824	2.342	0.221
TOTAL LOADINGS	1.684	9.824	2.342	0.221

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                         STORM RUNOFF DATA
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STORM OF THE  29TH JUNE 1978
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          TIME SAMPLING COMMENCED    0.19
          SAMPLING DURATION(MINS)  32.79
          DOSER CONCENTRATION(G/L)  40.50
          DOSE RATE(ML/MIN)    1.03

MEASURED PARAMETER CONCENTRATIONS
=================================

          T(MINS)    Q(L/S)     SS(MG/L)  DS(MG/L)  CA(MG/L)

            1.19       8.00      40.00     120.00     16.00
            4.40      10.36      33.00     102.00     13.20
            7.44      13.25      28.00      56.00     11.60
           10.48      21.29      27.00      96.00     12.20
           13.52      30.52      21.00      28.00      9.40
           16.56      24.42      23.00      20.00      9.40
           19.60      25.16      12.00      36.00      9.70
           22.64       9.23       6.30      36.00      9.70
           25.68       3.38       4.21      36.00      9.70
           28.72       1.24       3.44      36.00      9.70
           31.76       0.45       3.16      36.00      9.70

MEAN VALUES
FLOW WEIGHTED          13.61      21.62      51.41     10.71


           T(MINS)    BOD(MG/L) COD(MG/L) NO3(MG/L)   NH4(MG/L)

            1.19       9.70      98.30      10.00      0.70
            4.40       8.20     102.70       7.40      0.62
            7.44       6.50     107.00       5.40      0.58
           10.48       4.70      94.00       5.70      0.59
           13.52       6.20      86.00       4.60      0.54
           16.56       6.50      99.00       4.30      0.53
           19.60       4.70      79.00       3.80      0.53
           22.64       1.91      32.14       3.80      0.53
           25.68       0.89      14.95       3.80      0.53
           28.72       0.52       8.65       3.80      0.53
           31.76       0.38       6.34       3.80      0.53

MEAN VALUES
FLOW WEIGHTED           5.65      85.61       5.05      0.56
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STORM RUNOFF DATA

STORM OF THE 29TH JUNE 1978

(CONTINUED)

CUMULATIVE PARAMETER LOADINGS

T(MINS)	Q(CU.M)	SS(KG)	DS(KG)	CA(KG)
1.195	0.574	0.023	0.069	0.009
4.400	2.327	0.087	0.263	0.035
7.440	4.480	0.152	0.429	0.061
10.480	7.629	0.238	0.678	0.099
13.520	12.355	0.350	0.952	0.149
16.560	17.366	0.460	1.073	0.196
19.600	21.887	0.539	1.200	0.239
22.640	25.023	0.570	1.313	0.270
25.680	26.173	0.577	1.355	0.281
28.720	26.595	0.578	1.370	0.285
31.760	26.749	0.579	1.375	0.287
TOTAL LOADINGS	26.777	0.579	1.376	0.287

T(MINS)	BOD(KG)	COD(KG)	NO3(KG)	NH4(KG)
1.195	0.006	0.056	0.006	0.000
4.400	0.021	0.233	0.021	0.002
7.440	0.037	0.459	0.035	0.003
10.480	0.054	0.772	0.052	0.005
13.520	0.080	1.195	0.076	0.007
16.560	0.112	1.656	0.098	0.010
19.600	0.137	2.058	0.117	0.012
22.640	0.149	2.255	0.129	0.014
25.680	0.151	2.286	0.133	0.015
28.720	0.151	2.291	0.135	0.015
31.760	0.151	2.292	0.135	0.015
TOTAL LOADINGS	0.151	2.292	0.135	0.015

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                    STORM RUNOFF DATA
                    =================


STORM OF THE  1ST JULY 1978
===========================

          TIME SAMPLING COMMENCED  12.11
          SAMPLING DURATION(MINS)  29.75
          DOSER CONCENTRATION(G/L)  40.50
          DOSE RATE(ML/MIN)    0.38


MEASURED PARAMETER CONCENTRATIONS
=================================

          T(MINS)    Q(L/S)     SS(MG/L)  DS(MG/L)  CA(MG/L)

            1.19       8.00      39.00     56.00     15.70
            4.40       8.99      60.00     52.00     11.70
            7.44       9.44      27.00     64.00      9.40
           10.48      29.34      20.00     80.00     13.30
           13.52      20.74      25.00     88.00     12.20
           16.56      10.23      21.00     52.00     11.10
           19.60       3.75       9.60     52.00     11.10
           22.64       1.38       5.42     52.00     11.10
           25.68       0.50       3.89     52.00     11.10
           28.72       0.19       3.33     52.00     11.10

MEAN VALUES
FLOW WEIGHTED          9.41      26.71     70.03     12.23


          T(MINS)    BOD(MG/L) COD(MG/L) NO3(MG/L)   NH4(MG/L)

            1.19       3.00      34.00      7.50      0.34
            4.40       8.40      48.00      7.30      0.23
            7.44       2.80      51.00      6.70      0.22
           10.48       2.40      28.00      5.70      0.21
           13.52       0.20      53.00      6.00      0.25
           16.56       3.20      29.00      5.10      0.23
           19.60       1.36      13.80      5.10      0.23
           22.64       0.69       8.23      5.10      0.23
           25.68       0.44       6.18      5.10      0.23
           28.72       0.35       5.43      5.10      0.23

MEAN VALUES
FLOW WEIGHTED          2.59      37.77      6.08      0.24
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                         STORM RUNOFF DATA
                         =================


STORM OF THE  1ST JULY 1978
===========================                        (CONTINUED)


CUMULATIVE PARAMETER LOADINGS
=============================

          T(MINS)    Q(CU.M)    SS(KG)     DS(KG)     CA(KG)

           1.195      0.574      0.022      0.032      0.009
           4.400      2.202      0.103      0.120      0.031
           7.440      3.882      0.175      0.218      0.049
          10.480      7.419      0.254      0.482      0.092
          13.520     11.986      0.356      0.864      0.150
          16.560     14.810      0.422      1.073      0.183
          19.600     16.086      0.444      1.139      0.198
          22.640     16.553      0.448      1.164      0.203
          25.680     16.725      0.448      1.173      0.205
          28.720     16.788      0.449      1.176      0.205


TOTAL LOADINGS       16.799      0.449      1.177      0.205

          T(MINS)    BOD(KG)    COD(KG)    NO3(KG)    NH4(KG)

           1.195      0.002      0.020      0.004      0.000
           4.400      0.011      0.086      0.016      0.001
           7.440      0.020      0.169      0.028      0.001
          10.480      0.029      0.295      0.049      0.002
          13.520      0.036      0.473      0.076      0.003
          16.560      0.040      0.597      0.092      0.004
          19.600      0.043      0.627      0.099      0.004
          22.640      0.043      0.633      0.101      0.004
          25.680      0.043      0.634      0.102      0.004
          28.720      0.044      0.634      0.102      0.004


TOTAL LOADINGS        0.044      0.634      0.102      0.004
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                              STORM RUNOFF DATA
                              =================


      STORM OF THE  3RD JULY 1978
      ===========================

              TIME SAMPLING COMMENCED    14.27
              SAMPLING DURATION(MINS)    41.91
              DOSER CONCENTRATION(G/L)    40.50
              DOSE RATE(ML/MIN)      0.11


      MEASURED PARAMETER CONCENTRATIONS
      =================================

              T(MINS)     Q(L/S)      SS(MG/L)    DS(MG/L)    CA(MG/L)

                 1.19       8.00      201.00      232.00       17.60
                 4.40       9.43      158.00       72.20       12.80
                 7.44      28.45      123.00       98.50       13.50
                10.48      35.78      132.00       82.40        8.00
                13.52      22.59       92.00      102.40        8.30
                16.56      18.67       87.00      148.00        8.80
                19.60      13.85       72.00      156.00       11.40
                22.64       9.13       33.00      160.00       11.00
                25.68      21.46       57.00      168.00        8.50
                28.72      21.46       40.00      128.00        7.00
                31.76       7.87       16.57      128.00        7.00
                34.80       2.89        7.98      128.00        7.00
                37.84       1.06        4.82      128.00        7.00
                40.88       0.39        3.67      128.00        7.00

      MEAN VALUES
      FLOW WEIGHTED        14.55       91.81      123.74        9.77



              T(MINS)     BOD(MG/L) COD(MG/L) HC3(MG/L)    NH4(MG/L)

                 1.19       7.50       89.00        6.70        0.27
                 4.40       8.60       72.20        6.00        0.16
                 7.44       8.60       98.50        5.50        0.28
                10.48       7.30       82.40        4.30        0.19
                13.52       3.20      102.40        4.20        0.36
                16.56       4.50       74.10        4.60        0.23
                19.60       4.30       49.80        4.10        0.23
                22.64       4.70       22.40        4.60        0.29
                25.68       4.90       37.10        3.50        0.26
                28.72       2.60       28.80        3.80        0.17
                31.76       1.14       13.73        3.80        0.17
                34.80       0.61        8.20        3.80        0.17
                37.84       0.41        6.17        3.80        0.17
```

STORM RUNOFF DATA

STORM OF THE 3RD JULY 1978

(CONTINUED)

	T(MINS)	BOD(MG/L)	COD(MG/L)	NO3(MG/L)	NH4(MG/L)
	40.88	0.34	5.43	3.80	0.17
MEAN VALUES FLOW WEIGHTED		5.33	65.72	4.50	0.24

CUMULATIVE PARAMETER LOADINGS

	T(MINS)	Q(CU.M)	SS(KG)	DS(KG)	CA(KG)
	1.195	0.574	0.115	0.133	0.010
	4.400	2.242	0.415	0.386	0.035
	7.440	5.697	0.879	0.696	0.081
	10.480	11.554	1.628	1.223	0.143
	13.520	16.877	2.241	1.706	0.186
	16.560	20.640	2.578	2.172	0.218
	19.600	23.605	2.816	2.621	0.248
	22.640	25.701	2.932	2.952	0.271
	25.680	28.492	3.067	3.413	0.298
	28.720	32.407	3.256	3.992	0.328
	31.760	35.083	3.342	4.335	0.347
	34.800	36.064	3.355	4.460	0.354
	37.840	36.423	3.358	4.506	0.356
	40.880	36.555	3.358	4.523	0.357
TOTAL LOADINGS		36.579	3.358	4.526	0.357

T(MINS)	BOD(KG)	COD(KG)	NO3(KG)	NH4(KG)
1.195	0.004	0.051	0.004	0.000
4.400	0.018	0.185	0.014	0.001
7.440	0.047	0.496	0.034	0.001
10.480	0.094	1.022	0.062	0.003
13.520	0.123	1.506	0.085	0.004
16.560	0.138	1.841	0.102	0.005
19.600	0.151	2.028	0.115	0.006
22.640	0.160	2.103	0.124	0.006
25.680	0.174	2.197	0.135	0.007
28.720	0.186	2.326	0.149	0.008
31.760	0.194	2.399	0.159	[illegible]
34.800	0.195	2.401	0.163	0.009

STORM RUNOFF DATA

STORM OF THE 3RD JULY 1978

(CONTINUED)

T(MINS)	BOD(KG)	COD(KG)	NO3(KG)	NH4(KG)
37.840	0.195	2.403	0.164	0.009
40.880	0.195	2.404	0.165	0.209
TOTAL LOADINGS	0.195	2.404	0.165	0.209

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                         STORM RUNOFF DATA
                         =================


     STORM OF THE  19TH JULY 1978
     ============================

               TIME SAMPLING COMMENCED  19.58
               SAMPLING DURATION(MINS)  29.75
               DOSER CONCENTRATION(G/L)  43.60
               DOSE RATE(ML/MIN)   0.99


     MEASURED PARAMETER CONCENTRATIONS
     =================================

               T(MINS)   Q(L/S)    SS(MG/L)  DS(MG/L)  CA(MG/L)

                  1.19     8.00     44.00    170.00     23.60
                  4.40    12.84     64.00    165.00     20.20
                  7.44    10.83     40.00    164.00     18.60
                 10.48    12.57     25.00    145.00     16.00
                 13.52    23.51     22.00    110.00     14.40
                 16.56    21.63     24.00    122.00     15.40
                 19.60     7.93     10.70    122.00     15.40
                 22.64     2.91      5.82    122.00     15.40
                 25.68     1.07      4.04    122.00     15.40
                 28.72     0.39      3.38    122.00     15.40

     MEAN VALUES
     FLOW WEIGHTED        10.34     29.87    135.98     16.84


                T(MINS)   BOD(MG/L) COD(MG/L) NO3(MG/L)   NH4(MG/L)

                  1.19    14.20     66.70     11.80      1.30
                  4.40    10.80     39.80     11.00      1.70
                  7.44     7.30     39.90     10.70      2.00
                 10.48     8.20     28.90      8.40      1.10
                 13.52     6.50     28.90      8.20      0.95
                 16.56     6.50     27.90      8.10      0.84
                 19.60     2.57     13.40      8.10      0.84
                 22.64     1.13      8.08      8.10      0.84
                 25.68     0.61      6.13      8.10      0.84
                 28.72     0.41      5.41      8.10      0.84

     MEAN VALUES
     FLOW WEIGHTED         7.35     31.88      9.09      1.17
```

STORM RUNOFF DATA

STORM OF THE 19TH JULY 1978

(CONTINUED)

CUMULATIVE PARAMETER LOADINGS

T(MINS)	Q(CU.M)	SS(KG)	DS(KG)	CA(KG)
1.195	0.574	0.025	0.098	0.014
4.400	2.553	0.134	0.429	0.057
7.440	4.711	0.248	0.784	0.098
10.480	6.846	0.317	1.112	0.135
13.520	10.136	0.393	1.520	0.185
16.560	14.252	0.487	1.997	0.246
19.600	16.948	0.540	2.326	0.288
22.640	17.936	0.549	2.446	0.303
25.680	18.299	0.551	2.491	0.308
28.720	18.432	0.551	2.507	0.310
TOTAL LOADINGS	18.456	0.551	2.510	0.311

T(MINS)	BOD(KG)	COD(KG)	NO3(KG)	NH4(KG)
1.195	0.008	0.038	0.007	0.001
4.400	0.033	0.141	0.029	0.004
7.440	0.052	0.227	0.053	0.008
10.480	0.069	0.300	0.073	0.011
13.520	0.092	0.395	0.100	0.014
16.560	0.119	0.512	0.134	0.018
19.600	0.133	0.573	0.156	0.020
22.640	0.135	0.585	0.164	0.021
25.680	0.136	0.588	0.167	0.021
28.720	0.136	0.588	0.168	0.022
TOTAL LOADINGS	0.136	0.588	0.168	0.022

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                              STORM RUNOFF DATA
                              =================

      STORM OF THE  23RD JULY 1978
      ============================

            TIME SAMPLING COMMENCED   19.53
            SAMPLING DURATION(MINS)   17.59
            DOSER CONCENTRATION(G/L)   43.60
            DOSE RATE(ML/MIN)    0.95

      MEASURED PARAMETER CONCENTRATIONS
      =================================

            T(MINS)     Q(L/S)      SS(MG/L)   DS(MG/L)   CA(MG/L)

              1.19       8.00        36.00     108.00       0.00
              4.40      15.16        68.00     107.00       0.00
              7.44       5.56        26.84     107.00       0.00
             10.48       2.04        11.74     107.00       0.00
             13.52       0.75         6.21     107.00       0.00
             16.56       0.27         4.18     107.00       0.00

      MEAN VALUES
      FLOW WEIGHTED          5.41        45.58     107.26       0.00


             T(MINS)    BOD(MG/L) COD(MG/L) NO3(MG/L)   NH4(MG/L)

              1.19      11.00      25.40       5.80       0.44
              4.40       9.90      29.30       5.00       0.40
              7.44       3.82      13.91       5.00       0.40
             10.48       1.59       8.27       5.00       0.40
             13.52       0.77       6.20       5.00       0.40
             16.56       0.47       5.44       5.00       0.40

      MEAN VALUES
      FLOW WEIGHTED      8.11      23.02       5.21       0.41

      CUMULATIVE PARAMETER LOADINGS
      =============================

            T(MINS)     Q(CU.M)     SS(KG)     DS(KG)    CA(KG)

             1.195      0.574      0.021      0.062      0.000
             4.400      2.765      0.140      0.297      0.000
             7.440      4.655      0.242      0.500      0.000
            10.480      5.347      0.257      0.574      0.000
            13.520      5.602      0.260      0.601      0.000
            16.560      5.695      0.260      0.611      0.000

      TOTAL LOADINGS      5.712      0.262      0.613      0.000
```

STORM RUNOFF DATA

STORM OF THE 23RD JULY 1978

(CONTINUED)

T(MINS)	BOD(KG)	COD(KG)	NO3(KG)	NH4(KG)
1.195	0.006	0.015	0.003	0.000
4.400	0.029	0.075	0.015	0.001
7.440	0.044	0.121	0.024	0.002
10.480	0.046	0.129	0.028	0.002
13.520	0.046	0.131	0.029	0.002
16.560	0.046	0.131	0.030	0.002
TOTAL LOADINGS	0.046	0.131	0.030	0.002

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                         STORM RUNOFF DATA
                         =================


          STORM OF THE  26TH JULY 1978
          ============================

               TIME SAMPLING COMMENCED    5.13
               SAMPLING DURATION(MINS)   44.95
               DOSER CONCENTRATION(G/L)   43.60
               DOSE RATE(ML/MIN)    0.95


          MEASURED PARAMETER CONCENTRATIONS
          =================================

               T(MINS)    Q(L/S)     SS(MG/L)   DS(MG/L)   CA(MG/L)

                 1.19       8.00       23.00     120.00       0.00
                 4.40      10.58       25.00     112.00       0.00
                 7.44      25.49       25.00     104.00       0.00
                10.48      23.80       24.00      97.00       0.00
                13.52      18.83       22.00     104.00       0.00
                16.56      17.85       15.00      91.00       0.00
                19.60      32.36       14.00      75.00       0.00
                22.64      35.40        3.00      73.00       0.00
                25.68      23.01       10.00      73.00       0.00
                28.72      20.20       10.00      75.00       0.00
                31.76      16.57       13.00      82.00       0.00
                34.80       6.08        6.67      82.00       0.00
                37.84       2.23        4.34      82.00       0.00
                40.88       0.82        3.49      82.00       0.00
                43.92       0.30        3.18      82.00       0.00

          MEAN VALUES
          FLOW WEIGHTED            16.30       14.91      87.14       0.00


                T(MINS)    BOD(MG/L) COD(MG/L) NO3(MG/L)    NH4(MG/L)

                  1.19       11.80      30.20      10.90        0.56
                  4.40       11.60      31.20      10.10        0.41
                  7.44        9.90      27.30       9.20        0.41
                 10.48        8.60      36.10       8.80        0.41
                 13.52        7.10      23.40       8.30        0.50
                 16.56        6.90      11.70       7.50        0.46
                 19.60        7.30      17.60       6.20        0.30
                 22.64        2.20      15.00       5.40        0.28
                 25.68        4.70      15.00       5.30        0.28
                 28.72        4.90       6.80       4.60        0.24
                 31.76        4.30       8.00       4.70        0.22
                 34.80        1.77       6.10       4.70        0.22
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STORM RUNOFF DATA

STORM OF THE 26TH JULY 1978

(CONTINUED)

T(MINS)	BOD(MG/L)	COD(MG/L)	NO3(MG/L)	NH4(MG/L)
37.84	0.84	5.40	4.70	0.22
40.88	0.50	5.15	4.70	0.22
43.92	0.37	5.05	4.70	0.22
MEAN VALUES FLOW WEIGHTED	6.36	18.77	6.86	0.35

CUMULATIVE PARAMETER LOADINGS

T(MINS)	Q(CU.M)	SS(KG)	DS(KG)	CA(KG)
1.195	0.574	0.013	0.069	0.000
4.400	2.347	0.056	0.274	0.000
7.440	5.636	0.138	0.626	0.000
10.480	10.132	0.248	1.078	0.000
13.520	14.020	0.338	1.468	0.000
16.560	17.365	0.400	1.794	0.000
19.600	21.944	0.466	2.167	0.000
22.640	28.124	0.518	2.624	0.000
25.680	33.451	0.549	3.013	0.000
28.720	37.393	0.589	3.305	0.000
31.760	40.746	0.627	3.567	0.000
34.800	42.811	0.649	3.736	0.000
37.840	43.569	0.654	3.798	0.000
40.880	43.846	0.655	3.821	0.000
43.920	43.948	0.655	3.830	0.000
TOTAL LOADINGS	43.967	0.655	3.831	0.000

T(MINS)	BOD(KG)	COD(KG)	NO3(KG)	NH4(KG)
1.195	0.007	0.017	0.006	0.000
4.400	0.028	0.072	0.025	0.001
7.440	0.062	0.166	0.056	0.003
10.480	0.104	0.308	0.097	0.004
13.520	0.134	0.426	0.130	0.006
16.560	0.158	0.485	0.156	0.008
19.600	0.191	0.555	0.187	0.009
22.640	0.219	0.655	0.223	0.011
25.680	0.237	0.735	0.252	0.013

STORM RUNOFF DATA

STORM OF THE 26TH JULY 1978

(CONTINUED)

T(MINS)	BOD(KG)	COD(KG)	NO3(KG)	NH4(KG)
28.720	0.256	0.779	0.271	0.014
31.760	0.271	0.803	0.287	0.014
34.800	0.278	0.819	0.296	0.015
37.840	0.279	0.823	0.300	0.015
40.880	0.280	0.825	0.301	0.015
43.920	0.280	0.825	0.302	0.015
TOTAL LOADINGS	0.280	0.825	0.302	0.015

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                         STORM RUNOFF DATA
                         =================

     STORM OF THE  27TH JULY 1978
     ============================

          TIME SAMPLING COMMENCED  11.48
          SAMPLING DURATION(MINS)  23.67
          DOSER CONCENTRATION(G/L)  43.60
          DOSE RATE(ML/MIN)    1.03

     MEASURED PARAMETER CONCENTRATIONS
     =================================

          T(MINS)    Q(L/S)     SS(MG/L)   DS(MG/L)   CA(MG/L)

             1.19      8.00     882.00     164.00        0.00
             4.40     10.78     750.00     152.00        0.00
             7.44     17.82     259.00     120.00        0.00
            10.48     15.41     160.00     136.00        0.00
            13.52      5.65      60.57     136.00        0.00
            16.56      2.07      24.11     136.00        0.00
            19.60      0.76      10.74     136.00        0.00
            22.64      0.28       5.84     136.00        0.00

     MEAN VALUES
     FLOW WEIGHTED         7.75     372.30     138.05        0.00


           T(MINS)    BOD(MG/L) COD(MG/L) NO3(MG/L)   NH4(MG/L)

             1.19      0.00     504.00       5.40        0.00
             4.40      0.00     446.00       5.20        0.00
             7.44      0.00     161.00       6.10        0.00
            10.48      0.00     138.00       5.40        0.00
            13.52      0.00      53.77       5.40        0.00
            16.56      0.00      22.88       5.40        0.00
            19.60      0.00      11.56       5.40        0.00
            22.64      0.00       7.40       5.40        0.00

     MEAN VALUES
     FLOW WEIGHTED         0.00     233.47       5.56        0.00


     CUMULATIVE PARAMETER LOADINGS
     =============================

           T(MINS)    Q(CU.M)    SS(KG)     DS(KG)     CA(KG)

            1.195      0.574      0.506      0.094      0.000
            4.400      2.366      1.962      0.377      0.000
            7.440      4.975      3.172      0.725      0.000
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                         STORM RUNOFF DATA
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   STORM OF THE  27TH JULY 1978
   ============================                (CONTINUED)

             T(MINS)    Q(CU.M)    SS(KG)     DS(KG)     CA(KG)

             10.480      8.006      3.814      1.111      0.000
             13.520      9.927      4.056      1.373      0.000
             16.560     10.631      4.090      1.468      0.000
             19.600     10.890      4.095      1.504      0.000
             22.640     10.984      4.096      1.516      0.000

   TOTAL LOADINGS       11.001      4.096      1.519      0.000

             T(MINS)    BOD(KG)    COD(KG)    NO3(KG)    NH4(KG)

              1.195      0.000      0.289      0.003      0.000
              4.400      0.000      1.138      0.013      0.000
              7.440      0.000      1.868      0.028      0.000
             10.480      0.000      2.322      0.045      0.000
             13.520      0.000      2.532      0.055      0.000
             16.560      0.000      2.562      0.059      0.000
             19.600      0.000      2.567      0.061      0.000
             22.640      0.000      2.568      0.061      0.000

   TOTAL LOADINGS        0.000      2.568      0.061      0.000
```

STORM RUNOFF DATA

STORM OF THE 30TH JULY 1978

TIME SAMPLING COMMENCED 7.00
SAMPLING DURATION(MINS) 17.59
DOSER CONCENTRATION(G/L) 43.60
DOSE RATE(ML/MIN) 1.03

MEASURED PARAMETER CONCENTRATIONS

T(MINS)	Q(L/S)	SS(MG/L)	DS(MG/L)	CA(MG/L)
1.19	8.00	42.00	116.00	0.00
4.40	11.41	37.00	108.00	0.00
7.44	4.18	15.47	108.00	0.00
10.48	1.53	7.57	108.00	0.00
13.52	0.56	4.68	108.00	0.00
16.56	0.21	3.61	108.00	0.00
MEAN VALUES FLOW WEIGHTED	4.40	31.72	110.47	0.00

T(MINS)	BOD(MG/L)	COD(MG/L)	NO3(MG/L)	NH4(MG/L)
1.19	0.00	46.70	6.50	0.00
4.40	0.00	44.00	6.60	0.00
7.44	0.00	19.30	6.60	0.00
10.48	0.00	10.24	6.60	0.00
13.52	0.00	6.92	6.60	0.03
16.56	0.00	5.71	6.60	0.00
MEAN VALUES FLOW WEIGHTED	0.00	37.00	6.57	0.00

CUMULATIVE PARAMETER LOADINGS

T(MINS)	Q(CU.M)	SS(KG)	DS(KG)	CA(KG)
1.195	0.574	0.024	0.067	0.000
4.400	2.423	0.097	0.273	0.000
7.440	3.846	0.139	0.427	0.000
10.480	4.367	0.146	0.483	0.000
13.520	4.558	0.147	0.504	0.000
16.560	4.629	0.147	0.511	0.000
TOTAL LOADINGS	4.641	0.147	0.513	0.000

STORM RUNOFF DATA

STORM OF THE 30TH JULY 1978

(CONTINUED)

T(MINS)	BOD(KG)	COD(KG)	NO3(KG)	NH4(KG)
1.195	0.000	0.027	0.004	0.000
4.400	0.000	0.110	0.016	0.000
7.440	0.000	0.161	0.025	0.000
10.480	0.000	0.169	0.029	0.000
13.520	0.000	0.171	0.030	0.000
16.560	0.000	0.172	0.030	0.000
TOTAL LOADINGS	0.000	0.172	0.030	0.000

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                    STORM RUNOFF DATA
                    -----------------


STORM OF THE  30TH JULY 1978
----------------------------

         TIME SAMPLING COMMENCED    6.00
         SAMPLING DURATION(MINS)  23.67
         DOSER CONCENTRATION(G/L)  43.60
         DOSE RATE(ML/MIN)    1.03


MEASURED PARAMETER CONCENTRATIONS
---------------------------------

         T(MINS)    Q(L/S)     SS(MG/L)  DS(MG/L)  CA(MG/L)

           1.19       8.00       92.00    200.00      0.00
           4.40      12.27      279.00    188.00      0.00
           7.44      19.54      144.00    177.00      0.00
          10.48      17.66       75.00    174.00      0.00
          13.52       6.48       29.40    174.00      0.00
          16.56       2.38       12.68    174.00      0.00
          19.60       0.87        6.55    174.00      0.00
          22.64       0.32        4.30    174.00      0.00

MEAN VALUES
FLOW WEIGHTED         8.61      125.93    180.53      0.00


          T(MINS)   BOD(MG/L) COD(MG/L) NO3(MG/L)   NH4(MG/L)

           1.19       0.00      143.00     12.50      0.00
           4.40       0.00      147.00     10.00      0.00
           7.44       0.00      107.00      9.60      0.00
          10.48       0.00       94.00      9.60      0.00
          13.52       0.00       37.64      9.60      0.00
          16.56       0.00       16.97      9.60      0.00
          19.60       0.00        9.39      9.60      0.00
          22.64       0.00        6.61      9.60      0.00

MEAN VALUES
FLOW WEIGHTED         0.00      102.83     10.02      0.00


CUMULATIVE PARAMETER LOADINGS
-----------------------------

         T(MINS)    Q(CU.M)    SS(KG)     DS(KG)    CA(KG)

          1.195      0.574      0.053      0.115     0.000
          4.400      2.501      0.425      0.488     0.000
          7.440      5.402      1.011      1.015     0.000
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                         STORM RUNOFF DATA
                         -----------------

     STORM OF THE  30TH JULY 1978
     ----------------------------               (CONTINUED)

              T(MINS)    Q(CU.M)    SS(KG)     DS(KG)     CA(KG)

              10.480      8.796      1.386      1.610      0.000
              13.520     10.997      1.517      1.993      0.000
              16.560     11.805      1.536      2.134      0.000
              19.600     12.101      1.539      2.185      0.000
              22.640     12.209      1.540      2.204      0.000

     TOTAL LOADINGS      12.229      1.540      2.208      0.000

              T(MINS)    BOD(KG)    COD(KG)    NO3(KG)    NH4(KG)

               1.195      0.000      0.082      0.007      0.000
               4.400      0.000      0.362      0.029      0.000
               7.440      0.000      0.721      0.057      0.000
              10.480      0.000      1.063      0.090      0.000
              13.520      0.000      1.229      0.111      0.000
              16.560      0.000      1.252      0.118      0.000
              19.600      0.000      1.256      0.121      0.000
              22.640      0.000      1.257      0.122      0.000

     TOTAL LOADINGS       0.000      1.257      0.123      0.000
```

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                        STORM RUNOFF DATA
                        =================


        STORM OF THE  30TH JULY 1978
        ============================

               TIME SAMPLING COMMENCED    8.00
               SAMPLING DURATION(MINS) 114.87
               DOSER CONCENTRATION(G/L)   43.60
               DOSE RATE(ML/MIN)    1.03


        MEASURED PARAMETER CONCENTRATIONS
        =================================

               T(MINS)    Q(L/S)     SS(MG/L)  DS(MG/L)  CA(MG/L)

                  1.19      8.00      30.00     72.00      0.00
                  4.40      9.81      39.00    100.00      0.00
                  7.44     11.32      24.00    140.00      0.00
                 10.48     13.75      22.00    116.00      0.00
                 13.52     19.02      59.00    112.00      0.00
                 16.56     26.29     323.00     88.00      0.00
                 19.60     66.70     279.00     76.00      0.00
                 22.64     61.22     138.00     72.00      0.00
                 25.68     84.32     130.00     52.00      0.00
                 28.72    106.40     171.00     72.00      0.00
                 31.76     93.10     128.00     44.00      0.00
                 34.80    101.57      72.00     27.00      0.00
                 37.84     93.10      59.00     60.00      0.00
                 40.88     59.59      52.00     60.00      0.00
                 43.92     27.93      44.00     76.00      0.00
                 46.96     18.24      28.00     87.00      0.00
                 50.00     13.97      21.00    100.00      0.00
                 53.04     14.90      24.00    104.00      0.00
                 56.08     25.54      29.00    116.00      0.00
                 59.12     44.69      31.00     72.00      0.00
                 62.16     34.38      40.00     60.00      0.00
                 65.20     20.79      28.00     60.00      0.00
                 68.24     14.65      18.00     87.00      0.00
                 71.28     12.95      26.00    116.00      0.00
                 74.32     59.59      36.00    120.00      0.00
                 77.36     48.05      49.00     56.00      0.00
                 80.40     33.10      31.00     60.00      0.00
                 83.44     23.04      29.00     72.00      0.00
                 86.48     22.01      21.00     74.00      0.00
                 89.52     21.80      11.00     68.00      0.00
                 92.56     31.92      15.00     80.00      0.00
                 95.60     38.86      12.00     80.00      0.00
                 98.64     31.92      11.00     88.00      0.00
```

STORM RUNOFF DATA

STORM OF THE 30TH JULY 1978

(CONTINUED)

T(MINS)	Q(L/S)	SS(MG/L)	DS(MG/L)	CA(MG/L)
101.68	11.71	5.93	88.00	0.00
104.72	4.29	4.08	88.00	0.00
107.76	1.57	3.39	88.00	0.00
110.80	0.58	3.14	88.00	0.00
113.84	0.21	3.05	88.00	0.00
MEAN VALUES FLOW WEIGHTED	34.68	84.38	70.50	0.00

T(MINS)	BOD(MG/L)	COD(MG/L)	NO3(MG/L)	NH4(MG/L)
1.19	0.00	42.00	5.20	0.00
4.40	0.00	58.10	5.30	0.00
7.44	0.00	57.00	5.30	0.00
10.48	0.00	56.20	5.30	0.00
13.52	0.00	84.60	5.00	0.00
16.56	0.00	254.00	5.50	0.00
19.60	0.00	170.00	4.90	0.00
22.64	0.00	178.00	4.10	0.00
25.68	0.00	129.00	3.80	0.00
28.72	0.00	156.00	3.70	0.00
31.76	0.00	85.00	3.30	0.00
34.80	0.00	75.00	2.80	0.00
37.84	0.00	57.20	3.50	0.00
40.88	0.00	48.60	3.20	0.00
43.92	0.00	42.00	3.20	0.00
46.96	0.00	31.00	3.30	0.00
50.00	0.00	27.20	3.60	0.00
53.04	0.00	30.50	3.40	0.00
56.08	0.00	32.40	3.70	0.00
59.12	0.00	15.20	3.80	0.00
62.16	0.00	35.30	3.80	0.00
65.20	0.00	25.70	3.80	0.00
68.24	0.00	18.00	4.30	0.00
71.28	0.00	41.90	4.00	0.00
74.32	0.00	38.20	4.20	0.00
77.36	0.00	30.50	3.90	0.00
80.40	0.00	21.50	3.30	0.00
83.44	0.00	5.70	4.70	0.00
86.48	0.00	15.80	4.00	0.00
89.52	0.00	13.30	4.00	0.00
92.56	0.00	17.70	4.20	0.00
95.60	0.00	30.50	5.20	0.00

STORM RUNOFF DATA

STORM OF THE 30TH JULY 1978

(CONTINUED)

T(MINS)	BOD(MG/L)	COD(MG/L)	NO3(MG/L)	NH4(MG/L)
98.64	0.00	18.10	4.40	0.00
101.68	0.00	9.80	4.40	0.00
104.72	0.00	6.76	4.40	0.00
107.76	0.00	5.65	4.40	0.00
110.80	0.00	5.24	4.40	0.00
113.84	0.00	5.09	4.40	0.00
MEAN VALUES FLOW WEIGHTED	0.00	75.13	3.88	0.00

CUMULATIVE PARAMETER LOADINGS

T(MINS)	Q(CU.M)	SS(KG)	DS(KG)	CA(KG)
1.195	0.574	0.017	0.041	0.000
4.400	2.277	0.076	0.188	0.000
7.440	4.205	0.136	0.421	0.000
10.480	6.492	0.189	0.712	0.000
13.520	9.480	0.316	1.052	0.000
16.560	13.612	1.164	1.460	0.000
19.600	22.093	3.662	2.141	0.000
22.640	33.759	6.118	3.005	0.000
25.680	47.032	7.950	3.813	0.000
28.720	64.427	10.660	4.905	0.000
31.760	82.622	13.398	5.972	0.000
34.800	100.376	15.159	6.598	0.000
37.840	118.130	16.325	7.362	0.000
40.880	132.056	17.105	8.197	0.000
43.920	140.037	17.496	8.724	0.000
46.960	144.248	17.652	9.064	0.000
50.000	147.185	17.725	9.337	0.000
53.040	149.818	17.784	9.606	0.000
56.080	153.505	17.884	10.015	0.000
59.120	159.910	18.077	10.591	0.000
62.160	167.121	18.330	11.071	0.000
65.200	172.152	18.506	11.373	0.000
68.240	175.384	18.583	11.605	0.000
71.280	177.961	18.637	11.859	0.000
74.320	184.517	18.857	12.646	0.000
77.360	194.334	19.270	13.532	0.000
80.400	201.735	19.574	13.960	0.000

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                              STORM RUNOFF DATA
                              =================

      STORM OF THE  30TH JULY 1978
      ============================                  (CONTINUED)

              T(MINS)     Q(CU.M)      SS(KG)       DS(KG)      CA(KG)

              83.440     206.855      19.728       14.294        0.000
              86.480     210.964      19.831       14.594        0.000
              89.520     214.960      19.895       14.878        0.000
              92.560     219.859      19.960       15.244        0.000
              95.600     226.315      20.047       15.760        0.000
              98.640     232.770      20.121       16.301        0.000
             101.680     236.749      20.158       16.651        0.000
             104.720     238.208      20.166       16.780        0.000
             107.760     238.743      20.168       16.827        0.000
             110.800     238.939      20.168       16.844        0.000
             113.840     239.011      20.169       16.850        0.000


      TOTAL LOADINGS     239.024      20.169       16.851        0.000

              T(MINS)     BOD(KG)     COD(KG)      NO3(KG)      NH4(KG)

