



Monitoring Urban Stormwater Inflows to The Barker Inlet Wetland in Adelaide, South Australia

by

B.G. Williams

B.E(Hons) Grad.I.E.(Aust)

A Thesis for the Degree of
Master of Engineering Science

Department of Civil and Environmental Engineering

The University of Adelaide

December 1997

Table of Contents

<i>Table of Contents</i>	<i>i</i>
Table of Appendices.....	vii
List of Figures.....	ix
List of Tables.....	xv
List of Photographs.....	xix
<i>Abstract</i>	<i>xxi</i>
<i>Statement of Originality</i>	<i>xxiii</i>
<i>Acknowledgements</i>	<i>xxv</i>

Chapter 1 : Introduction

1.1 Need for Research.....	1
1.2 Study Objectives - Phase 1.....	2
1.3 Methodology.....	3
1.4 Structure of Thesis.....	3

Chapter 2 : Literature Review

2.1 Introduction	7
2.2 The Urban Hydrologic Cycle.....	8
2.3 Urban Stormwater Quality Processes.....	9
2.3.1 Atmospheric Deposition	10
2.3.2 Interception	10
2.3.3 Buildup	11
2.3.4 Washoff.....	12
2.3.5 Transport.....	13
2.3.6 Storage	14
2.3.7 Receiving Waters.....	15
2.4 Stormwater Pollution : Important Parameters.....	16

2.4.1 Total Suspended Solids	16
2.4.1.1 Sources of Suspended Sediment.....	17
2.4.1.2 Particle Size Distribution.....	18
2.4.1.3 Effect of Land Use.....	22
2.4.2 Turbidity	24
2.4.3 Dissolved Solids	25
2.4.3.1 Sources of Dissolved Solids	27
2.4.3.2 Electrical Conductivity	27
2.4.4 Nutrients	28
2.4.4.1 Nitrogen.....	29
2.4.4.2 Nitrogen Fixation.....	30
2.4.4.3 Nitrification	30
2.4.4.4 Ammonification.....	31
2.4.4.5 Denitrification.....	33
2.4.4.6 Phosphorus	33
2.4.4.7 Eutrophication	34
2.4.4.8 Blue-Green Algae.....	35
2.4.4.9 Sources of Phosphorus	37
2.4.5 pH	38
2.4.6 Dissolved Oxygen.....	38
2.4.7 Heavy Metals.....	41
2.4.7.1 Mercury.....	42
2.4.7.2 Cadmium	43
2.4.7.3 Lead	43
2.4.8 Petroleum Products.....	44
2.4.9 Micro-organisms.....	45
2.4.10 Pesticides	46
2.5 Selection of the Water Quality Parameters for this Study	47
2.6 Monitoring Stormwater Quantity.....	47
2.6.1 Control Section	47
2.6.2 Direct Measurement of Flow.....	49
2.6.2.1 Artificial Controls.....	49
2.6.2.2 Velocity Area Method	50
2.6.2.3 Dilution Gauging Methods	50
2.6.3 Indirect Measurement of Flow.....	50
2.7 Relevant Stormwater Studies in South Australia.....	51

Chapter 3 : Catchment Description

3.1 Introduction	53
3.2 The Barker Inlet Wetland Catchment.....	54
3.2.1 North Arm East Drain.....	56
3.2.2 Hindmarsh Enfield Prospect Drain.....	59
3.2.3 Dunstan Road Drain	63
3.2.4 South Road North Arm West Drain.....	66
3.2.5 Land Uses within the Barker Inlet Wetland Catchments.....	69
3.2.6 Soil Types within the Catchments	72
3.2.7 The Barker Inlet Wetland	74
3.3 The Magazine Creek Wetland Catchment.....	79
3.3.1 Eastern Parade Drain	79
3.3.2 The Magazine Creek Wetland	82

Chapter 4 : The Monitoring Network

4.1 Introduction	83
4.2 Primary Aims of the Monitoring Project.....	84
4.3 Rainfall Measurement.....	84
4.3.1 Barker Inlet Wetland Catchment	84
4.3.2 Magazine Creek Wetland Catchment	87
4.4 Stormwater Monitoring Stations.....	88
4.4.1 Barker Inlet Wetland Catchment	88
4.4.1.1 Flow Measurement	88
4.4.1.2 Instrumentation Cage.....	89
4.4.1.3 Continuous Monitoring Probes.....	92
4.4.1.4 Data Logger and Controller	94
4.4.1.5 Automatic Water Samplers.....	97
4.4.1.6 Trash Racks	97
4.4.2 Magazine Creek Wetland Catchment	99
4.4.2.1 Flow Measurement	99
4.4.2.2 Continuous Probes.....	100
4.4.2.3 Data Loggers and Controller.....	100
4.4.2.4 Automatic Water Sampler	100
4.5 Field Visit Procedures	100

4.5.1 Station Site Sheets	101
4.6 Composite Sample Preparation.....	101
4.7 Water Sample Quality Testing	103
4.7.1 Water Sample Storage	103
4.7.2 Water Quality Parameters of Interest.....	104
4.7.3 Palintest System.....	104
4.7.4 Hach System.....	105
4.8 In House Laboratory Testing	105
4.8.1 Total Suspended Solids Testing	105
4.8.2 Turbidity Testing	106
4.8.3 Total Phosphorous Testing	106
4.9 External Testing.....	107
4.9.1 Nutrients	107
4.9.2 Metals	107
4.9.3 Polyaromatic Hydrocarbons	108
4.10 Archiving Data.....	108
4.10.1 Hydsys Database.....	108
4.10.2 Excel Spreadsheets	109
4.11 Problems - Data Collection ‘Gremlins’.....	109

Chapter 5 : Channel Hydrology

5.1 Introduction	111
5.2 Flow Measurement	111
5.2.1 Broad Crested Weir Equations	112
5.3 Stage/Discharge Rating Tables.....	116
5.4 Backwater Problems.....	116
5.4.1 Trash Racks	117
5.5 Ultrasonic Velocity Probes.....	120
5.5.1 Doppler Theory.....	120
5.5.2 Unidata Doppler Probe	121
5.6 Flume Testing.....	122
5.6.1 Test Procedure	124

5.6.2 Test Results.....	124
5.7 Field Application.....	126
5.7.1 Cross Section Velocity Variation	127
5.8 Improving Stage/discharge Rating Curves	130
5.9 Summary of North Arm East Flow Measurement.....	134
5.10 Flow Measurement in the Hindmarsh Enfield Prospect Drain.....	134

Chapter 6 : Runoff Routing Model

6.1 Introduction	139
6.2 Data Availability	139
6.2.1 Stage 1	140
6.2.2 Stage 2	141
6.3 Rainfall Distribution	141
6.4 Event Volumes	142
6.5 RAFTS-XP Program	143
6.6 Modelling the Events Using RAFTS-XP.....	144
6.6.1 The Calibration Approach	145
6.6.2 Calibrated Model Parameters	145
6.6.3 Parameter Selection Technique	149
6.6.4 Peak Difference Weighting Technique.....	149
6.6.5 North Arm East Catchment Model Parameters	150
6.6.6 Parameter Verification.....	151
6.7 New Years Eve Storm.....	153
6.8 Investigation Into the Backwater Effect.....	155

Chapter 7 : Water Quality Results

7.1 Introduction	159
7.2 Rainfall and Runoff Characteristics	160
7.3 Sequential Samples	164
7.3.1 Sequential Sample Results.....	164

