COOPERATIVE RESEARCH CENTRE FOR **CATCHMENT HYDROLOGY**

BLACKBURN LAKE DISCHARGE AND WATER QUALITY MONITORING PROGRAM: DATA SUMMARY AND INTERPRETATION

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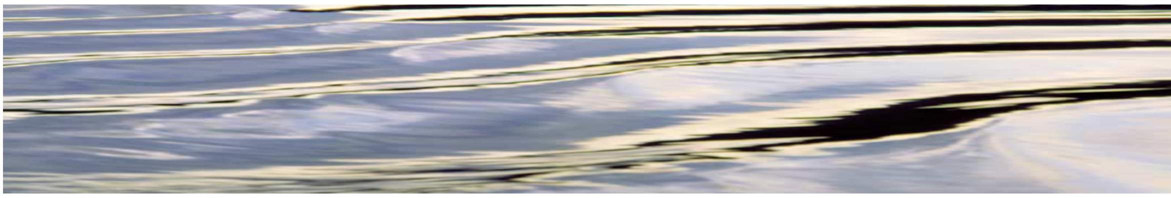
Sharyn RossRakesh / Chris Gippel / Francis Chiew / Peter Breen



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Blackburn Lake discharge and water quality monitoring program: data summary and interpretation

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Preface

This report documents work undertaken by the Cooperative Research Centre for Catchment Hydrology and the Cooperative Research Centre for Freshwater Ecology on the performance of an urban pollution control pond (Blackburn Lake). The study forms part of project Ul (Gross Pollutant Management and Urban Pollution Control Ponds) in the CRC's Urban Hydrology Program.

The Urban Hydrology Program investigates the sources, movement and modelling of pollutants in urban areas, gross pollutant management and the behaviour of urban pollution control ponds. This report summarises and interprets the data collected from two years of extensive flow and water quality monitoring from an urban pollution control pond.

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Abstract

This report documents work undertaken by the Cooperative Research Centre for Catchment Hydrology (CRCCH) and the Cooperative Research Centre for Freshwater Ecology (CRCFE) on the performance of an urban pollution control pond (Blackburn Lake).

The objectives of this project were to assess the performance of Blackburn Lake as a pollution control pond and to provide the CRCFE with flow and water quality data to assess pond performance models. To achieve this, two years of intensive flow and water quality data were collected and analysed. A range of water quality variables were measured, some on an event basis while other parameters were measured continuously. Data were collected from the inlets and the outlet of the lake as well as from several locations within the lake.

This report provides a summary of the water quality and flow monitoring program. It presents the methods used for data collection, data processing and outlines the availability of the data record. Much of the data is presented, analysed and interpreted to show relationships and trends that summarise the water quality entering Blackburn Lake, the physico chemical processes within the lake and the water quality leaving the lake.

Estimation of annual pollutant loads entering Blackburn Lake and loads leaving Blackburn Lake indicate that Blackburn Lake traps on average 74% of suspended solids, 57% of total phosphorus and 23% of total nitrogen.

Water quality data collected from within Blackburn Lake showed that the lake is strongly stratified. The data also reflect a reasonable degree of mixing, during events. Chemical reduction reactions such as denitrification were evident. Data for an intense storm event suggests that inflowing events may move underneath the lake surface water.

This report presents flow and water quality data collected from two years of monitoring. The pollutant trapping efficiency of Blackburn Lake was estimated and the physico-chemical processes occurring within the lake were described. A good quality data set has been produced and will be invaluable for further studies.

The data have been copied onto a CD and can be obtained from the CRC for Catchment Hydrology Centre Office.

Acknowledgements

This project involved a lot of fieldwork, and many thanks go to all those who contributed in some way or another. The authors would like to acknowledge the generous support in time and resources from the following people and organisations:

- Peter Dowland, from Melbourne Water, for supplying us with flow and rainfall data
- Andrew Sharpe and Elaine Bayes, from the CRCFE, for collecting much of the in-lake water quality data
- Sandra Sdraulig, from the Water Studies Centre at Monash University, for managing the laboratory analysis of collected water samples
- Ian Finlay and Tracey Walker for helping out with general field work on many occasions

Thank you to the following organisations for allowing us access to our monitoring sites:

- The Whitehorse City Council
- The Seventh Day Adventist Church
- The Blackburn Lake Primary School

Special thanks must go to the Blackburn lake Management Comniittee for allowing us access to historical information on Blackburn Lake, and to Myriam Ghali, a visiting student from Germany, who helped compile this information.

List of figures

List of tables

1 Introduction

Urban storages, originally designed for flood mitigation, are now being recognised for their potential to reduce the pollutant loading of a catchment. Continuous flow and water quality monitoring are needed to assess the pollutant trapping efficiency of these storages. Good data sets are also required for testing the performance of pollutant trapping models.

This project was a collaborative effort between the CRC for Catchment Hydrology (CRCCH) and the CRC for Freshwater Ecology (CRCFE). This report describes the collection and analysis of data from Blackburn Lake, an urban lake in Melbourne. The aims of this project were to assess the long term performance of Blackburn Lake and to provide a good data set for testing pond performance models and other urban stormwater studies.

The structure of the report is as follows:

Section 2 provides a background of Blackburn Lake. It includes a history of the lake, the physical characteristics of the lake and the catchment, a description of the monitoring sites and a map of their location within the catchment.

Section 3 describes the monitoring of hydrographic data and presents results of a lake water balance. It includes the methods used to estimate daily rainfall for each monitoring site from 3 nearby rainfall stations. This section also presents the method used to estimate all inflows on a daily time step so that a water balance could be assessed.

Section 4 describes the monitoring of water quality at the inlets and the outlet of Blackburn Lake. The methods used to sample and process continuous and event water quality data are outlined and examples of the various parameters are presented. This shows the range of the data and also the difference between water quality at the inlets and the outlet of the lake. The method used to estimate pollutant loads for individual storm events is presented. The results for all storm events for which water samples were collected are presented. Finally relationships between water quality variables are presented.

Section 5 describes the water quality data collected from within Blackburn Lake. This includes the sampling methodology employed to characterise several water quality parameters both spatially and temporally. The hydrologic conditions at the time of sampling have been described and the water quality data are presented. Analyses were carried out to highlight variability in the water quality data between different locations in the lake and different hydrologic conditions.

Section 6 presents the methodology used to estimate annual TSS, TP and TN loads entering and leaving Blackburn Lake to give an assessment of the lake's long term pollutant trapping efficiency.

Section 7 concludes the report by summarising the outcomes of the project and discusses the availability of the data on a CD.

2 Site description

2.1 Blackburn Lake

Lake history

A history of Blackburn Lake and the catchment was conducted to determine the exact age and origin of the lake and to document major landuse changes in the catchment. This investigation revealed that a land development company constructed the lake in 1888 for supplying water to local orchardists and in 1908 the Adult Deaf Society purchased 70 acres including the lake. In 1923 Melbourne Water (the then Melbourne Metropolitan Board of Works (M.M.B.W.)) began managing the lake and in 1963 purchased it and 16 acres of surrounding land. The existing lake wall and outlet structure was upgraded so that the lake could mitigate flooding downstream. The Nunawading Council purchased the land surrounding the lake from the Deaf Society in 1964 and in 1965 they declared the area a Sanctuary. In 1976 they also took over management of the Lake from Melbourne Water. In 1977 a gauging station was installed at the outlet and is currently managed by Melbourne Water.

Elliot (1973) carried out a comprehensive pollution survey and concluded that the lake sediments contained high levels of nutrients, were anaerobic, and that the status of the lake was eutrophic. There have been several major reported pollution events in the Blackburn catchment and these are outlined in Table 2.1.

Physical characteristics

The lake is approximately 500 m long and has an average width of 15 m. The deepest part of the lake is approximately 5 m, but on average it is 3 m. A bathymetric survey of the lake was carried out by the CRCCH in 1996 to determine the volume of the pond at the permanent (baseflow) water level (Figure 2.1). Melbourne Water had previously determined the volume and surface area of the lake to the spillway and to the top water level (TWL) (Table 2.2).

Table 2.1 Recent major reported pollution events in the Blackburn catchment

1985	An ammonia spill from an industrial premise on Rooks Road (Nunawading Gazette, 27/11/1985)
1988	A spill of blue ink from a scrap metal recycling plant into the main stormwater drain entering the lake (Nunawading Gazette, Vol.37:No.27)
1992	A diesel spill in 1992 from a truck being filled at a nearby factory (Nunawading Gazette, 1/7/1992)
1993	An illegal dumping of oil into the main inlet creek in 1993 (Nunawading Gazette, 12/1/93)
1996	A oil slick believed to be caused by an illegal dumping by a resident of the area. Reported to the Whitehorse Council (Nunawading Gazette, 7/8/96)

Table 2.2 Lake characteristics

	Base level	Primary Spillway	TWL
Volume (m^3)	57,000	70,000	100,000
Surface Area (m^2)	27,700	-	58,000

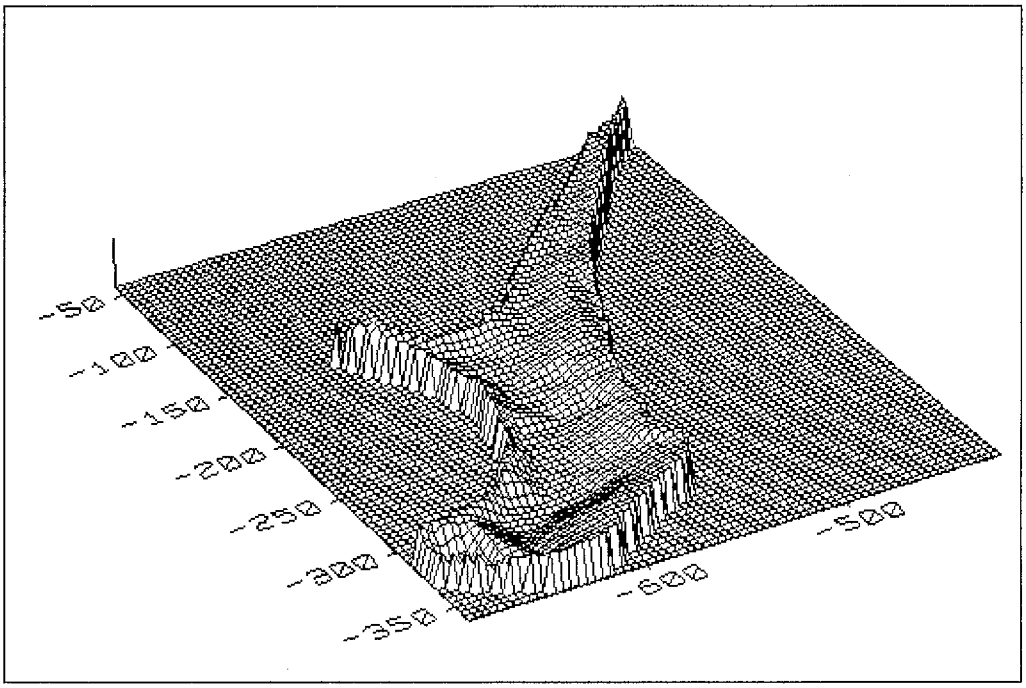

Figure 2.1 Results of Bathymetric survey of Blackburn Lake.
Conducted by the CRCCH, April 1996.

Table 2.3 Characteristics of stormwater drains entering Blackburn Lake.

Site	**Drain diameter (mm)**	**Drain Slope (m/m)**	**Manning's roughness**
A	609	0.0305	0.013
B	1050	0.0160	0.014
C	1875	0.020	0.012
D	1000	0.030	0.012
E	450	0.027	0.013

Lake inlets and outlet

There are 5 inlets to the lake and one outlet (Figure 2.2). The main inlet (Site C) discharges from a stormwater drain into a natural channel that meanders for about 300 m through across a floodplain before entering the lake. The channel has an average width and depth of 1 m. The other four inlets, all considerably smaller than the main inlet (C), comprise stormwater pipes which drain directly into the lake (site A) or into the main channel downstream of site C (sites B, D, E) (Table 2.3, Figure 2.2). The area surrounding the lake (sub-catchment F) is not channelled and runoff enters the lake typically via overland and sub-surface flow.

2.2 Blackburn Lake catchment

Blackburn Lake drains a fully urbanised catchment with an area of 2.96 km2 and is situated at the top of Gardiner's Creek catchment (Figure 2.3). Landuse is mixed, comprising residential, commercial, industrial and open space (Table 2.4). The catchment is situated in the eastern suburbs of Melbourne, approximately 20 km from the CBD. The long term average rainfall in the catchment is 700 mm per year. There are five sub-catchments, with the largest (C) comprising 70% of the total catchment area (Figure 2.1). The average slope of the catchment is 1:35, rising from 80 m to 120 m above sea level in an easterly direction.

The geology of the catchment is relatively uniform, consisting of massive Silurian siltstone. Prior to urbanisation, streams in the catchment were ephemeral. The catchment is now fully serviced by stormwater drains. The largest sub-catchment drain is perennial while the other sub-catchment drains only flow during storm events. External imports of water into the system that result in increased low flows may be derived from a variety of sources including excess garden watering and infiltration inflow.

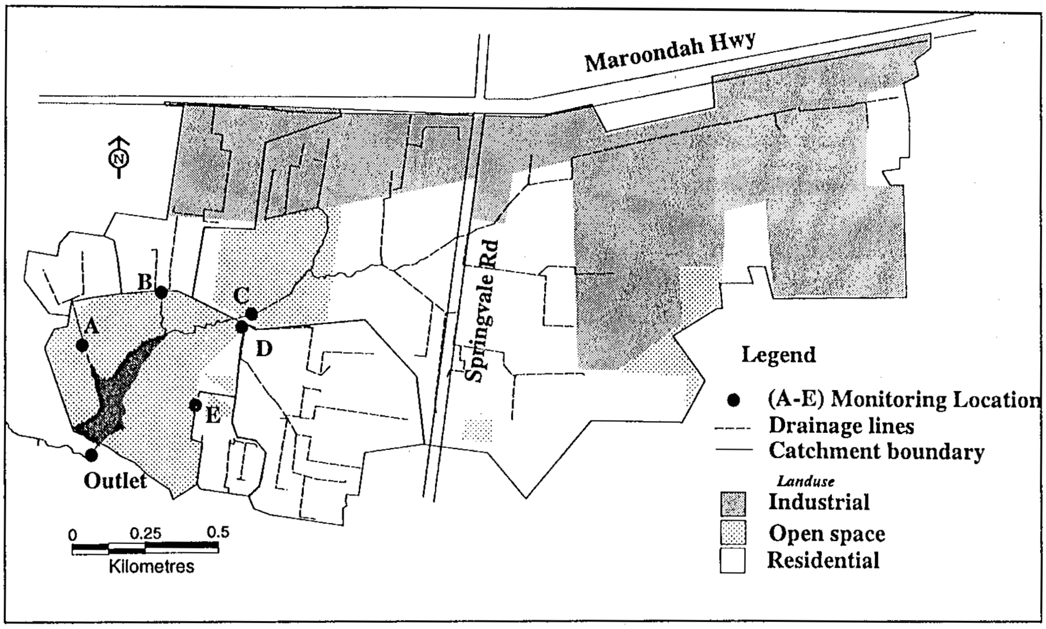

Figure 2.2 Blackburn Lake catchment boundary and monitoring site locations.

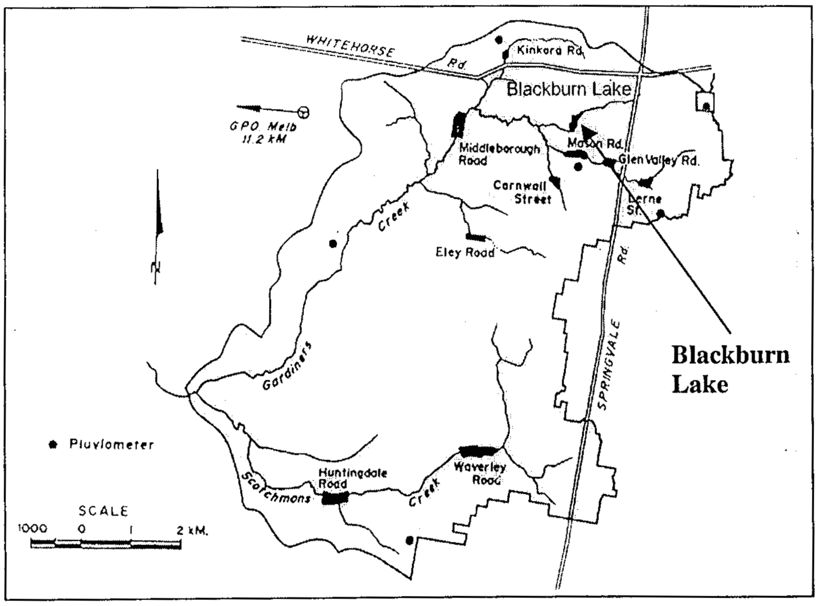

Figure 2.3 Map showing Blackburn Lake within the Gardener's Ck catchment.

Table 2.4 Catchment and sub-catchment characteristics

Total catchment characteristics	
Length (approx)	2000 m
Width (approx)	1125 m
Highest Elevation	120 m AHD
Lowest Elevation	80 m AHD
Average Slope	1:35
Long Axis	E/NE

Sub catchment	Area (ha)	Landuse type (%)			Fraction Impervious (%)
		residential	industrial	Open space	
A	6.2	100	0	0	49
B	21	32	68	0	68
C	202	47	53	0	67
D	31	100	0	0	44
E	5.7	100	0	0	48
F	26	0	0	100	0
Lake	3.4	na	na	na	0
Total	296	48	40	9.6	58

3 Hydrographic data

Six-minute rainfall data were available from three sites within the proximity of the catchment. Discharge was recorded at four of the Lake inlets and the outlet at two-minute intervals. Gaps in both the rainfall and flow records, resulting from equipment failure, have been infilled using modelled daily data. A complete two-year record of daily rainfall and flow data is available for the period 1/1/1996 - 1/1/1998. This chapter describes the monitored data and the analyses of the data.

3.1 Rainfall

Rainfall data are available from three Melbourne Water sites (Figure 3.1). Theissen polygons were used to distribute the contribution of rainfall to each of the subcatchments (see also Table 3.1). Over the two years of the pond monitoring study (1996-1998), there were 42, 49 and 73 days of missing daily rainfall data from the Mitcham Reservoir, Masons Road Retarding Basin and the Kinkorra Road Retarding Basin rainfall stations respectively. The missing daily rainfall data were infilled using a linear relationship between the stations (all correlations, R^2, were higher than 0.93).

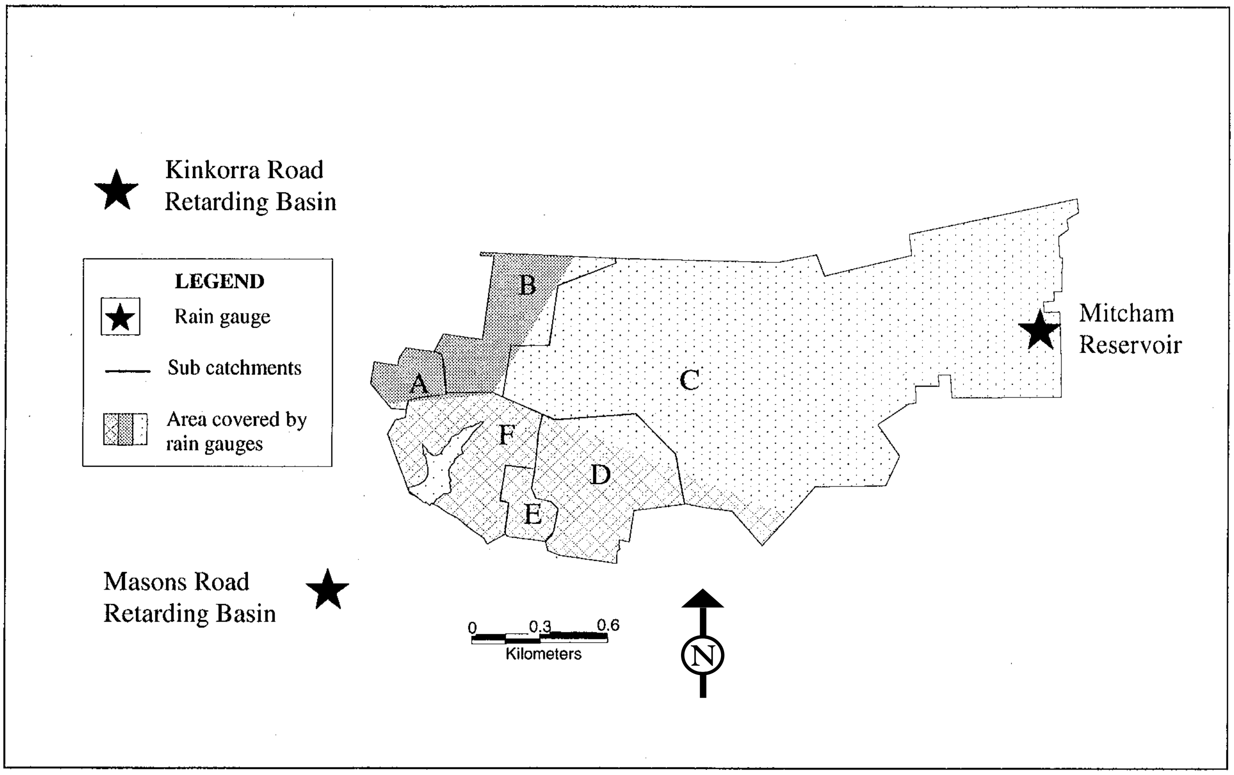

Figure 3.1 Rainfall station locations, and areas they cover using Theissen polygons.

Table 3.1 The percentage that each rainfall station contributes to each sub-catchment as determined by Theissen polygons.

Subcatchment	Rainfall stations		
	Mitcham Reservoir	Kinkorra Road Retarding Basin	Masons Road Retarding Basin
A	-	95%	5%
B	10%	90%	-
C	98%	-	2
D	16%	-	84%
E	-	-	100
F	-	-	100%
TOTAL	70%	8%	22%

3.2 Inflow data

Continuous 2-minute monitoring of inflows was carried out at sites A, B, C and E. The depth and velocity were recorded using STARFLOW Ultrasonic Doppler Instruments (Unidata 1997). These were mounted onto the bottom of the stormwater pipes and data downloaded approximately every two weeks. The instruments were set up to scan every 15 seconds, and record an average reading every two minutes.

Flow depth, measured by STARFLOW, uses a solid state pressure sensor designed to sense depth in front of the velocity transducer. The depth is purported to be measured to an accuracy of 0.25% of the calibrated range (0 to 2000 mm).

Flow velocity, measured by STARFLOW, employs a narrow inclined beam of ultrasonic pulses into the flow. These ultrasonic pulses are reflected by impurities moving towards or away from the beam. The reflections of the pulse produce a doppler shift frequency which provides instantaneous velocity measurements of the impurities carried by the flow. These reflections are averaged to give a mean velocity of the reflected impurities to an accuracy of 2%.

There were typically large amounts of scatter in the velocity-depth relationship (Figure 3.2). In addition, because the velocity varies throughout the cross-section, the mean pipe velocity is less than the velocity recorded by the instrument (at the centre of the pipe). It was estimated that the mean velocity was 10% to 20% less than the central velocity recorded by the instrument. This was based on field tests conducted using Starflow instruments (Wootton et al, 1998) and flume studies (Chow, 1959).

The mean pipe velocity was estimated from the depth data using the Manning equation. Table 3.2 shows the pipe slope and roughness used for the four inlet sites. The pipe slopes and roughness were determined by arbitrarily fitting Manning's equation to the velocity-depth data, accounting for the overestimation of the mean velocity (see Figure 3.2). The adopted Manning n values fell in the range reported in the literature for concrete pipes. The values were varied slightly so that a better fit of the data could be obtained. The slopes are similar to those surveyed for the sites and which also compared well with those obtained from council records.

Table 3.2 Characteristics of stormwater pipes used to calculate Manning's velocity.

Site	Pipe diameter (mm)	Pipe slope (m/m)	Pipe Roughness (Manning's *n*)
A	609	0.0305	0.013
B	1050	0.0160	0.014
C	1875	0.0200	0.012
D	1000	0.0300	0.012
E	450	0.0270	0.013

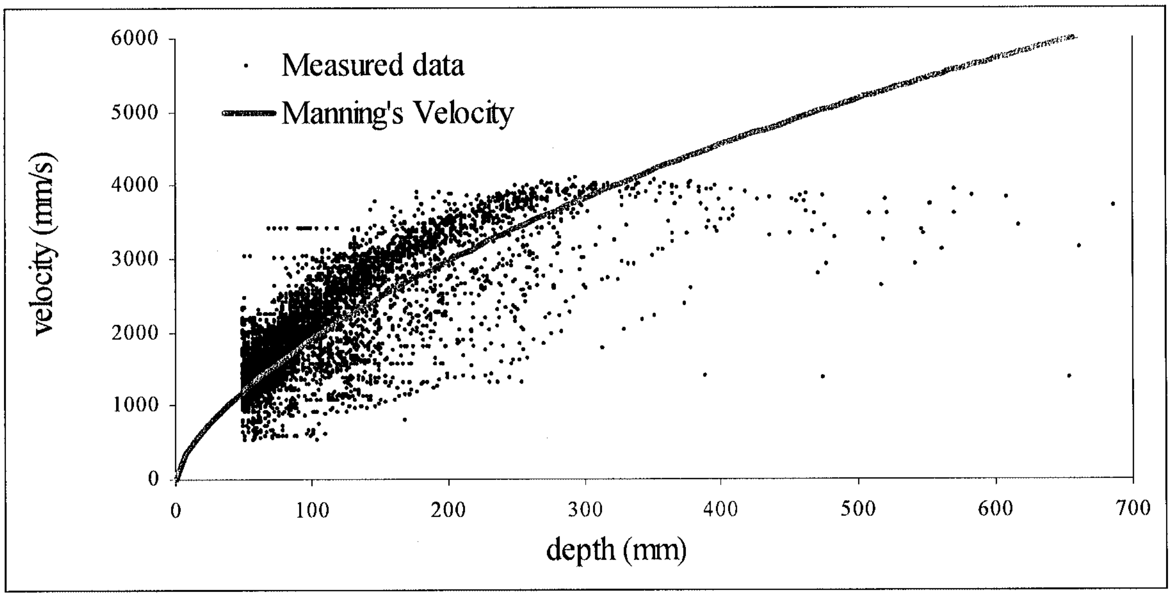

Figure 3.2 Relationship between depth and velocity for site C and calculated Manning's velocity. Includes 6169 data points over the period 1996 to 1998 (depths less than 50 mm and velocity below 500 mm/s were excluded from the plot)

Inflow characteristics

The main inlet (site C) accounts for about 80% of the total inflows into the pond. There were 135 days of missing data for this inlet over the two years of monitoring. There were significant gaps in the flow record for the other sites because water depths in the pipes were often below the threshold level required for STARFLOW to accurately measure depth. In total, there were 58% missing flow data from site A, 66% from site B, 86% from site D and 29% missing from site E.

At the main inlet (C), large single peak events typically lasted for about half an hour, reaching up to 5 m^3/s (see Figure 3.3). At the smaller inlets, peak discharge rates were much lower, ranging from 0.008 m^3/s at A, 0.2 m^3/s at B and 0.04 m^3/s at E for similar events. The events were 'flashy' in nature, and the smaller inlets generally ceased to flow between events. Base flow at the main inlet (C) was approximately 0.003 m^3/s.

3.3 Outflow data

At the outlet, water is released from the pond through a small glory hole spillway and flows under Lake Road through a 1.45 m pipe, where it discharges into the stream (Figure 3.4). The discharge was estimated using a rating curve at the glory hole orifice (Figure 3.5). Four rating equations representing the different hydraulic characteristics of the outlet structure were used (see Appendix A). Two gaugings were carried out to test the accuracy of the rating curve.

Stage height at the glory hole orifice was recorded during 1996 using a Starflow pressure sensor; in 1997, a Greenspan pressure sensor was used. Melbourne Water also recorded stage data at this site. These data were used to infill gaps during periods when the Starflow or Greenspan instruments failed. Subsequently it was possible to establish a complete two-year record (1996-1998) of stage and discharge at this site.

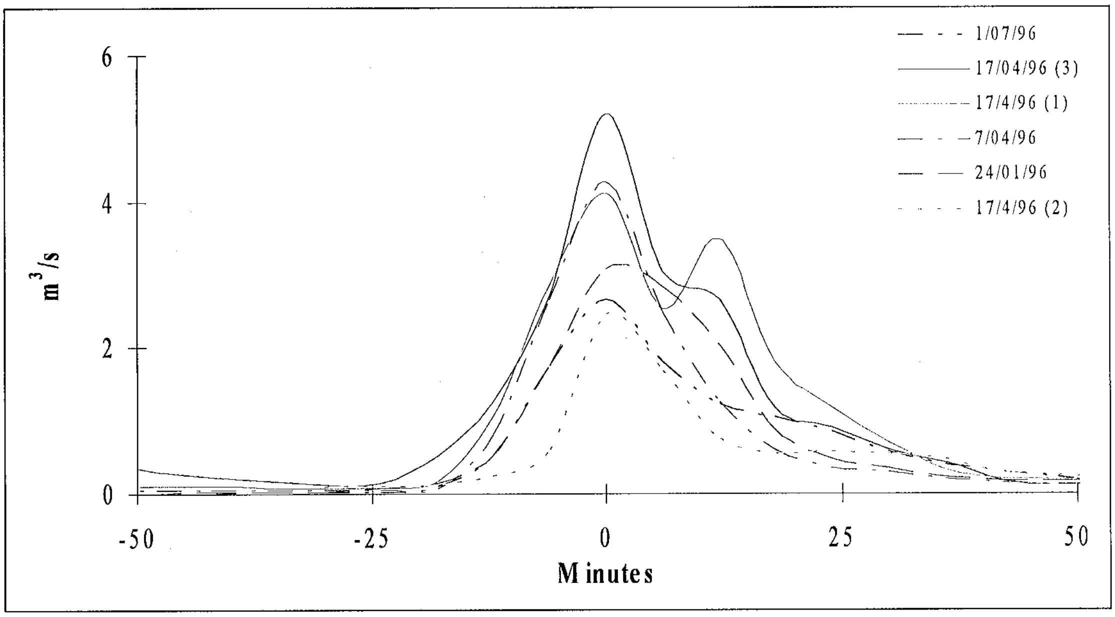

Figure 3.3 Selected large single peaked events from the main inlet (C).

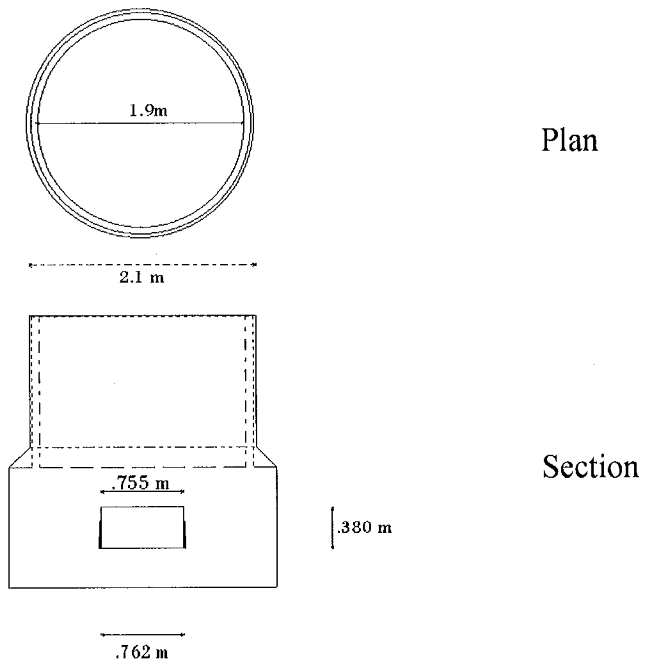

Figure 3.4 Glory hole structure at the outlet of the Lake.

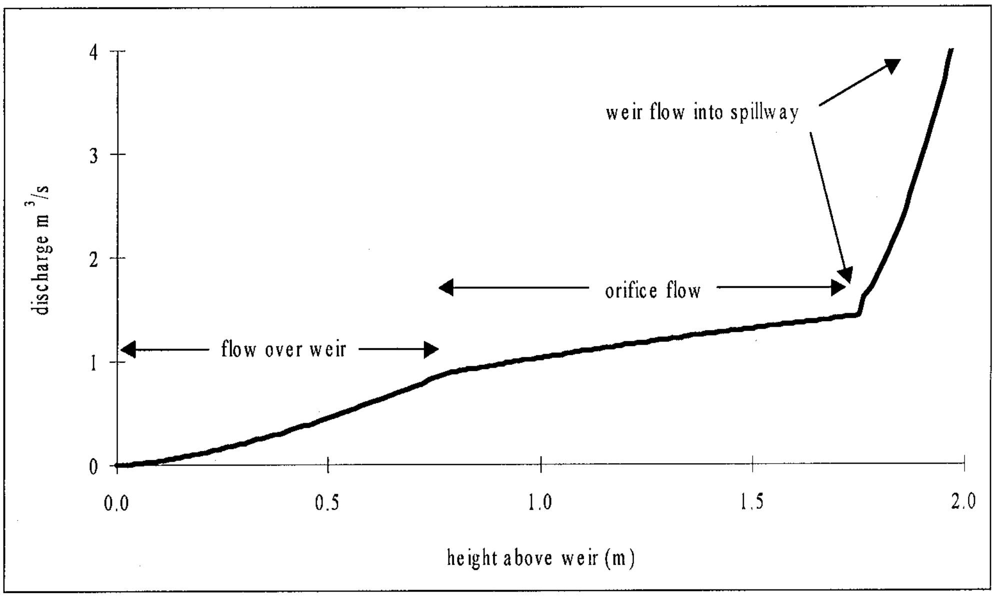

Figure 3.5 Stage discharge rating for outflow from Blackburn Lake.

3.4 Inflow and outflow characteristics

Storm events typically had a rapid rate of rise at the inlets, but the outlet had a slower rate of rise and a longer recession (Figure 3.6).

The lake attenuates flows such that flow rates downstream of the lake rarely exceed 1 m^3/s (Figure 3.7). The peak discharges during large events are significantly larger at the inflow than the outflow. Most of the time during lowflow periods, the outflows (0.1 m^3/s) are higher than the inflows into the lake (0.03 m^3/s).

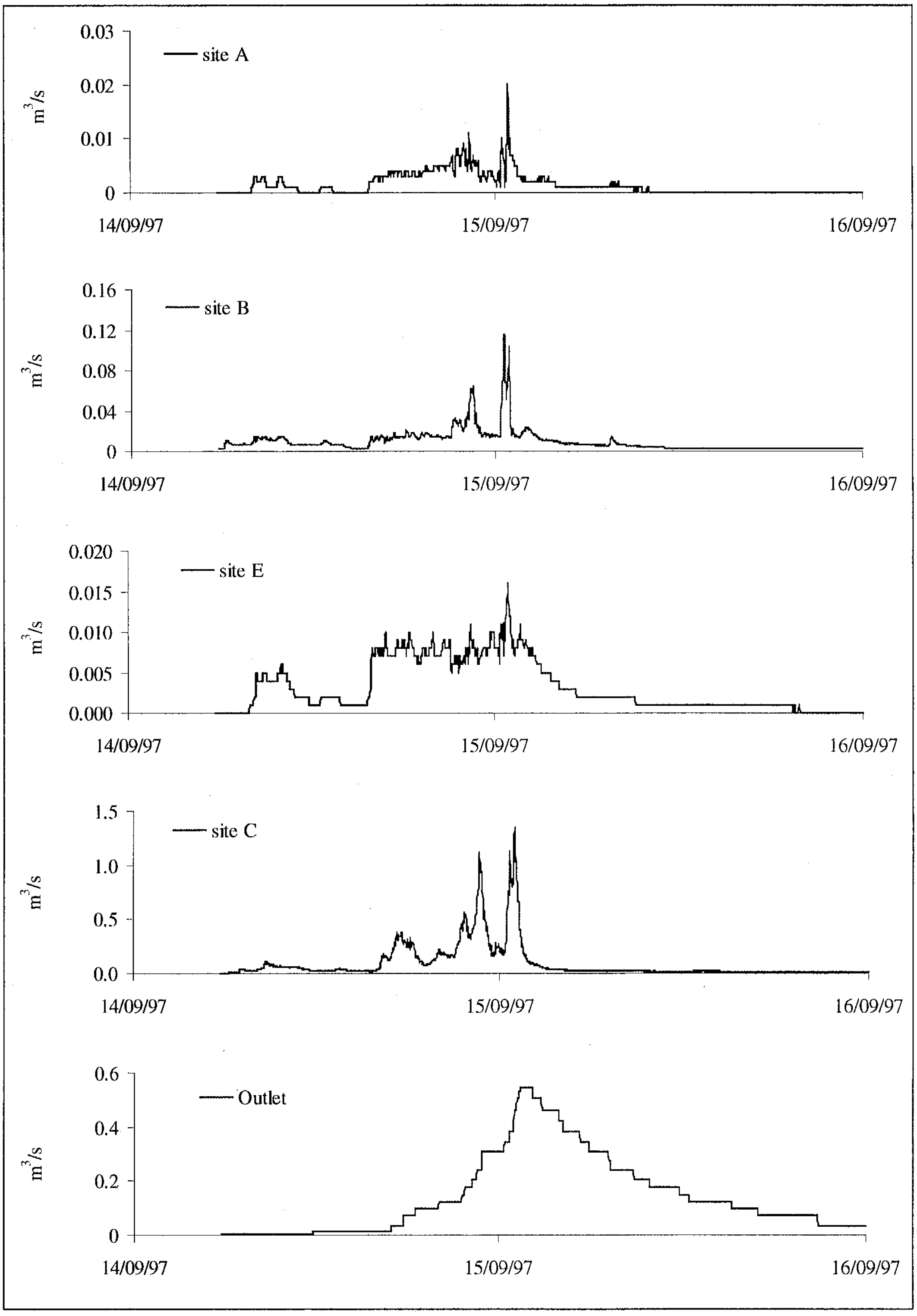

Figure 3.6 A typical event showing hydrographs for inflows to the lake from the sub catchments and the outflow from the lake.

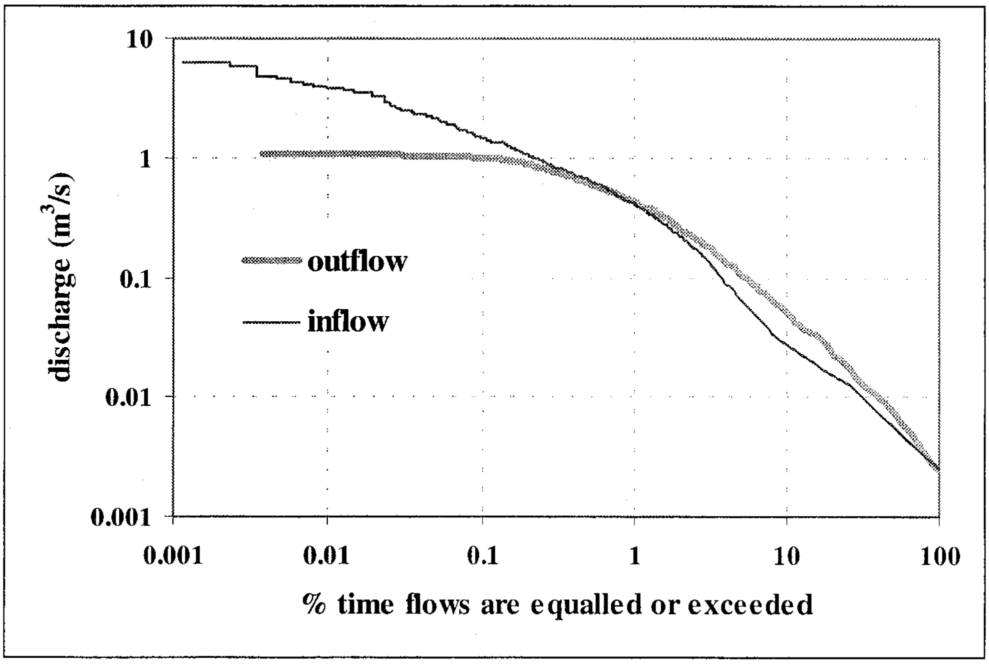

Figure 3.7 Flow duration curve for 2 years (1996 -1998) of inflow(C) and outflow from Blackburn Lake.

3.5 Modelling daily discharge

Daily rainfall-runoff model

Daily rainfall-runoff modelling was carried out to obtain continuous daily rainfall and runoff data at the lake inlets. Continuous data are required to establish a lake water balance and to determine annual pollutant loads. The rainfall-runoff model developed for urban catchments, by the CRCCH, was used for this purpose (Chiew and McMahon 1998). Appendix B describes the model and the method used to estimate daily runoff. The model has been tested on several catchments in southeastern Australia, and gives estimates of daily runoff satisfactorily.

Over the 731 days of the two year monitoring period, there were 136 days with missing data at the main inlet, site C. There were considerably more missing runoff data at sites A, B and D (532 missing days at A, 321 at B and 218 at E, see Table 3.3). The simulations for all four sites are satisfactory, although they are significantly poorer in sites A, B and D where there are considerably less data to calibrate the model (Figure 3.8). For the sites that did not have any flow data (D and F) the model parameters were based on those for similar sites (E) (see Appendix B). Figure 3.9 and Figure 3.10 show daily inflows and outflow for the period of monitoring based on the recorded outflow and the combined modelled inflows from each sub catchment.