               1.195       0.000       0.024        0.003        0.000
               4.400       0.000       0.110        0.012        0.000
               7.440       0.000       0.221        0.022        0.000
              10.480       0.000       0.350        0.034        0.000
              13.520       0.000       0.565        0.050        0.000
              16.560       0.000       1.302        0.071        0.000
              19.600       0.000       2.995        0.115        0.000
              22.640       0.000       5.024        0.167        0.000
              25.680       0.000       7.027        0.220        0.000
              28.720       0.000       9.524        0.285        0.000
              31.760       0.000      11.745        0.349        0.000
              34.800       0.000      13.163        0.403        0.000
              37.840       0.000      14.341        0.458        0.000
              40.880       0.000      15.087        0.505        0.000
              43.920       0.000      15.455        0.531        0.000
              46.960       0.000      15.612        0.545        0.000
              50.000       0.000      15.698        0.555        0.000
              53.040       0.000      15.774        0.564        0.000
              56.080       0.000      15.890        0.577        0.000
              59.120       0.000      16.033        0.601        0.000
              62.160       0.000      16.208        0.629        0.000
              65.200       0.000      16.366        0.648        0.000
              68.240       0.000      16.438        0.661        0.000
              71.280       0.000      16.512        0.671        0.000
              74.320       0.000      16.772        0.698        0.000
```

STORM RUNOFF DATA

STORM OF THE 30TH JULY 1978 (CONTINUED)

T(MINS)	BOD(KG)	COD(KG)	NO3(KG)	NH4(KG)
77.360	0.000	17.112	0.738	0.000
80.400	0.000	17.308	0.765	0.000
83.440	0.000	17.383	0.785	0.000
86.480	0.000	17.427	0.803	0.000
89.520	0.000	17.485	0.819	0.000
92.560	0.000	17.562	0.839	0.000
95.600	0.000	17.720	0.870	0.000
98.640	0.000	17.880	0.901	0.000
101.680	0.000	17.941	0.919	0.000
104.720	0.000	17.953	0.925	0.000
107.760	0.000	17.957	0.927	0.000
110.800	0.000	17.958	0.928	0.000
113.840	0.000	17.958	0.929	0.000
TOTAL LOADINGS	0.000	17.958	0.929	0.000

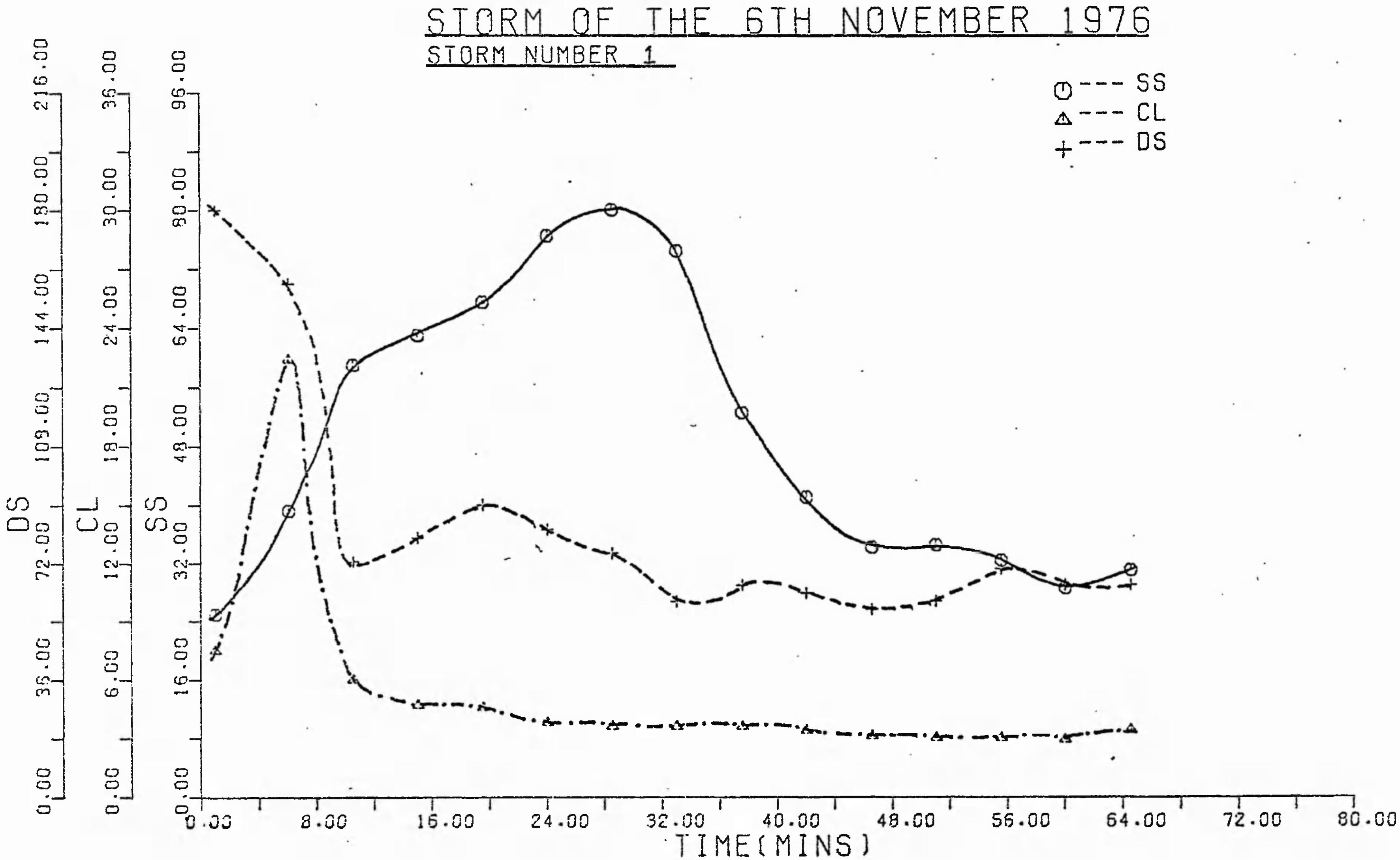
3.2. Storm Runoff Quality Data Graphs

Note:

Flow rate (Q) is in litres per second

All concentrations are in mg/l

Cumulative pollutant loads (e.g., C COD, C BOD) are expressed as percentages.

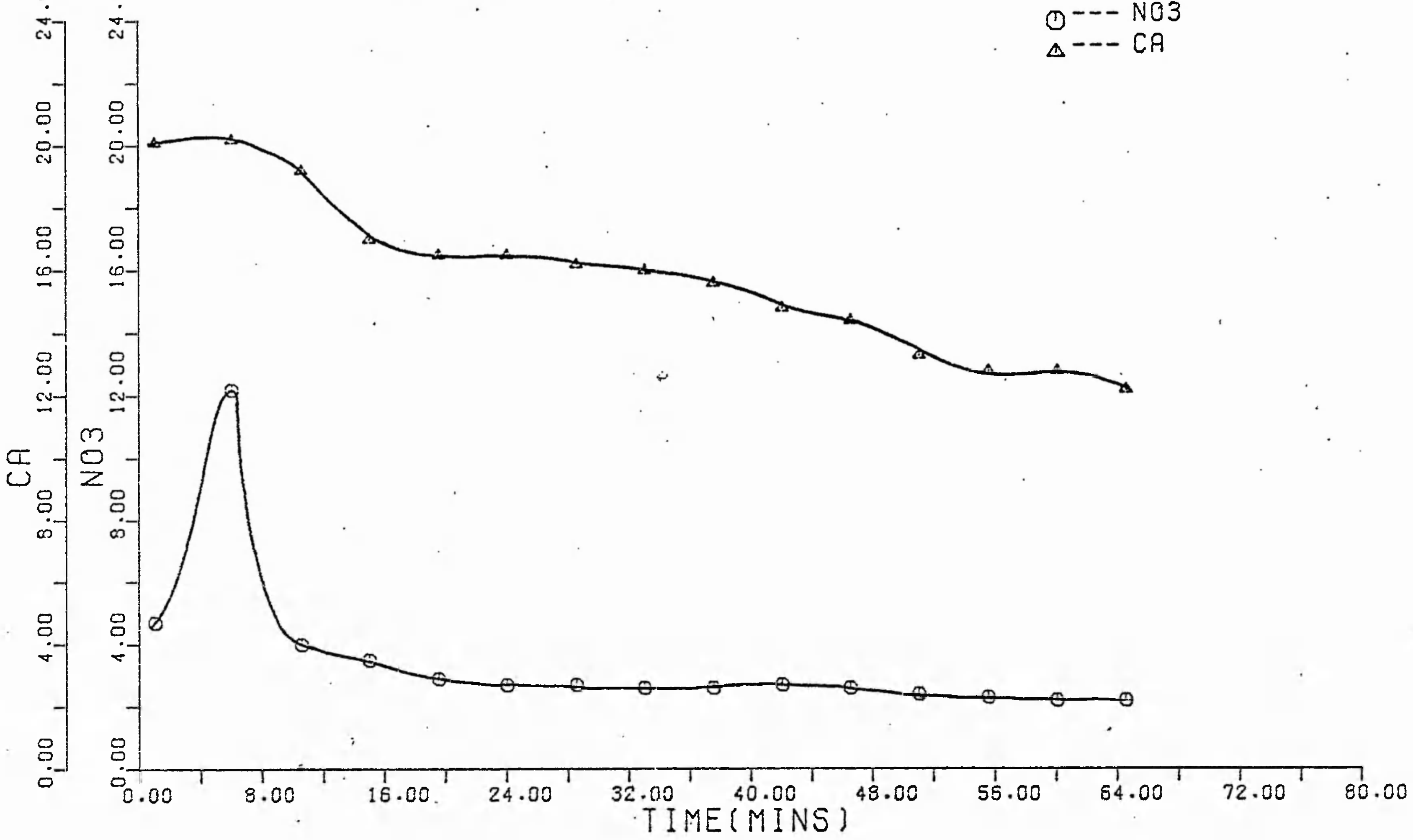


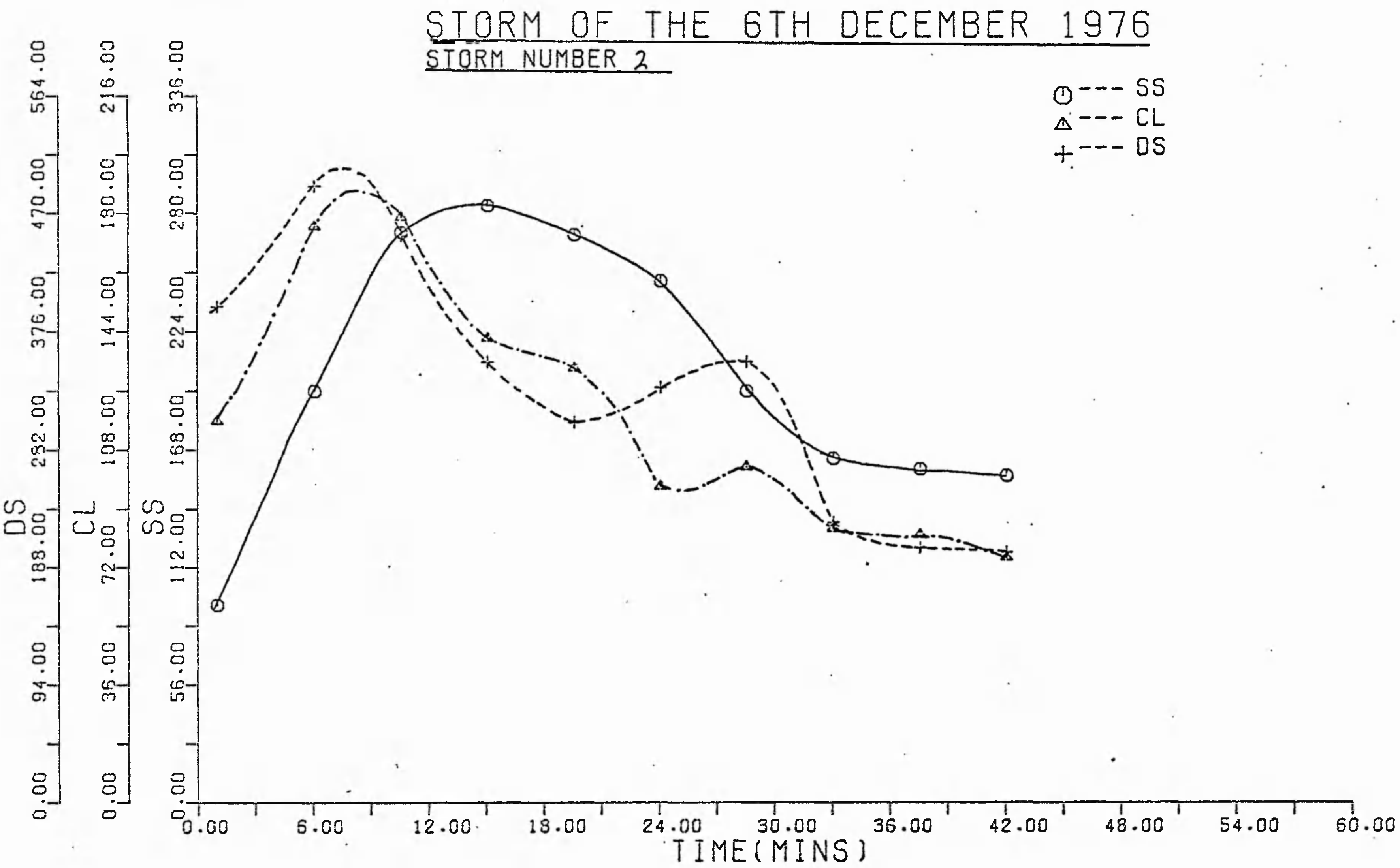
STORM OF THE 6TH NOVEMBER 1976

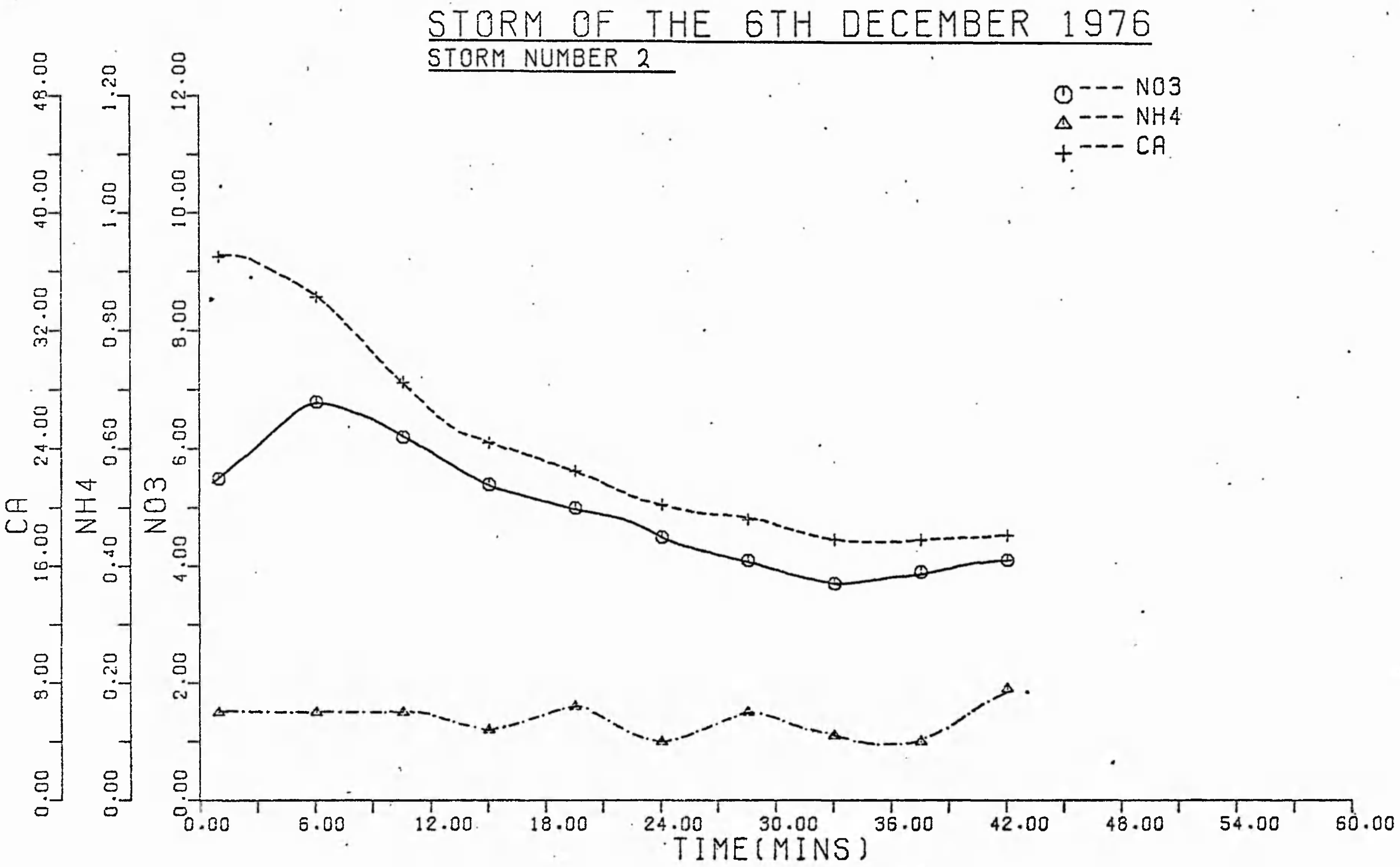
STORM NUMBER 1

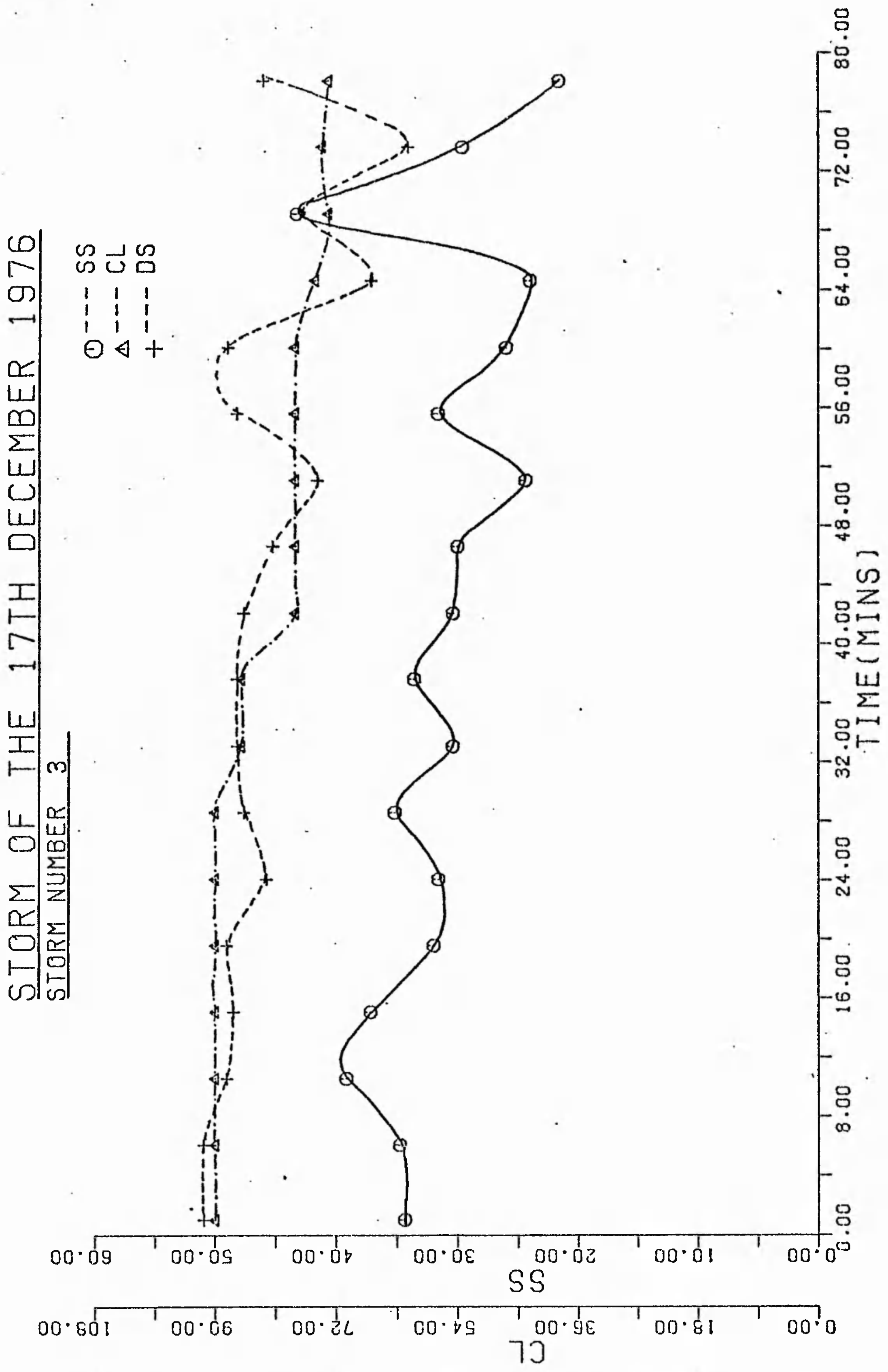
STORM OF THE 6TH NOVEMBER 1976

STORM NUMBER 1



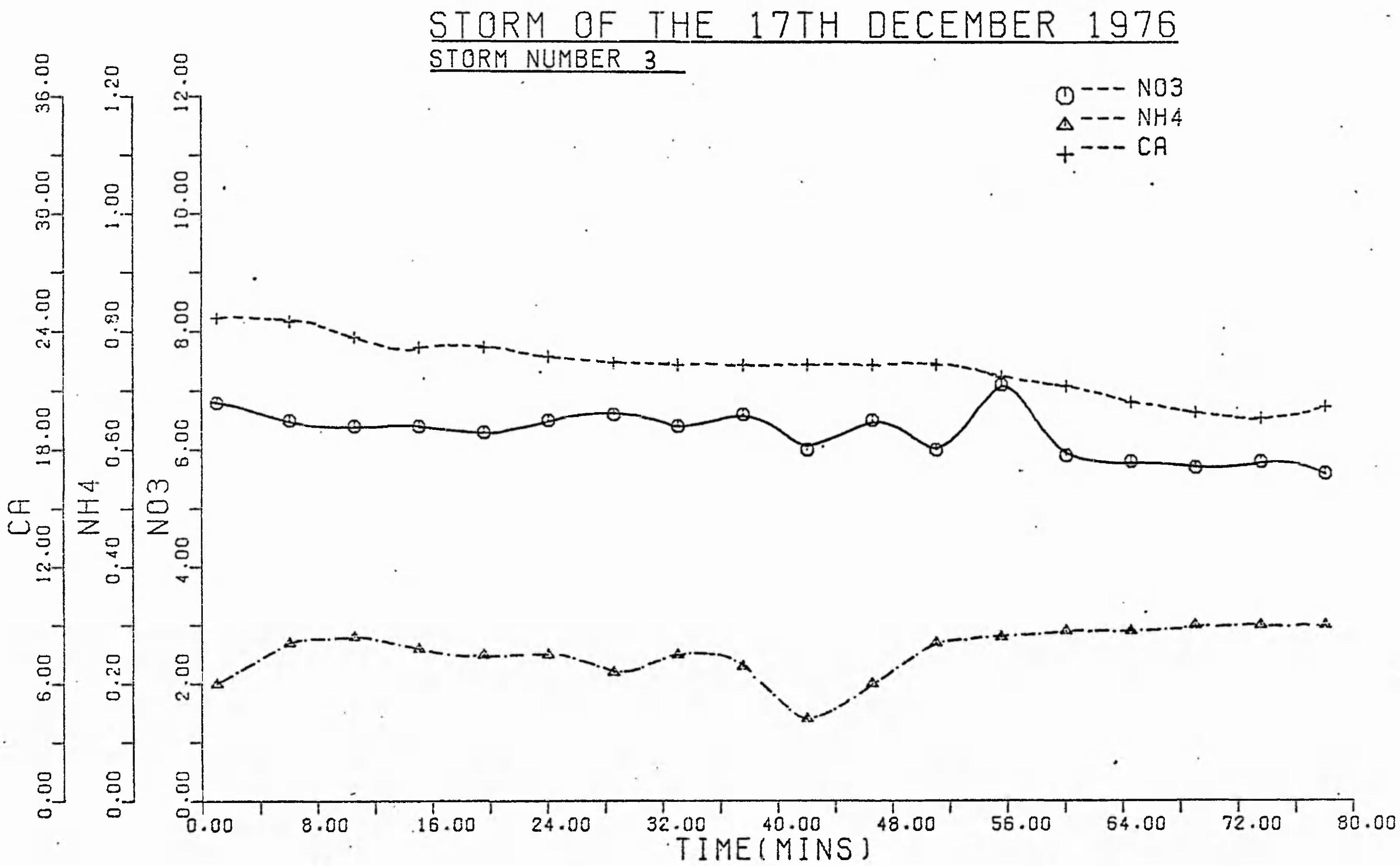

STORM OF THE 6TH DECEMBER 1976
STORM NUMBER 2
SS
CL
DS
DS
0.00
94.00
188.00
282.00
376.00
470.00
564.00
CL
0.00
36.00
72.00
108.00
144.00
180.00
216.00
SS
0.00
56.00
112.00
168.00
224.00
280.00
336.00
0.00
6.00
12.00
18.00
24.00
30.00
36.00
42.00
48.00
54.00
60.00
TIME(MINS)


STORM OF THE 6TH DECEMBER 1976
STORM NUMBER 2
--- NO3
--- NH4
--- CA
CA
NH4
NO3
0.00
8.00
16.00
24.00
32.00
40.00
48.00
0.00
0.20
0.40
0.60
0.80
1.00
1.20
0.00
2.00
4.00
6.00
8.00
10.00
12.00
0.00
6.00
12.00
18.00
24.00
30.00
36.00
42.00
48.00
54.00
60.00
TIME(MINS)



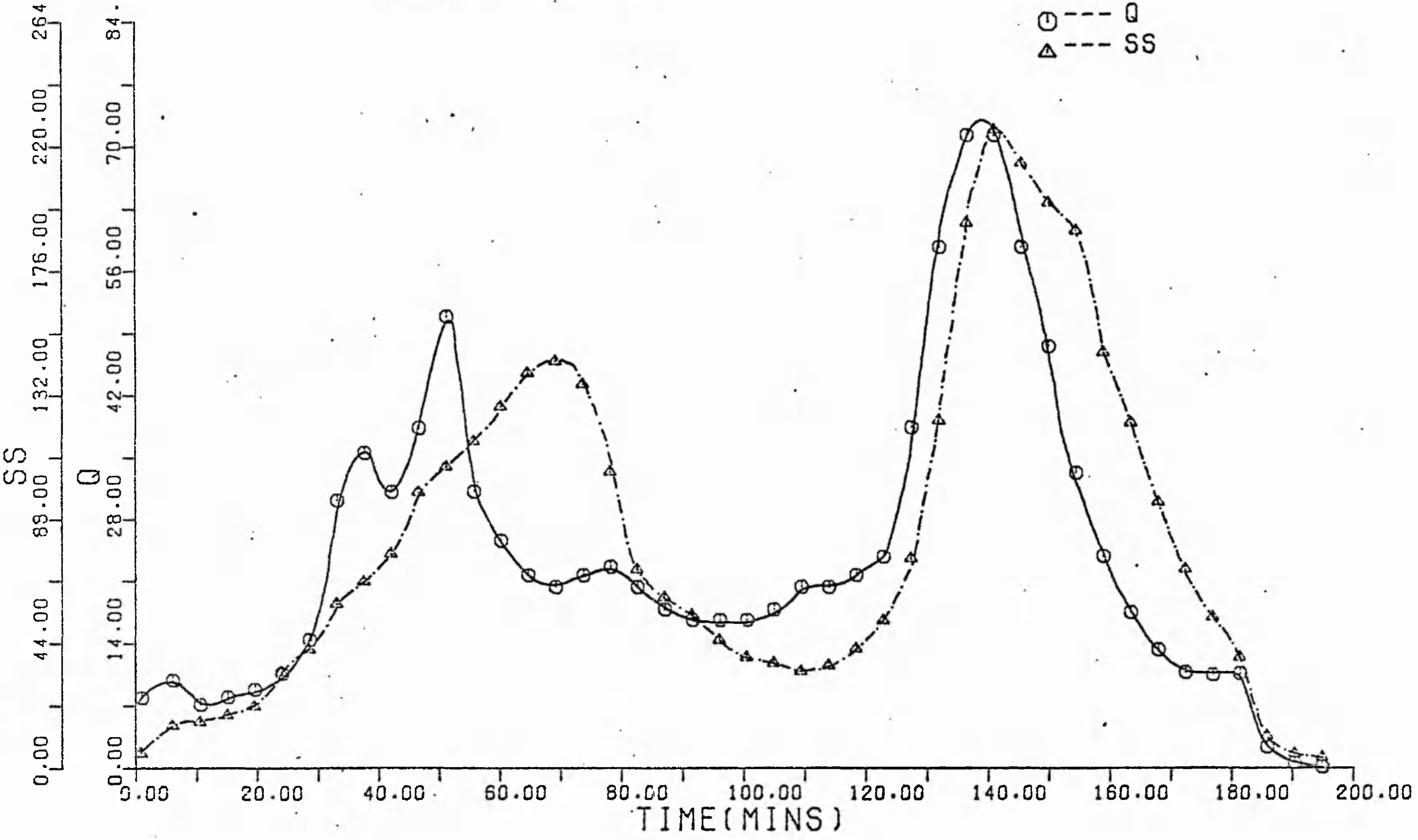
STORM OF THE 17TH DECEMBER 1976

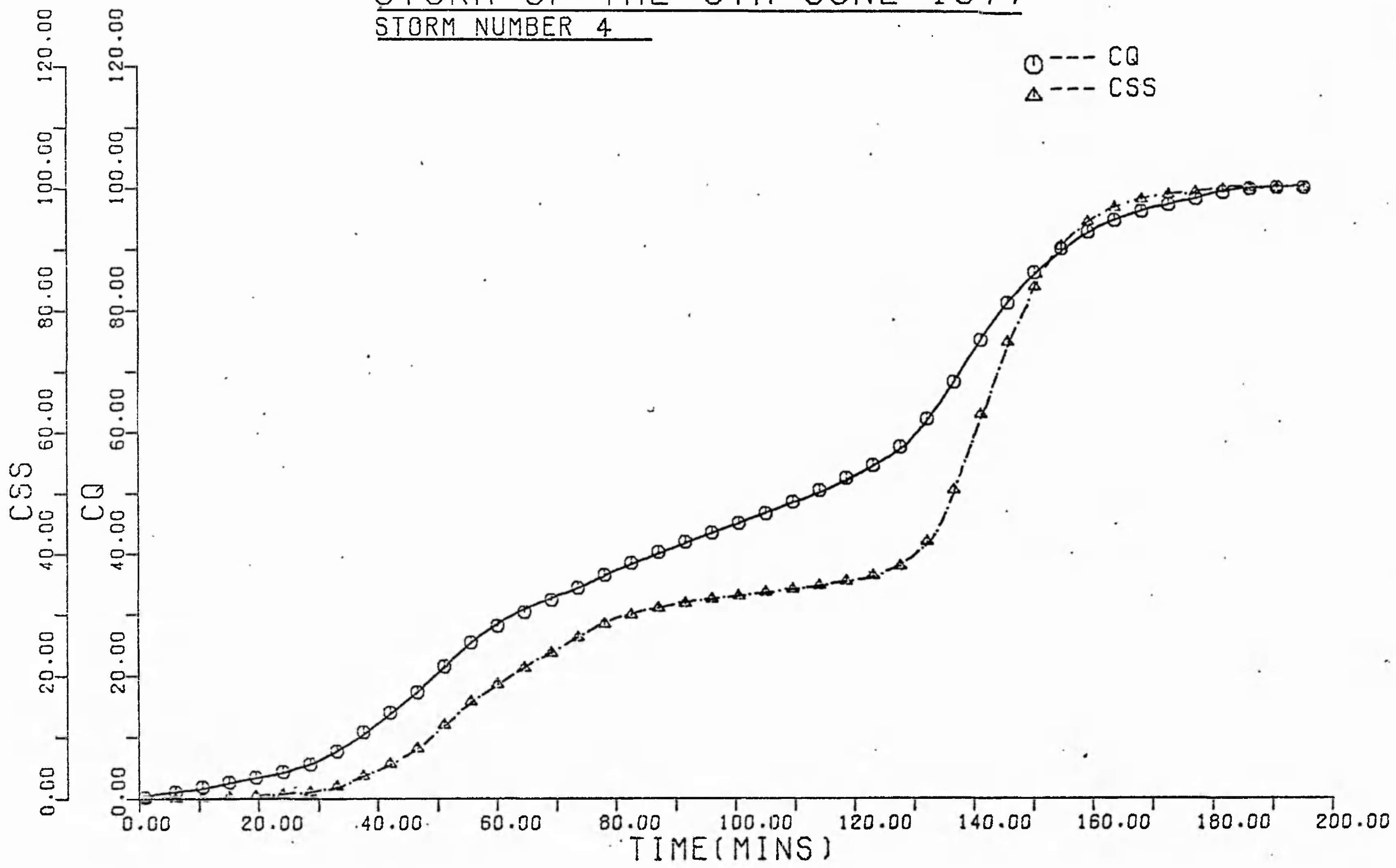
STORM NUMBER 3


STORM OF THE 17TH DECEMBER 1976
STORM NUMBER 3
NO3
NH4
CA
CA
0.00
6.00
12.00
18.00
24.00
30.00
36.00
NH4
0.00
0.20
0.40
0.60
0.80
1.00
1.20
NO3
0.00
2.00
4.00
6.00
8.00
10.00
12.00
0.00
8.00
16.00
24.00
32.00
40.00
48.00
56.00
64.00
72.00
80.00
TIME(MINS)

STORM OF THE 9TH JUNE 1977

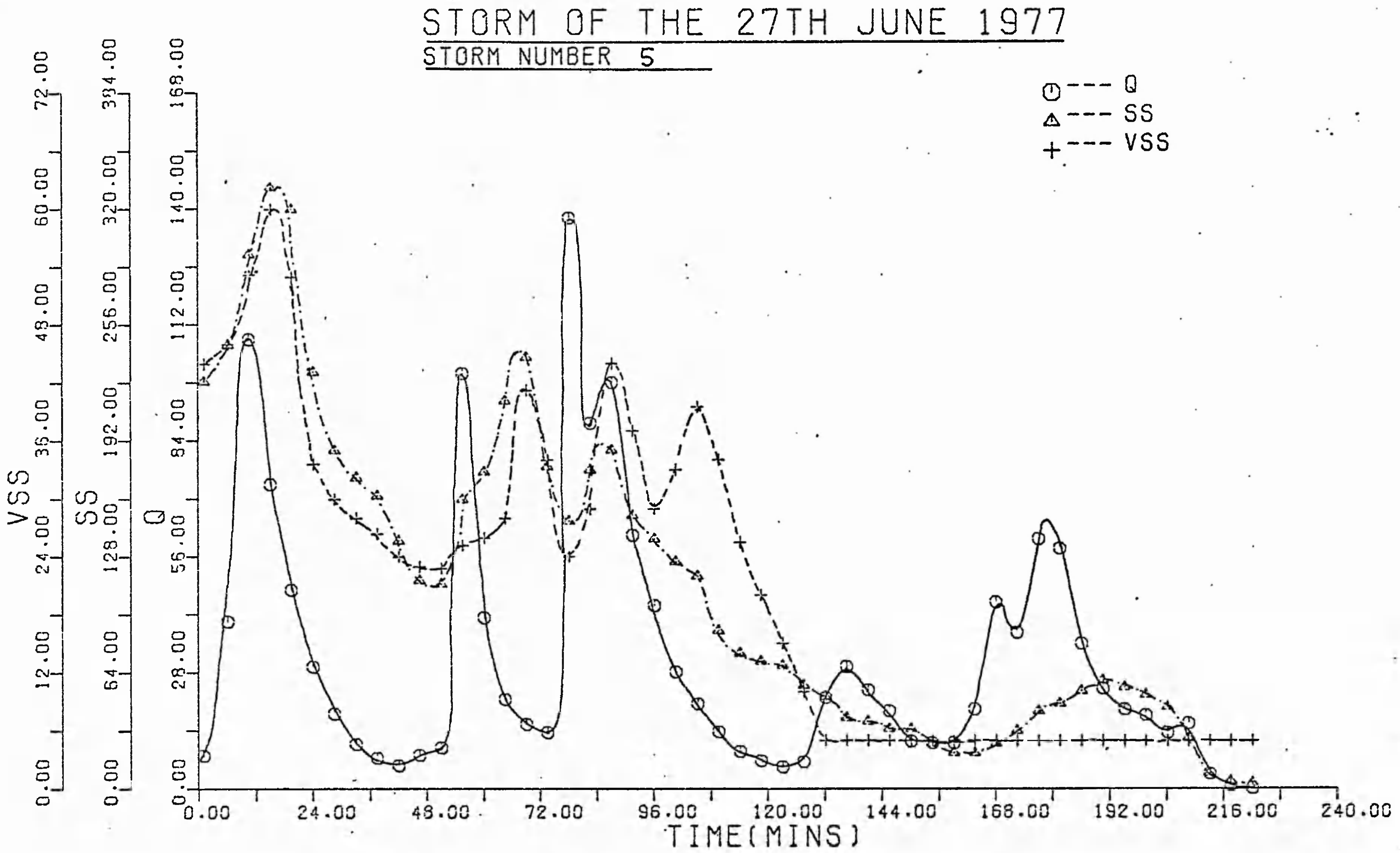
STORM NUMBER 4

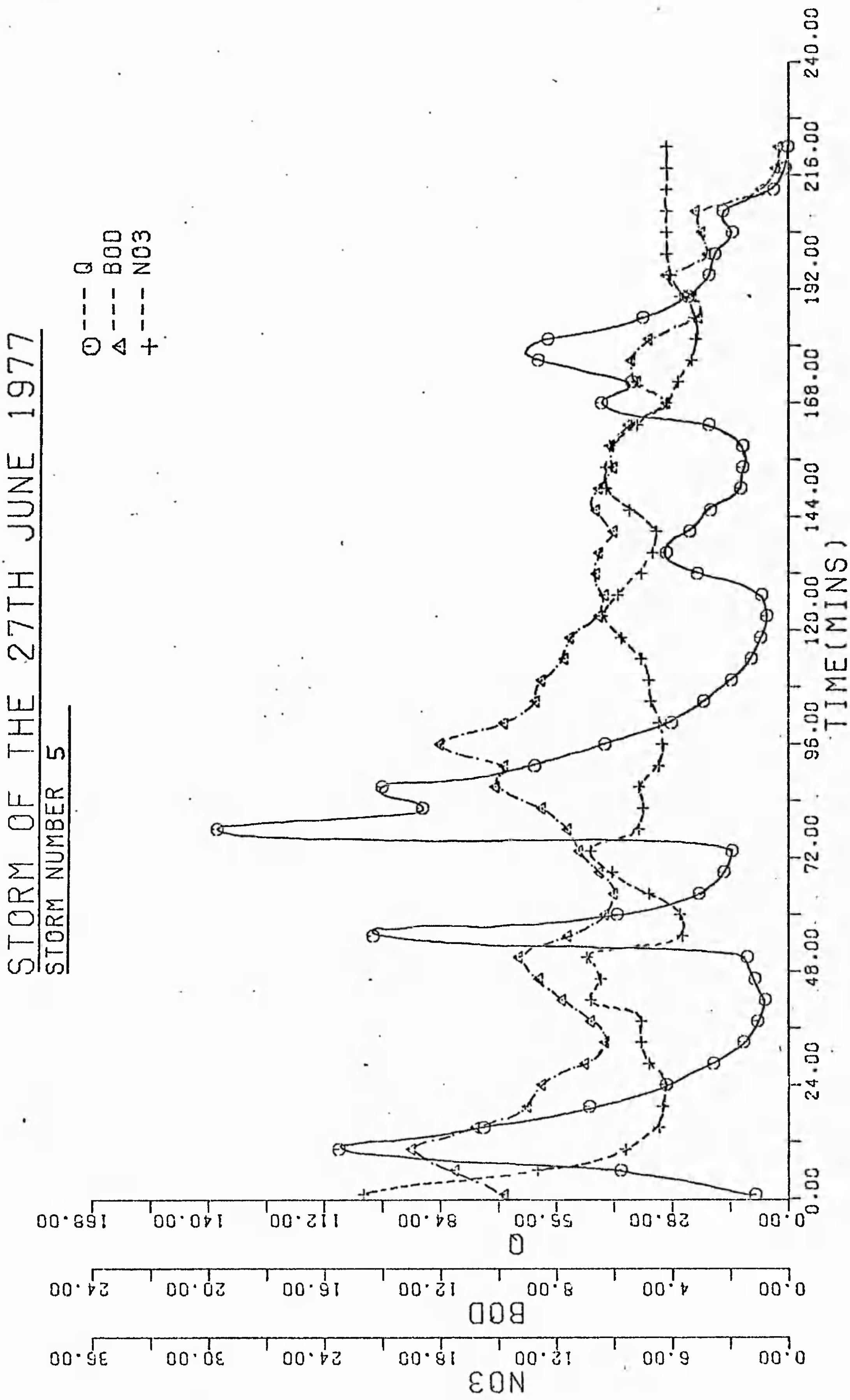