7.3.1.1 Total Suspended Solids	165
7.3.1.2 Turbidity	165
7.3.1.3 Total Phosphorus	166
7.3.2 Probability Curves	166
7.3.3 Sequential Sample Parameter Correlations	169
7.3.3.1 Turbidity Vs Total Suspended Solids	170
7.3.3.1.1 Turbidity Vs Total Phosphorus.....	174
7.3.3.1.2 Total Suspended Solids Vs Total Phosphorus.....	176
7.3.4 Water Quality Changes During Events.....	178
7.3.4.1 First Flush Phenomena	180
7.3.4.2 Hysteresis Plots.....	181
7.4 Event Mean Concentrations	182
7.4.1 Event Mean Concentration Results	182
7.4.2 EMC Probability Curves	188
7.4.3 Relative Contaminant Proportions	189
7.4.4 Event Mean Concentration Parameter Correlations	192
7.4.5 Discussion of Event Mean Concentration Results	194
7.4.5.1 Nutrients	194
7.4.5.2 Metals	197
7.4.6 Polycyclic Aromatic Hydrocarbons.....	199
7.5 Event Contaminant Loads	201
7.6 Annual Pollutant Loads	204
7.7 Distribution of Annual Contaminant Load.....	206
7.8 Continuous Real Time Monitoring	211
7.8.1 Overview of the Continuous Real Time Data Set	212
7.8.2 Electrical Conductivity	212
7.8.3 pH	215
7.8.4 Dissolved Oxygen.....	215
7.8.5 Water Temperature	216
7.8.6 Turbidity	217
7.8.6.1 Relationship Between Continuous and Laboratory Turbidity	220

Chapter 8 : Conclusions and Recommendations

8.1 Conclusions.....	225
8.2 Recommendations.....	230
8.3 Current and Future Research Phases.....	231
References.....	235

Table of Appendices

Appendix A : Wetland Pond Volumes
Appendix B : Station Site Sheets / Field Procedures
Appendix C : Stage / Discharge Rating Tables
Appendix D : Isohyetal Rainfall Distributions
Appendix E : RAFTS-XP Model Outputs
Appendix F : Pluviometer Data Set
Appendix G : Sequential Sample Parameter Correlations
Appendix H : Sequential Sample Results
Appendix I : Sequential Sample Hysteresis Plots
Appendix J : Event Mean Concentration Results
Appendix K : Event Mean Concentration Probability Curves
Appendix L : Event Mean Concentration Correlations
Appendix M :Event Load Probability Curves
Appendix N : Continuous Real Time Monitoring Data Set

List of Figures

Figure 2.1 : Schematic drawing of the hydrologic cycle. (Source : Allan, 1995).....	8
Figure 2.2 : Particle size distribution (>20 microns) in the Pakuranga catchment, Auckland. (Source : McKergow, 1994).....	19
Figure 2.3 : Average percentage of contaminant concentration associated with stormwater particles <20 microns for three storms in the Pakuranga catchment, Auckland. (Source : McKergow, 1994).....	19
Figure 2.4 : Particle size distribution (>20 microns) at the Pacific Steel site, Auckland (Source : Leersnyder, 1993).....	20
Figure 2.5 : Particle size distribution (>20 microns) at the Hayman Park site, Auckland (Source : Leersnyder, 1993).....	21
Figure 2.6 : Average percentage of contaminant concentration associated with stormwater particles less than 20 microns for all storms at Pacific Steel (PS) and Hayman Park (HP). (Source : Leersnyder 1993).....	21
Figure 2.7 : Averaged particle size distributions (Source : Passfield and Phillips 1996, unpublished)	23
Figure 2.8 : Composite sample concentrations of Lead for particles less than and greater than 44µm. (Source : Passfield and Phillips 1996, unpublished).....	24
Figure 2.9 : Electrical Conductivity versus the concentration of major ions for some West African rivers. (From Grove, 1972).....	27
Figure 2.10 : Simplified Nitrogen Cycle. Adapted from Gamble (1997).....	32
Figure 2.11 : Simplified Phosphorus Cycle. Adapted from Gamble (1997).	34
Figure 3.1 : The Barker Inlet Wetland Catchment Map	55
Figure 3.2 : The Barker Inlet Wetland Land Use Map.....	71
Figure 3.3 : Soil Association map of the Barker Inlet Wetland Catchment	73
Figure 3.4 : Schematic drawing of the Barker Inlet Wetland.....	76
Figure 4.1 : Rain Gauge location in the Barker Inlet Wetland catchment.....	86
Figure 4.2 : Broad Crested Weir.....	89
Figure 4.3 : Block diagram of Instrumentation.....	96
Figure 4.4(a) : Sequential samples during a storm event	102

Figure 4.4(b) : Calculating flow weighting for composite sample.....	102
Figure 5.1 : Dimensions of shallow V-notch weir section	113
Figure 5.2 : Broad Crested weir with Trapezoidal control section.....	114
Figure 5.3 : Triangular profile flat-V weir	115
Figure 5.4 : Diagrammatic representation of Ultrasonic Velocity Probe	120
Figure 5.5 : Velocity Test Layout in Adelaide University Flume	123
Figure 5.6 : Ultrasonic Velocity probes facing upstream.....	125
Figure 5.7 : Ultrasonic Velocity probes facing downstream.....	126
Figure 5.8 : Location of the velocity probes across the cross section of North Arm East Drain.....	127
Figure 5.9 : AU504101, North Arm East Drain storm event 24/5/95	127
Figure 5.10 : AU504101, North Arm East Drain storm event 25/5/95	128
Figure 5.11 : AU504101, North Arm East Drain storm event 16/7/95	128
Figure 5.12 : Expected Velocity Variation across the channel cross section.....	129
Figure 5.13 : Velocity Distribution A before the construction of trash racks in the North Arm East (AU504101) Drain.....	130
Figure 5.14 : Velocity Distribution B after the construction of trash racks in the North Arm East (AU504101) Drain.....	131
Figure 5.15 : Velocity Distributions A and B before and after the construction of trash racks in the North Arm East Drain (AU504101).....	132
Figure 5.16 : Stage Height record for event 13/4/96 in the North Arm East (AU504101) Drain	133
Figure 5.17 : Velocity Distribution B after the construction of trash racks in the HEP Drain (AU504102).....	135
Figure 5.18 : Flow rating curves, Hindmarsh Enfield Prospect (AU504102) Drain.....	135
Figure 5.19 : Velocity distribution of event 6/2/97 compared to velocity distribution B in the Hindmarsh Enfield Prospect (AU504102) Drain	136
Figure 6.1 : Rainfall Volume Vs Runoff Volume	143
Figure 6.2 : Calibrated event 1, 12/7/94	146
Figure 6.3 : Calibrated event 2, 8-9/6/95.....	147
Figure 6.4 : Calibrated event 3, 3/5/95	147
Figure 6.5 : Calibrated event 4, 25/5/95	148

Figure 6.6 : Calibrated event 5, 21/7/95	148
Figure 6.7 : RAFTS-XP model re-applied to calibration Event 3, 3/5/95.....	152
Figure 6.8 : RAFTS-XP model applied to calibration Verification Event 3, 4/4/95	153
Figure 6.9 : Predicted runoff from the 1995 New Years Eve event	154
Figure 6.10 : Backwatered event 1, 13/4/96.....	155
Figure 6.11 : Backwatered event 2, 31/7/96.....	156
Figure 6.12 : Backwatered event 3, 6/12/96.....	156
Figure 6.13 : Backwatered event 4, 4/7/96.....	157
Figure 7.1 : Event runoff volume (ML) probability curves.....	162
Figure 7.2 : Probability curve for event runoff volumes from the North Arm East (AU504101) Catchment (ML).....	163
Figure 7.3 : Sequential sample total suspended solids (mg/L) probability curves	167
Figure 7.4 : Sequential sample turbidity (NTU) probability curves.....	168
Figure 7.5 : Sequential sample total phosphorus (mg/L) probability curves.....	169
Figure 7.6 : Correlation between total suspended solids and turbidity for all sequential sample data from the North Arm East Catchment (AU504101).....	170
Figure 7.7 : Correlation between total suspended solids and turbidity for all sequential sample data from the Hindmarsh Enfield Prospect Catchment (AU504102).....	171
Figure 7.8 : Correlation between total suspended solids and turbidity for all sequential sample data from the Dunstan Road Catchment(AU504103)	171
Figure 7.9 : Correlation between total suspended solids and turbidity for all sequential sample data from the North Arm West Catchment (AU504104)	172
Figure 7.10 : Comparison of correlations between TSS and turbidity	173
Figure 7.11 : Correlation between turbidity and total phosphorus for all sequential sample data from the North Arm West Catchment (AU504104)	174
Figure 7.12 : Correlation between turbidity and total phosphorus for sequential samples during event 5-6/7/96 in the North Arm East Drain (AU504101).....	176
Figure 7.13 : Correlation between total suspended solids and total phosphorus for all sequential sample data from the North Arm West Catchment (AU504104).....	177
Figure 7.14 : Correlation between total suspended solids and total phosphorus for sequential samples during event 28-29/7/96 in the North Arm East Drain (AU504101).....	178
Figure 7.15 : Total suspended solids and turbidity concentration changes during event 13/4/97 in the North Arm East Drain (AU504101).....	179