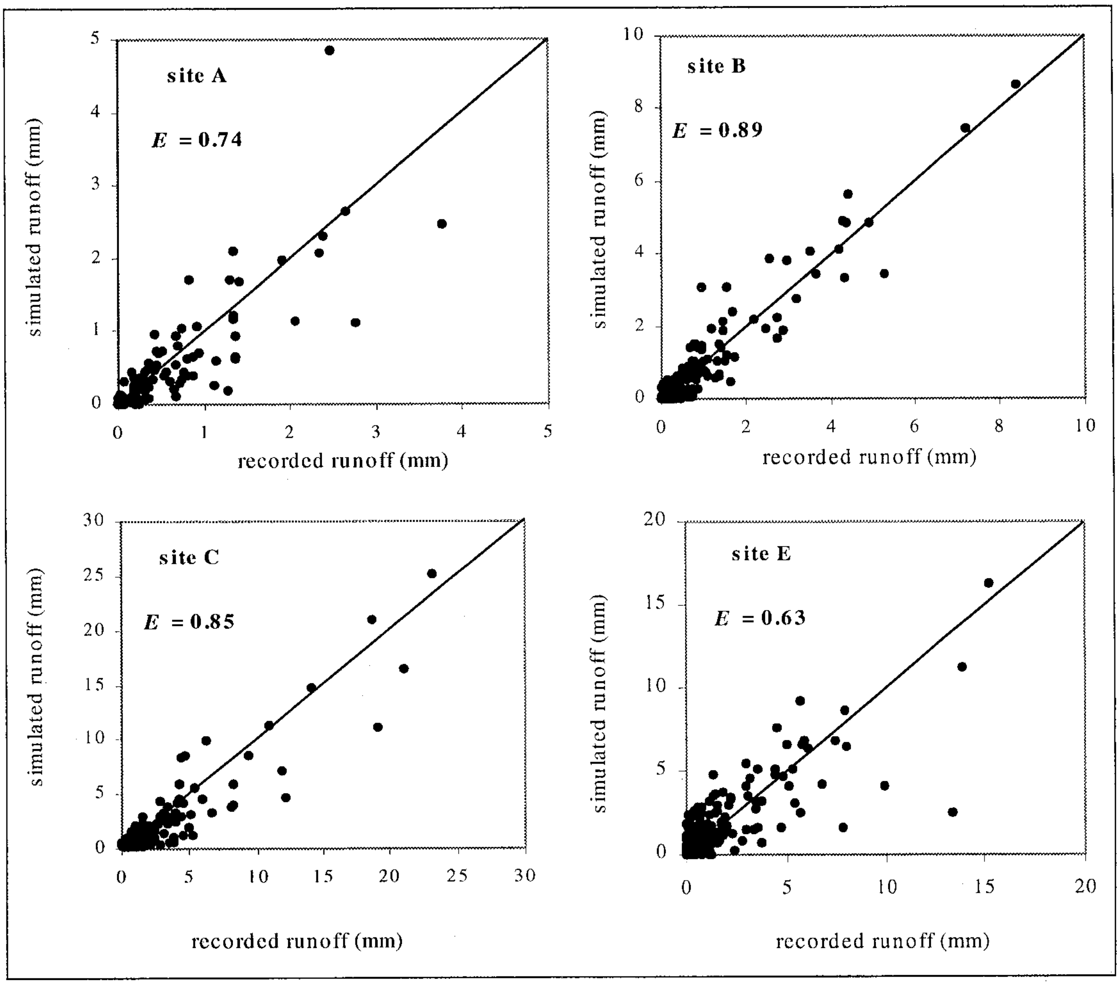

Figure 3.8 Modelled daily flows against measured flows

Table 3.3 Number of days modelled for each sub inlet

	Number of days modelled					
	Site A	**Site B**	**Site C**	**Site D**	**Site E**	**Site F**
1996	281	235	31	365	113	365
1997	251	86	105	365	105	365

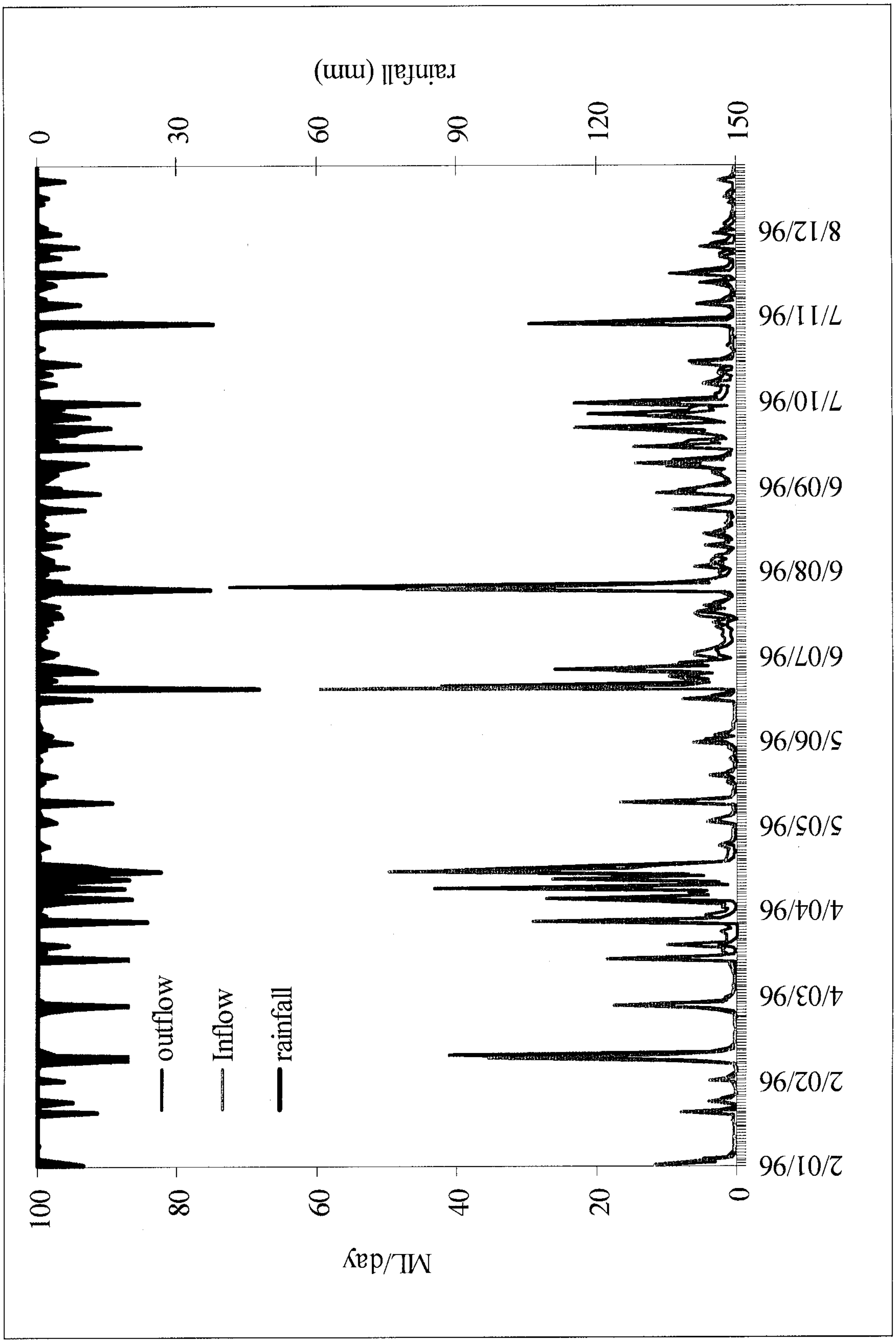

Figure 3.9 Total daily inflows (modelled) and daily outflow (1996)

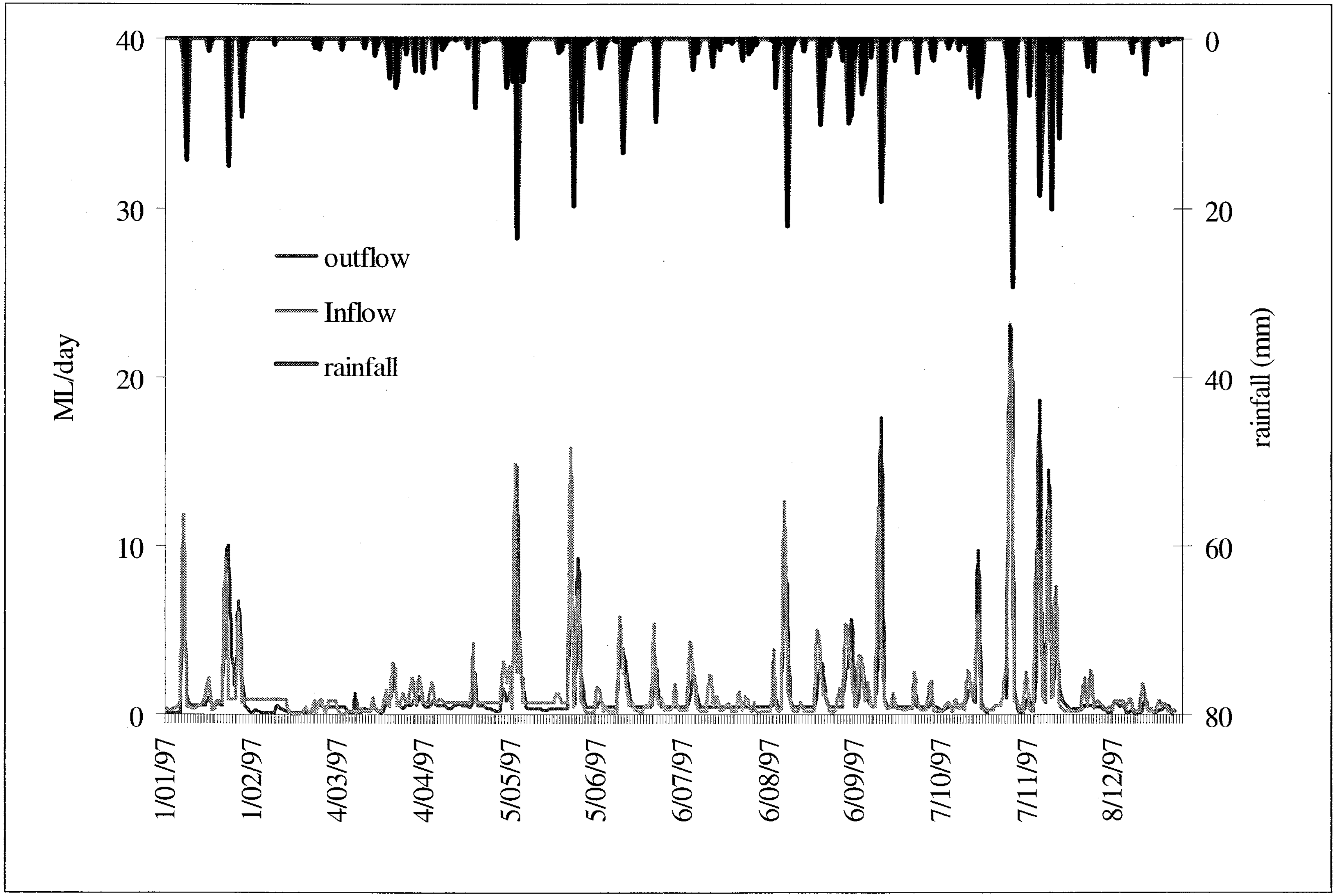

Figure 3.10 Total daily pond inflows and pond outflows (1997)

3.6 Lake water balance

The total lake inflows and outflows were estimated to check that the lake water budget balanced over the two-year monitoring period. The total inflows (inflows from all the inlets plus rain falling onto lake) and outflows (lake overflow and evapotranspiration) were within 1% of each other (Table 3.4).

Figure 3.11 shows the inflows and outflows over shorter consecutive periods. The agreement between the inflows and outflows over shorter time scales confirmed that the inflows and outflows were reasonably well estimated.

Table 3.4 Lake water balance. Annual inflow and outflow water volumes from Blackburn Lake.

Annual pond water balance	INFLOW (ML)								OUTFLOW (ML)		
	A	B	C	D	E	F	Lake*	**TOTAL**	ET*	outlet	**TOTAL**
1996	20.2	81.7	913.7	136.9	25.4	82.9	32.3	**1293**	29	1140	**1169**
1997	4	30	369.2	37.9	6.8	16	17.4	**481.3**	29	443	**472**

{A,B,C,D,E,S – sub inlets}

*Lake - total annual rainfall onto lake surface

*ET (Evapotranspiration) from the lake surface is estimated as 0.8 times pan evaporation

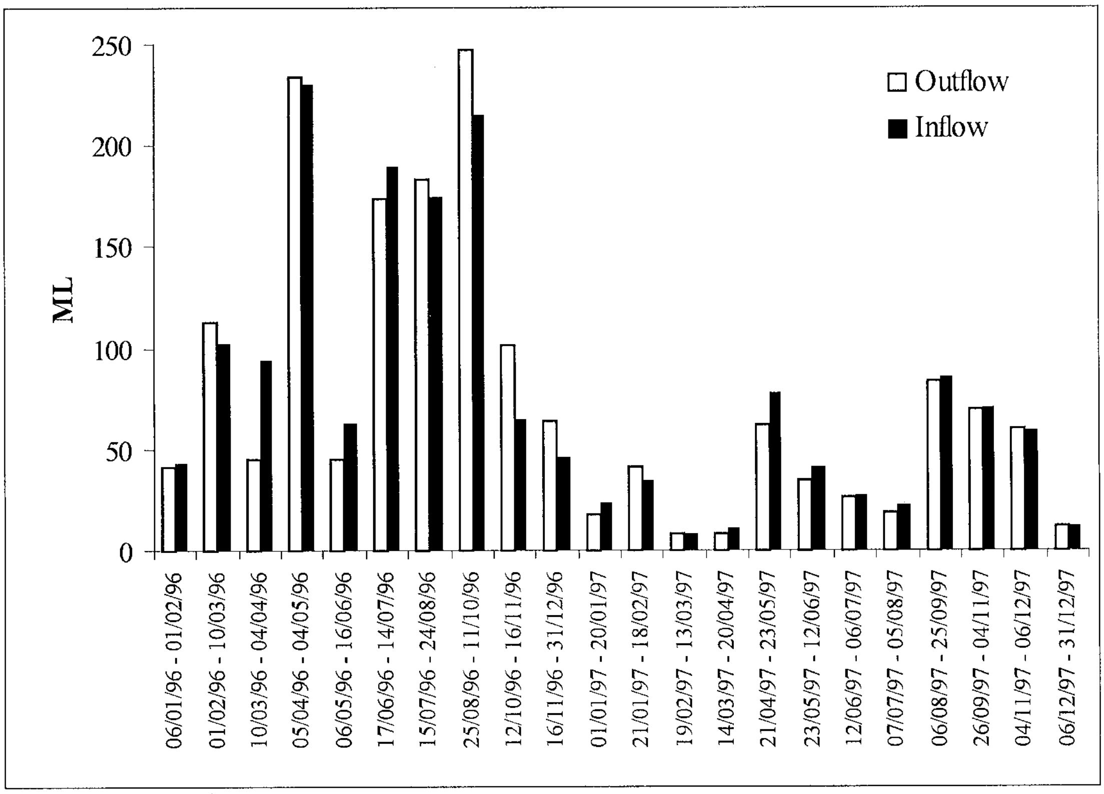

Figure 3.11 Total flow volumes over selected time periods (approximately 30 days in length).

4 Water quality at the inlets and the outlet of Blackburn Lake

The parameters measured to characterise the water quality entering and leaving Blackburn lake were turbidity, temperature, electrical conductivity (EC), total suspended solids (TSS), total nitrogen (TN) and total phosphorus (TP). All parameters were measured at the main inlet (Site C) and the outlet while only turbidity and temperature were monitored at Sites A, B, and E. Electrical conductivity was also monitored at Site B. Occasional manual water samples were taken during runoff events and during dry weather. Analyses of water samples for TSS, TP and TN were carried out at the Monash University Water Studies Centre.

4.1 Event water quality

Automatic event sampling

ISCO automatic water samplers were used at the main inlet and the outlet for collecting water samples during storm events. Stage activated sequential sampling was carried out and a two part program enabled different time intervals between sampling. Typically, smaller time intervals between samples were used for the first part of an event in order to sample the "first flush", followed by a longer time interval for the remainder of the event. At the main inlet, samples were taken every 10 minutes for the first hour (six samples), and then hourly for the remaining 18 samples. For several events the sampling regime was modified, such that 10 minute intervals were used to collect the first 12 samples and then 20 minutes for the remaining samples. This approach enabled relatively short events to be well sampled. Pollution concentrations at the outlet did not vary as much as at the inlet, so the sampling interval was not as critical. The sampler was programmed to take samples every 20 minutes for the first two hours (six samples), and then every hour for the remaining 18 samples (Figure 4.1).

A total of 1146 samples from 51 storm events were collected at the main inlet and 893 samples from 39 events at the outlet. At the inlet, 40 events were sampled in 1996 and 11 in 1997, while at the outlet 34 events were sampled in 1996 and five in 1997. There are two reasons for the limited number of samples in 1997. Firstly, there was only one third as much rainfall and, secondly, 1997 was plagued by instrumental problems. Despite these difficulties, the sampling program did characterise many storm events. All storm events which were sampled at the main inlet and/or the outlet are presented in Appendix C. The figures include rainfall and runoff data as well as the water quality parameters TSS, TP and TN.

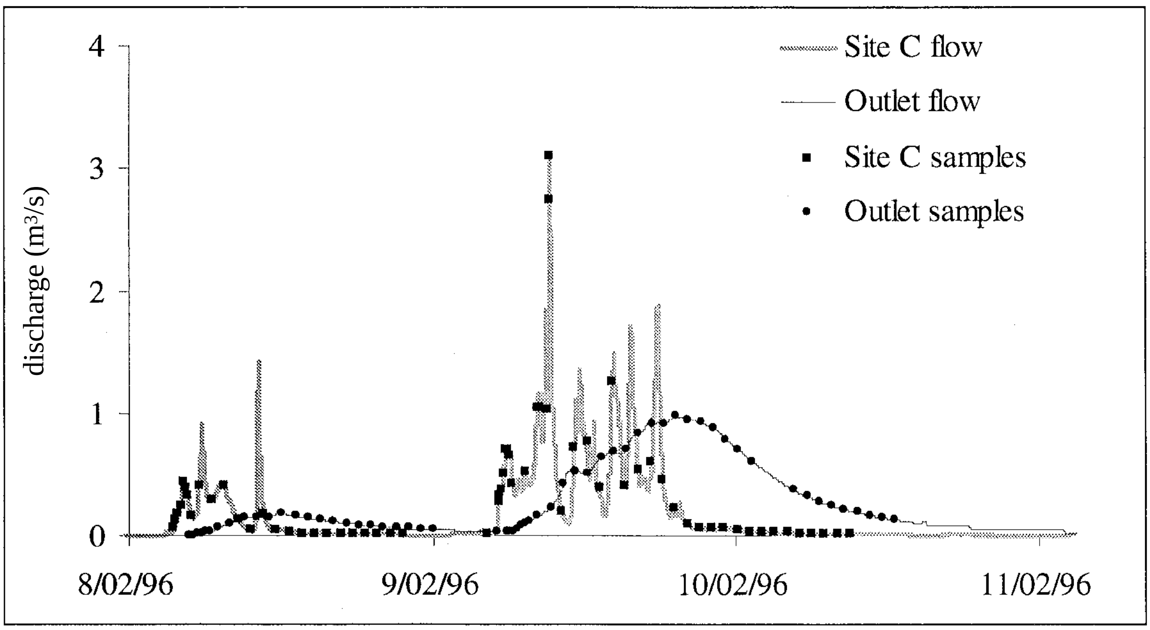

Fig 4.1 Water Samples in relation to inflow and outflow hydrographs

Manual event sampling

During several events instantaneous manual samples were collected from the other smaller inlets (A, B and E) (Table 4.1). Concentrations were generally lower at these sites compared with the main inlet site C (Figure 4.2).

Table 4.1 Number of manual samples taken at sub-inlets during storm events.

	Site A	Site B	Site E
Number of events	12	12	8
Number of samples	16	15	11

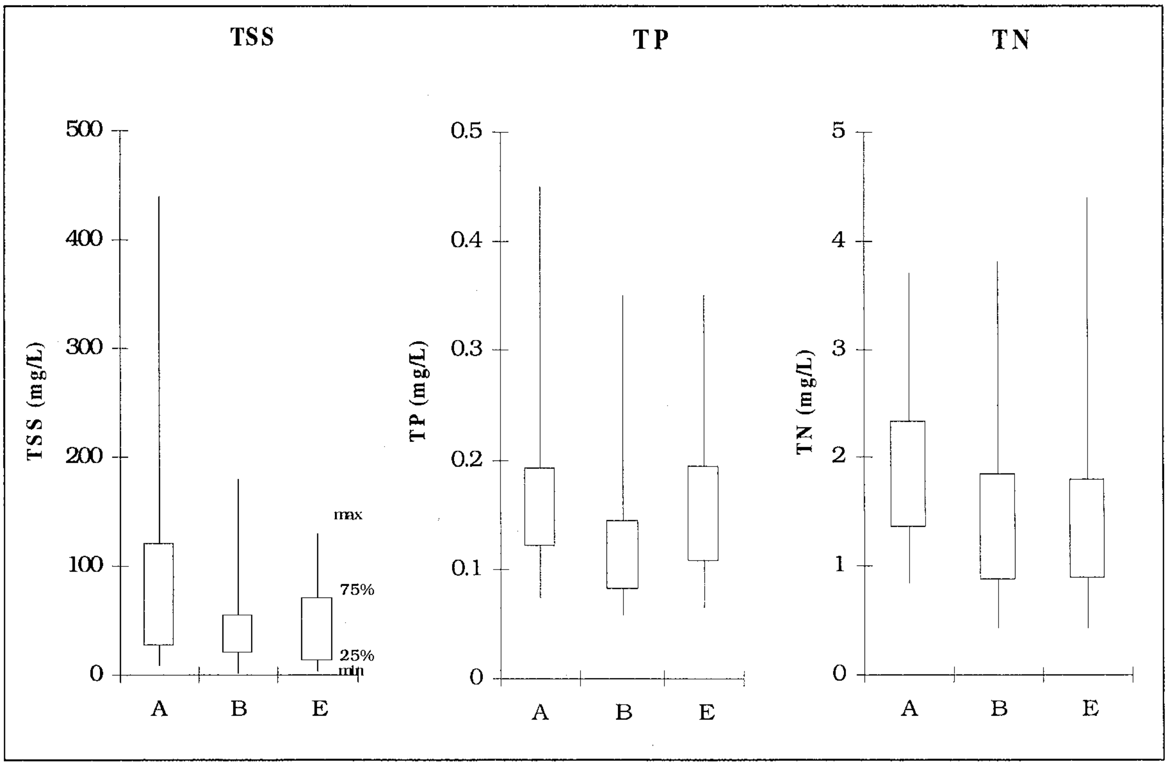

Figure 4.2 Cluster plots of water quality samples collected manually during storm events at sites A, B and E.

4.2 Lowflow water quality

Manual samples were taken approximately every two weeks at the main inlet and outlet in order to characterise low flow water quality. These samples were analysed for TSS, TP and TN. Although about 40 manual samples were taken from both the main inlet (C) and the outlet, only a subset of these was used to characterise the lowflow water quality. The criterion used here to objectively characterise lowflow conditions was that at least two days had elapsed since rainfall finished. Applying this criterion, the sample size reduced to 13 samples from both the inlet and the outlet (Table 4.2). The inlet TP and TN concentrations were typically higher than the outlet, however TSS concentrations were slightly higher at the outlet compared with the inlet (Figure 4.3).

4.3 Comparison with SEPP guidelines

The state environment protection policy (SEPP) outlines water quality objectives for the waterways of Victoria (EPA, 1995). The major goal is to:

"... attain and maintain levels of water quality which are sufficient to protect the specified uses of the surface waters of the policy area".

The SEPP outlines a number of water quality indicator parameters and maximum limits on contaminant concentrations. General water quality objectives are set out for all waters in Victoria, but in some instances, special values have been determined for specific catchments. TSS, TP and TN pollutant concentrations upstream and downstream of Blackburn Lake were compared with maximum acceptable limits outlined in the Draft Schedule F7 (EPA 1995). The values for TSS are specific to tributaries of the Yarra and refer to both baseflow and event concentrations. TP and TN are also specific to tributaries of the Yarra, but refer to lowflow concentrations only. The results show that TSS concentrations are higher than acceptable limits at the main inlet (site C) but lower at the outlet. Baseflow concentrations of TP at the outlet are below the maximum baseflow level but slightly above at the inlet. Baseflow concentrations of TN are above the acceptable limits both at the inlet and the outlet (Figure 4.4).

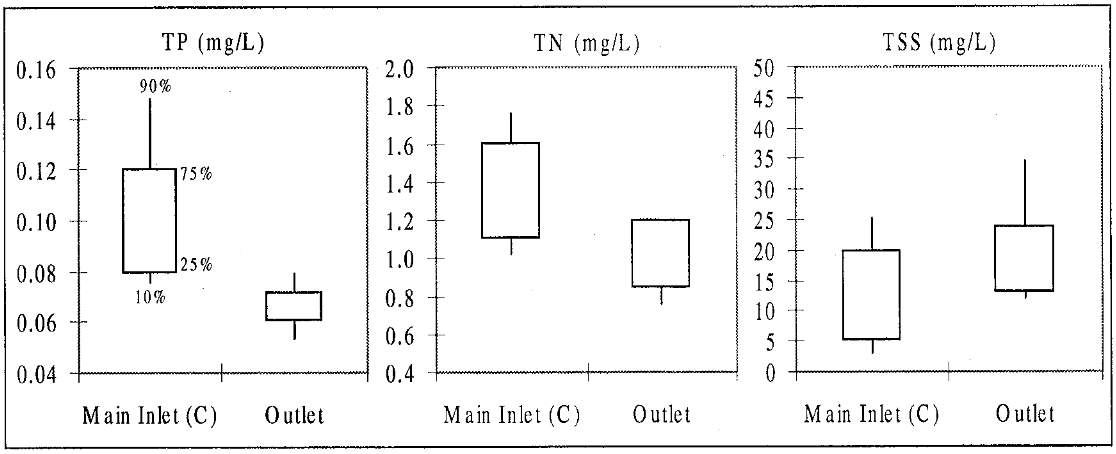

Figure 4.3 Cluster plots of lowflow water quality samples taken from the inlet Site C and the outlet.

Table 4.2 Low flow water quality (TN, TP, and TSS) at the main inlet and the outlet of Blackburn Lake.

Inflow					Outflow					No. of full days since last recorded rainfall
Date & Time	TSS (mg/L)	TP (mg/L)	TN (mg/L)	Inst. flow at time of sampling (m^3/s)	Date & Time	TSS (mg/L)	TP (mg/L)	TN (mg/L)	Inst. Flow (m^3/s)	
23/04/96 10:25	9	0.079	1.8	0.01	23/04/96 12:53	49	0.08	1.3	0.0013	3
30/04/96 14:20	4	0.05	1.6	0.004	30/04/96 15:05	37	0.072	1.2	-	2
11/05/96 18:15	50	0.1	1.8	0.003	11/05/96 18:40	13	0.054	1.2	0.006	2
16/10/96 11:05	23	0.079	1.4	0.004	16/10/96 12:18	24	0.077	1.2	0.0045	3
28/10/96 10:45	5	0.088	1.1	0.002	28/10/96 11:40	9	0.08	1.1	-	2
8/11/96 16:15	2	0.12	0.8	0.003	8/11/96 9:15	18	0.067	1	0.011	3
27/11/96 11:44	3	0.098	1.3	0.004	27/11/96 13:51	21	0.066	0.86	0.006	5
24/12/96 10:40	11	0.15	1	0.004	24/12/96 11:10	25	0.061	0.98	0.002	4
4/02/97 17:48	16	0.11	1.4	-	4/02/97 19:01	15	0.06	0.82	0.001	5
13/02/97 11:10	9	0.14	1.6	-	13/02/97 12:57	18	0.066	0.84	0.001	2
21/02/97 13:13	5	0.1	1.1	0.0008	21/02/97 14:00	16	0.062	0.69	0.001	10
6/03/97 15:50	20	0.075	1.2	0.0001	6/03/97 13:40	13	0.053	0.74	0.005	2
5/06/97 9:40	26	0.15	1.4	0.0006	5/06/97 14:50	12	0.042	0.86	0.005	3
Average	**14.1**	**0.103**	**1.34**	**0.003**	**Average**	**20.4**	**0.065**	**0.98**	**0.004**	**3.5**

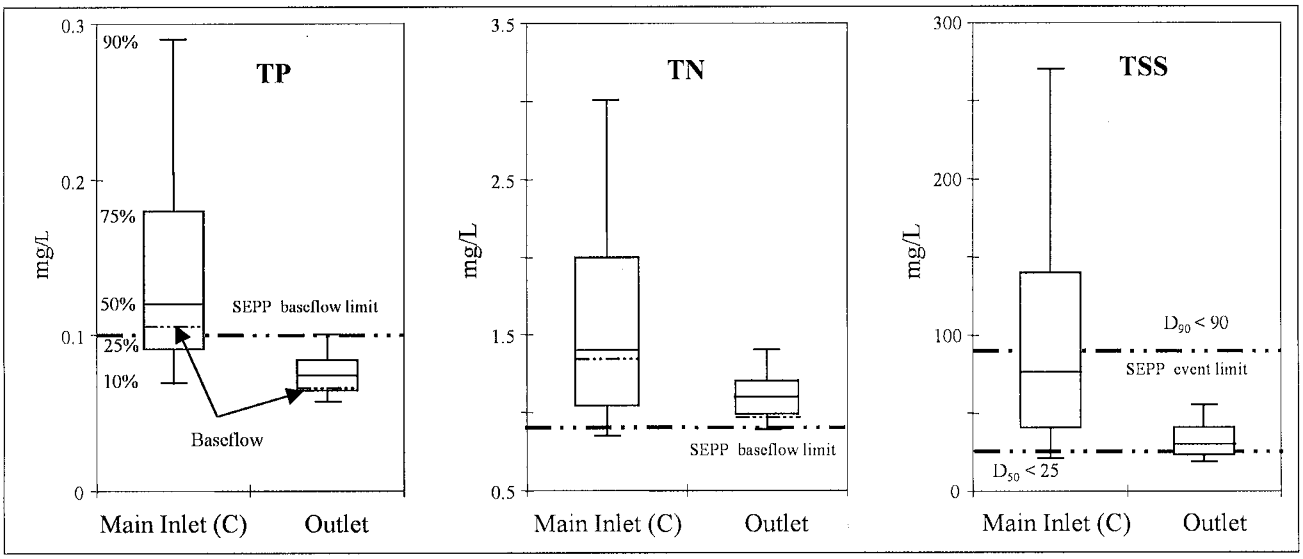

Figure 4.4 Box plots of TSS TN and TP concentrations for main inlet and the outlet of Blackburn Lake and recommended limits set by the State Environment Protection Policy (SEPP).

4.4 Continuous water quality monitoring

Unidata STARFLOW temperature sensors were used to record water temperature every two minutes and GREENSPAN sensors were used to record turbidity and electrical conductivity every two or 12 minutes. The turbidity and EC probes were calibrated at the beginning and middle of the monitoring program. The data were quality coded but no attempts have been made to infill missing data. The continuous water quality data indicated a high level of variability in response to flow (Figure 4.5).

Adjusting turbidity record for lens fouling

The growth of algae over the lens of turbidity sensors is a common problem. When this occurs, the light beam is erroneously scattered giving higher readings of turbidity than normal. Lens fouling can be detected as a gradual increase in the readings that is not associated with normal event responses and is particularly evident during long periods of low flow. Algal growth was a problem at the main inlet and the outlet because the sensors were permanently submerged in the flow. Water pumps were mounted onto the instruments approximately six months after monitoring began. The pumps sprayed water over the lens surface periodically, thereby alleviating the problem of agal growth. Prior to this, the lenses were manually cleaned approximately every two weeks.

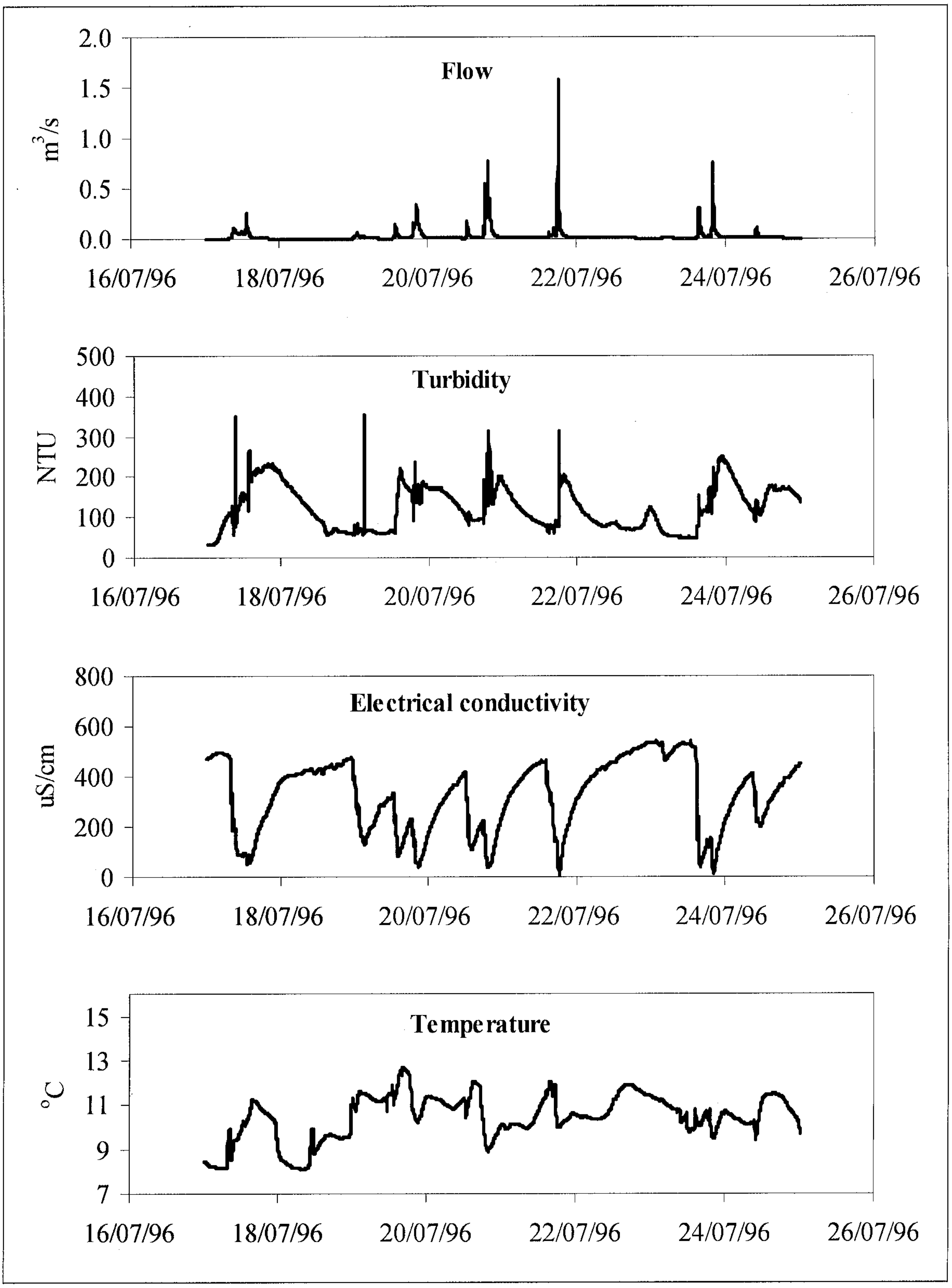

Figure 4.5 An example of continuous water quality parameters, EC, turbidity, and temperature from Site C

Algae-affected turbidity data were adjusted by firstly isolating the period affected, determining the rate of increase in turbidity due to algal growth, and then subtracting this rate from each reading within the affected period. The rate of increase was typically linear or logarithmic. Two examples of adjustment are given below. The first is from the main inlet (site C) where over an eight day period in April 1996 algae grew over the lens of the sensor increasing turbidity readings at a rate of 36.4 NTU per day (Figure 4.6). There were two small events during this period, the sensor stopped logging on the seventh day, and it was cleaned and resumed logging on the eighth day just prior to another event. A linear regression was fitted to the affected period and the slope of this line was subtracted from each value (Figure 4.6). In the second example, algal growth occurred over an extended dry period. During this period, algal growth occurred at a greater rate than in the first example. The data were firstly log transformed to linearise the algae growth rate and then the slope of a linear regression through this curve was used to adjust the values (Figure 4.7, A). The adjustment over-corrected the turbidity record, as the new values did not match the cleaned sensor values (Figure 4.7, B). Another linear regression was fitted from the start of the adjusted readings to the cleaned target value and the slope used to readjust the values.

After adjustment, the total length of good quality data for the outlet was 198 days in 1996 and 192 days in 1997, and for the inlet 134 in 1996 and 127 in 1997 (Table 4.3).

Table 4.3 Periods of record when the turbidity data was adjusted because of algae growth.

Main Inlet (Site C)	Outlet
5/2/1996 – 10/2/1996, 10/2/1996 – 22/2/1996, 6/3/1996-12/3/1996, 1/8/1996-7/8/1996, 26/8/1996-30/8/1996	17/2/1996-22/2/1996, 6/3/1996-16/3/1996, 2/4/1996-14/4/1996, 1/7/1996-8/7/1996, 29/7/1996-2/8/1996, 26/8/1996-30/8/1996, 2/9/1996-10/9/1996, 27/9/1996-30/9/1996, 1/11/1996-4/11/1996, 6/12/1996-10/12/1996, 13/12/1996-24/12/1996

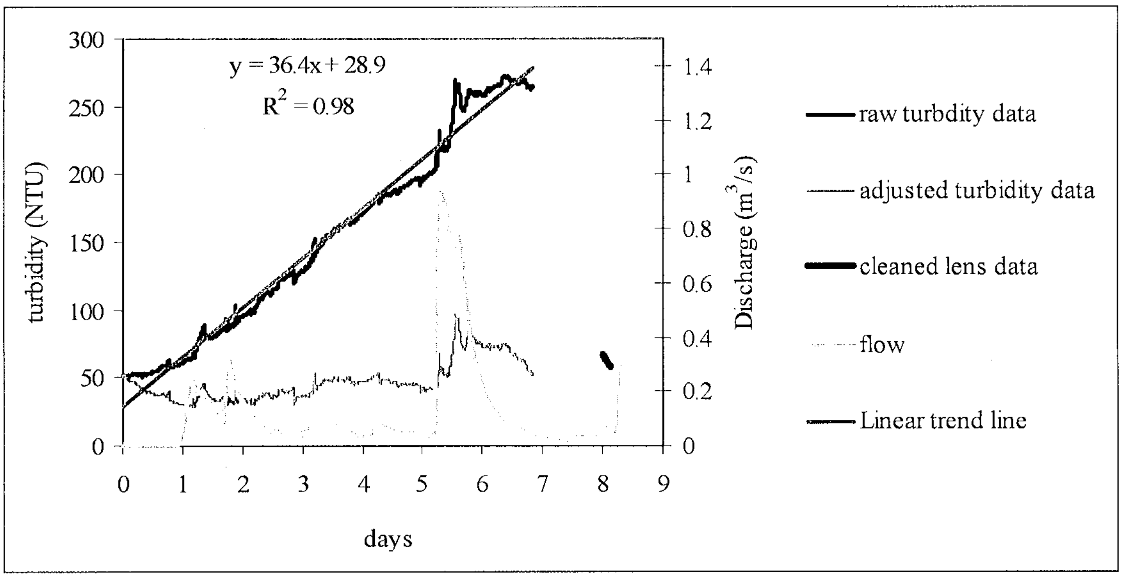

Figure 4.6 Turbidity readings affected by algae growth at the outlet. Period adjusted was 6/4/1996 – 14/4/1996

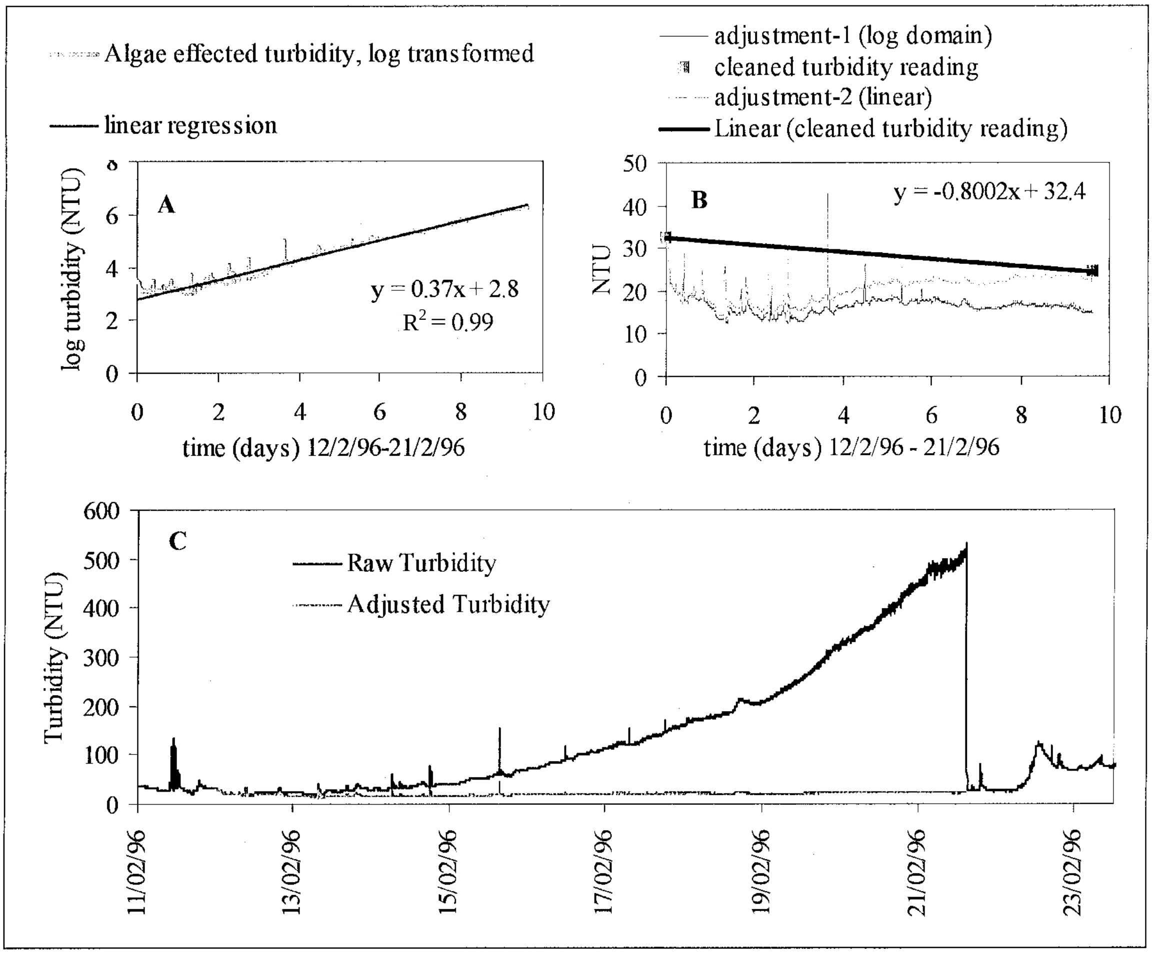

Figure 4.7 Main inlet (Site C) turbidity data adjustments because of algae growth during an extended dry period.

Comparison of inlet and outlet turbidity

The difference between turbidity at the inlet and the outlet can be observed in a cumulative probability plot (Figure 4.8). The curve was constructed using the quality coded and adjusted turbidity data set. The times selected were 10/7/1996 - 1/11/1996 and 1/7/1997 - 1/10/1997. The majority of these two periods had continuous turbidity data available. The results show that the inlet experiences higher turbidity for longer periods of time than the outlet. For 60% of the time turbidity at both the inlet and the outlet exceeded 40 NTU. For the remaining 40% of the time the outlet experiences higher turbidity than the inlet. This was also reflected in the lowflow TSS samples, where on average the outlet was higher than the inlet. This may be due to very fine clay particles from the previous event, draining from the lake, or phytoplankton present in the lake. The outlet exceeds 60 NTU, and the inlet 120 NTU, 10% of the time.

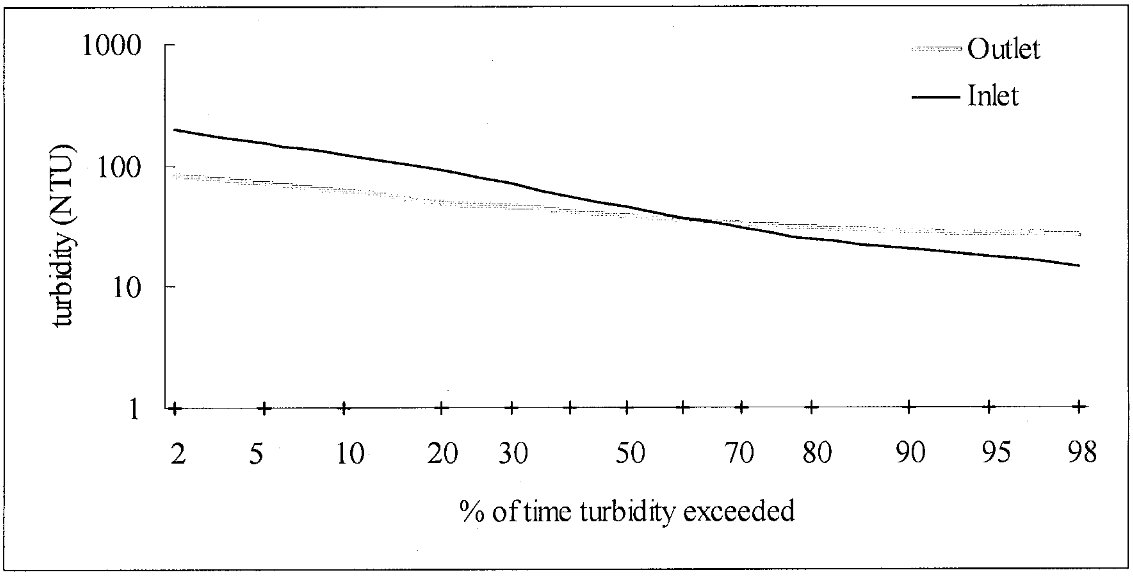

Figure 4.8 Cumulative probability plot of turbidity for the main inlet and the outlet of Blackburn Lake.