STORM OF THE 9TH JUNE 1977

STORM NUMBER 4


STORM OF THE 27TH JUNE 1977
STORM NUMBER 5
Q
SS
VSS
VSS
SS
Q
0.00
12.00
24.00
36.00
48.00
60.00
72.00
0.00
64.00
128.00
192.00
256.00
320.00
384.00
0.00
28.00
56.00
84.00
112.00
140.00
168.00
0.00
24.00
48.00
72.00
96.00
120.00
144.00
168.00
192.00
216.00
240.00
TIME(MINS)

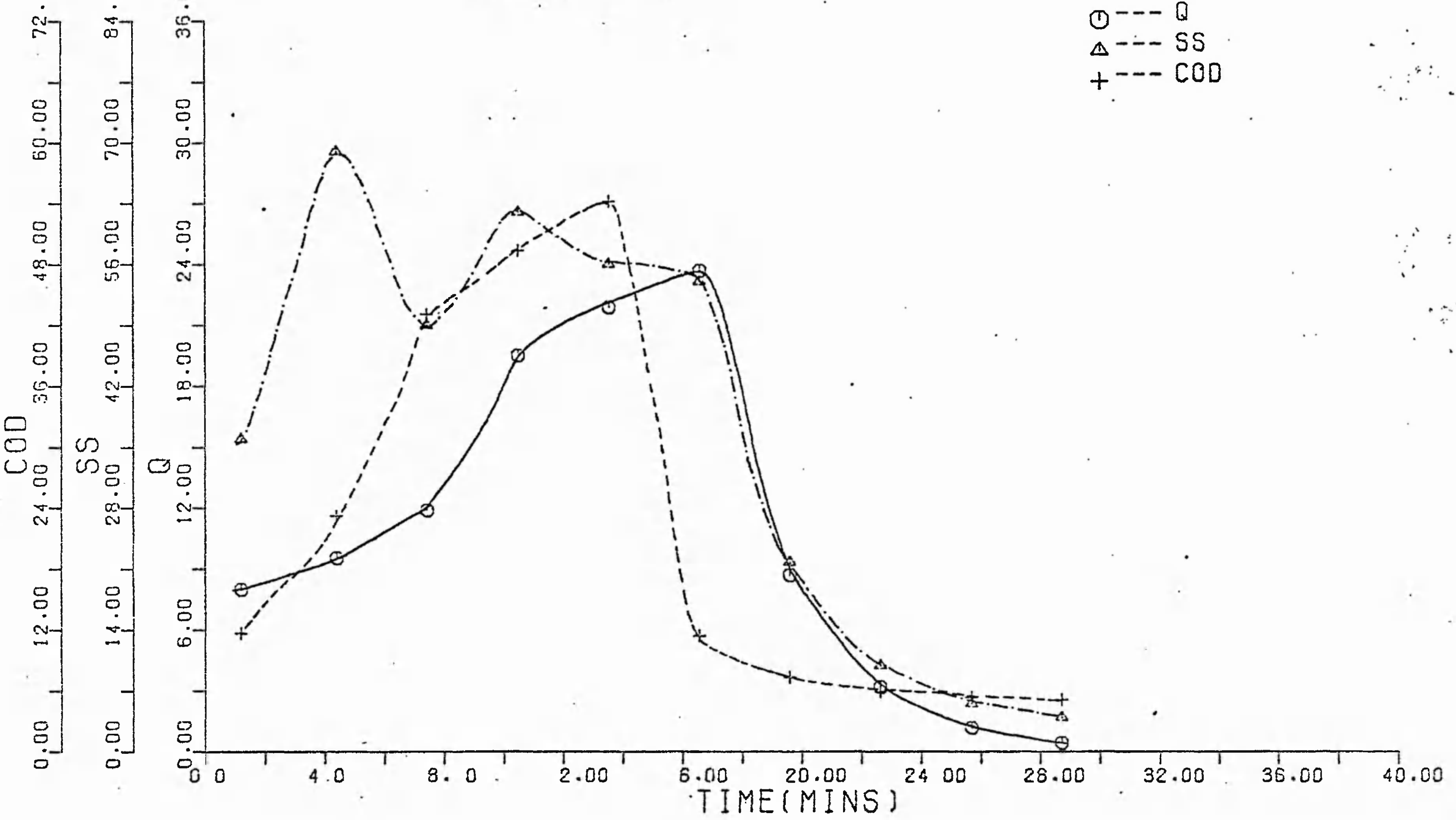


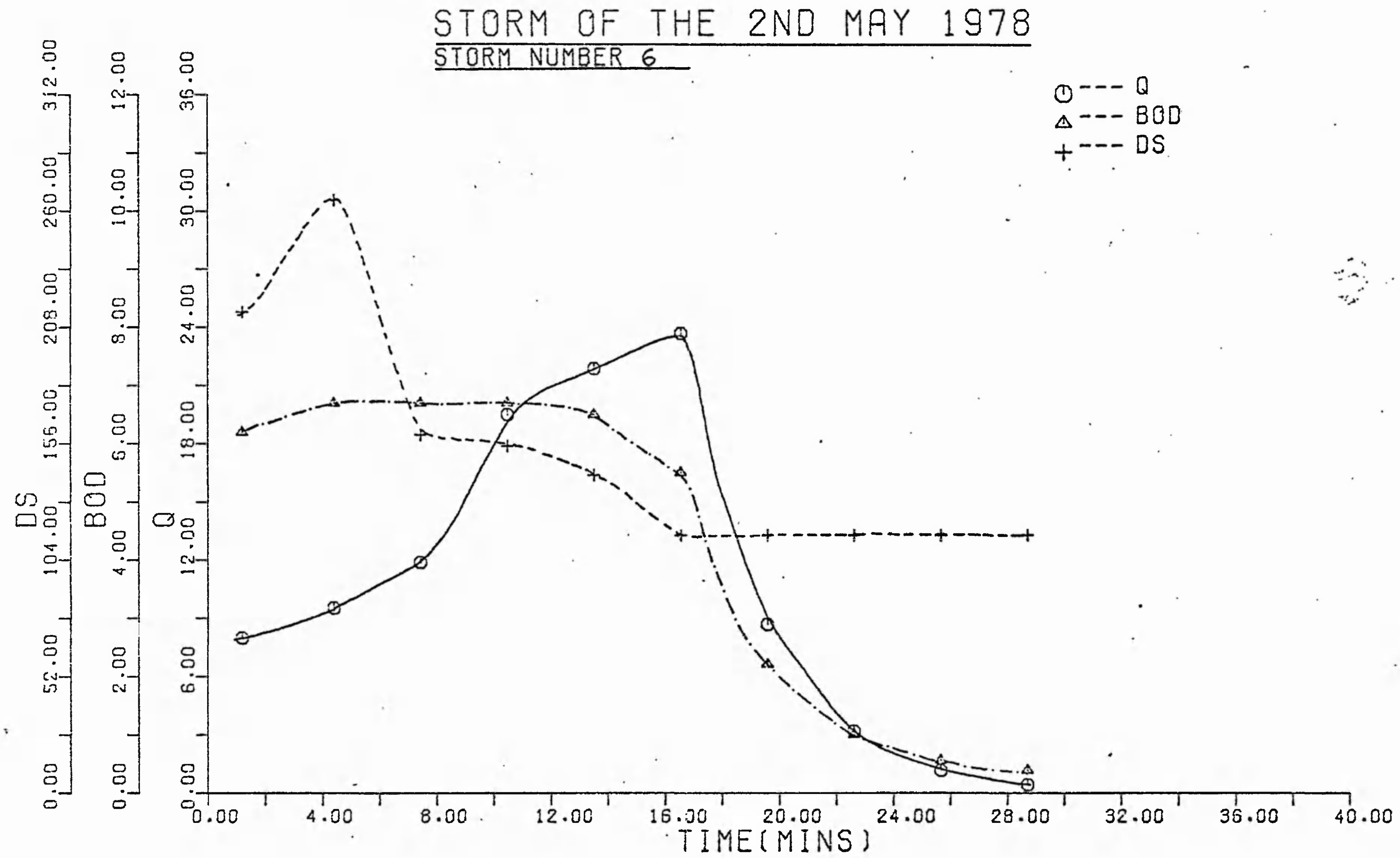
STORM OF THE 27TH JUNE 1977

STORM NUMBER 5

STORM OF THE 2ND MAY 1978

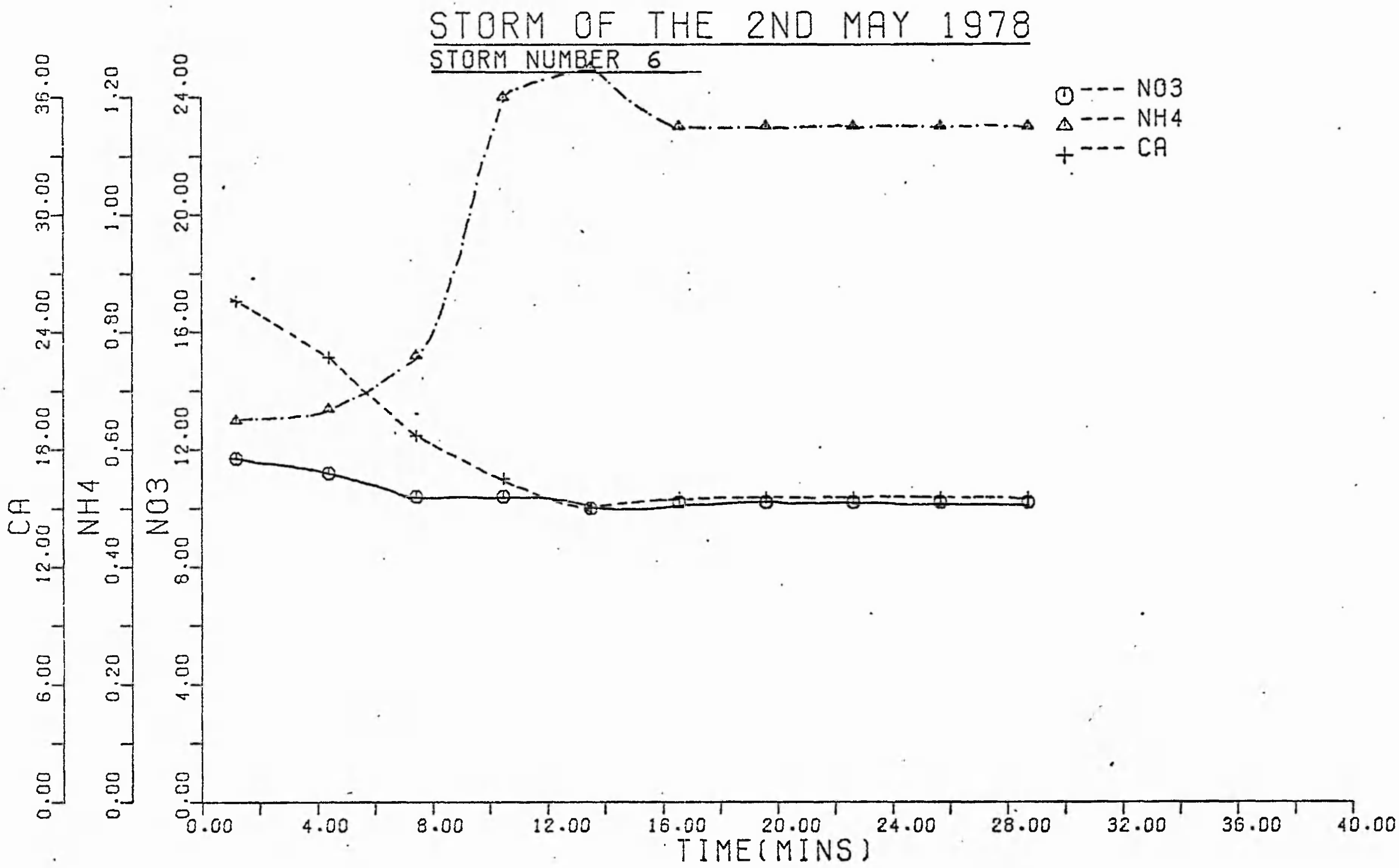
STORM NUMBER 6





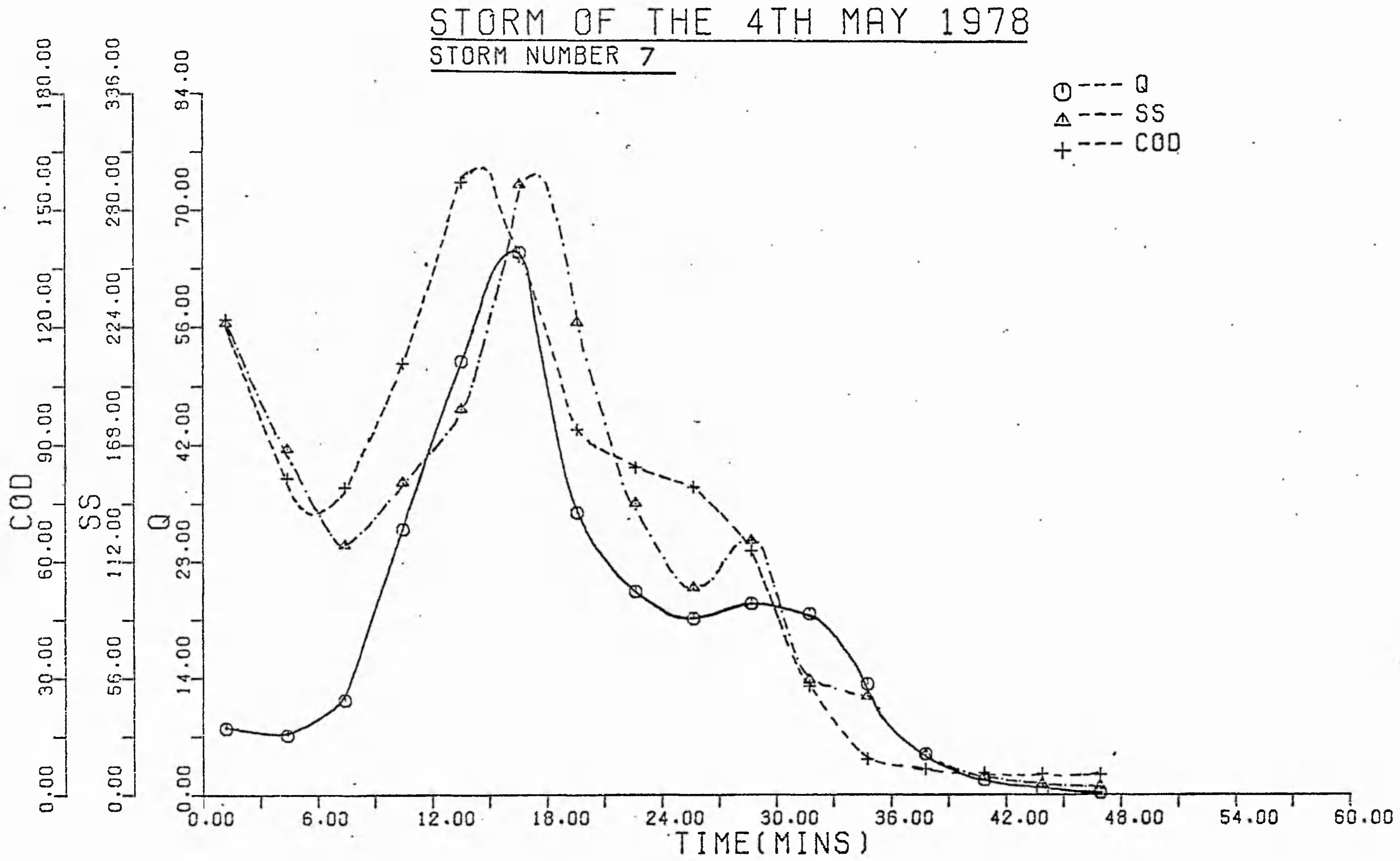
STORM OF THE 2ND MAY 1978

STORM NUMBER 6

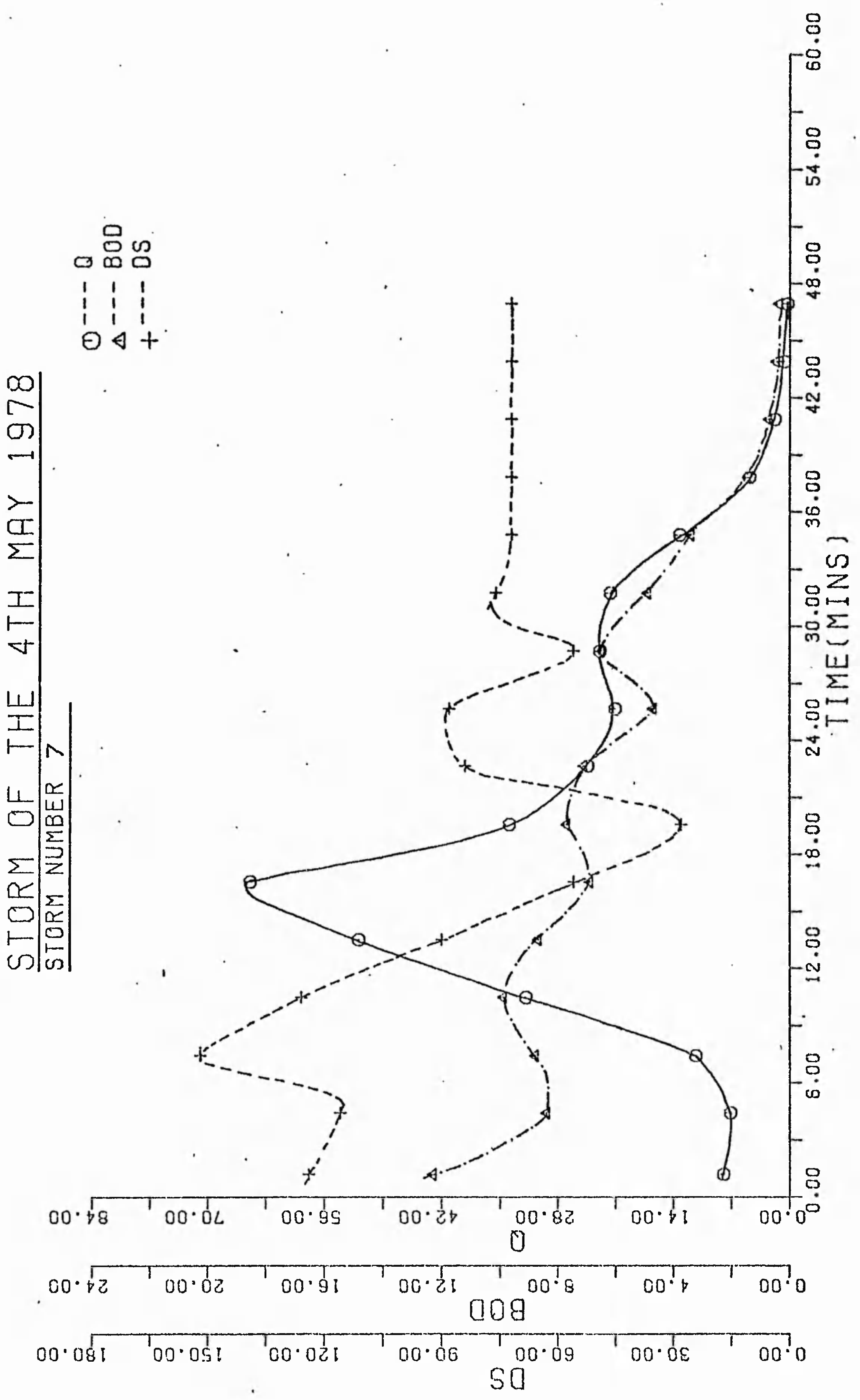


STORM OF THE 2ND MAY 1978

STORM NUMBER 6

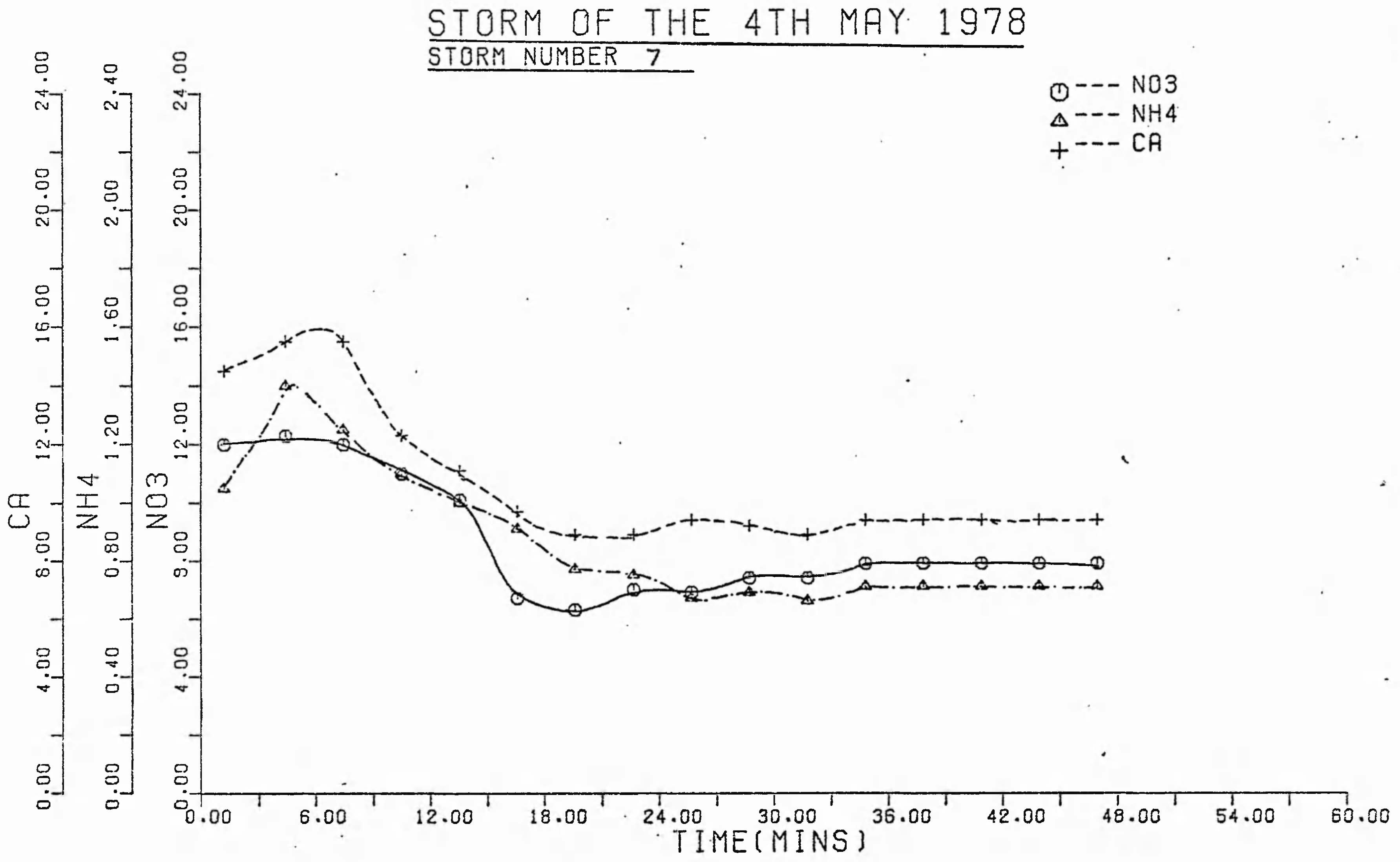

STORM OF THE 4TH MAY 1978

STORM NUMBER 7



STORM OF THE 4TH MAY 1978

STORM NUMBER 7

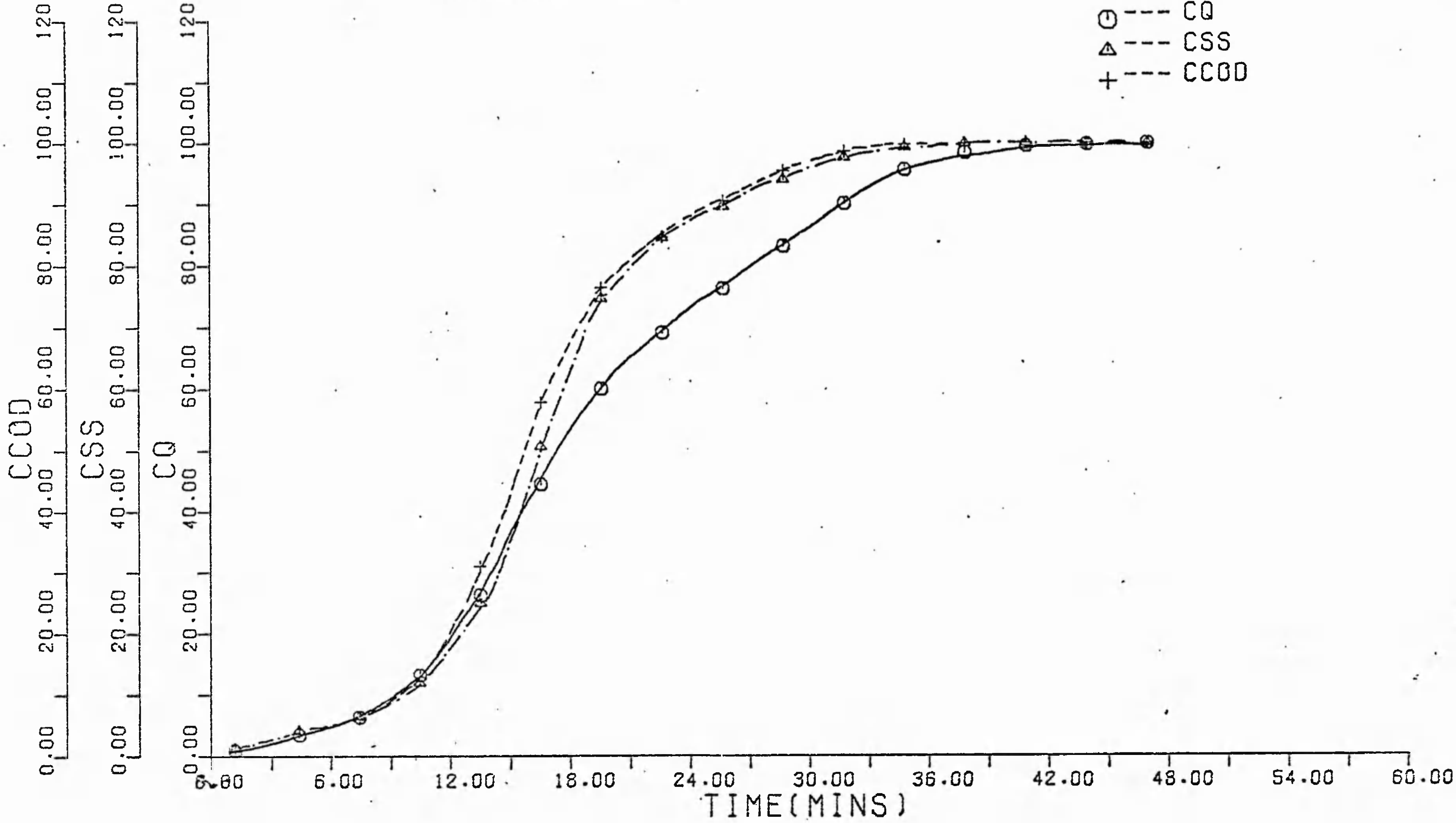


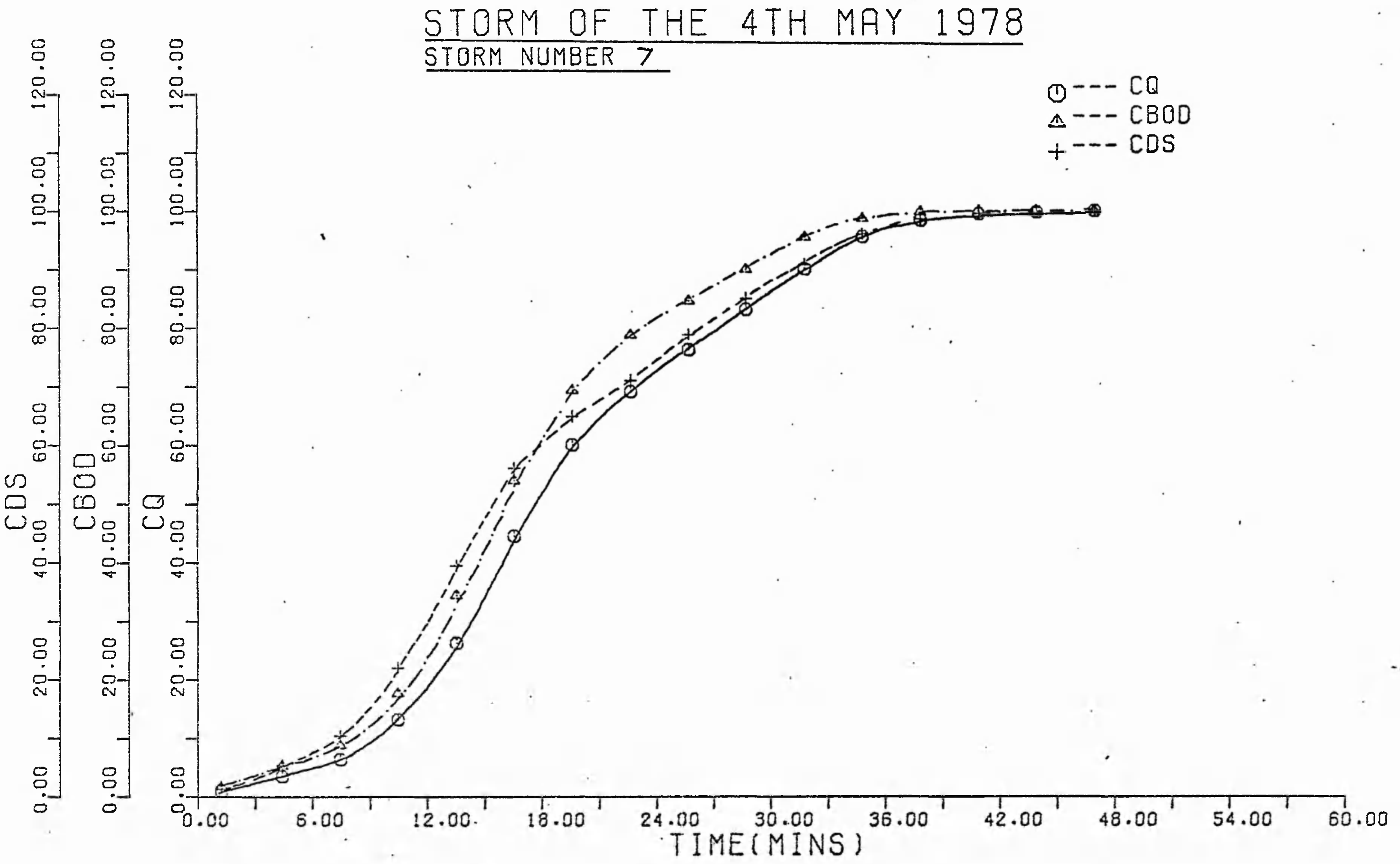
STORM OF THE 4TH MAY 1978

STORM NUMBER 7

STORM OF THE 4TH MAY 1978

STORM NUMBER 7



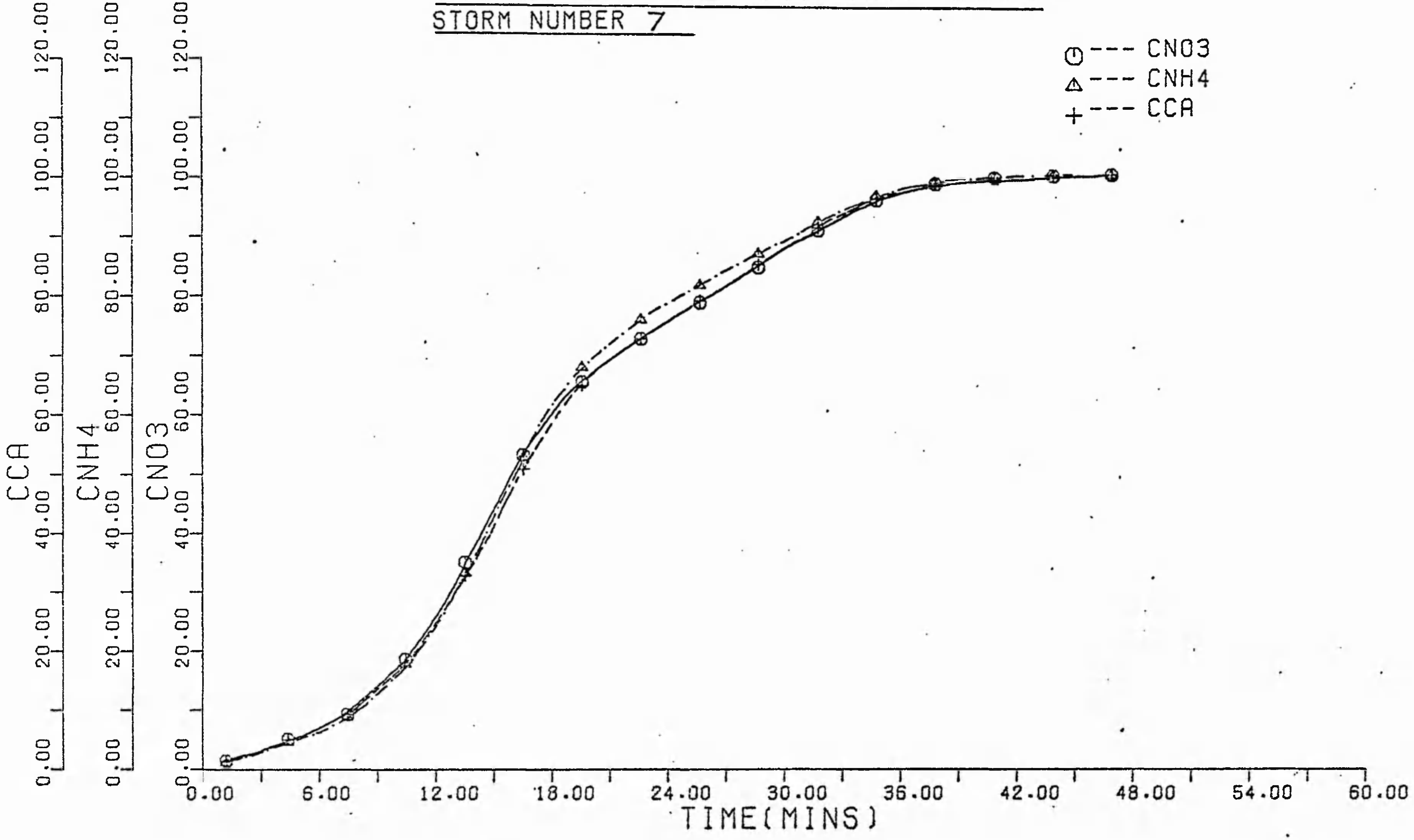


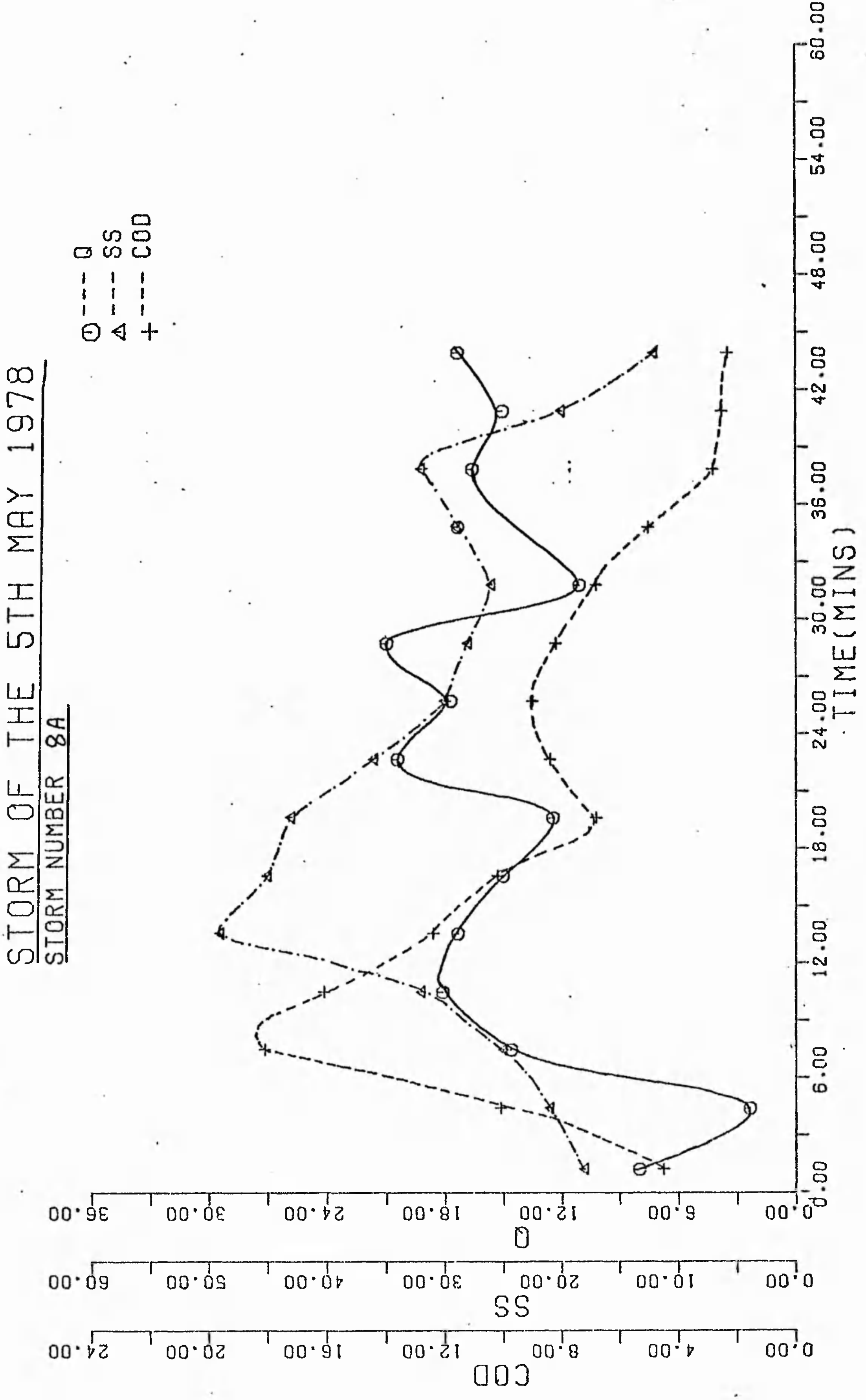
STORM OF THE 4TH MAY 1978

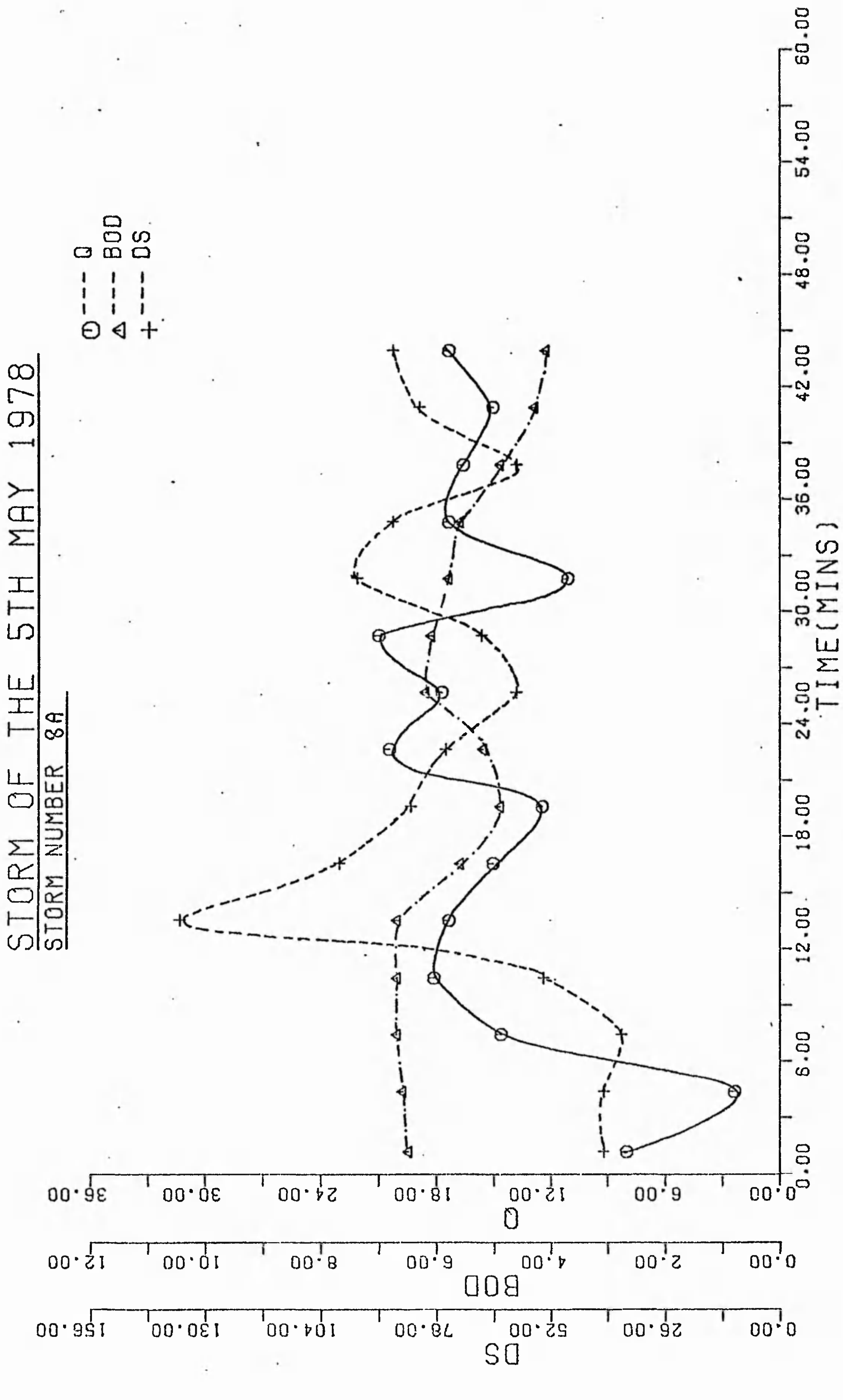
STORM NUMBER 7

STORM OF THE 4TH MAY 1978

STORM NUMBER 7

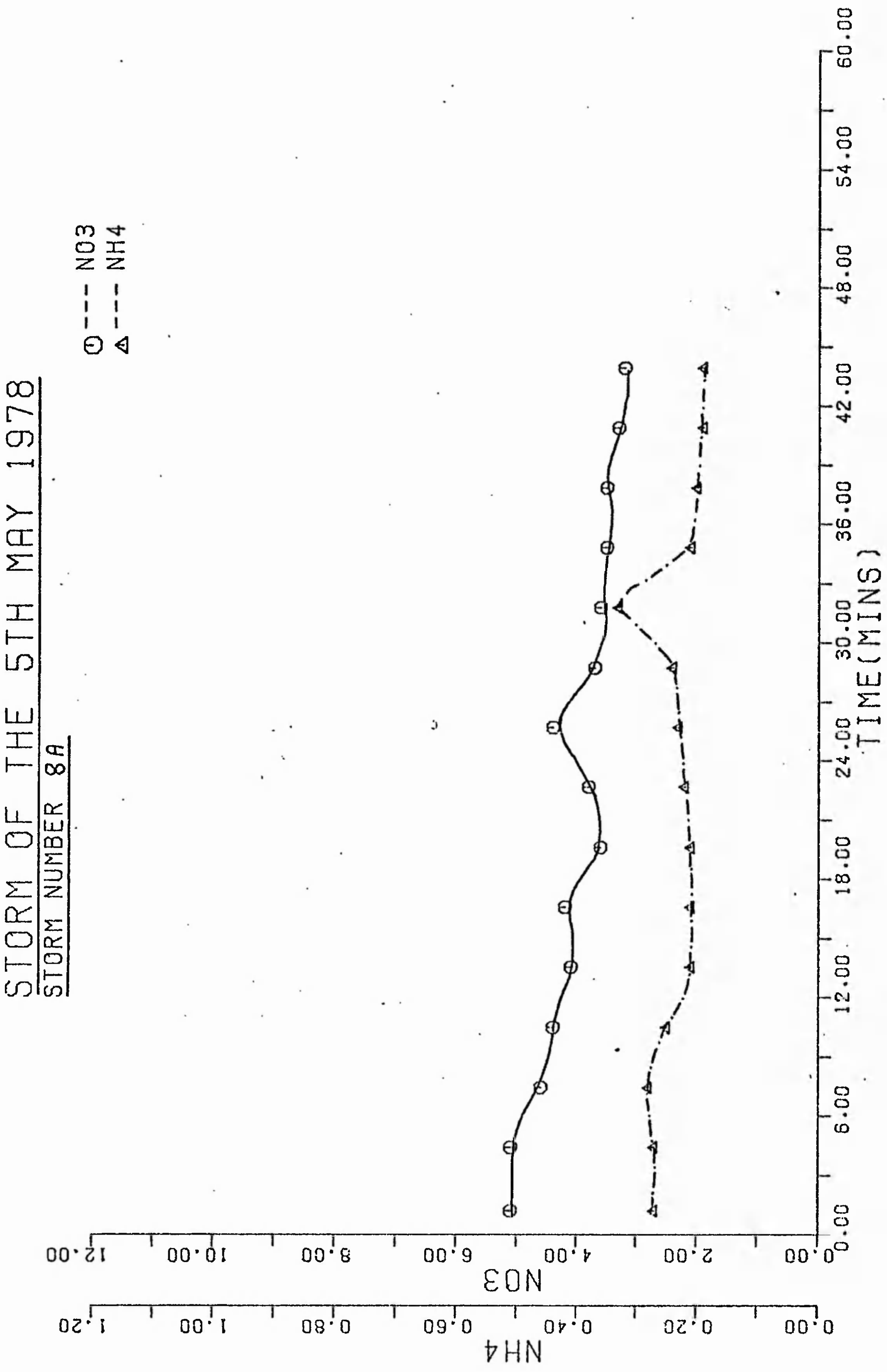



STORM OF THE 5TH MAY 1978
STORM NUMBER 8A
Θ ---- Q
△ ---- SS
+ ---- COD
TIME(MINS)
0.00
6.00
12.00
18.00
24.00
30.00
36.00
42.00
48.00
54.00
60.00
Q
0.00
6.00
12.00
18.00
24.00
30.00
36.00
SS
0.00
10.00
20.00
30.00
40.00
50.00
60.00
COD
0.00
4.00
8.00
12.00
16.00
20.00
24.00



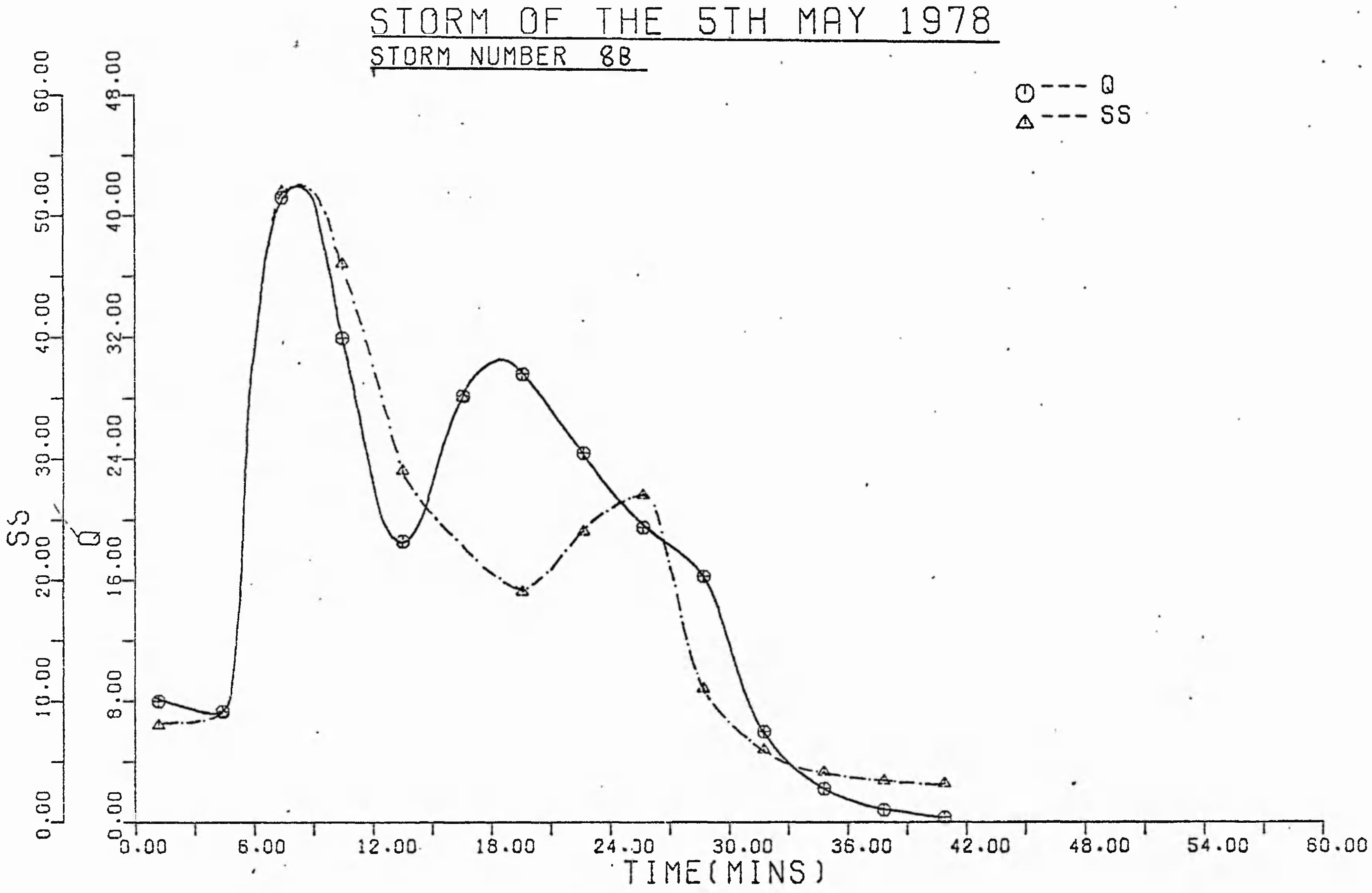
STORM OF THE 5TH MAY 1978

STORM NUMBER 8A



STORM OF THE 5TH MAY 1978

STORM NUMBER 8A

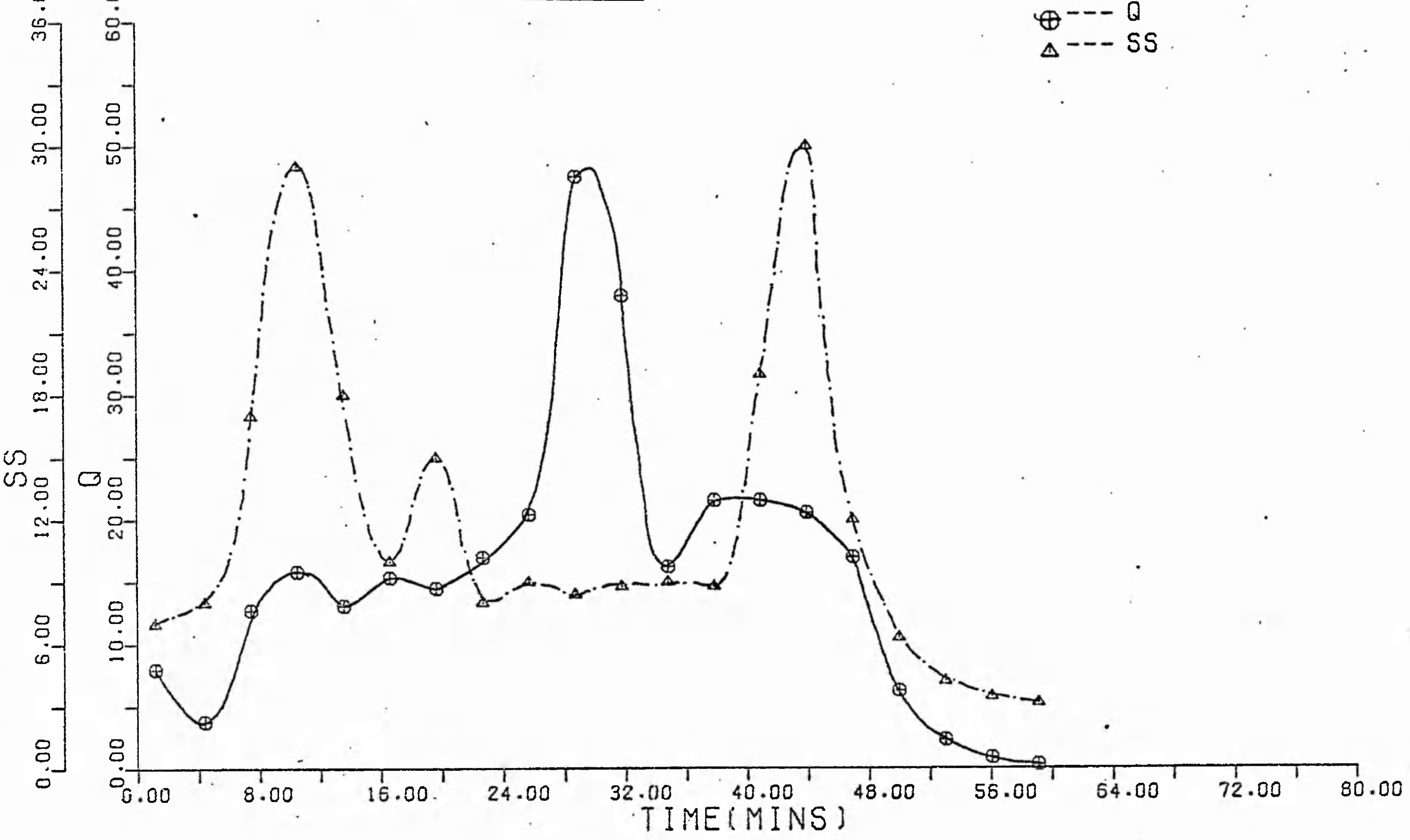


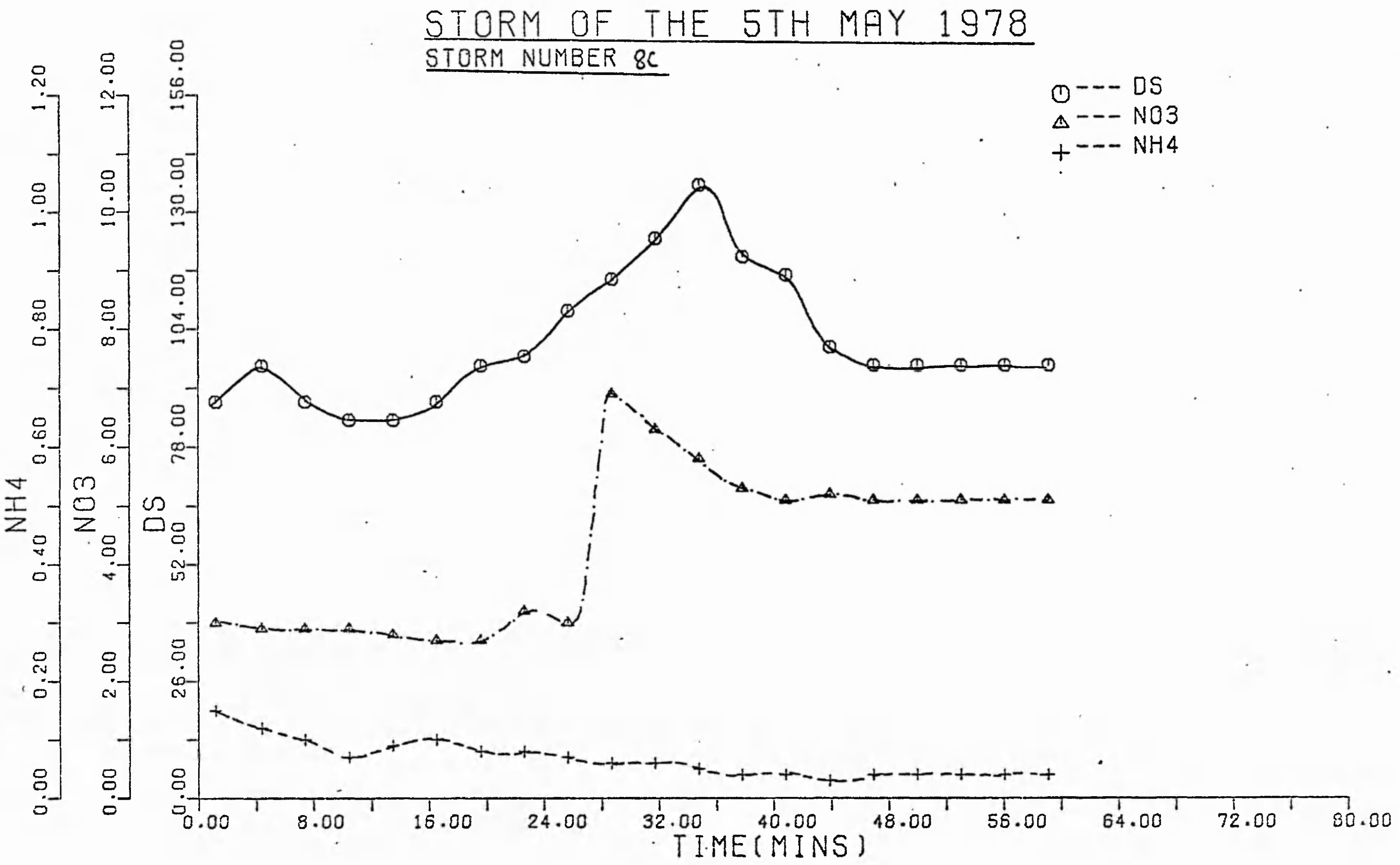
STORM OF THE 5TH MAY 1978

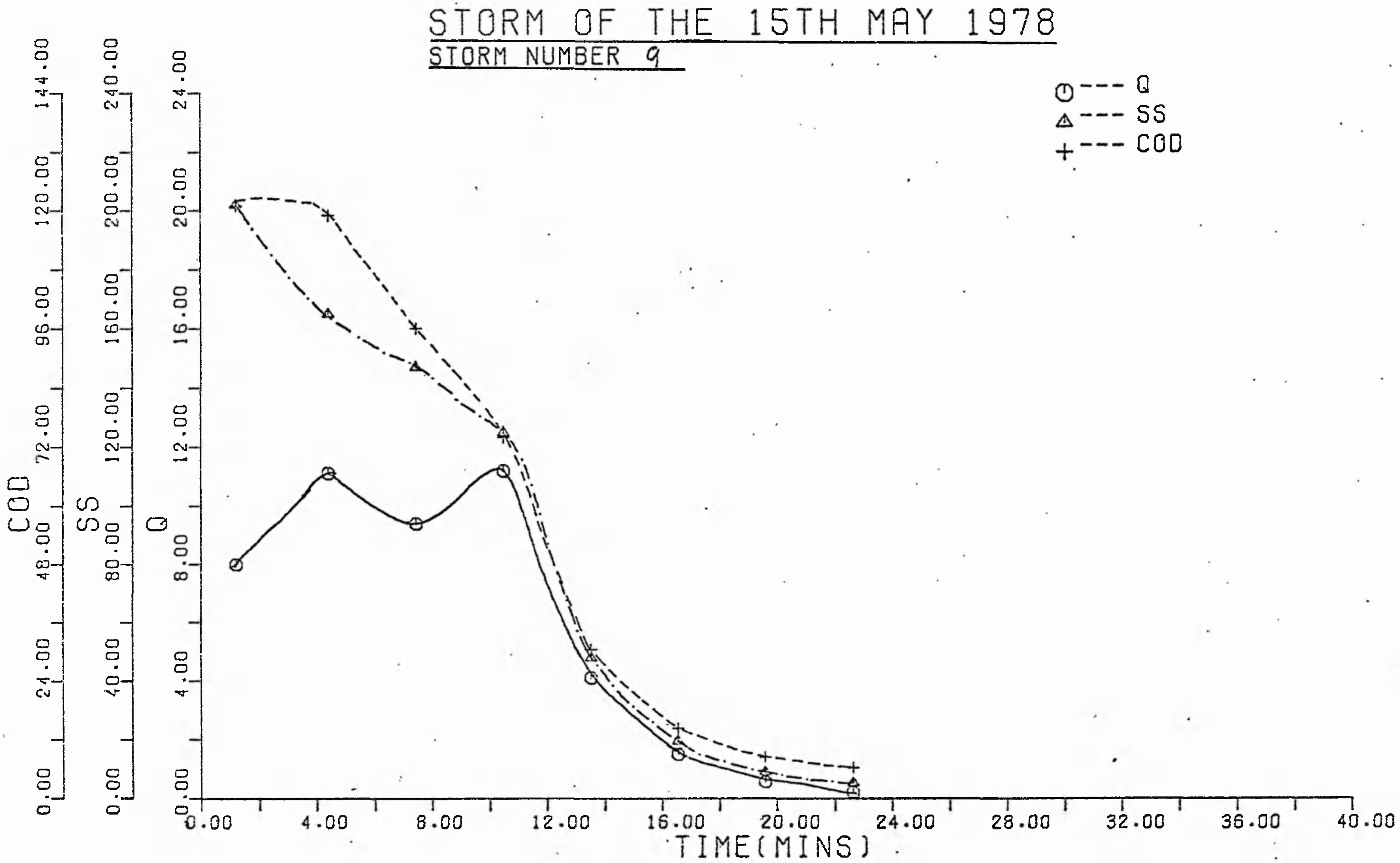
STORM NUMBER 88

STORM OF THE 5TH MAY 1978

STORM NUMBER 8C

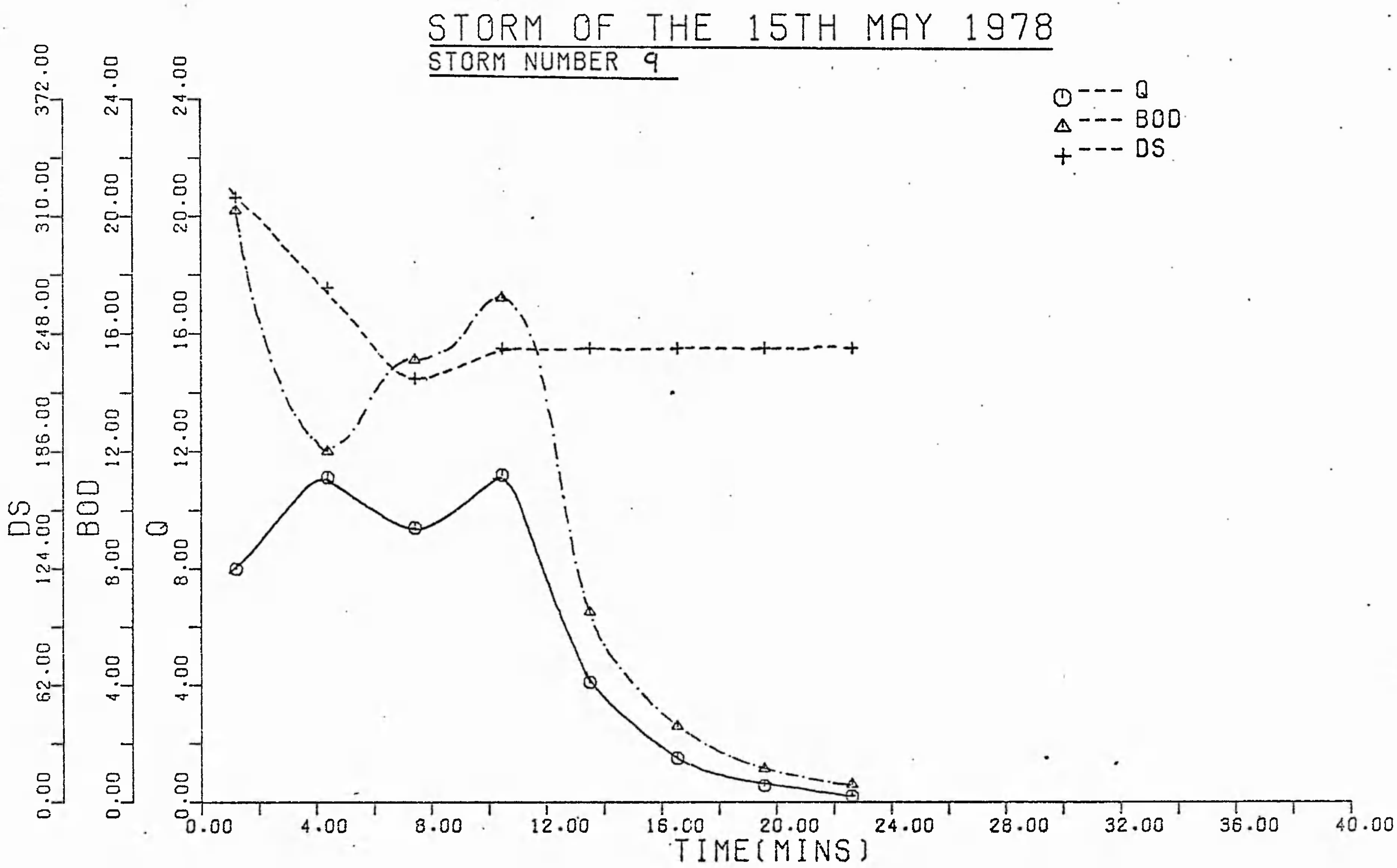


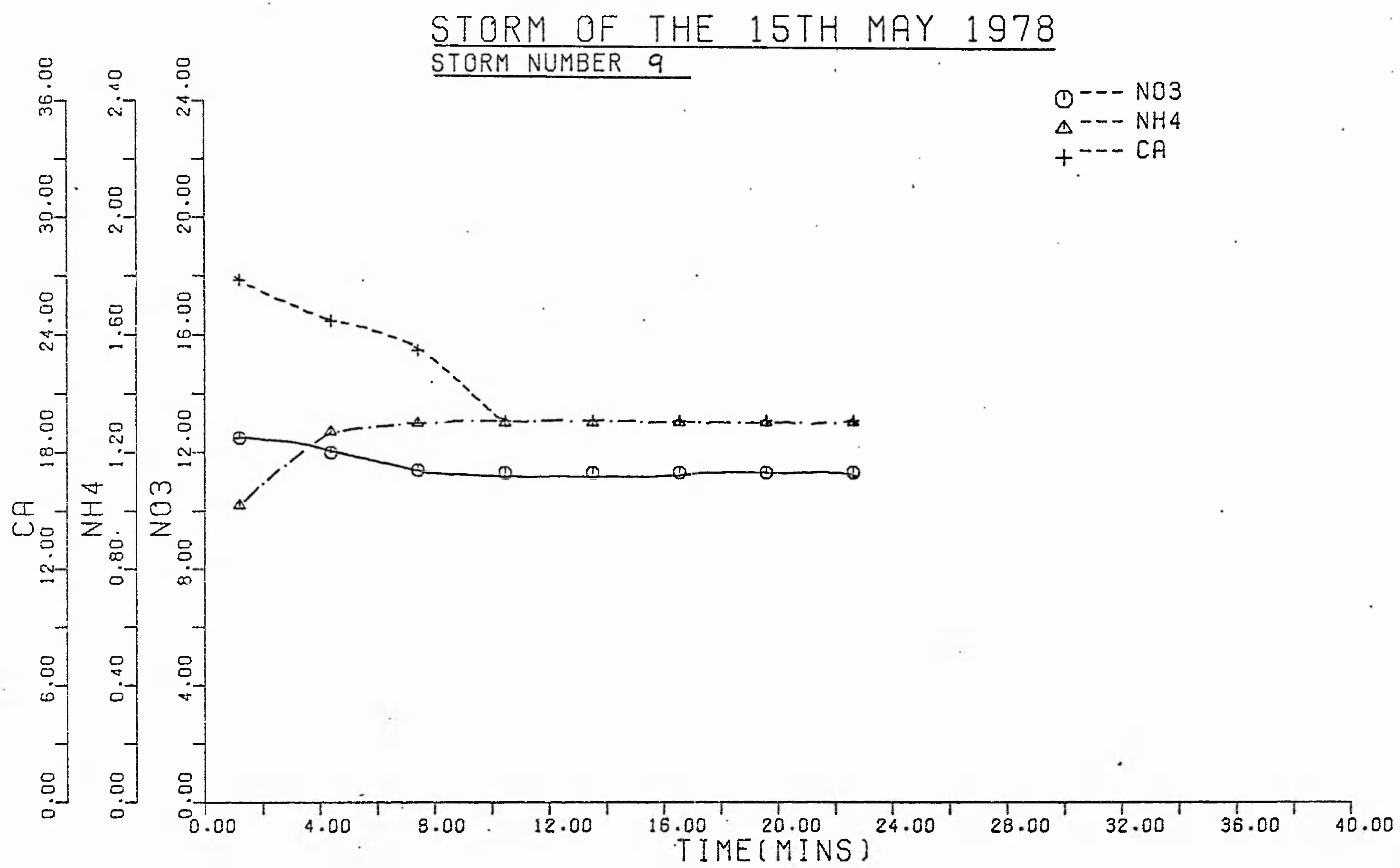

STORM OF THE 5TH MAY 1978
STORM NUMBER 8C
⊖ --- DS
△ --- NO3
+ --- NH4
NH4
0.00
0.20
0.40
0.60
0.80
1.00
1.20
NO3
0.00
2.00
4.00
6.00
8.00
10.00
12.00
DS
0.00
26.00
52.00
78.00
104.00
130.00
156.00
0.00
8.00
16.00
24.00
32.00
40.00
48.00
56.00
64.00
72.00
80.00
TIME(MINS)



STORM OF THE 15TH MAY 1978

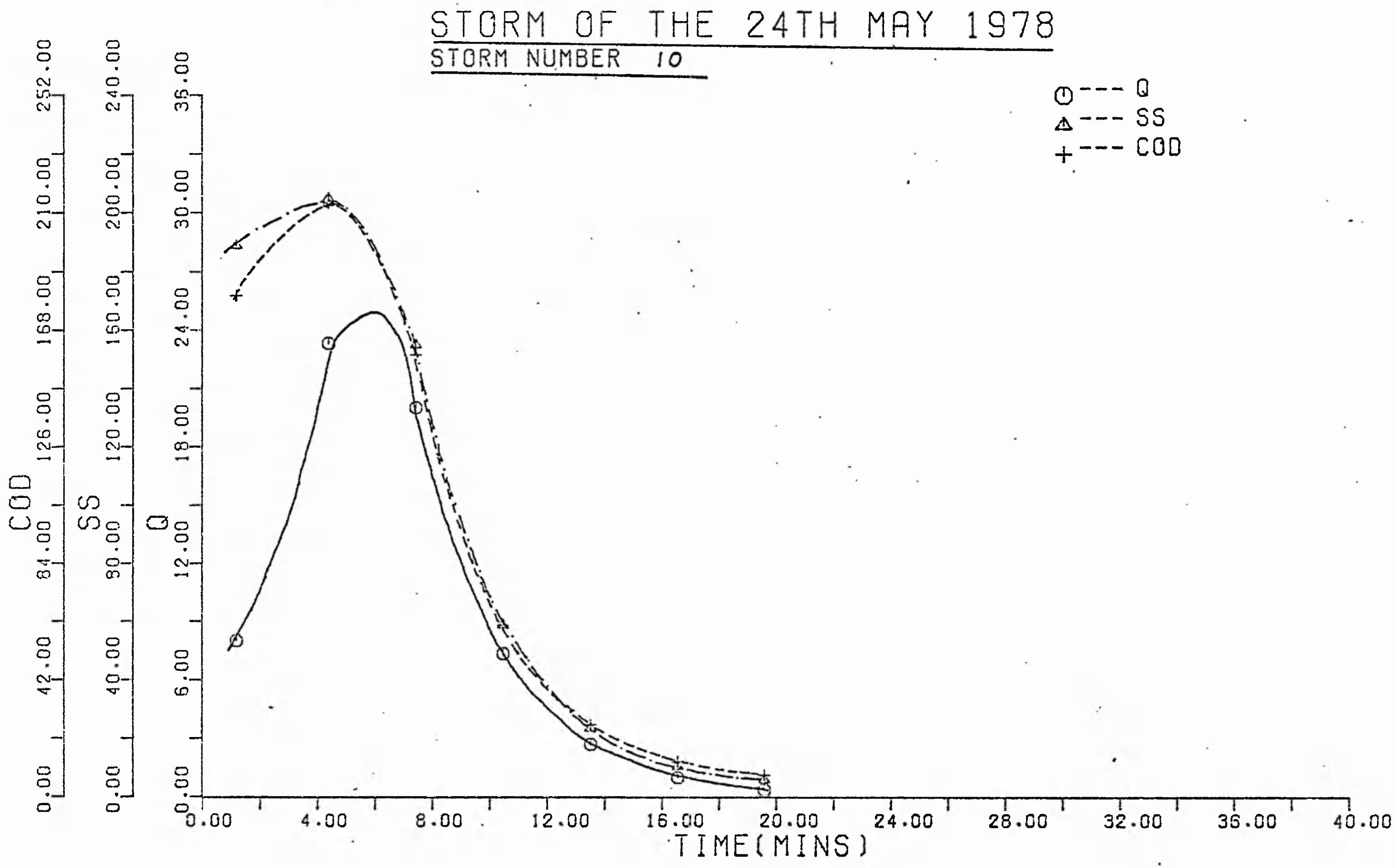
STORM NUMBER 9

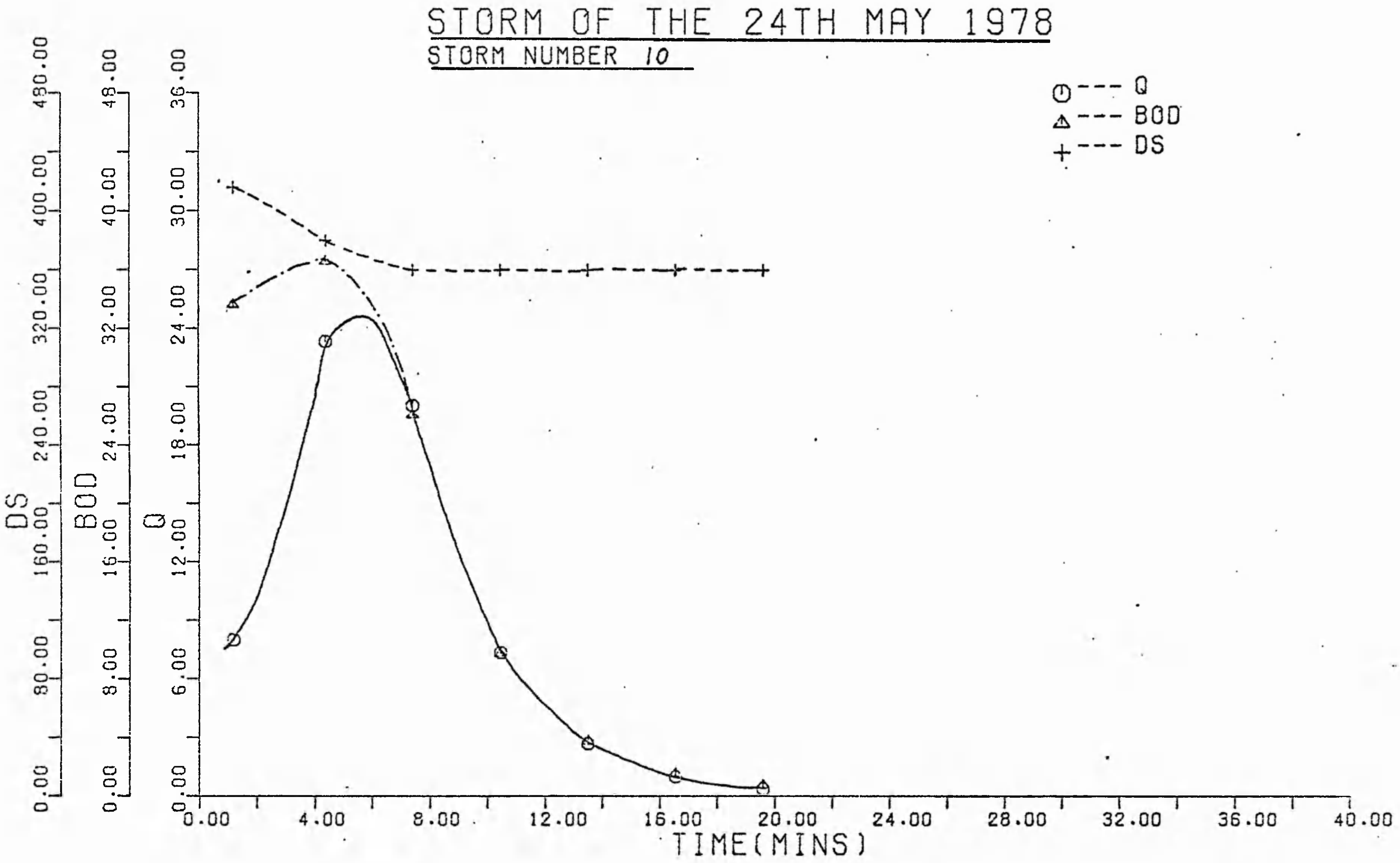

STORM OF THE 15TH MAY 1978
STORM NUMBER 9
Q
BOD
DS
DS
BOD
Q
0.00
62.00
124.00
186.00
248.00
310.00
372.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
36.00
40.00
TIME(MINS)

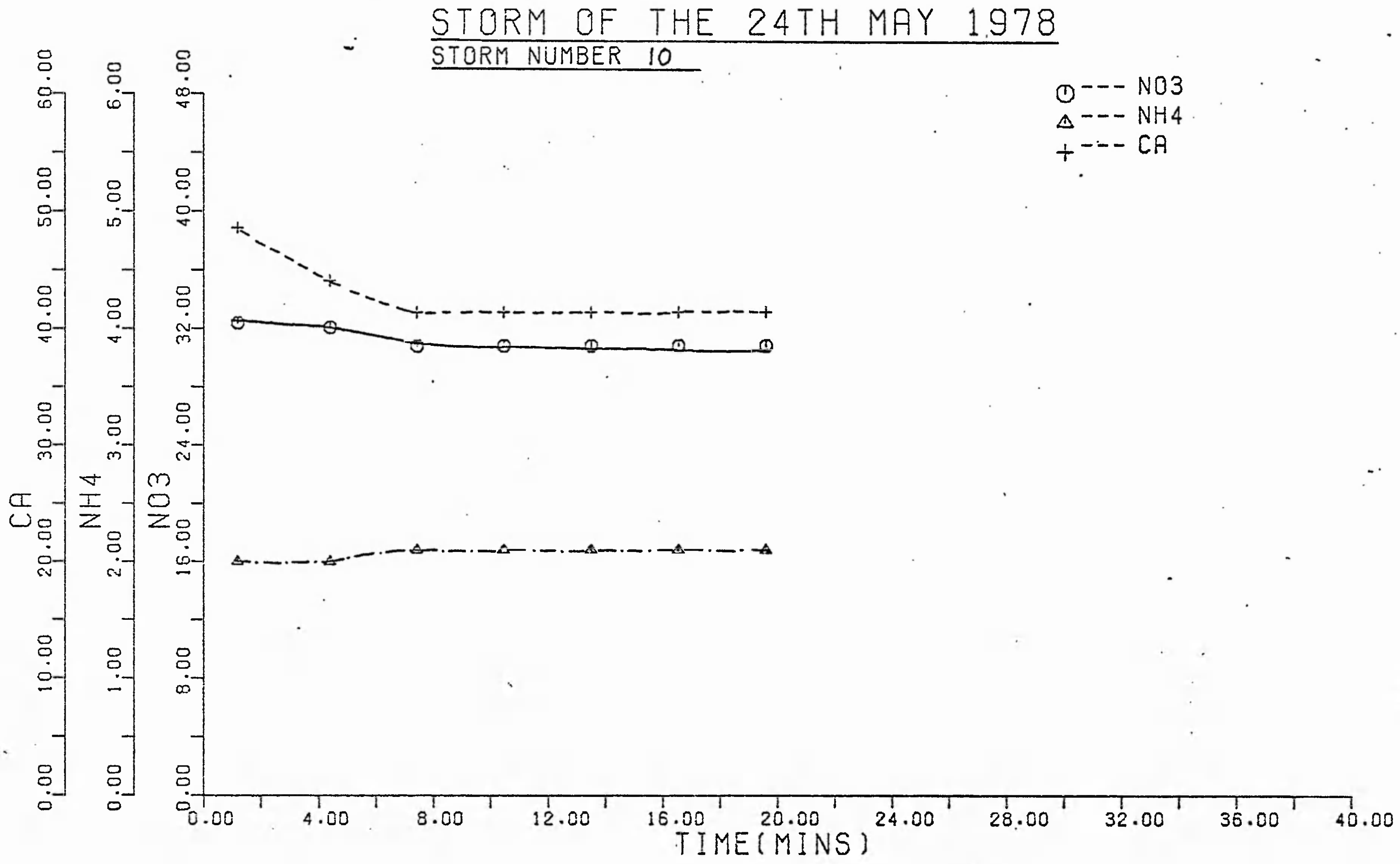


STORM OF THE 15TH MAY 1978

STORM NUMBER 9

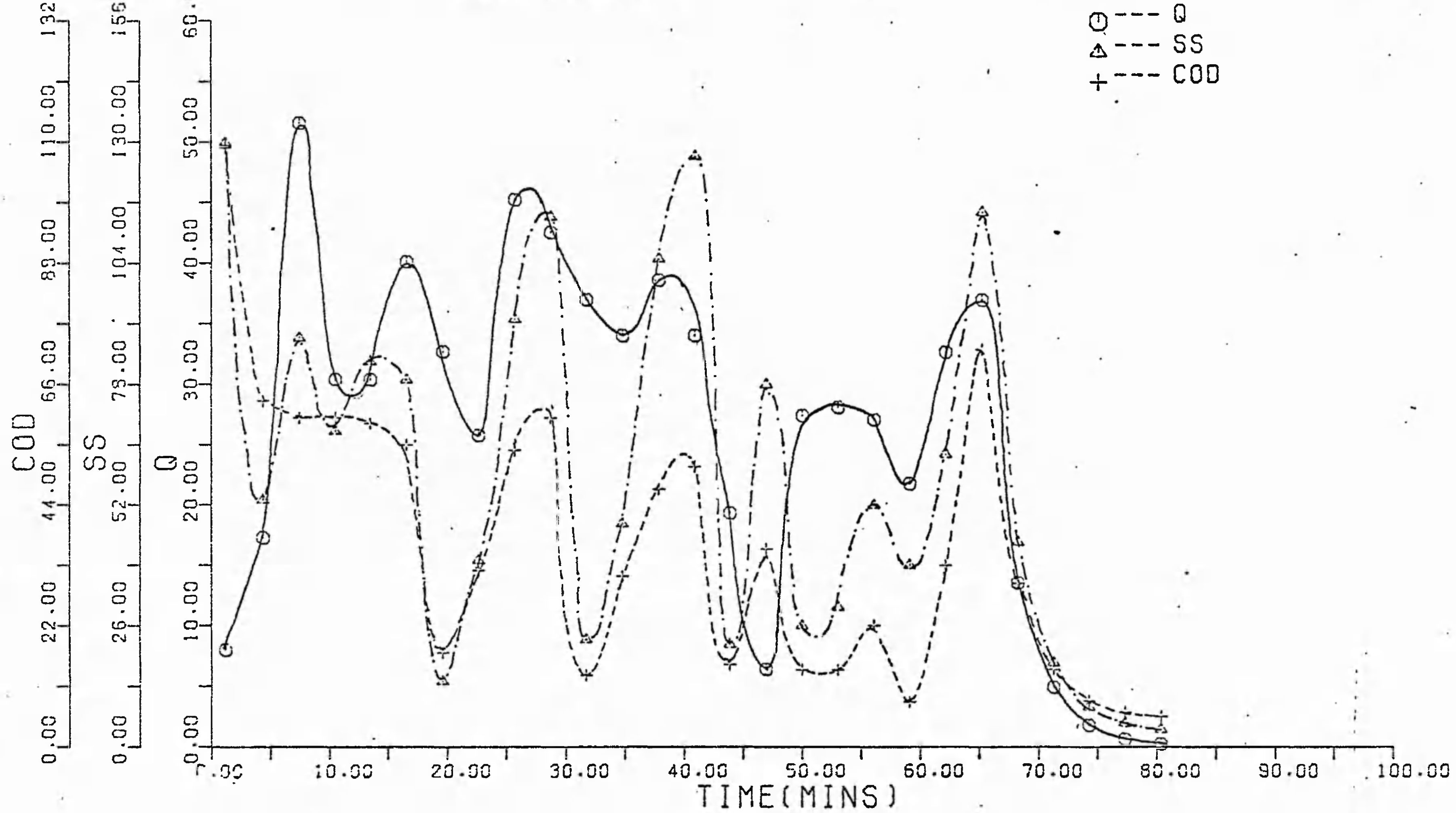

STORM OF THE 24TH MAY 1978
STORM NUMBER 10
Q
SS
COD
COD
SS
Q
0.00
42.00
84.00
126.00
168.00
210.00
252.00
0.00
40.00
80.00
120.00
160.00
200.00
240.00
0.00
6.00
12.00
18.00
24.00
30.00
36.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
36.00
40.00
TIME(MINS)


STORM OF THE 24TH MAY 1978
STORM NUMBER 10
Q
BOD
DS
DS
0.00
80.00
160.00
240.00
320.00
400.00
480.00
BOD
0.00
8.00
16.00
24.00
32.00
40.00
48.00
Q
0.00
6.00
12.00
18.00
24.00
30.00
36.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
36.00
40.00
TIME(MINS)


STORM OF THE 24TH MAY 1978
STORM NUMBER 10
---- NO3
---- NH4
---- CA
CA
0.00
10.00
20.00
30.00
40.00
50.00
60.00
NH4
0.00
1.00
2.00
3.00
4.00
5.00
6.00
NO3
0.00
8.00
16.00
24.00
32.00
40.00
48.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
36.00
40.00
TIME(MINS)

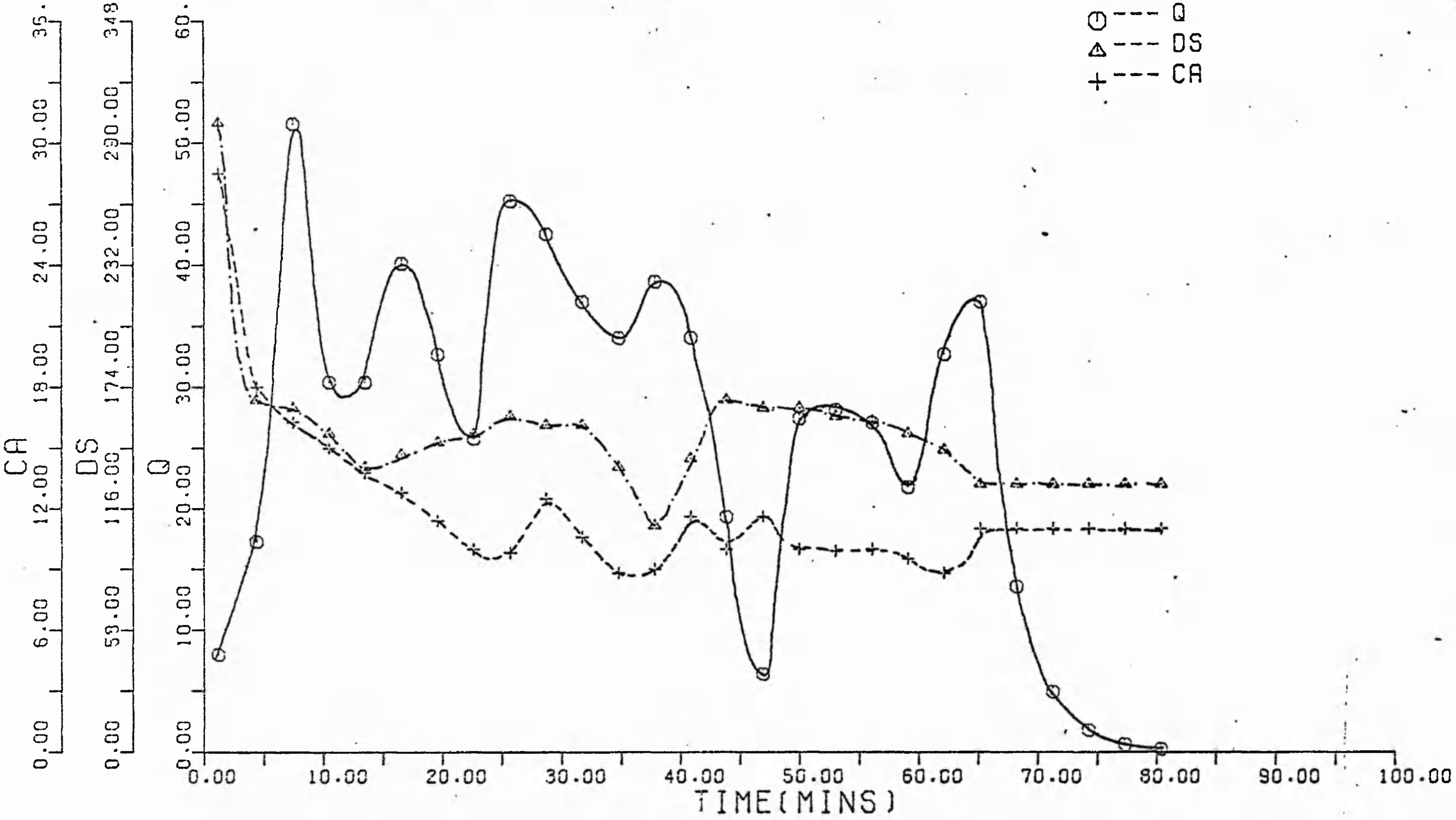
STORM OF THE 1ST JUNE 1978

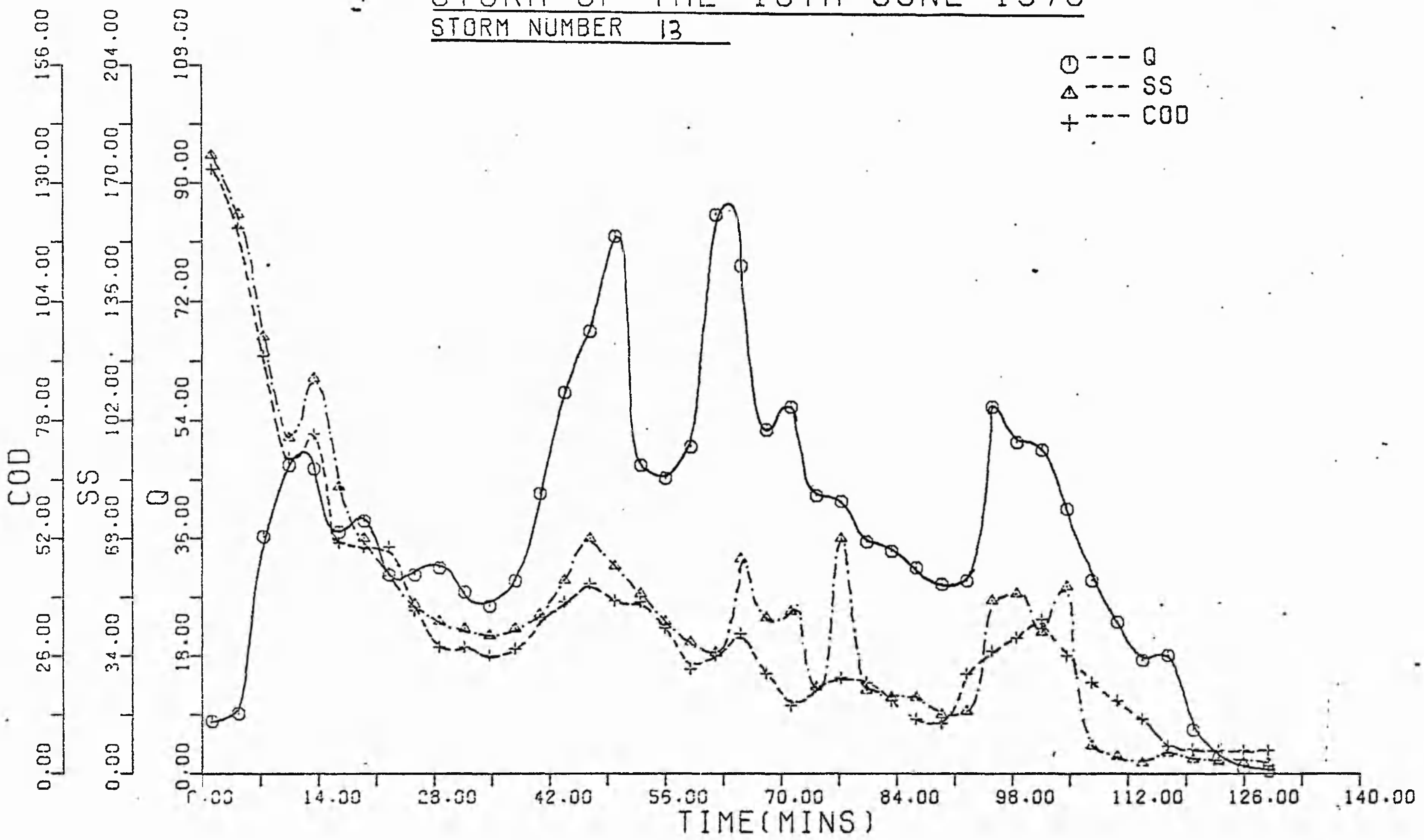
STORM NUMBER 12



STORM OF THE 1ST JUNE 1978

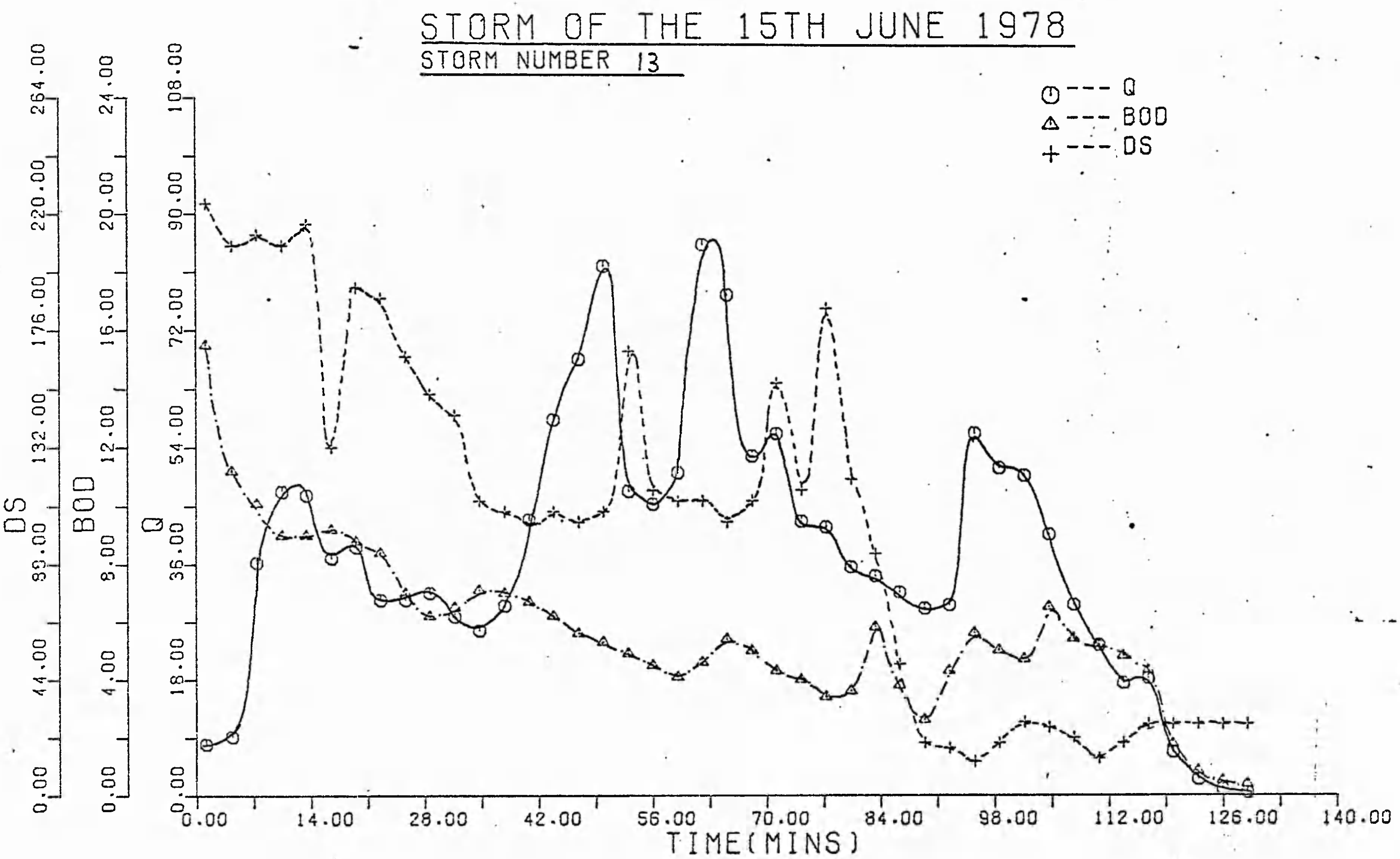
STORM NUMBER 12

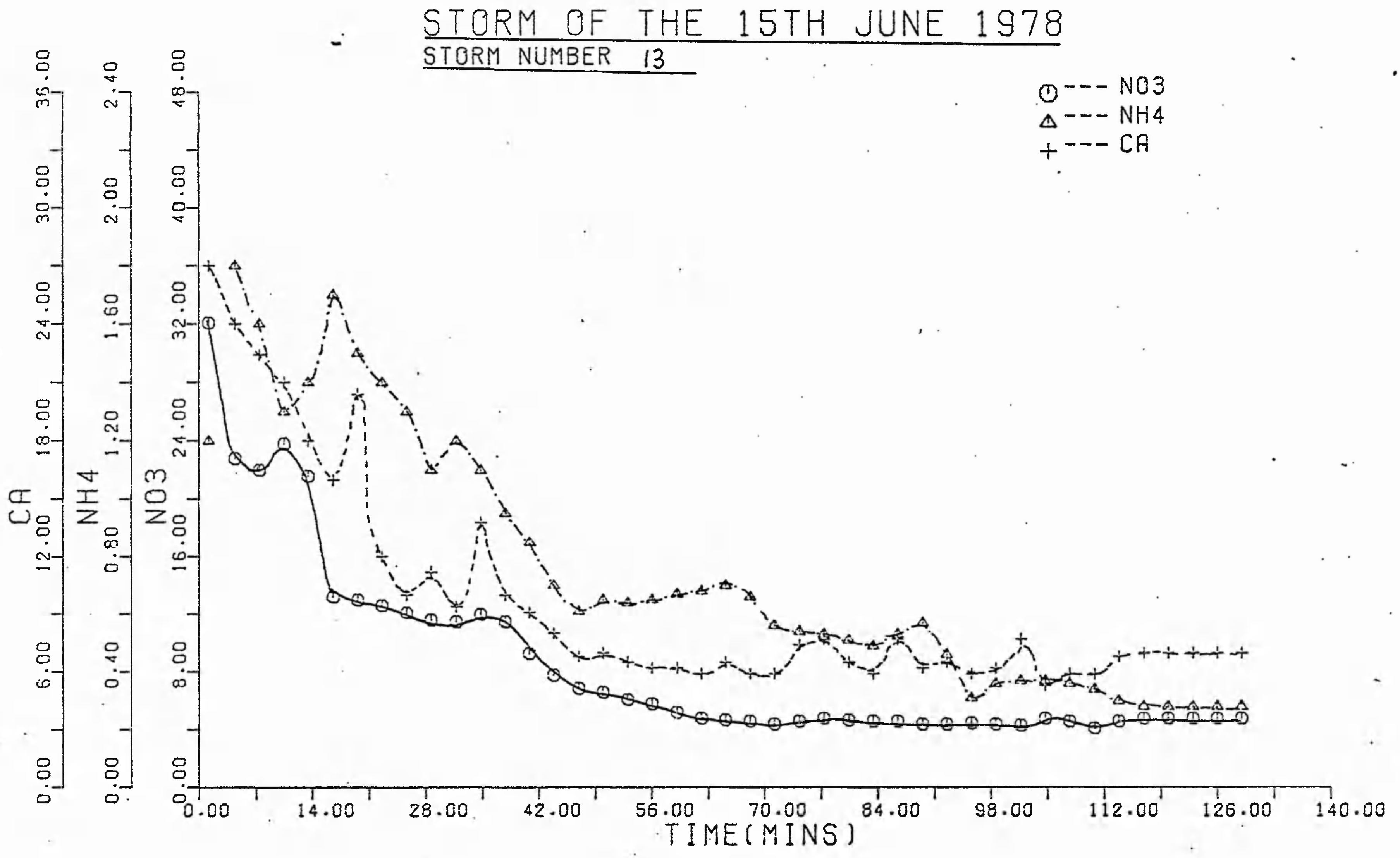




STORM OF THE 15TH JUNE 1978

STORM NUMBER 13


STORM OF THE 15TH JUNE 1978
STORM NUMBER 13
Q
BOD
DS
Q
BOD
DS
0.00
18.00
36.00
54.00
72.00
90.00