Figure 7.16 : Total phosphorus concentration changes during event 13/4/97 in the North Arm East Drain (AU504101).....	179
Figure 7.17 : Hysteresis plot of total phosphorus during event 13/4/97 in the North Arm East Drain (AU504101).....	181
Figure 7.18 : Total zinc event mean concentration (mg/L) probability curves	189
Figure 7.19 : EMC correlation between Total Suspended Solids and Lead in the North Arm East Drain (AU504101).....	194
Figure 7.20 : Lead (Pb) event load per unit area (mg/m ²) probability curves	203
Figure 7.21 : Nitrate + Nitrite Event Load Probability Curve (mg/m ²).....	204
Figure 7.22 : Distribution of event runoff volumes in the North Arm East (AU504101) Catchment for the 18 month period to 6/2/97	207
Figure 7.23 : Distribution of total nitrogen event loads in the North Arm East (AU504101) Catchment.....	208
Figure 7.24 : Distribution of total phosphorus event loads in the North Arm East (AU504101) Catchment.....	208
Figure 7.25 : Distribution of copper (Cu) event loads in the North Arm East (AU504101) Catchment.....	209
Figure 7.26 : Distribution of lead (Pb) event loads in the North Arm East (AU504101) Catchment.....	209
Figure 7.27 : Continuous electrical conductivity and flow during event 21/7/95 in the North Arm East (AU504101) Drain	213
Figure 7.28 : Continuous electrical conductivity and flow during event 2-3/5/95 in the North Arm East (AU504101) Drain	214
Figure 7.29 : Continuous electrical conductivity and flow during event 2-3/5/95 in the North Arm West (AU504104) Drain	214
Figure 7.30 : pH level in event 29/3/95 in the North Arm East (AU504101) Catchment.....	215
Figure 7.31 : Continuous dissolved oxygen and flow during event 25/5/95 in the North Arm East (AU504101) Drain.....	216
Figure 7.32 : Daily water temperature fluctuations in the North Arm East (AU504101) Drain.	217
Figure 7.33 : Low water temperature entering the wetland system from event 6/2/97 in the North Arm East (AU504101) Drain	217
Figure 7.34 : Continuous turbidity and flow during event 14/9/95 in the North Arm East (AU504101) Drain.....	218

Figure 7.35 : Continuous turbidity and flow during event 25/5/95 in the North Arm East (AU504101) Drain.....	219
Figure 7.36 : Continuous turbidity and laboratory TSS and turbidity during event 12/5/96 in the North Arm East (AU504101) Drain	220
Figure 7.37 : Relationship between continuous turbidity and laboratory measured turbidity during event 12/5/96 in the North Arm East (AU504101) Drain.....	220
Figure 7.38 : Continuous turbidity and laboratory TSS and turbidity during event 22/6/96 in the North Arm East (AU504101) Drain	221
Figure 7.39 : Relationship between continuous turbidity and laboratory measured turbidity during event 22/6/96 in the North Arm East (AU504101) Drain.....	221
Figure 7.40 : Continuous turbidity and laboratory TSS and turbidity during event 23/6/96 in the North Arm East (AU504101) Drain	222
Figure 7.41 : Relationship between continuous turbidity and laboratory measured turbidity during event 23/6/96 in the North Arm East (AU504101) Drain.....	222
Figure 7.42 : Continuous turbidity and laboratory TSS and turbidity during event 25/4/96 in the North Arm East (AU504101) Drain	223
Figure 7.43 : Relationship between continuous turbidity and laboratory measured turbidity during event 25/4/96 in the North Arm East (AU504101) Drain.....	223

List of Tables

TABLE 2.1 : Particle Size Fractions. Adapted from Chapman (1996).....	18
TABLE 2.2 : Typical concentrations of major ions in rainfall (mg/L).....	26
TABLE 2.3 : Nitrogen forms and concentrations in stormwater.....	29
TABLE 2.4 : Summary of various Cyanobacterial toxins and their effects (Source : Maier and Dandy, 1994)	36
TABLE 2.5 : The concentration of oxygen in fresh and salt water at saturation, at varying temperature. (Adapted from Laidler, 1991).....	39
TABLE 2.6 : Percentage oxygen saturation and water quality. (Adapted from Laidler, 1991).	40
TABLE 2.7 : Range of Dissolved Oxygen concentrations designated for water usage. (Adapted from NCSU, 1997).....	40
TABLE 2.8 : Polycyclic aromatic hydrocarbons in stormwater.....	45
TABLE 3.1 : Summary of Catchment and Station details.....	54
TABLE 3.2 : Land Use in the Barker Inlet Wetland catchment.....	69
TABLE 3.3 : Summary of Land Uses in the Barker Inlet Wetland Catchment.....	70
TABLE 4.1 : Pluviometers located in the Barker Inlet Wetland Catchment.....	87
TABLE 4.2 : Pluviometers located in the Magazine Creek Wetland Catchment.....	87
TABLE 4.3 : Details of continuous monitoring probes.....	92
TABLE 5.1 : Cease to flow levels in of the monitored open channels.....	115
TABLE 5.2 : Velocity of sound in water (m/s) at atmospheric pressure.....	122
TABLE 6.1 : Events Modelled in Stage 1	140
TABLE 6.2 : Verification Events for Stage 1.....	140
TABLE 6.3 : Storms modelled in Stage 2	141
TABLE 6.4 : Rainfall Depth, Volume and Runoff Volume.....	142
TABLE 6.5 : Calibrated Model Parameters for Stage 1.....	146
TABLE 6.6 : Weight given to Percentage Error in Peak Flow Prediction.....	150
TABLE 6.7 : Weighting calibrated events by parameter selection technique.....	150

TABLE 6.8 : The North Arm East Catchment Parameters.	151
TABLE 6.9 : RAFTS-XP parameters re-applied to calibration events.	151
TABLE 6.10 : RAFTS-XP parameters applied to verification events.	152
TABLE 7.1 : Rainfall during monitoring program.....	160
TABLE 7.2 : Average rainfall to runoff time lag in each Catchment	161
TABLE 7.3 : Sequential sample results from North Arm East Catchment (AU504101).....	164
TABLE 7.4 : Sequential sample results from Hindmarsh Enfield Prospect Catchment (AU504102).....	164
TABLE 7.5 : Sequential sample results from Dunstan Road Catchment (AU504103)	164
TABLE 7.6 : Sequential sample results from North Arm West Catchment (AU504104)	165
TABLE 7.7 : Sequential sample results from Eastern Parade Catchment (AU504201)	165
TABLE 7.8 : Relationships between turbidity and total suspended solids.....	172
TABLE 7.9 : Summary table of relationships between turbidity and total phosphorus.....	175
TABLE 7.10 : Individual events with good correlations between turbidity and total phosphorus in the North Arm East (AU504101) Catchment	175
TABLE 7.11 : Summary table of relationships between total suspended solids and total phosphorus.....	177
TABLE 7.12 : Individual events with good correlations between total suspended solids and total phosphorus in the North Arm East (AU504101) Catchment	178
TABLE 7.13 : North Arm East Drain (AU504101) Event Mean Concentrations (mg/L)	183
TABLE 7.14 : HEP Drain (AU504102) Event Mean Concentrations (mg/L)	184
TABLE 7.15 : Dunstan Road Drain (AU504103) Event Mean Concentrations (mg/L).....	185
TABLE 7.16 : North Arm West Drain (AU504104) Event Mean Concentrations (mg/L)...	186
TABLE 7.17 : Eastern Parade Drain (AU504201) Event Mean Concentrations (mg/L).....	187
TABLE 7.18 : Summary of event mean concentration results, median values (mg/L).....	188
TABLE 7.19 : Nutrient proportions (%) in urban stormwater	190
TABLE 7.20 : Metal proportions (%) in urban stormwater entering the Barker Inlet Wetland..	191
TABLE 7.21 : Low concentration heavy metal proportions (%) in urban stormwater entering the Barker Inlet Wetland.....	192
TABLE 7.22 : Correlations between parameter EMC in the North Arm East Catchment (AU504101).....	193