Turbidity at sites A, B and E

It was difficult to record turbidity at the other smaller inlets because the water depth in the pipes rarely exceeded the 50 mm, the depth required for the sensors to monitor turbidity accurately. Nevertheless, an edited data set contained data for 11 events from Site A, 68 events from site B, and 13 events from site E. In some cases only one data point per event was obtained and the data therefore is of limited use for determining pollutant loads. In addition, water samples that were taken during events did not often coincide with turbidity readings making it difficult to establish a relationship between turbidity and pollutant concentrations (Figure 4.9).

4.5 Estimation of event loads

The total TSS, TP and TN loads for the 51 and 39 events at the main inlet (C) and the outlet respectively were estimated by summing the product of runoff and pollution concentration over one minute time intervals. The one minute water quality concentrations were obtained for each event by linearly interpolating between samples. An event began at the onset of rainfall, and ended when flow resumed to a nominal baseflow level that was arbitrarily defined. When the start or end of an event was not well sampled, the average low flow concentration was used to represent the first and last minute of the event.

The accuracy of the pollutant loads calculated for each event (Appendix D) was estimated objectively by considering the proportion of the storm volume that was adequately sampled. This was calculated by assuming that a point water quality measurement is representative of the pollutant concentration over 10 minutes at the inlet (five minutes prior to and after the sampling) and 20 minutes at the outlet. The loads calculated for the events are tabulated in Appendix D together with event characteristics and the proportion of storm volume sampled estimated using the above criteria.

Event Mean Concentrations (EMC) were calculated for each event by dividing the total load by the runoff volume (Appendix D). There was no clear relationship between runoff and EMC (Figure 4.10). The close relationship between runoff and event load (Figure 4.10) is explained by spurious correlation (ie discharge is used to calculate load). Although spurious, these relationships can be used to infill load data on an event basis.

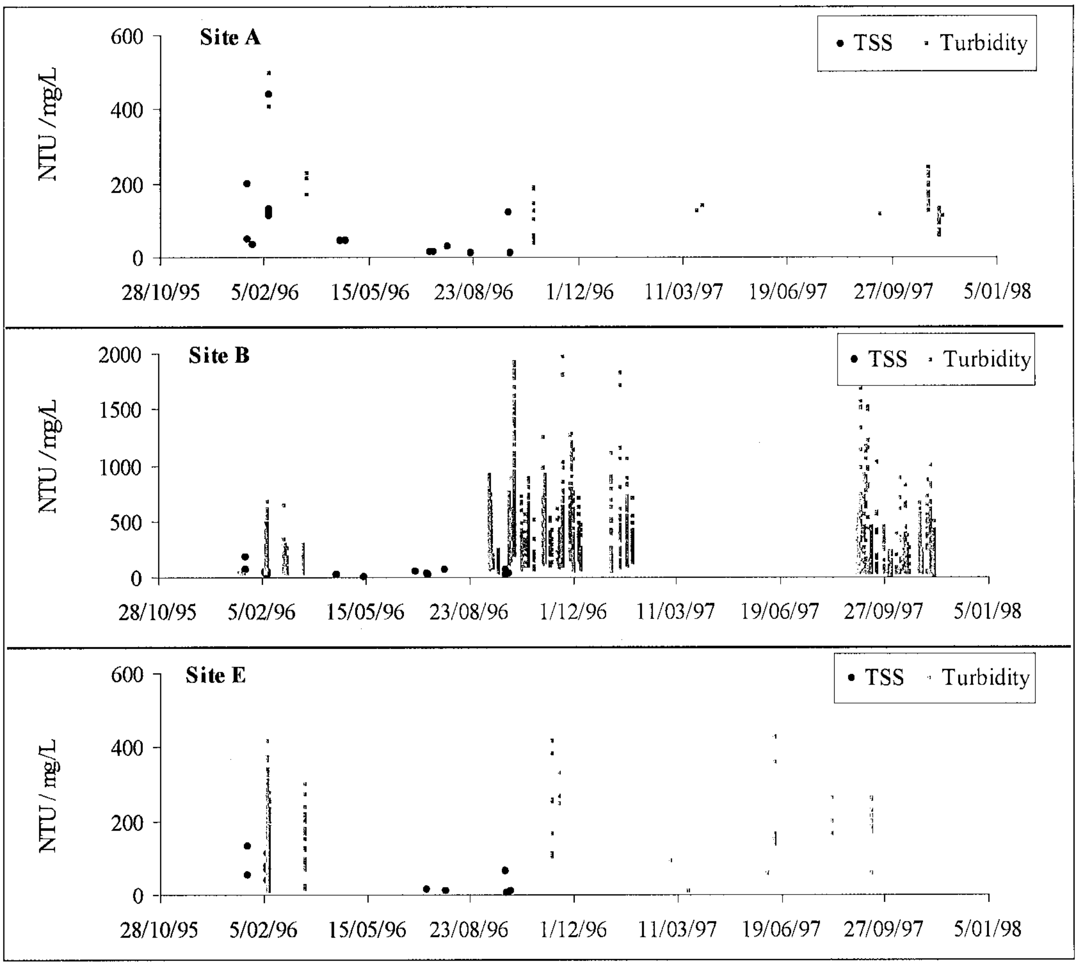

Figure 4.9 Turbidity data for depths greater than 50 mm and TSS samples for sites A, B and E.

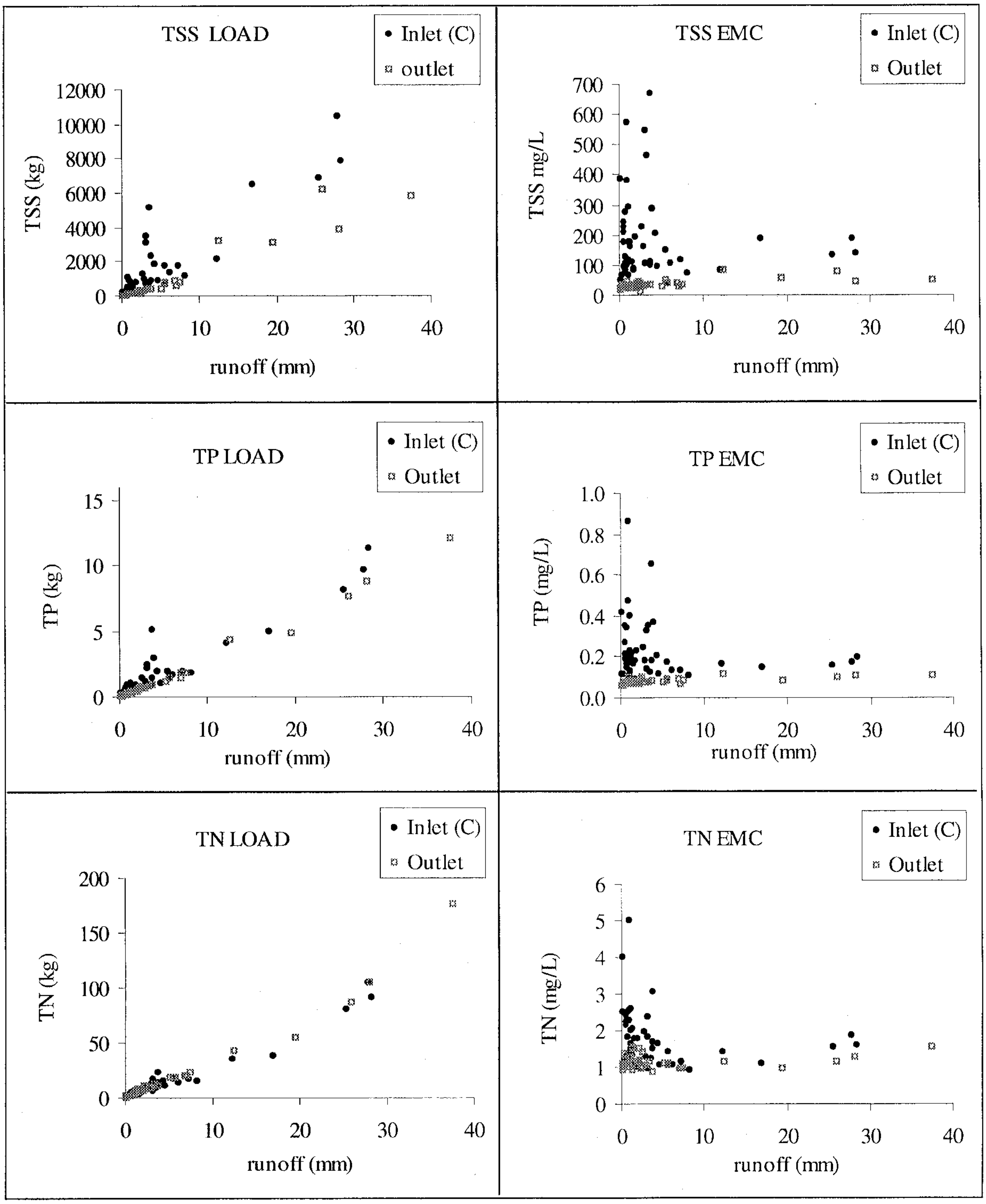

Figure 4.10 Relationships between event runoff and event EMC and event runoff and event load for inlet and outlet of Blackburn Lake.

4.6 Relationships between water quality data

TSS, TP, TN

There appears to be a close linear relationship between log TSS and log TP (see Figure 4.11 A). The relationship is better at the inlet (R^2 = 0.74) than at the outlet (R^2 = 0.42), which can be partly explained by the narrow range of data at the outlet. The relationship between TSS and TN is poor (Figure 4.11 B).

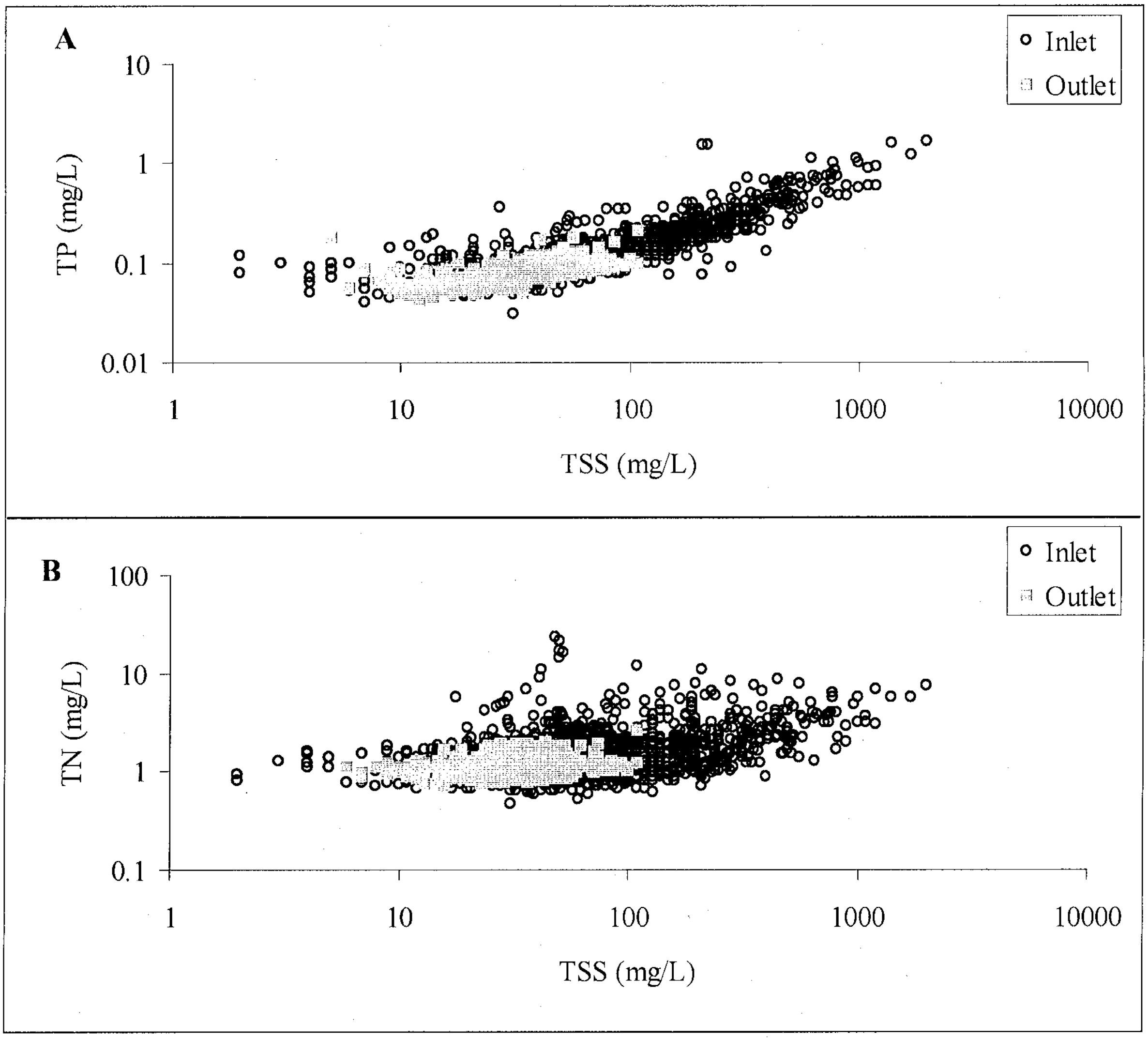

Figure 4.11 (A) Relationship between total suspended solids (TSS) and total phosphorus (TP). (B) Relationship between total suspended solids (TSS) and total nitrogen (TN). Figures include all water samples (events and lowflow) from the inlet and the outlet of Blackburn Lake. A total of 1186 samples from the inlet and 937 from the outlet.

Turbidity and water quality relationships

Outlet

There is a reasonable relationship between turbidity and TSS (R^2= 0.65) (Figure 4.12 A), and to a lesser extent between turbidity and TP (R^2=0.45) (Figure 4.12 B). There were no significant differences between the relationships for rising and falling limbs of the hydrographs. The relationship between turbidity and TN is poor (Figure 4.12 C).

Inlet

Further work needs to be carried out on the relationship between turbidity and TSS before it is acceptable for prediction of water quality parameters TSS and TP (Figure 4.12 D, E). The relationship between turbidity and TN was not significant (Figure 4.12 F).

Possible explanations for the scatter in this relationship could be variations in sediment characteristics such as geology or particle size. It was evident from the water samples collected during events that coarser, and more organic, sediment was being transported at the beginning of events, compared with finer silts and clay being transported at the end of events. It was hypothesised that two different relationships may be evident between TSS and turbidity, and an attempt was made to divide the record up into rising and falling limbs. Based on an intuitive distinction between rising and falling limbs a few events showed strong support for different relationships between turbidity and TSS (Figure 4.13). A more objective distinction for dividing the entire record into rising and falling hydrographs was required. The inflows to Blackburn Lake are very flashy and a simple division of positive and negative slopes for each data point on the hydrograph would result in a nonsensical division. Functions to smooth the data are not that useful because they tend to move peaks forward or backward in time. The criterion used was such that a point on the hydrograph was considered rising if the discharge measurement at that point was greater than the average of the previous three 2-minute measurements. Based on this division no difference was observed between the turbidity and TSS relationship (Figure 4.14).

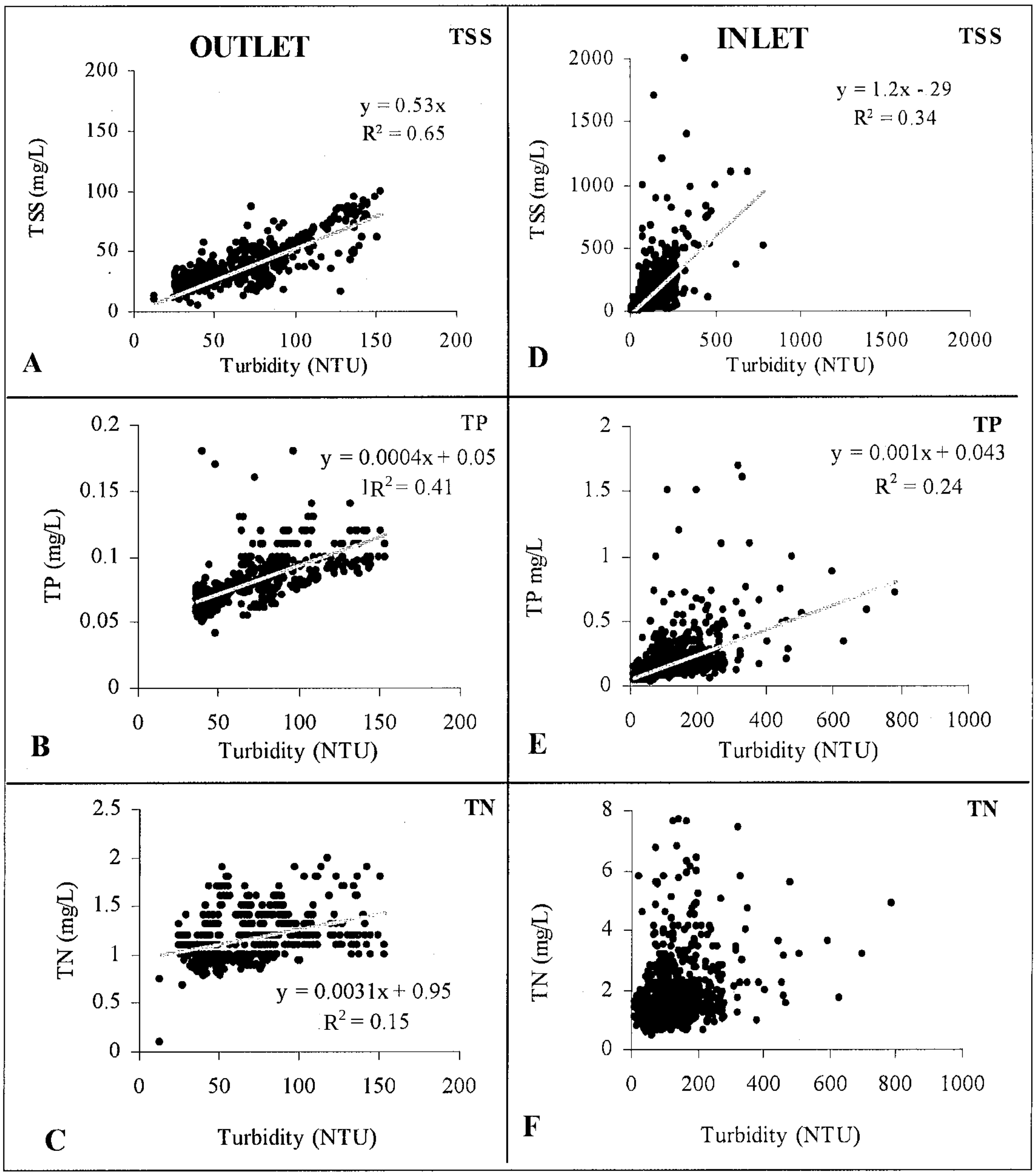

Figure 4.12 Relationship between turbidity and TSS, TP and TN at the main inlet and the outlet of Blackburn Lake

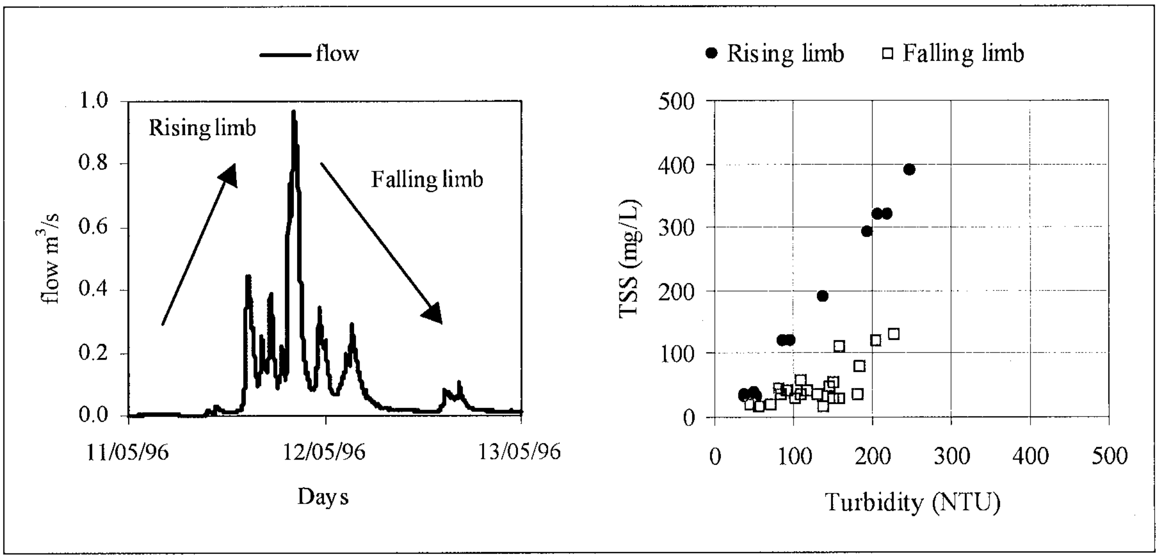

Figure 4.13 An event where there appears to be a difference in the relationship between turbidity and TSS for rising and falling limbs

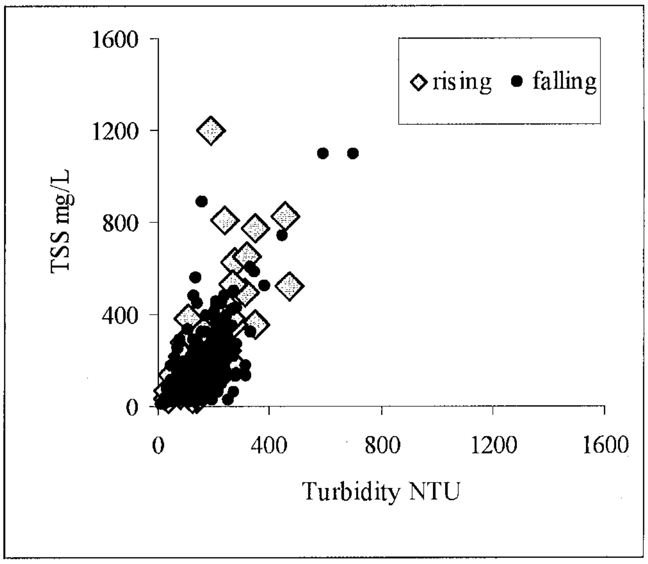

Figure 4.14 Objective delineation of rising and falling limbs of hydrographs and the corresponding relationships between turbidity and TSS

5 Water quality within Blackburn Lake

This chapter summarises the manual water sample data collected from within Blackburn Lake, presents both spatial and temporal variations and discusses the trophic status of the Lake. Water quality data collected during an event is presented, along with water quality and flow data collected from both the inlet and outlet of the lake. The data were divided into event and low flow periods and the spatial variation (between sites and between top and bottom samples) and the variation between periods are presented. The record was divided into seasons and the results give examples of both spatial and temporal variation. Finally generalised temperature and dissolved oxygen profiles for low flow conditions were constructed for each site.

5.1 Data collection

During 1996, manual water samples from within Blackburn Lake were taken approximately every two weeks. The samples were taken from five locations within the lake (Figure 5.1), and at two depths, 0.2 m from the top and 0.2 m from the bottom. Pond depths ranged from less than 1 m (site 1) to greater than 4 m (site 4). Water samples were analysed for total suspended solids (TSS), total phosphorus (TP), total nitrogen (TN), nitrates/nitrites (NO_x-N), ammonia (NH_4-N), filterable reactable phosphorus (FRP), biological oxygen demand (BOD) and chlorophyll. The Australian standard method expresses the weight of nitrogen or phosphorus within the sample and does not include oxygen or hydrogen.

Depth profiles of temperature, conductivity, turbidity, pH and dissolved oxygen (DO) were measured at each site at 0.2 m intervals. Major ions including chloride (Cl), sulphate (SO_4), calcium (Ca), sodium (Na), magnesium (Mg) and potassium (K) were measured on one occasion (7/5/1996) at each site at the top and bottom of the pond. The amount of Sulphate (SO_4 g/kg) within the lake bottom sediments was determined from five replicate sediment samples, collected from each site at five depths; ie 25 samples per site and 125 samples in total.

A CRCFE Urban Pond Project research design was based on the use of the Stranger Pond (Canberra) monitoring to identify the dominant pollutant transport and transformation pathways. In view of the complex and dynamic interactions between water column, sediment and algal compartments, the development of a dynamic model was required to represent and test these interdependent processes. The data collected for Blackburn Lake storm event pollution interception, in-lake water quality and sediment transfers, was used to validate the explanations of individual process components, and the overall integrated model.

The major analysis components of the CRCFE model comprised validation of the CSTR (Continuous Stirred Tank Reactor), the sediment redox model and of the integrated model. It was concluded that, notwithstanding major differences between Stranger Pond and Blackburn Lake (size, hydrology, pollutant loading, event frequency, suspended solids grading), both the individual component models and the integrated model based on Stranger Pond provided a robust and accurate estimate of water quality for Blackburn Lake for the full period of monitored data.

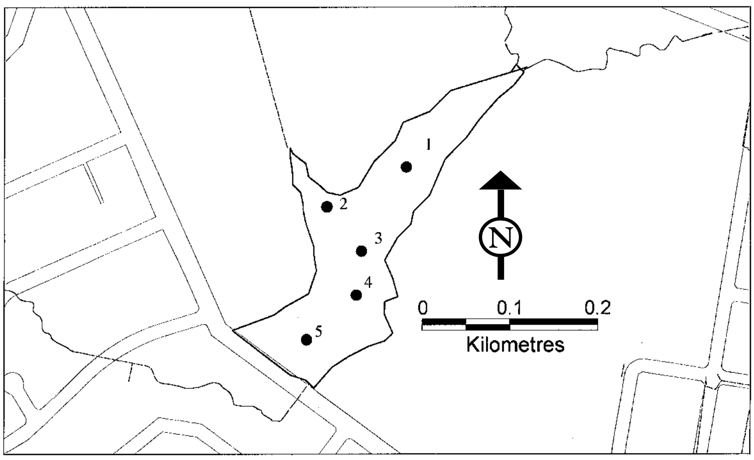

Figure 5.1 Plan view of the pond showing location of each sampling site

Sampling of the Blackburn Lake sediments was requested, in order to be able to modify the Stranger Pond based model to reflect the Blackburn Lake system. The sulfate content, along with iron, is an important determinant of the mass of phosphorus released per gram of carbon (BOD) deposited in the Lake by storm events.

Figure 5.1 shows the location of the sampling sites within the pond. Site 1 receives inflowing storm water from sub catchments B, C, D and E while Site 2 receives inflowing storm water from sub catchment A. The remaining sites (3, 4 and 5) are downstream of these two main inlets. Buoys were used to mark these sites and sampling was carried out in a small rowboat. Sampling generally took about 4-5 hours.

5.2 Hydrologic conditions

Water quality data was sampled during a wide range of hydrological conditions (Figure 5.2). The type of flow (event, recession or low flow) daily flow rates and antecedent conditions were used to describe hydrological characteristics at the time of sampling. On several occasions, water samples were collected both from within the lake, as well as from the inlet (C) and the outlet (Table 5.1). The hydrological record was broken into roughly four seasons ranging in length from 30 to 90 days. These periods were arbitrarily selected based on rainfall and in-pond water temperatures (Table 5.1). They represent warm-dry/stormy conditions (mid Jan - Mar), autumn rainfall (Apr), cool and dry (May - mid June) and cool and wet conditions (mid June - mid Oct).

5.3 Water quality data

Averages for all variables, including all sites and depths, provide a general indication of differences between sampling dates (Table 5.2). As well as temporal variability the pond experiences high spatial variability, both within and between sites (see Appendix E). In general ammonia (NH_4-N) and TN concentrations were higher at the bottom of the lake compared with the top, while nitrite and nitrate (NO_x-N) concentrations were generally higher at the top than the bottom. FRP concentrations at the top and the bottom were generally similar except during or just after events when the bottom concentrations become much higher than the top. Soluble nutrients during events (FRP, and NH_4-N) at sites 3 and 4 and, to a lesser extent at site 5, were typically higher at the bottom, while for sites 1 and 2 top and bottom concentrations were similar. NOx-N concentrations during events were reasonably similar between sites. TP and TSS concentrations at the top and the bottom were mostly similar except for samples taken during a large event on 11/4/96 when the bottom concentrations became much higher than the top. Sites 3 and 4 had the highest concentrations on the 11/4/96 but on most other occasions the sites appear reasonably similar. Chlorophyll was mostly higher at the top than the bottom of the pond and similar between sites. BOD was highly variable both spatially and temporally.

Dissolved oxygen and temperature measurements were taken at 0.2 m intervals at each site for the period of sampling (Appendix E). Sites 3, 4, and 5 (depths of between 3 - 5 m) stratify more than sites 1 and 2 because they are deeper than sites 1 and 2 which are relatively shallow (0.6 m - 1 m).

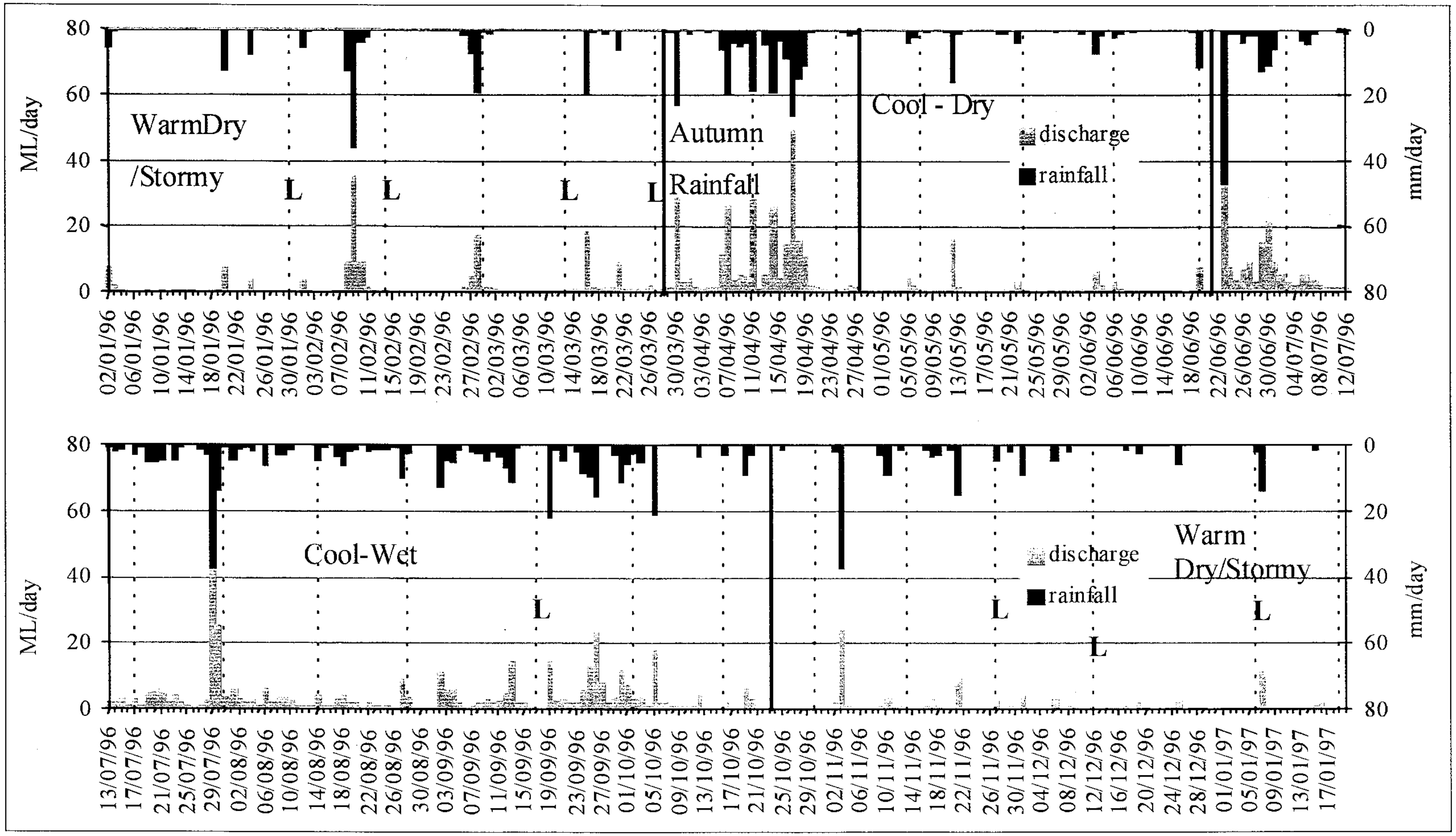

Figure 5.2 Dotted lines indicate times of water quality sampling within Blackburn Lake. Solid lines indicate the different seasonal divisions and 'L' indicates low flow samples

Table 5.1 Hydrological conditions at time of water quality sampling within Blackburn Lake.

	Total daily flow (ML/day)	Average daily flow rate (m^3/s)	Days since rainfall	Condition at time of sampling *	Size of last event (ML)	Average flow rate (ML/day)	Event data at C	Event data at Outlet	Low flow data at C	Low flow data at Outlet
30/01/96	0.2	0.003	4	L						
14/02/96	0.4	0.005	3	L	35.5					
29/02/96	1.9	0.021	0	R	17.5	2.4				
13/03/96	1.0	0.011	11	L	17.5					
27/03/96	0.8	0.010	4	L	9.89					
11/04/96	28.2	0.327	0	E		8				
24/04/96	1.3	0.014	4	L	50					
7/05/96	0.8	0.009	1	R			√	√		
23/05/96	0.6	0.007	1	R	3.89	1.4	√	√		
6/06/96	3.3	0.038	1	R	6.25		√			
19/06/96	7.7	0.089	0	E			√	√		
3/07/96	3.0	0.035	1	R	5.8		√	√		
17/07/96	3.4	0.039	1	E	3		√			
31/07/96	3.8	0.044	1	R	47.2		√	√		
14/08/96	4.6	0.053	0	E		4.9	√	√		
28/08/96	3.6	0.041	1	R	9		√	√		
17/09/96	0.8	0.009	4	L	14.6					
2/10/96	3.3	0.038	1	E	7.8					
16/10/96	2.5	0.029	4	L	4.6				√	√
30/10/96	0.6	0.007	4	L	0.9					
13/11/96	0.3	0.003	1	L	1					
27/11/96	2.3	0.027	5	E	9.6	1.3	√		√	√
12/12/96	0.3	0.003	4	L	1.2					
6/01/97	0.3	0.003	3	L						
19/01/97	0.3	0.003	11	L	4					

- L-low flow, E-event, R-recession.

Table 5.2 Average water quality data

	TSS (mg/L)	TP (mg/L)	TN (mg/L)	NO_x-N (mg/L)	NH_4-N (mg/L)	FRP (mg/L)	Temperature (°C)	DO (mg/L)	EC (μS/cm)	PH	Turbidity (NTU)	BOD (mg/L)
30/01/96	26	0.093	1.10	0.056	0.65	0.0084	20	29	188	6.4	44	5.1
14/02/96	21	0.078	1.02	0.22	0.30	0.007	17	34	178	6.6	53	2.1
29/02/96	30	0.078	1.14	0.20	0.45	0.0109	17	34	529	6.9	68	3.3
13/03/96	26	0.063	1.11	0.098	0.39	0.091	19	32	181	6.9	58	3.2
27/03/96	21	0.066	1.00	0.12	0.32	0.028	17	26	169	7	28	2.5
11/04/96	113	0.13	1.30	0.47	0.25	0.0027	13	63		7.1	195	1.7
24/04/96	86	0.11	1.31	0.50	0.18	0.0015	12	47	364	7	117	1.7
7/05/96	36	0.084	1.29	0.36	0.29	0.0053	13	31	234	6.9	95	1.3
23/05/96	36	0.080	1.19	0.29	0.33	0.0056	12	30	212	7	56	1.6
6/06/96	33	0.075	1.20	0.29	0.33	0.0068	11	45	214	7.1	73	3.5
19/06/96	22	0.060	1.28	0.27	0.43	0.0057	9	39	228	7.0	42	2.0
3/07/96	54	0.100	1.44	0.6	0.21	0.0019	10	50	208	7.1	133	1.7
17/07/96	35	0.080	1.35	0.51	0.32	0.0074	8	4	232	6.7		3.6
31/07/96	55	0.11	1.74	0.74	0.13	0.023	10	60	234	7	118	2.6
14/08/96	37	0.048	1.34	0.47	0.22	0.0025	10	42	271	7.0	73	2.5
28/08/96	39	0.073	1.18	0.34	0.13	0.0068	11	51	237	7.1	55	4.0
17/09/96	38	0.070	1.06	0.32	0.12	0.002	13	59	212	7.1	76	2.0
2/10/96	44	0.092	1.19	0.31	0.12	0.0067	12	53	261	7	114	1.8
16/10/96	27	0.083	1.20	0.26	0.19	0.0042	15	35	222	7	52	2.3
30/10/96		0.084	1.23	0.39	0.29	0.0053	15	40	228	7	63	2.7
13/11/96	29	0.077	1.13	0.2	0.29	0.0046	15	40	197	7	48	2.6
27/11/96	35	0.074	0.96	0.094	0.21	0.0058	18	58	191	7.1	68	3.4
12/12/96	27	0.075	1.19	0.13	0.28	0.0059	18	35	172	6.7		
6/01/97	23	0.074	1.22	0.12	0.45	0.0056	22	35	249	6.7	30	
19/01/97	23	0.10	1.43	0.089	0.57	0.0076						

5.4 Event water quality (11/4/1996)

During a large event, on the 11/4/1996, flow and water quality data were collected from both the inlets and outlet of Blackburn Lake as well as from within the lake. Continuous flow, turbidity and temperature data were available from the main inlet (C) and the outlet of the lake (Figure 5.3), while water quality data was collected within the lake (Figure 5.5). The discharge data in Figure 5.3 shows the strong flood attenuation characteristics of the lake. Continuous turbidity data shows that parts of the catchment responded very rapidly, with a major turbidity increase on the rising arm of the hydrograph. However, significant turbidity peaks also occur on the falling arm of the hydrograph associated with small increases in discharge; this probably reflects differences in catchment land use and variations in the efficiency of the drainage system (Figure 5.4). Turbidity levels in the outflow only start to increase on the falling arm of the outflow hydrograph, suggesting very little short-circuiting or surface skimming of inflow occurred.

The continuous temperature data shows that, for most of the runoff event, inflow (9° (C) was 4-5 (C cooler than the lake (14 (C). Previous data has already shown the lake can strongly stratify (Appendix E). This suggests that cool inflows to the lake may plunge into the cooler hypolimnion rather than mixing through the entire profile. Figure 5.6 shows profile data taken several hours after the inflow event. Both temperature and DO data show strong vertical stratification at all sites except 1. This indicates the inflow did not mix through the entire profile of the lake. Under stratified conditions DO in the hypolimnion is typically low. However, the stratification during the event shown in Figure 2.1 indicates reverse stratification, with the highest DO concentrations occurring in the hypolimnion. During event flow conditions, DO concentrations in the inflow would be high due to the turbulent flow conditions.

The data strongly indicates the inflow on the 11/04/96 has plunged into the hypolimnion of the lake without mixing through the profile. Other within-lake water quality data support this suggestion (Figure 5.5). Variables that are typically higher in runoff than in lake water column (FRP, TP, NO_x-N, TN & TSS) are all higher in the hypolimnion than in the epilimnion. NH_4-N which could be expected to be higher in the hypolimnion than epilimnion is the reverse. The high concentrations of pollutants in the hypolimnion could be due to both the load in the inflow and disturbance of the sediments caused by an inflow entering the hypolimnion. This event experienced the third highest rainfall intensity (over the monitoring period 1996 - 1997), reaching a maximum of 7.5 mm/hr. Such intense rainfall may have contributed to higher than average velocities within the pond, causing resuspension of the bed material.

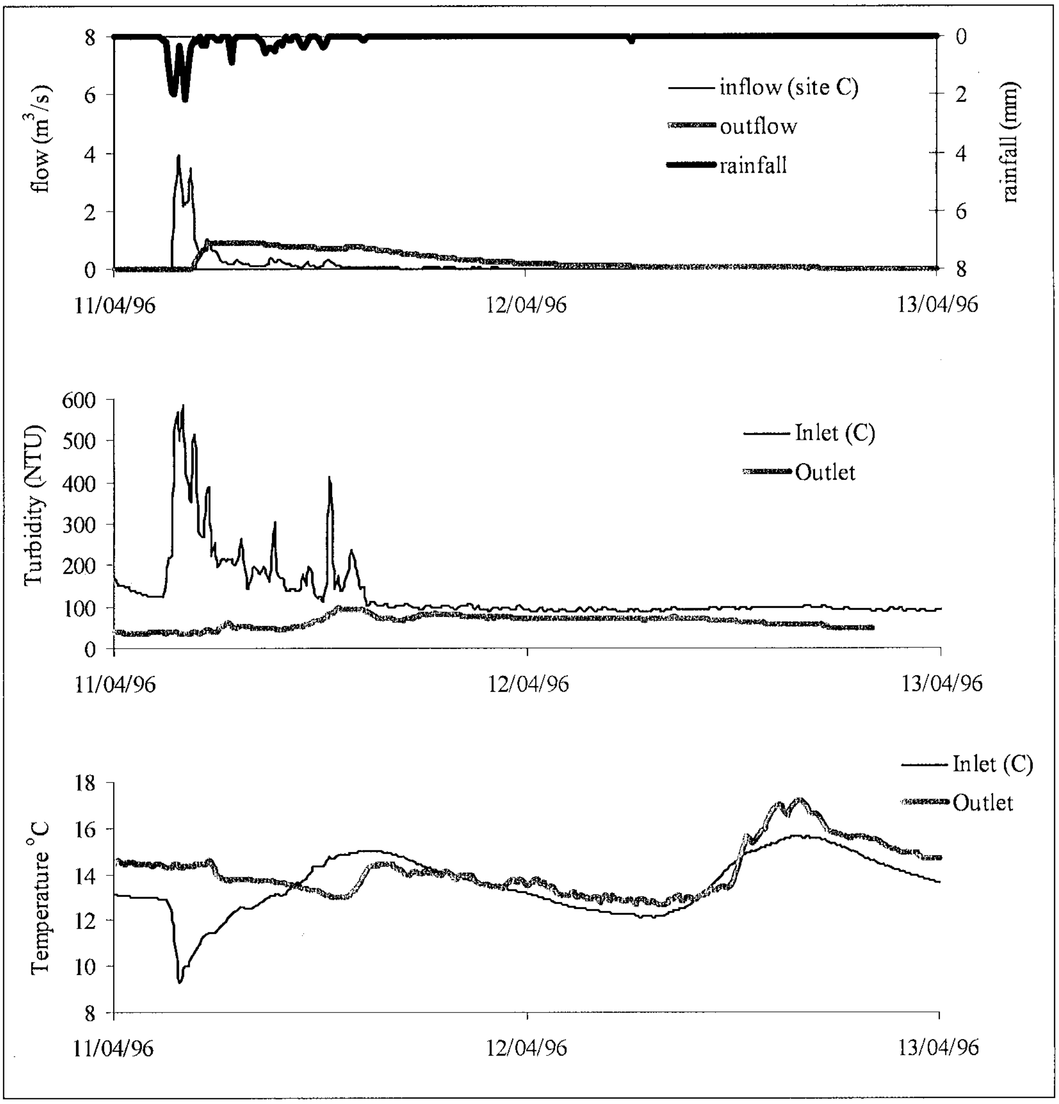

Figure 5.3 Hydrographic and water quality data from main inlet (site C) and the outlet.