108.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
0.00
44.00
88.00
132.00
176.00
220.00
264.00
0.00
14.00
28.00
42.00
56.00
70.00
84.00
98.00
112.00
126.00
140.00
TIME(MINS)

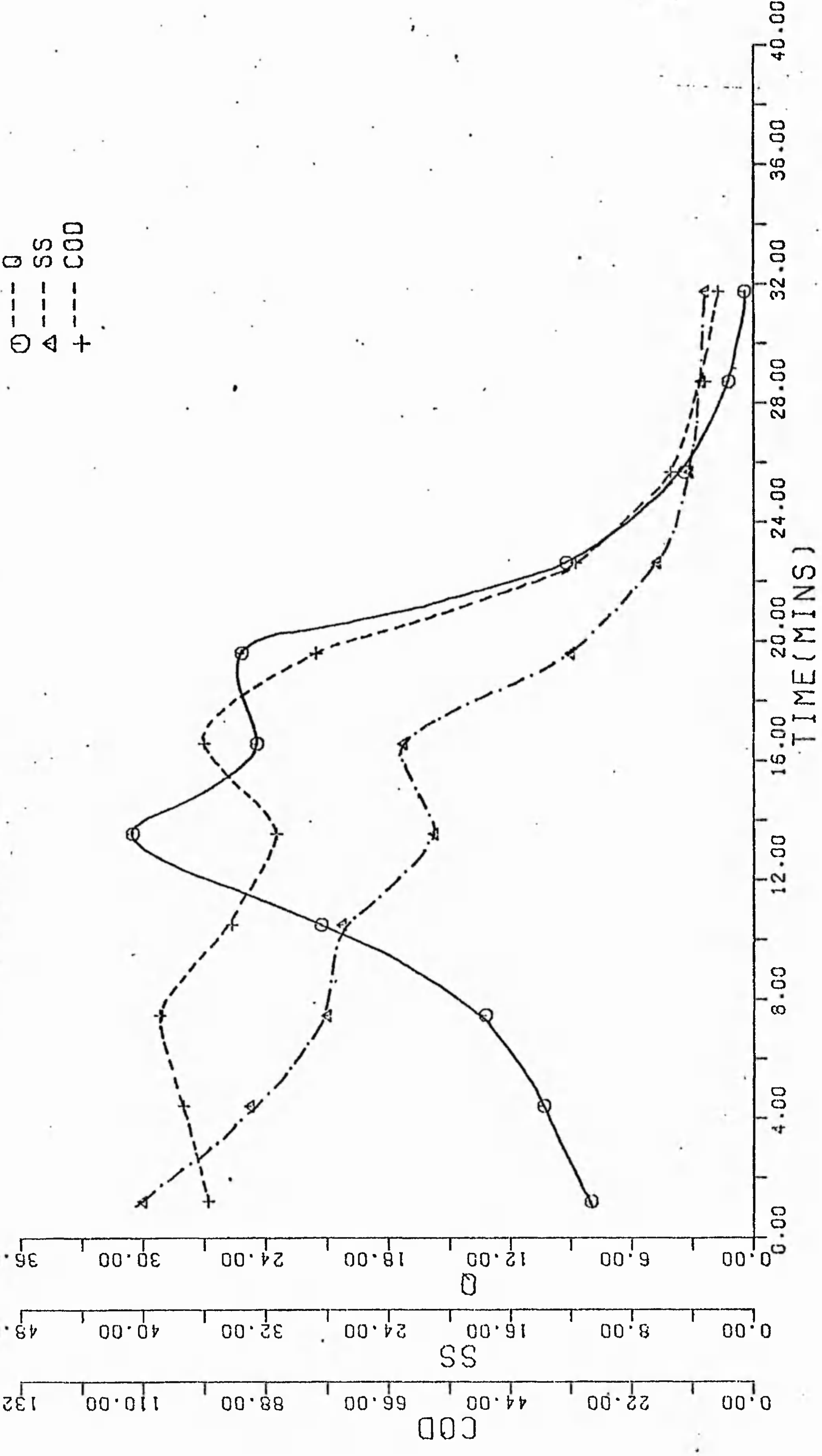


STORM OF THE 15TH JUNE 1978

STORM NUMBER 13

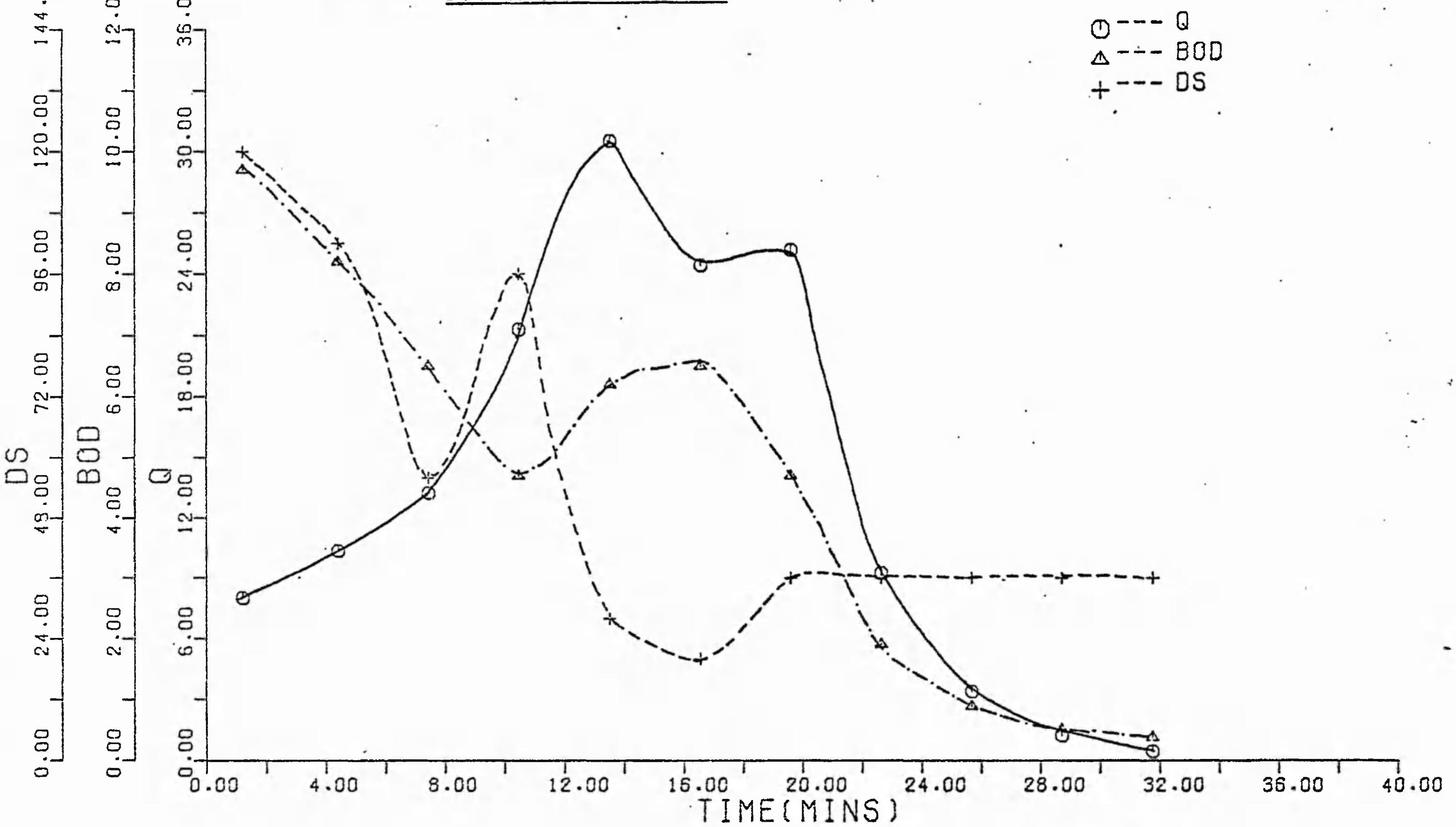
STORM OF THE 29TH JUNE 1978

STORM NUMBER 15



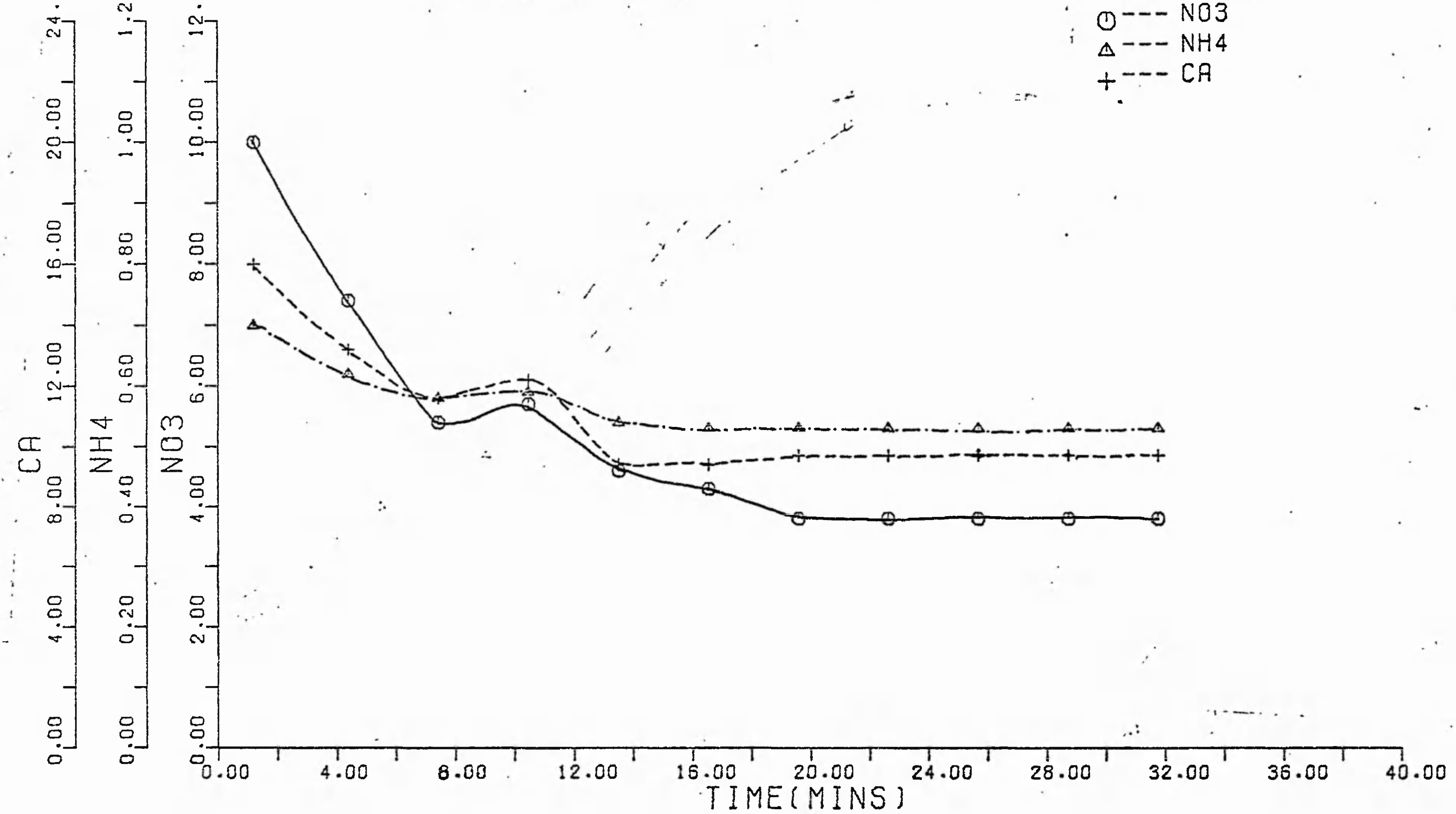
STORM OF THE 29TH JUNE 1978

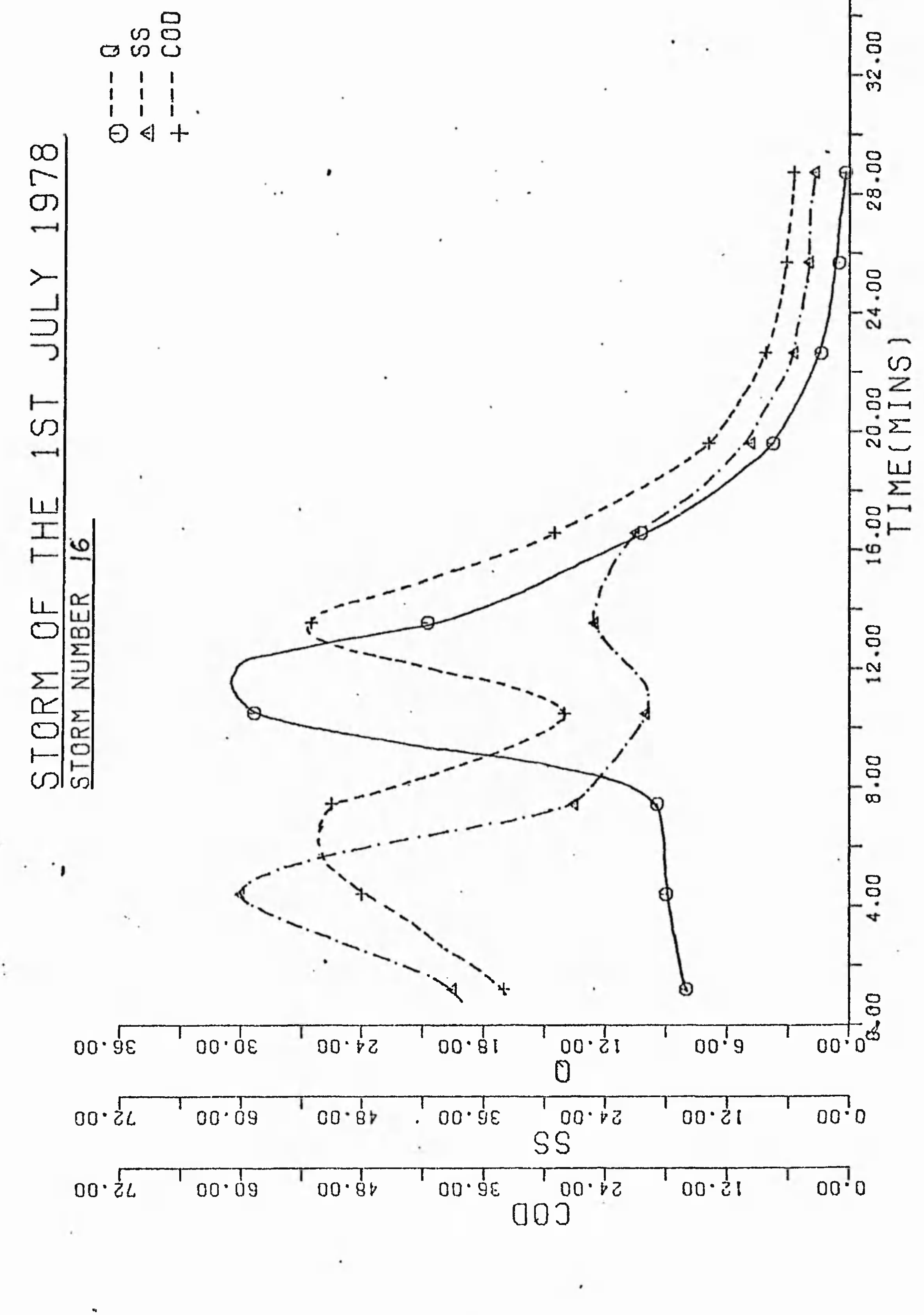
STORM NUMBER 15

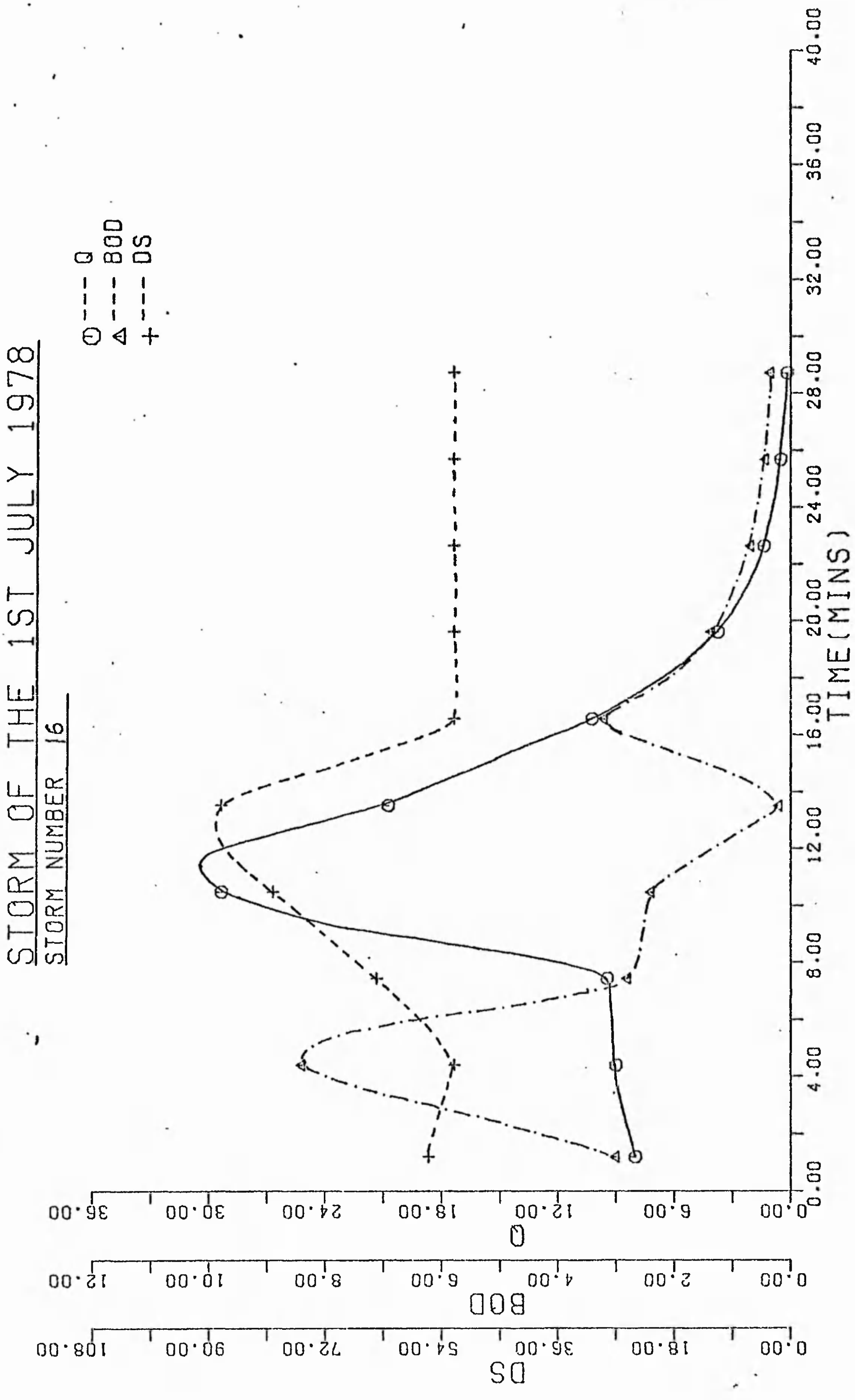


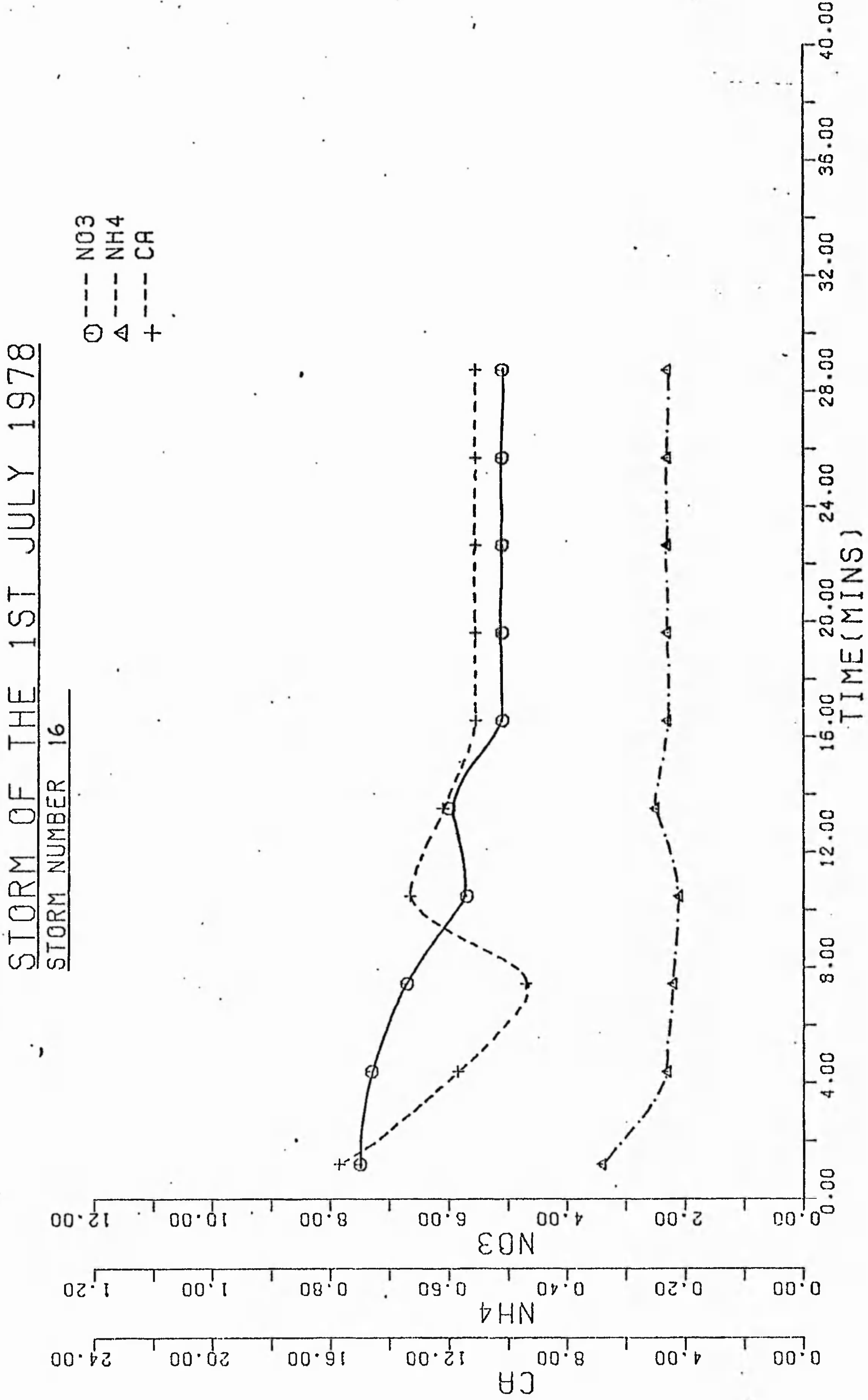
STORM OF THE 29TH JUNE 1978

STORM NUMBER 15



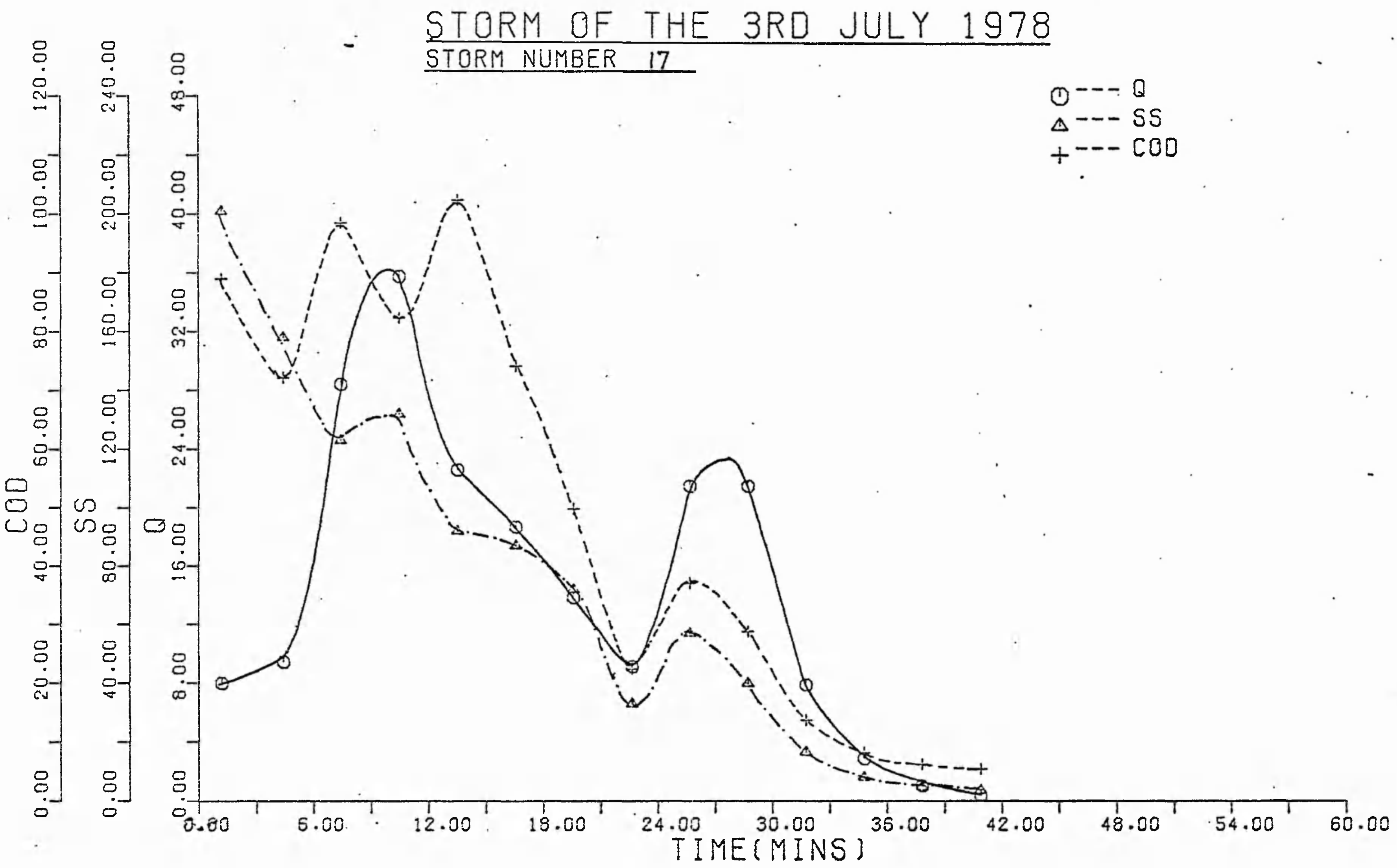

STORM OF THE 1ST JULY 1978
STORM NUMBER 16
Θ --- Q
△ --- SS
+ --- COD
TIME (MINS)
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
36.00
40.00
Q
0.00
6.00
12.00
18.00
24.00
30.00
36.00
SS
0.00
12.00
24.00
36.00
48.00
60.00
72.00
COD
0.00
12.00
24.00
36.00
48.00
60.00
72.00


STORM OF THE 1ST JULY 1978
STORM NUMBER 16
Q
BOD
DS
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
36.00
40.00
TIME (MINS)
0.00
6.00
12.00
18.00
24.00
30.00
36.00
Q
0.00
2.00
4.00
6.00
8.00
10.00
12.00
BOD
0.00
18.00
36.00
54.00
72.00
90.00
108.00
DS



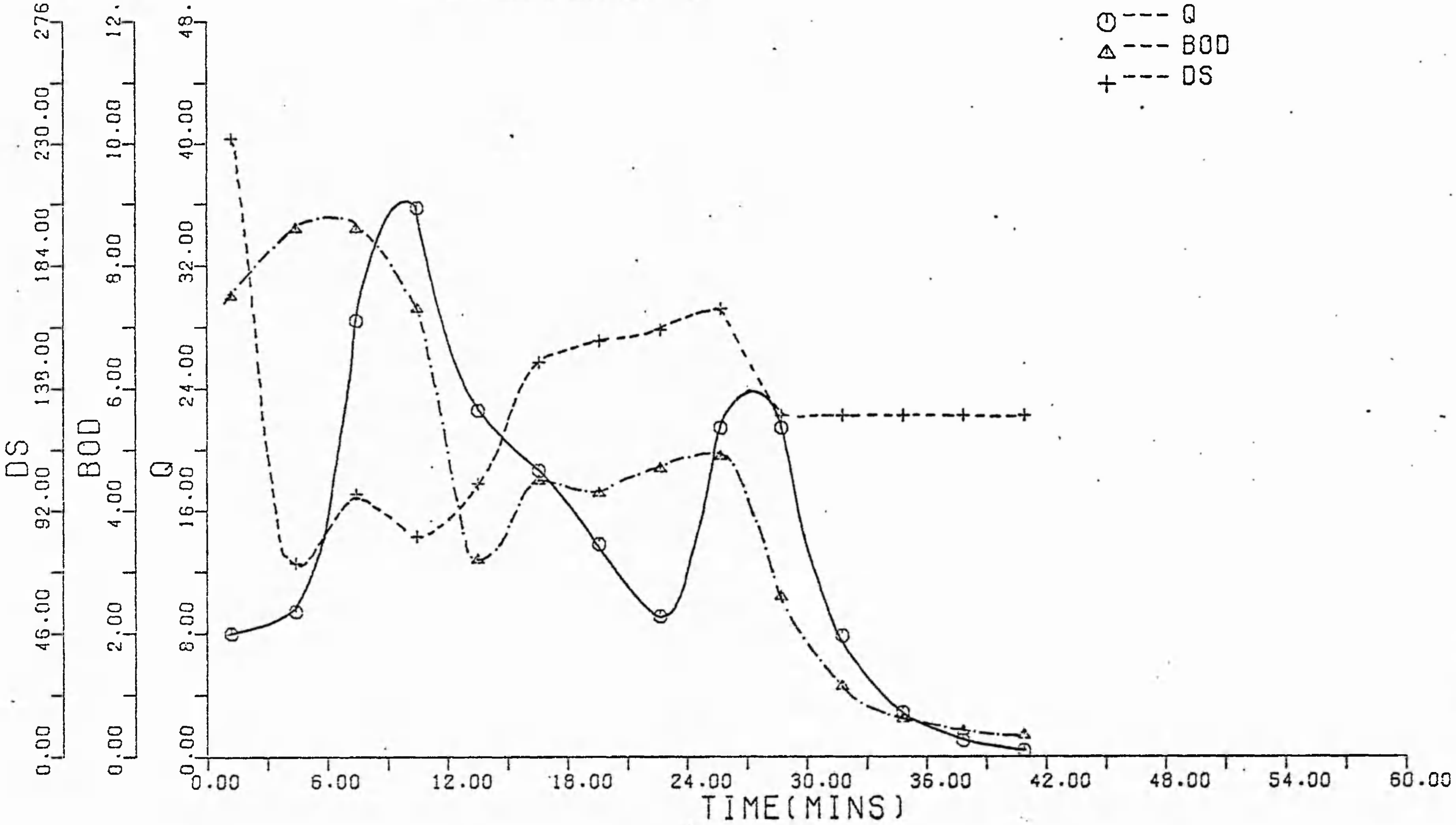
STORM OF THE 1ST JULY 1978

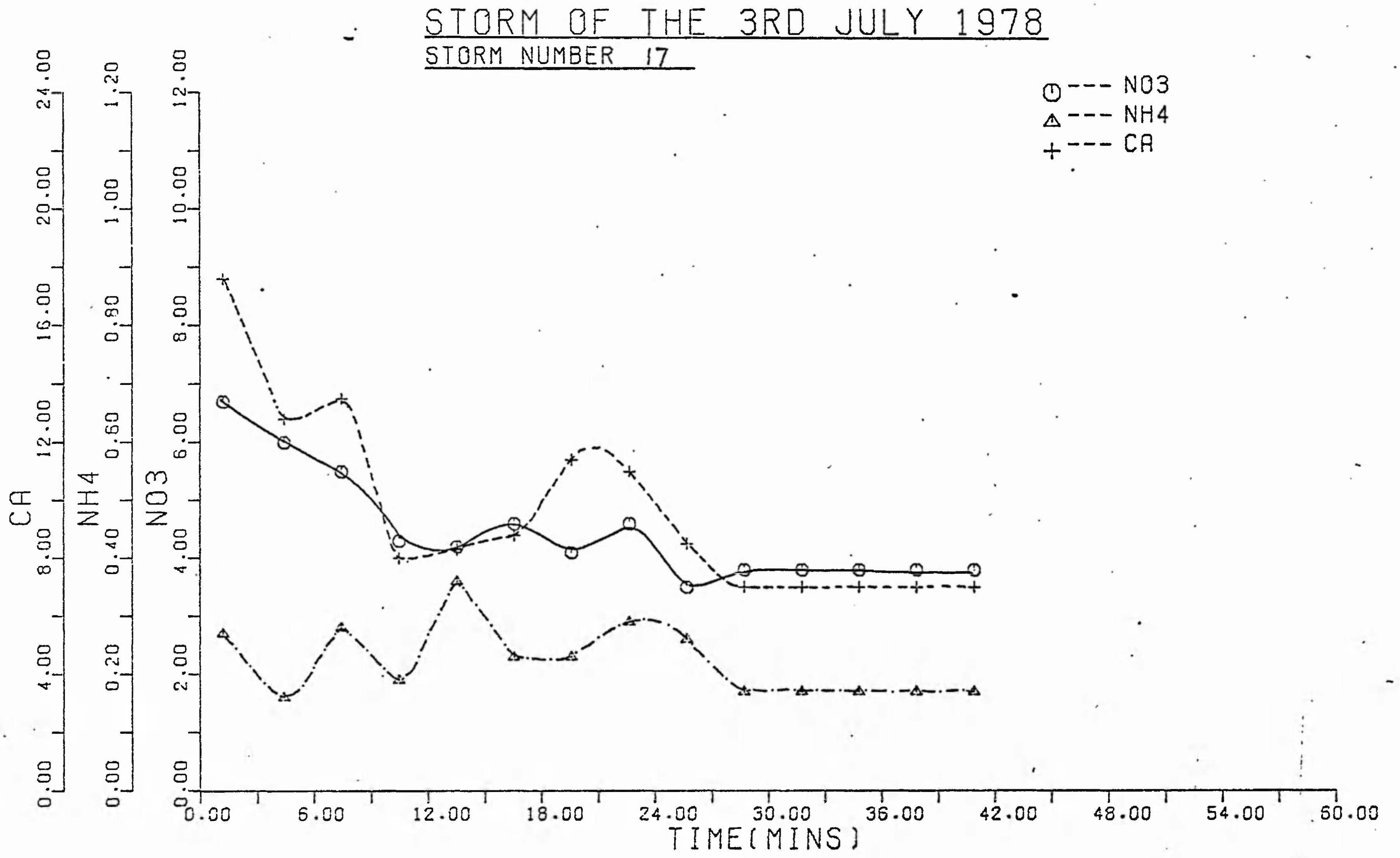
STORM NUMBER 16


STORM OF THE 3RD JULY 1978
STORM NUMBER 17
Q
SS
COD
COD
SS
Q
0.00
20.00
40.00
60.00
80.00
100.00
120.00
0.00
40.00
80.00
120.00
160.00
200.00
240.00
0.00
8.00
16.00
24.00
32.00
40.00
48.00
0.00
6.00
12.00
18.00
24.00
30.00
36.00
42.00
48.00
54.00
60.00
TIME(MINS)

STORM OF THE 3RD JULY 1978

STORM NUMBER 17



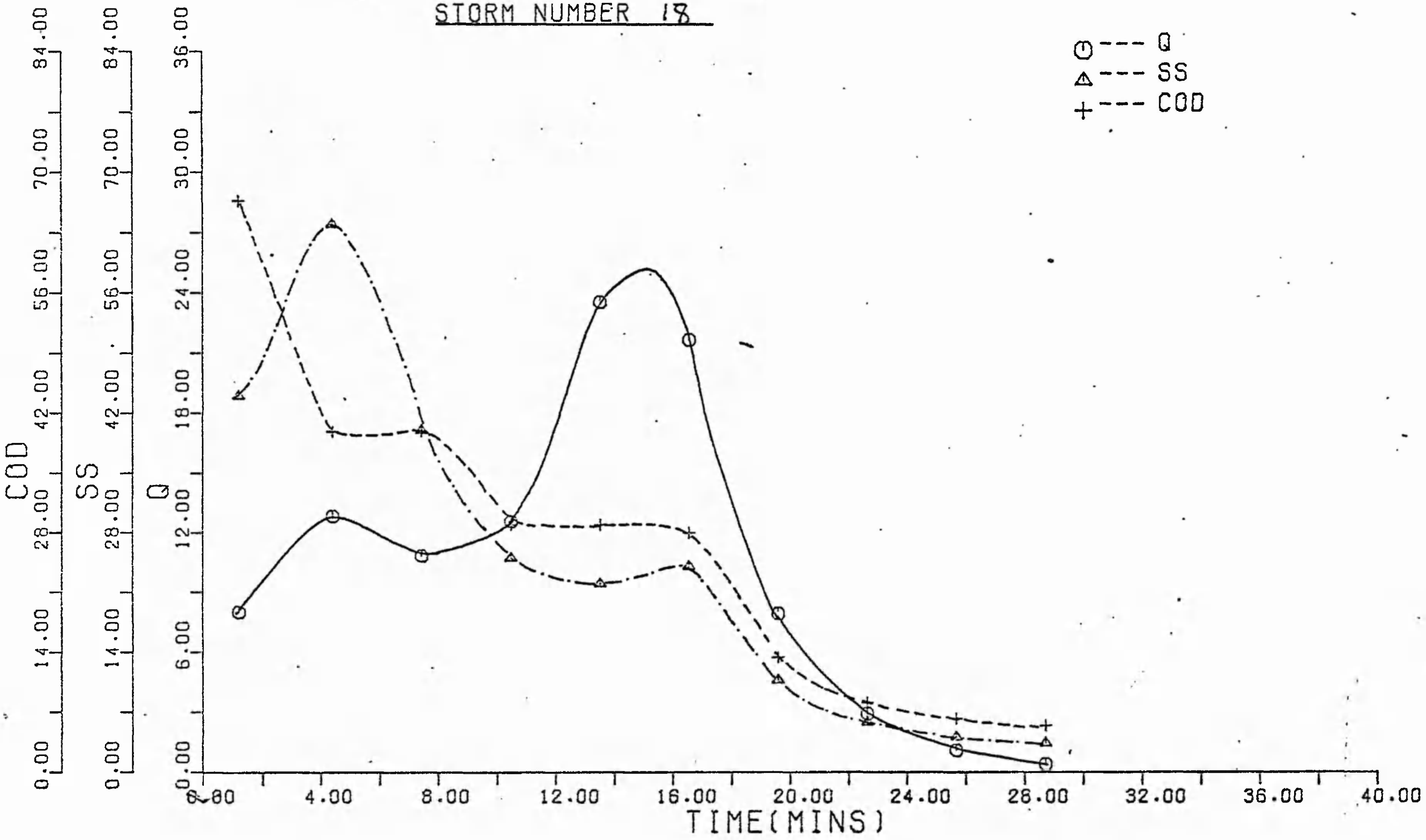


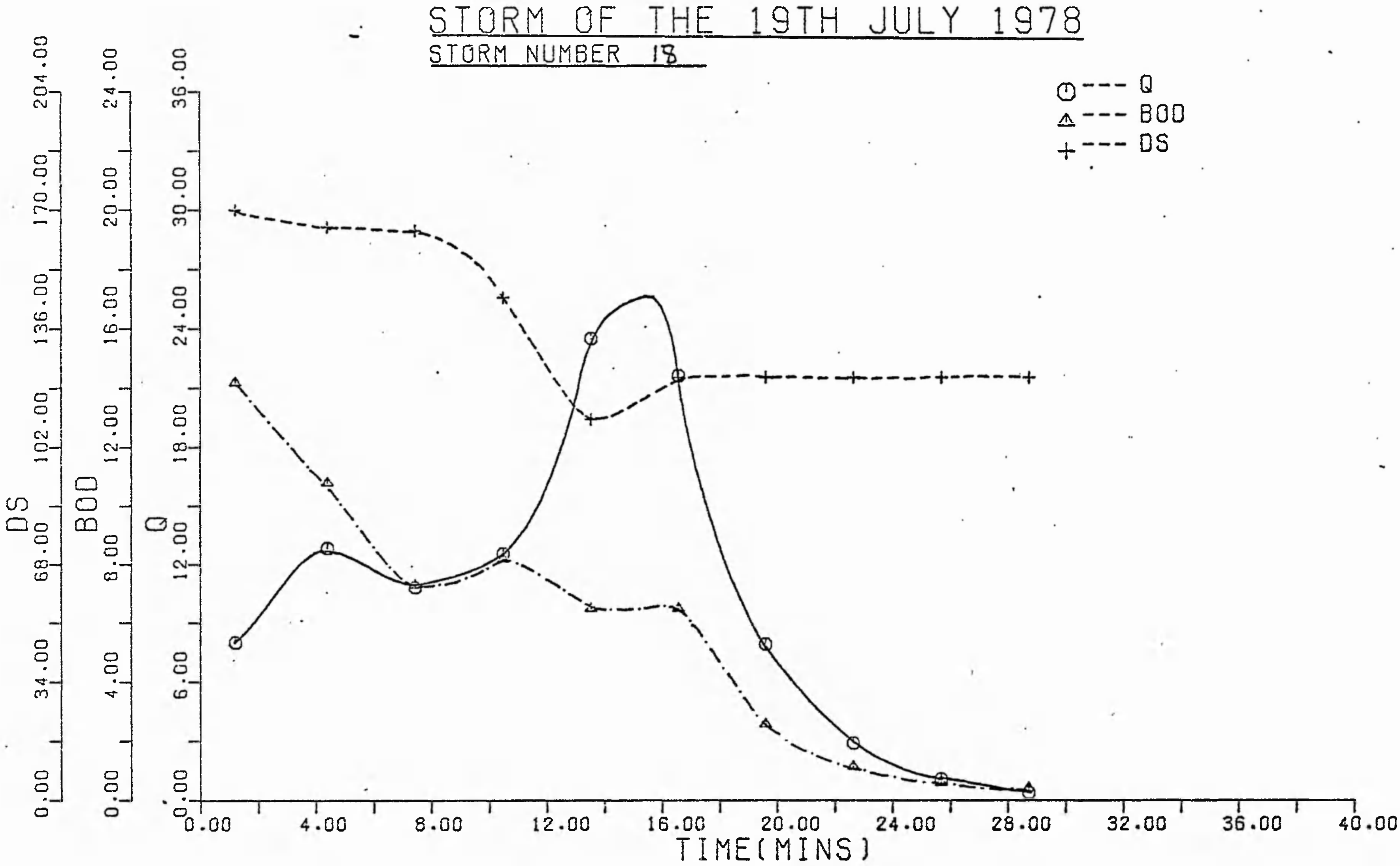
STORM OF THE 3RD JULY 1978

STORM NUMBER 17

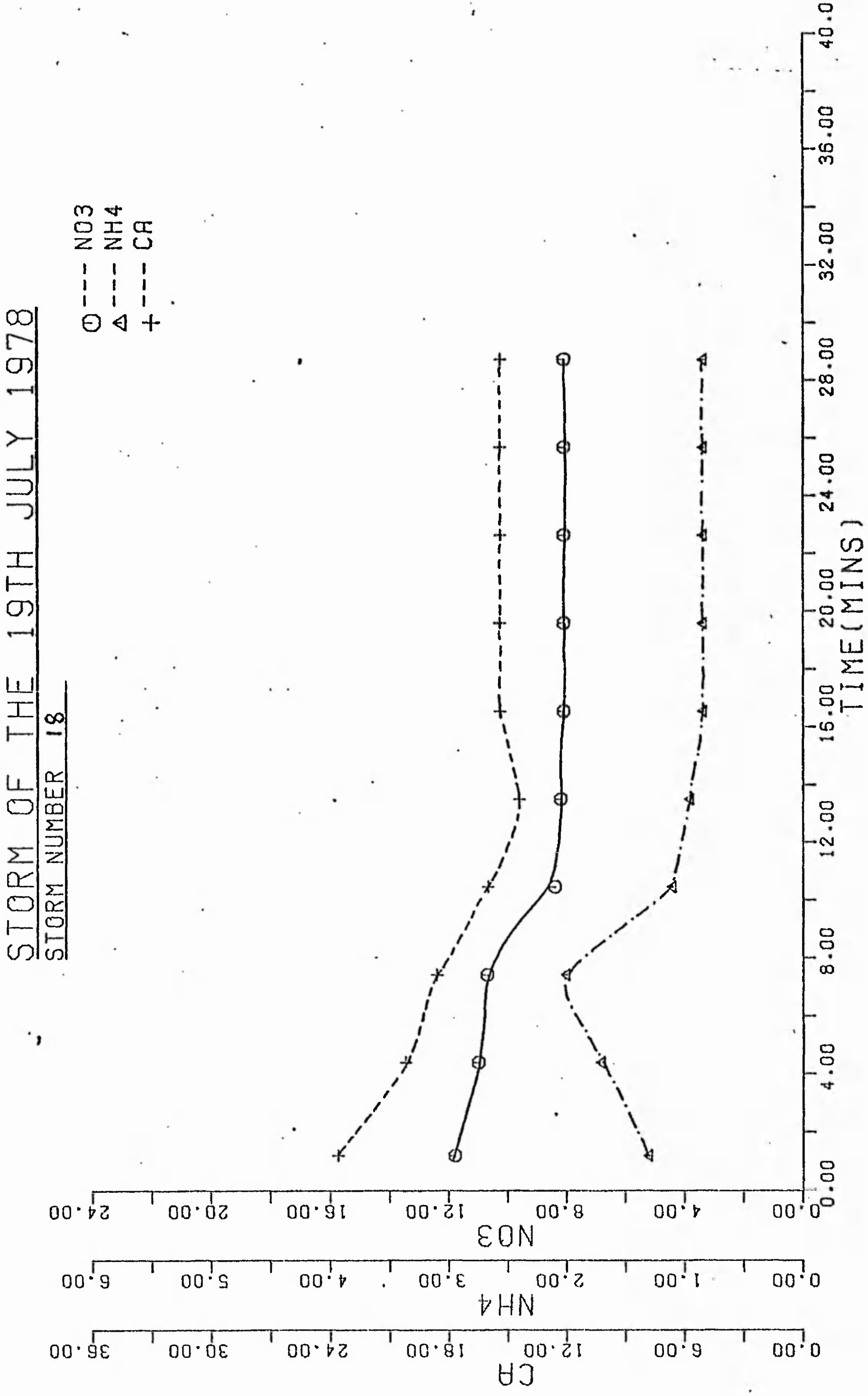
STORM OF THE 19TH JULY 1978

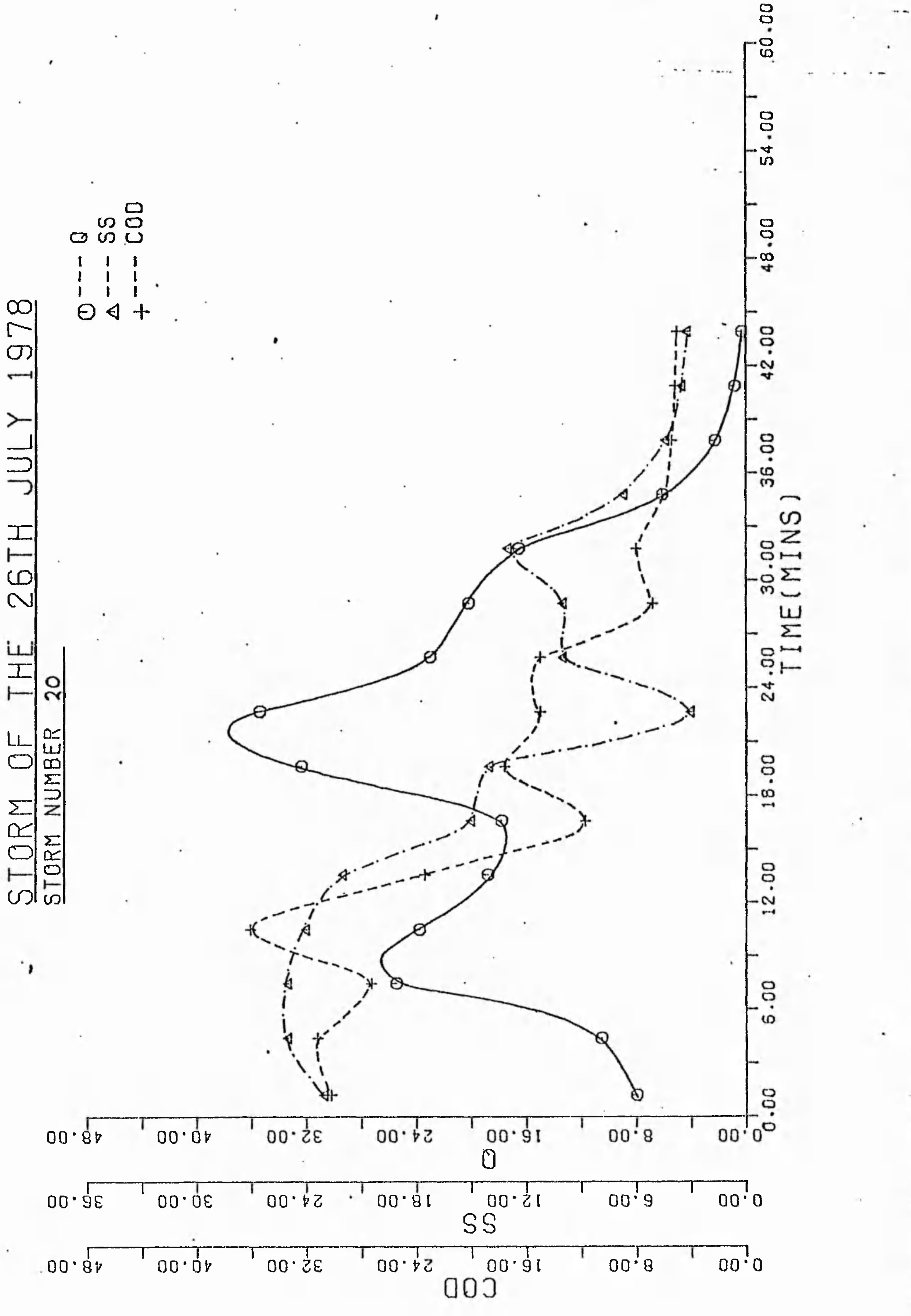
STORM NUMBER 18




STORM OF THE 19TH JULY 1978

STORM NUMBER 18


STORM OF THE 19TH JULY 1978
STORM NUMBER 18
○ ---- NO3
△ ---- NH4
+ ---- CA
TIME(MINS)
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
36.00
40.00
NO3
0.00
4.00
8.00
12.00
16.00
20.00
24.00
NH4
0.00
1.00
2.00
3.00
4.00
5.00
6.00
CA
0.00
6.00
12.00
18.00
24.00
30.00
36.00

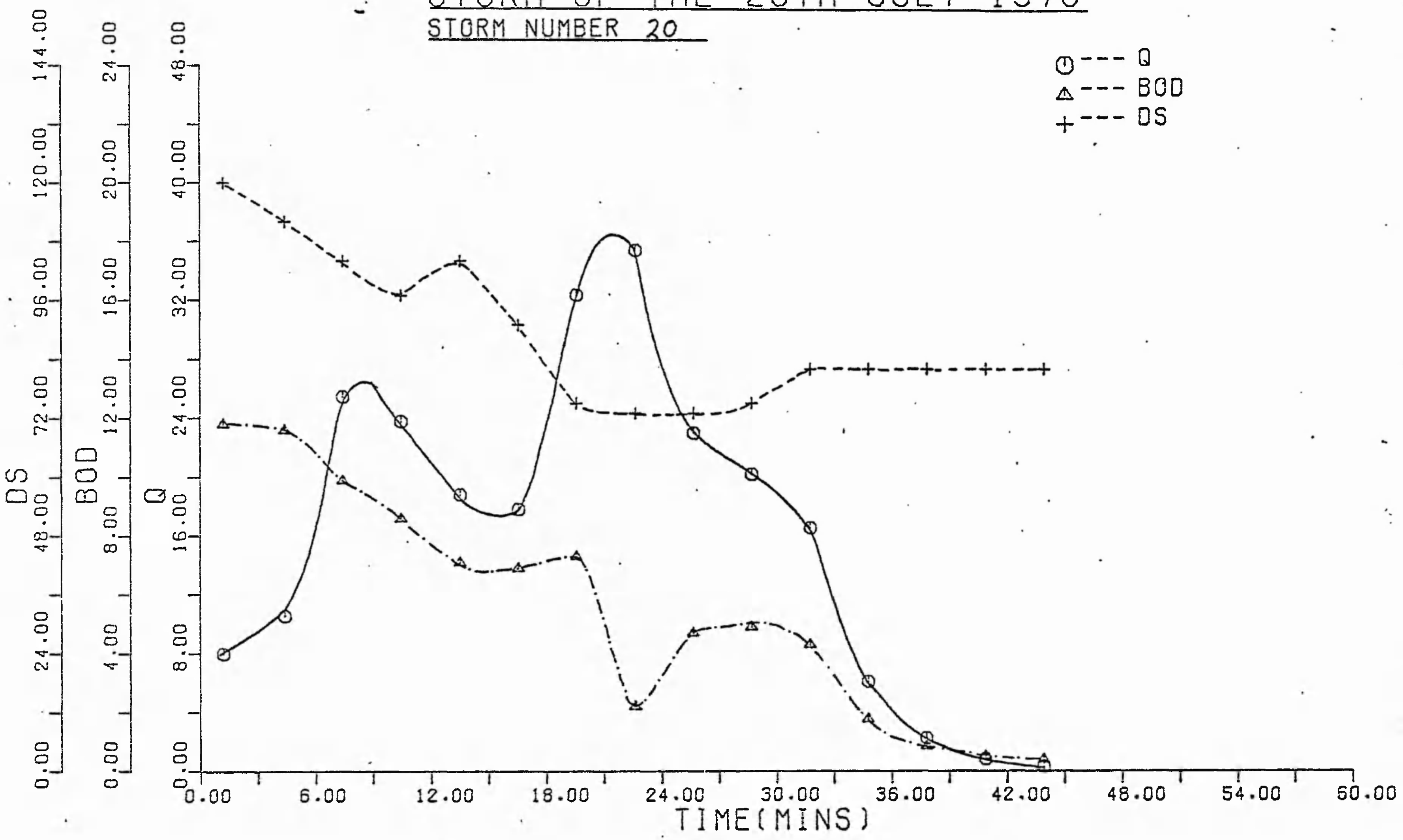


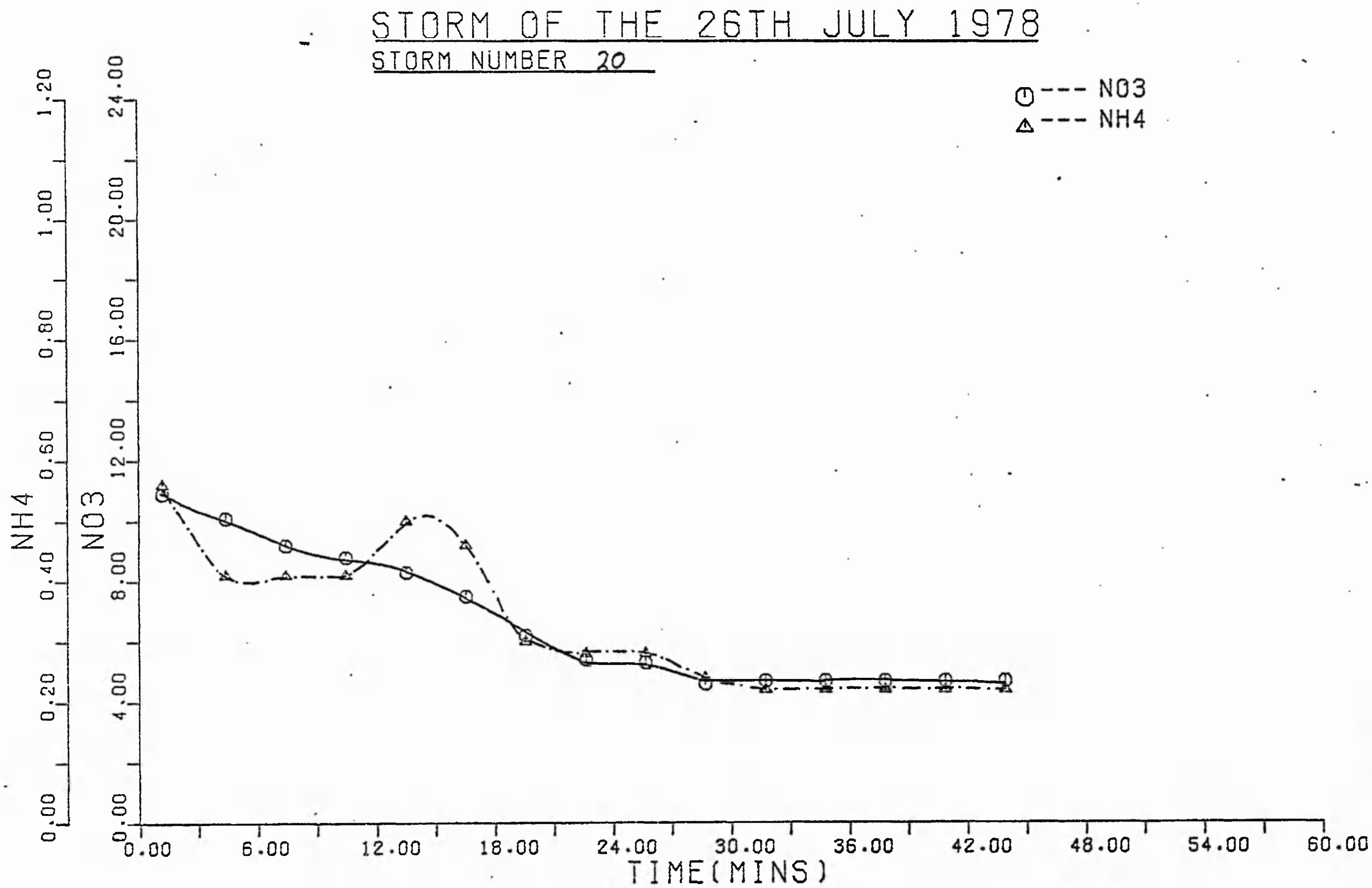
STORM OF THE 26TH JULY 1978

STORM NUMBER 20

STORM OF THE 26TH JULY 1978

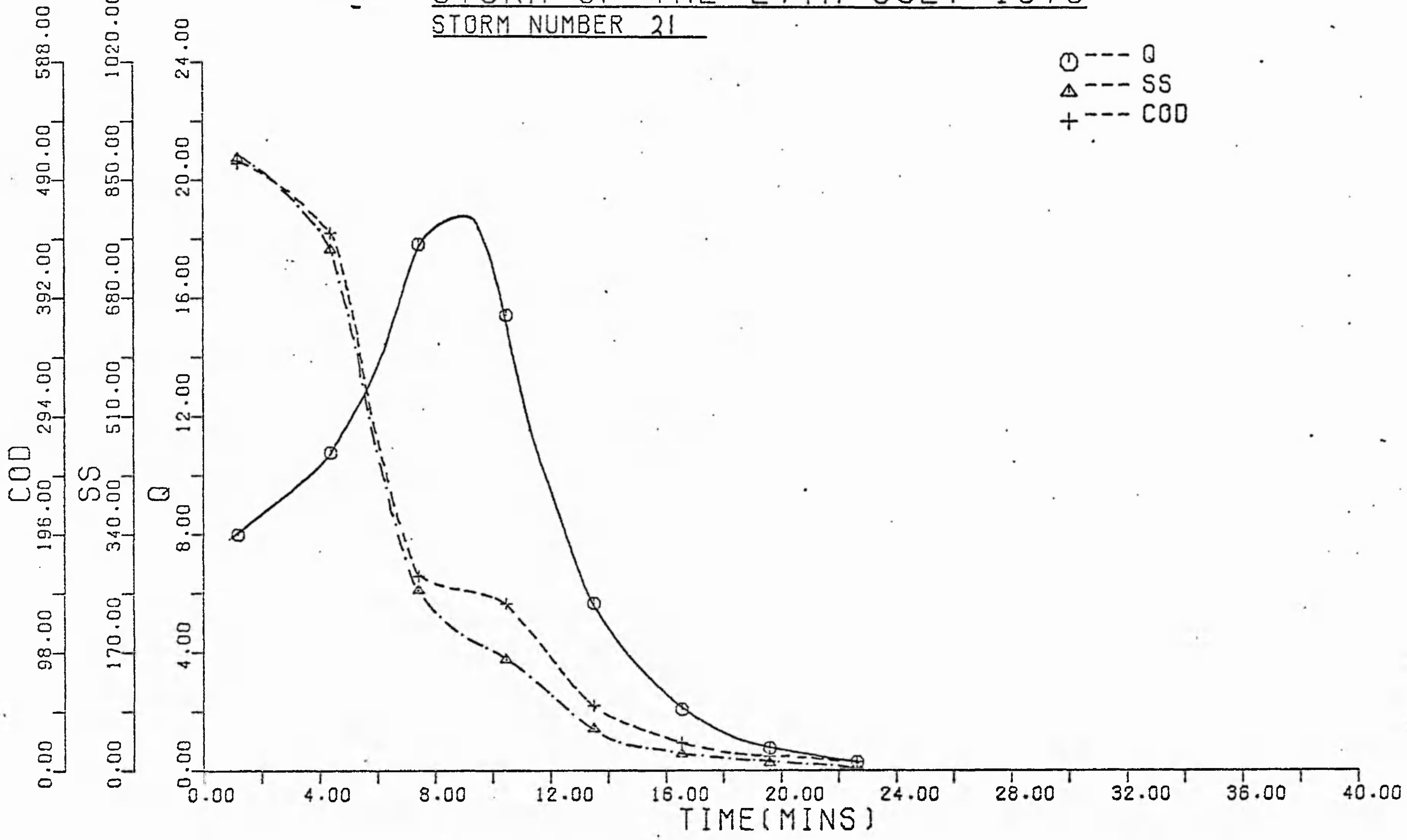
STORM NUMBER 20




STORM OF THE 26TH JULY 1978
STORM NUMBER 20
---- NO3
---- NH4
NH4
0.00
0.20
0.40
0.60
0.80
1.00
1.20
NO3
0.00
4.00
8.00
12.00
16.00
20.00
24.00
0.00
6.00
12.00
18.00
24.00
30.00
36.00
42.00
48.00
54.00
60.00
TIME(MINS)

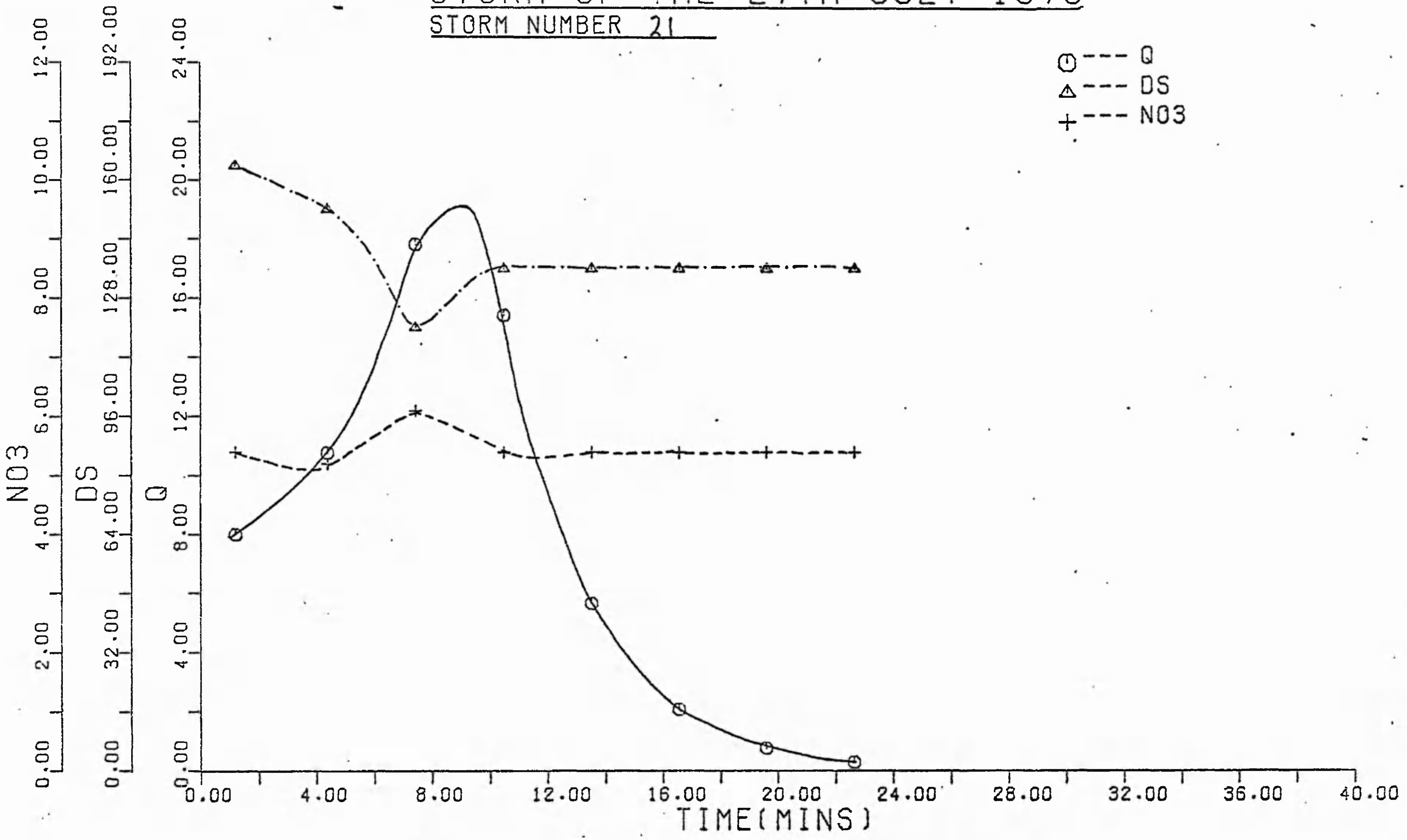
STORM OF THE 27TH JULY 1978

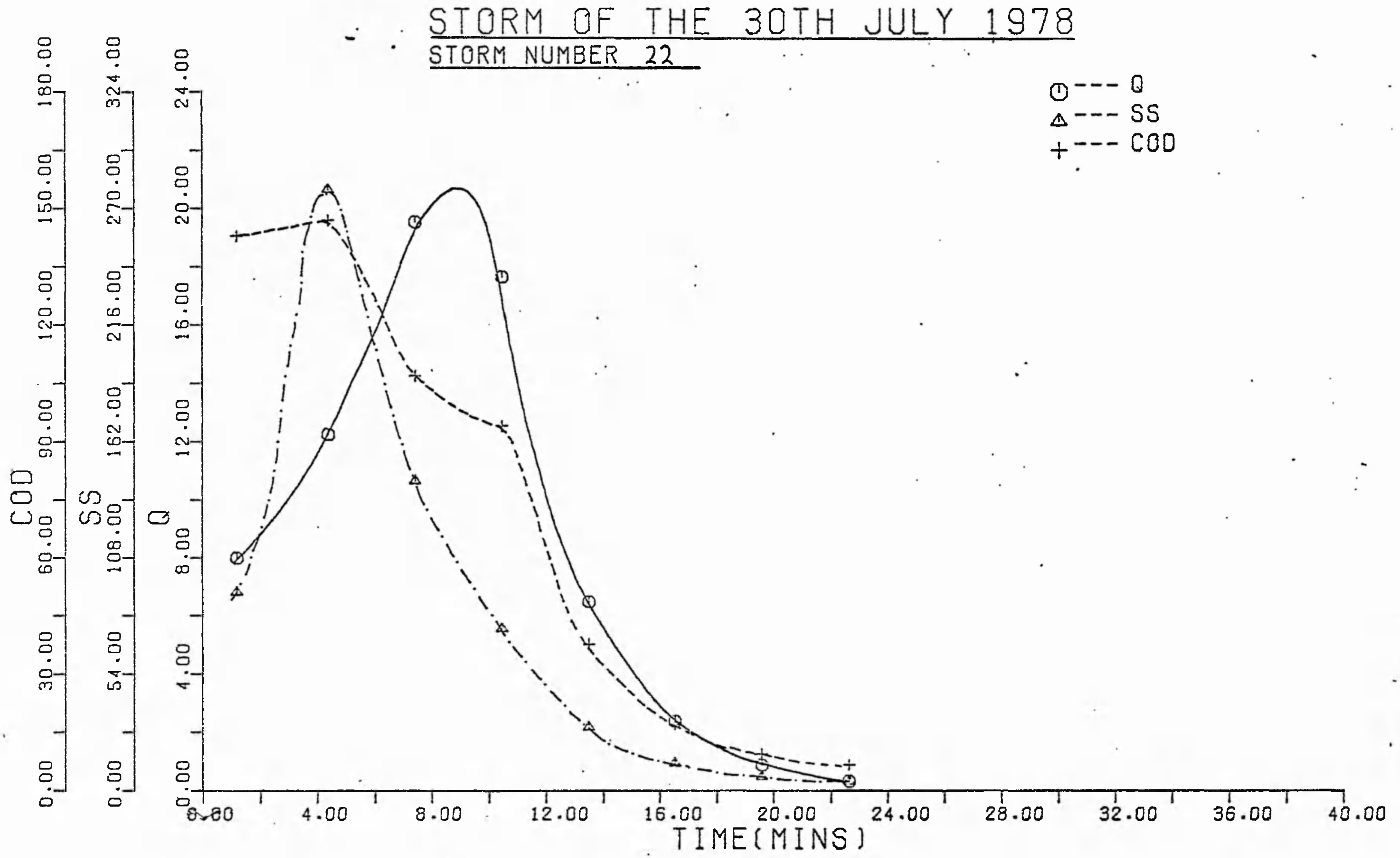
STORM NUMBER 21

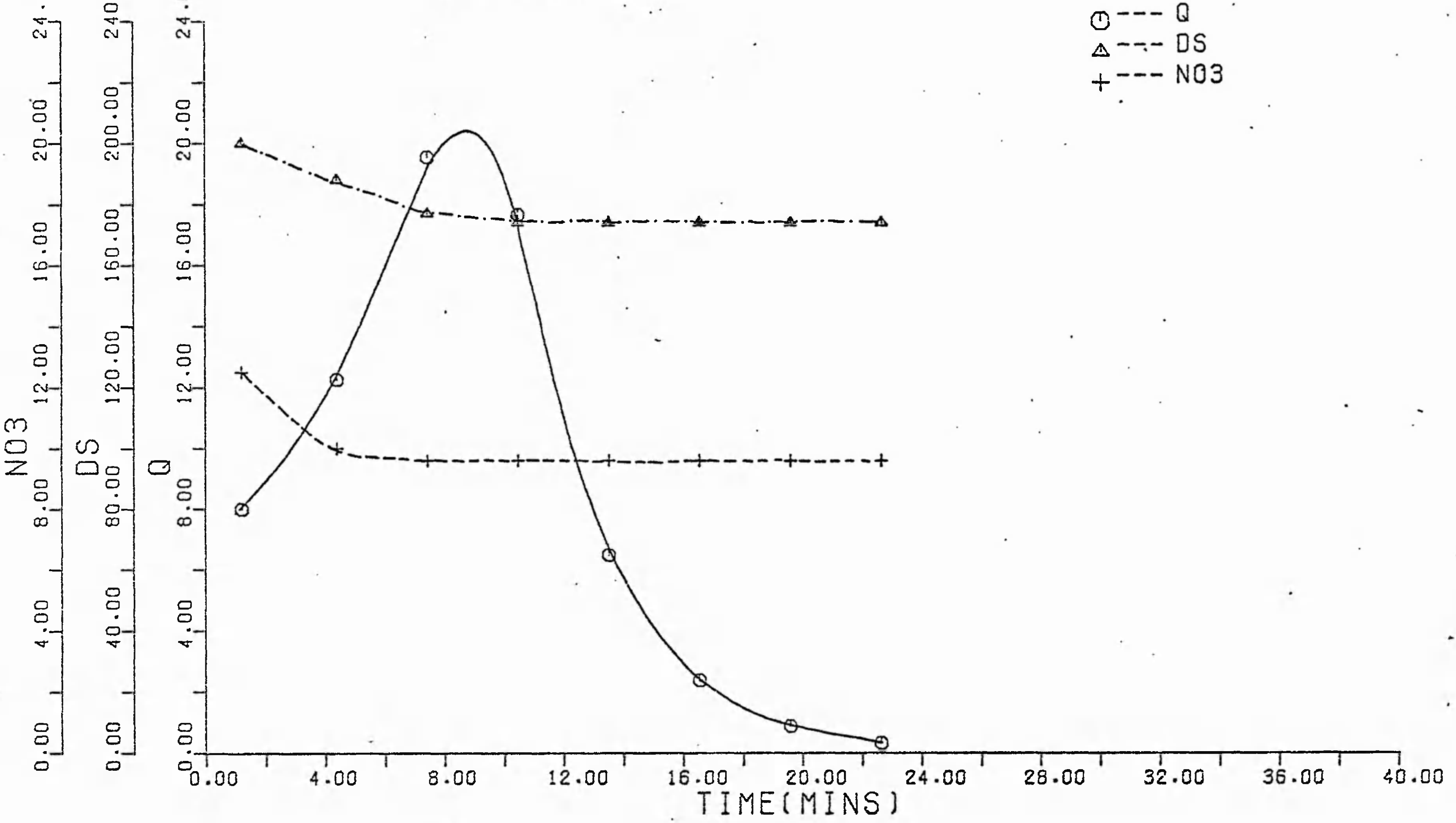


STORM OF THE 27TH JULY 1978

STORM NUMBER 21

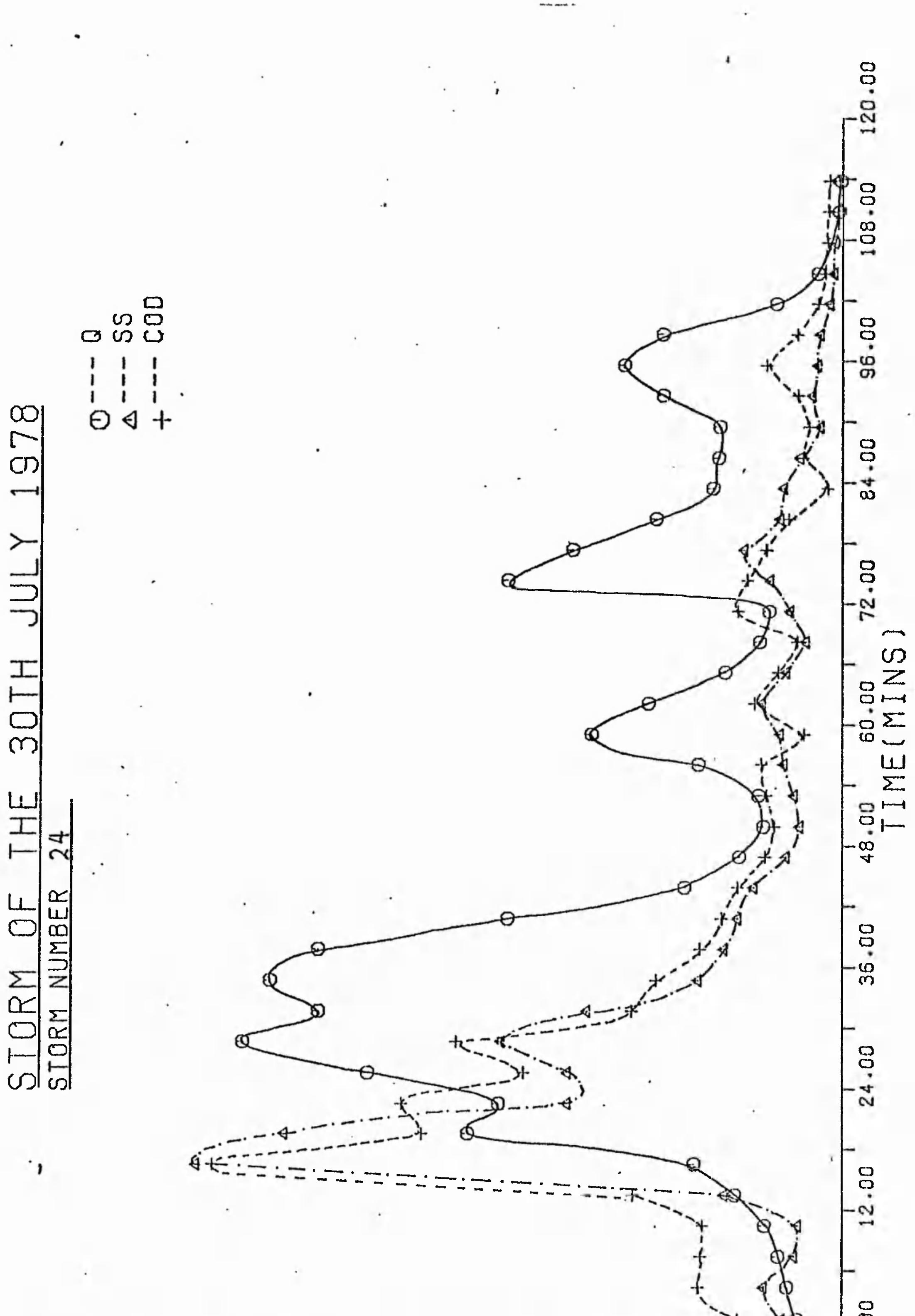



STORM OF THE 30TH JULY 1978
STORM NUMBER 22
Q
SS
COD
COD
0.00
30.00
60.00
90.00
120.00
150.00
180.00
SS
0.00
54.00
108.00
162.00
216.00
270.00
324.00
Q
0.00
4.00
8.00
12.00
16.00
20.00
24.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
36.00
40.00
TIME(MINS)



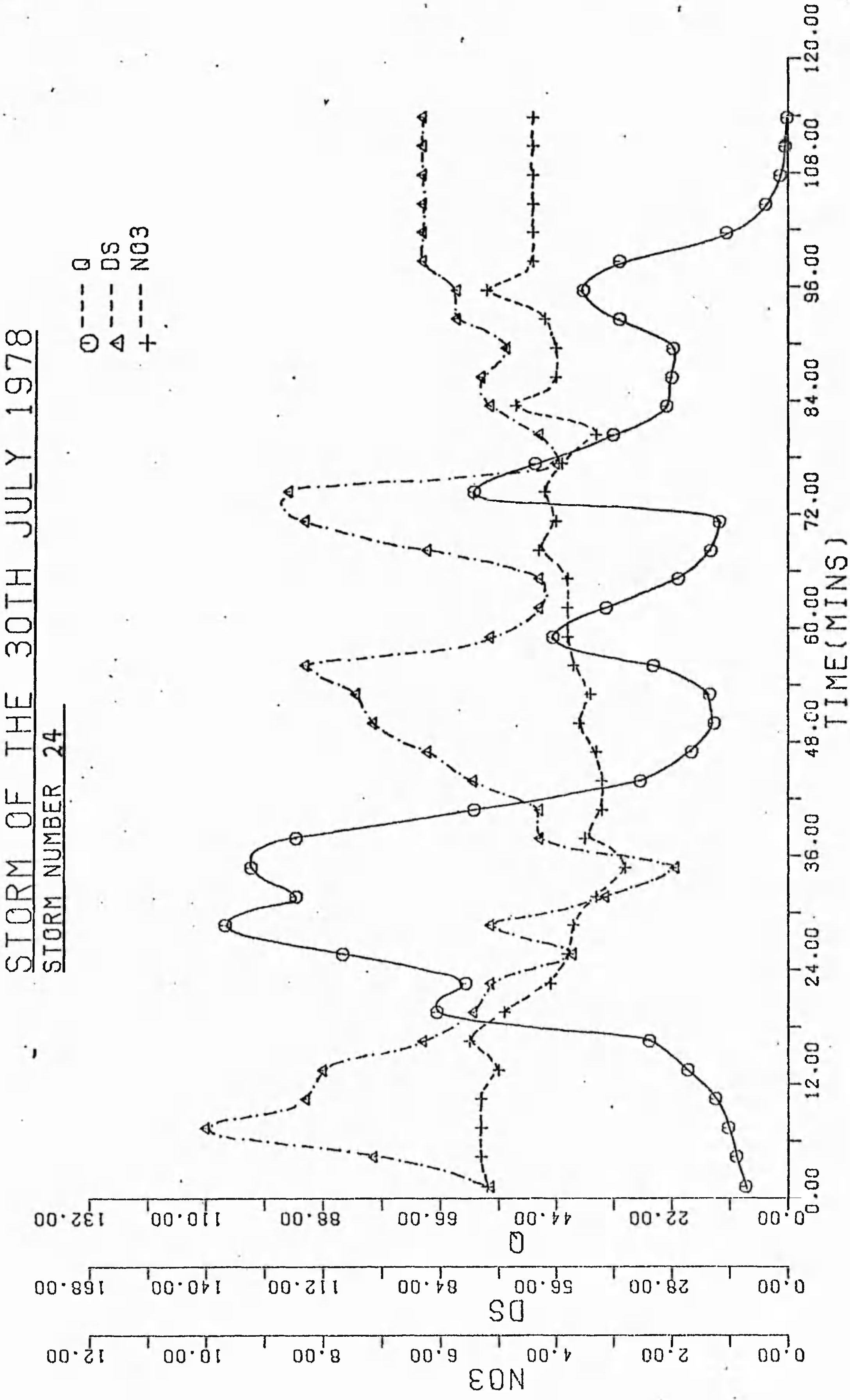
STORM OF THE 30TH JULY 1978

STORM NUMBER 22



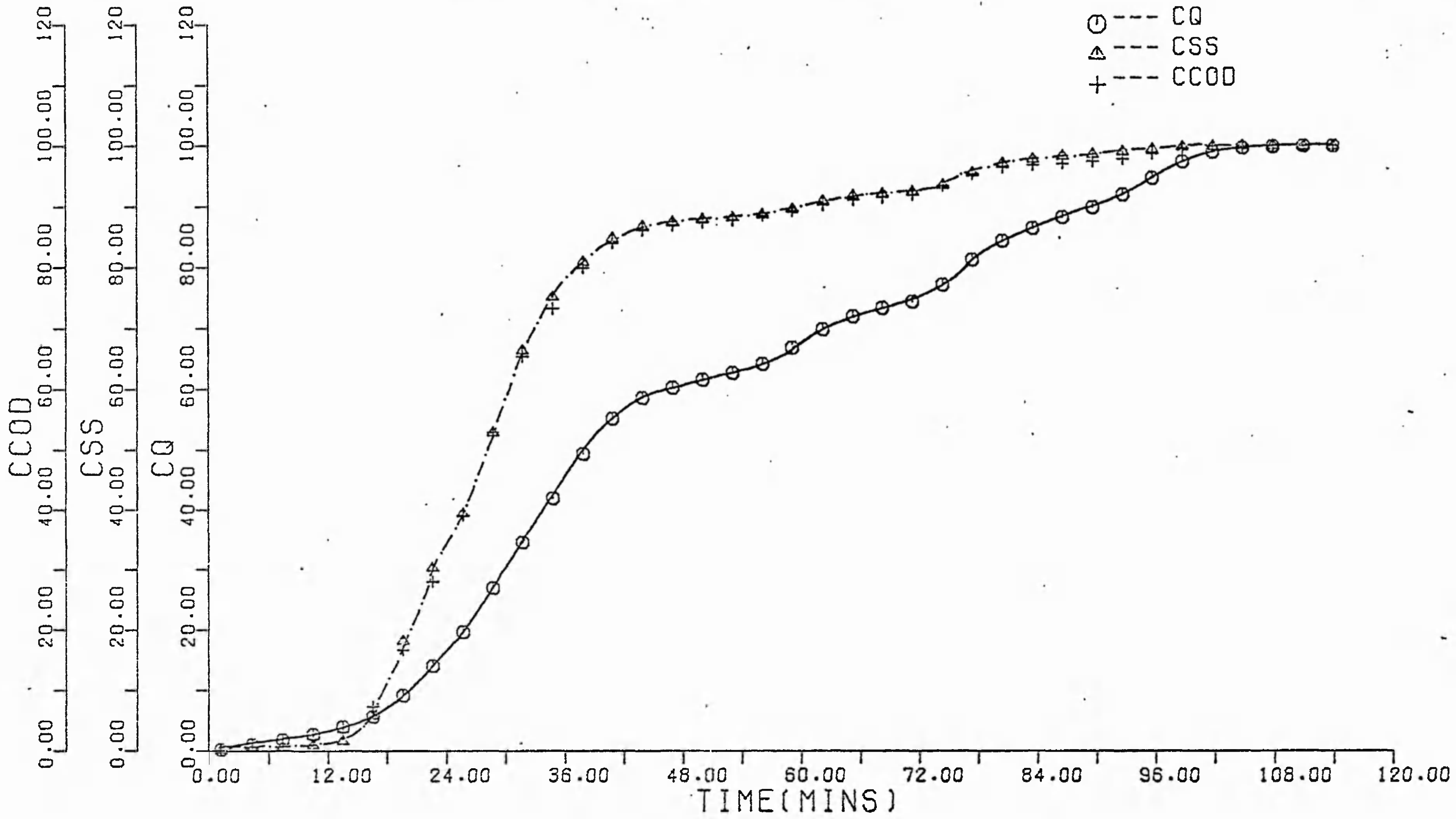
STORM OF THE 30TH JULY 1978

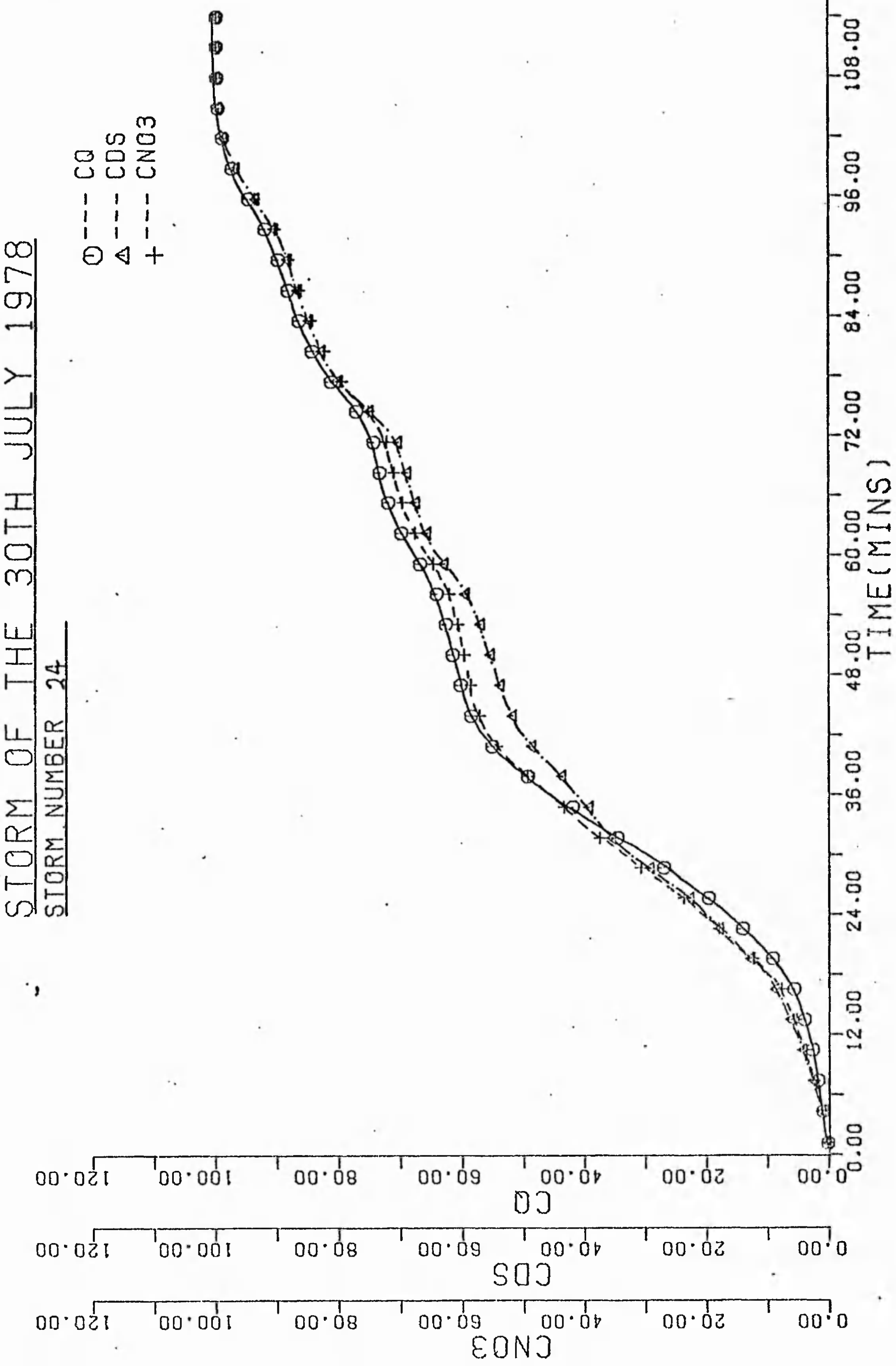
STORM NUMBER 24


STORM OF THE 30TH JULY 1978
STORM NUMBER 24
Q
DS
NO3
TIME(MINS)
0.00
12.00
24.00
36.00
48.00
60.00
72.00
84.00
96.00
108.00
120.00
Q
0.00
22.00
44.00
66.00
88.00
110.00
132.00
DS
0.00
28.00
56.00
84.00
112.00
140.00
168.00
NO3
0.00
2.00
4.00
6.00
8.00
10.00
12.00

STORM OF THE 30TH JULY 1978

STORM NUMBER 24




STORM OF THE 30TH JULY 1978
STORM NUMBER 24
CQ
CDS
CNO3
TIME(MINS)
0.00
12.00
24.00
36.00
48.00
60.00
72.00
84.00
96.00
108.00
120.00
CQ
CDS
CNO3
0.00
20.00
40.00
60.00
80.00
100.00
120.00

4. STORM RUNOFF MODEL OUTPUT