TABLE 7.23 : PAH event mean concentrations in the North Arm East (AU504101) Catchment.....	200
TABLE 7.24 : PAH event mean concentrations in the Dunstan Road (AU504103) Catchment	201
TABLE 7.25 : Summary of event loads entering the Barker Inlet Wetland, median values (kg)	202
TABLE 7.26 : Estimated Annual Yield of Heavy Metals (mg/m ²).....	205
TABLE 7.27 : Estimated Annual Yield of Nutrients (mg/m ²)	206
TABLE 7.28 : Build up time for each event in the North Arm East (AU504101) Catchment....	211
TABLE 7.29 : Continuous Probe Data Set.....	212
TABLE 8.1 : Summary of event mean concentration results, median values (mg/L).....	227
TABLE 8.2 : Estimated annual yield of nutrients and heavy metals (mg/m ²).....	228
TABLE 8.3 : The North Arm East Catchment Parameters for the RAFTS-XP model	229

List of Photographs

Photograph 3.1 : The North Arm East Drain (AU504101) monitoring station	57
Photograph 3.2 : Upstream of the North Arm East monitoring station, facing downstream..	57
Photograph 3.3 : Typical residential street in The North Arm East Catchment	58
Photograph 3.4 : Typical residential street in The North Arm East Catchment	58
Photograph 3.5 : Hindmarsh Enfield Prospect Drain (AU504102) monitoring station.....	60
Photograph 3.6 : Facing Downstream of the HEP monitoring station	60
Photograph 3.7 : The large swale drain upstream of the HEP Drain under low flow conditions. Facing Upstream.	61
Photograph 3.8 : The swale drain during a storm event. Facing Upstream.....	61
Photograph 3.9 : Main road in The Hindmarsh Enfield Prospect Catchment	62
Photograph 3.10 : Typical residential street in The Hindmarsh Enfield Prospect Catchment	62
Photograph 3.11 : Dunstan Road Drain (AU504103) monitoring station. Facing downstream.....	64
Photograph 3.12 : Facing upstream of the Dunstan Road monitoring station.....	64
Photograph 3.13 : Major truck park and refuelling station in The Dunstan Road Catchment	65
Photograph 3.14 : Major truck park and refuelling station in The Dunstan Road Catchment	65
Photograph 3.15 : The monitoring station at the North Arm West Drain (AU504104). Facing Upstream.....	67
Photograph 3.16 : Upstream of the North Arm West Drain. Facing Downstream.....	67
Photograph 3.17 : Typical residential street in The South Road North Arm West catchment	68
Photograph 3.18 : Typical residential street in The South Road North Arm West catchment	68
Photograph 3.19 : The Barker Inlet Wetland. Photograph taken from the South Road Connector facing South.	77
Photograph 3.20 : The Barker Inlet Wetland. Photograph taken from the South Road Connector facing South-West.....	77
Photograph 3.21 : The Barker Inlet Wetland. Photograph taken from the South Road Connector, facing north.	78
Photograph 3.22 : The Barker Inlet Wetland. Photograph taken from the South Road Connector, facing North-West.....	78
Photograph 3.23 : The monitoring station at the Eastern Parade Drain (AU504201). Facing Upstream.....	80

Photograph 3.24 : The Monitoring station at the Eastern Parade Drain (AU504201). Facing Downstream.....	80
Photograph 3.25 : Typical industrial land use in the The Eastern Parade Catchment.....	81
Photograph 3.26 : Typical industrial land use in the The Eastern Parade Catchment.....	81
Photograph 4.1 : Hampstead Centre (AU504114) Pluviometer in the Barker Inlet Wetland Catchment.....	85
Photograph 4.2 : Construction of the North Arm East Drain Weir	91
Photograph 4.3 : Construction of the instrument cage.	91
Photograph 4.4 : Instrumentation cage in the North Arm East Drain.....	93
Photograph 4.5 : Continuous monitoring probes during construction.....	93
Photograph 4.6 : Instrumentation cabinet at the North Arm East Drain.	95
Photograph 4.7 : Data logger and controller.....	95
Photograph 4.8 : Construction of trash racks at the HEP Drain.....	98
Photograph 4.9 : Trash racks at the North Arm East Drain.....	98
Photograph 5.1 : Trash racks in the North Arm East Drain.....	118
Photograph 5.2 : Trash rack basket full of gross pollutants	118
Photograph 5.3 : Storm event prior to the installation of trash racks. No backwater.....	119
Photograph 5.4 : Storm event after installation of trash racks. Backwatered.....	119
Photograph 5.5 : The Adelaide University flume with velocity probe.....	123

Abstract

The Barker Inlet Wetland in South Australia was established during 1994-1996 to protect the marine environment from the degrading effects of Adelaide's stormwater runoff. The Barker Inlet Wetland forms an integral part of a series of wetlands constructed on low-lying coastal land in the northern suburbs of Adelaide in South Australia. The "green band" of wetlands combine together to intercept and treat approximately 40% of Adelaide's stormwater runoff. The green band consists of The Greenfields, South Road Connector, Magazine Creek, Range and Barker Inlet Wetlands. Together the wetlands occupy approximately 337ha and are the world's largest constructed urban wetlands.

A monitoring programme funded by the MFP Development Corporation was initiated in 1994 to monitor the performance of the largest of these wetlands, The Barker Inlet Wetland. This research project represents phase one of the monitoring program and concentrates on the inflow quality and quantity of stormwater entering the Barker Inlet Wetland which has four major catchments draining into it. Although all classed as urban, these catchments have significant differences in the extent of residential, industrial and commercial land uses which are reflected in the monitoring results. The quality and quantity of stormwater inflows to the Magazine Creek Wetland are also monitored from a catchment with a large proportion of industrial land uses.

The accurate measurement of stormwater quantity from the monitored catchments was given careful attention in this research as the flow rate and event runoff volumes directly affect the determination of event water quality loads. The use of ultrasonic Doppler velocity probes to supplement measurement weirs and stage/discharge relationships was adopted in this research.

The monitoring network combines continuous monitoring of water quality as well as event based automatic water sampling. The estimated annual yield of pollutants including nutrients and heavy metals were determined from approximately 18 months of monitoring. The normalised annual pollutant load from the industrial catchments was far greater than from the residential catchments. The pollutant concentrations at the Hindmarsh Enfield Prospect (AU504102) station were low due to the large grass swale drain upstream of the monitoring station.

The distribution of the estimated annual event load is such that a few large storms each year contribute to a large proportion of the total annual load. The largest 9 events by event volume (25% of the total 36 events) monitored in the North Arm East (AU504101) Catchment contributed to 62% of the annual total nitrogen load. The same 9 events contribute 53% of the total phosphorus annual load, 62% of the annual copper load and 61% of the annual lead load. This highlights the importance of event sampling rather than just base flows and smaller events. The effect of dry periods between events on the concentration of pollutants in the North Arm East (AU504101) catchment was investigated. On average, events with a longer build up period recorded higher concentrations of pollutants.

Normalised event load probability plots (mg/m^2) are presented in this thesis which compare the yield of pollutants from the four catchments with varying land uses discharging into the Barker Inlet Wetland.

When combined with subsequent phases of this monitoring project, of which two are currently underway, design guidelines for monitoring contaminant loads in urban stormwater ponds will be developed. The results from this research along with these water quality guidelines will hopefully lead to an improvement in management and design practices for urban constructed wetlands.

Statement of Originality

This work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. I give consent to this copy of my thesis, when deposited in the University Library, being available for loan and photocopying.

SIGNED : ..

DATE : 17/12/97

Acknowledgements

The author would like to thank his supervisor, Trevor Daniell of the University of Adelaide, for his invaluable advice and support. The author is indebted to Trevor for the enormous amount of time, patience and encouragement given during the term of this project. His interest and guidance was greatly appreciated.