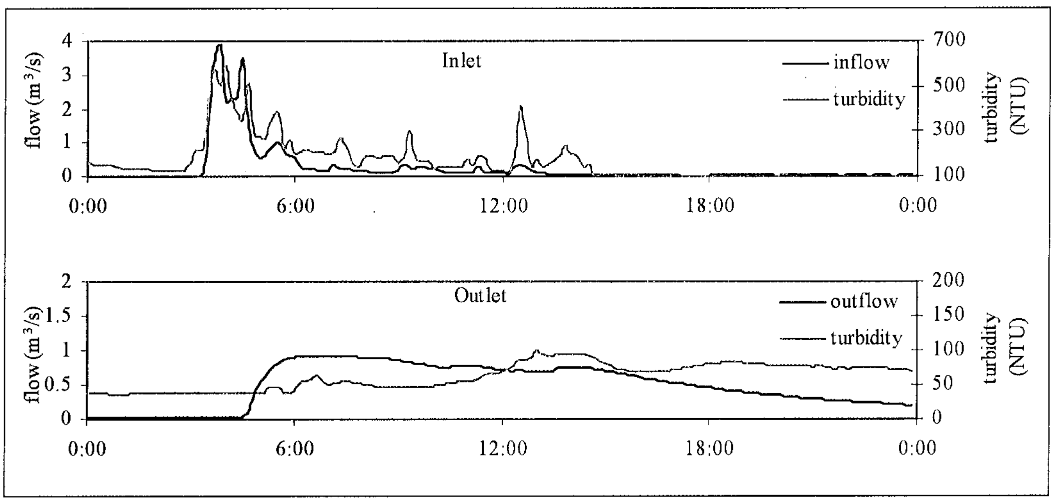

Figure 5.4 Synchronised turbidity and flow data for event on 11/4/1996 at the inlet and outlet.

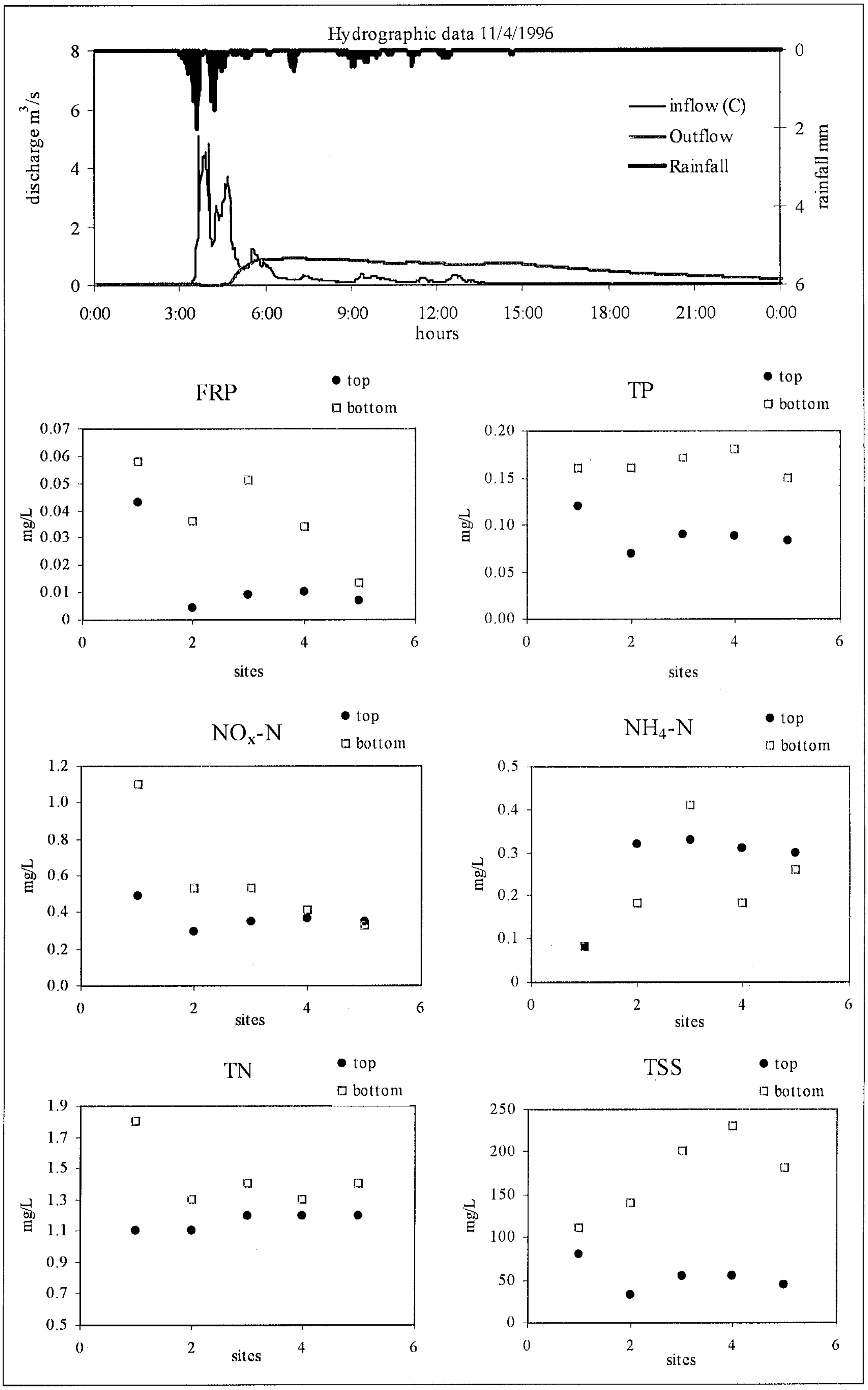

Figure 5.5 Nutrient concentrations collected during event on 11/4/1996

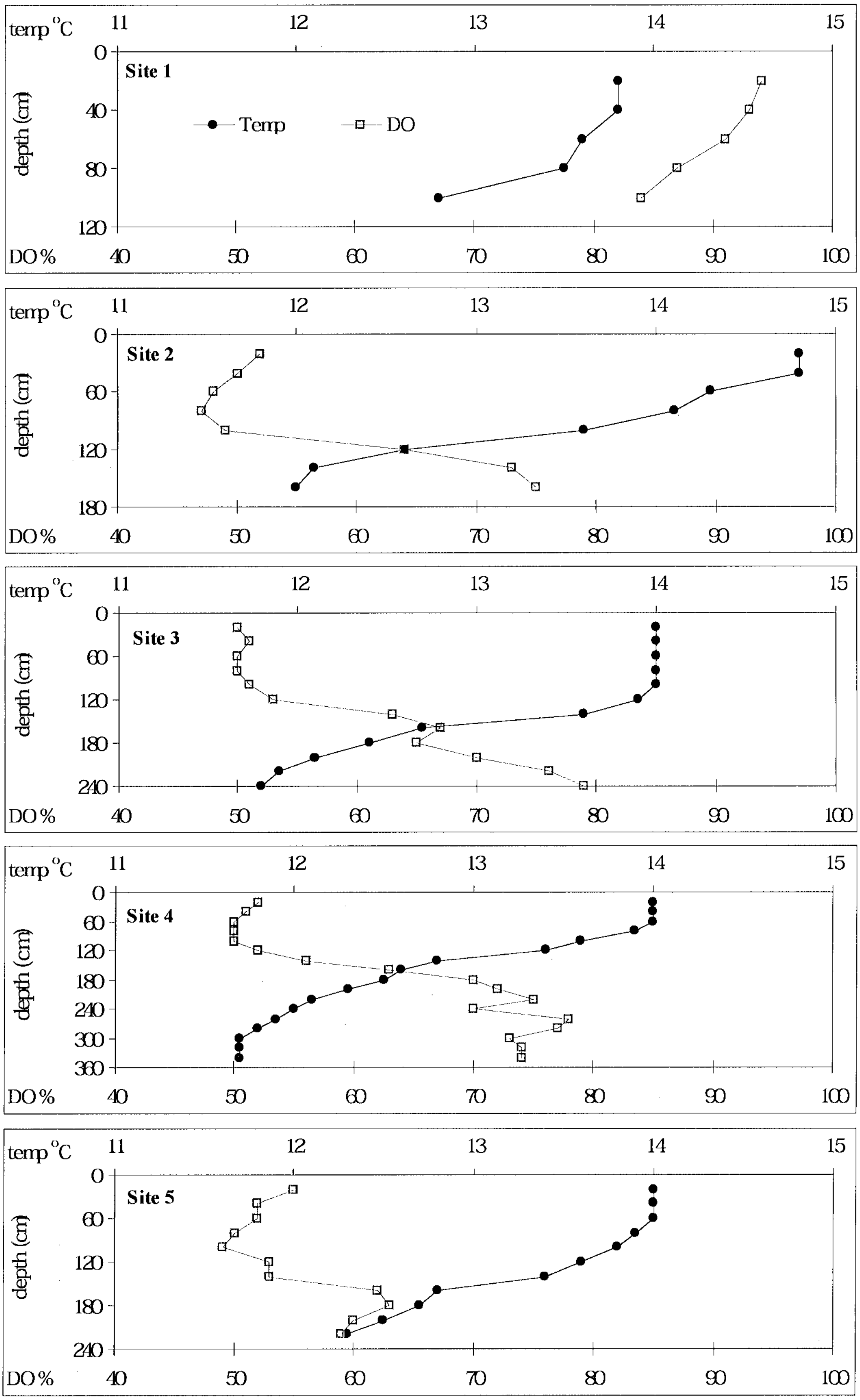

Figure 5.6 Temperature and dissolved oxygen (DO) taken on 11/4/1996 from 5 sampling sites at several depths.

5.5 Trends

Events /low flow

The data were divided into two groups; events and low flow. Low flow was defined as samples taken at least four days after an event while the event samples were taken during the recession of events, except on one occasion (11/4/1996) when samples were taken during the middle of the event. Concentrations of TSS, TP, TN, FRP, NH_4-N, NO_x-N, BOD and chlorophyll from the top and the bottom sampling sites were averaged over the two periods (Table 5.3).

For each site, both the top and bottom FRP concentrations were higher during event periods than low flow periods. During low flow conditions, FRP concentrations were higher at the bottom of the lake compared with at the top of the lake, particularly at sites 3, 4 and 5. Due to limited oxygen present in the water column below 2 m, higher FRP concentrations observed in the bottom water samples are indicative of sediment reduction processes. During events, the bottom concentrations of FRP were also higher at sites 2, 3 and 4. This may be indicative of lake bottom resuspension and is also supported by TSS data. TP showed similar patterns to those of FRP. Concentrations of TP were generally higher during events than during low flow conditions at the top layer of the lake, but the pattern was variable at the bottom of the lake. The relationship between TP concentrations at the top and the bottom during high and low flows is similar to that of FRP concentrations.

Ammonia concentrations were higher during events for samples from the top layer, with samples at the bottom being more variable. Sites 3 and 4 have relatively high concentrations of ammonia during low flow conditions, which may be attributed to denitrification processes.

Average nitrate concentrations were higher during events than during low flows, for each site and for top and bottom samples. Concentrations were higher at the top than the bottom of the lake at sites 3 and 4 during low flow conditions, a situation that could be indicative of denitrification in the hypolimnion. Sites 3 and 4 were also slightly lower both during events and low flow conditions. During event periods the relative concentrations of top and bottom samples varied between sites.

At the top of the lake, total nitrogen concentrations were typically lower during dry conditions than during events. Concentrations at the bottom showed a similar trend except at sites 3 and 4 where during low flows concentrations were higher than during events.

Nitrogen and phosphorus concentrations were averaged over all the sites (Figure 5.7 and Figure 5.8), and the patterns are similar to those mentioned above. The most notable difference being for ammonia which was highest at the bottom of the lake during low flow conditions.

Chlorophyll concentrations were generally higher during low flow periods than during events. This was evident for samples taken at both the top and the bottom layers of the lake. Chlorophyll concentrations were typically higher at the top of the lake than at the bottom during both high and low flow conditions. These patterns are possibly related to the growth of algae during low flows and preferentially at the surface.

BOD concentrations were found to be variable aerially and vertically and between low flow and event periods.

Table 5.3 Average top (T) and bottom (B) nutrients for low flow and event periods from each sites(1-5).

	Low flow									
	1T	1B	2T	2B	3T	3B	4T	4B	5T	5B
FRP (µg/L)	6	5	4	4	5	9	4	8	6	7
TP (mg/L)	0.08	0.09	0.06	0.07	0.07	0.10	0.06	0.11	0.06	0.08
NH_4-N (mg/L)	0.12	0.13	0.10	0.15	0.11	1.10	0.10	1.11	0.11	0.42
NO_x-N (mg/L)	0.16	0.16	0.18	0.18	0.38	0.07	0.19	0.07	0.18	0.12
TN (mg/L)	1.03	1.07	0.93	0.98	0.93	1.82	0.92	1.60	0.96	1.18
TSS (mg/L)	31	32	19	26	18	38	18	32	20	33
BOD (mg/L)	3.1	2.8	2.7	2.0	2.3	4.5	2.4	3.7	2.2	1.7
Chlorophyll (µg/L)	26	23	20	18	20	11	20	11	19	14
	Event									
	1T	1B	2T	2B	3T	3B	4T	4B	5T	5B
FRP (µg/L)	13	22	7	11	8	12	9	12	9	9
TP (mg/L)	0.090	0.090	0.070	0.080	0.070	0.12	0.070	0.090	0.070	0.080
NH_4-N (mg/L)	0.19	0.20	0.19	0.22	0.20	0.47	0.19	0.50	0.20	0.25
NO_x-N (mg/L)	0.45	0.56	0.34	0.40	0.41	0.33	0.40	0.33	0.39	0.38
TN (mg/L)	1.31	1.42	1.19	1.19	1.20	1.49	1.21	1.44	1.22	1.26
TSS (mg/L)	46	52	31	42	31	89	29	60	28	57
BOD (mg/L)	2.9	2.7	2.6	1.8	2.1	2.4	2.4	2.6	2.0	2.0
Chlorophyll (µg/L)	8	8	13	9	13	8	14	6	11	6

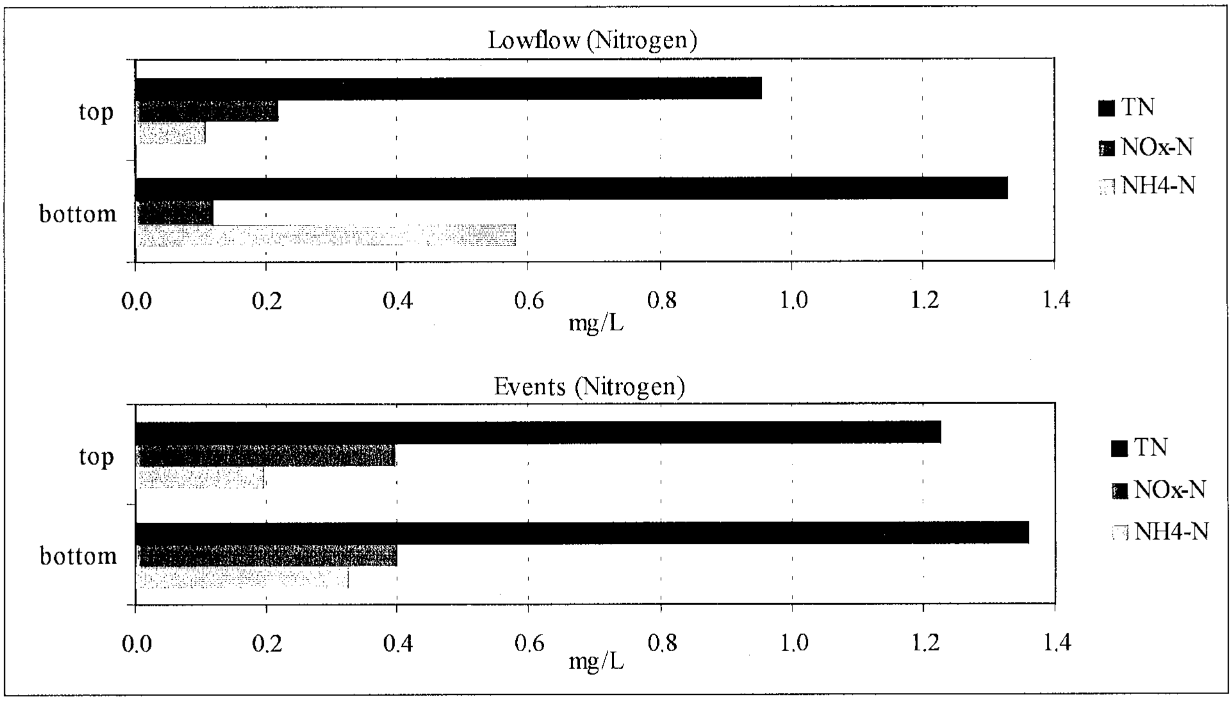

Figure 5.7 Differences between average nitrogen concentrations for low flow and event periods (sites 1-5) and differences between top and bottom concentrations.

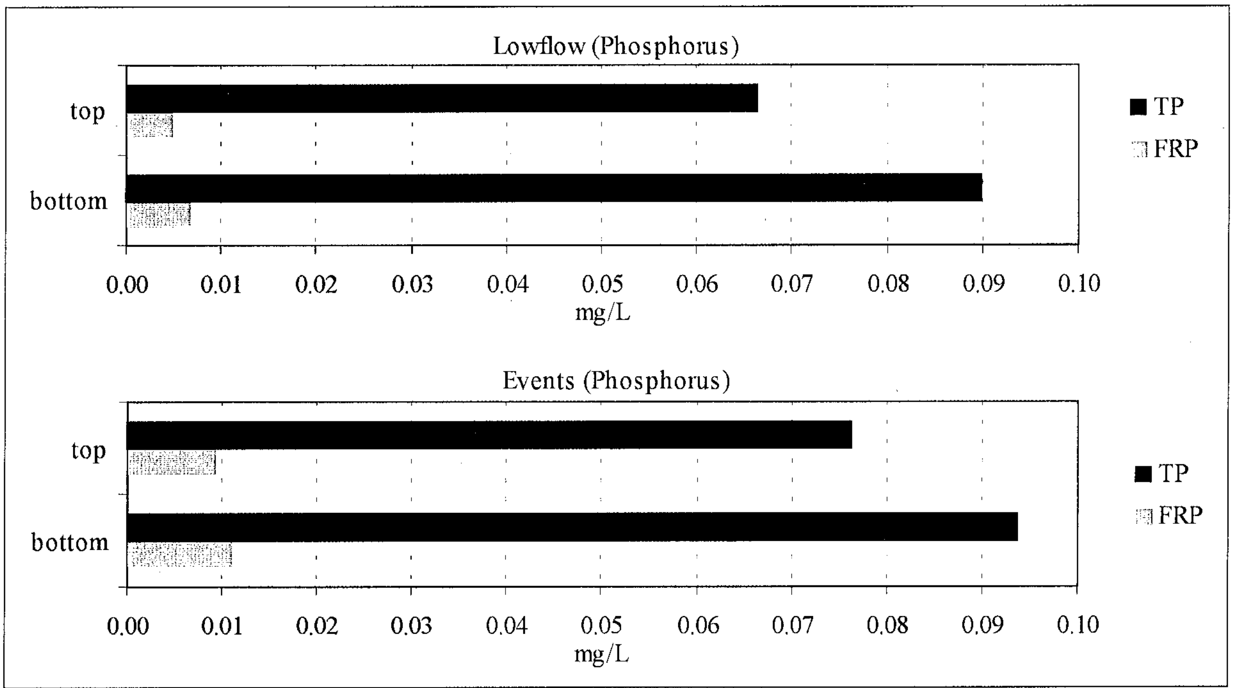

Figure 5.8 Differences between average phosphorus concentrations for low flow and event periods (sites 1-5) and differences between top and bottom concentrations.

Seasonal Differences

Seasonal differences can be observed in the data. The records was roughly divided into four seasons ranging from 30-90 days, roughly representing warm-dry/stormy conditions, autumn rainfall, cool and dry periods and wet periods (see Section 5.2). Nutrient concentrations at the top and the bottom of the lake from all the sites were averaged over each period (Figure 5.9). These results show a pattern between wet and dry periods and between top and bottom layers of the lake.

FRP & TP

Higher TP and FRP concentrations occur in the Autumn Rainfall and Cool Wet periods because of increased runoff. High TP and FRP concentrations in the hypolimnion in the Autumn Rainfall period suggest a storm inflow has plunged into this zone rather than fully mixing. Temperature stratification, density differences and event intensity are the likely cause of this hydraulic behaviour. Moderately higher FRP and TP concentrations in the hypolimnion during warmer periods (JFM & NDJ) are likely to be the result of release from sediments under stratified conditions.

TN, NH_4-N, NO_x-N.

TN has a broadly similar pattern to TP, although it is not as strongly influenced by event inflows in the Autumn Rainfall period. High TN concentrations in the hypolimnion during the warmer periods (JFM & NDJ) are very strongly influenced by NH_4-N concentrations and are likely to be the result of release from the sediments under stratified conditions. Seasonal patterns in NO_x-N concentrations show peaks in the Autumn Rainfall and Cool Wet periods, most probably because of increased concentrations in runoff during these wetter periods. Concentrations of NO_x-N in the warmer periods (JFM & NDJ) are the reverse of NH_4-N, with NO_x-N concentrations in the hypolimnion being low. This is likely to be due to the increased denitrification activity in the sediments during periods of stratification and low DO.

TSS

The pattern of higher TSS concentrations in the Autumn Rainfall and Cold Wet periods is likely to be the result of increased runoff. In particular, the higher concentrations in the hypolimnion in the Autumn Rainfall period suggests that a storm event inflow plunged into this zone, rather than behaving as a plug flow. The increased TSS concentrations in the hypolimnion during this inflow event could be due to both the influent load and the potential disturbance of the in-situ sediments. The reason for the higher TSS concentration in the hypolimnion during other periods is not clear. However the lake does support a considerable carp population and bioturbation by these animals may be an explanation. Another possibility may be related to sampling. As the bed is highly organic a flocculant surface layer may exist, which may have been included in the near bed samples.

BOD

There is no major temporal pattern in BOD concentrations in the epilimnion. However there are increased BOD concentrations in the hypolimnion during the warmer periods (JFM & NDJ). This probably reflects an increase in nitrification as a response to elevated NH_4-N concentrations.

Chlorophyll

Chlorophyll concentrations were generally high and indicative of enrichment. Concentrations in the epilimnion were higher than in the hypolimnion under all conditions, except the autumn rainfall period. A consistent difference between the epilimnion and hypolimnion concentrations suggests the phytoplankton present were either motile or able to adjust their buoyancy. In general algae with these abilities tend to occur in enriched environments.

Generalised dissolved oxygen and temperature profiles

Average profiles for dissolved oxygen and temperature were constructed for each site, for low flow conditions during the warm-dry/stormy seasons. The sampling times used were 30/1/96, 14/2/96, 13/3/96, 27/3/96, 16/10/96, 30/10/96, 27/11/96, 12/12/96 and the 6/1/96 (Figure 5.10). For these periods the profiles were reasonably similar, and average values for each depth were used to construct a generalised profile. The individual profiles for sampling times during the recession of events were much more variable and no attempt to average them was made. The average profiles for each site (Figure 5.10) show spatial variation between sites. Sites 3, 4 and 5 were more stratified and dissolved oxygen is zero at depths greater than 2 m.

The low flow DO profiles indicate that, under warm dry conditions, positive DO concentrations can be maintained down to a depth of about 2m. This is consistent with experience elsewhere (eg. Stranger Pond, Canberra) and supports the recommendation that stormwater treatment ponds should not be deeper than 2m.

While DO profiles may be reasonably smooth, temperature profiles may be more complicated. The temperature profiles suggest there may be several thermal, and hence density, layers in the profile. These layers may influence the effectiveness of wind mixing, and influence the hydraulic behaviour of inflows depending on the temperature and discharge of the inflow volume.

Associated data shown in Figure E.9 (Appendix E) suggests that significant DO chemoclines can exist in the absence of a strong thermocline (eg. 23/05/96 - 14/08/96). This suggests that, even at temperatures of around 10^{o} C heterotrophic activity in the sediments could reduce hypolimnion water column DO concentrations. It also indicates the organic nature of the lake sediments.

Site and seasonal variation

All the data including the depth-integrated parameters were averaged for each season and over each depth to show site variation as well as seasonal variation (Figure 5.11 and Figure 5.12). While spatial patterns among the sites are not strong, some differences were evident. For instance, the shallower sites (1 & 2) tend to have higher mean DO concentrations and temperatures, because they are less susceptible to stratification. The inlet sites (1 & 2), but particularly 1 which is on the major inflow catchment, have higher concentrations of FRP and NO_x-N during periods of greatest runoff (Autumn Rainfall and Cool Wet periods). In the Autumn Rainfall period, FRP shows a clear decline from the major inlet (site 1) through sites 3, 4 and 5 towards the outlet. The anaerobic activity in the sediments during the warmer periods (JFM & NDJ), which is reflected in increased NH_4-N at sites 3, 4 and 5, is also reflected in low pH values at these sites for that period. The reduced pH may be the result of increased CO_2 being released from the sediments into the water column.

The seasonally averaged Chlorophyll data appear to show a strong temporal trend in phytoplankton biomass that is not strictly seasonal. High Chlorophyll concentrations are evident in the initial warm period (JFM), but appear to be washed out of the system by the high runoff event which occurred in the Autumn Rainfall period (11/04/96). The daily flow for 11/04/96 was 28.2 ML/d, which is approximately half the lake volume (at normal water level), and Chlorophyll concentrations were reduced by about half. Chlorophyll concentrations steadily build up over the remaining sample period with phytoplankton growth rates apparently independent of season or temperature. Subsequent inflows were not of sufficient volume to cause significant wash out of phytoplankton.

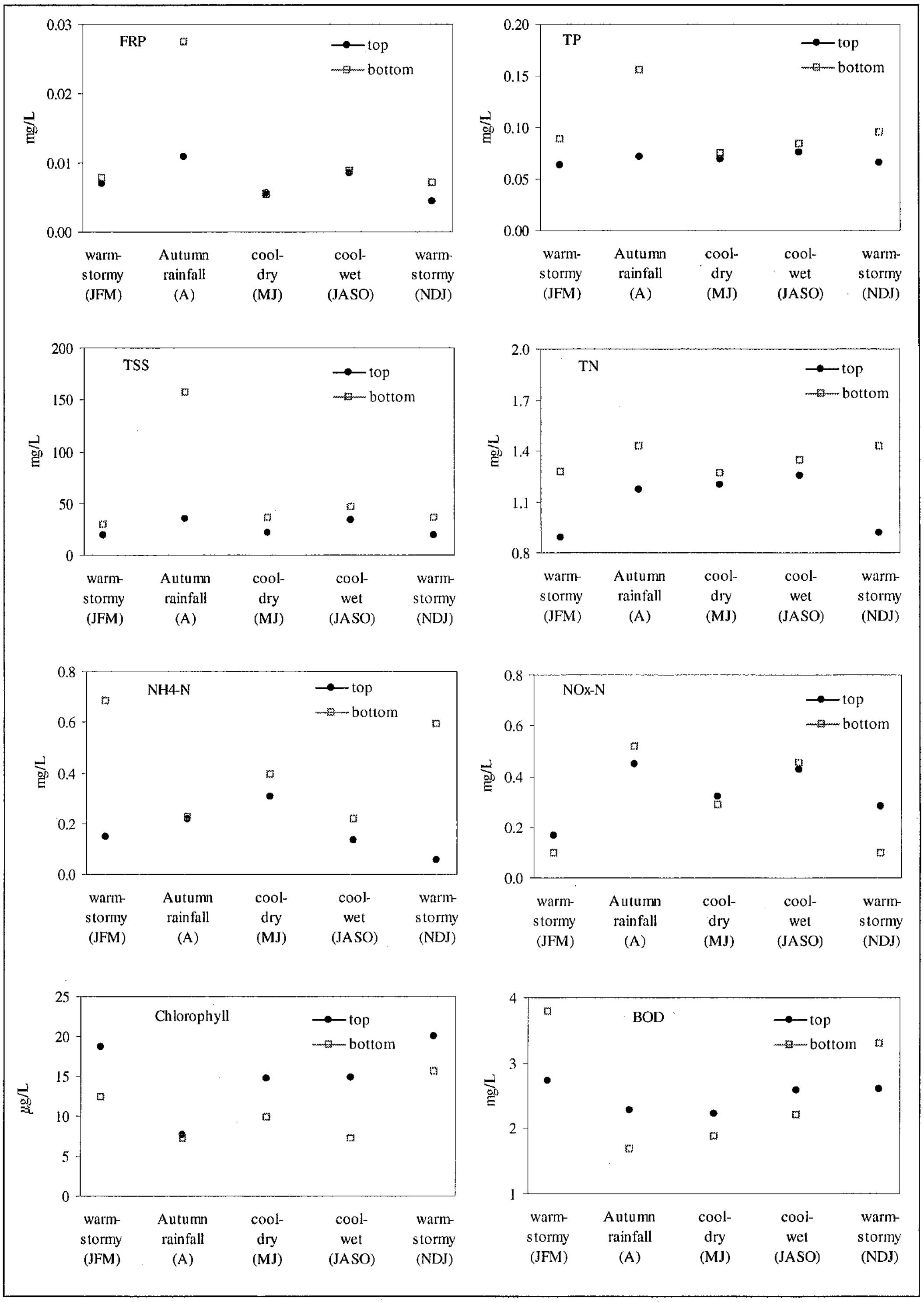

Figure 5.9 Average seasonal nutrient concentrations

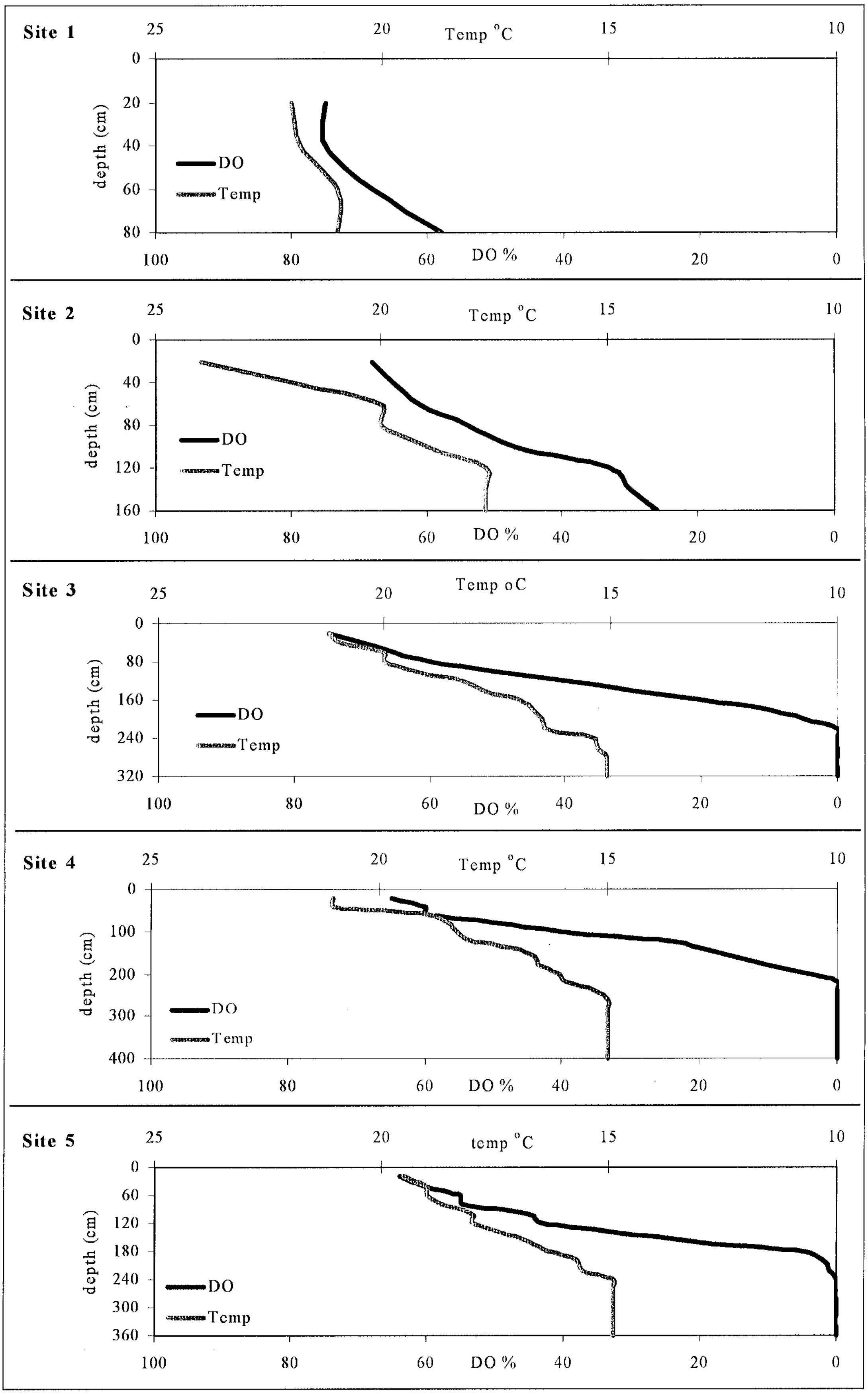

Figure 5.10 Low flow average dissolved oxygen profiles from the warm dry/stormy period.

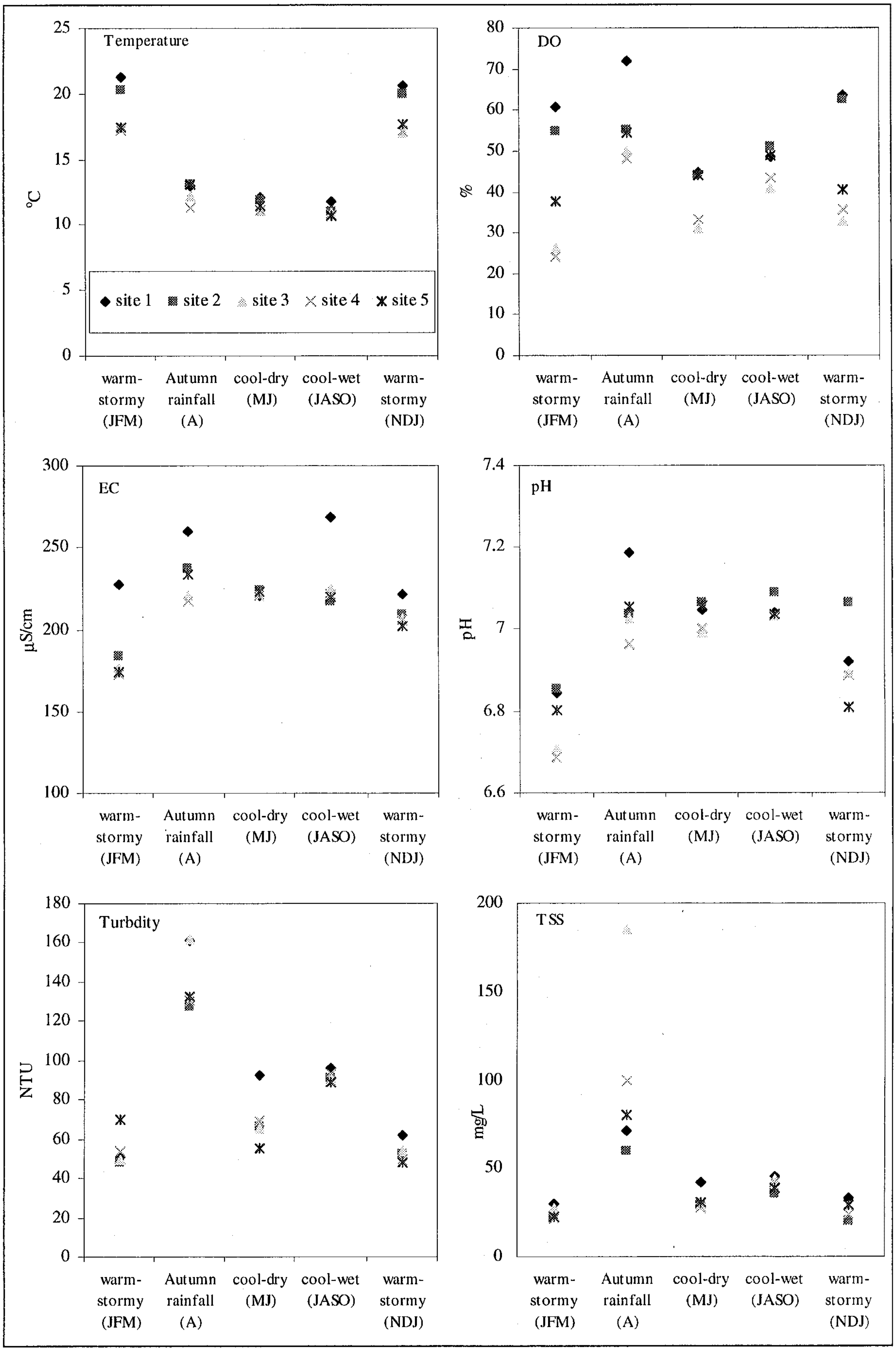

Figure 5.11 Seasonal averages, showing differences between sites.

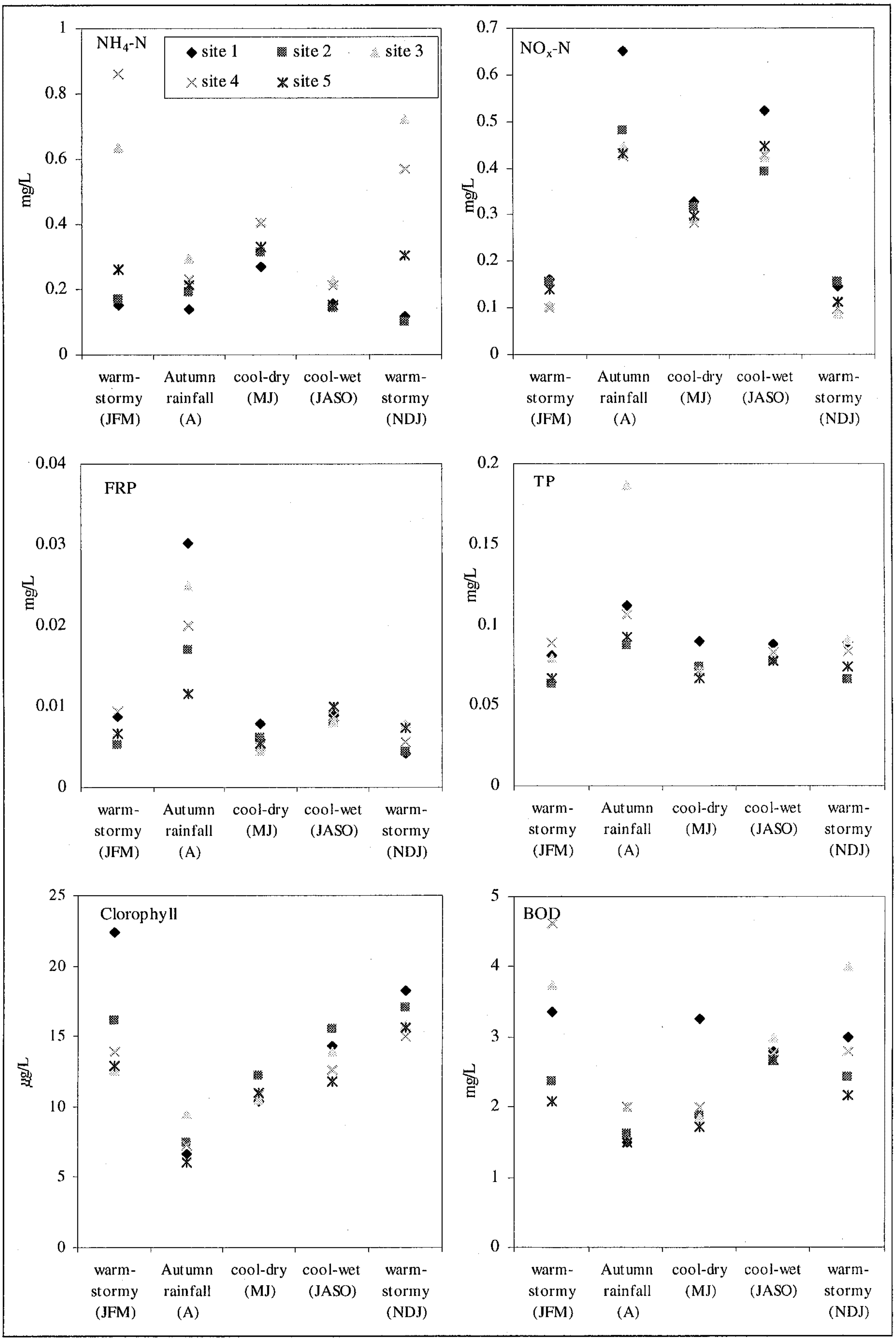

Figure 5.12 Seasonal averages, showing differences between sites

5.6 Major ions

Samples collected from the 5 sites within the lake on the 7/5/1996 were analysed for major ion content (see Table 5.4). The main purpose of collecting this data was for the CRCFE pond project in Canberra (Stranger Pond). Without any information on the quality of the groundwater below Blackburn Lake it is difficult to interpret these results.

5.7 Conclusions

The results of the in-pond water quality monitoring have allowed a number of physicochemical and biological processes occurring within the lake to be characterised. While some spatial variation occurs within the lake, most of the important patterns relate to vertical variations within the profile, hydraulic behaviour of inflows and seasonal temporal patterns. The in-pond water quality data clearly identify vertical stratification to be an important feature of pond behaviour. The development of vertical stratification influences both processes during events and the inter-event periods. The following points summarise the data from the in-pond monitoring program:

- Stormwater management ponds deeper than 2 m can stratify very strongly during warm periods
- Stratification can influence the hydraulic behaviour of ponds during inflow events to either increase or decrease retention period
- The thermal stratification in shallow stormwater management systems remains a significant design and research issue
- During warm periods soluble nutrients can either be released from the sediments (NH4-N, FRP) or consumed by the sediments (NOx-N). These transformations are microbially mediated processes and their activity is broadly reflected in other variables (eg. increased BOD due to nitrification, decreased pH because of increased CO2 concentrations due to microbial respiration).

Table 5.4 Major ions from five sites within Blackburn Lake on 7/5/1996.

Site	Chloride (Cl) (mg/L)	Sulphate (SO_4) mg/L	Calcium (Ca) mg/L	Sodium (Na) mg/L	Magnesium (Mg) mg/L	Potassium (K) mg/L
1T	28	13	17	20	4.7	2.8
1B	28	12	17	20	4.7	2.8
2T	30	14	17	20	5.1	2.9
2B	30	14	18	20	5.2	2.9
3T	30	14	18	21	5.3	2.9
3B	21	10	15	14	4	2.5
4T	30	13	18	21	5.1	2.9
4B	18	9	14	13	3.6	2.4
5T	31	14	18	21	5.3	2.9
5B	30	14	18	20	5.2	2.8

6 Pond performance

This chapter describes the estimates of the TSS, TP and TN loads at the pond inlets and the pond outlet. The estimates were used to determine the pollutant removal efficiency of the pond in 1996 and 1997.

6.1 Outlet load calculations

TSS, TP and TN data were available from monitoring over 43 storm events. The correlations between TSS and turbidity (R^2= 0.65), and between TSS and TP (R^2= 0.45), were reasonably high. As turbidity was recorded continuously these relationships were used to estimate daily TSS and TP loads. The TSS and TP loads could only be calculated using these relationships for 53% of the time, because turbidity data was either missing or erroneous for the other 47% of the time. Loads calculated using turbidity accounted for 72 % of the runoff in 1997 and 45 % of the runoff in 1997.

When turbidity data were not available, the TSS and TP loads were estimated using the relationship between the daily pollutant loads and daily runoff. The relationships were fairly strong as shown by the plots in Figure 6.1. Over the two year period, 121 kg of TP and 58 tonne of TSS were exported from the catchment (Table 6.1 and Table 6.2).

Unlike TSS and TP, the TN load could not be determined using the continuous turbidity record, because the relationship between turbidity and TN was not significant. The TN load could only be determined accurately for events when the automatic sampling occurred. The 43 events sampled accounted for 47% of the storm runoff in 1996 and 2.5% in 1997. Data from these events were used to establish a relationship between event TN load and event runoff (R^2 = 0.98, see section 4.6). This relationship was used to estimate the TN load for the remaining storm events when automatic sampling did not take place. This accounted for 28% and 67% of the total storm runoff in 1996 and 1997 respectively. The TN loads for the low flow periods (remaining 26% of the total runoff) was estimated as the product of runoff and the average dry weather TN concentration.