```
STORM OF THE  2ND MAY 1978 (6)
********************************

STORM STATISTICS
****************

STORM DURATION (HRS)               =  1.47

TOTAL RAINFALL (MM)                =   1.755

TOTAL RAINFALL VOLUME (LITRES)     =   60369.0

DEPRESSION STORAGE LOSS (LITRES)   =  16514.1

INFILTRATION LOSS (LITRES)         =  14910.7

TOTAL PREDICTED DISCHARGE (LITRES) =   28944.2

MAX INTENSITY FOR 10 MINS (MM/HR)  =  3.9780

AVERAGE INTENSITY (MM/HR)          =  0.9750

TOTAL OBSERVED DISCHARGE (LITRES)  =   18840.7

PERCENTAGE RUNOFF                  =  47.95

TOTAL GULLY DISCHARGE (LITRES)     =  4420.4

% GULLY RUNOFF/TOTAL RUNOFF        =  15.27

% GULLY/TOTAL FOR THE FIRST FLUSH  =  18.03

FIRST FLUSH TIME                   =  13.05

FIRST FLUSH VOLUME (LITRES)        =  22153.7

% GULLY RUNOFF/TOTAL GULLY VOLUME  =  42.53
```

```
STORM OF THE  4TH MAY 1978 (7)
*********************************

STORM STATISTICS
****************


STORM DURATION (HRS)                 =  0.39

TOTAL RAINFALL (MM)                  =   3.393

TOTAL RAINFALL VOLUME (LITRES)       =  116713.3

DEPRESSION STORAGE LOSS (LITRES)     =  24257.2

INFILTRATION LOSS (LITRES)           =  49926.3

TOTAL PREDICTED DISCHARGE (LITRES) =     42529.8

MAX INTENSITY FOR 10 MINS (MM/HR)  = 15.0930

AVERAGE INTENSITY (MM/HR)            =  5.0895

TOTAL OBSERVED DISCHARGE (LITRES)  =     57334.0

PERCENTAGE RUNOFF                    =  36.44

TOTAL GULLY DISCHARGE (LITRES)       =  6527.5

% GULLY RUNOFF/TOTAL RUNOFF          =  15.35

% GULLY/TOTAL FOR THE FIRST FLUSH  =    18.17

FIRST FLUSH TIME                     =   8.34

FIRST FLUSH VOLUME (LITRES)          =  32533.9

% GULLY RUNOFF/TOTAL GULLY VOLUME  =    62.80
```

```
STORM OF THE  15TH MAY 1978 (9)
********************************

STORM STATISTICS
****************

STORM DURATION (HRS)                    =  0.35

TOTAL RAINFALL (MM)                     =   1.170

TOTAL RAINFALL VOLUME (LITRES)          =   40246.0

DEPRESSION STORAGE LOSS (LITRES)        =  16442.0

INFILTRATION LOSS (LITRES)              =   9283.5

TOTAL PREDICTED DISCHARGE (LITRES)      =   14520.4

MAX INTENSITY FOR 10 MINS (MM/HR)       =  3.5100

AVERAGE INTENSITY (MM/HR)               =  1.9500

TOTAL OBSERVED DISCHARGE (LITRES)       =    7610.5

PERCENTAGE RUNOFF                       =  36.08

TOTAL GULLY DISCHARGE (LITRES)          =  1689.3

% GULLY RUNOFF/TOTAL RUNOFF             =  11.63

% GULLY/TOTAL FOR THE FIRST FLUSH       =  11.78

FIRST FLUSH TIME                        =  16.53

FIRST FLUSH VOLUME (LITRES)             =  13045.0

% GULLY RUNOFF/TOTAL GULLY VOLUME       =  16.25
```

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STORM OF THE  24TH MAY 1978 (10)
--------------------------------

STORM STATISTICS
----------------


STORM DURATION (HRS)               =  0.38

TOTAL RAINFALL (MM)                =   1.755

TOTAL RAINFALL VOLUME (LITRES)     =   60369.0

DEPRESSION STORAGE LOSS (LITRES)   =  17232.6

INFILTRATION LOSS (LITRES)         =  14882.0

TOTAL PREDICTED DISCHARGE (LITRES) =   28254.3

MAX INTENSITY FOR 10 MINS (MM/HR)  =  5.9670

AVERAGE INTENSITY (MM/HR)          =  2.7000

TOTAL OBSERVED DISCHARGE (LITRES)  =   10769.5

PERCENTAGE RUNOFF                  =  46.80

TOTAL GULLY DISCHARGE (LITRES)     =  4441.9

% GULLY RUNOFF/TOTAL RUNOFF        =  15.72

% GULLY/TOTAL FOR THE FIRST FLUSH  =  16.53

FIRST FLUSH TIME                   =  10.06

FIRST FLUSH VOLUME (LITRES)        =  24632.7

% GULLY RUNOFF/TOTAL GULLY VOLUME  =  42.74
```

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STORM OF THE  31ST MAY 1978 (11)
--------------------------------

STORM STATISTICS
----------------

STORM DURATION (HRS)                  =  0.05
TOTAL RAINFALL (MM)                   =   0.234
TOTAL RAINFALL VOLUME (LITRES)        =    8049.2
DEPRESSION STORAGE LOSS (LITRES)      =   5746.8
INFILTRATION LOSS (LITRES)            =       0.0
TOTAL PREDICTED DISCHARGE (LITRES)    =    2302.4
MAX INTENSITY FOR 10 MINS (MM/HR)     =  1.4040
AVERAGE INTENSITY (MM/HR)             =  2.3400
PERCEN                                =  .61222
TOTAL OBSERVED DISCHARGE (LITRES)     =    1409.5
PERCENTAGE RUNOFF                     =  28.60
TOTAL GULLY DISCHARGE (LITRES)        =      0.0
% GULLY RUNOFF/TOTAL RUNOFF           =   0.00
% GULLY/TOTAL FOR THE FIRST FLUSH     = ******
FIRST FLUSH TIME                      =  17.09
FIRST FLUSH VOLUME (LITRES)           =       0.0
% GULLY RUNOFF/TOTAL GULLY VOLUME     =   0.00
```

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STORM OF THE  IST JUNE 1978 (12)
--------------------------------

STORM STATISTICS
----------------

STORM DURATION (HRS)                  =  2.42

TOTAL RAINFALL (MM)                   =   5.867

TOTAL RAINFALL VOLUME (LITRES)        =  201804.8

DEPRESSION STORAGE LOSS (LITRES)      =  11278.5

INFILTRATION LOSS (LITRES)            =      0.0

TOTAL PREDICTED DISCHARGE (LITRES)    =  190526.3

MAX INTENSITY FOR 10 MINS (MM/HR)     =  4.9140

AVERAGE INTENSITY (MM/HR)             =  2.1595

PERCEN                                =  .62508

TOTAL OBSERVED DISCHARGE (LITRES)     =  119093.4

PERCENTAGE RUNOFF                     =  94.41

TOTAL GULLY DISCHARGE (LITRES)        =  8938.8

% GULLY RUNOFF/TOTAL RUNOFF           =   4.69

% GULLY/TOTAL FOR THE FIRST FLUSH     =  11.32

FIRST FLUSH TIME                      =  18.42

FIRST FLUSH VOLUME (LITRES)           =  71632.1

% GULLY RUNOFF/TOTAL GULLY VOLUME     =  86.00
```

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STORM OF THE 29TH JUNE 1978 (15)
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STORM STATISTICS
----------------

STORM DURATION (HRS)                 =  0.54

TOTAL RAINFALL (MM)                  =   0.968

TOTAL RAINFALL VOLUME (LITRES)       =   33299.2

DEPRESSION STORAGE LOSS (LITRES)     =  10571.7

INFILTRATION LOSS (LITRES)           =       0.0

TOTAL PREDICTED DISCHARGE (LITRES)   =   22727.6

MAX INTENSITY FOR 10 MINS (MM/HR)    =  2.8773

AVERAGE INTENSITY (MM/HR)            =  1.0561

PERCEN                               = 1.14427

TOTAL OBSERVED DISCHARGE (LITRES)    =   26006.4

PERCENTAGE RUNOFF                    =  68.25

TOTAL GULLY DISCHARGE (LITRES)       =  3827.2

% GULLY RUNOFF/TOTAL RUNOFF          =  16.84

% GULLY/TOTAL FOR THE FIRST FLUSH    =  18.19

FIRST FLUSH TIME                     =   0.50

FIRST FLUSH VOLUME (LITRES)          =  19066.5

% GULLY RUNOFF/TOTAL GULLY VOLUME    =  36.82
```

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STORM OF THE  1ST JULY 1978 (16)
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STORM STATISTICS
----------------


STORM DURATION (HRS)                      =  1.51

TOTAL RAINFALL (MM)                       =   1.863

TOTAL RAINFALL VOLUME (LITRES)            =   64081.7

DEPRESSION STORAGE LOSS (LITRES)          =  11178.6

INFILTRATION LOSS (LITRES)                =        0.0

TOTAL PREDICTED DISCHARGE (LITRES)        =   52903.1

MAX INTENSITY FOR 10 MINS (MM/HR)         =  2.8245

AVERAGE INTENSITY (MM/HR)                 =  0.9980

PERCEN                                    =  .30321

TOTAL OBSERVED DISCHARGE (LITRES)         =   16040.7

PERCENTAGE RUNOFF                         =  82.56

TOTAL GULLY DISCHARGE (LITRES)            =  6788.6

% GULLY RUNOFF/TOTAL RUNOFF               =  12.83

% GULLY/TOTAL FOR THE FIRST FLUSH         =  14.56

FIRST FLUSH TIME                          =   1.40

FIRST FLUSH VOLUME (LITRES)               =  42205.6

% GULLY RUNOFF/TOTAL GULLY VOLUME         =  65.31
```

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STORM OF THE  3RD JULY 1978 (17)
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STORM STATISTICS
================

STORM DURATION (HRS)                  =  1.55

TOTAL RAINFALL (MM)                   =   8.569

TOTAL RAINFALL VOLUME (LITRES)        =  294743.3

DEPRESSION STORAGE LOSS (LITRES)      =  23157.5

INFILTRATION LOSS (LITRES)            = 139866.7

TOTAL PREDICTED DISCHARGE (LITRES)    =  131719.1

MAX INTENSITY FOR 10 MINS (MM/HR)     =  8.6194

AVERAGE INTENSITY (MM/HR)             =  4.4320

TOTAL OBSERVED DISCHARGE (LITRES)     =   33407.5

PERCENTAGE RUNOFF                     =  44.69

TOTAL GULLY DISCHARGE (LITRES)        =  8814.7

% GULLY RUNOFF/TOTAL RUNOFF           =   6.69

% GULLY/TOTAL FOR THE FIRST FLUSH     =  11.61

FIRST FLUSH TIME                      =   1.18

FIRST FLUSH VOLUME (LITRES)           =  68784.5

% GULLY RUNOFF/TOTAL GULLY VOLUME     =  84.81
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STORM OF THE  23RD JULY 1978 (19)
=================================

STORM STATISTICS
================

STORM DURATION (HRS)               = 1.07

TOTAL RAINFALL (MM)                =  0.789

TOTAL RAINFALL VOLUME (LITRES)     =  27125.9

DEPRESSION STORAGE LOSS (LITRES)   = 14521.4

INFILTRATION LOSS (LITRES)         =  4663.7

TOTAL PREDICTED DISCHARGE (LITRES) =   7940.8

MAX INTENSITY FOR 10 MINS (MM/HR)  = 2.6162

AVERAGE INTENSITY (MM/HR)          = 1.6898

TOTAL OBSERVED DISCHARGE (LITRES)  =   5053.8

PERCENTAGE RUNOFF                  = 29.27

TOTAL GULLY DISCHARGE (LITRES)     =  609.9

% GULLY RUNOFF/TOTAL RUNOFF        =  7.68

% GULLY/TOTAL FOR THE FIRST FLUSH  =  7.70

FIRST FLUSH TIME                   = 20.05

FIRST FLUSH VOLUME (LITRES)        =  7459.0

% GULLY RUNOFF/TOTAL GULLY VOLUME  =  5.87
```

```
STORM OF THE  26TH JULY 1978 (20)
---------------------------------

STORM STATISTICS
----------------

STORM DURATION (HRS)                 =  0.54

TOTAL RAINFALL (MM)                  =   1.800

TOTAL RAINFALL VOLUME (LITRES)       =   61900.8

DEPRESSION STORAGE LOSS (LITRES)     =  11177.4

INFILTRATION LOSS (LITRES)           =      0.0

TOTAL PREDICTED DISCHARGE (LITRES)   =   50723.5

MAX INTENSITY FOR 10 MINS (MM/HR)    =  3.3252

AVERAGE INTENSITY (MM/HR)            =  1.9631

PERCEN                               =  .85045

TOTAL OBSERVED DISCHARGE (LITRES)    =   43137.9

PERCENTAGE RUNOFF                    =  81.94

TOTAL GULLY DISCHARGE (LITRES)       =  7016.0

% GULLY RUNOFF/TOTAL RUNOFF          =  13.83

% GULLY/TOTAL FOR THE FIRST FLUSH    =  15.67

FIRST FLUSH TIME                     =   5.28

FIRST FLUSH VOLUME (LITRES)          =  40806.7

% GULLY RUNOFF/TOTAL GULLY VOLUME    =  67.50
```

```
STORM OF THE  27TH JULY 1978 (21)
---------------------------------

STORM STATISTICS
----------------


STORM DURATION (HRS)                   =  2.55

TOTAL RAINFALL (MM)                    =   2.421

TOTAL RAINFALL VOLUME (LITRES)         =   83273.6

DEPRESSION STORAGE LOSS (LITRES)       =  15541.5

INFILTRATION LOSS (LITRES)             =  18965.0

TOTAL PREDICTED DISCHARGE (LITRES)     =   48767.2

MAX INTENSITY FOR 10 MINS (MM/HR)      =  2.5660

AVERAGE INTENSITY (MM/HR)              =  0.8253

TOTAL OBSERVED DISCHARGE (LITRES)      =   10279.5

PERCENTAGE RUNOFF                      =  58.56

TOTAL GULLY DISCHARGE (LITRES)         =  5588.0

% GULLY RUNOFF/TOTAL RUNOFF            =  11.46

% GULLY/TOTAL FOR THE FIRST FLUSH      =  12.52

FIRST FLUSH TIME                       =  24.04

FIRST FLUSH VOLUME (LITRES)            =  40181.3

% GULLY RUNOFF/TOTAL GULLY VOLUME      =  53.76
```

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STORM OF THE  30TH JULY 1978 (24)
=================================

STORM STATISTICS
================


STORM DURATION (HRS)                 =  1.47

TOTAL RAINFALL (MM)                  =   7.407

TOTAL RAINFALL VOLUME (LITRES)       =  254778.2

DEPRESSION STORAGE LOSS (LITRES)     =  11339.4

INFILTRATION LOSS (LITRES)           =       0.0

TOTAL PREDICTED DISCHARGE (LITRES)   =  243438.8

MAX INTENSITY FOR 10 MINS (MM/HR)    = 11.2780

AVERAGE INTENSITY (MM/HR)            =  4.1148

PERCEN                               =  .96904

TOTAL OBSERVED DISCHARGE (LITRES)    =  235901.9

PERCENTAGE RUNOFF                    =  95.55

TOTAL GULLY DISCHARGE (LITRES)       =  8991.3

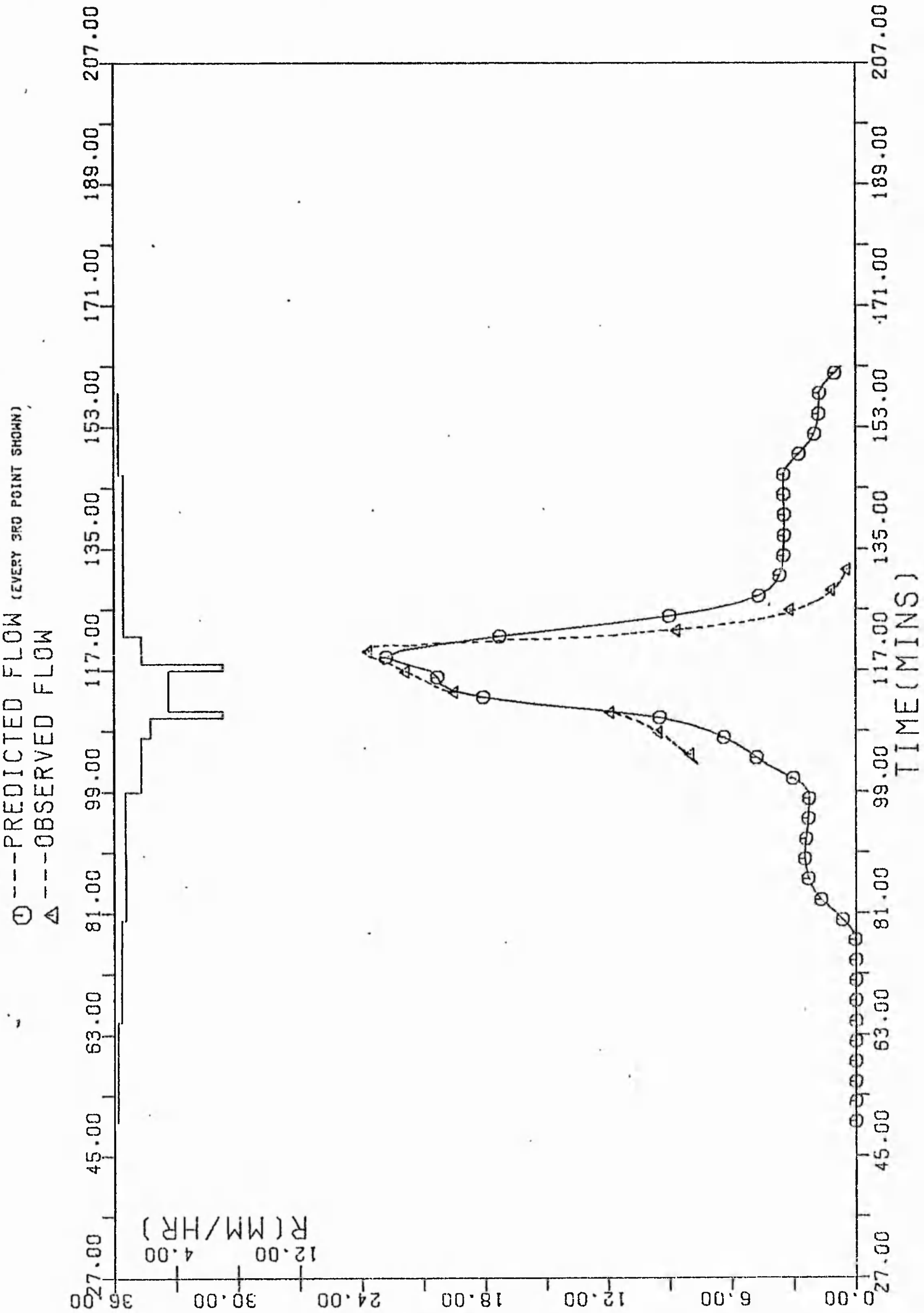
% GULLY RUNOFF/TOTAL RUNOFF          =   3.69

% GULLY/TOTAL FOR THE FIRST FLUSH    =  12.21

FIRST FLUSH TIME                     =   6.26

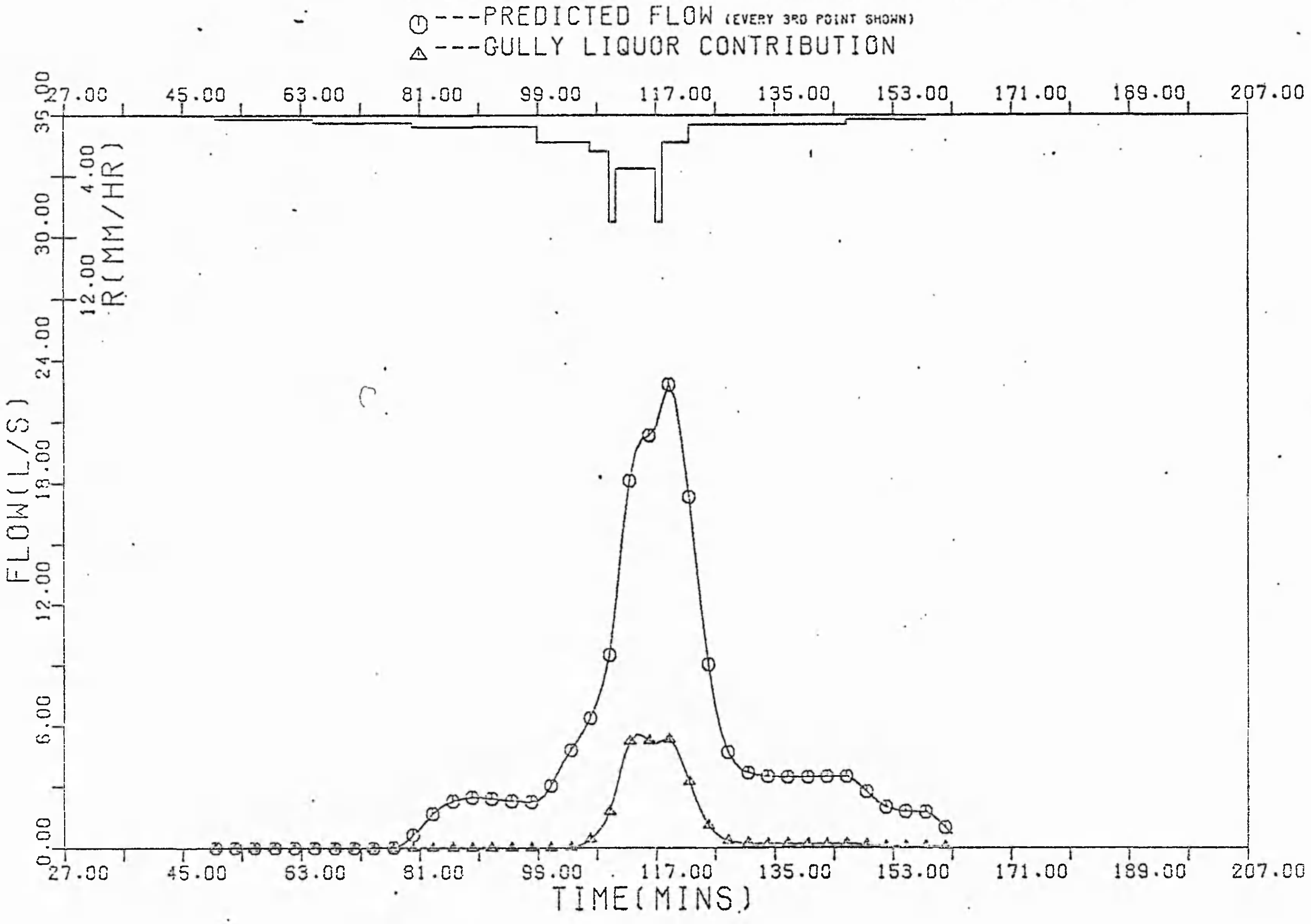
FIRST FLUSH VOLUME (LITRES)          =  67645.2

% GULLY RUNOFF/TOTAL GULLY VOLUME    =  86.51
```