Thanks are also extended to the other members of the monitoring team including Doug McCarty, Stan Woithe, Rachel French, Sarah Murphy, Dr. David Walker, Bruce Lucas and Neil Woithe. Without their assistance in the laboratory and the field this project would not have been possible. Thankyou especially to the author's girlfriend Rachel French and to Sarah Murphy for their assistance with printing, collating and binding the final copies of this thesis.

The author would also like to thank the MFP Development Corporation for the funding of this research project and ongoing projects. In particular the author extends his thanks to Paul Manning for his valuable input to this research project.

Valuable assistance was also provided by many other people throughout this study. The author wishes to particularly acknowledge the help of the persons listed below.

The laboratory staff in the Department of Civil & Environmental Engineering Department at the University of Adelaide for help with the construction of the flow monitoring stations in the field and their ongoing support throughout the project.

The office staff in the Department of Civil & Environmental Engineering Department at the University of Adelaide who were always friendly and willing to help with general day to day tasks.

Fellow postgraduate students in particular Robert Alaia, Simon Gamble, James Pannell and Matthew Burnett. Simon was a source of inspiration and motivation who gave valuable intellectual input even when up against the tallest of brick walls.

Finally the author wishes to thank his parents Geoff and Sandy Williams, his brothers Trevor and Mark and his girlfriend Rachel French for their patience and continual love and support during the length of the project.



Chapter 1

Introduction

1.1 Need for Research

Many different management systems are being used to improve the quality of stormwater. The improved design and management of such systems can only occur by long term inflow, intermediate and outflow monitoring of both quantity and quality of stormwater. There is also a need for the establishment of better water quality guidelines which are more focused on the stormwater quality from urban catchments. These guidelines can only be established by the collection of more accurate contaminant yields from urban catchments such as the loads of heavy metals and nutrients.

This stormwater study was initiated in 1994 to determine the performance of one of the world's largest constructed wetlands, The Barker Inlet Wetland at Wingfield in South Australia. The stormwater monitoring programme is a long term study funded by the MFP Development Corporation involving a number of phases and a team of researchers. This thesis presents the results of the first stage of monitoring of the inflow to the Barker Inlet Wetland system which has four major catchments draining into it. Although all classed as

urban, these catchments have significant differences in the extent of residential, industrial and commercial land uses which are reflected in the monitoring results. The results from the monitoring of stormwater inflows to the Magazine Creek Wetland from a single industrial catchment are also presented.

1.2 Study Objectives - Phase 1

There are a number of objectives which this stormwater study aimed to fulfil. The long term programme incorporating further monitoring phases aims to determine guidelines for better design and management of sustainable urban wetlands for water quality control. Phase one of monitoring aimed to determine the quality and quantity of urban stormwater runoff from different catchments that discharge into the Barker Inlet and Magazine Creek Wetlands. To fulfil this broad objective a number of specific tasks were established :

Quantity

- Establish rainfall monitoring network;
- Develop theoretical stage discharge relationships for all streamflow monitoring stations;
- Incorporate Doppler ultrasonic velocity probes as an alternative flow measurement device;
- Verification of theoretical stage discharge relationships using recorded event velocity data;
- Addressing and solving flow measurement backwater problems created by the construction of gross pollutant traps upstream of monitoring stations; and
- Develop and calibrate a runoff routing model for the North Arm East Catchment.

Quality

- Determine water quality parameters to monitor;
- Establish consistent, accurate and efficient testing procedures for water quality;
- Determine the most productive timing of samples during each event;
- Determine parameter concentrations for storm events-event mean concentrations;
- Determine changes in parameter concentrations during storm events;
- Establish concentration ranges;

- Relate the differences in water quality between catchments to variations in the proportions of residential, industrial and commercial land uses;
- Determine correlations between water quality parameters and establish models;
- Maintenance of continuous water quality probes; and
- Correlation of continuous water quality measurement to laboratory analysis results.

Loads

- Determine stormwater runoff pollutant loads entering the Barker Inlet and Magazine Creek wetlands by combining quality and quantity measurement;
- Determine annual pollutant load inputs to the wetlands;
- Estimate annual catchment yield of heavy metals and nutrients; and
- Determine the proportion of total load that comes in storm events.

1.3 Methodology

In order to achieve the study objectives outlined above, a comprehensive monitoring network was designed and constructed in 1994, commissioned by MFP Development Corporation. The monitoring programme involved accurate rainfall measurement by a network of pluviometers throughout the catchment in conjunction with monitoring stations positioned on the outlet of each subcatchment. Each monitoring station utilises a number of continuous monitoring probes, a measurement weir, automatic water sampler, data logger and controllers.

In order to determine the stormwater runoff quality from the catchments storm events were sampled by automatic water samplers. Event samples were combined into a single composite sample to determine event mean concentrations of important contaminants. The individual sequential samples were also tested to determine the concentration changes during each event.

1.4 Structure of Thesis

A review of current literature concerning urban stormwater and its contamination is presented in Chapter 2. The processes leading to the contamination of stormwater and the importance of

each parameter with regards to a stormwater monitoring programme are discussed also. The processes that occur in stormwater runoff and in receiving waters such as the phosphorus and nitrogen cycles are discussed. The problems that pollutants cause are outlined, such as high nutrient levels causing algal blooms and eutrophication.

Chapter 3 describes both the Barker Inlet Wetland and its catchment as well as the Magazine Creek Wetland and its catchment. Varying catchment properties are outlined including catchment size, land use types, channel types, soil types and pipe network systems.

The monitoring network established to measure the quality and quantity of the stormwater runoff is outlined in Chapter 4. The development of the network includes automatic samplers and sampler controllers, continuous monitoring probes, data loggers and pluviometers. A discussion of site visit procedures and water sample collection, storage and laboratory testing is included in Chapter 4. The data archiving procedures are also outlined in this chapter.

Chapter 5 discusses the flow measurement of stormwater runoff. The theoretical discharge equations are outlined as are the stage/discharge rating curves. Chapter 5 also discusses the problem of relying on stage/discharge relationships and investigates alternative flow measurement devices. The results from flume testing and field application of ultrasonic velocity probes and their use in deriving dynamic rating tables to counter backwater problems caused by the construction of trash racks downstream of the monitoring stations is also presented.

Chapter 6 presents the results from applying a runoff routing model, *RAFTS-XP*, to the North Arm East Catchment. A discussion on storm event selection, rainfall distribution, model calibration and parameter selection techniques is included. The runoff routing model of the North Arm East (AU504101) Catchment is also used to predict the runoff from the 1995 New Years Eve storm event for which rainfall but not runoff is available. The model is also used to investigate the effect that the installation of trash racks upstream of the monitoring stations has had on runoff.

The results of the monitoring programme, including four years of data collection, are presented in Chapter 7. The stormwater quality results include the results from the analysis of

sequential sample and event composite samples. The results are tabulated as well as presented in a number of probability curves designed to give a clearer indication of the differences in water quality between the catchments. The event loads results are also presented. A discussion of the differences of stormwater quality between the catchments with varying catchment sizes, land uses and channel types is presented.

In Chapter 8 conclusions and recommendations from the research project are presented. The water quality assessment of the four catchments discharging into the Barker Inlet Wetland as well as the Eastern Parade Drain discharging into the Magazine Creek Wetland are summarised. Recommendations from the monitoring program are outlined and include additional research paths that need to be explored to complement and extend the results of this study.

Chapter 2

Literature Review

2.1 Introduction

Stormwater runoff is gradually becoming accepted as a resource rather than as a nuisance. Stormwater runoff however is a source of pollution, and needs to be treated before it becomes a useful resource. Artificial wetlands and sedimentation basins are becoming popular as a retrofitting tool on the outlet of many urban catchments as they are designed to retain urban stormwater and improve its quality.

This chapter reviews the contaminants found in urban stormwater and briefly discusses the processes that lead to the contamination of stormwater in an urban catchment. A more extensive review of the contamination processes of urban stormwater is outlined in Duncan (1995). The source of each contaminant in stormwater is described as well as the adverse effects that they cause to the receiving environment. The concentration ranges that the contaminants are likely to be present in are outlined, however a more extensive review is outlined in Makepeace et al. (1995).

A good monitoring program for urban stormwater requires both quantity and quality are measured so that pollutant loads can be determined. The various types of quantity measurement of stormwater are discussed and its importance to the overall stormwater monitoring process.