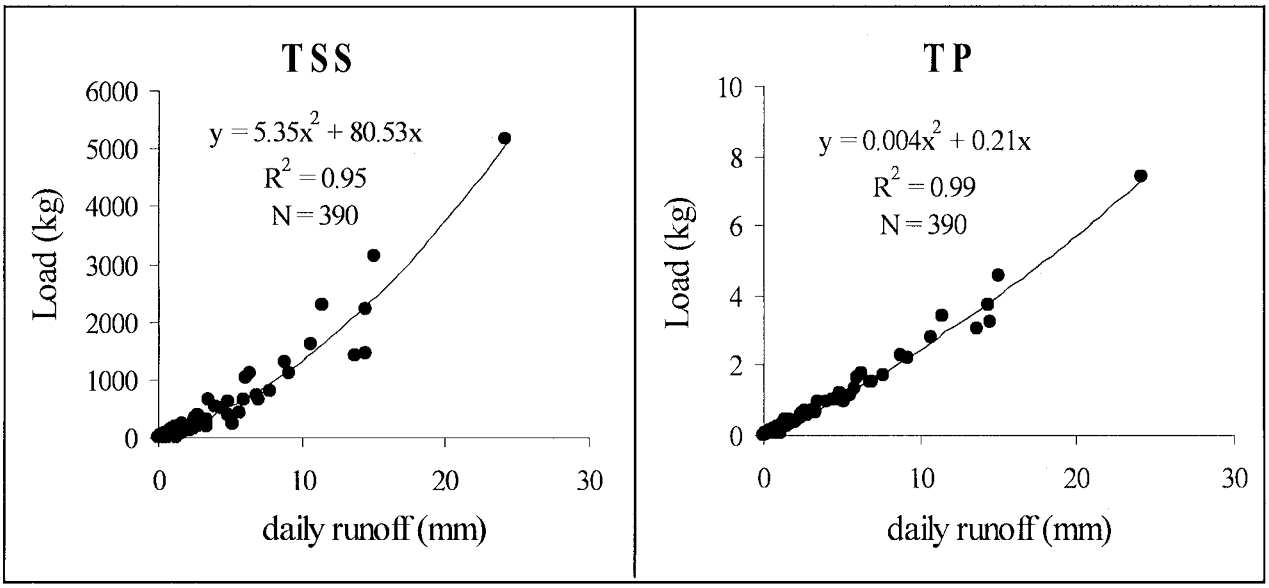

Figure 6.1 Relationship between total daily runoff and total daily TSS and TP load for the outlet.

Table 6.1 Results of outlet TP load calculations for 1996 and 1997 using continuous turbidity data and predictive relationships.

TP		Estimated directly from turbidity relationship	Estimated from daily runoff-load relationship	Total
1996	Runoff (mm)	298	127	425
	Load (kg)	66	24	**90**
1997	Runoff (mm)	73	85	158
	Load (kg)	15	17	**32**

Table 6.2 Results of Outlet TSS load calculations for 1996 and 1997 using continuous turbidity data and predictive relationships.

TSS		Estimated directly from turbidity relationship	Estimated from daily runoff-load relationship	Total
1996	Runoff (mm)	298	127	425
	Load (tonne)	35	11	**46**
1997	Runoff (mm)	73	85	158
	Load (tonne)	5.5	7.6	**13**

Table 6.3 Outlet TN loads estimated using water samples and event runoff and event load relationships

TN		Estimated directly from event samples	Estimated from event load versus runoff relationships	Low flow	Total
1996	Runoff (mm)	203	120	102	425
	Load (kg)	711	383	293	**1387**
1997	Runoff (mm)	3.8	106	48	158
	Load (kg)	11	339	138	**488**

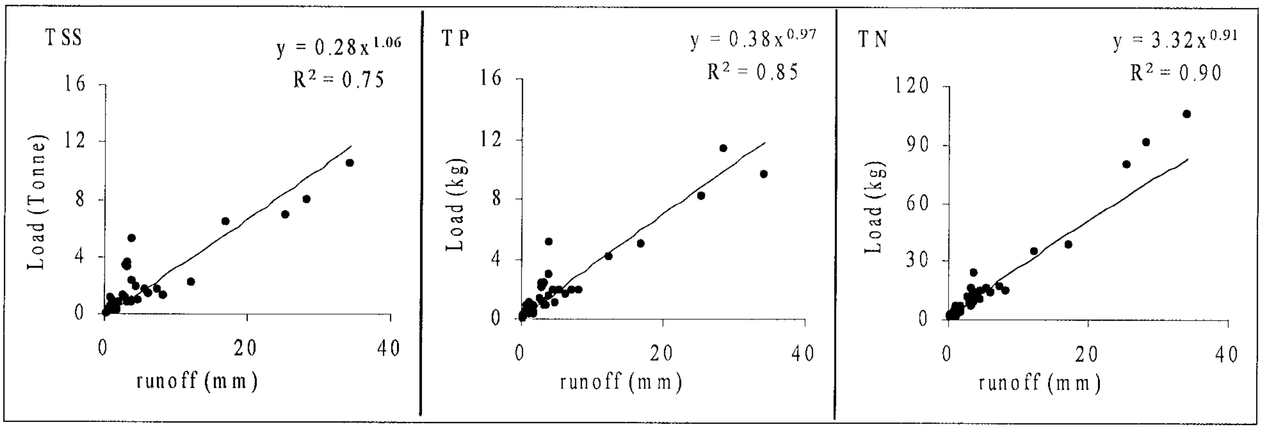

Figure 6.2 Relationships between event runoff and events loads for main inlet (C), TSS, TP and TN.

6.2 Inlet load calculations

Loads from main inlet (Site C)

Long term estimation of loads entering Blackburn Lake through the main inlet could be not be determined using the continuous turbidity record, because the relationships between turbidity and TSS, TP and TN were poor (see Section 4.7). The pollutant load could be accurately estimated for the 57 storms when automatic sampling was carried out. This accounted for 43% of the total runoff in 1996 and 7% of the total runoff in 1997. Figure 6.2 shows the relationships between the sampled event loads and event runoff. The relationships are reasonably good and were used to estimate the pollutant loads for the unsampled storm events. These events accounted for a further 42% and 74% of the total runoff volume in 1996 and 1997 respectively. The pollutant loads for the remaining time (low flow periods, 15% in 1996 and 18% in 1997) were estimated as the product of runoff and the dry weather TN concentration.

Loads from sub catchments

The pollutant loads from the other sub catchments could not be determined directly because there was insufficient event water quality data at the sites. As these catchments were considerably smaller than catchment C, the loads at these inlets were estimated as the ratio of runoff at that inlet compared to site C, multiplied by the loads at site C. Applying this method, total loads from the sub catchments were 26% of the total annual load from site C (Table 6.5).

Table 6.4 Results of load calculations for site C

Site C		SAMPLED STORM EVENTS Loads calculated directly	UNSAMPLED STORM EVENTS Loads estimated from event load vs event runoff relationship	Low Flow	Total
1996	Runoff (mm)	200	193	63	456
	TSS load (tonne)	62	59	2.0	**123**
	TP load (kg)	70	70	14	**154**
	TN load (kg)	591	552	185	**1328**
1997	Runoff (mm)	14	149	37	200
	TSS load (tonne)	12	44	0.91	**57**
	TP load (kg)	11	55	6.6	**73**
	TN load (kg)	66	446	86	**598**

Table 6.5 TSS, TP and TN annual loads from the sub-inlets (A, B, D, E, and S)

Site	% of C	Total load 1996			Total load 1997		
		TSS (tonne)	TP (kg)	TN (kg)	TSS (tonne)	TP (kg)	TN (kg)
C	100	123	154	1328	57	73	598
A	1	1.3	1.6	14	0.6	0.8	6.4
B	8	9.9	12	107	4.6	5.8	48
D	10	13	16	135	5.4	7.4	61
E	2	2.2	2.8	24	1.0	1.3	11
F	5	5.9	7.5	64	2.8	3.5	29
Total		**155**	**194**	**1672**	**71**	**92**	**753**

6.3 Long term efficiency of Blackburn Lake

The sediment trap efficiency (STE) of Blackburn Lake has been determined using total loads of TSS, TP and TN for a two-year period (1996 - 1997). Total annual loads show that on average the lake traps 74 % of TSS loads, 57 % of the TP loads and 23 % of TN loads (Table 6.6). The trapping efficiency of the pond was slightly better in 1997 particularly for TN.

Table 6.6 Sediment Trap Efficiency (STE) of Blackburn Lake. Total loads entering and leaving Blackburn Lake for 1996 and 1997.

Sediment trapping efficiency (STE)		TSS			TP			TN		
		tonne	kg	kg/ha/yr	tonne	kg	kg/ha/yr	tonne	kg	kg/ha/yr
1996	In	155	154660	528	0.20	195	0.67	1.8	1672	5.7
	Out	46	45520	155	0.09	90	0.31	1.4	1387	4.7
	STE %	**71**			**54**			**17**		
1997	In	71	71271	243	0.092	92	0.31	0.75	753	2.6
	Out	13	13047	45	0.032	32	0.11	0.49	488	1.7
	STE %	**82**			**65**			**35**		
Total	In	226	225931	386	0.29	287	0.49	2.4	2425	4.1
	Out	59	58567	100	0.12	122	0.21	1.9	1875	3.2
	STE %	**74**			**57**			**23**		

7 Conclusions

The objectives of this project were to assess the performance of Blackburn Lake as a pollution control pond, and to provide the CRCFE with flow and water quality data to assess pond performance models. To achieve this, two years of intensive flow and water quality data were collected and analysed. A range of water quality variables were measured; some were measured on an event basis while other parameters were measured continuously. Data were collected from the inlets and the outlet of the lake as well as from several locations within the lake.

This report provides a summary of the water quality and flow monitoring program. It presents the methods used for data collection, data processing and outlines the availability of the data record. Much of the data is presented, analysed and interpreted to show relationships and trends that summarise the water quality entering Blackburn Lake, the physico chemical processes within the lake and the water quality leaving the lake.

Estimation of annual pollutant loads entering Blackburn Lake and loads leaving Blackburn Lake indicate that Blackburn Lake traps on average 74% of suspended solids, 57% of total phosphorus and 23% of total nitrogen.

Water quality data collected from within Blackburn Lake showed that the lake is strongly stratified. Chemical reduction reactions such as denitrification were evident.

The data has been copied onto a CD and can be obtained from the CRCCH. The CD contains a file that describes the format of the data. Briefly the data available are:

- Daily rainfall and runoff data for inflows to and outflow from Blackburn Lake
- Event hydrographic and water quality data for 50 storm events collected from the main inlet and the outlet of the lake (data includes: rainfall, discharge, turbidity, EC, temperature and total suspended solids, total phosphorus and total nitrogen).
- Instantaneous logged flow and water quality data for all the monitoring sites for the period of record (data includes: rainfall, discharge, temperature, turbidity, electrical conductivity and TSS, TP and TN).
- Depth integrated water quality data collected from 5 sites within Blackburn Lake every 2 weeks during 1996.

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Appendix A: Derivation of outlet stage - discharge rating

Four equations representing the different hydraulics for the outlet structure were applied to the stage data (Table A.1).

[illegible] onvert stage to discharge

[illegible] iced Equation	Reference
[illegible] $H^{3/2}$	Senturk 1994, p205 C_d is not included, this equation is the upper limit.
[illegible] $[H-.19]^{.5}$	The co-efficient of discharge was assumed to be $C_d = 0.9$
[illegible] $6[H-1.77]^{3/2}+1.276[H-0.19]^{.5}$	Senturk 1994, p244 - 246 $C_d = Q/(2\pi RH^{1.5})$ taken from (USBR)*
[illegible] $[H\ 1.77]^{.5}+1.276[H-0.19]^{.5}$	Senturk 1994, p248 Losses not included.

[illegible] *gn of Small Dams*

Where	**Q**	**the discharge**	**m^3/s**
	H	**height of water above the weir**	**m**
	L	**length of the weir**	**m**
	W	**height of the sides of the weir**	**m**
	g	**gravitational acceleration**	**m/s^2**
	R	**radius of the circular pipe**	**m**
	Cd	**co-efficient of discharge**	

Appendix B: Modelling daily discharge

This appendix presents a description of the rainfall-runoff model used to estimate daily flows for the sub catchments of Blackburn Lake.

Daily rainfall-runoff model

The daily rainfall-runoff model developed for urban catchments, by the CRCCH (see Chiew and McMahon 1998) was used to estimate daily runoff for days when recorded data are not available. The model (Figure B.1) considers the catchment to consist of effective impervious areas (surfaces that are directly connected to the drainage system) and pervious areas (remaining parts of the catchment). All the rain falling onto the effective impervious area becomes runoff after a daily initial loss is satisfied (due to water infilling the surface depressions and pores).

Two storages are used to represent the pervious area. Surface runoff occurs when the storage capacities are exceeded (when saturation occurs). Water from the soil stores recharges a groundwater store when the storage exceeds a certain amount ('field capacity'). Recharge is calculated as a parameter (which mimics the hydraulic conductivity) times the amount that the storage exceeds 'field capacity'. Baseflow from the groundwater store is simulated using a linear recession. Evapotranspiration is dependent upon the soil water levels and the potential rate. The evapotranspiration is satisfied first from the larger store, therefore allowing for some redistribution of water between the two stores.

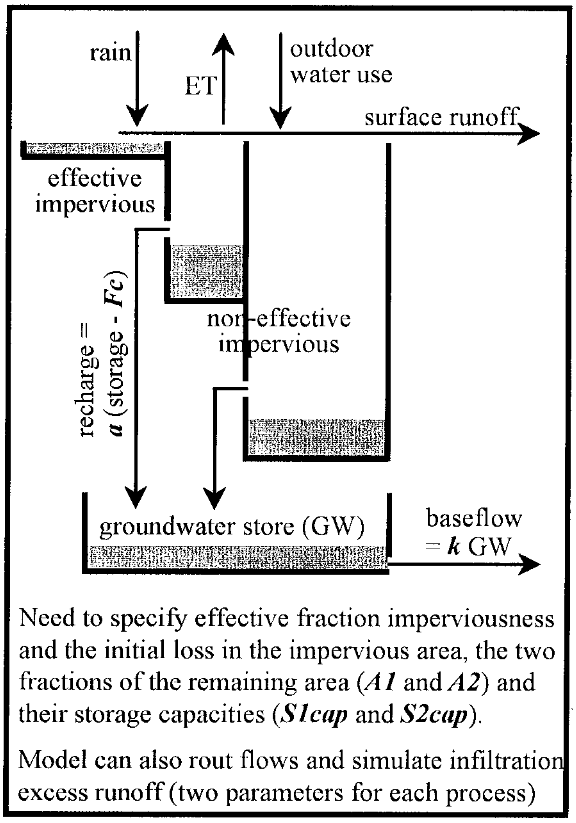

Figure B.1 Structure of daily runoff model

Estimating fraction of effective impervious area

A very large proportion of runoff in urban catchments come from directly connected impervious surfaces (effective impervious area). The key variable for estimating urban runoff is therefore effective impervious area (see Chiew and McMahon 1998). Although areal photographs for Blackburn Lake are available, they cannot be used to accurately determine the fraction of effective impervious area. There are several reasons for this. First, it is sometimes difficult to distinguish the impervious surfaces from the pervious surfaces. Second, some of the impervious surfaces may not be directly connected to the drainage system. Third, some of the drains may be blocked by debris. A separate study of the Blackburn Lake catchment concluded that the fraction of total impervious surface determined from aerial photographs is about two times larger than the actual fraction of effective impervious area (see Smith, 1998).

Here, the fraction of effective impervious area was determined from a plot of event runoff and event rainfall. As runoff from small events is generated only from the effective impervious surfaces, the slope of the runoff-rainfall plot gives an estimate of the fraction effective impervious area, and the intercept of the rainfall axis is an estimate of the initial loss (Figure B.2).

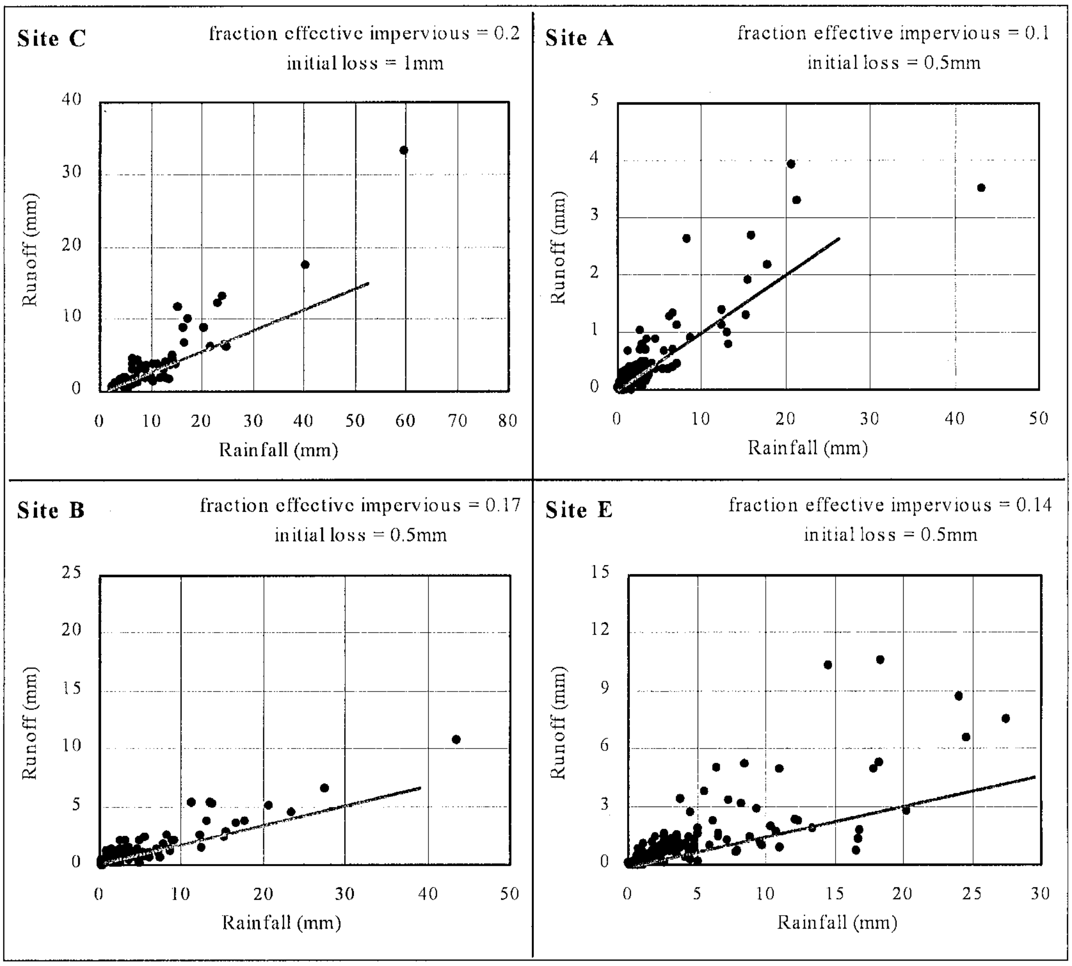

Figure B.2 Rainfall - runoff relationships for events for each site

Determination of pervious area parameters

The catchment models for sites A, B, C and D were calibrated against the available runoff data. An automatic pattern search optimisation routine was used. The parameters were chosen such that the objective function, defined as the sum of squares of the difference between the simulated and recorded flows, was minimised. The optimised parameters were then used to estimate the daily runoff for the days when data were not available.

Table B.1 Rainfall Runoff model parameters

Site	Catchment Area (ha)	Impervious Area Parameter		Pervious area parameter						
		Fraction Impervious	Rainfall threshold	S1cap	S2cap	A1	A2	Fc	a	k
A	6.2	0.10	0.5	139	199	0.17	0.83	140	1	0.10
B	20.8	0.17	0.5	40	100	0.10	0.90	61	0.05	0.05
C	202	0.20	1	44	121	0.61	0.39	27	0	0
D	31	0.14	0.5	139	199	0.17	0.83	140	0.1	0.10
E	5.7	0.14	0.5	139	199	0.17	0.83	140	1	0.10
F	30	0.01	0	139	199	0.17	0.83	140	1	0.10

Simulation of infiltration excess runoff and routing of flows are not required.

Appendix C: Hydrographic and water quality data collected during storm events from the inlet and the outlet of Blackburn Lake

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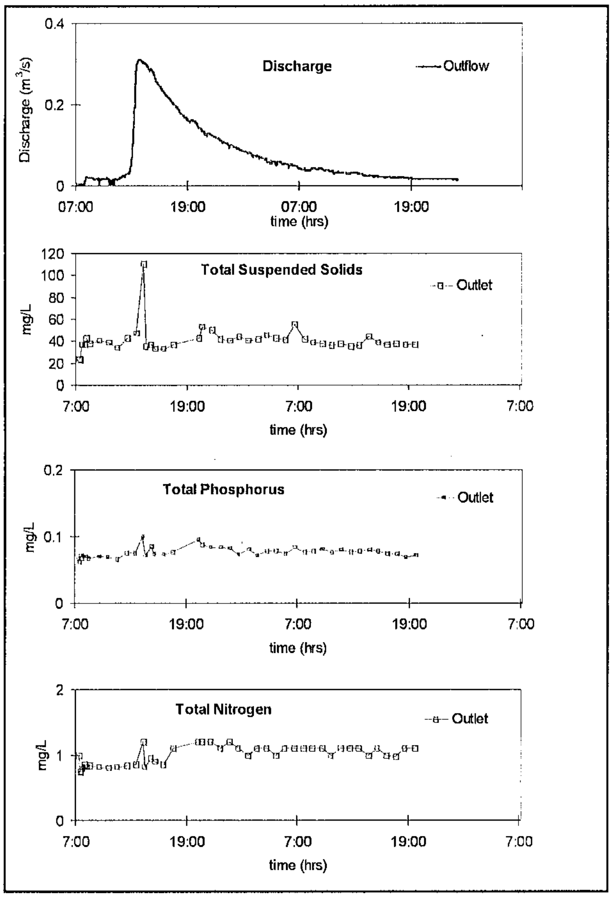

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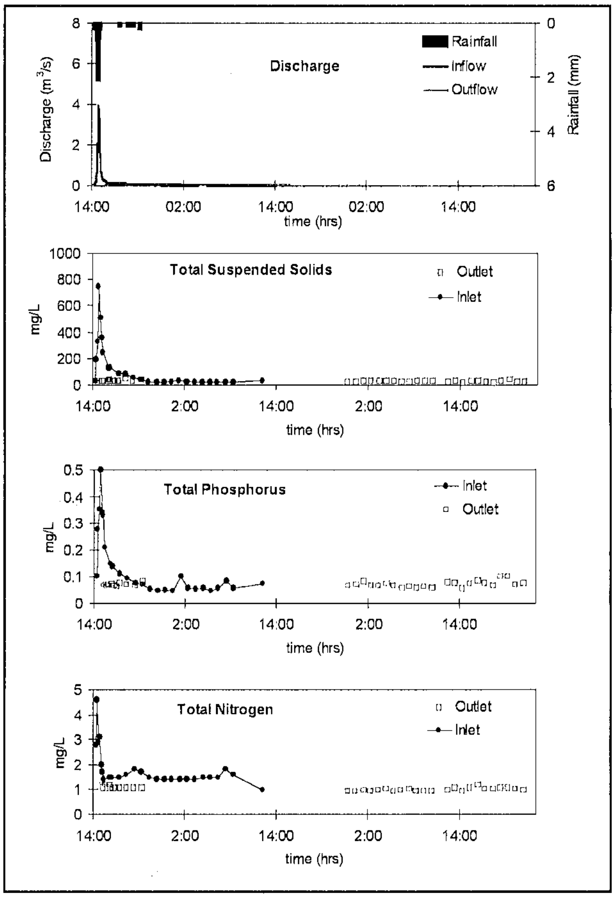

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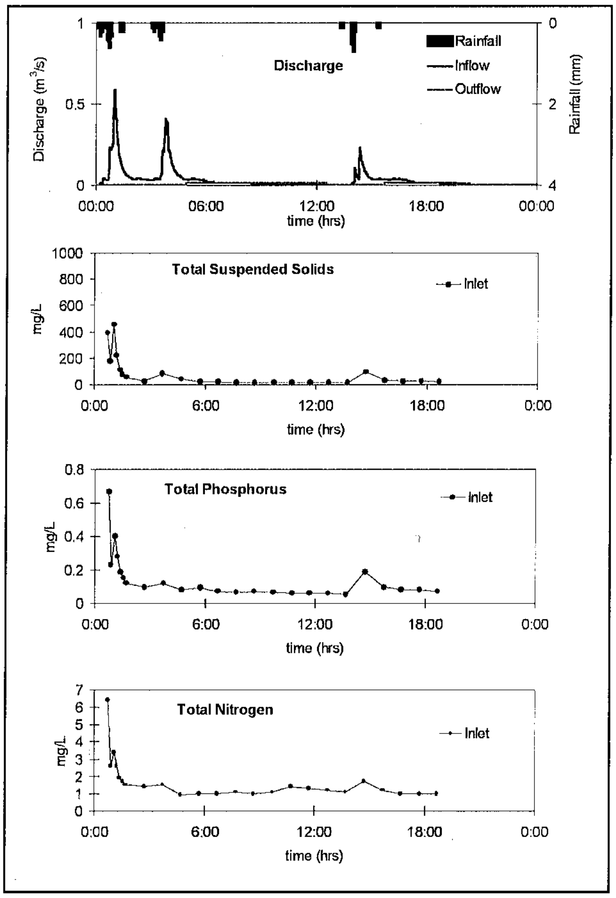

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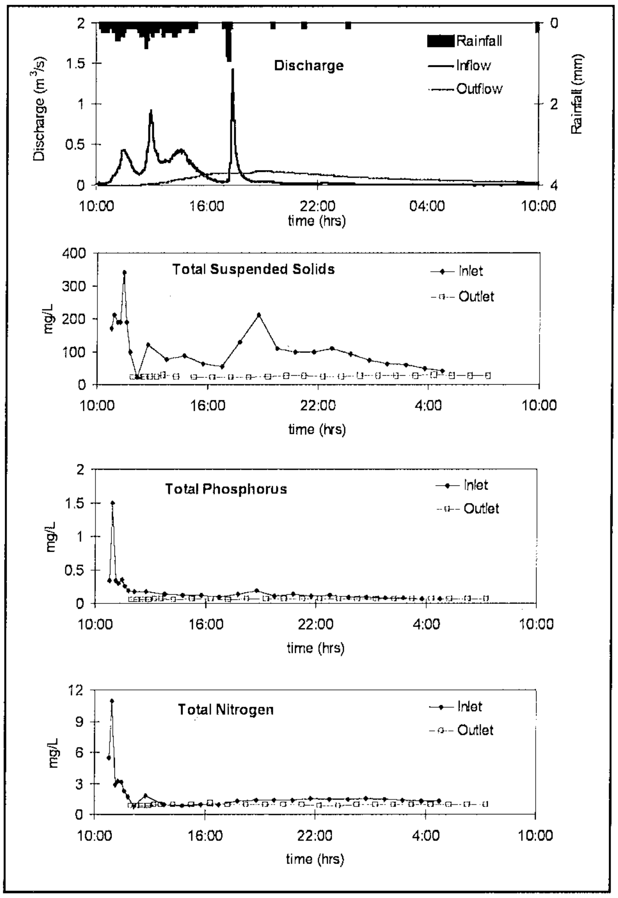

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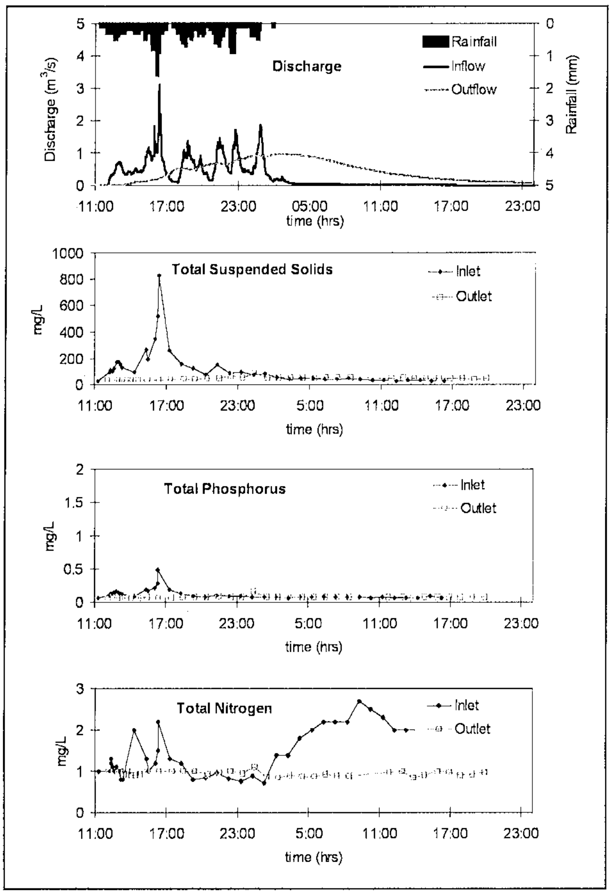

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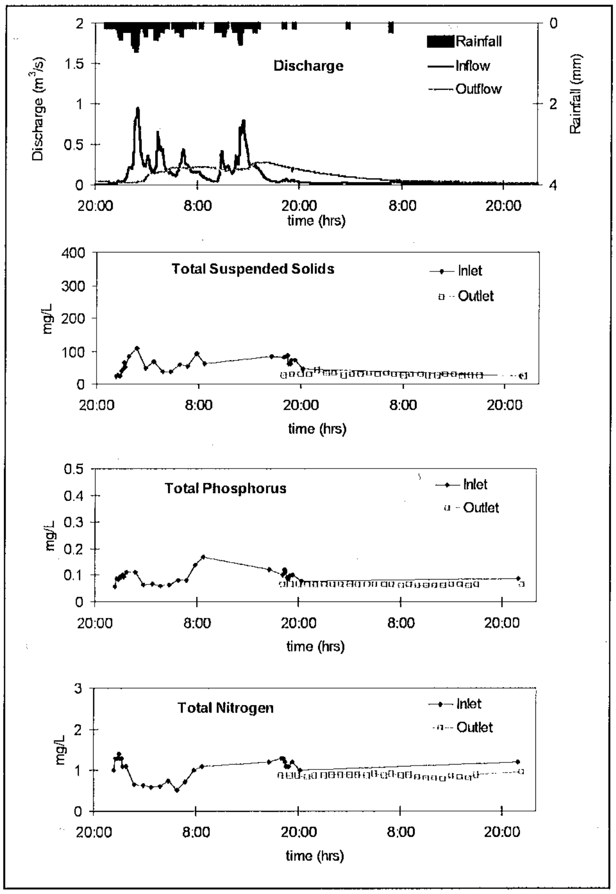

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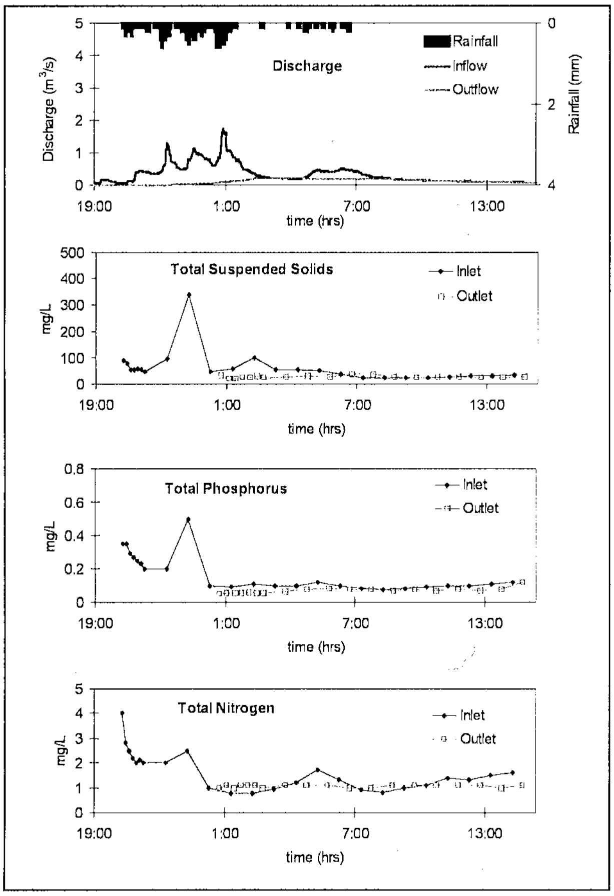

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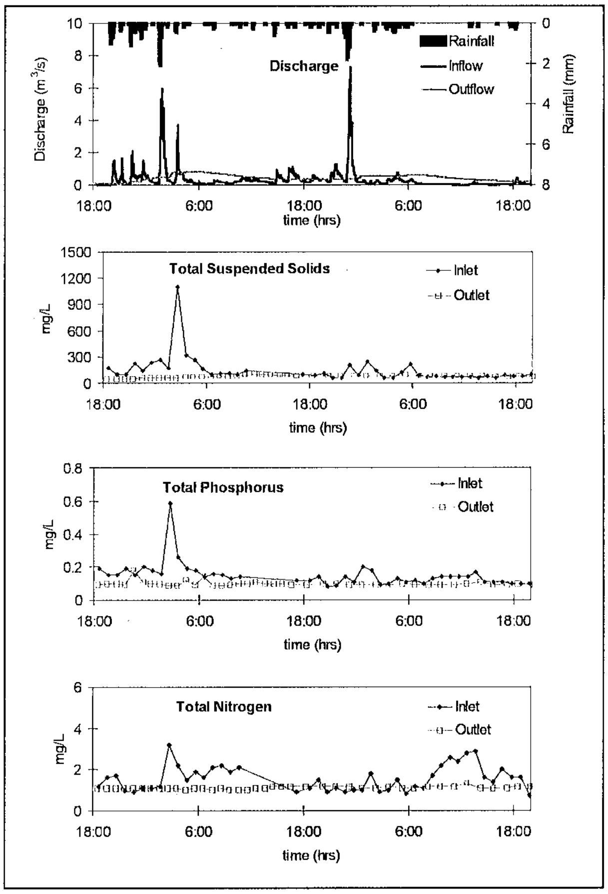

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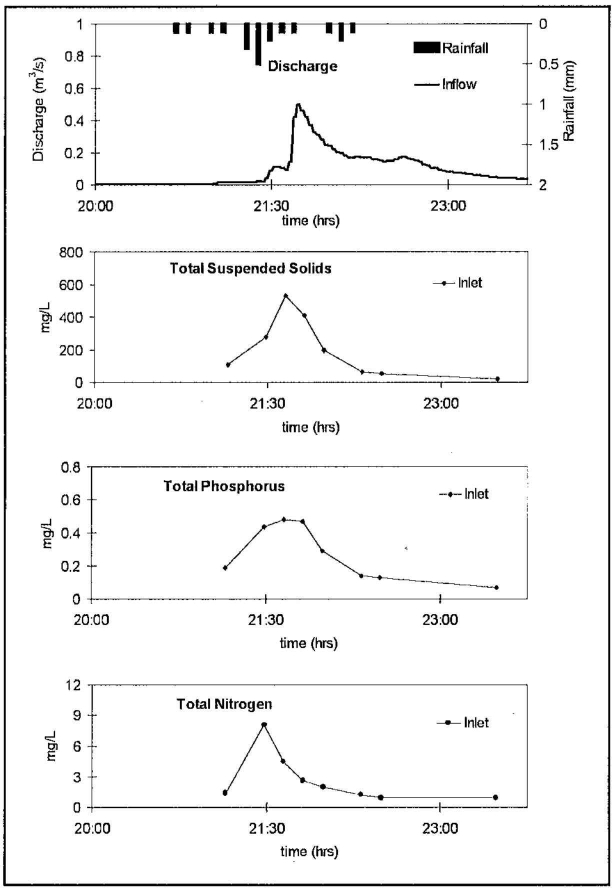

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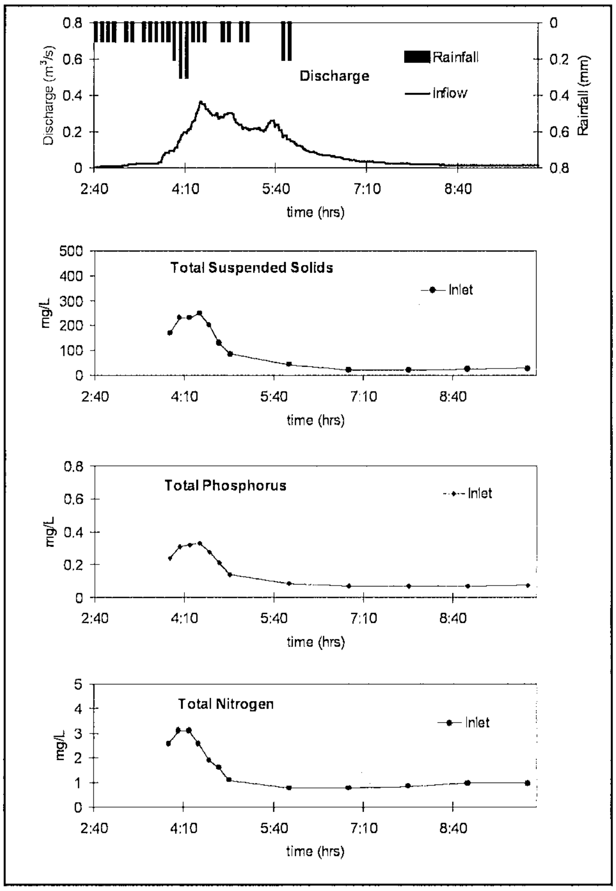

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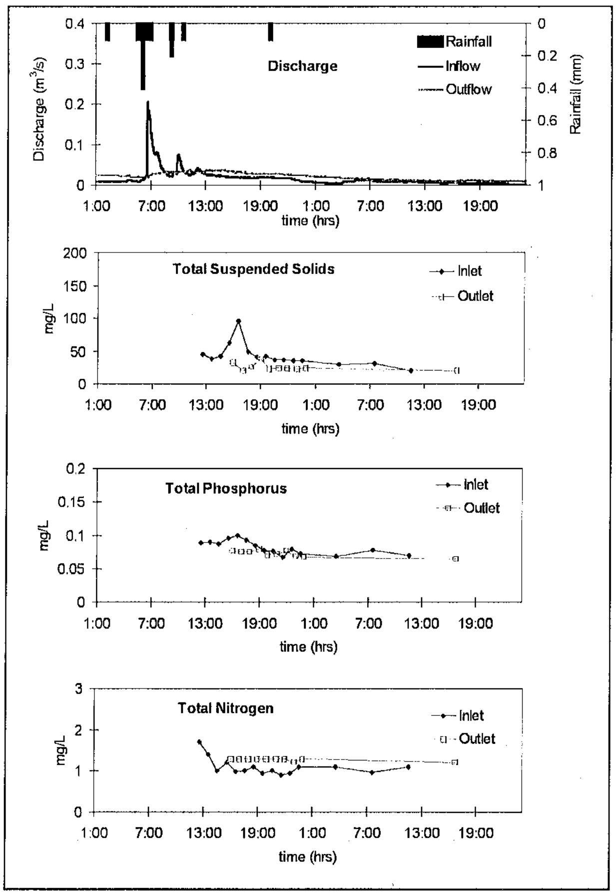

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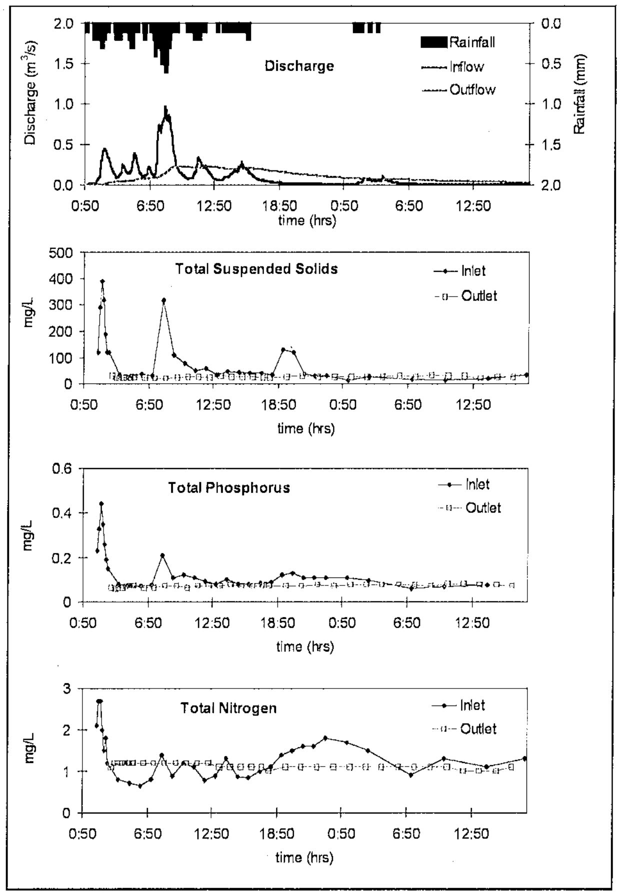

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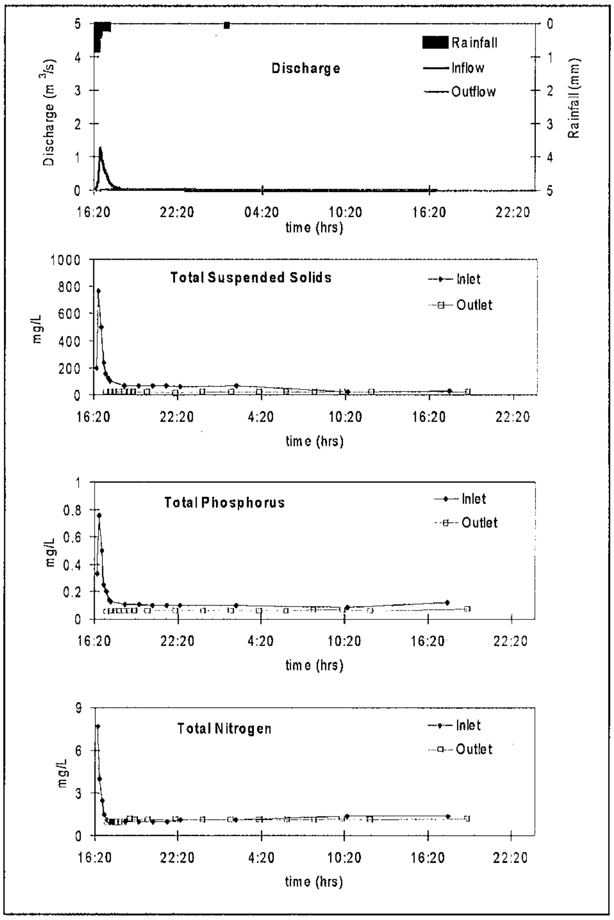

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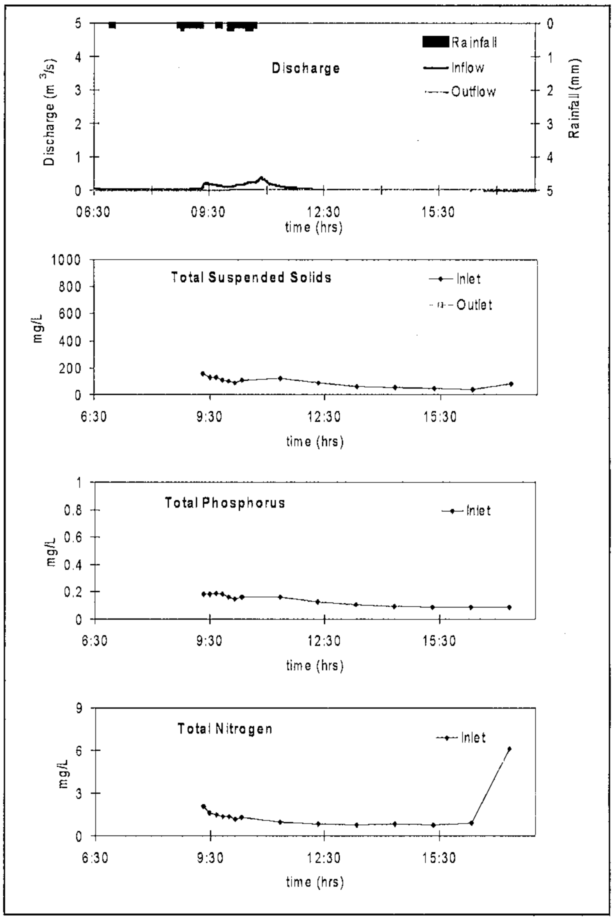