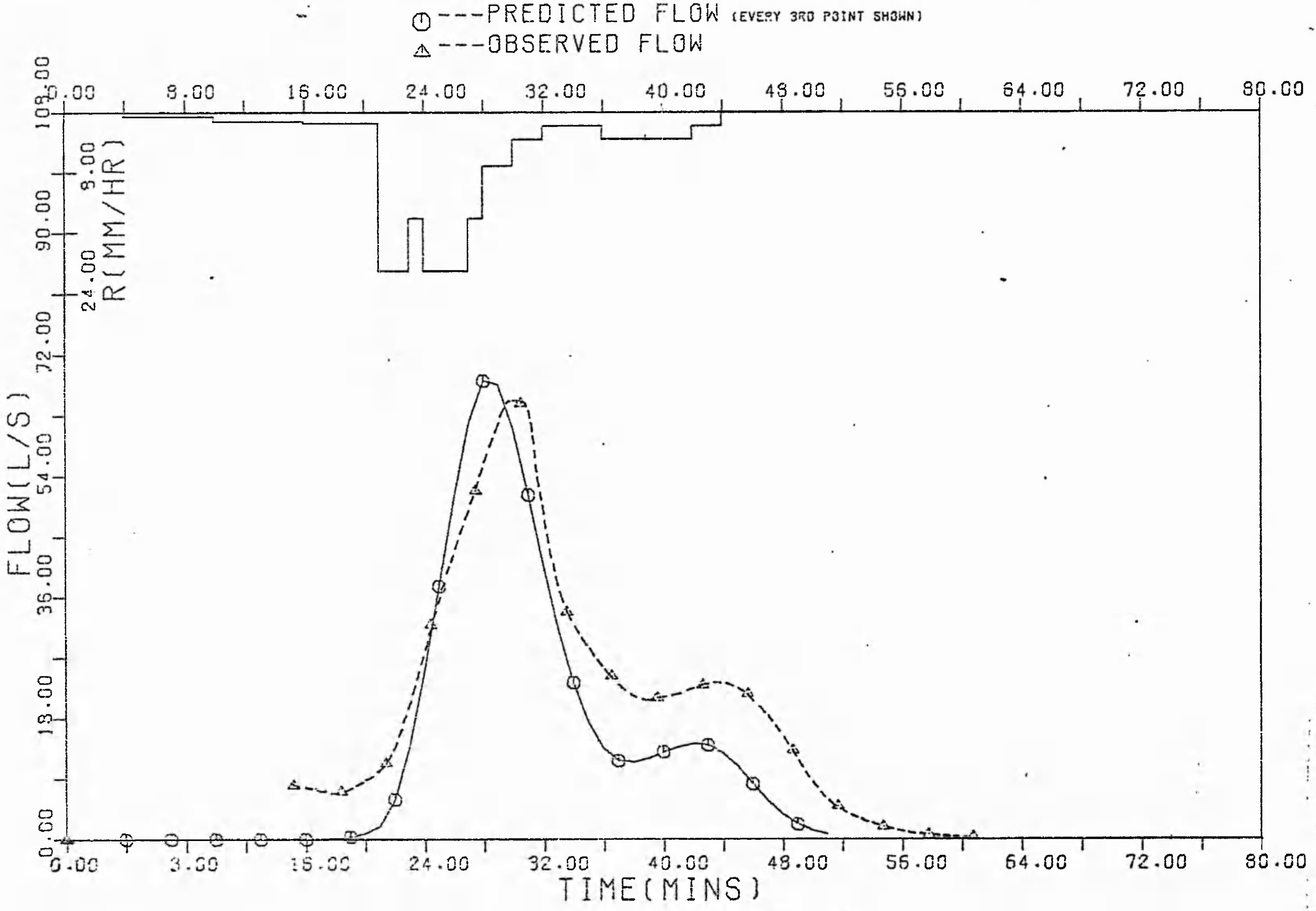


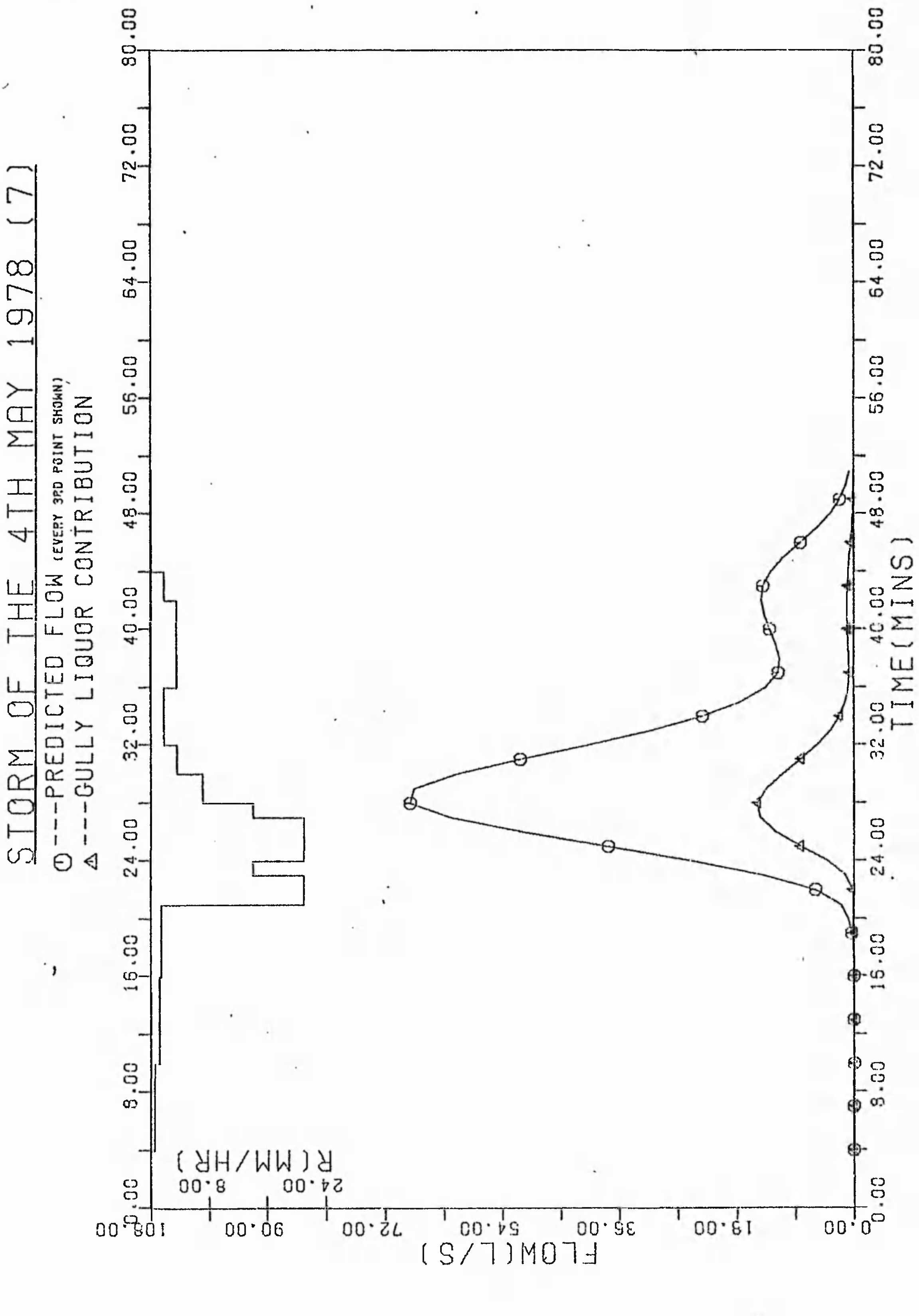
STORM OF THE 2ND MAY 1978 (6)

STORM OF THE 2ND MAY 1978 (6)

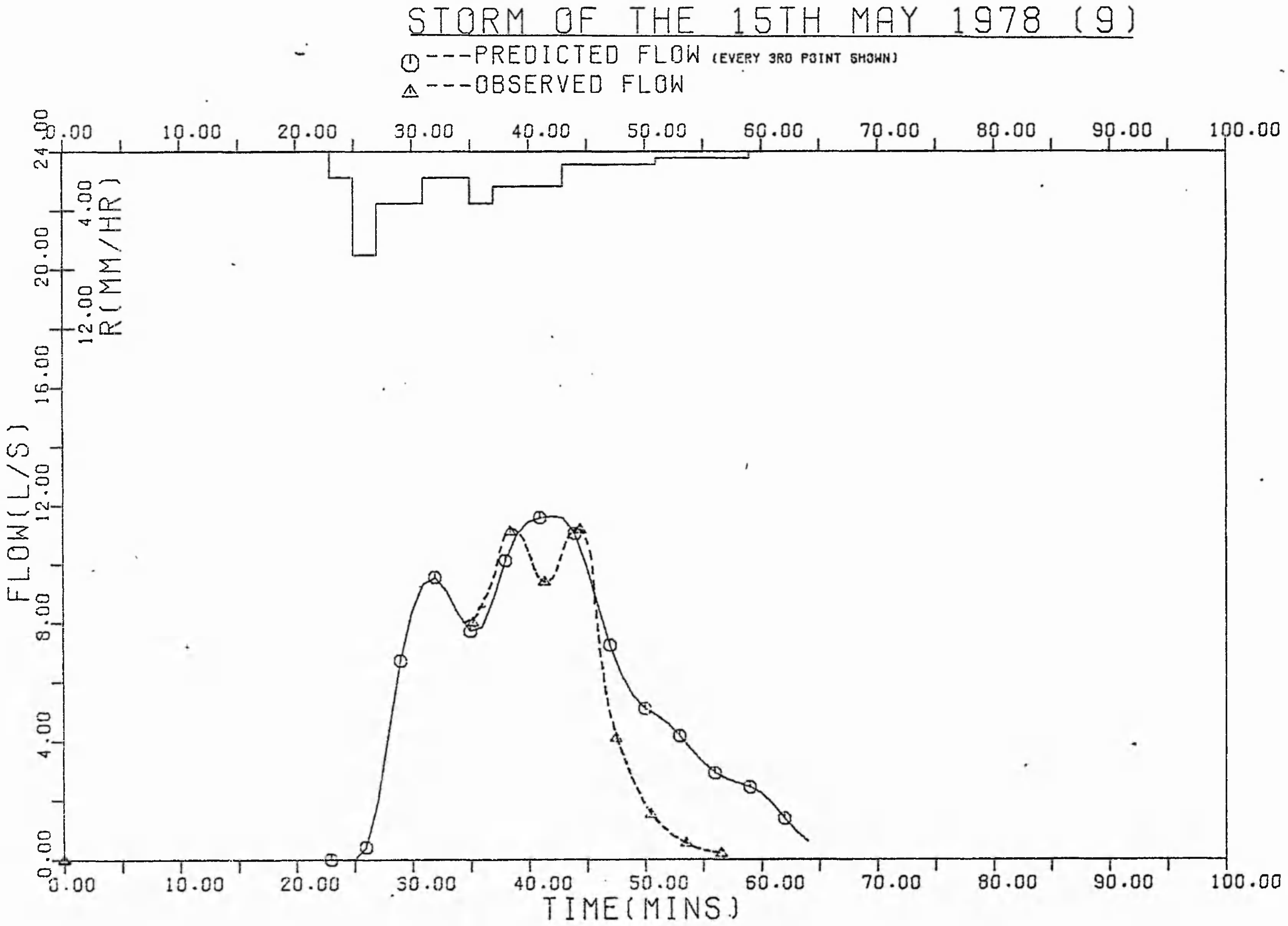


STORM OF THE 4TH MAY 1978 (7)

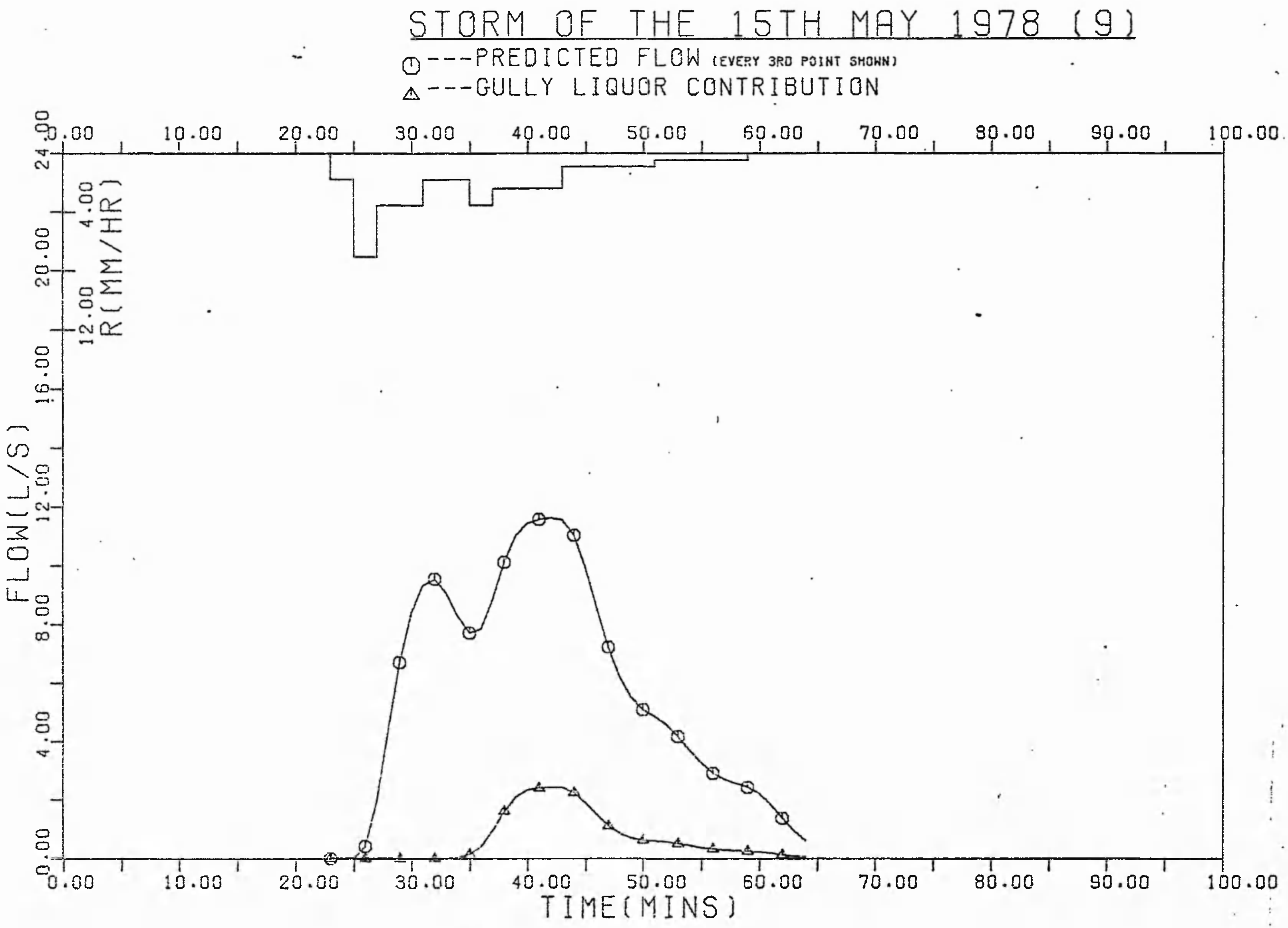




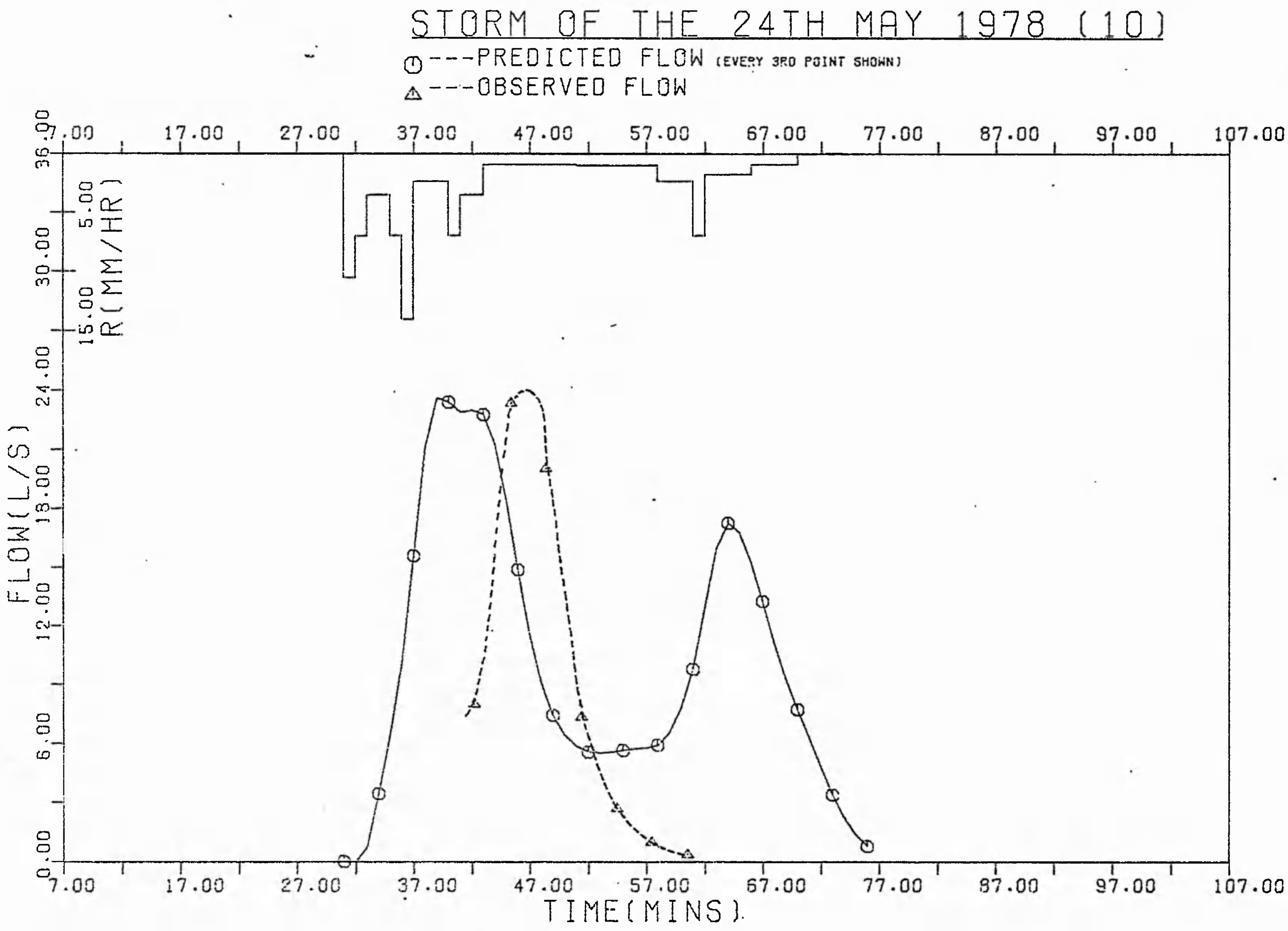
STORM OF THE 4TH MAY 1978 (7)



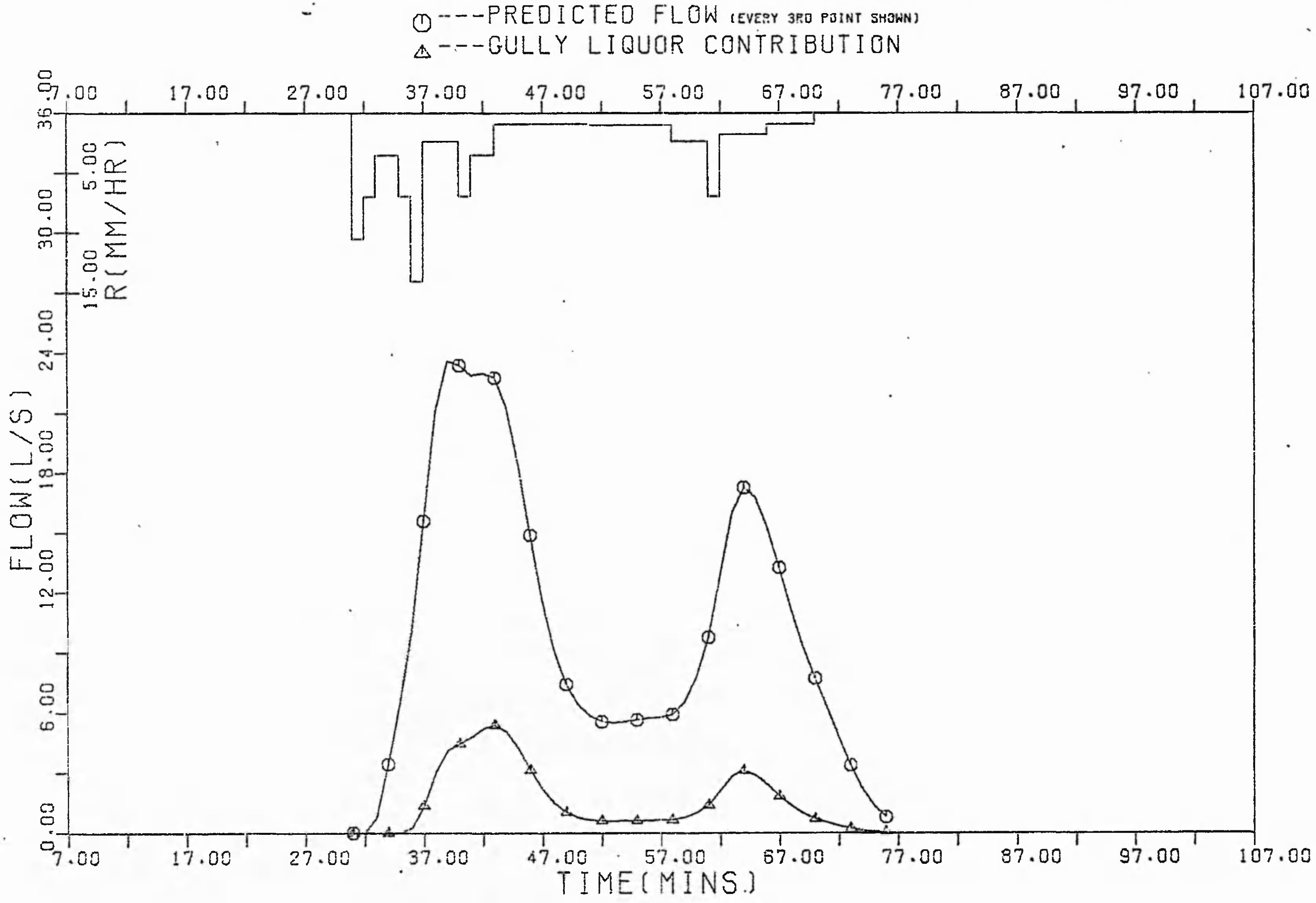
STORM OF THE 15TH MAY 1978 (9)



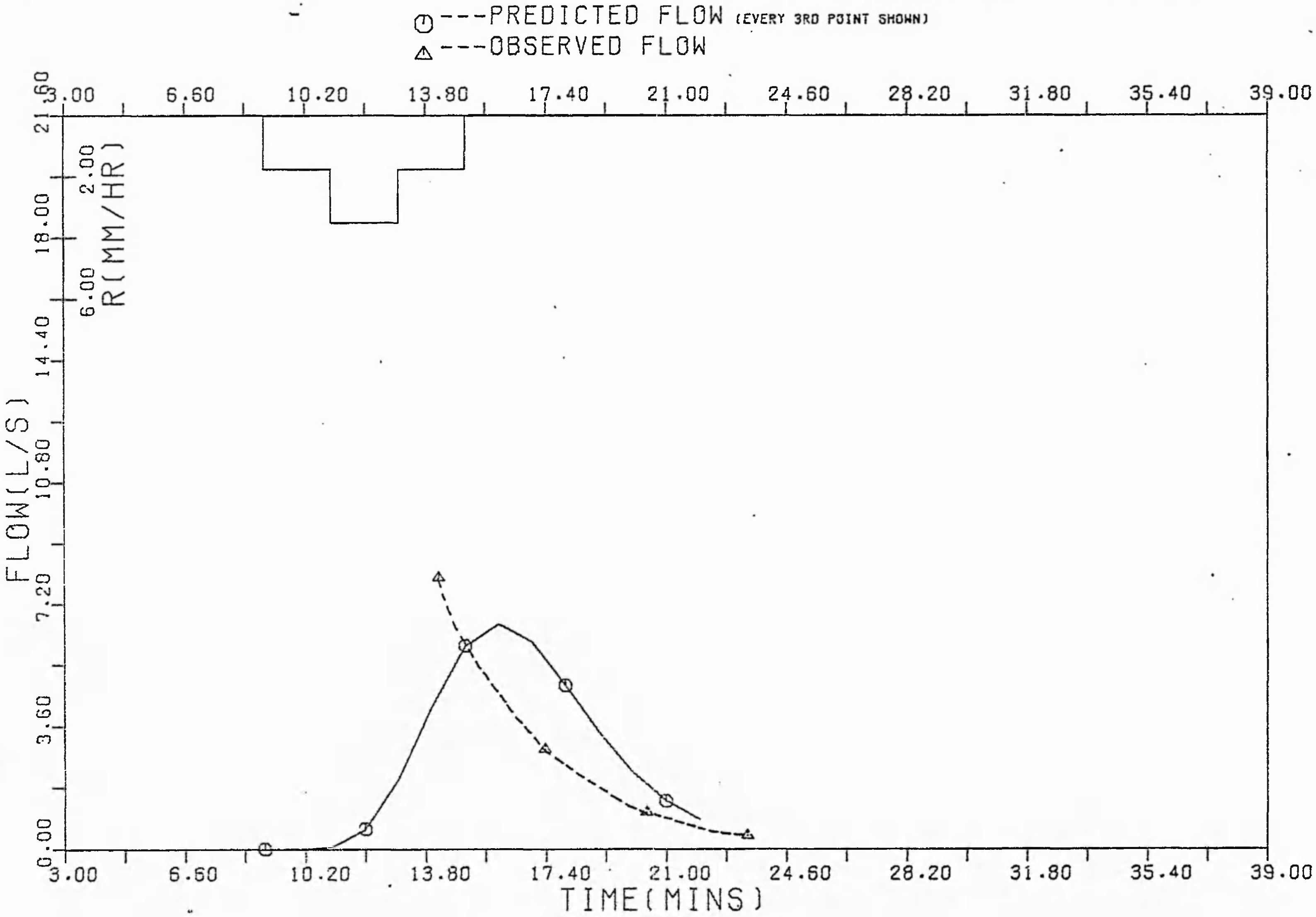
STORM OF THE 15TH MAY 1978 (9)

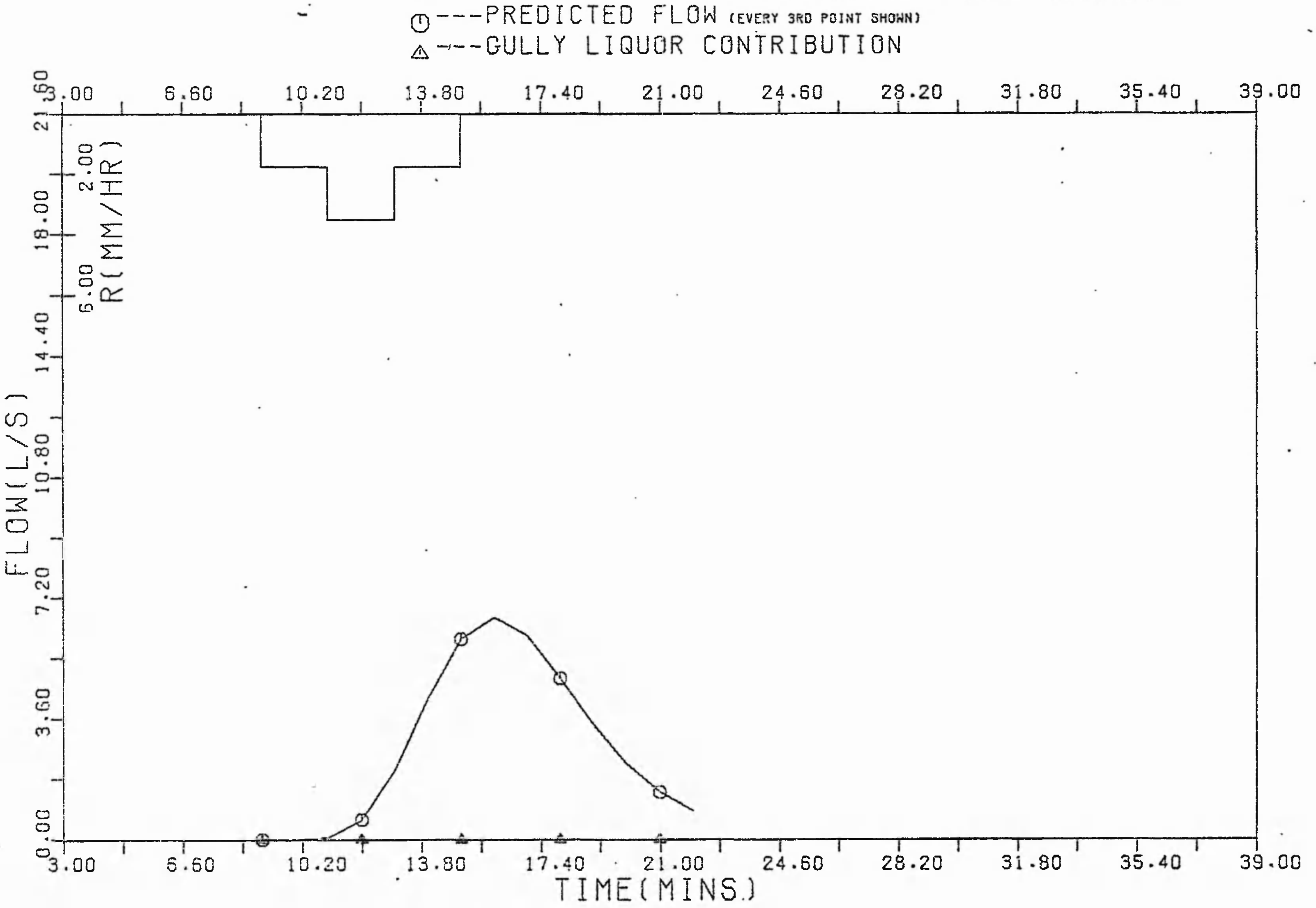

STORM OF THE 24TH MAY 1978 (10)
---PREDICTED FLOW (EVERY 3RD POINT SHOWN)
---OBSERVED FLOW
R(MM/HR)
5.00
15.00
FLOW(L/S)
0.00
6.00
12.00
18.00
24.00
30.00
36.00
TIME(MINS)
7.00
17.00
27.00
37.00
47.00
57.00
67.00
77.00
87.00
97.00
107.00

STORM OF THE 24TH MAY 1978 (10)



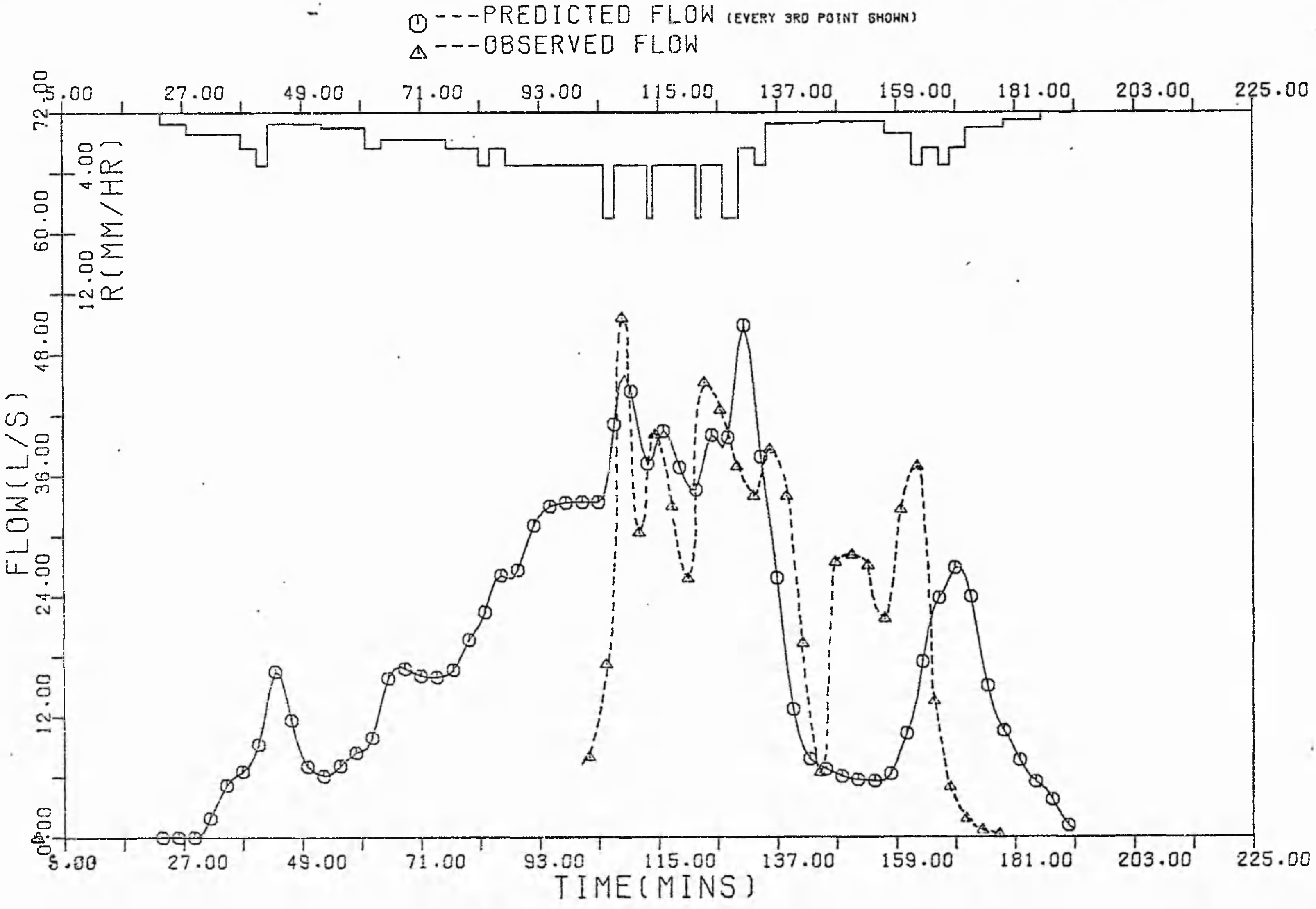
STORM OF THE 31ST MAY 1978 (11)

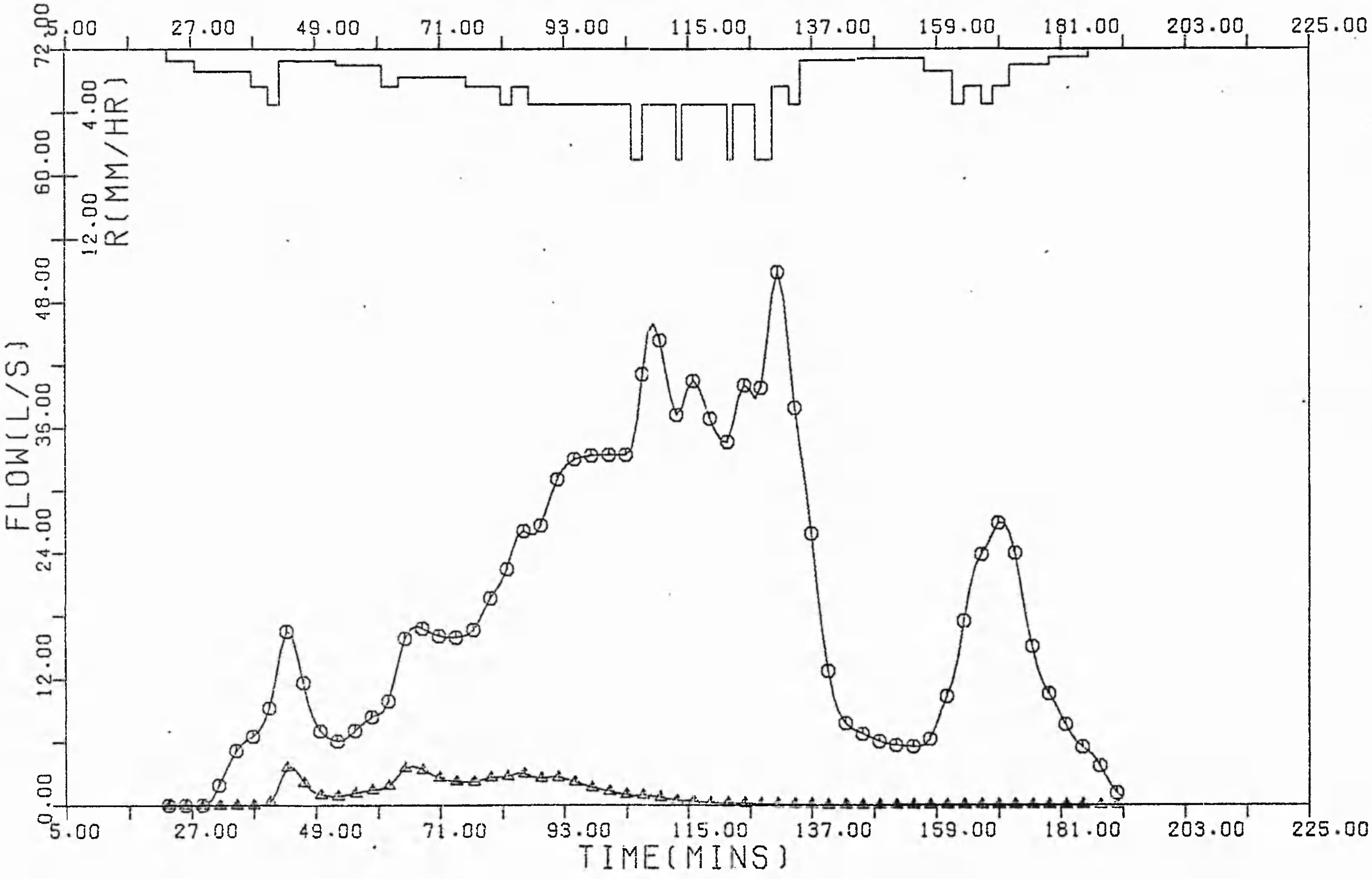




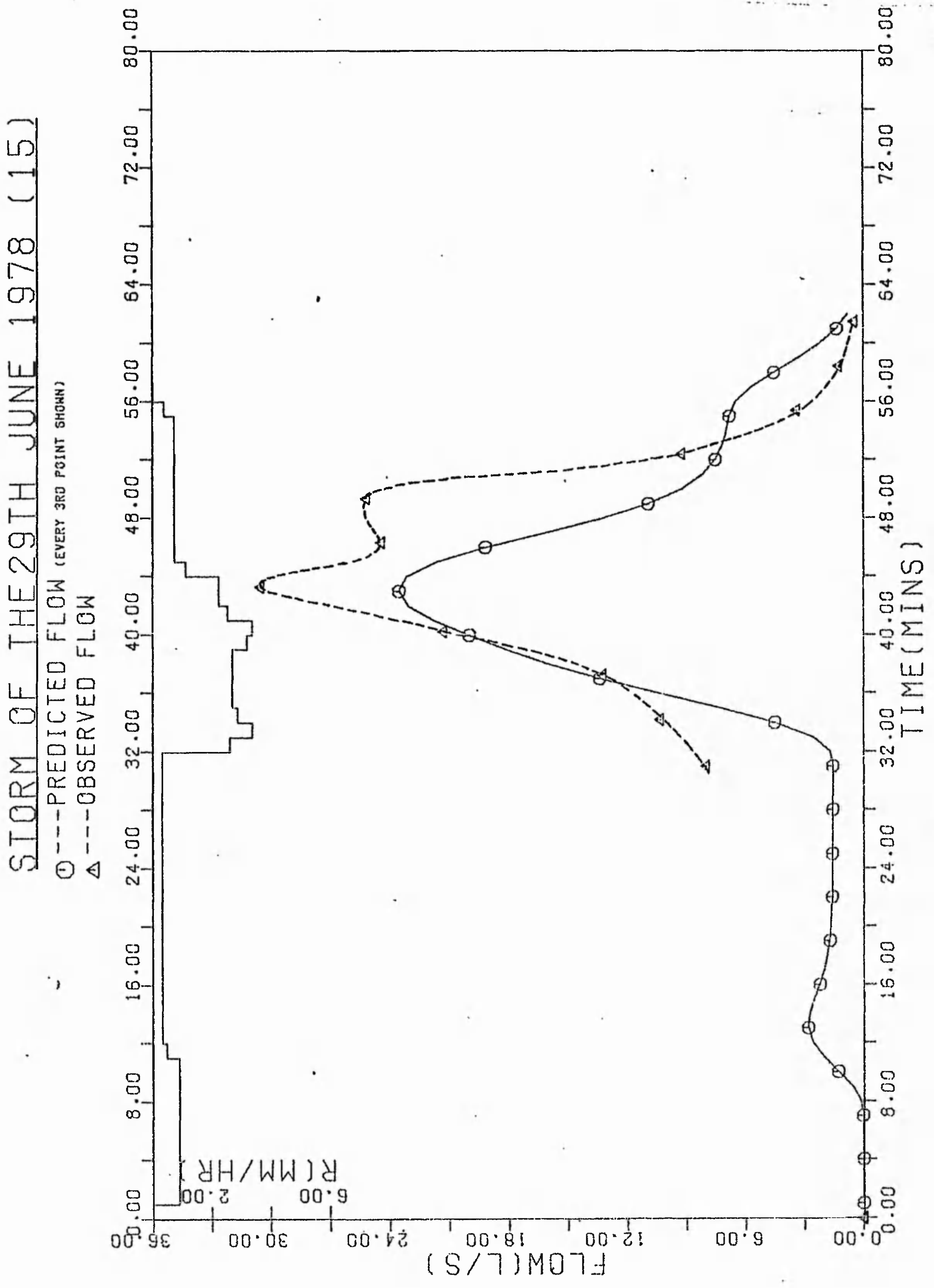
STORM OF THE 31ST MAY 1978 (11)

STORM OF THE 1ST JUNE 1978 (12)

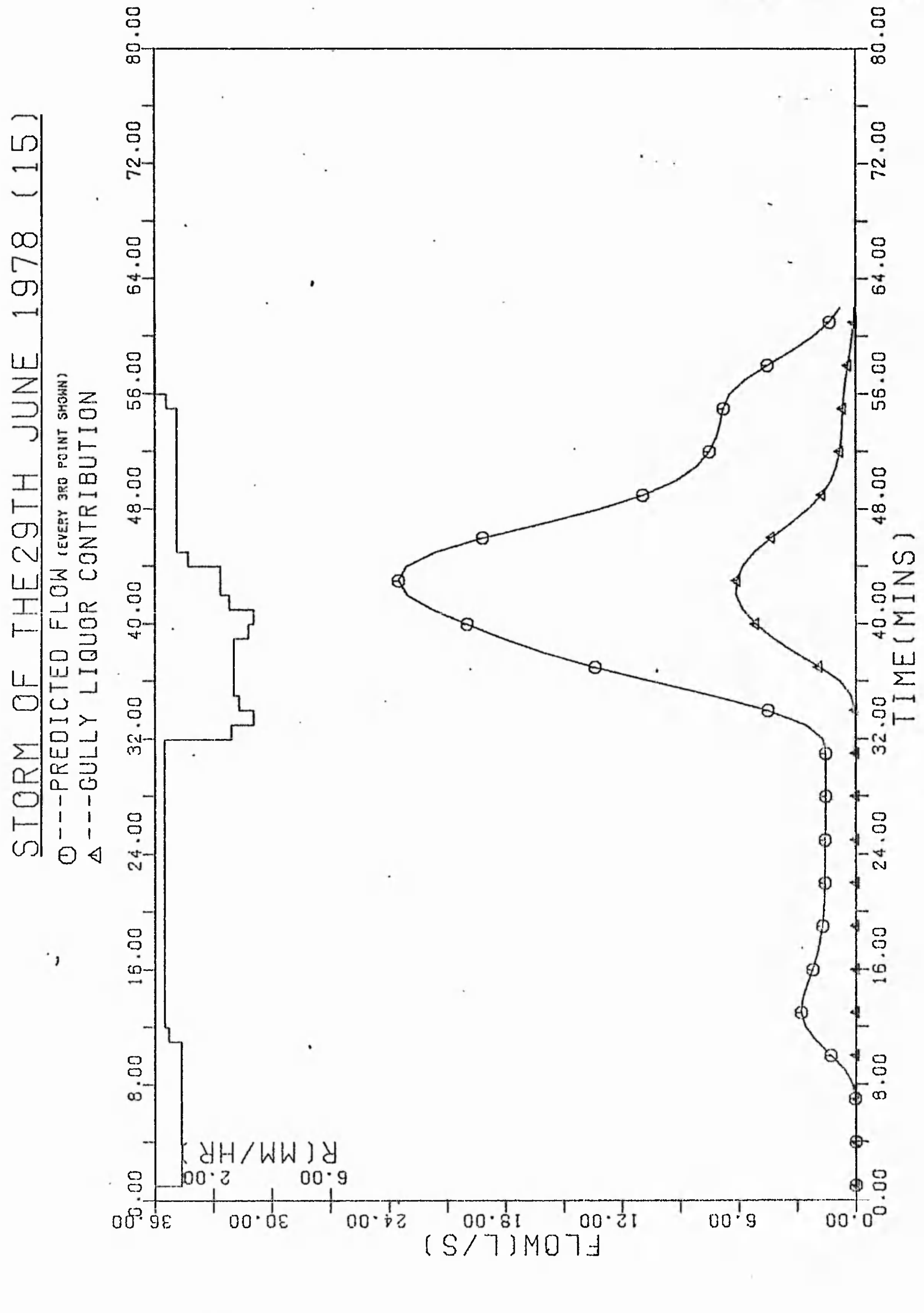




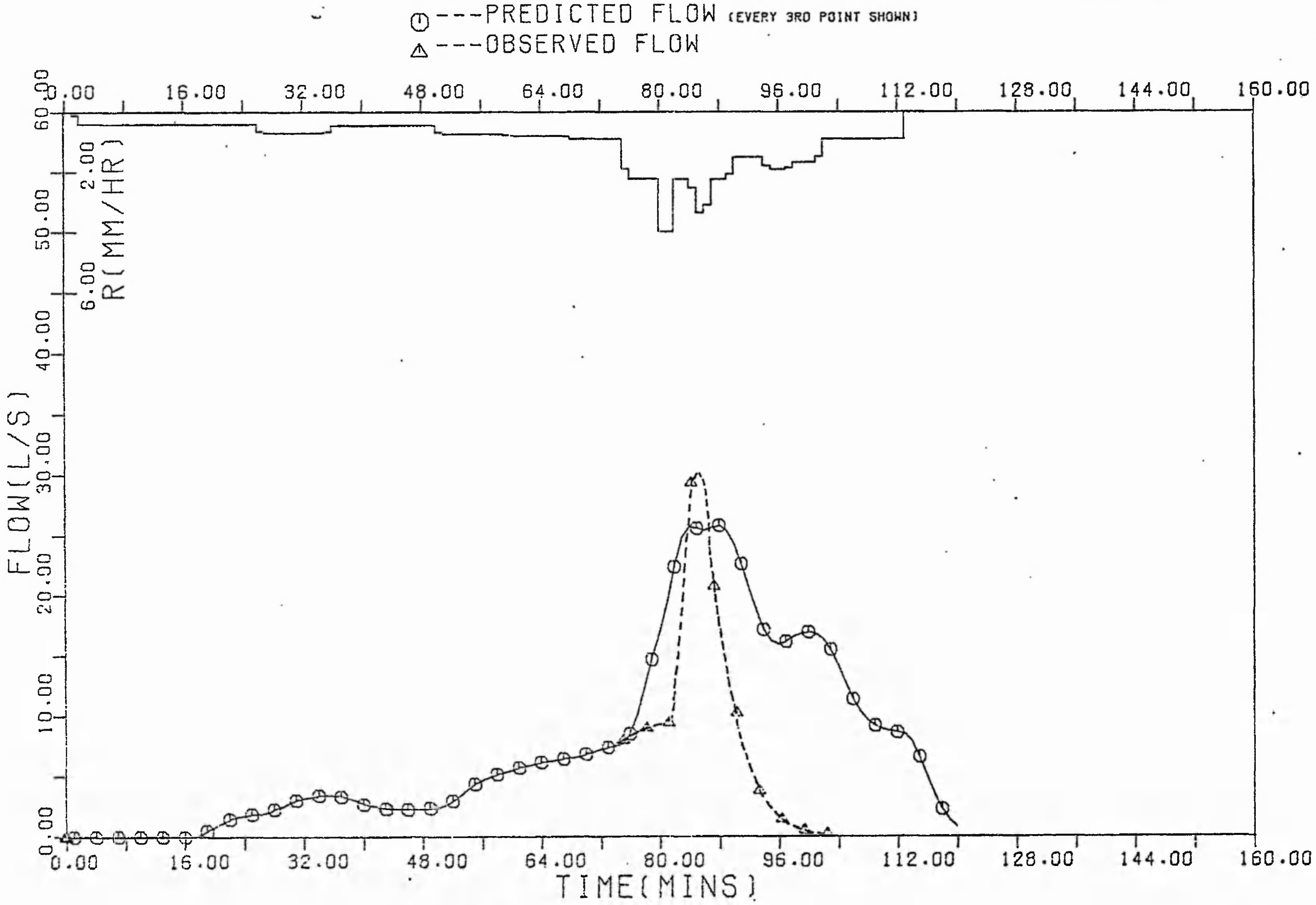
STORM OF THE IST JUNE 1978 (12)

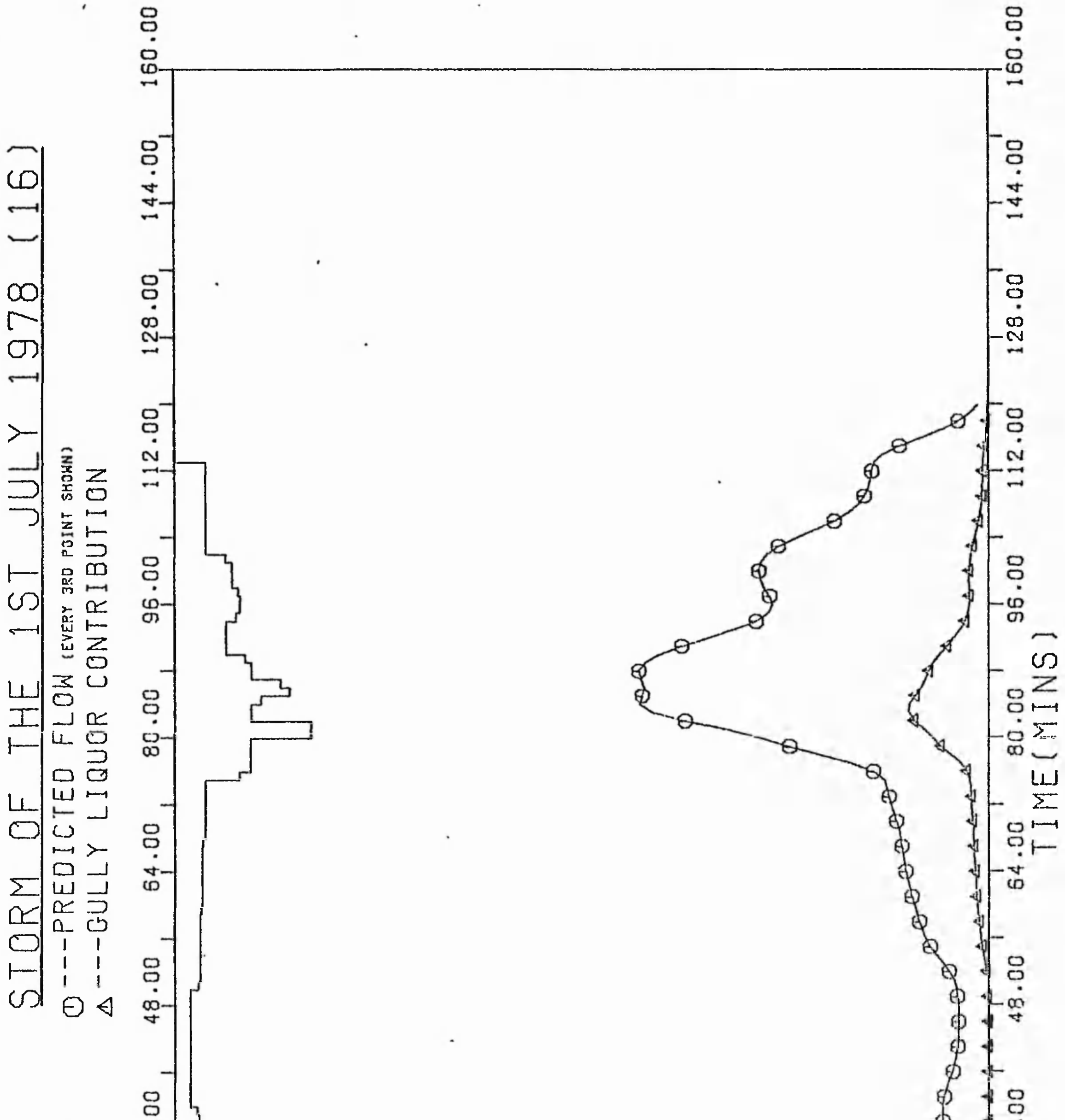


STORM OF THE 29TH JUNE 1978 (15)

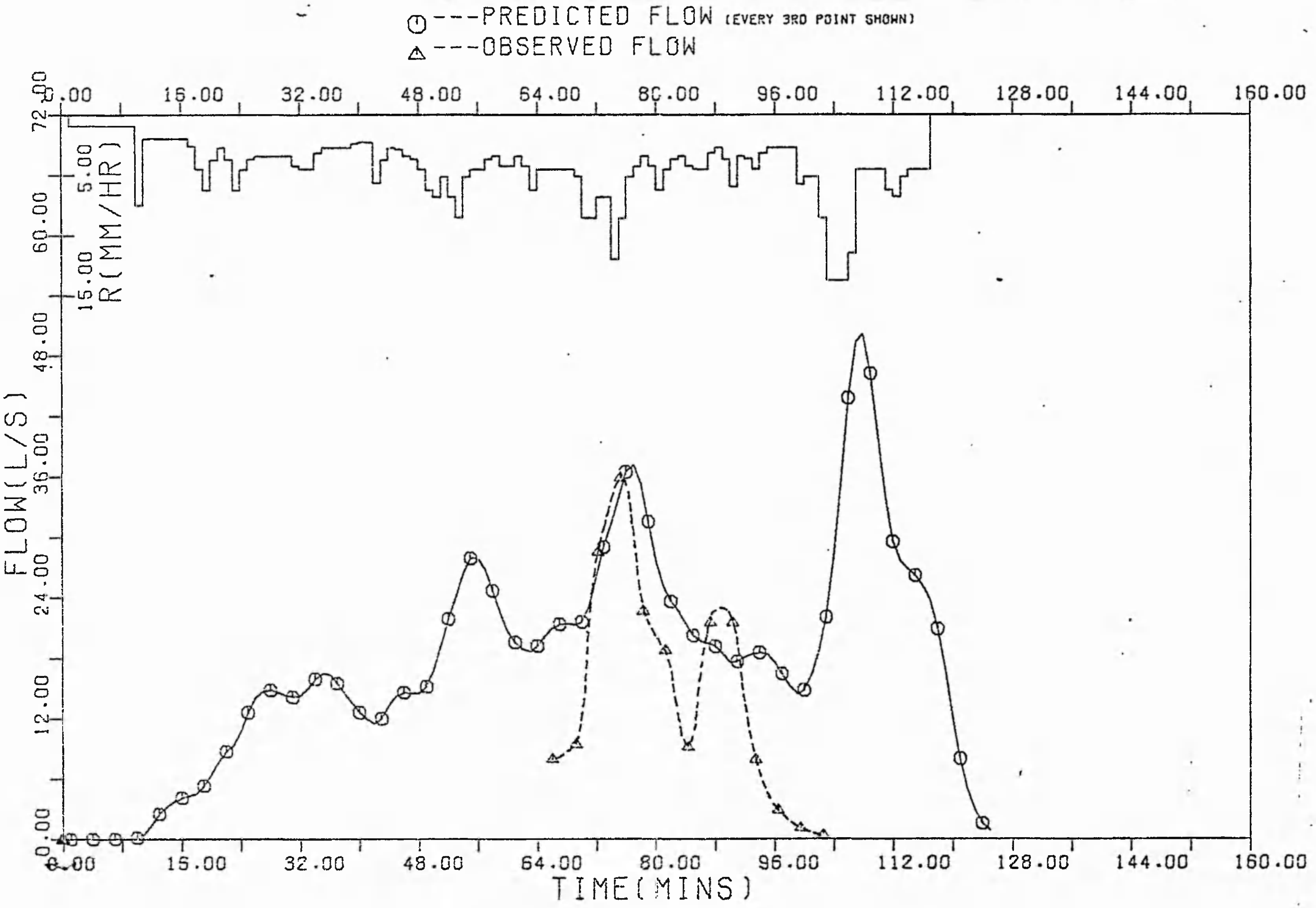

STORM OF THE29TH JUNE 1978 (15)
⊖---PREDICTED FLOW (EVERY 3RD POINT SHOWN)
△---GULLY LIQUOR CONTRIBUTION
TIME(MINS)
0.00
8.00
16.00
24.00
32.00
40.00
48.00
56.00
64.00
72.00
80.00
FLOW(L/S)
0.00
6.00
12.00
18.00
24.00
30.00
36.00
R(MM/HR)
2.00
6.00

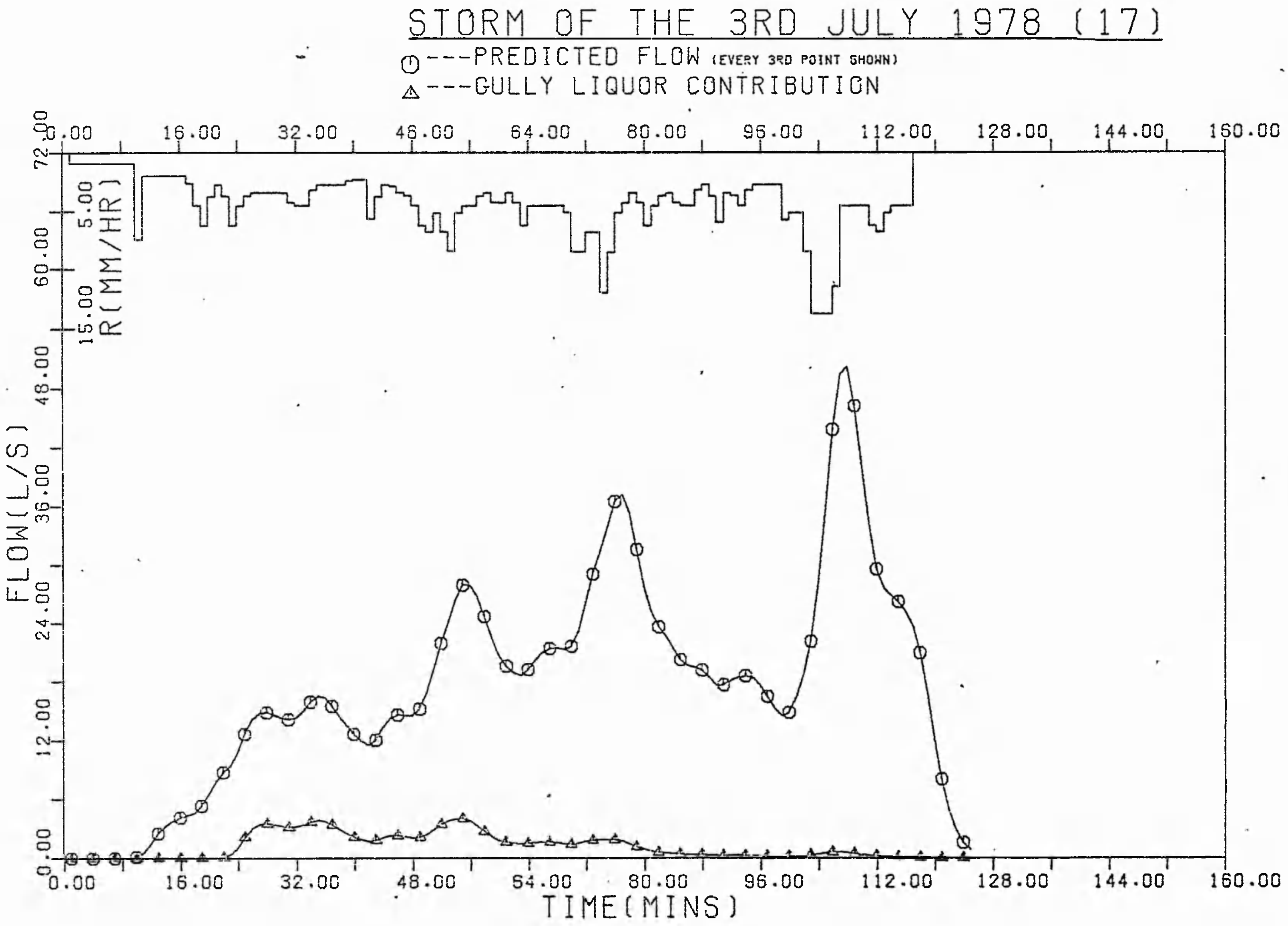
STORM OF THE 1ST JULY 1978 (16)