2.2 The Urban Hydrologic Cycle

Runoff occurs when precipitation falls on a catchment with a sufficient volume to exceed processes such as soil infiltration, evaporation, transpiration, interception and surface storage. Runoff from urban catchments is referred to as stormwater runoff whereas from a rural catchment it is simply rural runoff. Figure 2.1 below depicts the urban hydrologic cycle in schematic form.

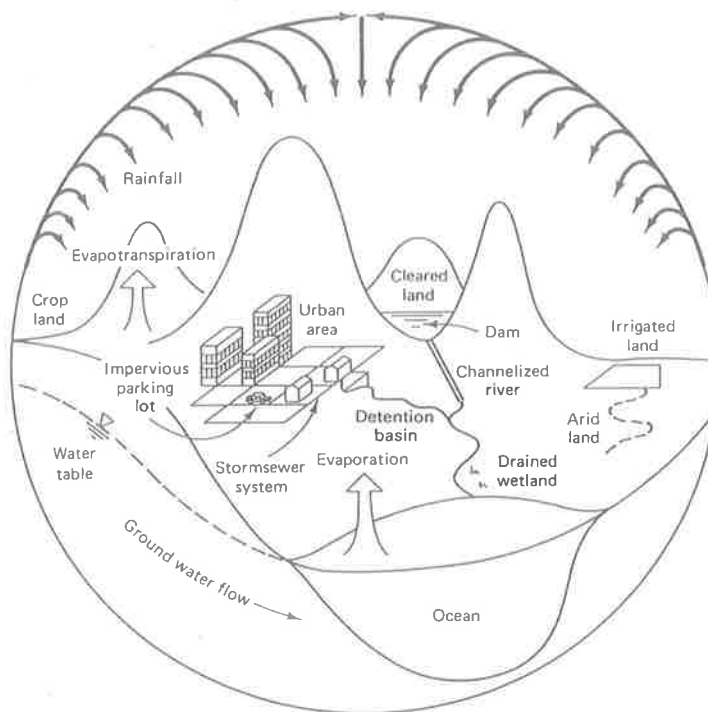


Figure 2.1 : Schematic drawing of the hydrologic cycle. (Adapted from McCuen, 1989)

The hydrologic cycle describes the movement of water between the atmosphere, the catchment, the receiving waters and back again to the atmosphere. Solar energy is the main driving force behind the hydrologic cycle. Solar energy drives evaporation, transferring water from water storages (including oceans, rivers, surface storages and plants) to the atmosphere.

Precipitation from rain transfers water from the atmosphere back to the catchment, plants and receiving water body.

The precipitation takes alternate pathways when it hits an urban catchment. Some rainfall infiltrates the soil and enters groundwater storages, is intercepted by plants, stored as surface storage, becomes overland flow or enters the pipe network and open channel system and is transported to the receiving water body.

Stormwater runoff is that part of precipitation that directly runs off the surface of the catchment. The runoff increases in volume towards the bottom of a catchment due to the increased contributing areas. Stormwater runoff is reduced in the early stages of a storm due to infiltration and surface storage. Infiltration is a variable factor and is dependent on antecedent catchment wetness.

In an urban environment stormwater runoff is usually collected from paved areas in street gutters and from household roofs and then directed into an underground pipe network system.

The stormwater then typically discharges from a pipe network into an open channel system and is directed to a receiving water body such as a wetland, river, ocean or estuary.

The trend towards increasing urbanisation and increased impervious area means that more precipitation is becoming stormwater runoff and less is being lost to infiltration, surface storage and evapotranspiration. The effectiveness of modern day drainage networks results in increases in stormwater runoff quantities with larger peak flows and faster velocities. This in turn increases stormwater pollution concentrations from catchments as increased velocities of runoff entrain more particulate matter and hence contaminants adsorbed to the sediment particles.

2.3 Urban Stormwater Quality Processes

Stormwater runoff occurs when rainfall falls on an urban (built up) catchment. Stormwater runoff is often contaminated with pollutants such as sediment, heavy metals, hydrocarbons and high nutrient levels. Duncan (1995) describes the physical processes which are associated

with the contamination of urban stormwater and categorises the main processes into the following headings :

- Atmospheric deposition;
- Interception;
- Buildup;
- Washoff;
- Transport;
- Storage; and
- Receiving waters.

2.3.1 Atmospheric Deposition

Atmospheric deposition consists of two components, namely wet deposition or washout (during rain), and dry deposition or fallout (without rain). Washout and fallout can be a significant source of pollutants in stormwater (Duncan, 1995). When measured separately, such as in studies by Malmquist and Svensson (1977) and Randall et al. (1981), it has been shown that storm water contamination is caused predominantly by washout.

Atmospheric deposition has high spacial variability on a large scale with deposition of contaminants typically higher in urban areas. Atmospheric deposition typically supplies as much nitrogen as is observed in stormwater runoff and a smaller proportion of suspended solids, phosphorus, COD and heavy metals (Duncan 1995).

2.3.2 Interception

Interception is the process by which rainfall is intercepted by artificial structures such as buildings and roofs, plants and associated debris such as leaf litter before it reaches the ground. Throughfall is rain which reaches the ground after passing through the tree canopy or dripping from it, whereas stemflow is the part of intercepted rainfall which runs down the tree trunks. There is very little literature describing the effects of growing plants on urban water quality although studies by Halverson et al. (1984) and Rolfe et al. (1978) suggest that dust

and dirt deposited on the trees in the urban environment is the major source of contaminants in throughfall and stemflow (Duncan, 1995).

Plant debris such as fallen leaves, seeds and flowers can affect the quality of rainwater that passes through them. Studies such as Cordery (1977), Prasad et al. (1980) and Dorney (1986) show that nutrients such as phosphorus and nitrogen, and organic matter are greatly increased in runoff percolating through fallen leaves and crop residues (Duncan, 1995). Leaves and seeds are a major source of phosphorus in urban runoff (Cowan & Lee 1973, Kluesener & Lee 1974). Nutrient release from whole leaves is slow in the order of several days, however fine chopping and drying greatly speed up the process (Duncan, 1995). This can explain the findings of Shaheen (1975), that nutrient levels in washoff from roads increases with traffic volume (Duncan, 1995).

The behaviour of intercepted rainfall as runoff from buildings and roofs is very similar to build up and washoff from other impervious surfaces, including increased pollution with antecedent dry periods and a strong first flush (Duncan, 1995). The only standout difference is the high concentrations of zinc and copper in roof runoff. The contamination of runoff is due to galvanised iron roofs and fittings and is dependent on the duration of rainfall, atmospheric concentration of sulphur dioxide and the area of exposed metal in the catchment (Duncan, 1995).

2.3.3 Buildup

Buildup is the process of accumulation of dry deposition on impervious areas. Duncan (1995) describes buildup as a dynamic equilibrium process acting between deposition and removal at a point, and between contributing and non-contributing areas. Sources of deposition include dustfall, vehicles, construction and demolition, vegetation and garden chemicals (Duncan, 1995). Removal processes include wind, eddies caused by passing vehicles, decomposition, street sweeping and washoff by rain.

Deposition has been found to be dependent on time and traffic volume. Build up load increases with antecedent dry periods (Sartor and Boyd, 1972; Ellis, 1977). The deposition of many pollutants on roads was found to be proportional to traffic volumes in a study by

Shaheen (1975). Pollutants related to traffic can be either directly related such as rubber, oil and metals, or indirectly related but caused by vehicular movement such as the breakup of leaves and seeds releasing nutrients.

2.3.4 Washoff

Duncan (1995) describes washoff as “the process by which accumulated dry deposition is removed from impervious surfaces by rainfall and runoff, and is incorporated in the flow”. The washoff process is distinct from the build up process but often the two are difficult to separate. A great deal of theoretical research has involved modelling the washoff process. Most authors represent the washoff process by an exponential function, however numerous shortcomings with this form have been documented. Duncan (1995) proposes an alternative washoff function based on rainfall intensity. Many studies, such as Sartor and Boyd (1972), relate washoff to rainfall intensity, and some relate it to rainfall volume. A line of thought by some authors that washoff is related directly to flow was contradicted by the findings of a recent study by Spangberg and Niemczynowicz (1992; 1993) who attribute washoff to rainfall. Spangberg and Niemczynowicz recorded turbidity as a measure of washoff from a small asphalt car park. They found that the turbidity frequently lagged about 35 seconds behind rainfall but preceded the flow hydrograph by about 60 seconds.