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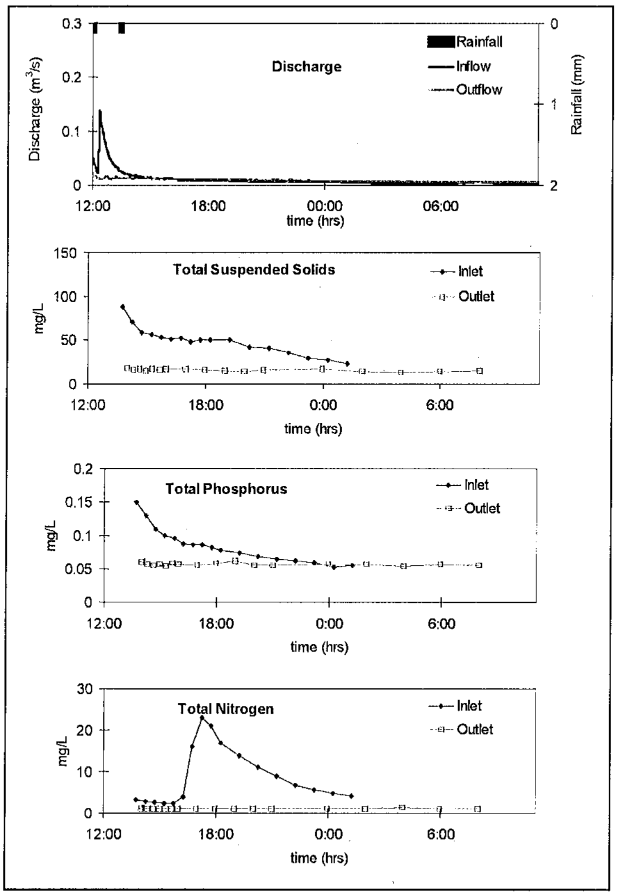

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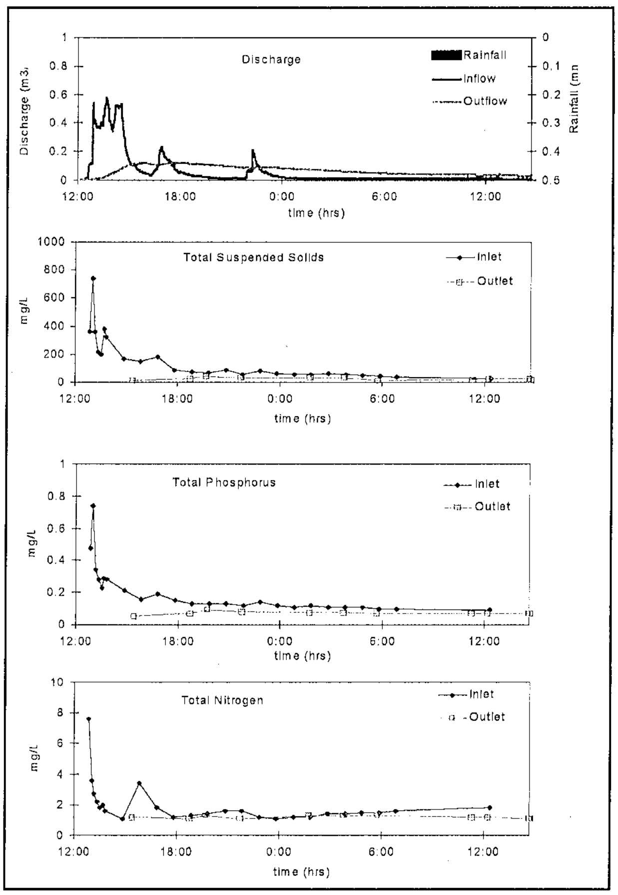

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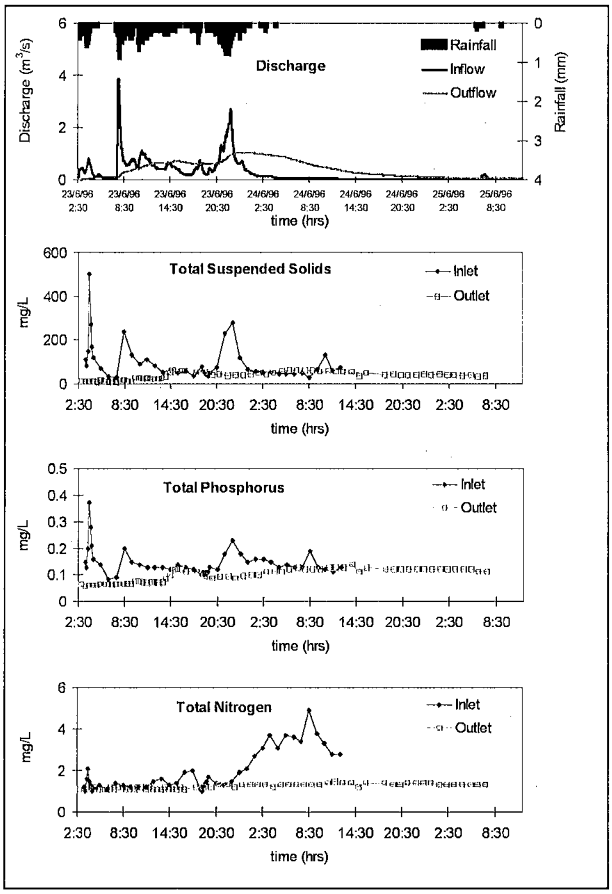

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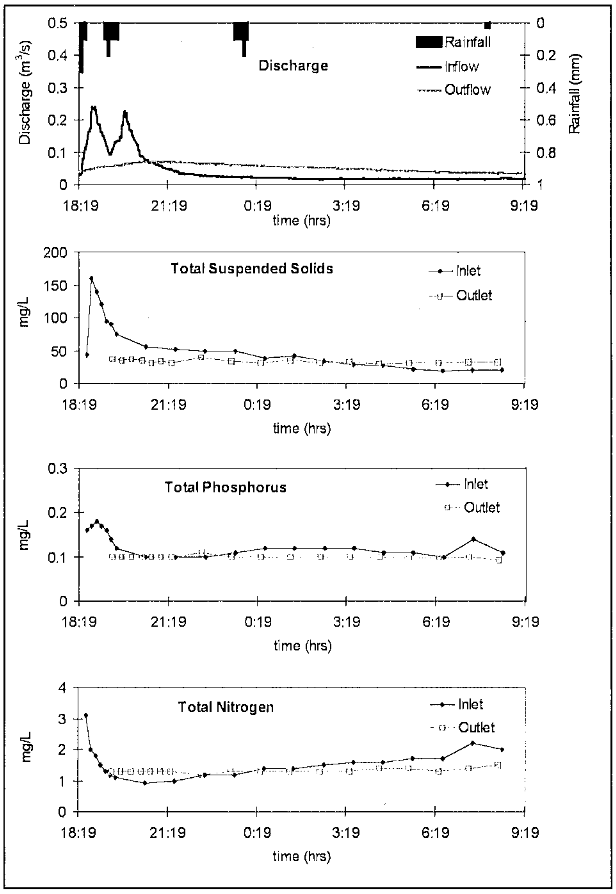

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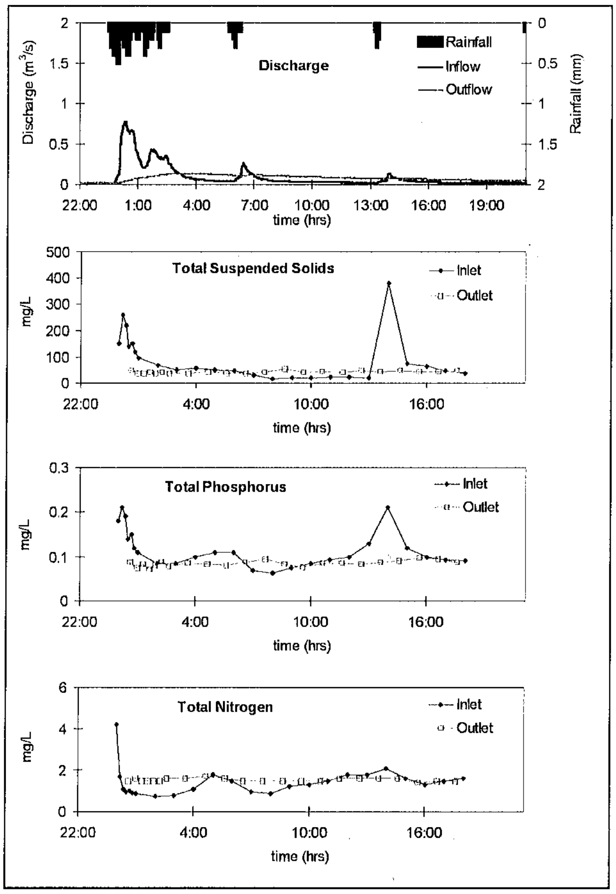

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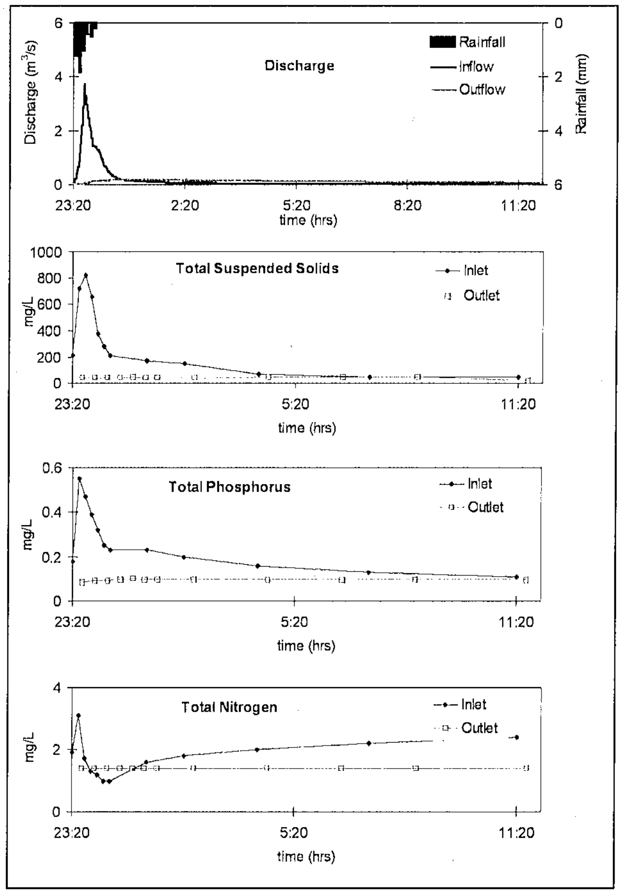

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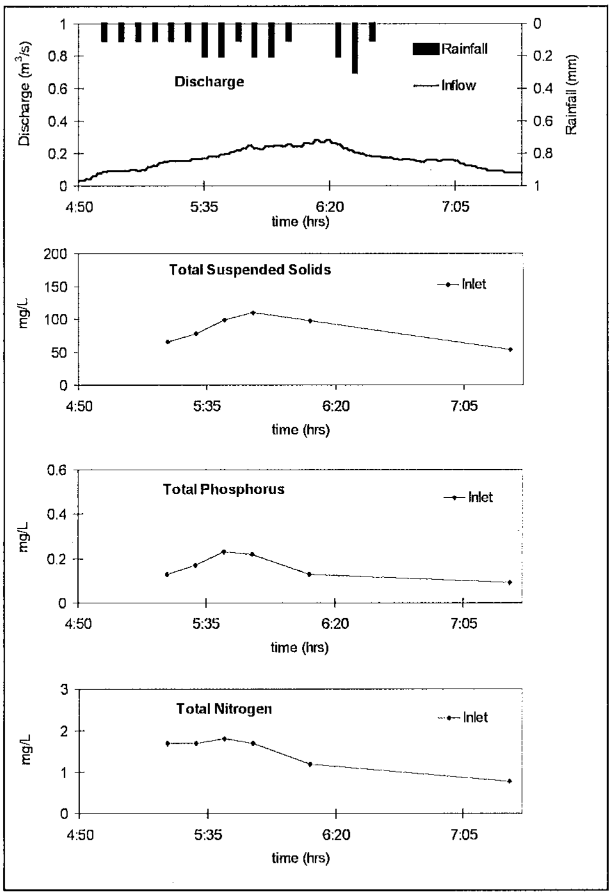

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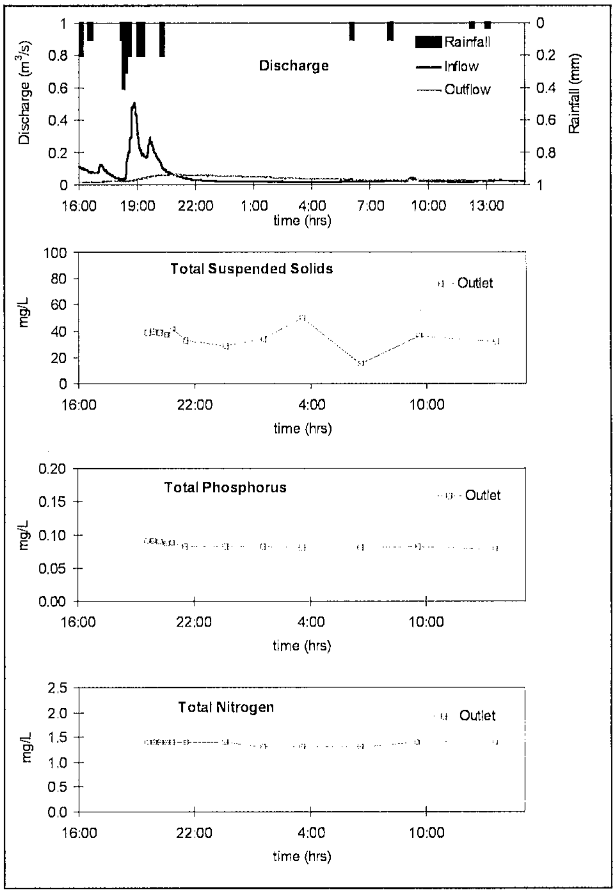

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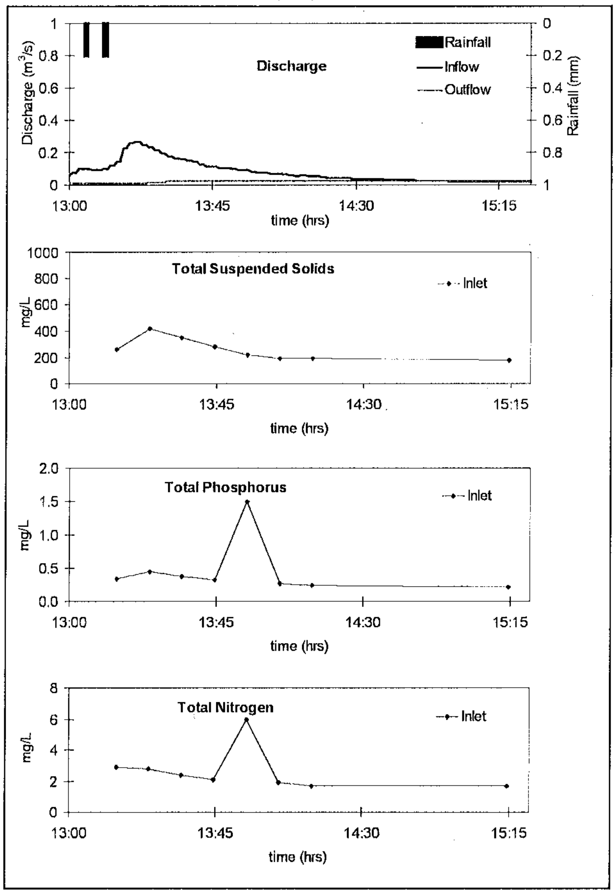

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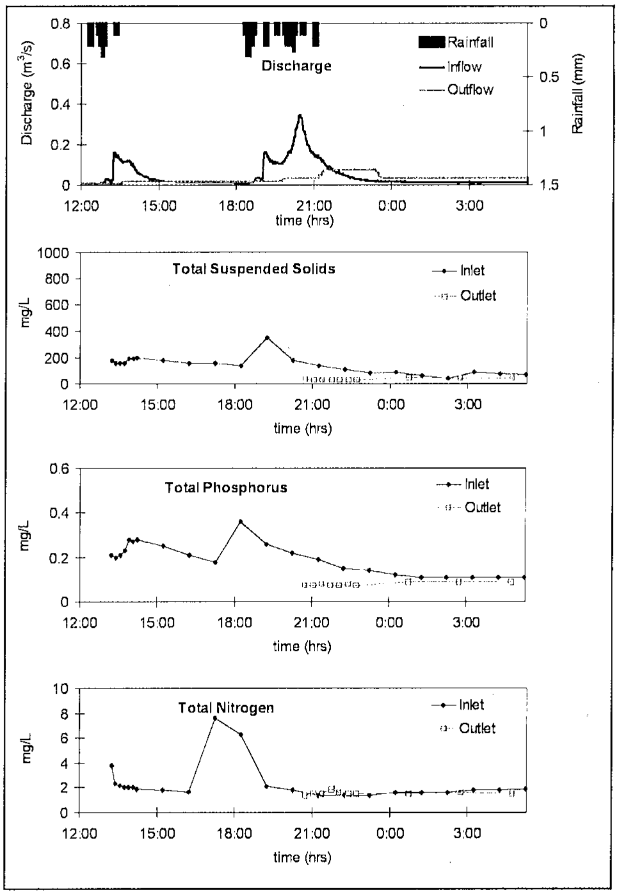

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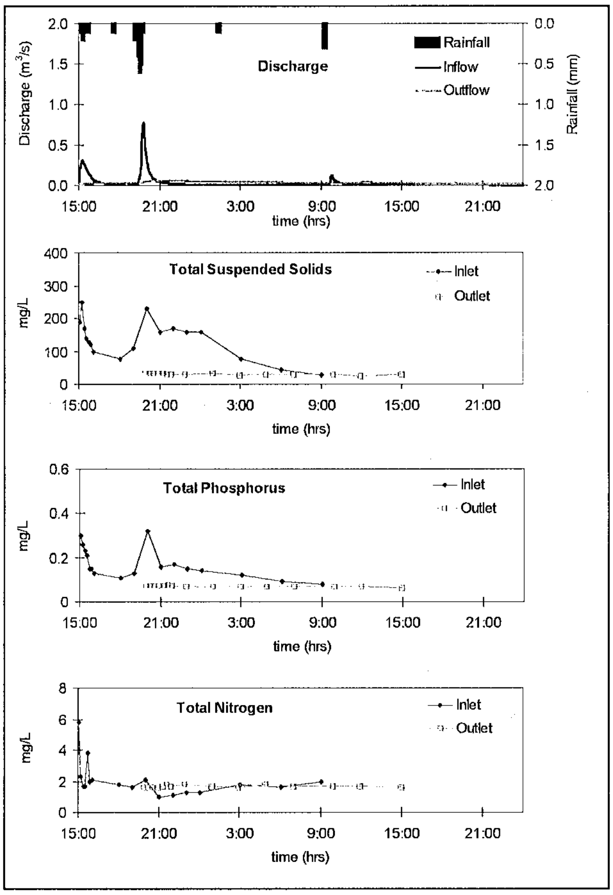

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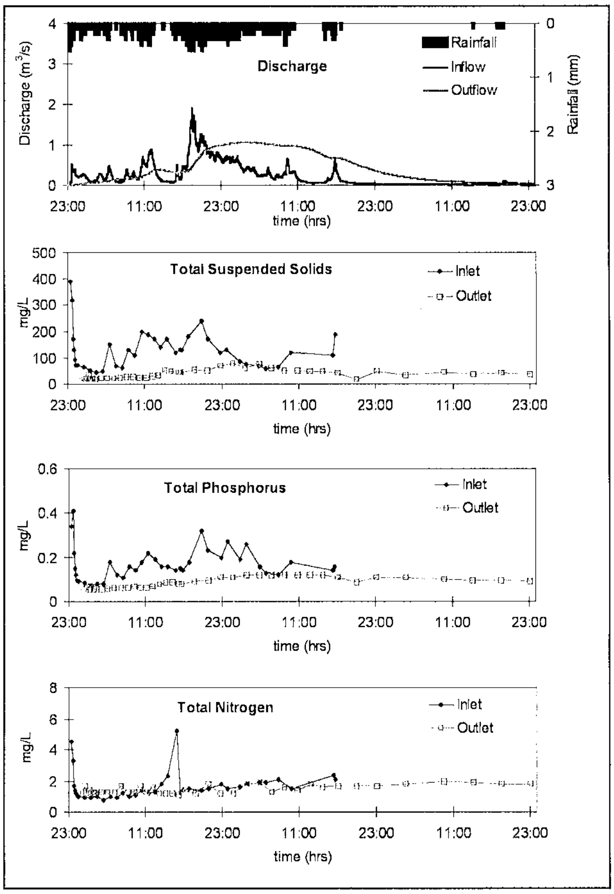

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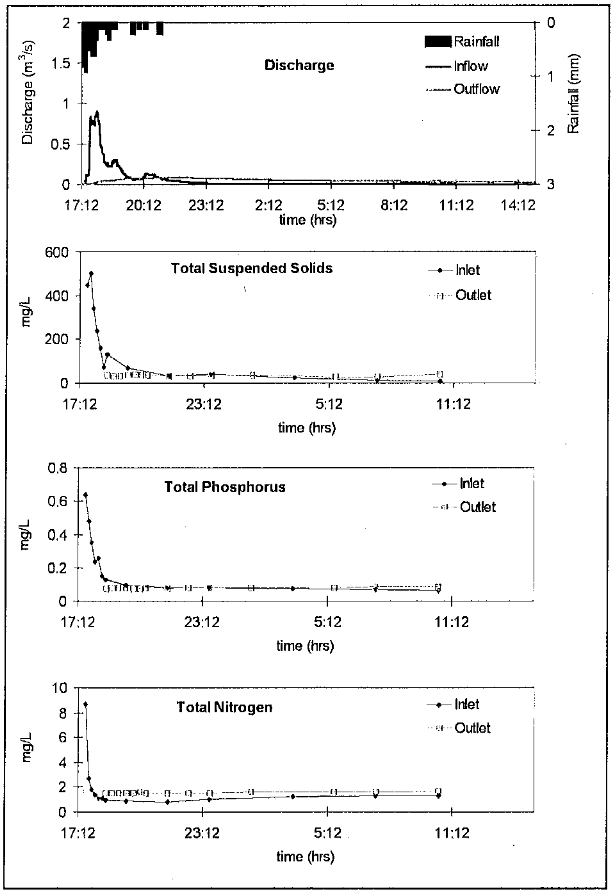

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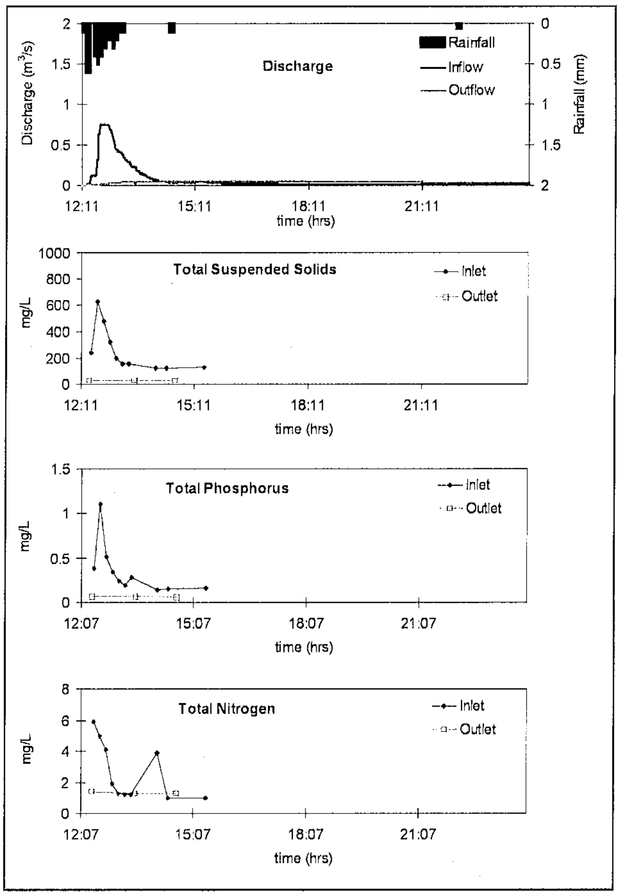

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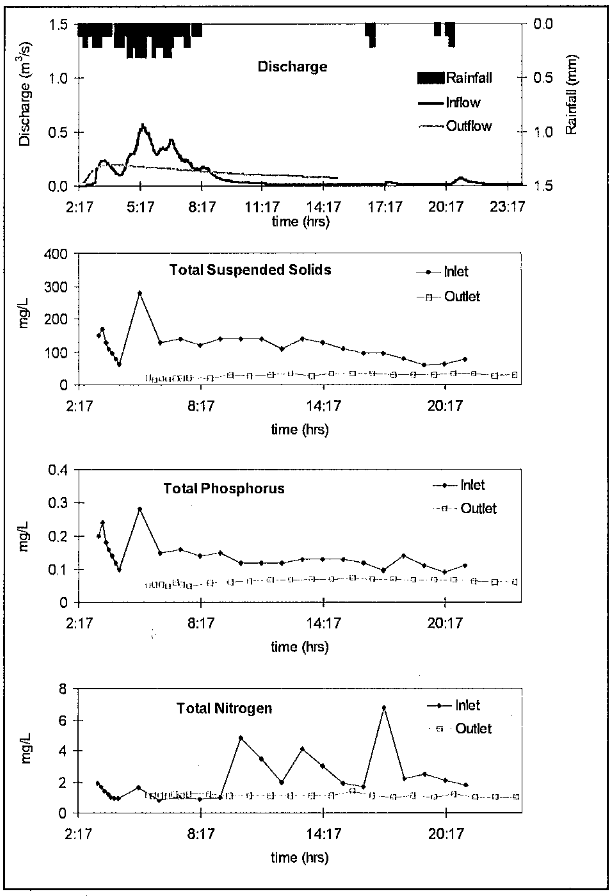

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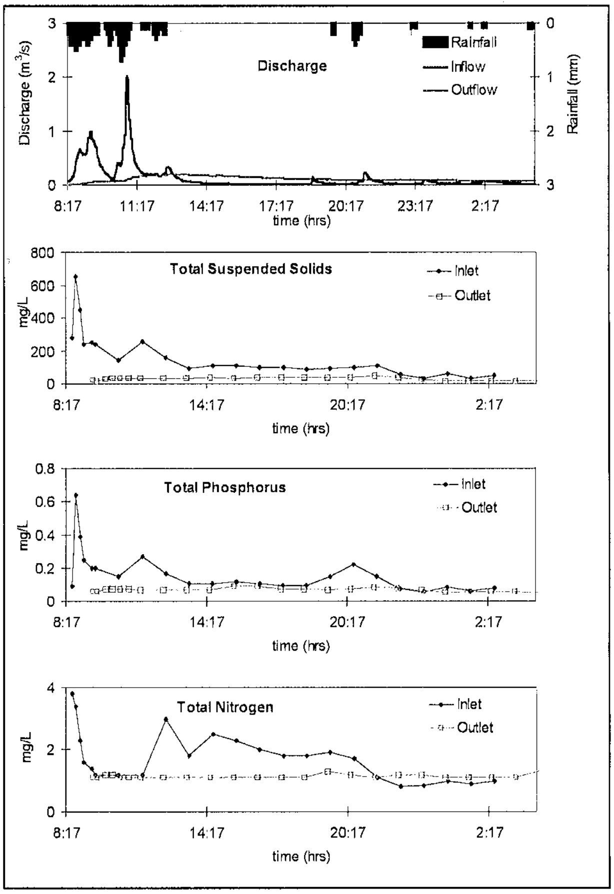

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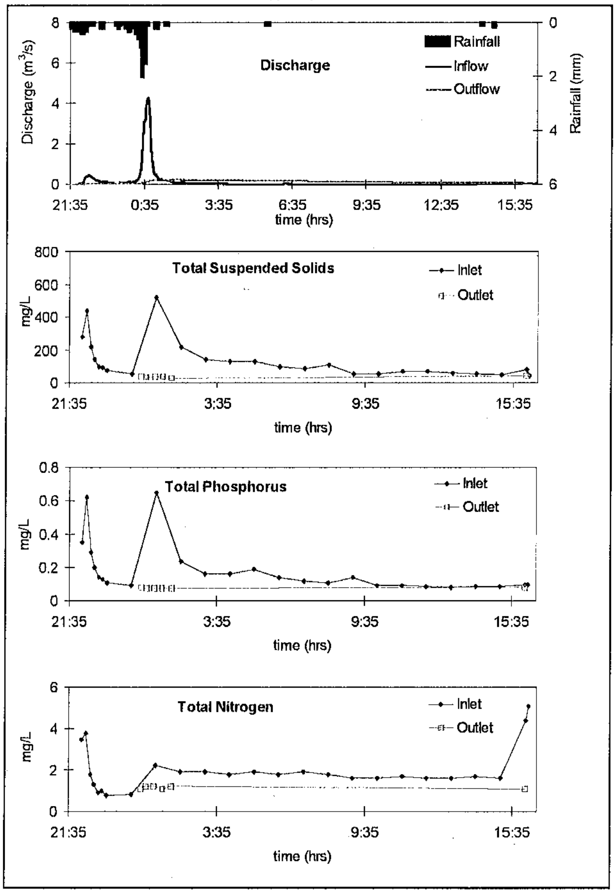

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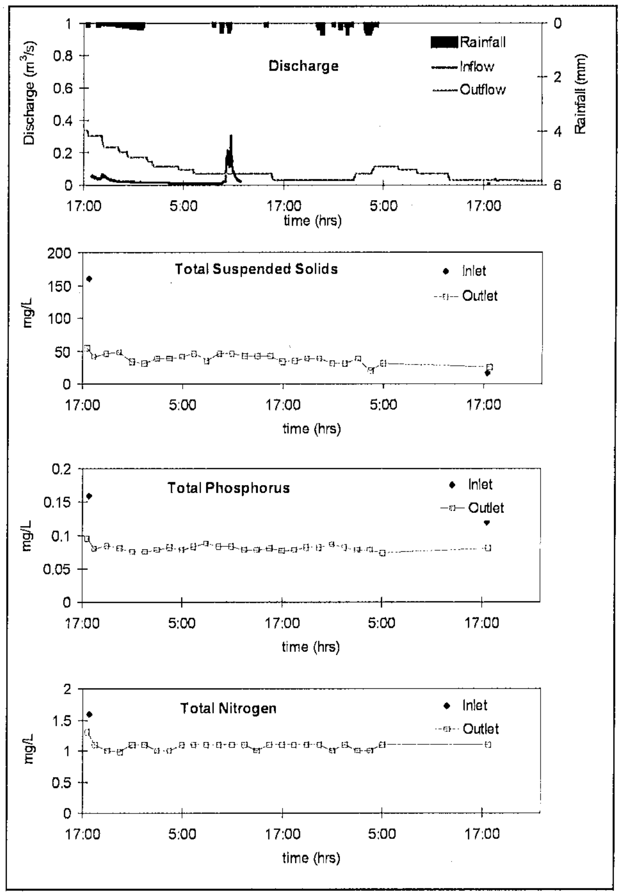

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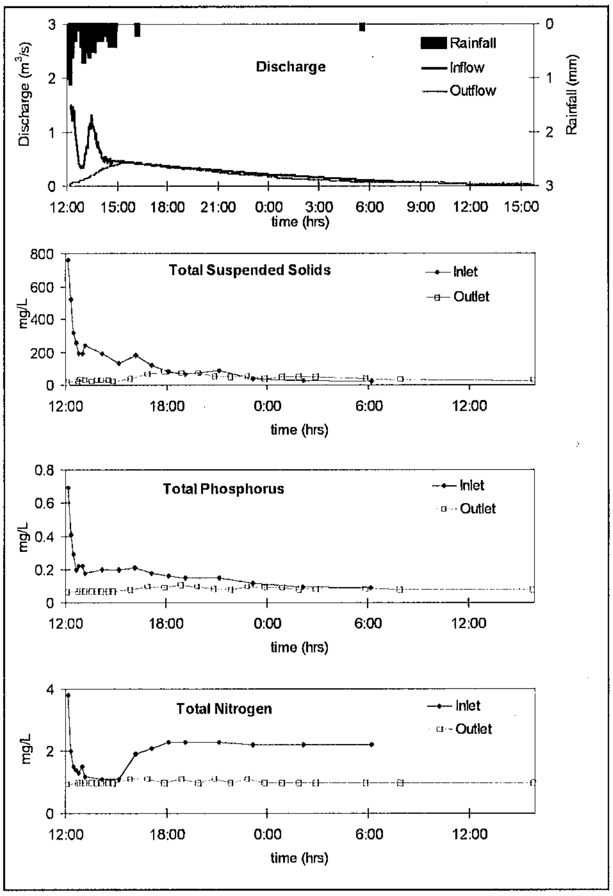

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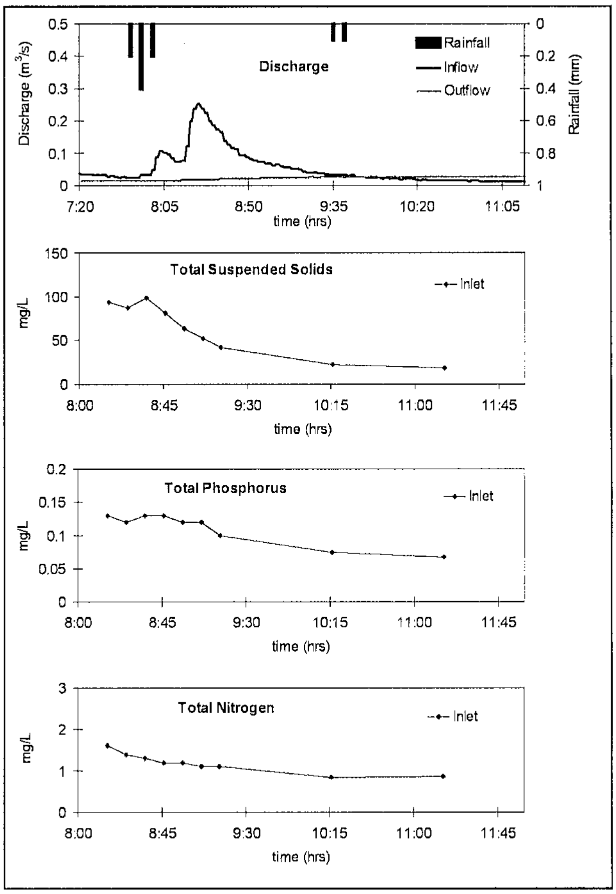

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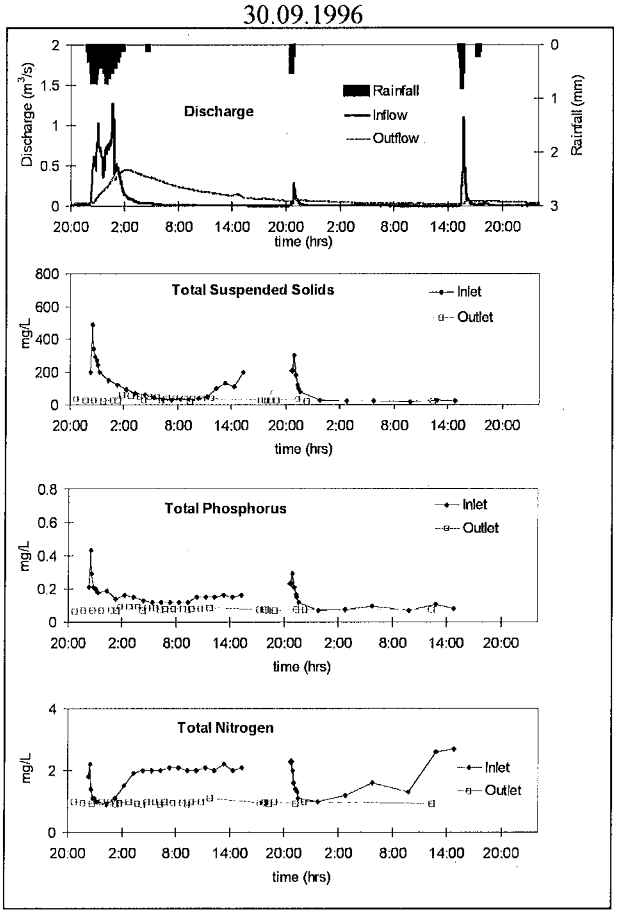

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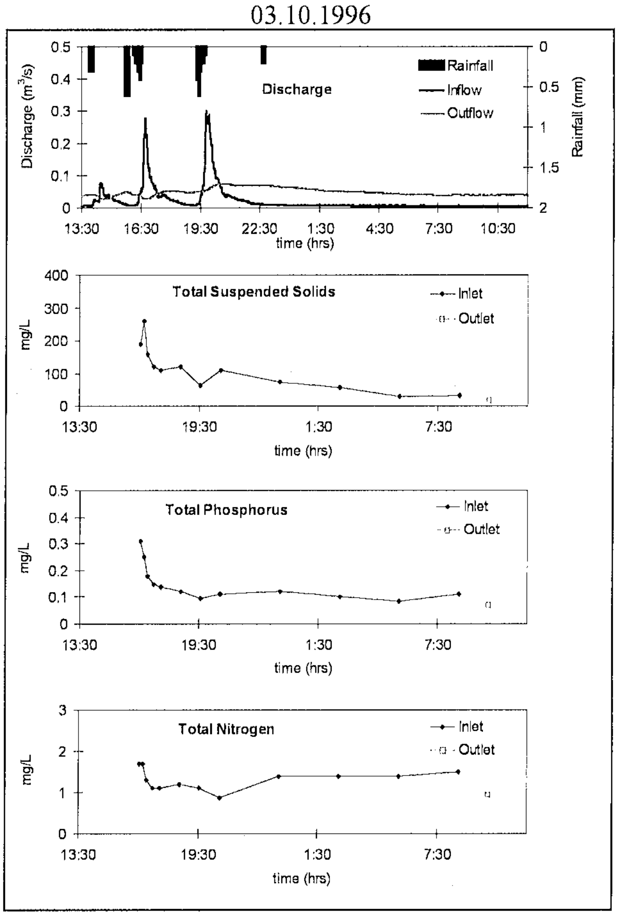

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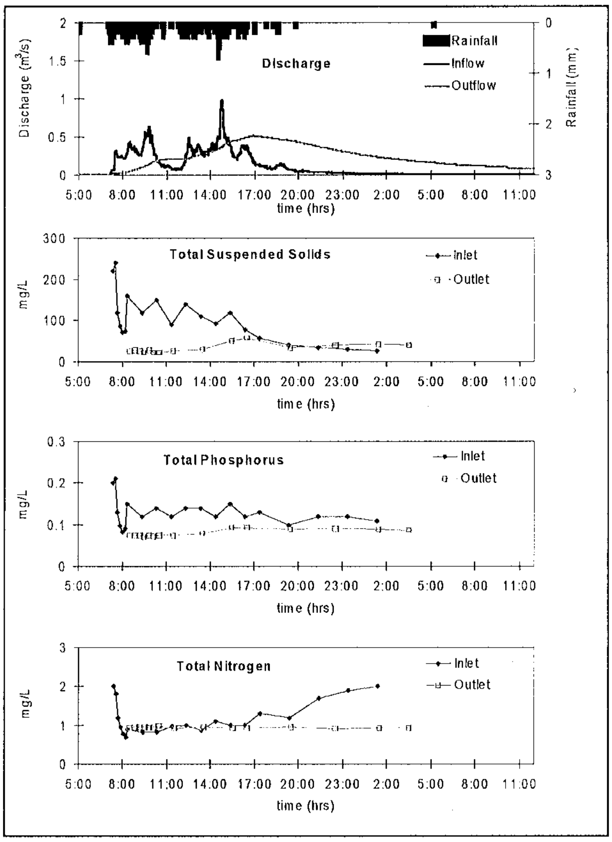

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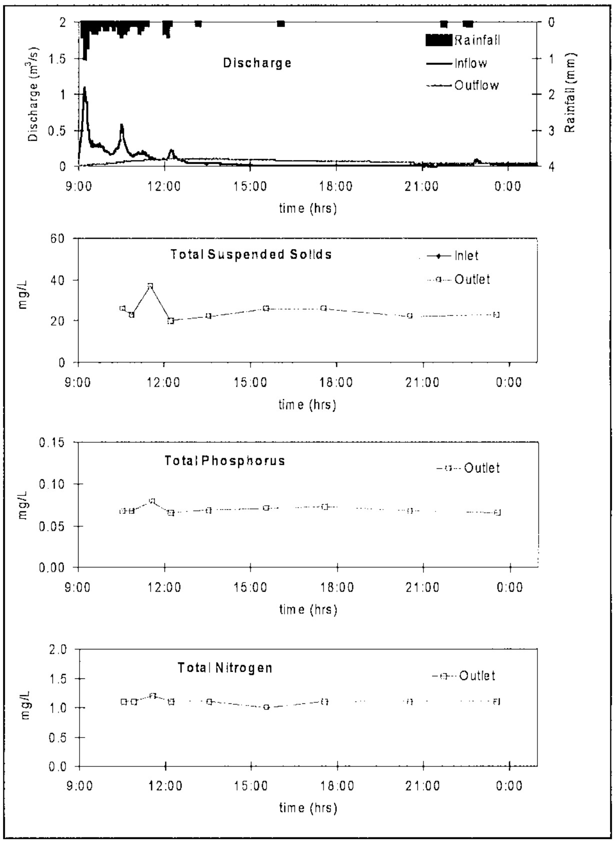

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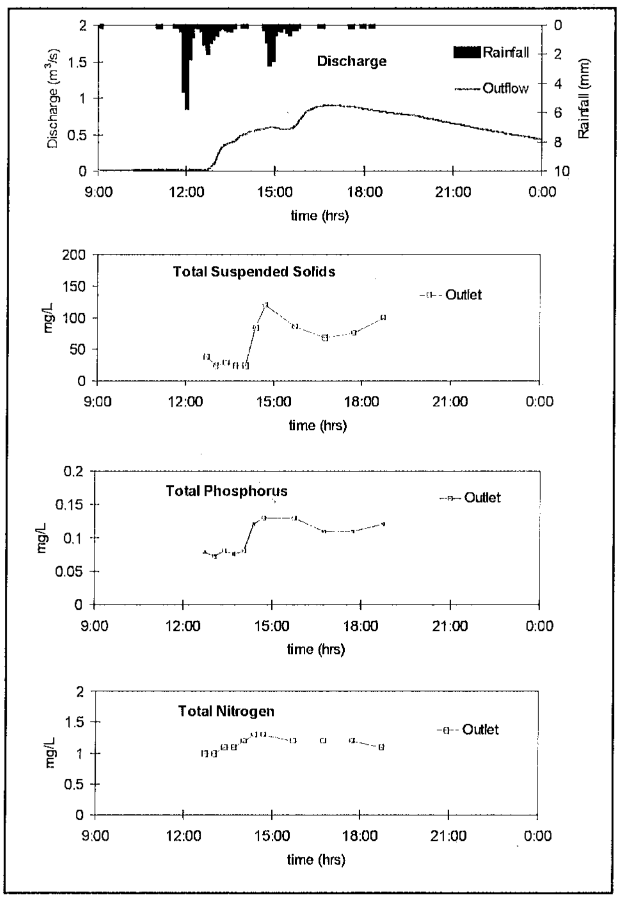