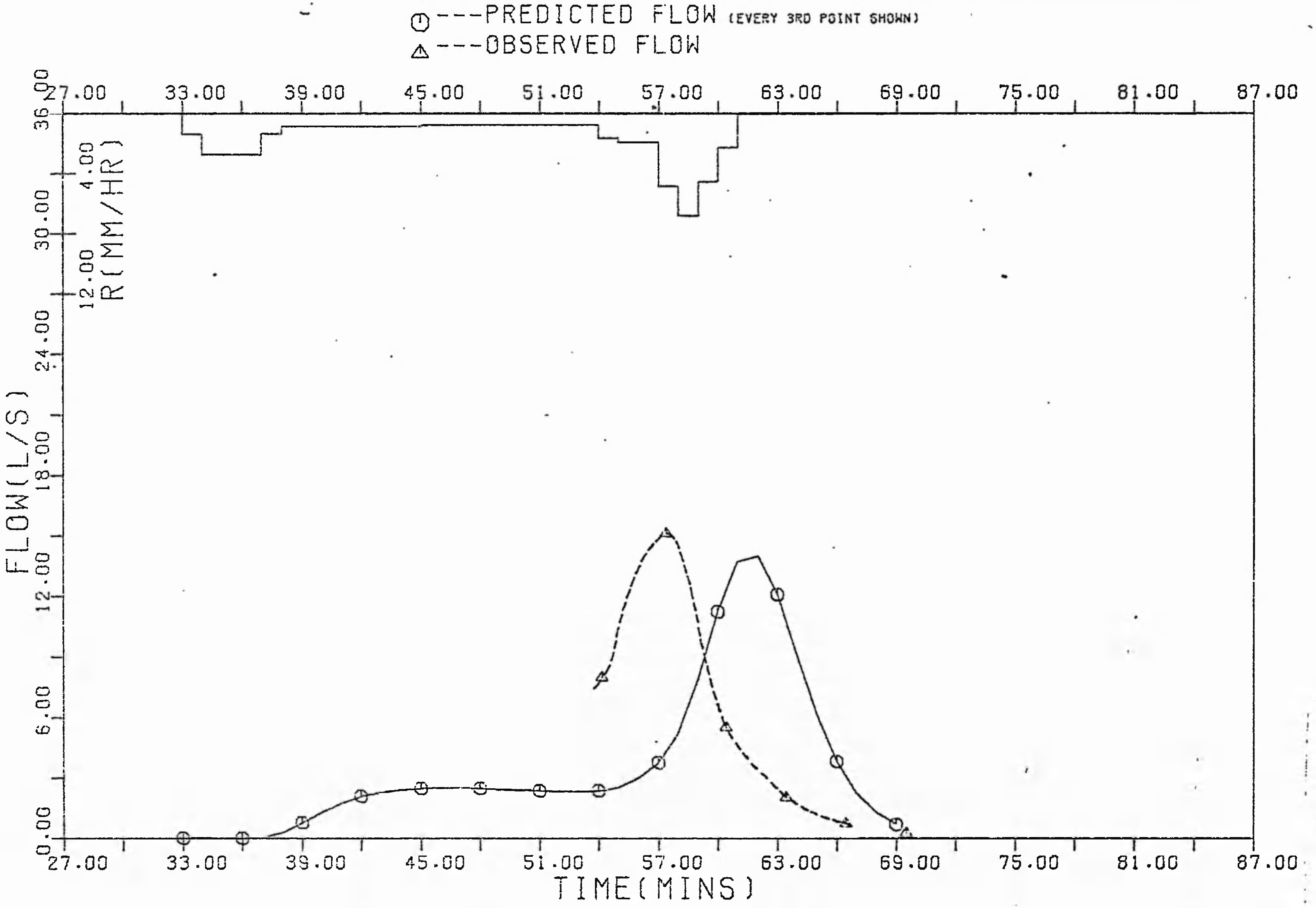



STORM OF THE 1ST JULY 1978 (16)
⊖---PREDICTED FLOW (EVERY 3RD POINT SHOWN)
△---GULLY LIQUOR CONTRIBUTION
R(MM/HR)
2.00
6.00
0.00
16.00
32.00
48.00
64.00
80.00
96.00
112.00
128.00
144.00
160.00
TIME(MINS)
0.00
10.00
20.00
30.00
40.00
50.00
60.00
FLOW(L/S)

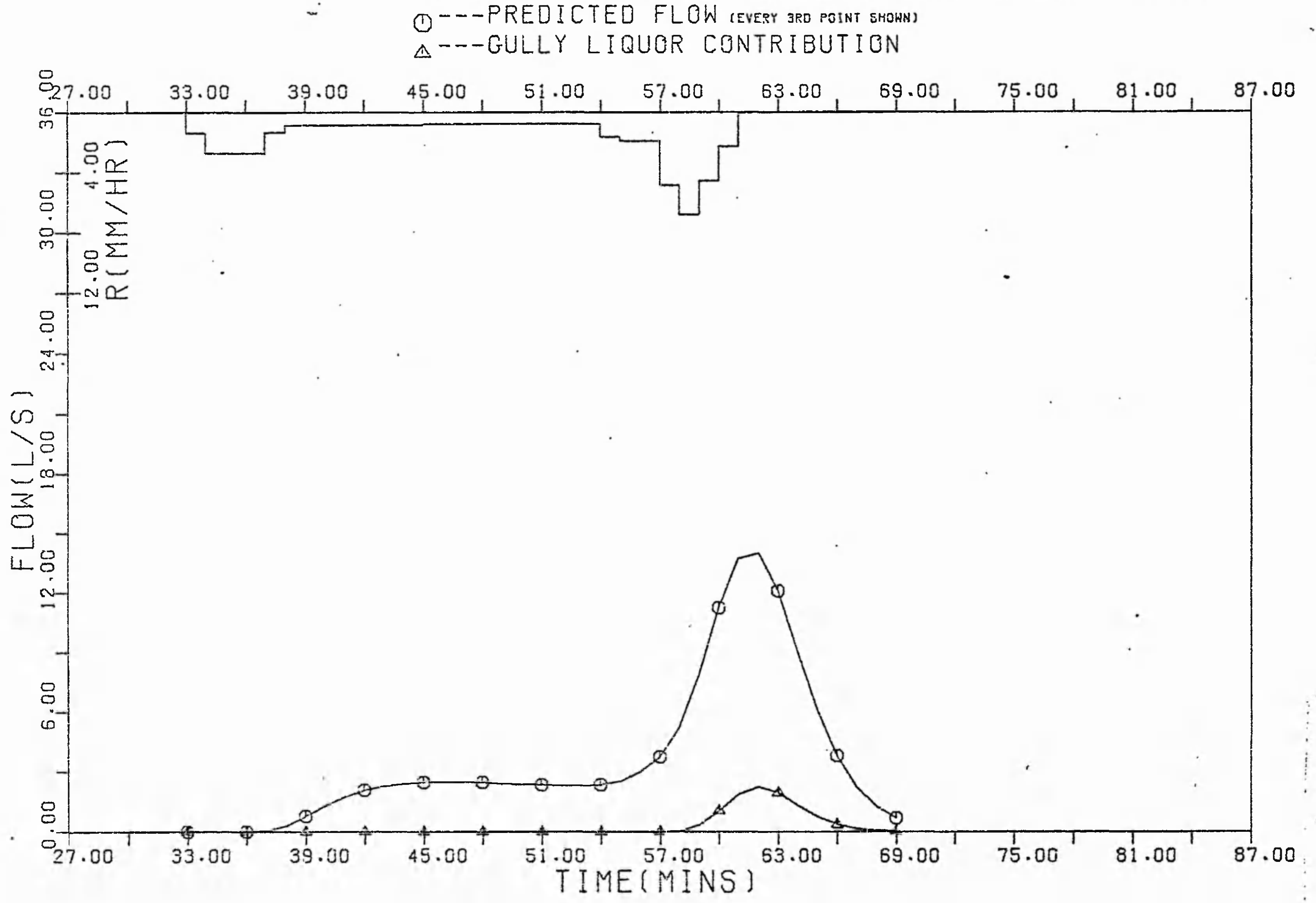
STORM OF THE 3RD JULY 1978 (17)



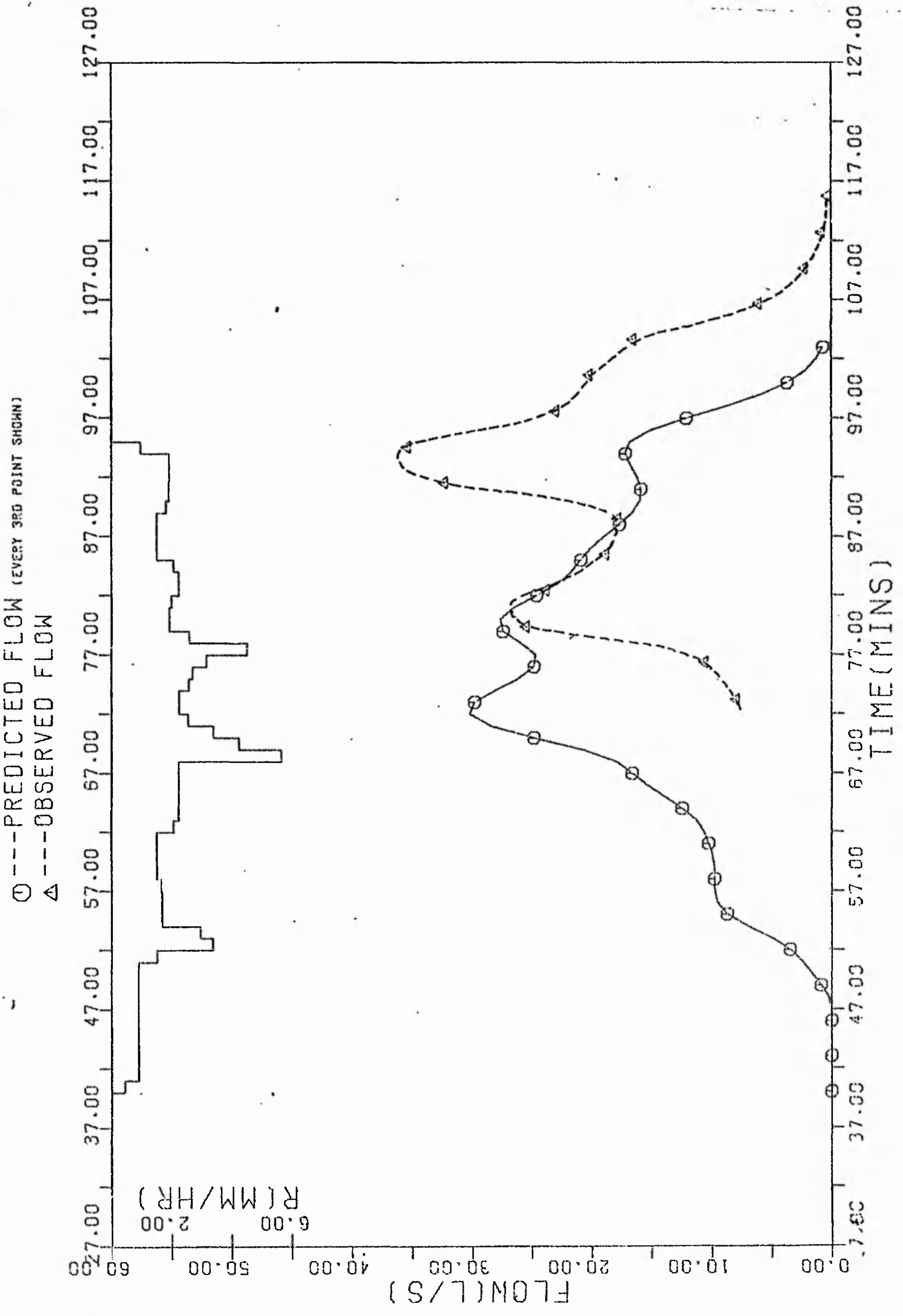

STORM OF THE 3RD JULY 1978 (17)
---PREDICTED FLOW (EVERY 3RD POINT SHOWN)
---GULLY LIQUOR CONTRIBUTION
R(MM/HR)
5.00
15.00
FLOW(L/S)
0.00
12.00
24.00
36.00
48.00
60.00
72.00
TIME(MINS)
0.00
16.00
32.00
46.00
64.00
80.00
96.00
112.00
128.00
144.00
160.00

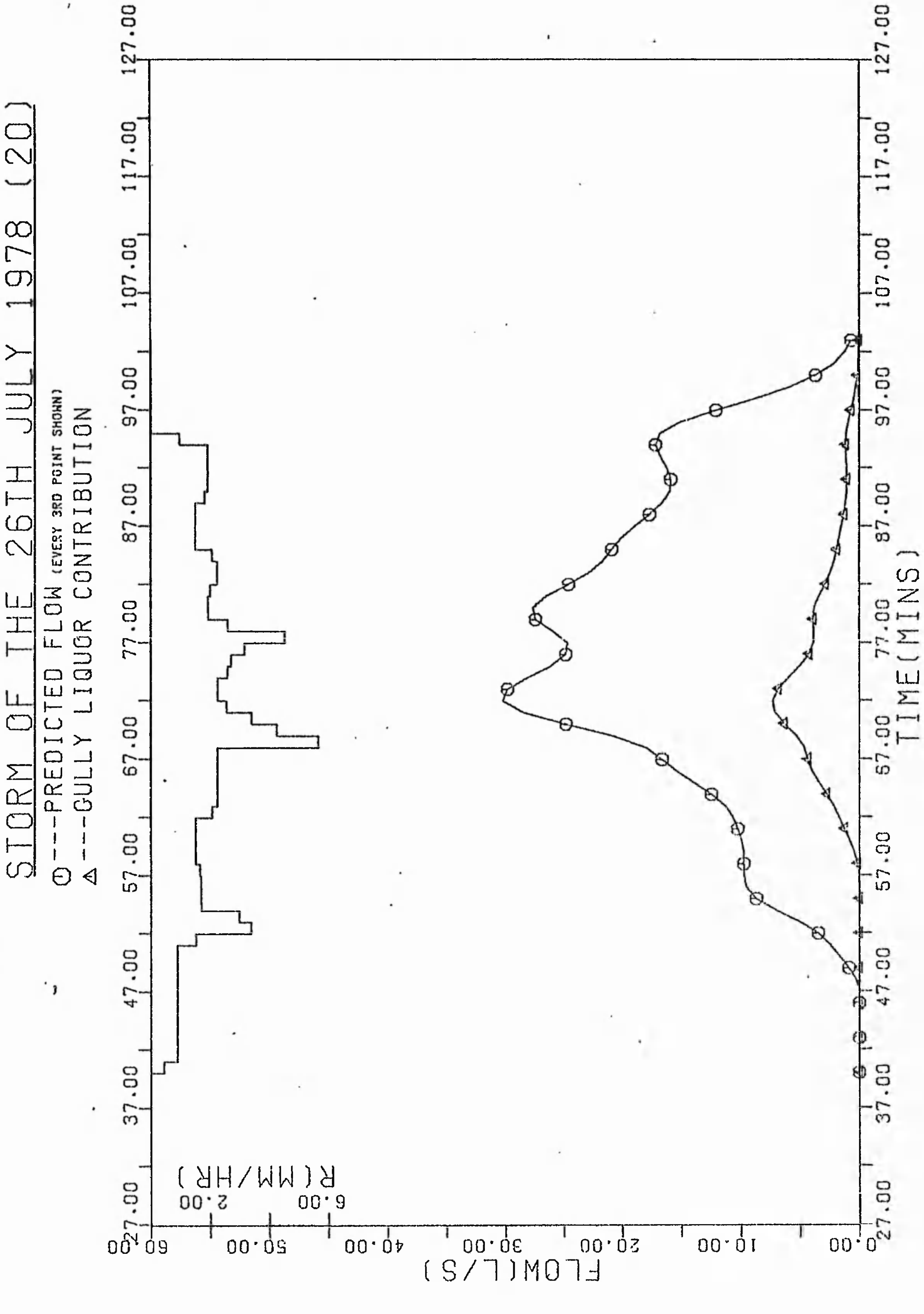

STORM OF THE 23RD JULY 1978 (19)

STORM OF THE 23RD JULY 1978 (19)



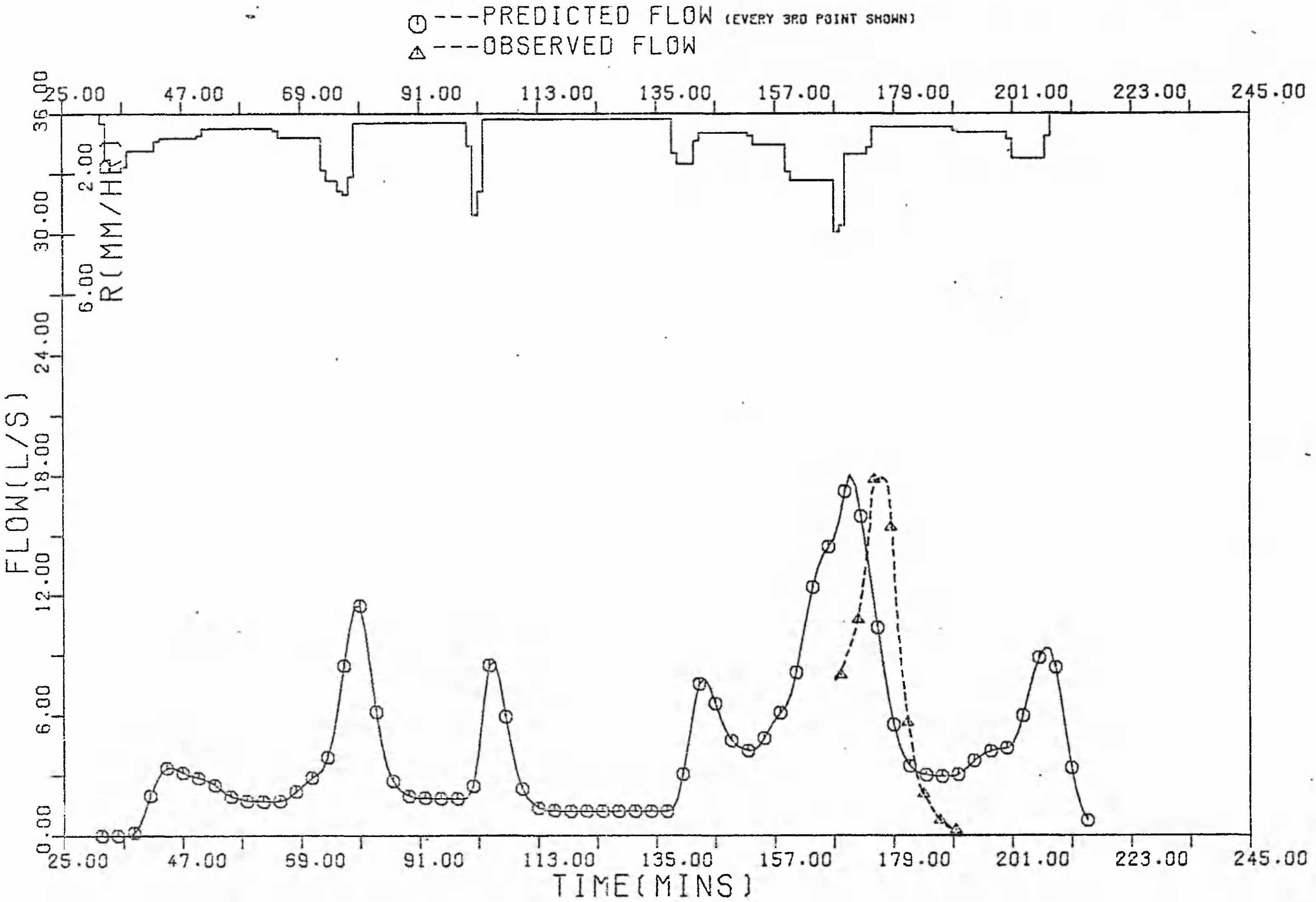
STORM OF THE 26TH JULY 1978 (20)



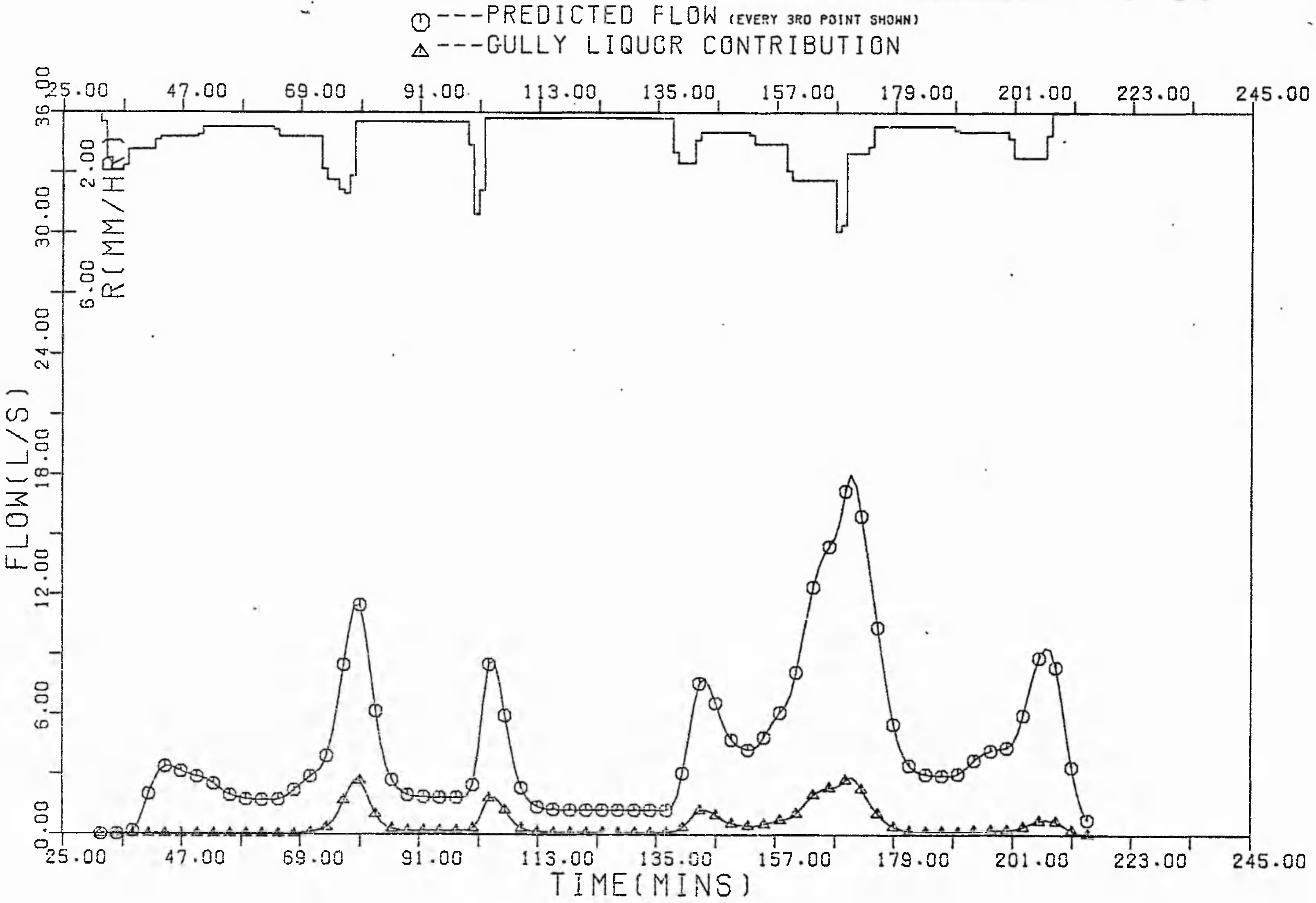


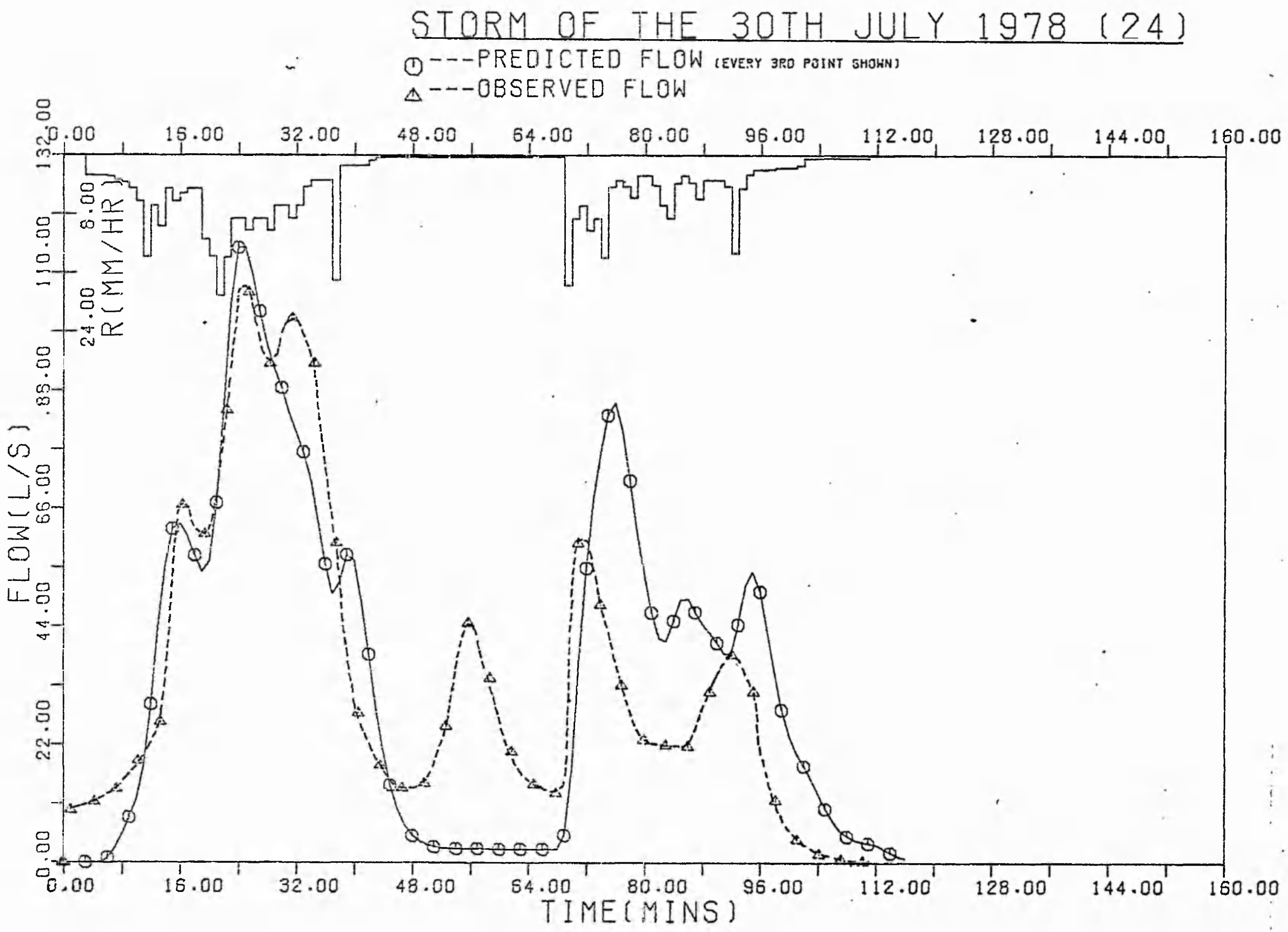
STORM OF THE 26TH JULY 1978 (20)

STORM OF THE 27TH JULY 1978 (21)

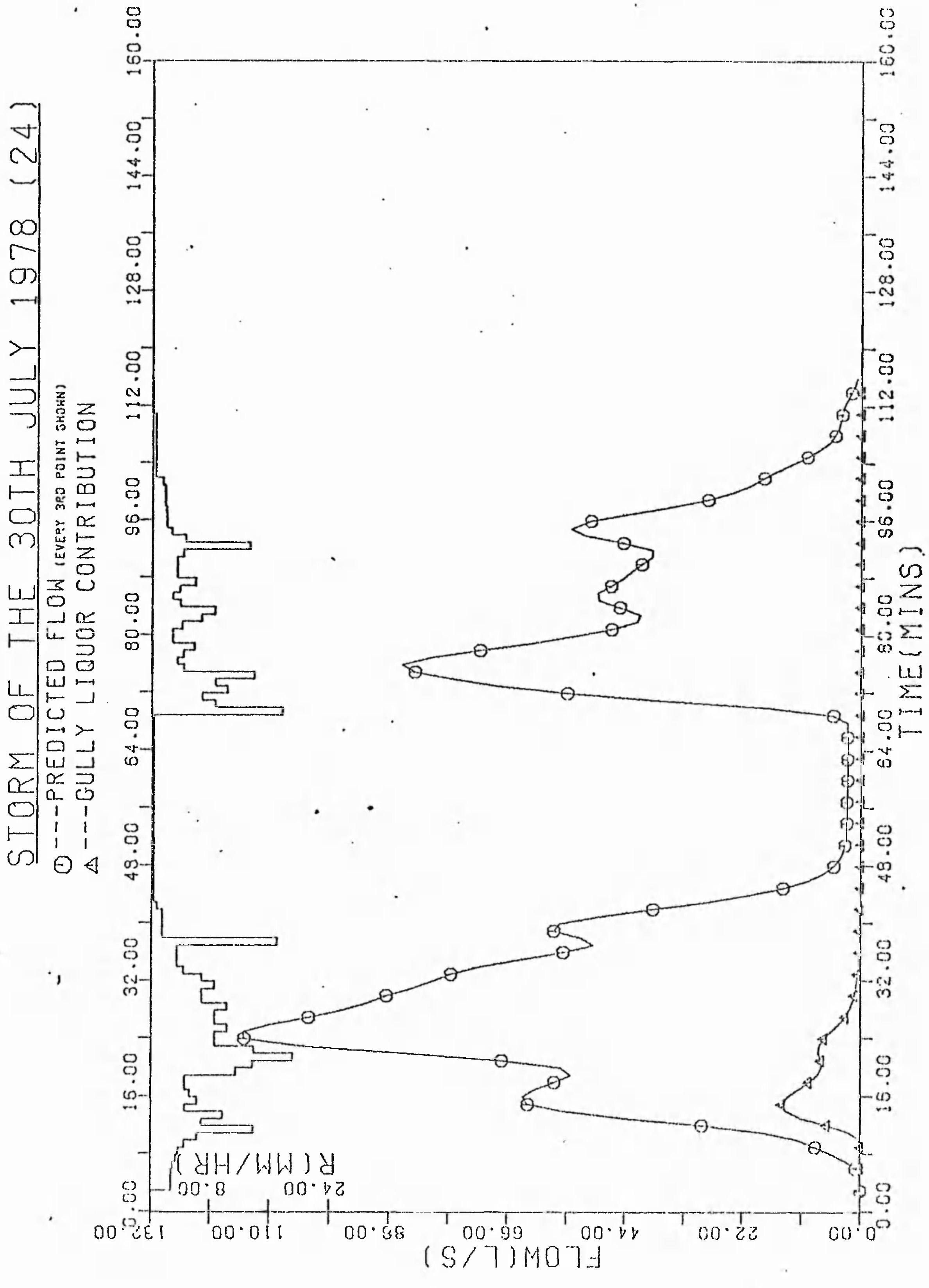


STORM OF THE 27TH JULY 1978 (21)





STORM OF THE 30TH JULY 1978 (24)



STORM OF THE 30TH JULY 1978 (24)

5. MULTIPLE REGRESSION OUTPUT

LIST OF SYMBOLS

DUR = storm duration (Mins.)

ROVOL = runoff volume (M^3)

AVIN = average intensity (mm)

AV10 = average intensity for the most intense 10 minutes (mm)

PI = peak intensity (mm)

ADP = antecedent dry period (days)

AWI = antecedent wetness index

PPT = total rainfall (mm)

SPE = total rainfall of previous event (mm)

```
STORM PARAMETERS
----------------

STORM NO     DUR     ROVOL    AVIN     AV10      PI     ADP      AWI     PPT     SPE

     6.   107.000   60.369   0.975    3.978   7.020   0.000   46.200   1.755   1.900
     7.    39.000  116.713   5.090   15.093  21.060   0.000   44.300   3.393   0.200
     9.    35.000   40.246   1.950    3.510   7.020   0.000   46.300   1.170   3.300
    15.    54.000   33.299   1.056    2.877   3.379   0.000   48.700   0.968   0.200
    16.   111.000   64.081   0.998    2.824   3.997   0.000   45.100   1.863   1.900
    19.    27.000   27.125   1.690    2.616   6.808   0.000   46.900   0.789   3.100
    20.    54.000   61.901   1.963    3.325   5.657   1.000   47.700   1.800   4.500
    24.   107.000  254.778   4.115   11.278  19.131   0.000   48.000   7.407   2.800
    12.   151.000  197.780   2.270    4.914   7.020   0.000   49.700   5.750   0.200
    10.    38.000   60.369   2.700    5.967  14.040   7.000   57.000   1.755   0.100
```

```
STORM PARAMETERS
----------------

STORM NO    DUR      ROVOL     AVIN     AV10      PI      ADP      AWI      PPT      SPE

     6.   107.000   60.369   0.975    3.978    7.020   0.000   46.200   1.755   1.900
     7.    39.000  116.713   5.090   15.093   21.060   0.000   44.300   3.393   0.200
     9.    35.000   40.246   1.950    3.510    7.020   0.000   46.300   1.170   3.300
    15.    54.000   33.299   1.056    2.877    3.379   0.000   48.700   0.968   0.200
    16.   111.000   64.081   0.998    2.824    3.997   0.000   45.100   1.863   1.900
    19.    27.000   27.125   1.690    2.616    6.808   0.000   46.900   0.789   3.100
    20.    54.000   61.901   1.963    3.325    5.657   1.000   47.700   1.800   4.500
    24.   107.000  254.778   4.115   11.278   19.131   0.000   48.000   7.407   2.800
    12.   151.000  197.780   2.270    4.914    7.020   0.000   49.700   5.750   0.200
    10.    38.000   60.369   2.700    5.967   14.040   7.000   57.000   1.755   0.100
    11.     6.000    8.049   2.340    2.340    3.510   6.000   56.000   0.234   1.200
    17.   115.000  294.743   4.432    8.619   13.756   0.000   45.700   8.569   2.200
    21.   175.000   83.274   0.825    2.566    3.947   0.000   45.100   2.421   0.200
```

```
MEAN STORM CONCENTRATIONS
-------------------------

STORM NO     FLOW      SS       DS       BOD      COD      NO3      NH4

   6.       10.980   50.280  158.330    5.700   30.920   10.410    1.060
   7.       20.230  172.200   78.880    7.230   99.870    8.310    0.880
   9.        5.860  138.890  257.860   14.190   89.740   11.690    1.240
  15.       13.610   21.620   51.410    5.650   85.610    5.050    0.560
  16.        9.410   26.710   70.030    2.590   37.770    6.080    0.240
  19.        5.410   45.580  107.260    8.110   23.020    5.210    0.410
  20.       16.300   14.910   87.140    6.360   18.770    6.860    0.350
  24.       34.680   84.380   70.500    0.000   75.130    3.880    0.000
  12.       25.710   68.170  149.970    0.000   41.370    0.000    0.000
  10.        9.180  155.470  374.940   27.140  159.110   31.480    2.050
  11.        3.150  294.970  368.000   31.790  313.650    0.000    5.300
  17.       14.550   91.810  123.740    5.330   65.720    4.500    0.240
  21.        7.750  372.300  138.055    0.000  233.470    5.560    0.000
 MEAN        13.602  118.253  156.624    8.776   98.012    7.618    0.948
STD DEV      8.933  109.219  109.300   10.022   88.325    7.925    1.436
```

```
STORM LOADS
-----------

STORM NO DISCHARGE    SS        DS        BOD       COD       NO3       NH4

     6.      19.596    0.985     3.005     0.112     0.606     0.204     0.021

     7.      58.249   10.031     4.595     0.421     5.817     0.484     0.051

     9.       8.312    1.156     2.146     0.118     0.747     0.097     0.010

    15.      26.777    0.579     1.376     0.151     2.292     0.135     0.015

    16.      16.799    0.449     1.177     0.044     0.634     0.102     0.004

    19.       5.712    0.260     0.613     0.046     0.131     0.030     0.002

    20.      43.967    0.655     3.831     0.280     0.825     0.302     0.015

    24.     239.024   20.169    16.851     0.000    17.958     0.929     0.000

    12.     125.600    8.562    18.837     0.000     5.196     0.000     0.000

    10.      11.361    1.766     4.268     0.308     1.809     0.358     0.023

    11.       2.176    0.642     0.801     0.069     0.682     0.000     0.012

    17.      36.579    3.358     4.526     0.195     2.404     0.165     0.009

    21.      11.001    4.096     1.519    45.100     2.568     0.061     0.000

   MEAN       46.550    4.054     4.888     3.603     3.205     0.221     0.012

STD DEV      66.547    5.787     5.937    12.469     4.771     0.258     0.014
```

```
MULTIPLE REGRESSION ANALYSIS FOR SUSPENDED SOLIDS
=================================================

CORRELATION COEFFICIENTS
========================


                SS

    DUR       0.3767

   AVIN       0.7731

   AV10       0.7794

     PI       0.7591

    ADP      -0.1743

    AWI      -0.0539

    PPT       0.9368

    SPE      -0.1107


ANALYSIS OF REGRESSION
======================

 PARAMETER       COEFF              STD ERR             T-VALUE

    DUR          -0.1260             0.0068             -18.4621
   AVIN          -4.9852             0.2592             -19.2333
   AV10           0.6970             0.0936               7.4450
     PI           0.1706             0.0470               3.6331
    ADP           0.8246             0.1518               5.4311
    AWI          -0.7885             0.1022              -7.7145
    PPT           5.2270             0.2026              25.8034
    SPE          -0.4754             0.0761              -6.2474
CONSTANT         43.4995             5.3717               8.0979

STANDARD ERROR OF ESTIMATE =   0.1289

MULTIPLE CORRELATION (R)   =   1.0000

DETERMINATION (R SQUARED)  =   1.0000

CORRECTED R SQUARED        =   0.9996
```

```
MULTIPLE REGRESSION FOR SUSPENDED SOLIDS LOAD (KG)
--------------------------------------------------

CORRELATION COEFFICIENTS
------------------------


                SS

  DUR       0.3767

 AVIN       0.7731

 AV10       0.7794

  AWI      -0.0539

  PPT       0.9368


ANALYSIS OF REGRESSION
----------------------

 PARAMETER      COEFF             STD ERR          T-VALUE

    DUR         -0.0979           0.0138          -7.0940
   AVIN         -4.3487           0.8713          -4.9909
   AV10          1.1830           0.2085           5.6747
    AWI         -0.1119           0.0593          -1.8881
    PPT          4.2495           0.3122          13.6133
CONSTANT         8.8338           3.0730           2.8747

STANDARD ERROR OF ESTIMATE =  0.5765

MULTIPLE CORRELATION (R)   =  0.9983

DETERMINATION (R SQUARED)  =  0.9966

CORRECTED R SQUARED        =  0.9923
```

```
MULTIPLE REGRESSION FOR SUSPENDED SOLIDS LOAD (KG)
--------------------------------------------------

CORRELATION COEFFICIENTS
------------------------


             SS

  DUR      0.3767

   PI      0.7591

  ADP     -0.1743

  PPT      0.9368



ANALYSIS OF REGRESSION
----------------------

 PARAMETER      COEFF              STD ERR           T-VALUE

    DUR        -0.0298             0.0187            -1.5952
     PI         0.2742             0.1261             2.1745
    ADP        -0.4362             0.2012            -2.1682
    PPT         2.6250             0.4487             5.8498
CONSTANT       -2.6382             1.4234            -1.8535

STANDARD ERROR OF ESTIMATE =  1.2031

MULTIPLE CORRELATION (R)   =  0.9906

DETERMINATION (R SQUARED)  =  0.9814

CORRECTED R SQUARED        =  0.9664
```

```
MULTIPLE REGRESSION FOR DISSOLVED SOLIDS LOAD (KG)
--------------------------------------------------

CORRELATION COEFFICIENTS
------------------------


                DS

   DUR       0.6771

  AVIN       0.4449

  AV10       0.3975

    PI       0.3856

   ADP      -0.0895

   AWI       0.1933

   PPT       0.9444

   SPE      -0.1747



ANALYSIS OF REGRESSION
----------------------

 PARAMETER      COEFF          STD ERR        T-VALUE

   DUR          0.1523         0.0505         3.0165
  AVIN          6.9554         1.9181         3.6263
  AV10         -1.1306         0.6927        -1.6321
    PI          0.3005         0.3475         0.8647
   ADP         -3.4844         1.1236        -3.1012
   AWI          2.3809         0.7563         3.1480
   PPT         -1.4562         1.4990        -0.9714
   SPE          0.7449         0.5631         1.3229
CONSTANT     -126.6374        39.7509        -3.1858

STANDARD ERROR OF ESTIMATE =  0.9538

MULTIPLE CORRELATION (R)   =  0.9988

DETERMINATION (R SQUARED)  =  0.9977

CORRECTED R SQUARED        =  0.9789
```

```
MULTIPLE REGRESSION FOR DISSOLVED SOLIDS LOAD (KG)
--------------------------------------------------

CORRELATION COEFFICIENTS
------------------------


                DS

   DUR       0.6771

  AVIN       0.4449

  AV10       0.3975

   AWI       0.1933

   PPT       0.9444


ANALYSIS OF REGRESSION
----------------------

 PARAMETER     COEFF           STD ERR        T-VALUE

    DUR           0.0371         0.0446         0.8321
   AVIN           2.9587         2.8137         1.0515
   AV10          -1.0274         0.6732        -1.5261
    AWI           0.2091         0.1914         1.0927
    PPT           2.4049         1.0080         2.3857
CONSTANT        -14.4123         9.9235        -1.4523

STANDARD ERROR OF ESTIMATE =  1.8618

MULTIPLE CORRELATION (R)   =  0.9820

DETERMINATION (R SQUARED)  =  0.9643

CORRECTED R SQUARED        =  0.9197
```

```
MULTIPLE REGRESSION FOR COD LOAD (KG)
-------------------------------------

CORRELATION COEFFICIENTS
------------------------


                COD

   DUR        0.3502

  AVIN        0.6745

  AV10        0.6833

   AWI        0.0056

   PPT        0.8952


ANALYSIS OF REGRESSION
----------------------

 PARAMETER       COEFF               STD ERR            T-VALUE

    DUR            -0.1492              0.0263            -5.6704
   AVIN            -7.7486              1.6608            -4.6655
   AV10             1.6576              0.3974             4.1714
    AWI            -0.0067              0.1130            -0.0590
    PPT             5.0104              0.5950             8.4206
CONSTANT            9.6818              5.8575             1.6529

STANDARD ERROR OF ESTIMATE =   1.0989

MULTIPLE CORRELATION (R)    =  0.9908

DETERMINATION (R SQUARED)   =  0.9817

CORRECTED R SQUARED         =  0.9589
```

```
MULTIPLE REGRESSION FOR BOD LOAD (KG)
==============================================

CORRELATION COEFFICIENTS
=======================


              BOD

  DUR      -0.3390

 AVIN       0.8527

 AV10       0.8318

  AWI      -0.2517

  PPT       0.7912


ANALYSIS OF REGRESSION
======================

 PARAMETER     COEFF          STD ERR         T-VALUE

   DUR        -0.0157         0.0160         -0.9843
  AVIN        -0.6424         0.7271         -0.8835
  AV10         0.0516         0.0624          0.8267
   AWI        -0.0134         0.0787         -0.1699
   PPT         0.7950         0.6563          1.2113
CONSTANT       1.4221         4.6498          0.3058

STANDARD ERROR OF ESTIMATE =  0.0256

MULTIPLE CORRELATION (R)   =  0.9971

DETERMINATION (R SQUARED)  =  0.9942

CORRECTED R SQUARED        =  0.9651
```

```
MULTIPLE REGRESSION FOR NITRATE LOAD (KG)
=========================================

CORRELATION COEFFICIENTS
========================


                NO3

  DUR        0.3624

 AVIN        0.7711

 AV10        0.7792

  AWI        0.1406

  PPT        0.9748



ANALYSIS OF REGRESSION
======================

 PARAMETER      COEFF             STD ERR          T-VALUE

   DUR           0.0054            0.0022           2.4370
  AVIN           0.2721            0.1154           2.3581
  AV10          -0.0228            0.0211          -1.0790
   AWI           0.0839            0.0231           3.6372
   PPT          -0.0143            0.0481          -0.2970
CONSTANT        -4.4315            1.2357          -3.5861


STANDARD ERROR OF ESTIMATE =  0.0379

MULTIPLE CORRELATION (R)   =  0.9977

DETERMINATION (R SQUARED)  =  0.9953

CORRECTED R SQUARED        =  0.9837
```

```
MULTIPLE REGRESSION FOR AMMONIUM LOAD (KG)
------------------------------------------

CORRELATION COEFFICIENTS
------------------------


               NH4

   DUR      -0.1463

  AVIN       0.8461

  AV10       0.9432

   AWI      -0.4703

   PPT       0.8645


ANALYSIS OF REGRESSION
----------------------

 PARAMETER      COEFF             STD ERR          T-VALUE

   DUR         -0.0015            0.0039          -0.3947
  AVIN         -0.0760            0.1779          -0.4271
  AV10          0.0111            0.0153           0.7264
   AWI         -0.0036            0.0192          -0.1852
   PPT          0.0685            0.1606           0.4267
CONSTANT        0.2564            1.1375           0.2254

STANDARD ERROR OF ESTIMATE =   0.0063

MULTIPLE CORRELATION (R)   =   0.9878

DETERMINATION (R SQUARED)  =   0.9758

CORRECTED R SQUARED        =   0.8549
```

```
MULTIPLE REGRESSION FOR SS MEAN CONCENTRATION
=============================================

CORRELATION COEFFICIENTS
========================


              SS

   DUR     -0.3536

  AVIN      0.6982

  AV10      0.6461

    PI      0.7316

   ADP      0.4180

   AWI      0.2379

   PPT      0.1592

   SPE     -0.3596


ANALYSIS OF REGRESSION
======================

 PARAMETER      COEFF            STD ERR         T-VALUE

    DUR          0.9027           4.1402          0.2180
   AVIN         90.8515         157.2591          0.5777
   AV10        -38.0297          56.7974         -0.6696
     PI         18.3360          28.4949          0.6435
    ADP         -5.1181          92.1193         -0.0556
    AWI         -2.9626          62.0093         -0.0478
    PPT        -29.3979         122.9039         -0.2392
    SPE        -17.2739          46.1660         -0.3742
CONSTANT       101.4061        3259.1244          0.0311

STANDARD ERROR OF ESTIMATE = 78.2009

MULTIPLE CORRELATION (R)   =  0.8935

DETERMINATION (R SQUARED)  =  0.7984

CORRECTED R SQUARED        = -0.8147
```

```
MULTIPLE REGRESSION FOR SS MEAN CONCENTRATION
---------------------------------------------

CORRELATION COEFFICIENTS (inc. S.11)
------------------------


               SS

  DUR      -0.5421

 AVIN       0.4600

 AV10       0.2185

   PI       0.2282

  ADP       0.6747

  AWI       0.5699

  PPT      -0.1551

  SPE      -0.3237



ANALYSIS OF REGRESSION
----------------------

 PARAMETER      COEFF            STD ERR          T-VALUE

   DUR         -0.2380           4.7053          -0.0506
  AVIN         89.7369         182.8414           0.4908
  AV10        -13.5075          62.3206          -0.2167
    PI         -7.2304          24.0625          -0.3005
   ADP         29.6452         102.5324           0.2891
   AWI        -12.7599          71.5677          -0.1783
   PPT          1.9946         140.1368           0.0142
   SPE        -15.9849          53.6646          -0.2979
CONSTANT      652.3719        3757.4477           0.1736


STANDARD ERROR OF ESTIMATE = 90.9236

MULTIPLE CORRELATION (R)    =  0.8798

DETERMINATION (R SQUARED)   =  0.7741

CORRECTED R SQUARED         = -0.1294
```

```
MULTIPLE REGRESSION FOR SS MEAN CONCENTRATION
---------------------------------------------

CORRELATION COEFFICIENTS
------------------------


              SS

  DUR      -0.3536

 AV1N       0.6982

 AV10       0.6461

  AWI       0.2379

  PPT       0.1592


ANALYSIS OF REGRESSION
----------------------

 PARAMETER      COEFF             STD ERR          T-VALUE

   DUR            0.6798            1.1571          0.5875
  AV1N           64.6574           73.0361          0.8853
  AV10           -2.2887           17.4746         -0.1310
   AWI            4.7925            4.9678          0.9647
   PPT          -25.8563           26.1662         -0.9882
CONSTANT       -266.9644          257.5679         -1.0364

STANDARD ERROR OF ESTIMATE = 48.3260

MULTIPLE CORRELATION (R)    =  0.8319

DETERMINATION (R SQUARED)   =  0.6920

CORRECTED R SQUARED         =  0.3070
```

```
MULTIPLE REGRESSION FOR DS MEAN CONCENTRATION
---------------------------------------------

CORRELATION COEFFICIENTS
------------------------


                  DS

   DUR      -0.2542

  AVIN      -0.0232

  AV10      -0.1335

    PI       0.0943

   ADP       0.7809

   AWI       0.7055

   PPT      -0.2133

   SPE      -0.1763


ANALYSIS OF REGRESSION
----------------------

  PARAMETER       COEFF              STD ERR           T-VALUE

    DUR              3.7663             7.5976            0.4957
   AVIN            175.9614           288.5850            0.6097
   AV10            -78.5510           104.2285           -0.7536
     PI             40.6870            52.2909            0.7781
    ADP            -36.1919           169.0474           -0.2141
    AWI             28.2162           113.7928            0.2480
    PPT           -105.0068           225.5400           -0.4656
    SPE             -1.3534            84.7189           -0.0160
CONSTANT         -1519.9772          5980.7943           -0.2541


STANDARD ERROR OF ESTIMATE =143.5058

MULTIPLE CORRELATION (R)    =  0.8846

DETERMINATION (R SQUARED)   =  0.7825

CORRECTED R SQUARED         = -0.9573
```

```
MULTIPLE REGRESSION FOR DS MEAN CONCENTRATION
---------------------------------------------

CORRELATION COEFFICIENTS (inc. S.11)
------------------------


                  DS

  DUR         -0.4407

 AVIN         -0.0110

 AV10         -0.2452

   PI         -0.0936

  ADP          0.8563

  AWI          0.8042

  PPT         -0.3542

  SPE         -0.2137



ANALYSIS OF REGRESSION
----------------------

 PARAMETER      COEFF              STD ERR           T-VALUE

   DUR            2.9639            5.8720            0.5047
  AVIN          175.1775          228.1775            0.7677
  AV10          -61.3001           77.7731           -0.7882
    PI           22.7017           30.0289            0.7560
   ADP          -11.7368          127.9556           -0.0917
   AWI           21.3241           89.3132            0.2388
   PPT          -82.9228          174.8842           -0.4742
   SPE           -0.4466           66.9709           -0.0067
CONSTANT      -1132.3865         4689.1190           -0.2415

STANDARD ERROR OF ESTIMATE =113.4684

MULTIPLE CORRELATION (R)    =   0.9046

DETERMINATION (R SQUARED)   =   0.8183

CORRECTED R SQUARED         =   0.0913
```

```
MULTIPLE REGRESSION FOR DS MEAN CONCENTRATION
---------------------------------------------

CORRELATION COEFFICIENTS
------------------------


                 DS

  DUR        -0.2542

 AVIN        -0.0232

 AV10        -0.1335

  AWI         0.7055

  PPT        -0.2133



ANALYSIS OF REGRESSION
----------------------

 PARAMETER       COEFF                 STD ERR              T-VALUE

   DUR             1.5834                2.2551               0.7021
  AVIN           111.9079              142.3366               0.7862
  AV10           -19.9381               34.0555              -0.5855
   AWI            20.1233                9.6815               2.0785
   PPT           -49.1260               50.9941              -0.9634
CONSTANT        -951.4410              502.0011              -1.8953

STANDARD ERROR OF ESTIMATE = 94.1803

MULTIPLE CORRELATION (R)    =  0.7908

DETERMINATION (R SQUARED)   =  0.6253

CORRECTED R SQUARED         =  0.1570
```

```
MULTIPLE REGRESSION FOR COD MEAN CONCENTRATION
----------------------------------------------

CORRELATION COEFFICIENTS
------------------------


              COD

   DUR     -0.3928

  AVIN      0.4446

  AV10      0.4141

   AWI      0.6015

   PPT      0.0165


ANALYSIS OF REGRESSION
----------------------

 PARAMETER      COEFF              STD ERR             T-VALUE

    DUR           -0.3442            0.7754            -0.4440
   AVIN          -24.8510           48.9399            -0.5078
   AV10           13.5613           11.7094             1.1582
    AWI            9.0671            3.3288             2.7238
    PPT           -2.0677           17.5334            -0.1179
CONSTANT        -358.3856          172.6041            -2.0763

STANDARD ERROR OF ESTIMATE = 32.3822

MULTIPLE CORRELATION (R)    =  0.8724

DETERMINATION (R SQUARED)   =  0.7611

CORRECTED R SQUARED         =  0.4626
```

```
MULTIPLE REGRESSION FOR BOD MEAN CONCENTRATION
==============================================

CORRELATION COEFFICIENTS
========================


            BOD

 DUR      -0.6776

AVIN       0.2289

AV10       0.0405

 AWI       0.0427

 PPT      -0.2298



ANALYSIS OF REGRESSION
======================

 PARAMETER      COEFF            STD ERR          T-VALUE

   DUR          -2.5949           2.4672          -1.0518
  AVIN        -114.3796         112.2446          -1.0190
  AV10           9.5842           9.6362           0.9946
   AWI         -13.4325          12.1462          -1.1059
   PPT         101.6819         101.3188           1.0036
CONSTANT       796.2875         717.8065           1.1093

STANDARD ERROR OF ESTIMATE =  3.9531

MULTIPLE CORRELATION (R)   =  0.8917

DETERMINATION (R SQUARED)  =  0.7951

CORRECTED R SQUARED        = -0.2296
```

```
MULTITPLE REGRESSION FOR NO3 MEAN CONCENTRATION
===============================================

CORRELATION COEFFICIENTS
========================


                NO3

   DUR       -0.1703

  AVIN       -0.1115

  AV10       -0.0790

   AWI       -0.4780

   PPT       -0.3828



ANALYSIS OF REGRESSION
======================

 PARAMETER      COEFF            STD ERR          T-VALUE

    DUR         -0.0191           0.2410          -0.0793
   AVIN         -1.0177          12.5996          -0.0808
   AV10          0.1917           2.3044           0.0832
    AWI         -0.9538           2.5197          -0.3785
    PPT         -0.0701           5.2542          -0.0133
CONSTANT        54.3034         134.9487           0.4024

STANDARD ERROR OF ESTIMATE =  4.1438

MULTIPLE CORRELATION (R)   =  0.5899

DETERMINATION (R SQUARED)  =  0.3480

CORRECTED R SQUARED        = -1.2821
```

```
MULTIPLE REGRESSION FOR NH4 MEAN CONCENTRATION
----------------------------------------------

CORRELATION COEFFICIENTS
------------------------


              NH4

  DUR      -0.1411

 AVIN       0.2543

 AV10       0.3067

  AWI      -0.2378

  PPT       0.1450



ANALYSIS OF REGRESSION
----------------------

 PARAMETER      COEFF              STD ERR          T-VALUE

   DUR          -0.3108            0.4004          -0.7762
  AVIN         -14.3215           18.2172          -0.7862
  AV10           1.3400            1.5639           0.8568
   AWI          -1.5887            1.9713          -0.8059
   PPT          12.3141           16.4439           0.7489
CONSTANT        94.3179          116.4993           0.8096


STANDARD ERROR OF ESTIMATE =  0.6416

MULTIPLE CORRELATION (R)   =  0.7323

DETERMINATION (R SQUARED)  =  0.5363

CORRECTED R SQUARED        = -1.7821
```

APPENDIX 3

AN ASSESSMENT OF THE IMPORTANCE OF ROADSIDE GULLY POTS IN DETERMINING THE QUALITY OF STORMWATER RUNOFF.

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ABSTRACT

Roadside gully pots on an urban estate have been monitored for a period of one year to obtain measurements of various pollution parameters. The results of an analysis of these parameters for the first year of study is presented and initial conclusions drawn on the relative importance of the different sources of pollution and of the effect of rainfall, dry periods, seasonal variations and human activity upon the quality of the stored water within the gully pots.

Examination of the stormwater runoff, (using an automatically triggered sampling machine) indicates that the quality of the 'first flush' may be substantially attributed to the discharge of gully pot liquors.

Three different forms of pollutant run off curve have been identified dependent upon the origin and nature of the material in question. Equating the levels of pollutants in gully pots to those found in the stormwater runoff has provided an indication of the principal origins of the pollutant.

The preliminary results of a laboratory simulation of the removal of solids from a gully pot are presented.

INTRODUCTION

Gully pots are placed along the roadside to act as inlet points for rainwater and stormwater runoff to the sewerage system. Their principal purpose is to remove solid material transported by the runoff which may subsequently cause sewer blockage. They also act as a water seal to prevent the release of bad odours from the sewer.

Although in recent years the nature and polluting character of stormwater runoff has been the attention of several studies

(1,3,4,5,6,7 and 9) the role of gully pots in removing sediments and concentrating polluting matter is not known to have formed the core of any major study. As early as 1900 Folwell (2) noted the accumulation with subsequent putrefaction of organic matter and drew attention to the inefficiency of cleansing cycle. The U.S. Dept of the Interior (9) produced a general report on the pollution of storm runoff which included a minor section on gully pots. The report indicated BOD values from 35 to 225mg/l in the supernatant liquid and concluded that "catch basins (gully pots) may be one of the most important single sources of pollution from stormwater flows". Other works including Sartor et al. (5) and Tucker (6) have come to similar conclusions. Tucker noted the anaerobic breakdown of organic material and reported wide variations in stored water quality between gully pots at the same and different locations, with values of BOD up to 350mg/l and the COD up to 965mg/l.

Pollution of stormwater

The pollution of stormwater results from the contamination of rainwater through contact with various substances from the time of origin in the atmosphere until the moment of its discharge into a receiving body of water. This quality variation may be brought about by such a wide variety of different events that the complex changes which result are difficult to isolate. However, in broad outline pollution of stormwater runoff may be attributed to the following principal sources:

1 Open land contributes dust and soil particles which accumulate in roadside gutters and it acts as a source of nutrients and micro-organisms. In heavy storms runoff can occur directly off open land resulting in high solid loads.

2 Vegetation and animal activity leads to the deposit of grasscuttings, leaves, faecal matter, etc.

3 Roof and road surfaces provide collecting areas for pollutants and are themselves sources of inorganic solids, cement, sand, eroded road material and salt.