A phenomenon that occurs often but not always in urban washoff is “a first flush”. First flush has many definitions, but can be defined as the pollutant peak concentration preceding the hydrograph flow peak. There are two distinctive types of first flush. The first is “channel first flush”, which is when particulate matter that fell out in the hydrograph tail of the preceding event is picked up and flushed down the channel in the rising limb of the next event. The second is “catchment first flush”. “Catchment first flush” is a characteristic of small catchments (Spangberg and Niemczynowicz, 1992; 1993), and is dependent on rainfall intensity (Yaziz et al. 1989). Yaziz et al. (1989) relate both the magnitude and lead time of first flush to rainfall intensity.

The quality of washoff is affected by land use and surface characteristics (Duncan, 1995). Construction activity or other soil disturbance activities within a catchment can increase washoff loads by more than one hundred fold (Konno and Nonomura, 1981).

2.3.5 Transport

Duncan (1995) defines transport as “the movement of contaminants in urban runoff through gutters, pipes and channels”. Sediment transport in stormwater flow has a strong association with many key contaminants (Cullen 1980; Marsalek 1990, 1992). Dempsey et al. (1993) concluded that a removal of suspended sediment from urban runoff will lead to a substantial decrease in the load of many water quality parameters. A bimodal sediment size distribution has been observed by Ellis (1977). Ellis concluded this from the observation of a characteristic double peak in suspended solids concentrations during a number of events. Ellis attributed the first peak to finer material deposited in the channel from the preceding event, and the second peak, with a wide band of distributed particle sizes, to sediment washed off the catchment.

The transport of contaminants can be directly related to the energy of the stormwater. ^{runoff} The more energy in a stormwater flow, the larger the size of the particles that the stormwater flow has the ability to entrain and transport. Hence larger flows have more larger particles than smaller flows.

Leaves from trees are a major source of nutrients and organic matter, and fall during a short period namely autumn each year. Whole leaves and other plant debris are transported in stormwater flow. Duncan (1995) summarises from Prasad et al. (1980) and Cowen & Lee (1973) that the dry weight content of nutrients in leaves is typically about 0.2% total phosphorus, and 1% total nitrogen. The leaching of nutrients from whole leaves is slow however traffic breaking up the leaves increases the leaching rate.

Artificial litter such as paper and plastic are also transported in stormwater flows and are an unsightly contaminant of urban waterways. The installation of trash racks and floating booms has proved effective, although prevention at the source is still the better alternative.

The experience with the trash racks in the Barker Inlet and Magazine Creek Wetland channels has shown that approximately 1 to 3 tonnes of gross pollutants are collected at each of the five trash rack locations from any storm event. This underlines the effectiveness of the trash racks and indicates that the trash racks play an integral part in the management of stormwater

quality in the Barker Inlet and Magazine Creek Wetlands. The amount of gross pollutants collected in trash racks from the Patawalonga stormwater system in South Australia is approximately 400 tonnes each year (Menzies, 1997). Public awareness is still low with regards to the disposal of artificial litter and garden waste and there is still scope for better control at the source by community education.

2.3.6 Storage

The quality of urban stormwater can be substantially improved by storage. Duncan (1995) defines the term storage to include “natural lakes, artificial basins, deep ponds and shallow wetlands, with detention times ranging from minutes to months”.

The reduction of suspended solids by sedimentation is the most important water quality process occurring in storage. Duncan (1995) concludes from authors such as Whiteley et al. (1993), Wu et al. (1988) and Baca et al. (1982) that reductions of suspended solids of 80% or more have been achieved in storage. During high inflows to storages or in storages not designed for sedimentation, scour can occur and entrain previous deposits such as in the findings of Dally (1984), and increase suspended solid loads.

As the pond surface area to catchment area ratio increases the removal efficiencies tend to increase (Lawrence 1986, Yousef et al. 1986(b)). Duncan (1995) states that removal efficiency is also dependent on initial load to the storage. Typically, the higher the input load concentration the higher the removal efficiency but with a slightly higher output concentration (Randall et al. 1982; Grizzard et al. 1986). This is thought to be due to high suspended solids loads including larger particle sizes which settle out more easily in storage (Ferrara and Witkowski, 1983).

There are conflicting design requirements for flood control and for water quality improvement. Duncan (1995) states that “the best flood control is achieved with the basin as empty as possible” and that “the best quality control is obtained with long detention time and a substantial permanent pool”. Storage design is therefore a compromise between the two objectives.

2.3.7 Receiving Waters

Duncan (1995) defines receiving waters according to conventional usage as “receiving waters must be downstream of the interest, but not so far downstream that other areas have a dominant effect. They must have some perceived environmental, aesthetic, or functional value which could potentially be compromised by the urban runoff”. Duncan (1995) states that it is due to the key position of receiving water in the hydrologic cycle that they play a major role in both the definition and measurement of any potential problems. The guidelines to protect receiving waters are usually formulated taking into account the key features which are relative scale, perceived value and natural characteristics. The ANZECC (1992) water quality guidelines for receiving water bodies both in Australia and New Zealand were determined “from a review of the most recent overseas criteria documents, particularly those produced by the United States (USEPA, 1986), Canada (CCREM, 1991) and the World Health Organisation (WHO, 1980, 1984)” and from “a broad review of the relevant Australian information (both published and unpublished) to supplement or modify overseas information where this was judged to be inappropriate”.

The ANZECC (1992) water quality guidelines are not a very appropriate set of guidelines for the stormwater quality from phase 1 of this monitoring project. The ANZECC (1992) guidelines are often taken out of context in urban stormwater studies with little emphasis placed on the establishment of new more appropriate stormwater guidelines. The ANZECC (1992) water quality guidelines are more appropriate to the water quality that exits wetland systems and enters the estuarine or marine environment as the receiving water body. The guidelines provide an approximate indication of the allowable pollutant concentrations in stormwater to protect the receiving water environment.

The establishment of more appropriate stormwater quality guidelines is a major long term objective that this monitoring project aims to fulfil. The guidelines will be established from the results from this phase of the monitoring project and importantly incorporating the inflow and outflow results from other current and future phases of monitoring.

2.4 Stormwater Pollution : Important Parameters

Stormwater runoff contains many pollutants which degrade the quality of receiving waters. This section describes and discusses the effects urban stormwater pollutants have on receiving waters such as streams, rivers, wetlands and estuarine environments. Parameters that are considered important in the contamination of urban stormwater runoff include :

- Total Suspended Solids (TSS);
- Turbidity;
- Total Dissolved Solids (TDS);
- Electrical Conductivity (EC);
- Nutrients (Nitrogen and Phosphorus);
- pH;
- Dissolved Oxygen (DO);
- Biochemical Oxygen Demand (BOD);
- Heavy Metals;
- Petroleum Products;
- Micro-organisms; and
- Pesticides.

2.4.1 Total Suspended Solids

The suspended sediment concentration of stormwater runoff is the total quantity of suspended organic and inorganic particulate matter in water. High concentrations of suspended sediment in stormwater diminish the water quality in a number of ways as there is a strong association between suspended sediments and other pollutants such as nutrients and heavy metals. Contaminants such as heavy metals and nutrients are most often attached to the finer particle sizes.

The suspended solids in water scatter the light that hits them and makes the water look turbid. The scattering of light is responsible for turbidity or cloudiness of water (Laidler, 1991). The sediment suspended in the water limits the depth to which sunlight can penetrate. This

influences the amount of plant life in the water body, as plants need light to carry out photosynthesis.

Suspended solids in stormwater runoff consists of solid particles eroded from the surface of the catchment and particles resuspended from gutter, pipe and channel flow. A standard definition of particulate matter refers to particles of diameter greater than $0.45 \mu\text{m}$ (Chapman, 1996). This means that particles with diameters less than $0.45 \mu\text{m}$, including colloids are by definition dissolved matter.