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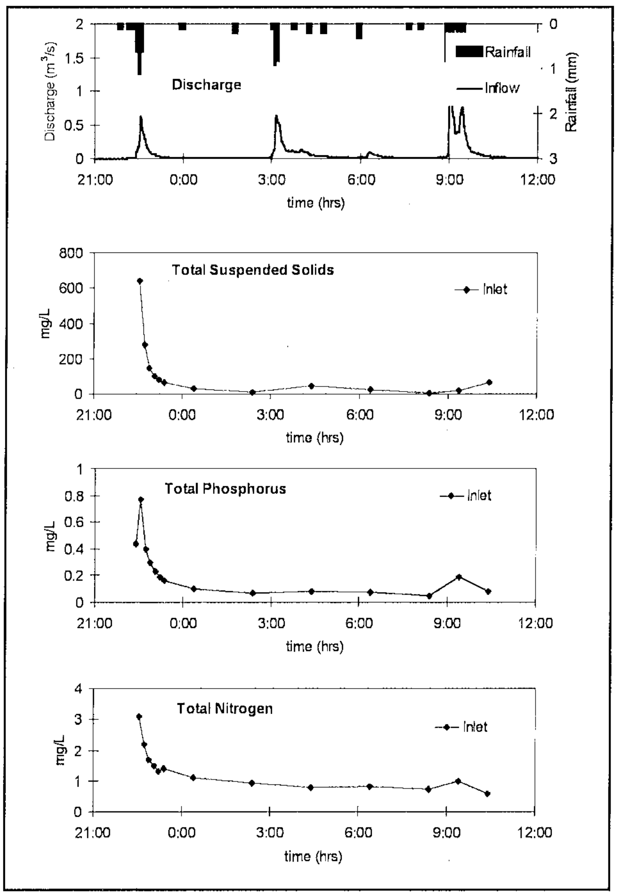

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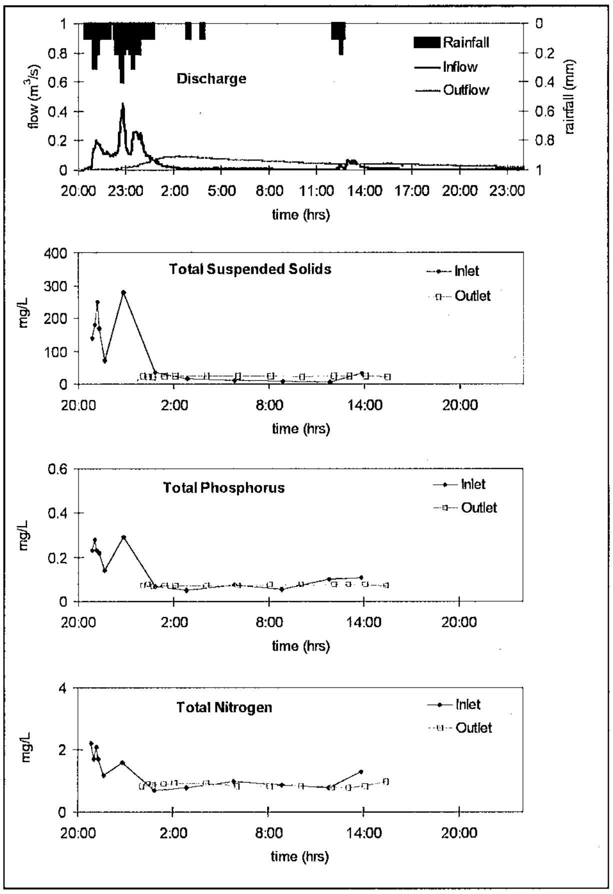

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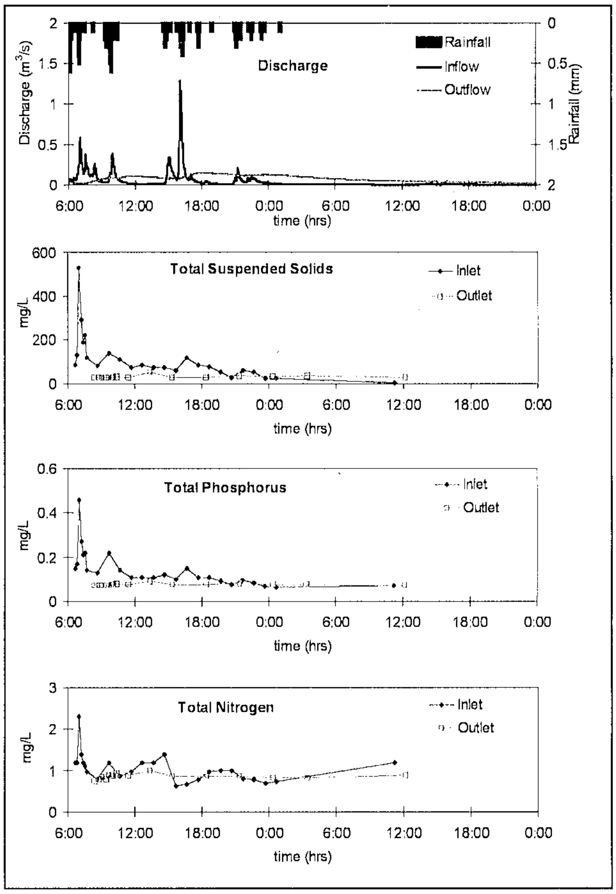

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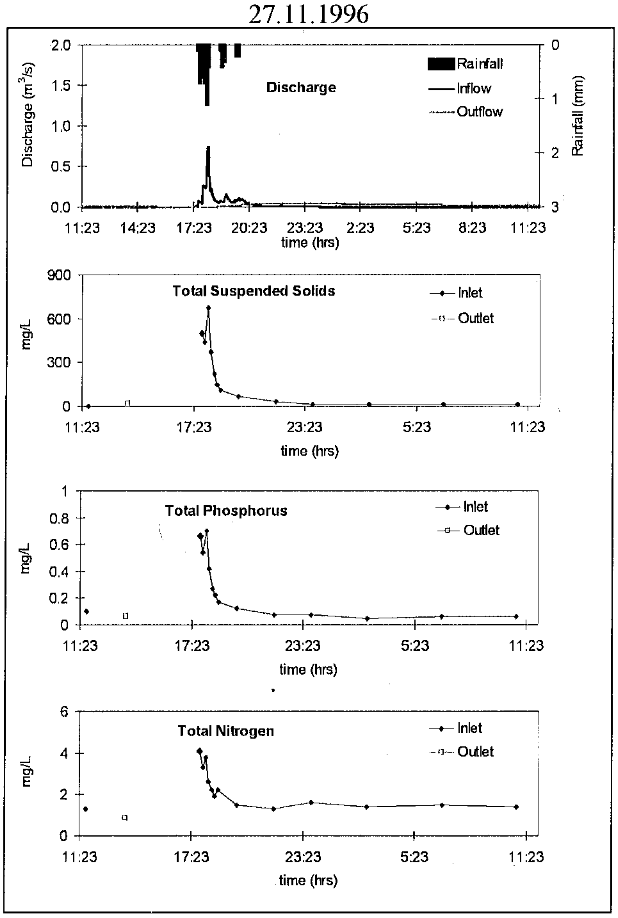

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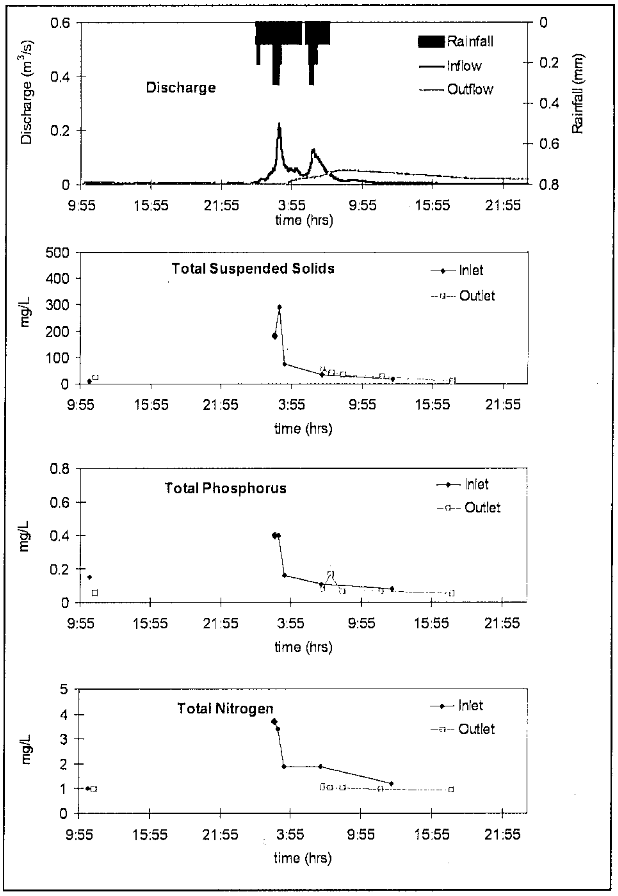

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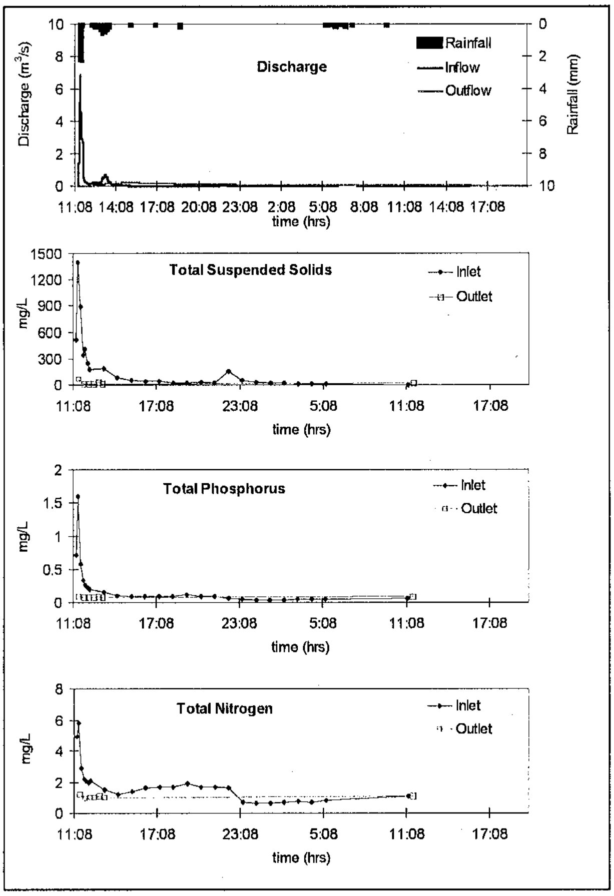

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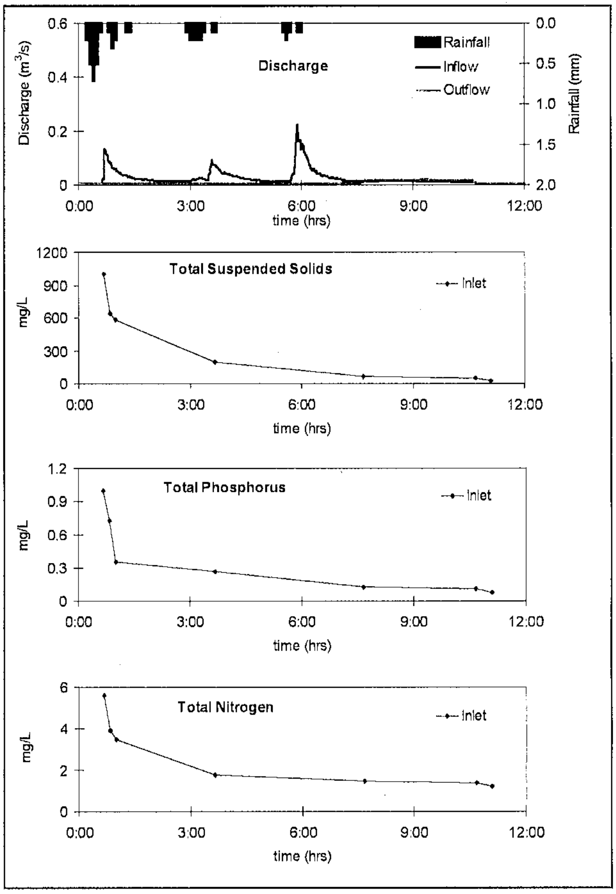

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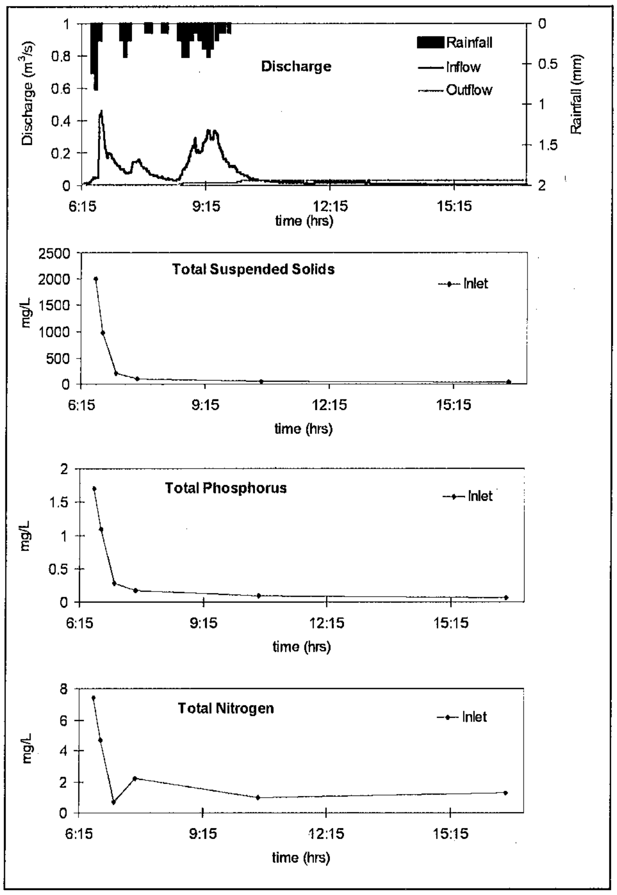

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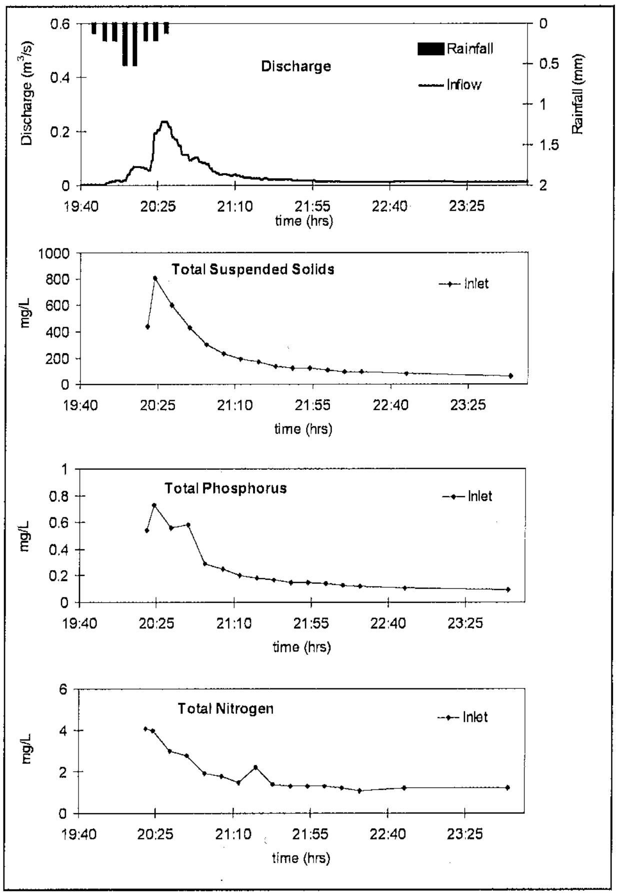

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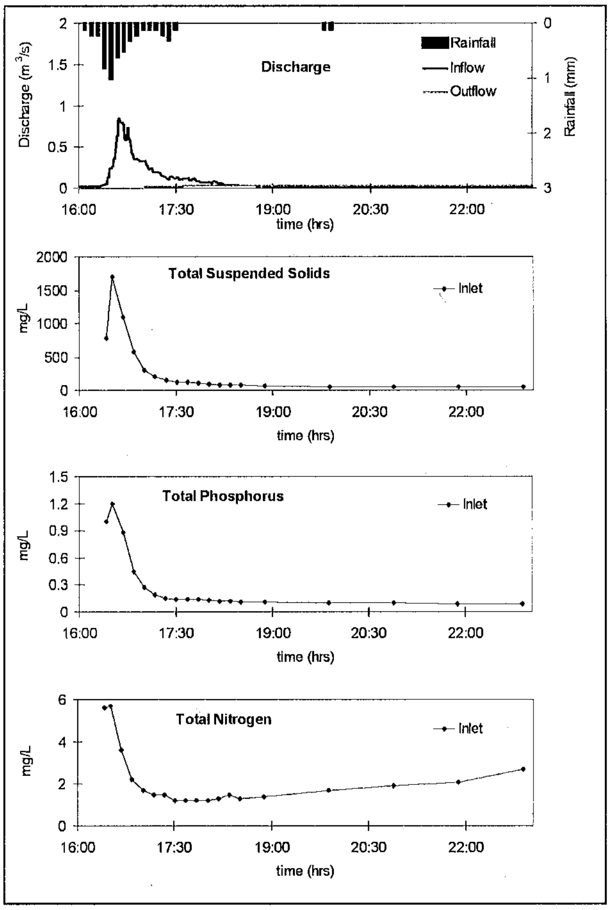

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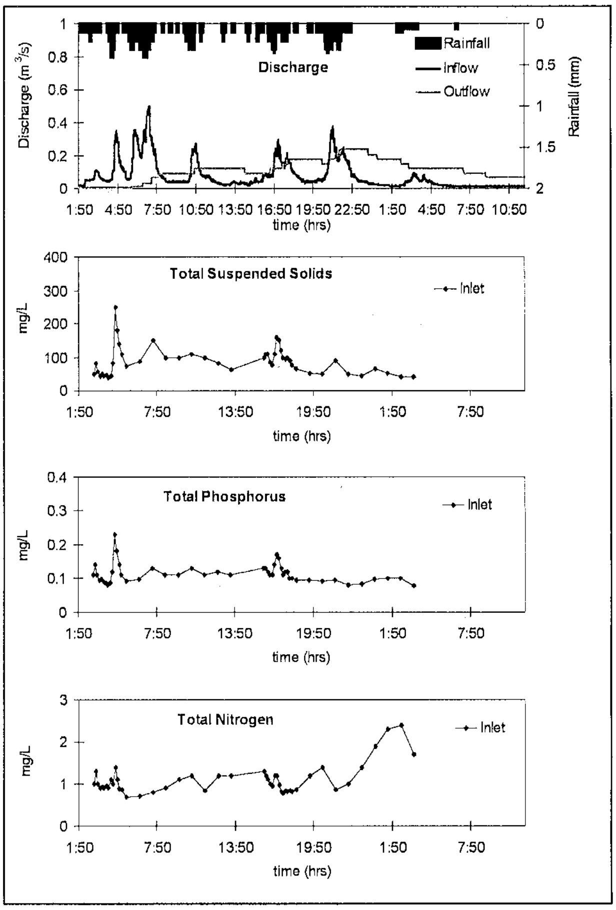

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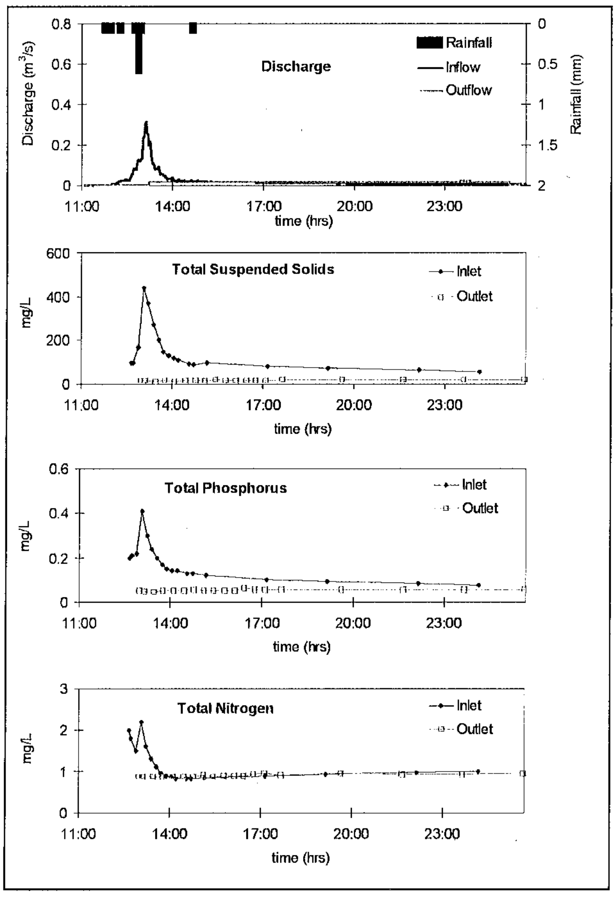

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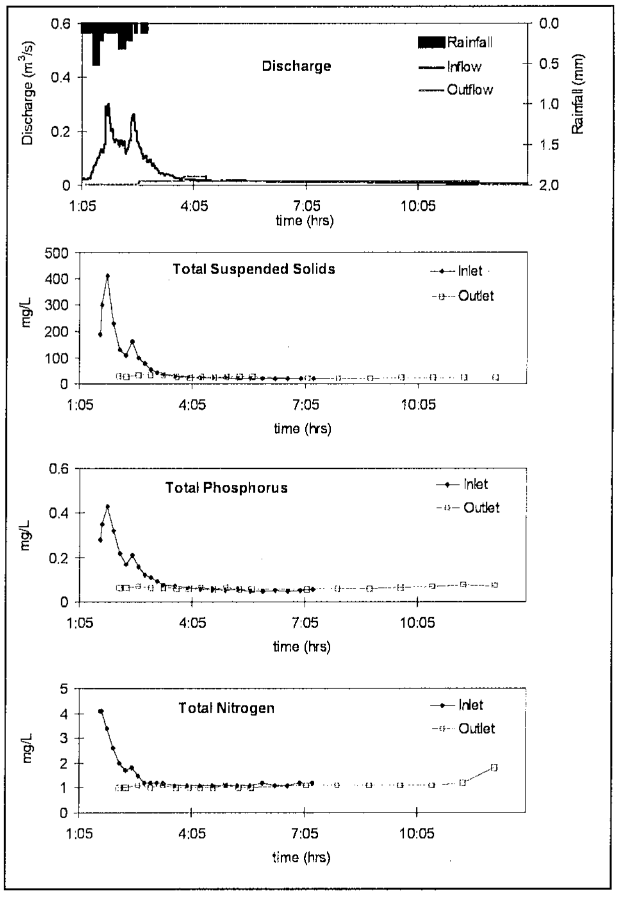

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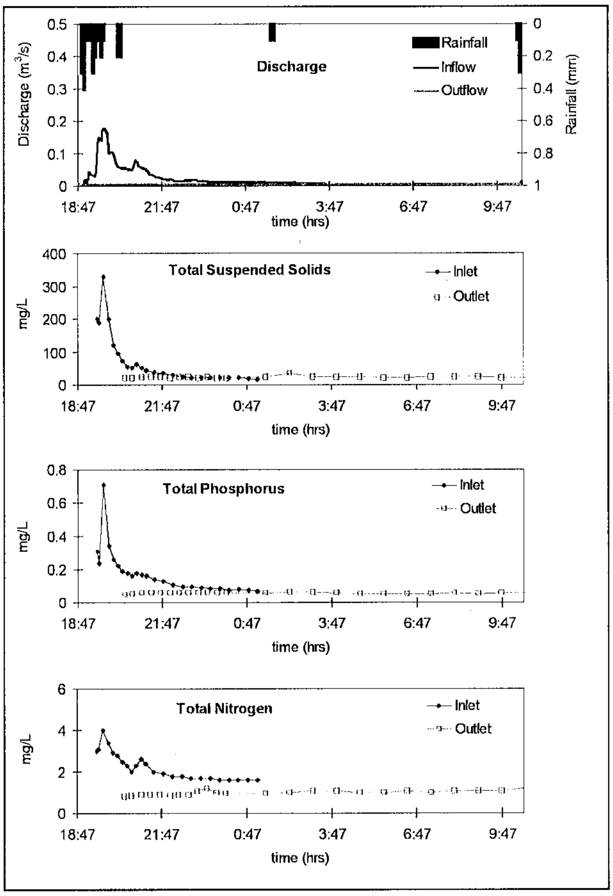
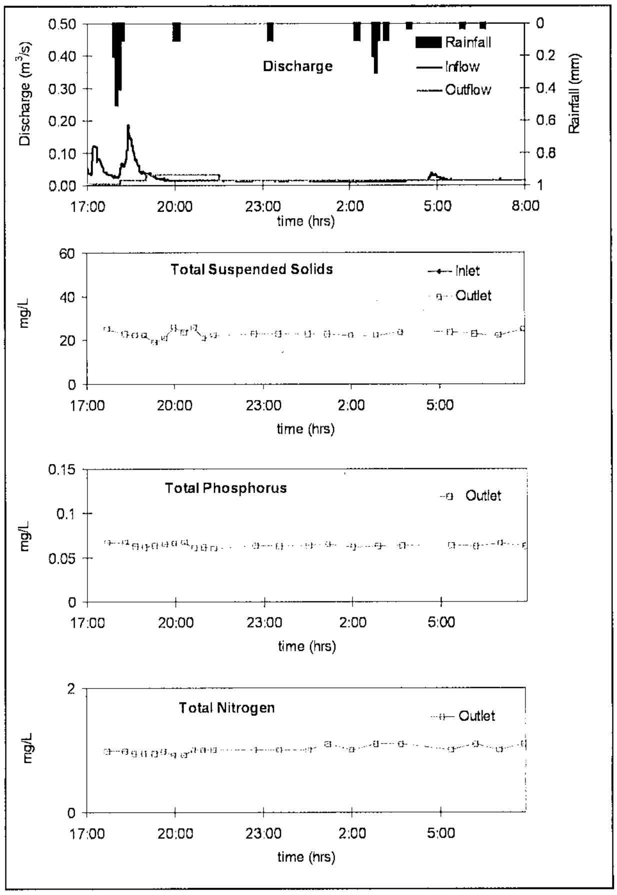
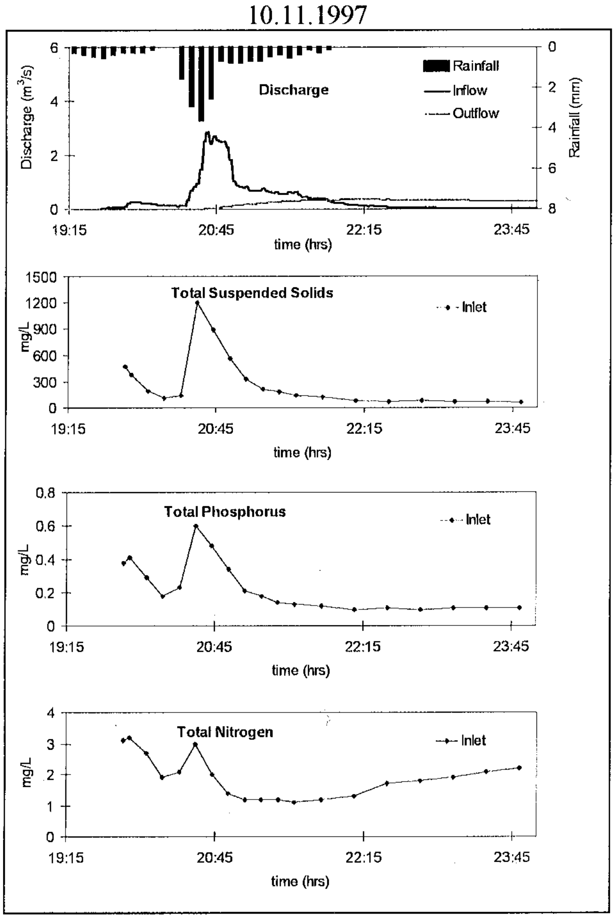


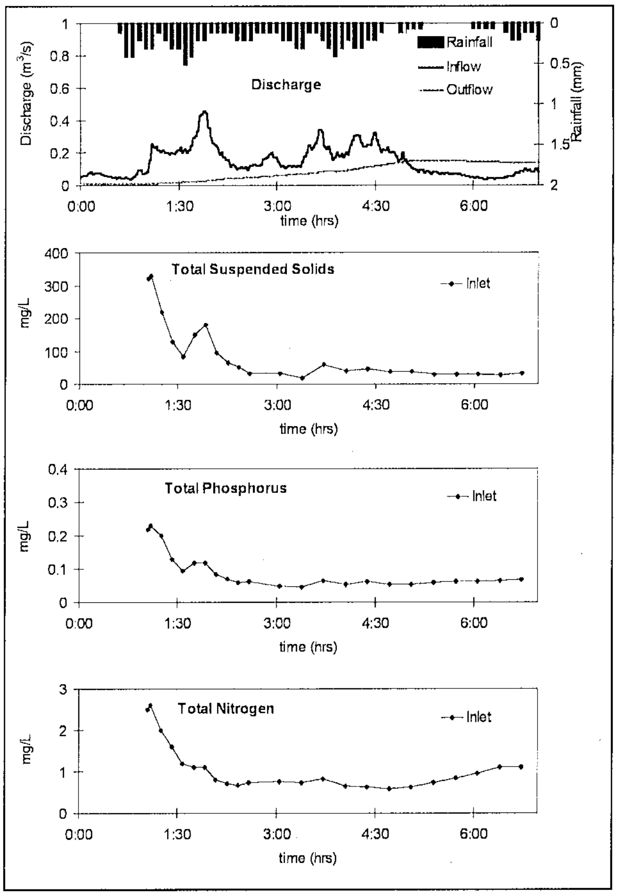
17.10.1997



10.11.1997



14.11.1997



Appendix D: Summary of storm event water quality loads from the inlet and the outlet of Blackburn Lake

Table D.1 Summary of total event loads of TSS, TP and TN for the main inlet (Site C) and the outlet.

Event Number	Location	time	date	Event Duration (min)	Event Rainfall (mm)	Event Volume (m^3)	Event Runoff (mm)	Representativeness (%)	TSS		TP		TN	
									load (kg)	EMC (mg/L)	load (kg)	EMC (mg/L)	load (kg)	EMC (mg/L)
1	Inlet		20/01/96											
	Outlet	7:56	20/01/96											
		0:00	22/01/96	2405	M	11056		68	483.60	43.74	0.89		11.49	1.04
2	Inlet	14:17	24/01/96											
		17:59	24/01/96	223	6.4	6762	3.34	90	3137.87	464.03	2.35	0.35	16.00	2.37
	Outlet	14:17	24/01/96											
		22:01	26/01/96	3365	7.4	6340	2.13	34	229.35	36.18	0.50	0.08	6.73	1.06
3	Inlet	0:00	1/02/96											
		0:00	2/02/96	1441	5.6	3145	1.55	55	350.70	111.50	0.52	0.17	5.59	1.78
	Outlet													
4	Inlet	10:00	8/02/96											
		22:00	8/02/96	721	12	7757	3.83	46	855.72	110.32	1.39	0.18	11.76	1.52
	Outlet	10:00	8/02/96											
		9:59	9/02/96	1440	13	7146	2.40	80	183.65	25.72	0.46	0.06	6.84	0.96
5	Inlet	11:00	9/02/96											
		6:00	10/02/96	1141	40	34652	17.12	46	6445.60	186.01	4.95	0.14	38.37	1.11
	Outlet	11:00	9/02/96											
		23:59	10/02/96	2220	40	58299	19.59	62	3106.58	53.29	4.86	0.08	54.91	0.94
6	Inlet	20:00	27/02/96											
		20:17	28/02/96	1458	21	16740	8.27	25	1177.65	70.35	1.83	0.11	15.14	0.90
	Outlet	20:00	27/02/96											
		23:58	29/02/96	3119	21	21457	7.21	28	587.60	27.38	1.46	0.07	20.06	0.93
7	Inlet	19:00	6/04/96											
		15:21	7/04/96	1222	14	25004	12.35	38	2114.49	84.57	4.04	0.16	35.22	1.41
	Outlet	19:00	6/04/96											
		16:00	7/04/96	1261	25	9102	3.06	72	257.89	28.33	0.65	0.07	9.70	1.07
8	Inlet	18:00	16/04/96											
		9:00	18/04/96	2340	44	56450	27.9	34	10458.50	185.27	9.67	0.17	105.30	1.87
	Outlet	18:00	16/04/96											
		20:00	18/04/96	3001	48	77629	26.1	58	6201.49	79.89	7.62	0.10	87.11	1.12
9	Inlet	20:36	26/04/96											
		23:40	26/04/96	185	2	1238	0.61	82	260.83	210.62	0.33	0.27	2.74	2.21
	Outlet													
10	Inlet	2:41	5/05/96											
		10:00	5/05/96	440	3	2326	1.15	62	257.20	110.58	0.40	0.17	3.47	1.49
	Outlet													

Table D.1 (continued)

Event Number	Location	time	date	Event Duration (min)	Event Rainfall (mm)	Event Volume (m^3)	Event Runoff (mm)	Representativeness (%)	TSS load (kg)	TSS EMC (mg/L)	TP load (kg)	TP EMC (mg/L)	TN load (kg)	TN EMC (mg/L)
11	Inlet	6:00	6/05/96											
		11:42	7/05/96	1783	1.7	2363	1.17	15	81.20	34.36	0.22	0.09	3.86	1.63
	Outlet	6:00	6/05/96											
		23:59	7/05/96	2520	1.7	3256	1.09	21	85.06	26.12	0.20	0.06	3.64	1.12
12	Inlet	0:53	12/05/96											
		17:58	13/05/96	2466	17	14853	7.34	39	1743.54	117.39	1.96	0.13	17.11	1.15
	Outlet	0:53	12/05/96											
		18:08	13/05/96	2476	17	15828	5.32	61	428.64	27.08	1.16	0.07	17.46	1.10
13	Inlet	16:30	22/05/96											
		15:50	22/05/96	80	2.9	2228	1.1	97	847.00	380.16	0.88	0.86	5.11	5.02
	Outlet	16:30	22/05/96											
		23:59	23/05/96	1890	2.9	3103	1.04	42	62.26	20.06	0.20	0.06	3.44	1.11
14	Inlet	6:00	6/06/96											
		18:00	6/06/96	721	2.4	2300	1.14	45	237.85	103.41	0.35	0.15	3.04	1.32
	Outlet													
15	Inlet	12:00	7/06/96											
		18:00	7/06/96	361	0.4	525	0.26	31	25.98	49.49	0.06	0.12	2.11	4.02
	Outlet	12:00	7/06/96											
		11:00	8/06/96	1381	0.4	792	0.27	46	12.54	15.84	0.05	0.06	0.88	1.11
16	Inlet	12:00	19/06/96	1131										
		6:50	20/06/96		M	5566	2.75	53	1252.52	225.01	1.36	0.24	10.93	1.96
	Outlet	12:00	19/06/96											
		14:40	20/06/96	1601	M	6511	2.19	28	154.77	23.77	0.47	0.07	7.83	1.20
17	Inlet	2:38	23/06/96											
		12:31	24/06/96	2034	M	51639	25.5	37	6845.33	132.56	8.11	0.16	80.17	1.55
	Outlet	2:38	23/06/96											
		11:59	25/06/96	3442	M	84072	28.2	74	3823.02	45.47	8.77	0.10	105.10	1.25
18	Inlet	18:19	26/06/96											
		9:25	27/06/96	907	M	2312	1.14	53	148.23	64.12	0.29	0.12	3.32	1.44
	Oulet	18:19	26/06/96											
		9;25	27/06/96	907	M	2910	0.98	74	96.64	33.21	0.28	0.10	3.74	1.29
19	Inlet	22:00	28/06/96											
		21:00	29/06/96	1381	8.4	7564	3.74	53	761.82	100.72	0.89	0.12	9.20	1.22
	Outlet	22:00	28/06/96											
		21:00	29/06/96	1381	8.4	6925	2.33	65	288.26	41.62	0.59	0.09	10.32	1.49
20	Inlet	23:20	1/07/96											
		2:30	2/07/96	190	5		0	90	3325.00		2.29		9.97	
	Outlet	23:20	1/07/96											
		18:55	2/07/96	1175	5	7681	2.58	42	288.05	37.50	0.74	0.10	10.75	1.40

Table D.1 (continued)

Event Number	Location	time	date	Event Duration (min)	Event Rainfall (mm)	Event Volume (m^3)	Event Runoff (mm)	Representativeness (%)	TSS		TP		TN	
									load (kg)	EMC (mg/L)	load (kg)	EMC (mg/L)	load (kg)	EMC (mg/L)
21	Inlet	4:59	5/07/96											
		7:29	5/07/96	150	2.2	1564	0.77	62	131.00	83.76	0.26	0.17	2.05	1.31
	Outlet													
22	Inlet													
	Outlet	16:00	6/07/96											
		15:00	7/07/96	1381	3.8	3497	1.17	36	115.24	32.96	0.29	0.08	4.44	1.27
23	Inlet	11:00	17/07/96											
		15:25	17/07/96	249	1.2	1066	0.53	58	240.07	225.30	0.37	0.35	2.58	2.42
	Outlet													
24	Inlet	12:00	19/07/96											
		5:14	20/07/96	1035	4.6	2892	1.43	48	504.72	174.55	0.61	0.21	5.88	2.03
	Outlet	12:00	19/07/96											
		5:14	20/07/96	1035	4.6	1105	0.37	36	33.65	30.47	0.08	0.07	1.49	1.35
25	Inlet	15:00	23/07/96											
		23:59	23/07/96	540	3.1	2610	1.29	52	462.91	177.37	0.59	0.23	5.27	2.02
	Outlet	15:00	23/07/96											
		0:00	25/07/96	1981	3.9	4370	1.47	33	125.29	28.67	0.30	0.07	6.84	1.57
26	Inlet	23:00	28/07/96											
		23:59	30/07/96	2940	55	57523	28.4	28	7847.90	136.43	11.36	0.20	90.85	1.58
	Outlet	23:00	28/07/96											
		0:00	1/08/96	4381	55	112103	37.7	32	5814.05	51.86	12.02	0.11	175.18	1.56
27	Inlet	17:12	6/08/96											
		10:31	7/08/96	1040	6.5	3963	1.96	62	773.06	195.06	0.91	0.23	6.99	1.76
	Outlet	17:12	6/08/96											
		14:59	7/08/96	1308	6.5	4105	1.38	44	139.97	34.10	0.33	0.08	6.22	1.52
28	Inlet	12:11	14/08/96											
		18:00	14/08/96	349	4.2	2541	1.26	83	747.87	294.29	1.01	0.40	6.63	2.61
	Outlet	12:11	14/08/96											
		0:00	15/08/96	710	4.2	1861	0.63	7	46.31	24.89	0.12	0.06	2.21	1.19
29	Inlet	2:17	27/08/96											
		15:00	27/08/96	764	8.2	6210	3.07	44	1005.21	161.87	1.12	0.18	8.04	1.29
	Outlet	2:17	27/08/96											
		0:00	28/08/96	1304	10	6192	2.08	72	168.62	27.23	0.39	0.06	6.90	1.11
30	Inlet	8:17	2/09/96											
		2:33	3/09/96	1097	13	9061	4.48	51	1857.62	205.01	1.85	0.20	14.69	1.62
	Outlet	8:17	2/09/96											
		4:26	3/09/96	1210		8428	2.83	72	272.34	32.31	0.61	0.07	9.50	1.13

Table D.1 (continued)

Event Number	Location	time	date	Event Duration (Min)	Event Rainfall (mm)	Event Volume (m^3)	Event Runoff (mm)	Representativeness (%)	TSS load (kg)	TSS EMC (mg/L)	TP load (kg)	TP EMC (mg/L)	TN load (kg)	TN EMC (mg/L)
31	Inlet	21:35	11/09/96											
		13:59	12/09/96	985	11	8008	3.96	24	2279.20	284.62	2.93	0.37	13.54	1.69
	Outlet	21:35	11/09/96											
		0:00	13/09/96	1586	11	10178	3.42	14	364.43	35.81	0.78	0.08	11.68	1.15
32	Inlet	M	19/09/96											
	Outlet	17:00	19/09/96											
		0:00	22/09/96	3301	13	17087	5.74	41	636.70	37.26	1.37	0.08	18.34	1.07
33	Inlet		26/09/96											
	Outlet	12:00	26/09/96											
		15:45	27/09/96	1666	12	16957	5.7	60	821.42	48.44	1.46	0.09	17.54	1.03
34	Inlet	8:00	29/09/96											
		12:00	29/09/96	241	0.2	723	0.36	78	46.00	63.66	0.08	0.11	0.89	1.23
	Outlet													
35	Inlet	20:00	30/09/96											
		0:00	3/10/96	3121	18	11333	5.6	46	1706.17	150.55	1.93	0.17	15.96	1.41
	Outlet	20:00	30/09/96											
		0:00	3/10/96	3121	18	22626	7.6	52	790.88	34.95	1.79	0.08	21.99	0.97
36	Inlet	13:30	3/10/96											
		12:00	4/10/96	1351	5	1812	0.9	37	188.14	103.82	0.26	0.14	2.27	1.25
	Outlet													
37	Inlet	5:00	5/10/96											
		2:08	6/10/96	1269	21	12616	6.23	38	1340.37	106.24	1.65	0.13	13.23	1.05
	Outlet	5:00	5/10/96											
		12:00	6/10/96	1861	21	20910	7.02	38	849.63	40.63	1.84	0.09	19.66	0.94
38	Inlet													
	Outlet	9:00	19/10/96											
		1:00	20/10/96	961	8.4	4038	1.36	41	97.55	24.16	0.28	0.07	4.34	1.07
39	Inlet													
	Outlet	10:00	3/11/96											
		19:55	4/11/96	2036	34	37518	12.6	25	3179.89	84.76	4.26	0.11	43.12	1.15
40	Inlet	20:00	9/11/96											
		15:00	10/11/96	1141	12	3791	1.87	40	331.97	87.58	0.68	0.18	4.32	1.14
	Outlet													

Table D.1 (continued)

Event Number	Location	time	date	Event Duration (Min)	Event Rainfall (mm)	Event Volume (m^3)	Event Runoff (mm)	Representativeness (%)	TSS		TP		TN	
									load (kg)	EMC (mg/L)	load (kg)	EMC (mg/L)	load (kg)	EMC (mg/L)
41	Inlet	20:00	17/11/96											
		10:00	18/11/96	841	6.6	2849	1.41	37	447.99	157.26	0.54	0.19	3.74	1.31
	Outlet	20:00	17/11/96											
		20:59	18/11/96	1500	7.2	4490	1.51	40	106.79	23.78	0.33	0.07	3.99	0.89
42	Inlet	6:00	21/11/96											
		0:00	23/11/96	2521	13	6607	3.26	33	707.08	107.02	0.94	0.14	6.41	0.97
	Outlet	6:00	21/11/96											
		0:00	23/11/96	2521	13	11567	3.89	25	367.29	31.75	0.90	0.08	10.03	0.87
43	Inlet	11:23	27/11/96											
		11:59	28/11/96	1147	4.8	1717	0.85	62	469.95	273.75	0.58	0.34	4.27	2.49
	Outlet													
44	Inlet	9:55	24/12/96											
		12:00	25/12/96	1609	6	2037	1.01	27	197.05	96.74	0.43	0.21	4.67	2.29
	Outlet	9:55	24/12/96											
		0:00	26/12/96	2286	6	2795	0.94	20	125.91	45.05	0.19	0.07	2.76	0.99
45	Inlet	11:08	27/01/97											
		10:34	28/01/97	1407	11	7728	3.82	75	5139.01	665.01	5.05	0.65	23.45	3.03
	Outlet	11:08	27/01/97											
		20:00	28/01/97	1973	11	7785	2.62	9	102.69	13.19	0.68	0.09	7.84	1.01
46	Inlet	0:00	21/03/97											
		12:00	21/03/97	721	4.6	1109	0.55	24	270.96	244.41	0.30	0.27	2.36	2.13
	Outlet													
47	Inlet	6:17	23/03/97											
		16:59	23/03/97	643	5.8	2294	1.13	32	267.25	116.50	0.30	0.13	2.35	1.02
	Outlet													
48	Inlet	19:47	26/07/97											
		0:00	27/07/97	254	2	583	0.29	90	225.43	386.86	0.24	0.42	1.47	2.52
	Outlet													
49	Inlet	16:00	7/08/97											
		23:00	7/08/97	421	5	1932	0.95	91	1105.90	572.27	0.91	0.47	4.95	2.56
	Outlet													
50	Inlet	1:50	11/08/97											
		11:59	12/08/97	2050	23	9541	4.71	48	868.34	91.01	1.05	0.11	10.16	1.06
	Outlet													