4 Motor Traffic acts as a source of oil, exhaust gases, petrol, particles from car bodies and tyres.

5 Factories are a sources of dust and gaseous emissions in the atmosphere that subsequently settle or are washed down in rainfall.

6 Human activity within a catchment leads to the accumulation of litter, detergents from car washing and garden fertilizers.

The relative importance of these sources of pollution at any given location will be governed by the type of land use ie urban, industrial or commercial, and by individual catchment characteristics such as building density, slope, soil type etc.

For any given storm the degree of pollution is determined by the following factors:-

1 Intensity and duration of rainfall;

2 Length of the preceding dry period, which controls the build-up of pollutants in gutters and the quality of stored water;

3 Seasonal variations that occur in the rainfall pattern, temperature(which affects the degradation of organic matter), leaf fall, use of salt as a de-icer; and

4 Effectiveness of Council cleansing procedures.

The present study is being undertaken to gain an insight into the relative importance of the above listed factors in influencing the quality of stored water in roadside gully pots. The significance of this water in determining the degree of pollution of stormwater runoff is also being considered.

CATCHMENT CHARACTERISTICS, SAMPLING AND ANALYSIS

The catchment selected for study is at the Clifton Grove estate on the south side of Nottingham, England. Clifton Grove is a small urban estate covering an area of some 10.6 hectares, of which approximately 5.5 hectares are impervious, and which consists totally of middle income private housing. Built between 1973 and 1976 the development is spaciously arranged with areas of open land designated "amenity areas" interspersing areas of housing arranged around cul-de-sacs. In accordance with modern practice the estate is sewered on a separate system with the stormwater runoff draining directly into the River Trent.

The Clifton Grove catchment consists of seven subcatchments defined by the "arms" of the sewers. Each subcatchment being divided into microcatchments that are drained by individual gully pots.

The whole system contains 108 gully pots receiving runoff from the surface of roadways and paved areas. Each pot normally holds about 95 litres of water resulting in a total volume of stored water of 10,240 litres, there being no other storage of water in the system. Four gully pots were selected for detailed examination of pollution parameters over an extended period and the pots chosen were situated in microcatchments which illustrated different physical features. The following catchment characteristics were considered:-

1 Impervious area.

2 Slope.

3 Number of houses (important in determining the degree of human activity in the catchment).

4 Presence of open land which might contribute to the runoff entering the gully pot.

5 Situation on the estate. (cul-de-sac feeder road).

Table 1 outlines the nature of gully pot catchments chosen.

Table 1

Gully Pot	Slope	Imp. Area.	No. of Houses	Open Land	Situation
1	0.044	$140m^2$	0	No	Subsidiary Rd.
6	0.038	$680m^2$	4	Yes	Cul-de-sac
7	0.040	$513m^2$	2.5	Possibly	Feeder Road
8	0.047	$270m^2$	2	Little	Cul-de-sac

Sampling of the gully pot liquors was initially undertaken weekly but subsequently this was reduced to fortnightly. In addition, other gully pots were sampled during dry periods and randomly selected samples of another 25 were taken on one day to assess the variation of pollution parameters and test the significance of a single sample in representing the quality of the stored water. All samples were drawn from a depth of 110mm below the surface of the water using a 1 litre bottle attached to a rod.

Sampling of the total runoff was achieved with a Rock and Taylor Multipurpose sampling machine which could receive a maximum of 48 x 500ml samples. The machine was triggered by a float switch that simultaneously activated a constant head/ continuous injection doser upstream of the sampler. The doser discharged lithium chloride at a constant rate of 1 ml/sec and the lithium chloride surface water mixture was sampled downstream. The concentration of lithium in the stream enabled the flow rate in the sewer to be calculated. Samples were drawn from the stormwater flow over a period of 100 sec, there being a cycle time of 270 sec between samples.

RESULTS AND COMMENTS

The results of the analysis to date are presented in Tables 2 & 3. Figures 2 to 4 and 6 to 8 show graphically the temporal variation of some of the pollution parameters.

(a) Seasonal fluctuations and dry periods

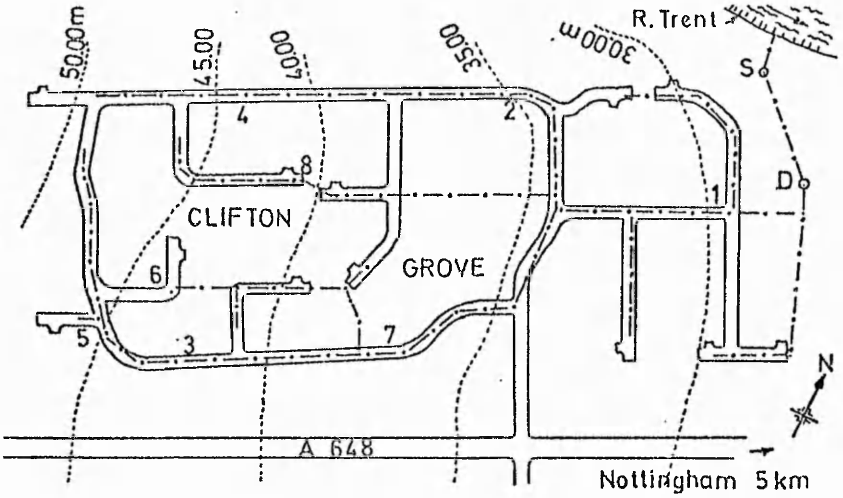
Seasonal variation may be clearly seen in the results. Of all the parameters investigated ammonium appeared to behave in the most predictable fashion (Fig.3). It retained consistently low values throughout the winter months, high values only being associated with summer dry

Table 2
Variation and mean values of parameter concentrations for the whole observation period. (All concentrations in mg/l).

	SS	DS	BOD	COD	DO	NH_4^+	NO_3^-	CL^-	pH	Ca^{2+}
Maximum	213	17,475	46	163	11.2	9.13	132	9800	12.94	272
Minimum	0.2	35	0.9	8.7	0	0.05	0.8	1.8	6.30	4
Mean	21.4	397	6.8	39.1	6.1	0.96	7.8	142.3	8.35	30.7
Standard Deviation	20.6	1,114	8.3	23.4	3.2	1.49	14.2	578	0.74	30.2

Table 3
Variation of parameter concentration for a randomly selected sample of 25 gully pots, samples being collected on the same day. (All concentrations in mg/l).

	SS	DS	BOD	COD	NH_4^+	NO_3^-	CL^-	pH	Ca^{2+}	ZN^{2+}
Maximum	252.8	292.5	41.6	428.6	4.62	28	36	8.38	35.8	0.570
Minimum	2.8	62.5	0.25	0	0.21	2.5	9.5	7.55	17.6	0
Mean	36.0	143.2	13.7	67.3	1.39	9.6	18.2	7.87	25.7	0.090
Standard Deviation	61.8	52.6	11.4	111.2	1.03	6.3	6.5	0.20	3.7	0.132
95% Confidence Limits	64.5%	13.5%	31.3%	60.4%	26.9%	25.4%	13%	0.91%	5.3%	52.4%



D Manhole containing dosing equipment.
S " " sampling "

Figure 1. Plan of Clifton Grove Estate, Nottingham, showing main storm sewer system.

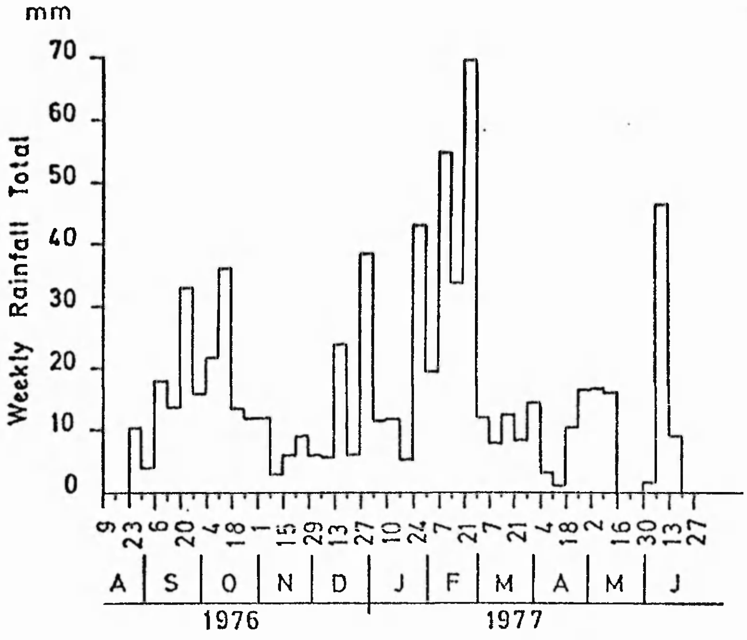


Figure 2. Weekly rainfall totals for observation period, for Meteorological Office raingauge 116959: weeks beginning Monday 09.00 G.M.T.

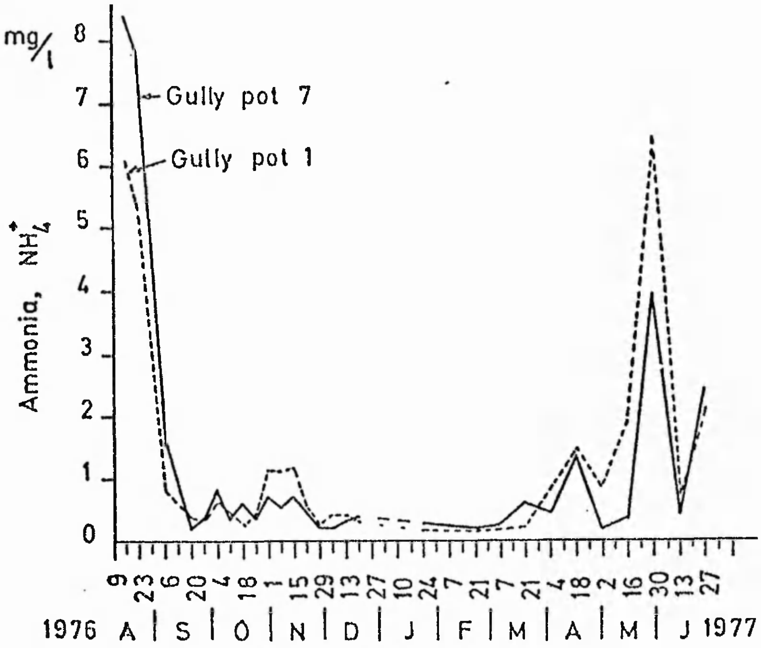


Figure 3. Temporal variations in nitrate concentration in gully pot liquors 1 and 7.

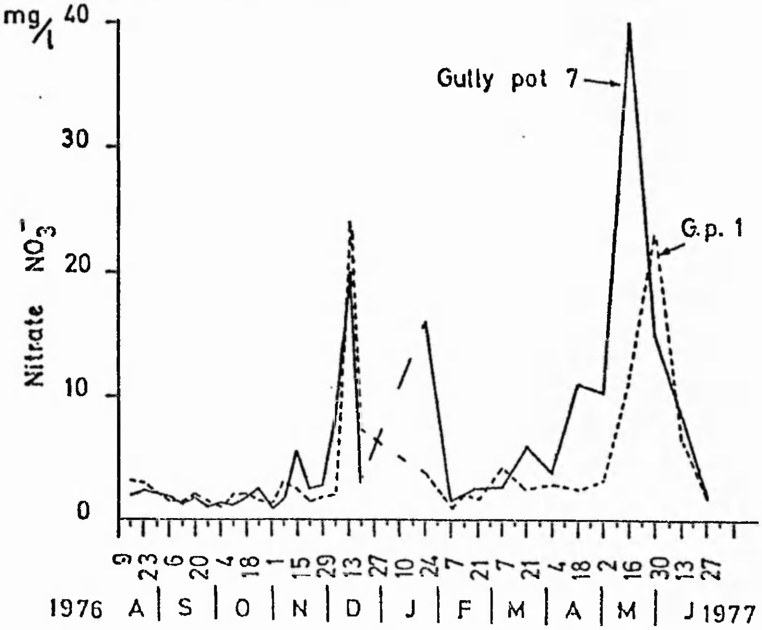


Figure 4. Temporal variations in nitrate concentration in gully pot liquors 1 and 7.

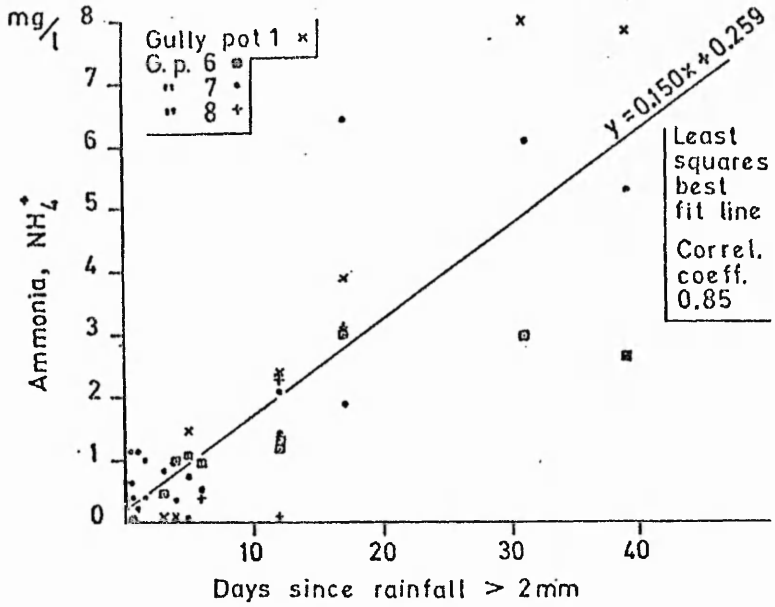


Figure 5. Correlation of ammonia concentration with number of days since rainfall greater than 2mm for gully pots 1,6,7 and 8.

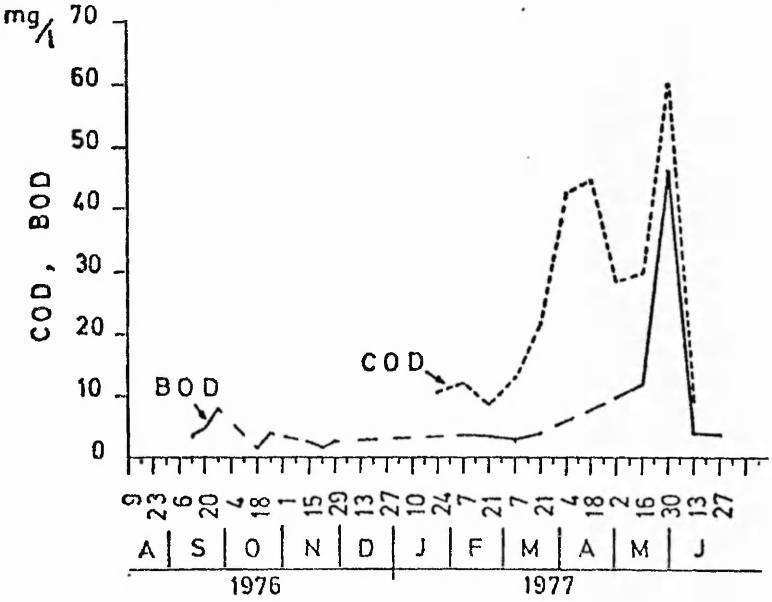


Figure 6. Temporal variations in B.O.D. and C.O.D. in gully pot liquor 1.

periods. Nitrate also showed high values during the summer (Fig.4) and was possibly the source of the high ammonium values through the action of anaerobic bacteria. It is interesting to note that in the summer of 1977 nitrate values did not decrease through this conversion mechanism, possibly due to the fresh input of nitrate from car-wash liquors.

However, in the summer of 1976 when car washing was prohibited due to the water shortage low nitrate levels were recorded. High nitrate values were also recorded during periods of winter road salting, the input being thought attributable to the impure rock salt employed. This influx of nitrate did not significantly affect ammonium values due principally to the inhibition of bacterial action by the low temperatures. The build up of ammonium over a dry period is illustrated by Fig.5.

Values of BOD and COD (Fig.6) showed a similar but more variable pattern in comparison to that observed for ammonia, low values occurred during winter months and high peaks were coincident with summer dry periods. The inhibition of bacterial action is reflected in the BOD values observed during the winter months. BOD remained virtually constant and winter dry spells did not cause any significant build up in oxygen demand.

Dissolved solids (Fig.7) mirror in a general fashion the changes already mentioned for specific parameters. The increase in pollutants and dissolved material over dry periods may be attributed to the following events:-

1 Input from sweeping and wind blown material e.g. grasscuttings and organic debris providing fresh material for 2).

2 Anaerobic digestion of organic matter to soluble compounds by bacterial action.

3 Input of soluble material from human activity i.e. car washing.

4 Evaporation increasing effective concentration (minor).

In winter the major event to influence dissolved solids concentration was road salting, (Fig.8). This was not only the cause of sharp increases in the values of dissolved solids, sodium and chloride but also increases were observed for nitrate, potassium and calcium. These parallel increases being thought attributable to the impure rock salt employed.

Autumn leaf fall was considered to have no significant effect upon this catchment. Tucker (6) had reported clogging of gully pots by leaves with subsequent high increases in suspended solids, BOD and COD. However, due

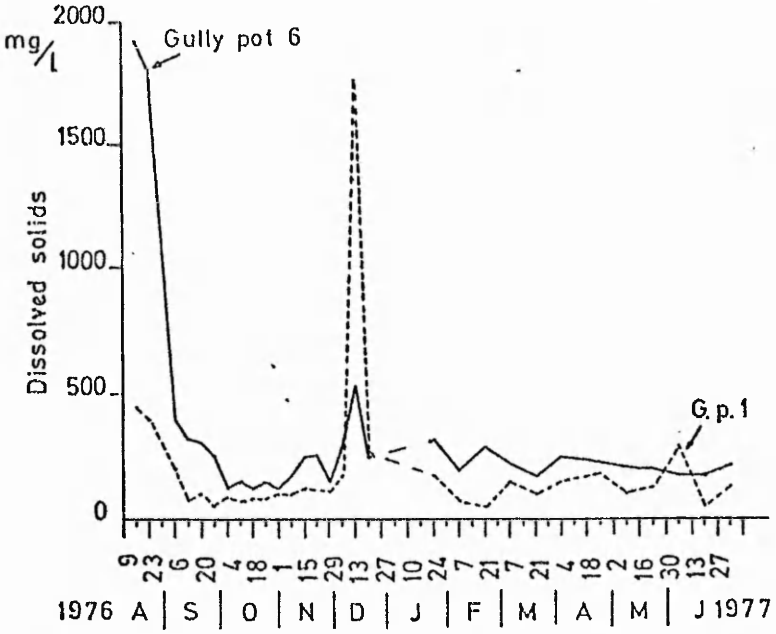


Figure 7. Temporal variations in dissolved solids concentration in gully pot liquors 1 and 6.

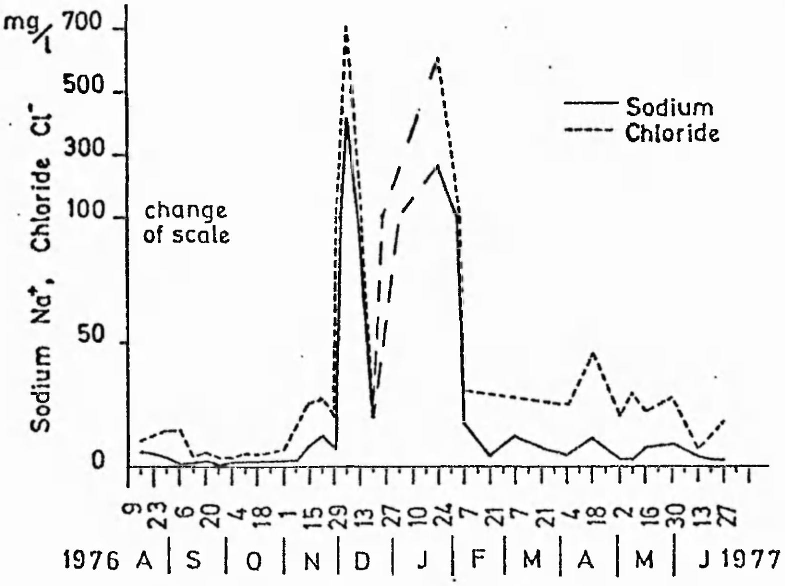


Figure 8. Temporal variations in sodium and chloride concentration in gully pot liquor 1.

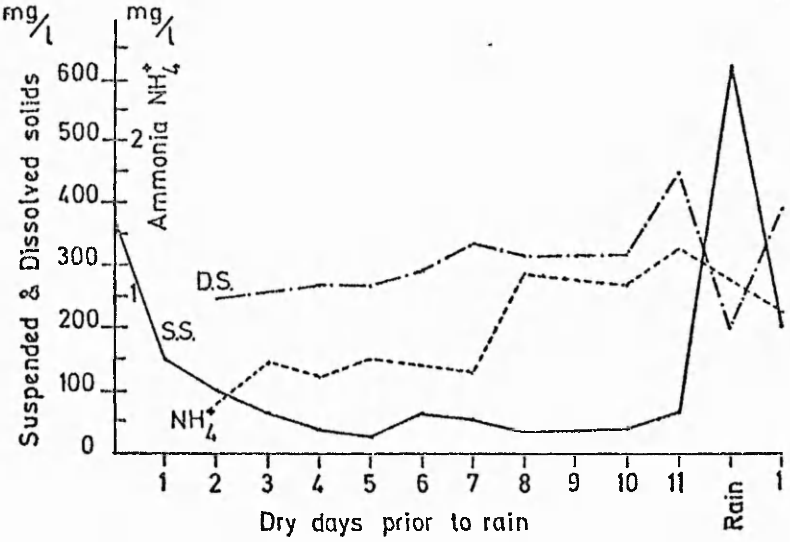


Figure 9. Variation over a dry period of suspended solids, dissolved solids and ammonia concentrations in gully pot liquor 4.

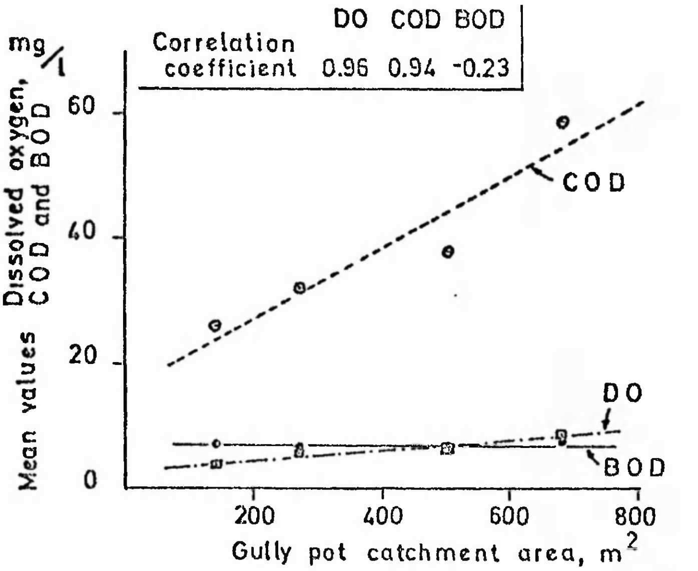


Figure 10. Correlation of mean values of dissolved oxygen, B.O.D. and C.O.D. with gully pot catchment area.

to regular street sweeping and the presence of only a few deciduous trees of any size on the estate no changes in quality from this cause were identified.

A significant parameter in specifying the quality of stored water is the dissolved oxygen level. Dissolved oxygen was observed to fall to zero after a period of 4 to 7 days dry weather. This resulted in septic conditions in the gully pot followed by the development of anaerobic digestion with subsequent increases in the values of BOD, COD and dissolved solids. During hot weather the production of hydrogen sulphide was evident and the gully pots developed a pungent smell.

Day to day examination of gully pot liquor during a dry period (Fig.9) showed a decrease in the amount of suspended solids following an inverse exponential form. The period of this decrease ranged from a few hours to five days dependent upon the type of material input (fine dusts associated with building sand had the slowest settling rate). General increases in dissolved solids were also observed. Observations during a rainstorm showed a sharp increase in suspended solids due to wash off from road surfaces and the stirring of bottom sediments. The levels of dissolved solids decreased to the same value as those of the incoming rainwater and then adjusted to a new steady state dependent upon the nature of the soluble material input.

(b) Human activity and catchment size

The nature and level of human activity in the micro-catchment of a gully pot is thought to be a significant factor in determining the chemical composition of the pot liquor. Unusually high values of parameters that are not mirrored in measurements from other gully pots may often be ascribed to human activity in the catchment. Some of the observations which may be attributed to human influence are listed below:-

1 Oil washed from road surfaces and in particular driveways was often present in the gully pots as a thin film on the surface of the liquor.

2 Frothiness due to car-wash liquids was commonly observed. Extreme cases of this were associated with abnormal nitrate levels, and during dry periods this may have had an influence upon ammonia levels.

3 In the summer months grasscuttings were found in abundance in gully pots and gutters and their presence could contribute to BOD levels during dry periods.

4 pH values up to 12.9 were recorded, probably due to the use of garden fertilisers and other agricultural chemicals which were blown or washed into the gully

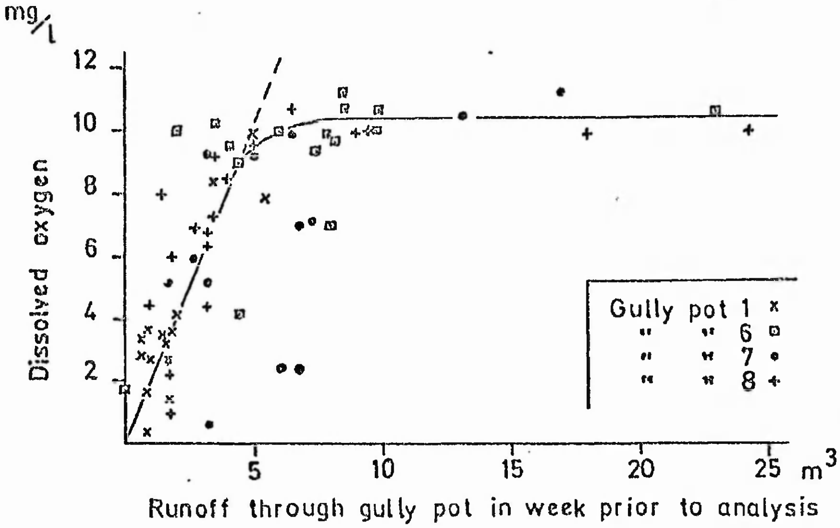


Figure 11. Variation of dissolved oxygen concentration with runoff through gully pots 1,6,7 and 8 for week prior to analysis.

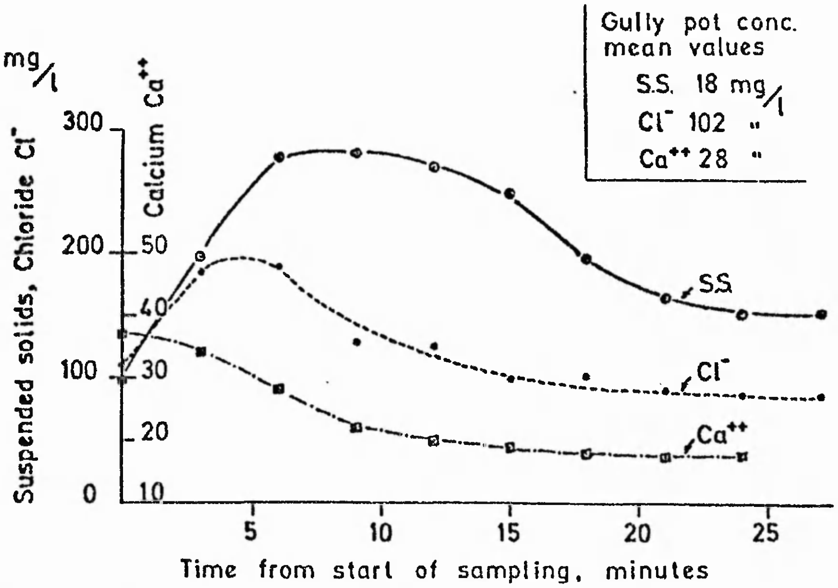


Figure 12. Pollutant runoff curves corresponding to storm water runoff (6 Jan 1976) illustrating the removal of different materials from the Clifton Grove Catchment. (Note mean values of pollutant concentrations in observed gully pots prior to storm).

pots.

5 Salting of driveways was found to add large quantities of dissolved material above and beyond that due to council road saltings.

The level of human activity might be expected to correlate well with catchment area in an urban estate i.e. the larger the catchment area the greater the likelihood of human activity affecting the gully pot. Fig.10, a plot of mean values of COD and BOD against catchment area, shows that values of COD correlate well with catchment area i.e. human activity, whilst the values of BOD appear to be independent of area. This suggests that the polluting input due to human activity is principally not organic in nature. Dissolved oxygen (Fig.10) showed a dependence upon catchment area, however, this was less a result of the human influence but was directly related to the volume of runoff through the gully pot. A graph of total runoff through the gully pot for the week prior to analysis plotted against values of dissolved oxygen is given in Fig. 1 . The graph indicates that to keep a gully pot fully aerated a runoff volume of $6m^3$ per week is necessary. However, to keep dissolved oxygen at a reasonable level e.g. above 6mg/l, and assuming a typical weekly summer rainfall of 6mm a catchment area of $500m^2$ would be needed. The majority of gully pot catchment areas at Clifton Grove are smaller than this, e.g. gully pot 1, which is consequently rarely fully aerated. It would seem that to reduce pollution of gully pots by increasing the dissolved oxygen level, larger catchment areas should be employed.

(c) Council cleansing procedures

The normal council cleansing procedure was to have the estate swept by hand fortnightly and the gully pots emptied on average once every 4 months. However, during the period of this study the gullys were emptied only once. The frequency of street sweeping appeared to be sufficient to keep the gutters and the estate generally clean and tidy. Despite the fact that pots were only emptied once, no exceptional depths of settled material were noted and a frequency of cleansing every 4 to 6 months appeared to be adequate as far as solid material was concerned. However, when the gully pot liquors were at their most polluting i.e. during summer dry periods, such a frequency was inadequate to maintain the pots in a wholesome state.

(d) Storm runoff

Three principal types of pollutant runoff curve have been identified (Fig.12). The type of curve followed is dependent upon the nature of the material being removed and its origin. For example a parameter whose principal origin is in gully liquors will follow a curve of type 3 in figure 12, this type of removal is typical of ammonia, calcium and potassium. Pollutants whose prime origin is on the road surface or atmosphere will follow curves of types 1 or 2. The position of the peak of these curves is determined by the removal coefficient (i.e. ease of mobilisation) of the material. For example, suspended solids have a low removal coefficient and consequently peak concentrations are observed later in the storm. Soluble matter such as salt possesses high mobility giving rise to an earlier peak concentration. Comparison of levels of parameters as found in stormwater runoff compared to parameter levels found in gully pots confirms this argument (Fig.12). During winter months nitrate values were also found to be higher in runoff than in gully pots for the storms analysed to date, examination of roof runoff revealed its principal origins to be in rainfall.

The 108 gully pots on the Clifton Grove estate contain a total volume of some 10,240 litres. Comparing this volume to the storm runoff volume of 1,045,000 litres for the catchment over a 1 hr M5 rainfall of 19mm, reveals that gully liquors contribute some 1% of the total runoff. However some 40% of daily rainfall at Clifton Grove is equal to or less than 1mm resulting in a runoff volume of which gully liquors may contribute upwards of 20% of the total runoff. Bearing in mind that the greater part of the original gully liquors are discharged in the earlier stages of runoff the significance of gully pot quality in determining the day to day polluting nature of the 'first flush' of storm runoff can be seen.

(e) Laboratory simulation

Initial results from a laboratory simulation of the removal of settled material from gully pots have indicated that for all but the lowest flows complete mixing of the storm water inflow and the pot liquor is established rapidly and prevails during runoff. The removal of solids by the disturbance of the bottom sediments is dependent upon:-

1 rate of flow of water into the gully pot;

2 size of the gully pot;

3 depth of sediment within the pot; and

4 mass of sediment available for release.

The typical removal of sediment is illustrated by Figure 13. The rising limb, when material is being released from the bottom sediments, can be defined by an equation of the form:

$$c = A(1 - e^{Bt})$$

where c = concentration of suspended solids in the outflow

t = time

A and B are constants dependent upon flow rate.

And the falling limb, after all available material has been released by an equation of the form:-

$$c = Ae^{-Bt}$$

The mass of sediment resuspended and released in runoff is relatively small compared to the mass remaining in the bottom of the gully pot. This indicates the general efficiency of gully pots in trapping heavier particulate matter. However, the finer sediment washed over is of greater significance in determining the polluting character of storm runoff.

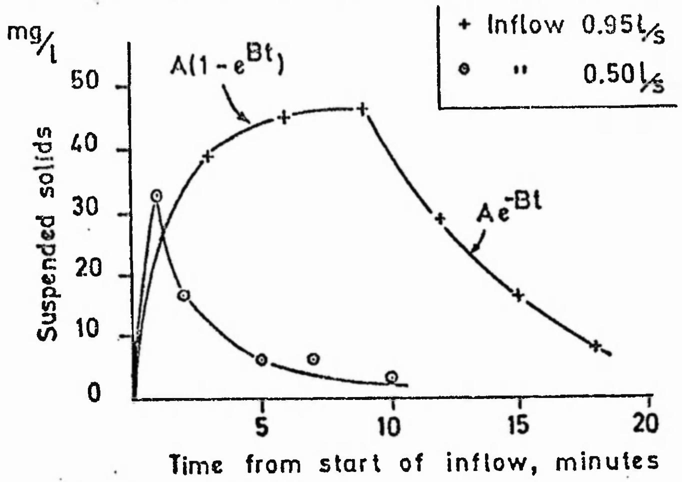


Figure 13. Laboratory simulation of the removal of solid material from a gully pot under steady flow conditions. (Initial depth of material in gully pot was 50 mm).

CONCLUSIONS

There are a large number of variables which determine the quality of the stored water in any one gully pot or the effect of any one source of pollution. As a result it is difficult to isolate factors and express their effect in a quantitative manner from such a short study. However, the following general conclusions may be drawn from the work to date:-

1 The most important climatic influence affecting quality of gully pot liquors is summer dry periods. These dry periods result in sharp increases in the values of BOD, COD, nitrate, ammonia and dissolved solids.

2 The loss of dissolved oxygen and the consequent anaerobic conditions is possibly the major cause of pollution.

3 Over dry periods human activity in the vicinity of a gully pot causes a significant deterioration of the pot liquor quality.

4 Human activity leads to variation in quality between gully pots.

5 COD values for the liquor appear to be dependent upon human activity/catchment area. BOD appears to be unaffected.

6 Dissolved oxygen levels are related to catchment area. The introduction of wider spacing between gully pots would increase average dissolved oxygen levels and hence reduce pollution of runoff due to gully liquors.

7 Comparison of pollutant runoff curves and values of certain parameters in gully pots provides an indication of the principal origins of pollutants.

8 Gully pots are efficient in the removal of heavier particulates from stormwater runoff.

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MATHEMATICAL SIMULATION OF POLLUTANT CONTRIBUTIONS TO URBAN RUNOFF FROM ROADSIDE GULLY POTS

by

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ABSTRACT

A mathematical model to predict the contribution of pollutants from roadside gully pots to stormwater runoff is presented. The model has been used to assess the importance of the stored sediments and water in gully pots in determining the pollutant loads in stormwater runoff.

LIST OF SYMBOLS

C	Concentration of material in the outflow from a gully pot, mg/l.
C_o	Initial concentration of material in suspension in a pot, mg/l.
Q	Water flow rate, l/s.
V	Volume of a gully pot, l.
P	Percentage of gully pot fluid mixed.
K	Rate of release of bottom sediments, mg/s.
M	Total mass of material available for release from the bottom sediments, mg.

INTRODUCTION

Roadside gully pots form reservoirs of polluted water that may adversely affect the quality of stormwater runoff (Fletcher et al.,1978; Mance and Harman,1978; Tucker,1975; Sartor et al.,1974). The stored water may be particularly polluting after periods of dry weather, when anaerobic degradation of the bottom sediments produces increases in BOD and COD, through the release of soluble organic compounds, ammonium and other pollutants. The degree to which the gully liquors may contribute to the pollutant load of stormwater runoff can only be estimated by consideration of the volume and quality of the stored water on a catchment in relation to the volume and quality of the stormwater runoff. However, a quantitative assessment of the contribution may be possible through mathematical simulation of the pollutant removal process involved. This has been attempted in the following manner:-

a) Laboratory investigations into the removal of dissolved solids and settled sediments from gully pots for different inlet water flow rates, using purpose-built apparatus and, hence, to develop and calibrate equations describing the pollutant transport process.

b) Development of a rainfall-runoff model and its integration with the pollutant transport model enabling the simulation to predict the contribution to storm discharge made by water stored in the gully pots prior to runoff.

c) Contemporaneous on-site monitoring of rainfall, runoff volume and quality and the quality of stored water in gully pots was undertaken to provide the necessary data for utilising the model.

The site investigation was conducted on a small, separately sewered, residential, suburban catchment at Clifton Grove, Nottingham, U.K. The catchment covers some 10.6ha, of which 3.7ha are impervious roof and road surfaces. The storm sewer system has a mean slope of 4.5%, contains 108 gully pots with a total volume of stored water of some 92000 litres. Research on the factors affecting the quality of water stored in gully pots and the instrumentation used on this catchment have been reported elsewhere (Fletcher et al.,1978; Pratt and Adams,1981; Pratt and Henderson,1981).

LABORATORY INVESTIGATIONS

The Removal of Dissolved Material from Gully Pots

The removal of dissolved material was investigated by dosing a gully pot, typical of the type used on the Clifton Grove catchment, with a known concentration of salt solution and, for a given inlet water flow rate, continuously monitoring the pot liquor concentration using a conductivity probe. Salt removal was characterised by an exponential decay in concentration at all inlet flow rates. The pot liquors were completely mixed with the incoming water flow for flow rates greater than 0.121/s, however, below this value 'short-circuiting' occurred and the percentage of the pot in a mixed state varied with the incoming flow rate (Fig. 1). The change in concentration of dissolved components in the gully liquor could be expressed as:-

$$dC/dt = -\ (QP/100V).C \qquad (1)$$

$$C = C_o e^{-tQP/100V} \qquad (2)$$

where $P = 100$, when $Q \geq 0.121/s$; and, $P = 664.0Q + 19.7$, when $Q < 0.121/s$

The Removal of Sediments from Gully Pots

The removal of sediment was investigated using material obtained from municipal gully emptying tankers operating in the study catchment and its environs. Prior to use, the material was sterilised, dried and sieved: large twigs, paper, etc. were removed. 2kg of dry sediments were added to the base of the test gully pot, water was added and the contents were left for two days to allow the solids to wet thoroughly. Tests were performed for inlet water flows ranging from 0.1 to 1.01/s.

The removal of sediment occurred in two fractions: material already in suspension, which obeyed the same equation as determined for the

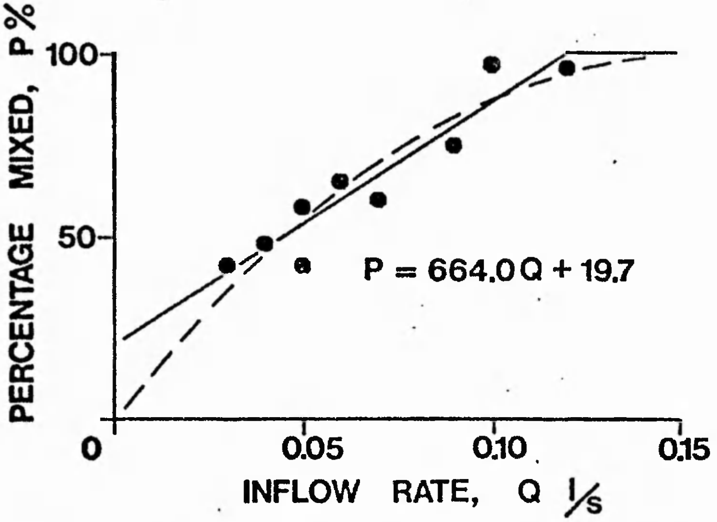

Fig. 1. Relationship Between the Percentage of a Gully Pot Mixed and the Inlet Flow Rate.

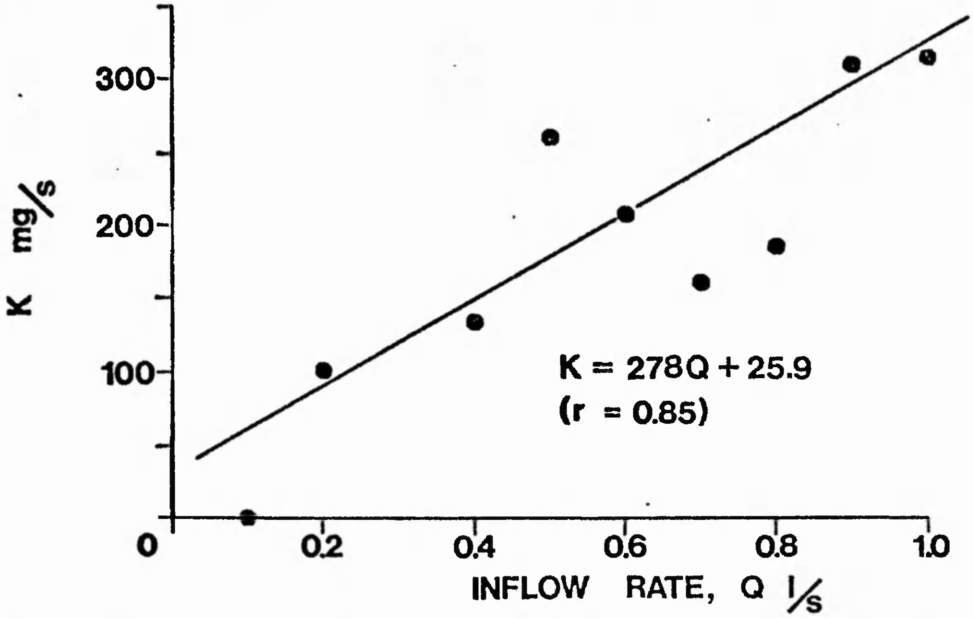

Fig. 2. Relationship Between the Rate of Re-suspension of the Bottom Sediments, K, and the Inlet Flow Rate.

TABLE 1. Characteristics of the Discharge of Gully Liquors (12 Storms).

	Mean	Range
Rainfall, mm	3.2	1.0 - 8.6
Storm Duration, min	94	33 - 178
'First Flush' Duration, min	53	22 - 85
% Gully Liquors Discharged	54	6 - 87
% Contribution to Total Runoff	11	3 - 17
% Contribution to 'First Flush'	14	8 - 18
% 'First Flush' Volume/Total Runoff	69	28 - 94

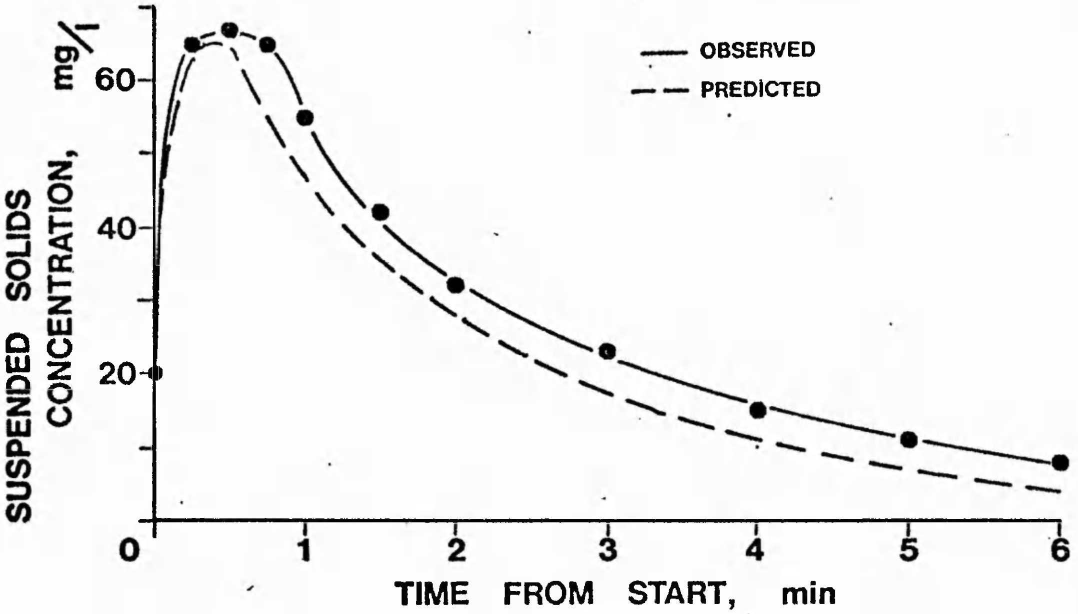

Fig. 3. The Removal of Suspended Solids from a Gully Pot for a Flow Rate of 0.81/s.

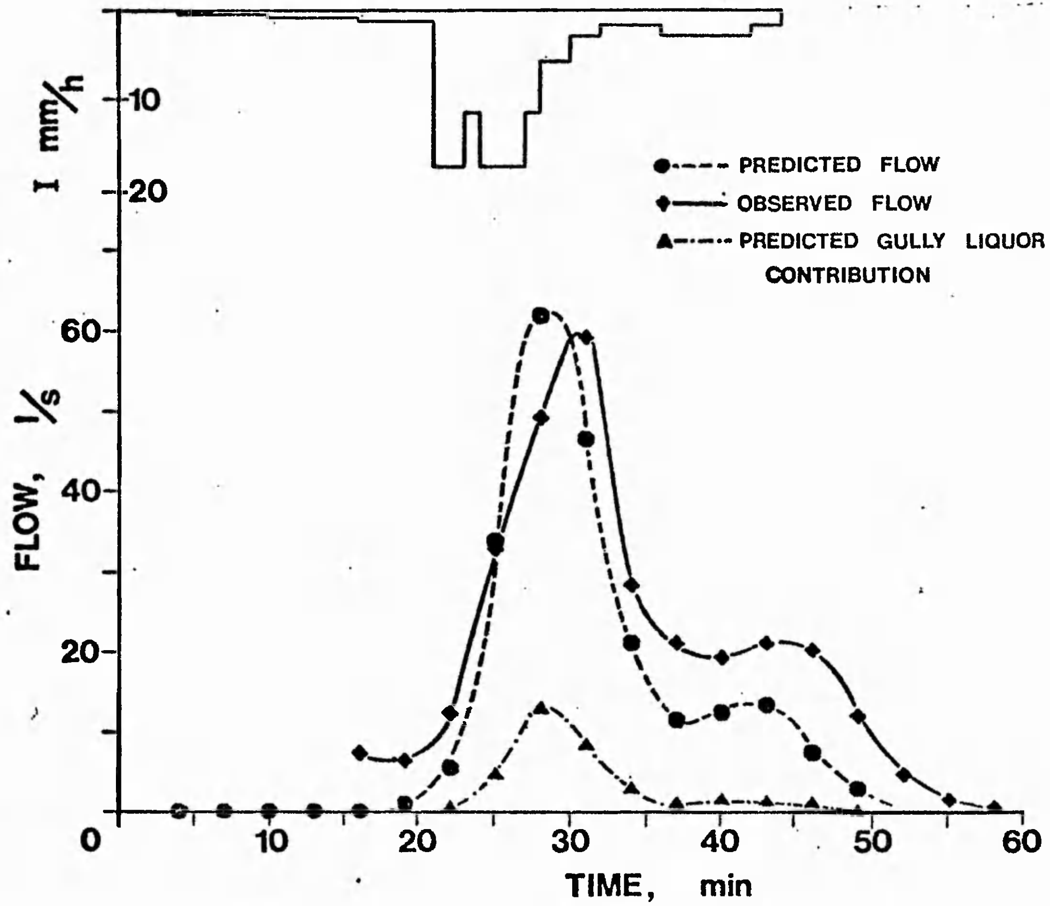

Fig. 4. Performance of the Rainfall-Runoff Model Showing Predicted and Observed Discharge and the Predicted Gully Liquor Contribution to Discharge at the Outfall.

dissolved material, and material re-suspended from the bottom sediments by the stirring action of the incoming flow. The total mass of material released from the bottom sediments, M, and the rate of release, K, were dependent upon the inlet flow rate:-

For $0 \leqslant t < M/K$, $$dC/dt = K/V - (Q/V).C \qquad (3)$$

$$C = K/Q \ . \ (1 - e^{-tQ/V}) \qquad (4)$$

When all the available material has been released, i.e. $M/K \leqslant t \leqslant \infty$,

$$C = K/Q \ . \ (1 - e^{-MQ/KV}).e^{(-tQ/V \ + \ MQ/KV)} \qquad (5)$$

The test results showed that there was good correlation between K and the inlet flow rate (r = 0.85, Fig. 2), however, the rapid rate of release of material resulted in a limitation of the accuracy with which the time to solids exhaustion could be determined and a poorer correlation between M and the inlet flow rate resulted (r = 0.75). When K and M were defined by linear regression equations and an average value of initial suspended solids was taken, then a good simulation of the laboratory results was obtained (Fig. 3). The results showed that the gully pot was efficient in retaining trapped sediments: a maximum of only 0.2% of the bottom sediments was removed by the highest flow rate examined. The resuspended sediments were rapidly removed and recorded concentrations of 90mg/l suggested that this source of material might be of importance in the 'first flush' of storms with high inlet flow rates. However, the removal of dissolved pollutants from gully pots represented the greatest influence on the outflow quality.

Whilst the removal of dissolved solids was thought to be a good simulation of what occurs in the field, the removal of sediments probably represented the least polluting situation, as in the field, greater depths of sediment, the occurrence of bacterial degradation and scums might all result in the discharge of greater solids loads from gully pots.

RAINFALL-RUNOFF MODEL

The rainfall-runoff model was based upon recent research in the U.K. (Kidd,1976; Kidd,1978; Price and Kidd,1978). The computer program was written in FORTRAN V, required 9 pages of computer storage and took from 10 to 15s of CPU time in execution. It comprised the following subroutines:-

a)HYETO Subroutine formulating the rainfall hyetograph from tipping bucket raingauge time-tip count data and applying a constant proportional loss model to account for differences between the observed and predicted discharge volumes.

b)DEPSTO Subroutine calculating the depression storage applicable to each road sub-catchment from a general regression equation (Kidd,1978) and formulating the net rainfall hyetographs applying to both road and roof sub-catchments.

c)LINRES Subroutine calculating the inlet hydrograph for each sub-catchment from the net rainfall hyetograph using a single linear reservoir routing model. The road sub-catchment surface routing coefficients were defined by a general regression equation (Kidd,1978): the roof surface routing coefficients were assigned empirically.

d)MUSK Subroutine calculating fixed Muskingum-Cunge coefficients for the pipe network (Price and Kidd,1978).

e)ROUTE Subroutine for routing the inlet hydrographs through the pipe network, using the Muskingum-Cunge coefficients, to form the outlet hydrographs.

f)GULLYS Subroutine calculating the contribution from water stored in gully pots to the outlet hydrographs and pollutant concentrations and loads at the storm sewer outfall derived from gully pots. The inlet flow rates applicable to each gully were calculated from the road sub-catchment inlet hydrograph divided by the number of gully pots in the sub-catchment.

Within the limitations of the available data, the model appears to give a reasonable simulation of the storm runoff hydrograph (Fig. 4). The model gave satisfactory results for the prediction of dissolved pollutants in runoff that were derived from gully pots, however, application of the model to the prediction of the contribution of solid material was dependent upon further evidence confirming that the laboratory results adequately described the field behaviour. Research is currently in progress.

Calculation of the discharge of gully liquors by the model can be used as a quantitative method of defining the duration of the 'first flush'. The 'first flush' is here defined as "that portion of a storm runoff event during which 90% of the total discharge of original gully liquors has occurred". This definition is more flexible than a fixed time (e.g. first 30min of runoff (Mance and Harman,1978)) and more consistent with the nature of the 'first flush'.

TABLE 2. Percentage of Pollutant Contributions from Gully Pots in 11 Storms.

Constituents	Contribution to Total Storm Load Mean %	Range %
Suspended Solids	10.6	1.9 - 22.4
Dissolved Solids	20.7	3.8 - 40.2
COD	20.5	2.9 - 49.2
BOD	13.9	2.7 - 30.4
Nitrate	15.7	2.6 - 24.6
Ammonium	31.5	9.5 - 80.9

POLLUTANT CONTRIBUTIONS FROM GULLY POTS

The model indicated that the original gully liquors were rarely completely discharged. A maximum of 86% discharge was recorded for a storm of some 9mm, but 50 - 70% discharge was typical for most storms investigated (TABLE 1). At the storm sewer outfall, gully pot liquors

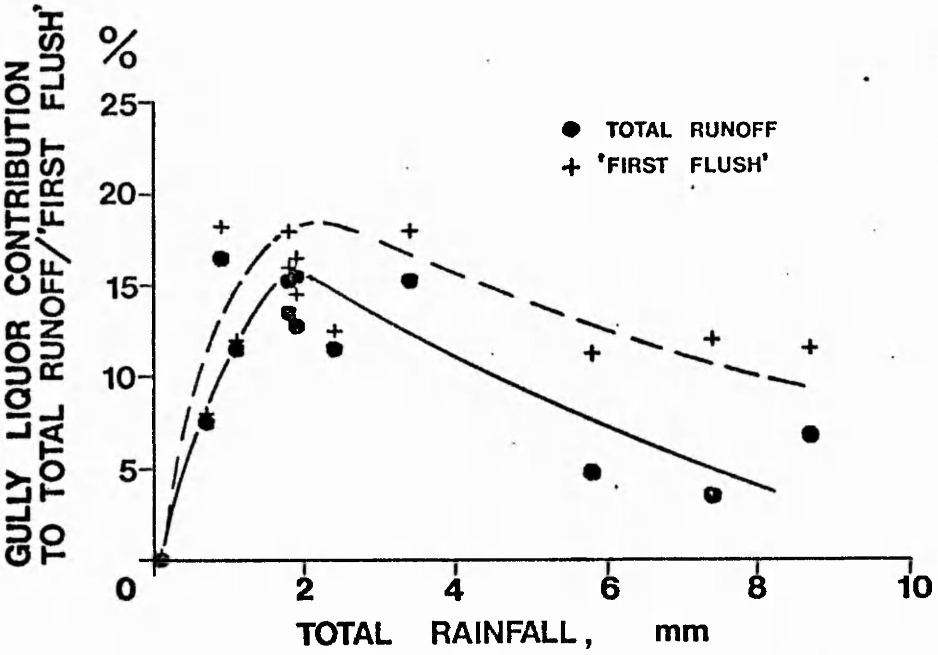

Fig. 5. Percentage of Gully Liquor Contribution to the Total Runoff and the 'First Flush'.

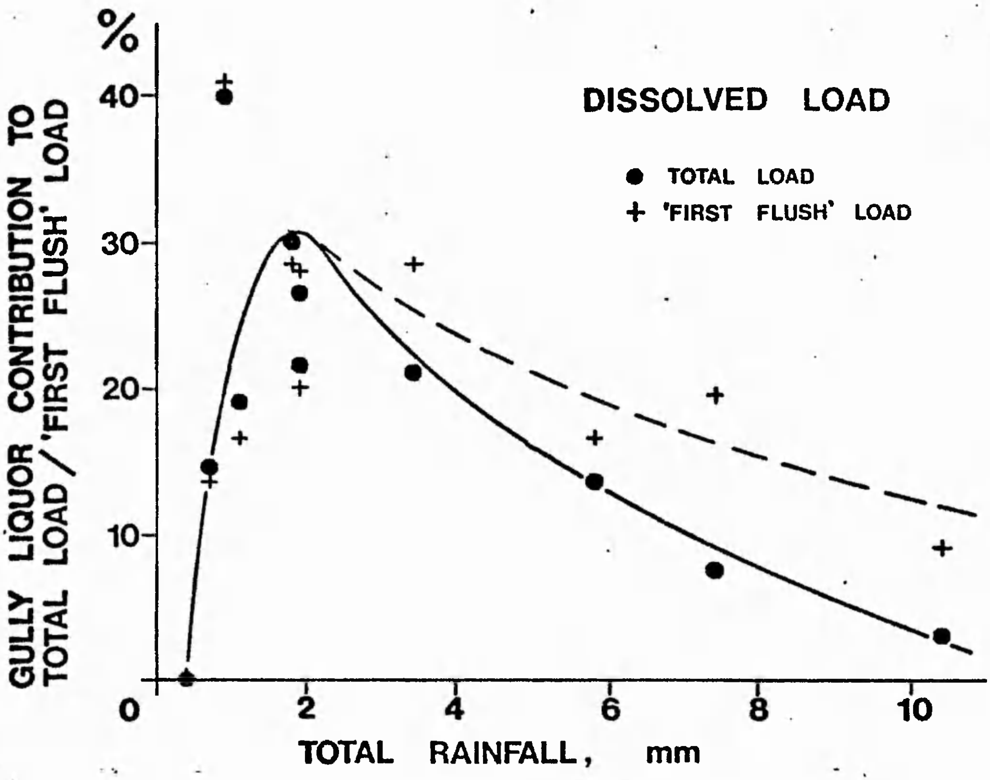

Fig. 6. Percentage of Dissolved Loads, Derived from Gully Liquors, Contributed to the Total Storm and the 'First Flush' Loads.

contributed up to 17% of the total runoff volume, being of most significance for storms of 1 to 3mm rainfall (Fig. 5). For storms less than 1mm, roof runoff predominated over road runoff in the total runoff volume, whilst for storm events producing more than 5mm rainfall, original gully pot liquors became depleted.

Pollutant contributions from gully pots were of most significance for storms of 1 to 3mm rainfall e.g. dissolved solids (Fig. 6). For the majority of storms monitored, the suspended solids contribution from gully pots was derived from material already in suspension and not from the re-suspension of bottom sediments, since inlet flow rates rarely exceeded 0.21/s. Of the other constituents investigated, significant contributions were recorded for ammonium (up to 80%), COD (up to 49%), dissolved solids (up to 40%) and for BOD (up to 30%) in the total runoff quality from original gully pot liquors (TABLE 2). Some of the highest contributions were recorded for a storm which occurred after 10 days dry weather.

The 'first flush', as defined above, comprised a high percentage of the pollutant load in the monitored events. For long duration storms, the 'first flush', although only consisting of 30 to 50% of the total storm runoff, carried between 60 and 90% of the pollutant load (TABLE 3).

TABLE 3. Typical Polluting Characteristics of the 'First Flush' for Long Duration Storms Producing More than 3mm (Mean Rainfall 5.6mm).

	Contribution of	
	'First Flush' to Total Storm, %	Gully Liquor to 'First Flush', %
Volume	41	14
Suspended Solids Load	68	4
Dissolved Solids Load	58	21
COD Load	75	11
Ammonium Load	69	16

CONCLUSIONS

Mathematical simulation of the removal of pollutants from roadside gully pots has shown that:-

a) Gully pots may be efficient in retaining trapped sediments and may not be an important source, themselves, of the solids load in stormwater runoff.

b) The removal of dissolved pollutants from gully pots was readily achieved, although the total removal of original gully liquors during a storm event occurred only infrequently. The dissolved pollutants may represent a greater threat to stormwater discharge quality.

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