Table D.1 (continued)

Event Number	Location	time	date	Event Duration (Min)	Event Rainfall (mm)	Event Volume (m^3)	Event Runoff (mm)	Representativeness (%)	TSS		TP		TN	
									load (kg)	EMC (mg/L)	load (kg)	EMC (mg/L)	load (kg)	EMC (mg/L)
51	Inlet	11:00 0:10	10/09/97 11/09/97	791	2.2	1155	0.57	64	204.66	177.22	0.22	0.19	1.47	1.27
	Outlet	11:00 1:39	10/09/97 11/09/97	880	2.2	785	0.26	58	14.73	18.76	0.04	0.06	0.72	0.92
52	Inlet	1:05 7:35	27/09/97 27/09/97	391	3.2	1453	0.72	85	185.74	127.83	0.26	0.18	2.64	1.82
	Outlet	1:05 13:00	27/09/97 27/09/97	716	3.2	642	0.22	82	15.62	24.31	0.04	0.06	0.68	1.06
53	Inlet	18:47 1:10	2/10/97 3/10/97	384	2.4	1059	0.52	79	101.93	96.27	0.22	0.21	2.26	2.13
	Outlet	18:47 10:37	2/10/97 3/10/97	951	2.4	1165	0.39	83	28.23	24.23	0.07	0.06	1.17	1.00
54	Inlet													
	Outlet	17:00 7:51	17/10/97 18/10/97	892	3.4	1006	0.34	80	23.05	22.91	0.06	0.06	1.02	1.01
55	Inlet	19:17 0:00	10/11/97 11/11/97	284	18	6428	3.18	100	3492.83	543.36	2.10	0.33	11.58	1.80
	Outlet													
56	Inlet	0:00 6:53	14/11/97 14/11/97	414	11	3656	1.81	94	306.31	83.77	0.31	0.09	3.63	0.99
	Outlet													

Appendix E: Water quality data collected from within Blackburn Lake

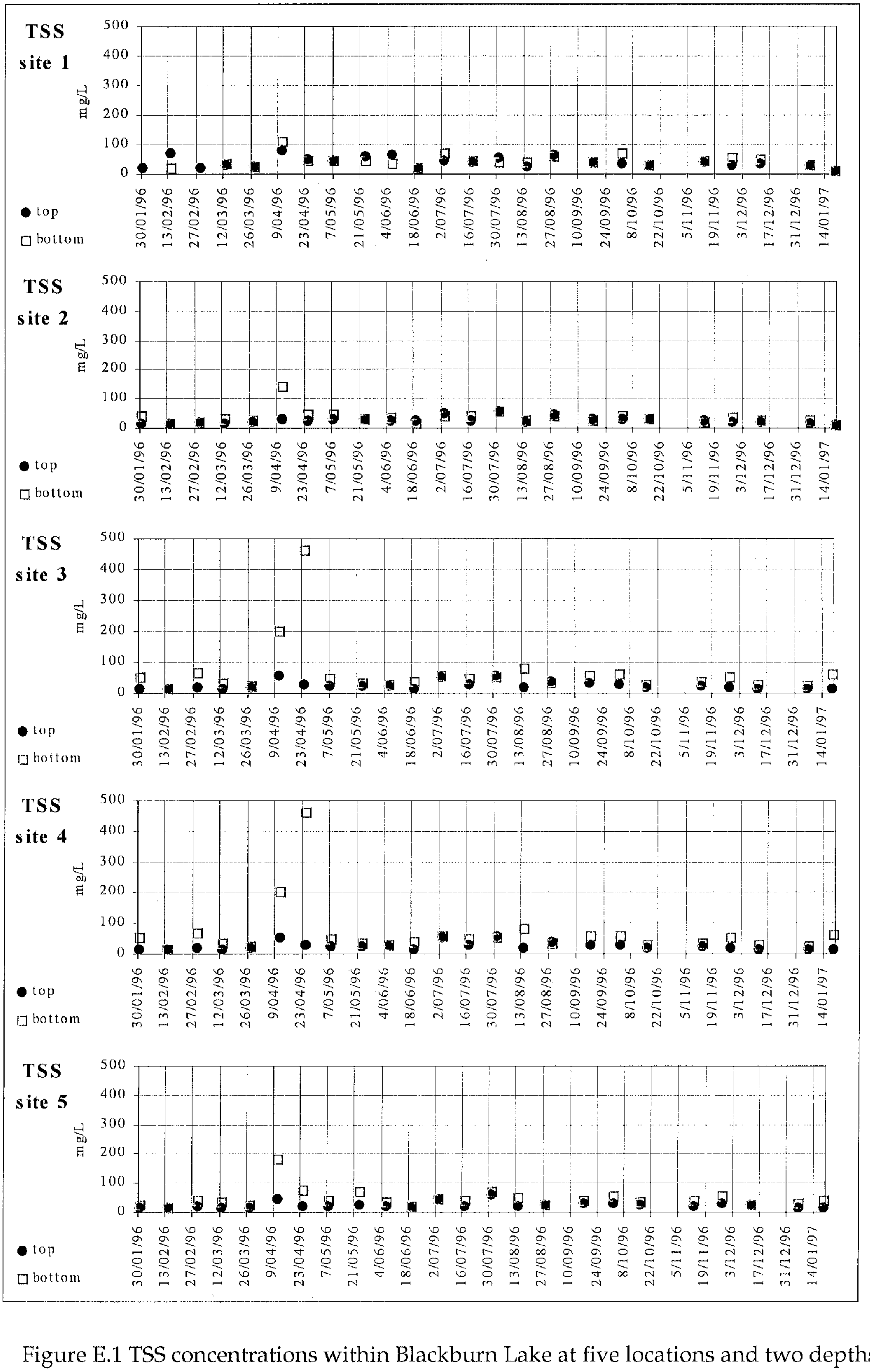


Figure E.1 TSS concentrations within Blackburn Lake at five locations and two depths

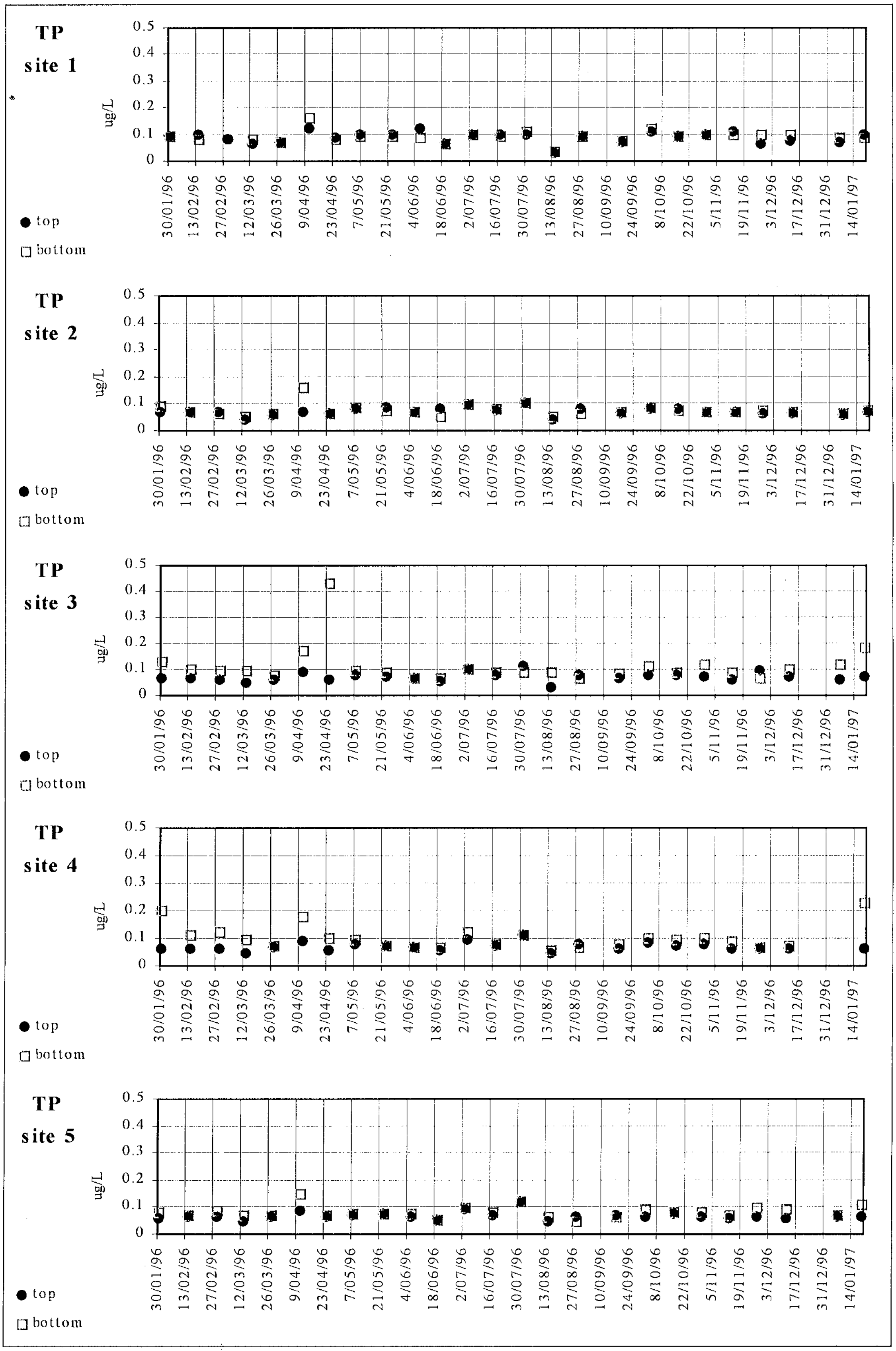


Figure E.2 TP concentrations within Blackburn Lake at five locations and two depths

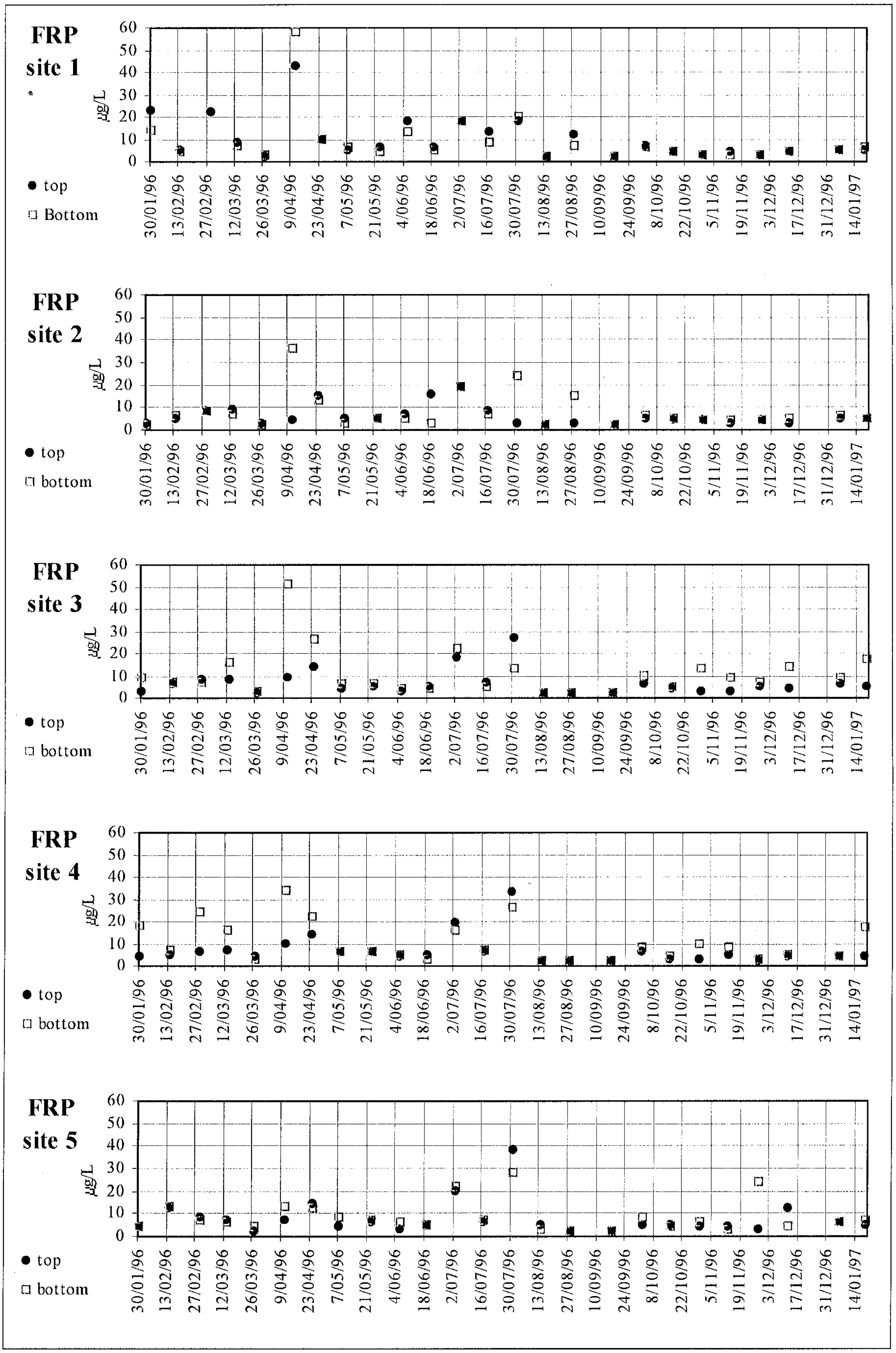


Figure E.3 FRP concentrations within Blackburn Lake at five locations and two depths

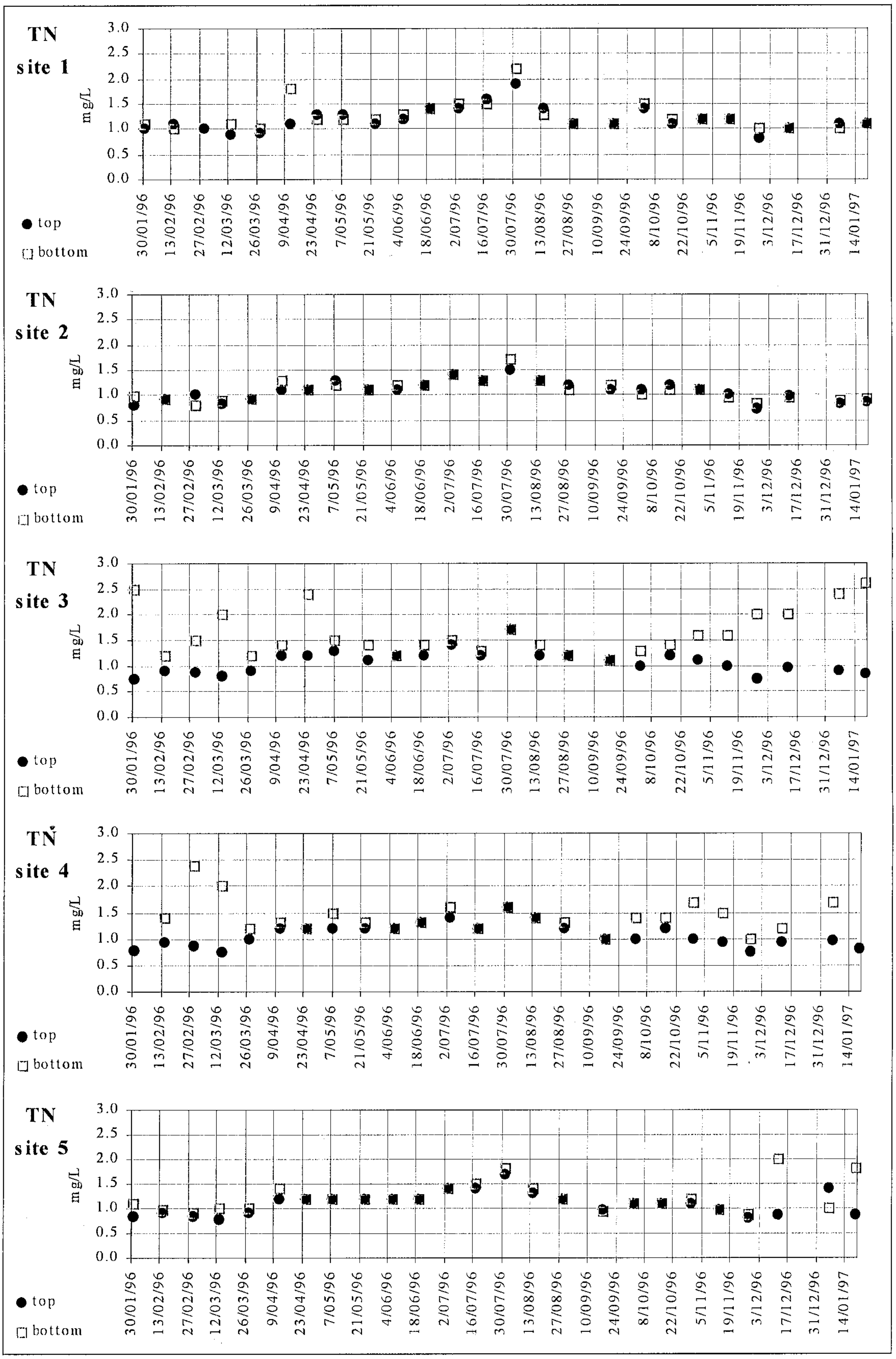


Figure E.4 TN concentrations within Blackburn Lake at five locations and two depths

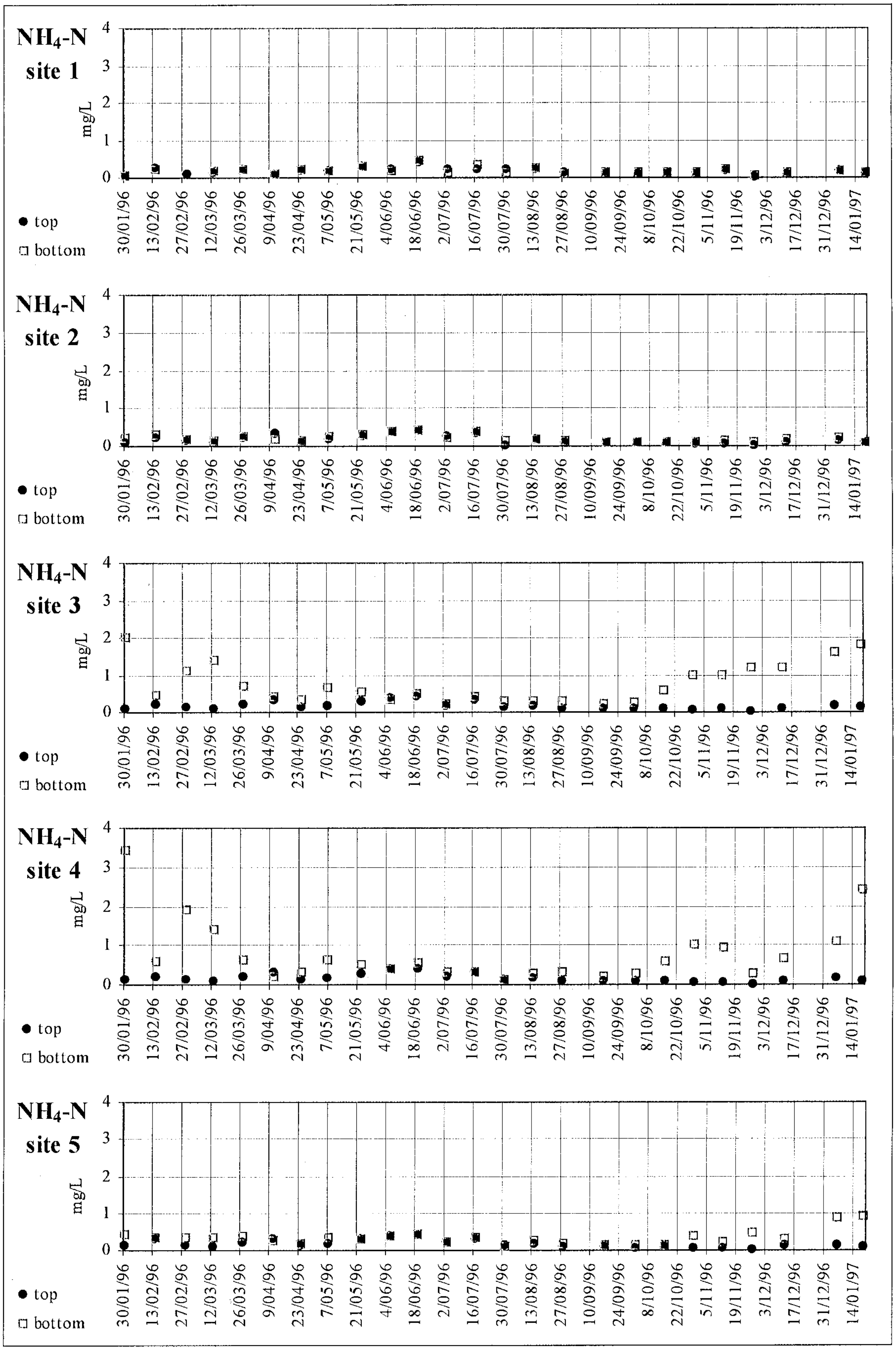


Figure E.5 Nitrates and nitrites concentrations within Blackburn Lake at five locations and two depths

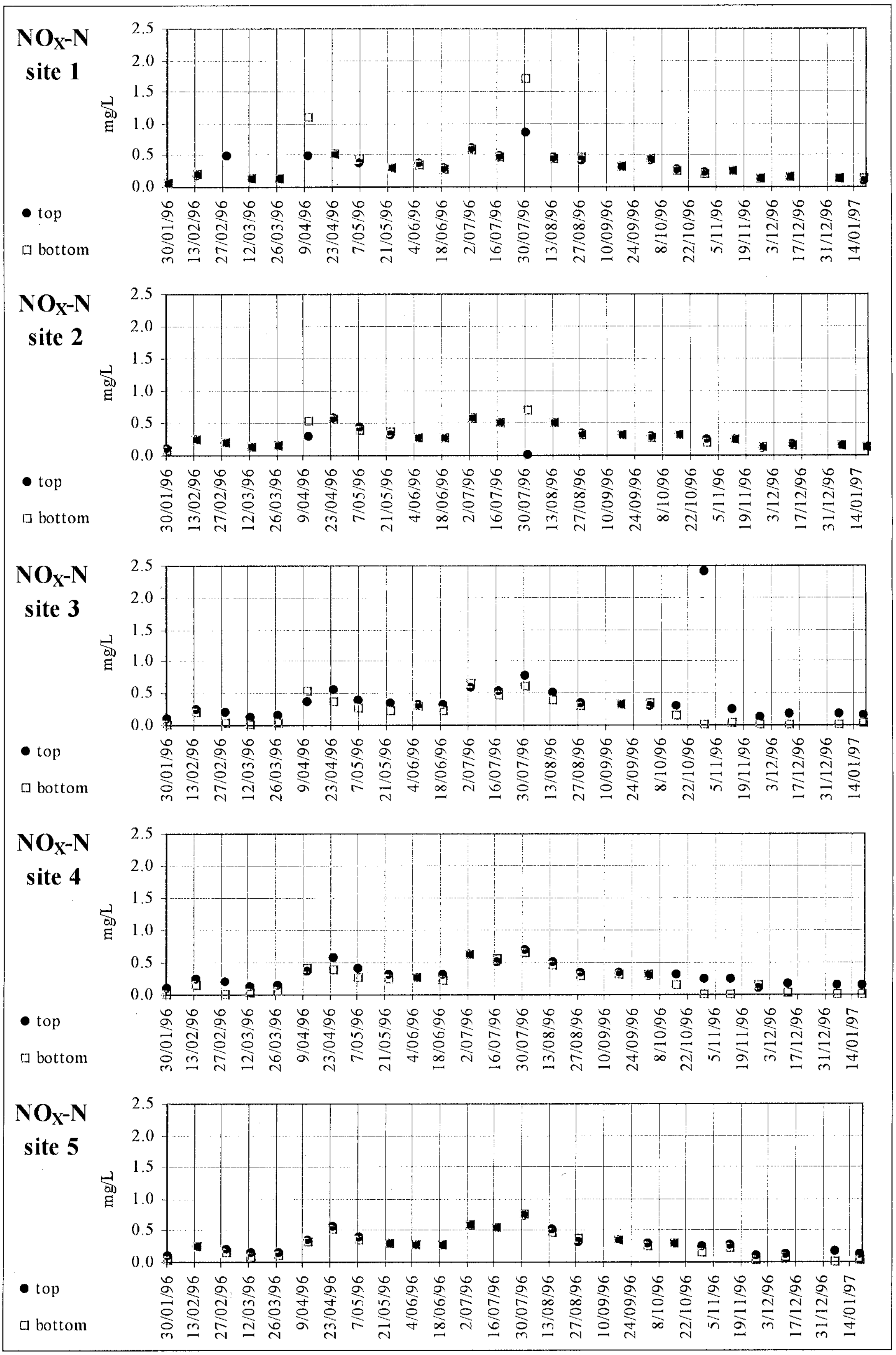


Figure E.6 Ammonia concentrations within Blackburn Lake at five locations and two depths

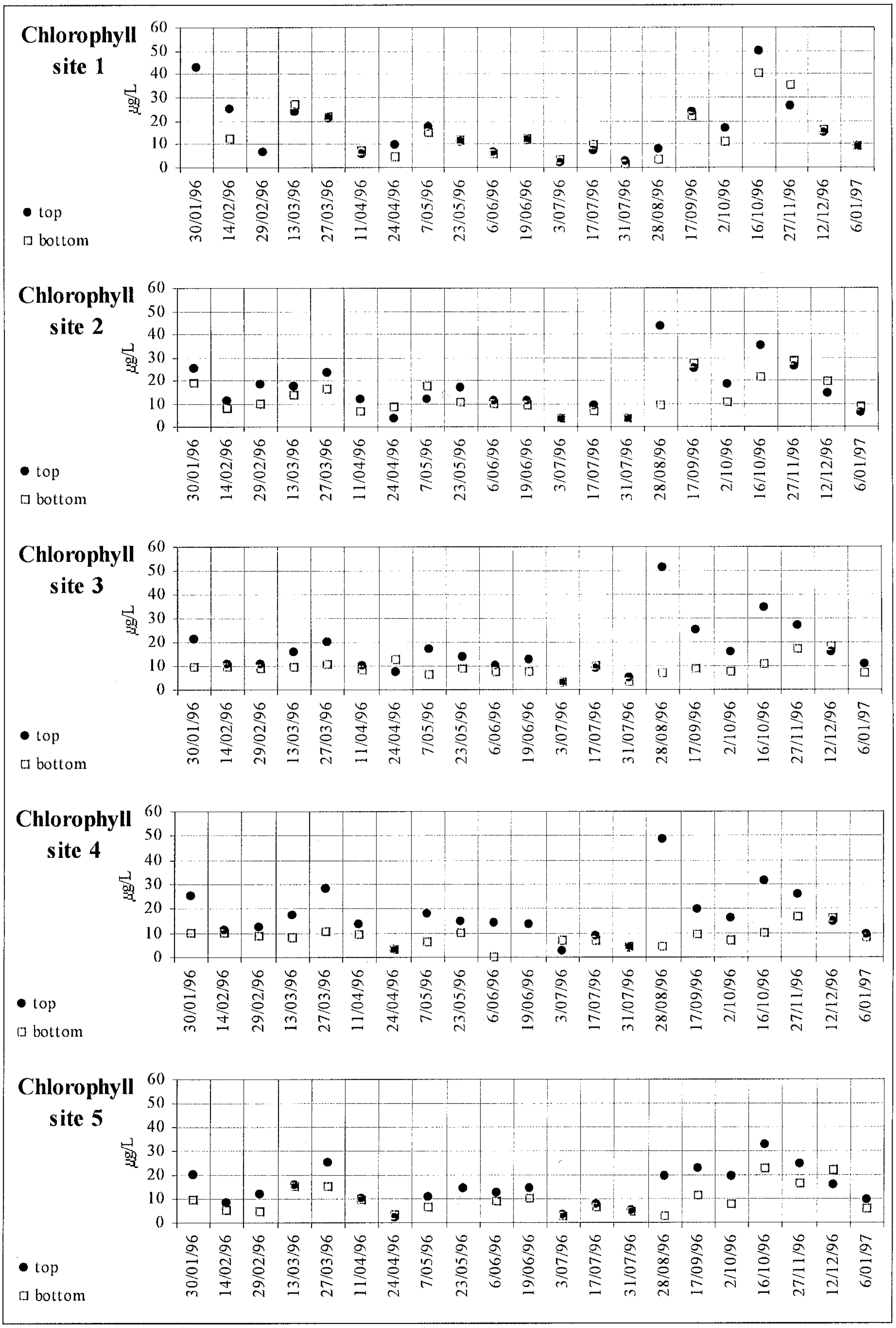


Figure E.7 Chlorophyll concentrations within Blackburn Lake at five locations and two depths

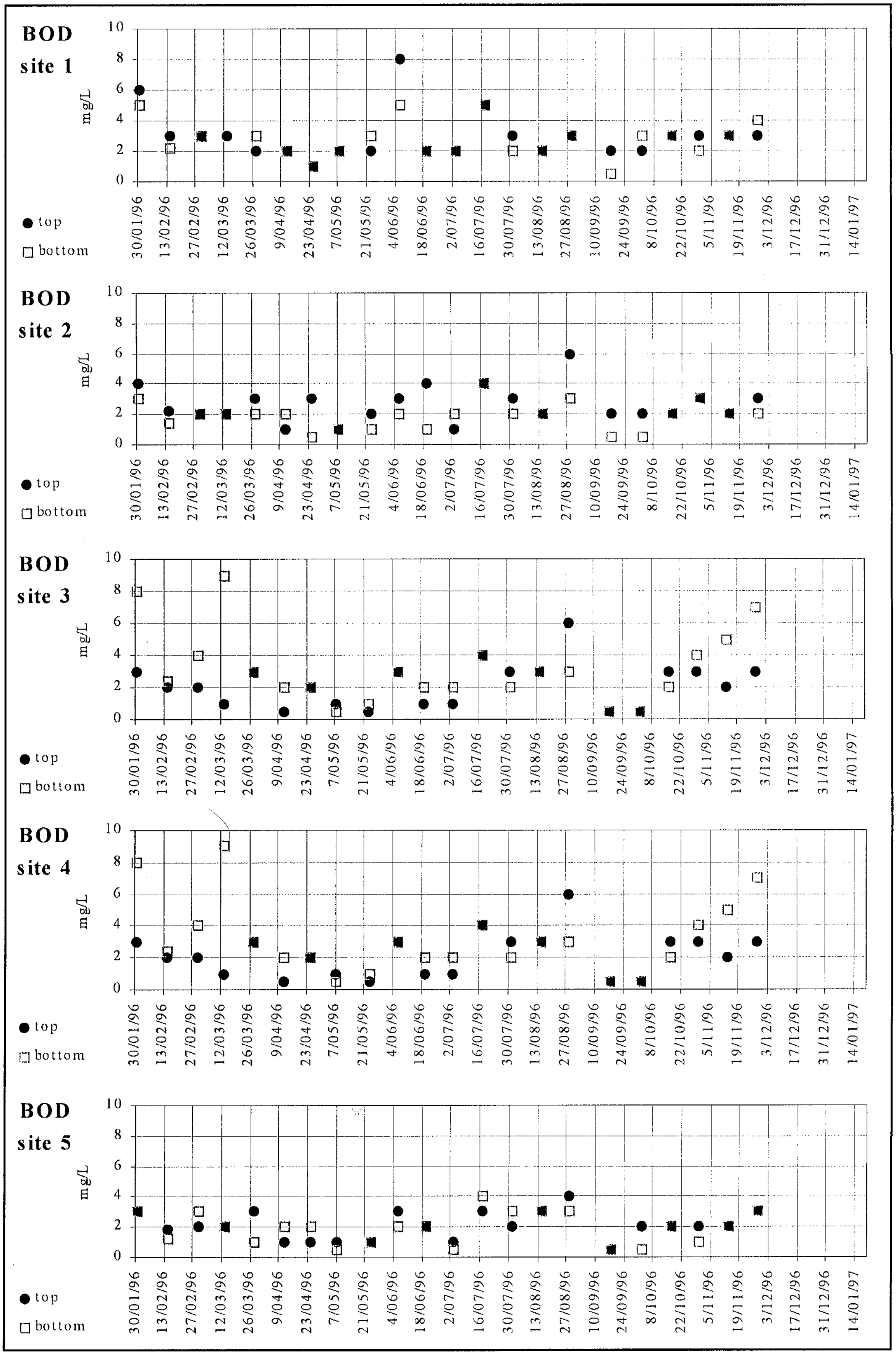


Figure E.8 BOD concentrations within Blackburn Lake at five locations and two depths

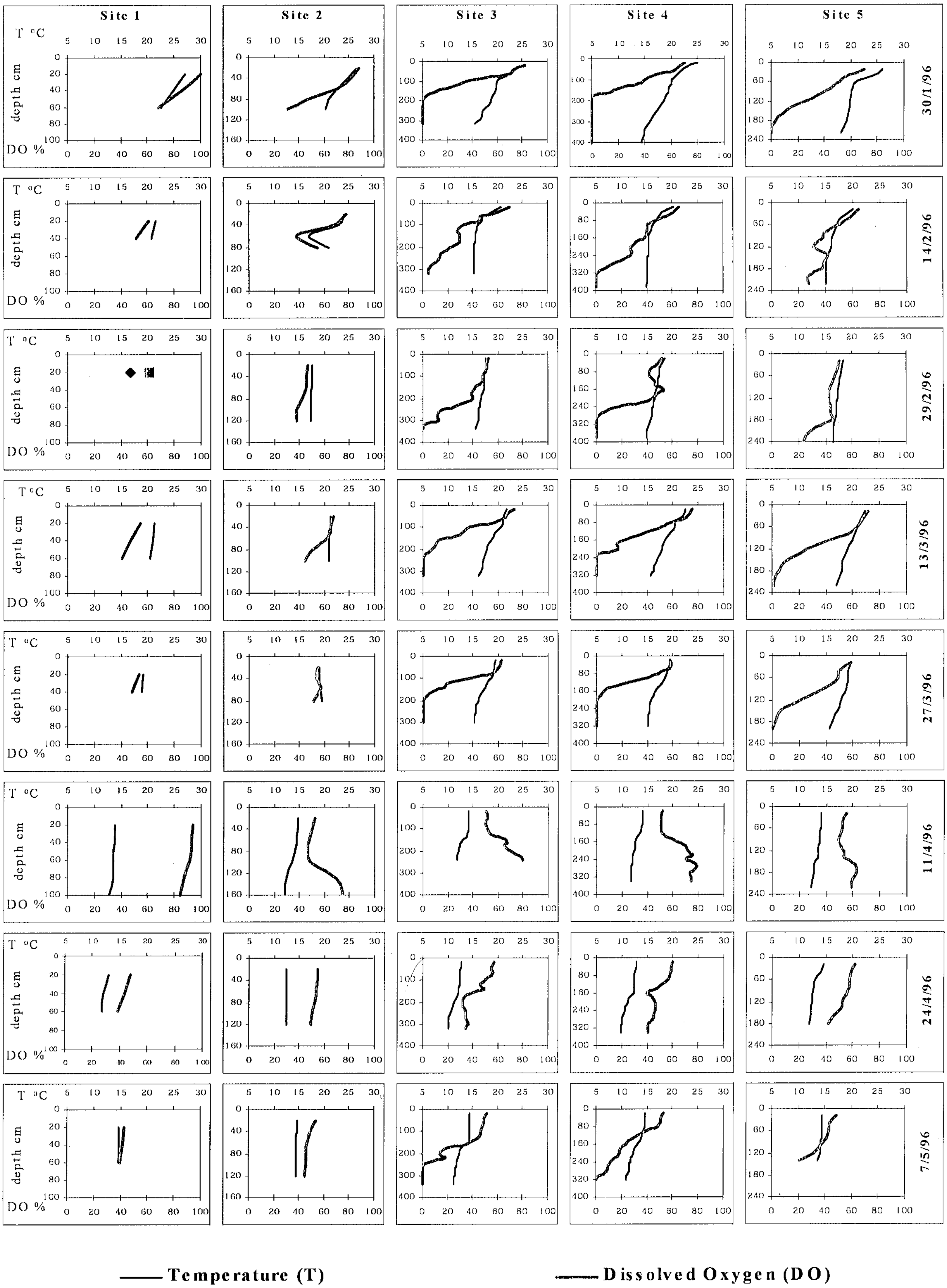


Figure E.9 Temperature and dissolved oxygen profiles.

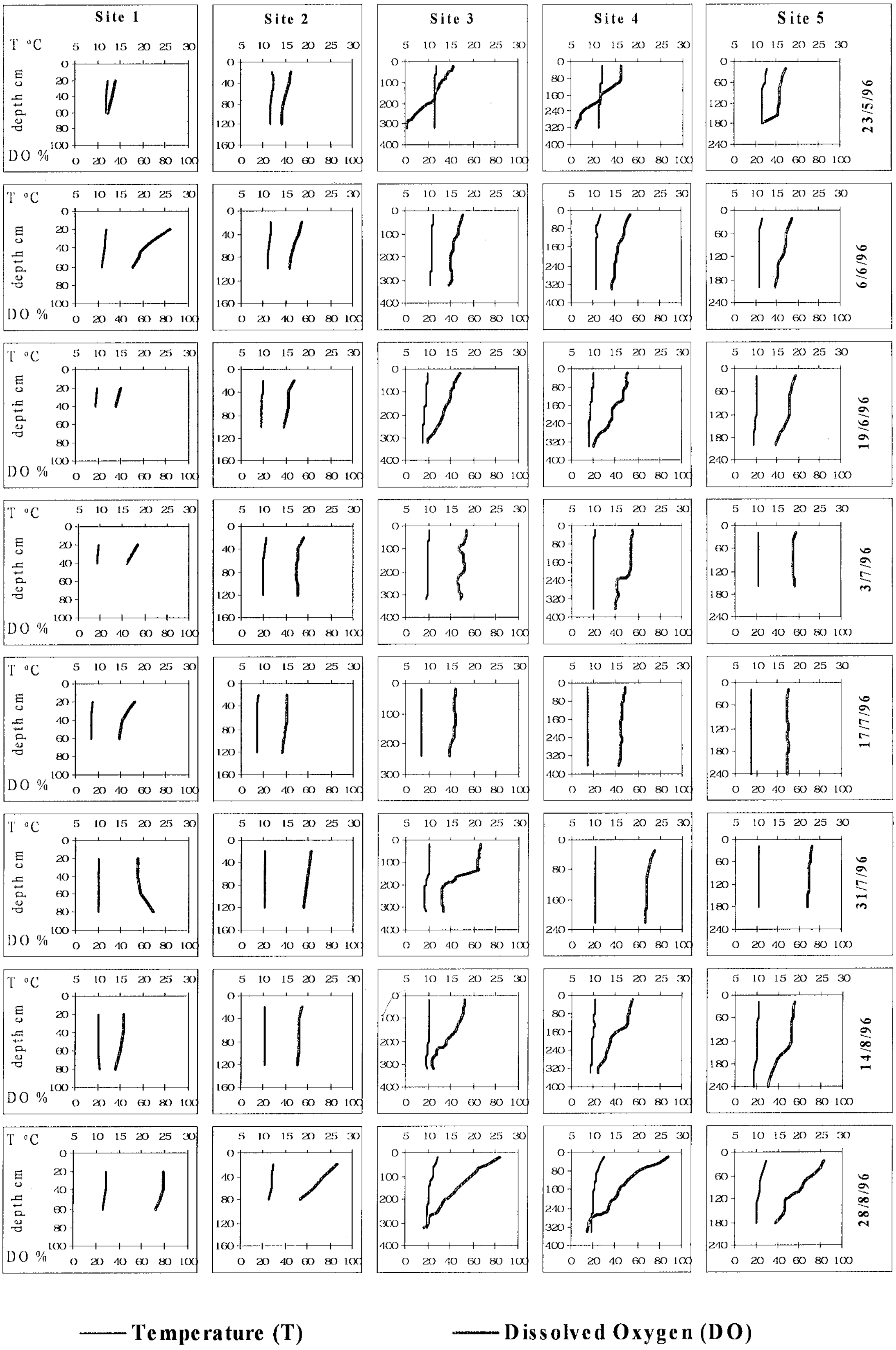


Figure E.9 Continued

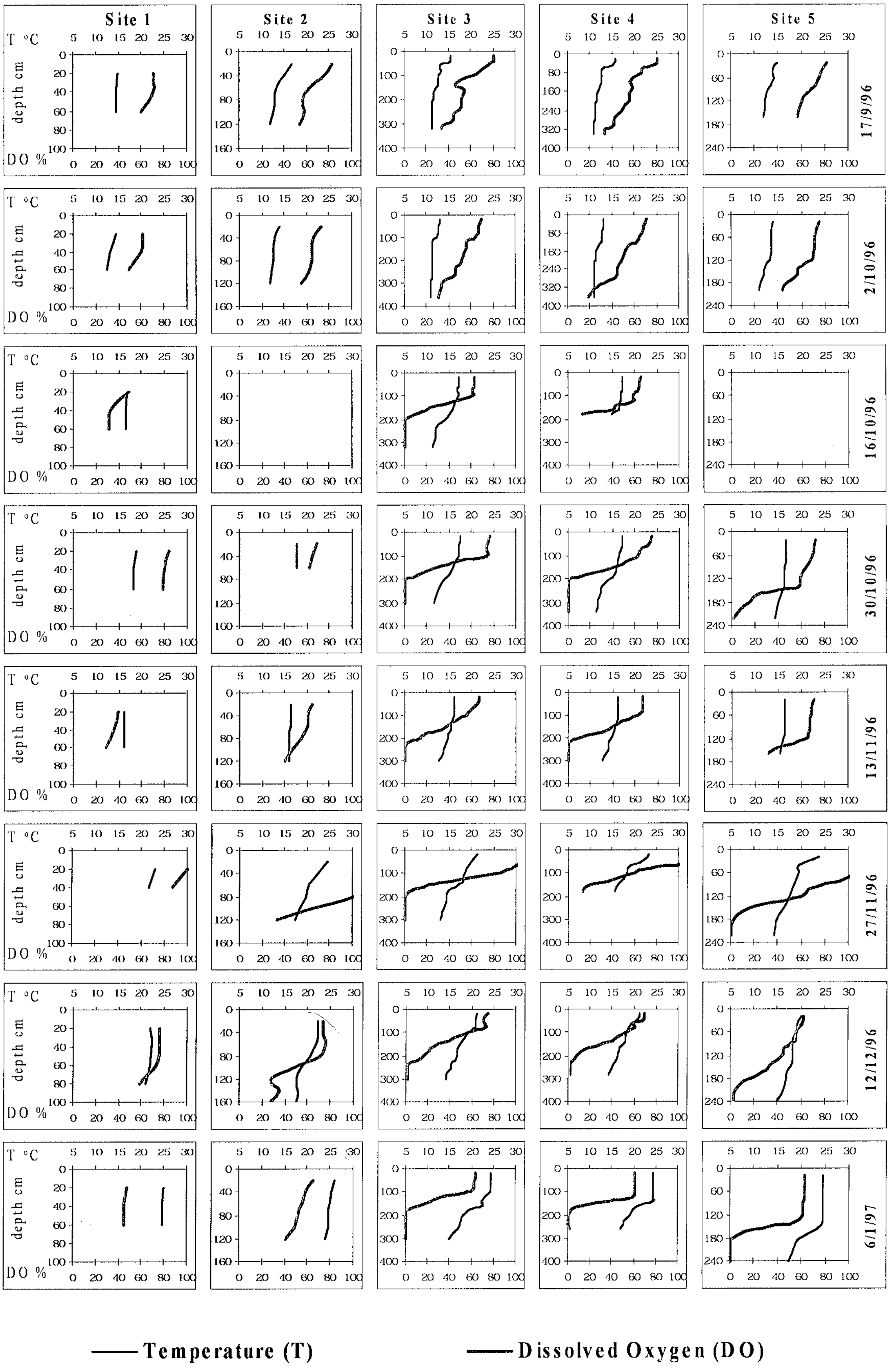


Figure E.9 continued