Makepeace et al. (1995) reviewed literature published throughout the world on urban stormwater contaminants. The literature review presented by Makepeace et al. (1995) includes a description of each water quality parameter as well as a range of concentrations observed throughout the world from a large number of urban stormwater studies. The mean concentrations of total suspended solids published by Makepeace et al. (1995) ranged from 4 to 1223mg/L . The mean total suspended solids concentrations entering the Barker Inlet Wetlands found in this study ranged from 44mg/L in the Hindmarsh Enfield Prospect (AU504102) catchment to 472mg/L in the Dunstan Road (AU504103) catchment. The stormwater entering the Magazine Creek Wetland from the Eastern Parade (AU504201) catchment had an overall mean derived from all the monitored events of 1535mg/L , which is outside the total suspended solids range published by Makepeace et al. (1995).

The guideline outlined for total suspended solids by ANZECC (1992) for protection of aquatic ecosystems is that a maximum increase of 10% above the background seasonal mean concentration is permissible. The Canadian guidelines are similar to those of ANZECC (1992) except the maximum permissible 10% increase is allowed only on a background total suspended solid concentration of 100mg/L .

2.4.1.1 Sources of Suspended Sediment

The main source of suspended sediment from the catchment results from soil erosion. The rate of soil erosion can vary dramatically and is dependent on factors such as soil characteristics, precipitation frequency and intensity, slope of the land surface and land disturbance such as agriculture, mining and construction (Smith et al., 1990,91). Other

sources for suspended solids include atmospheric deposition, breakdown of pavement surfaces, vehicular wear, vegetation, litter and spills (Marsalek, 1992). Atmospheric deposition of suspended sediment in rainfall may be a significant source of solids in runoff with typical average concentrations in the order of 20mg/L recorded at urban sites (Duncan 1995).

Organic particles also form an important component of suspended sediment, however most suspended sediment is inorganic by weight. Meybeck (1982) found that the organic carbon content of suspended sediment matter found in rivers ranges from 0.5 % to 20 % of total suspended solids.

2.4.1.2 Particle Size Distribution

The surface area of a sediment particle is a key property which controls adsorption capacity. The surface area to volume ratio of small particles is larger than for large particles which means that smaller particles have a greater adsorption capacity. The finest particles are generally the richest in trace elements.

Particle size fractions group sediments into clay, silt, sand and gravel fractions. The fraction sizes vary between authors, however a guide to the fractions is outlined in table 2.1 below.

TABLE 2.1 : Particle Size Fractions. Adapted from Chapman (1996)

Fraction Name	Particle Size Fraction
Clay	< 4 μ m
Silt	4 μ m - 64 μ m
Sand	64 μ m - 2mm
Gravel	> 2mm

Laboratory particle size distributions of urban stormwater have been determined by many authors such as USEPA (1983, 1986), Grizzard, et al. (1986), Randall et al. (1982), Whipple and Hunter (1981), Leersnyder (1993), McKergow (1994) and Passfield and Phillips (1996, unpublished) to name a few.

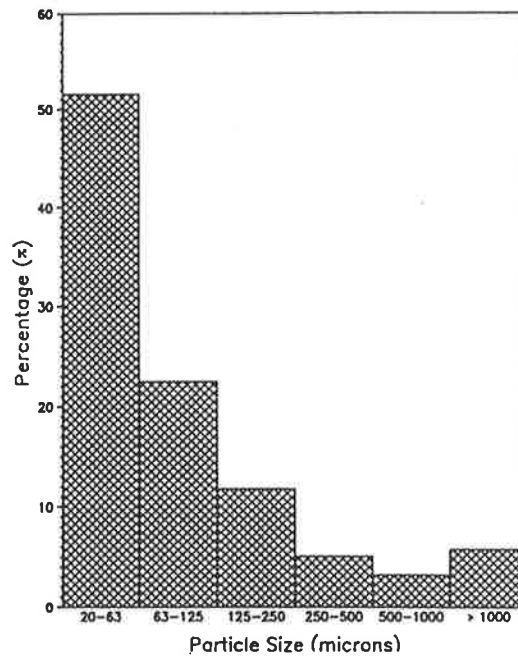


Figure 2.2 : Particle size distribution (>20 microns) in the Pakuranga catchment, Auckland. (Source : McKergow, 1994)

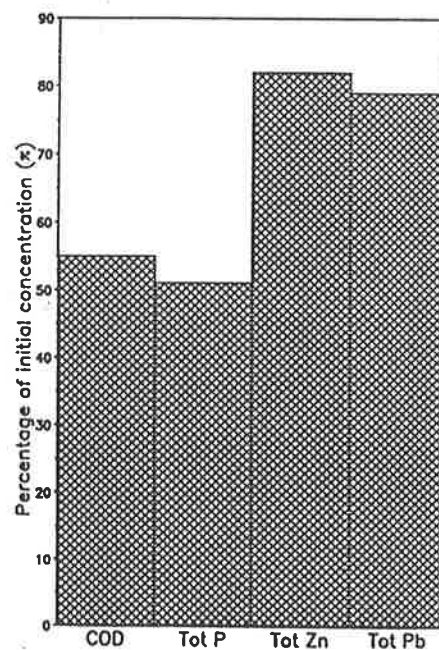


Figure 2.3 : Average percentage of contaminant concentration associated with stormwater particles <20 microns for three storms in the Pakuranga catchment, Auckland. (Source : McKergow, 1994)

The particle size distributions observed from three storms in the Pakuranga catchment study in New Zealand are outlined in Figure 2.2. The results show that the largest proportion (52%) of suspended solids are contained in the silt fraction (20-63 μ m). Figure 2.3 outlines the contaminant concentration associated with the stormwater particles less than 20 μ m in size.

Approximately 82% of total zinc and 78% total lead are associated with the smaller particle sizes, and over half of total phosphorus. The results of McKergow (1994) are similar to the observations of two other catchments studied in New Zealand namely the Pacific Steel and Hayman Park catchments (Leersnyder, 1993). The particle size distributions of the Pacific Steel catchment are outlined in Figure 2.4 and Hayman Park in Figure 2.5. 79% of the particles in the Pacific Steel site are contained in the silt fraction and 49.8% in the Hayman Park catchment. Figure 2.6 outlines the contaminant concentrations associated with the particles less than 20 μ m in size. Approximately 84% of total phosphorus in the Pacific Steel catchment and 78% in the Hayman Park catchment is associated with the smaller diameter particles (<20 μ m). A similar trend for the heavy metal of total lead, zinc and copper is observed.

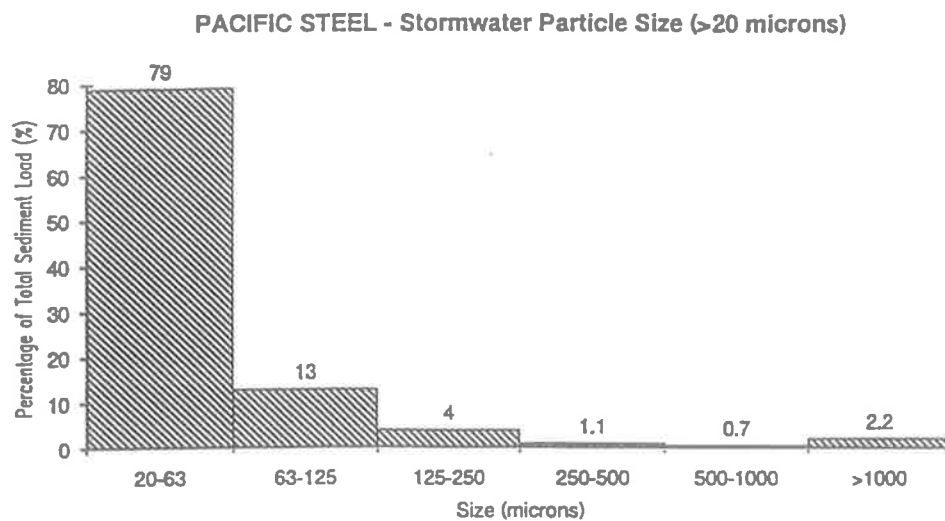


Figure 2.4 : Particle size distribution (>20 microns) at the Pacific Steel site, Auckland
(Source : Leersnyder, 1993)

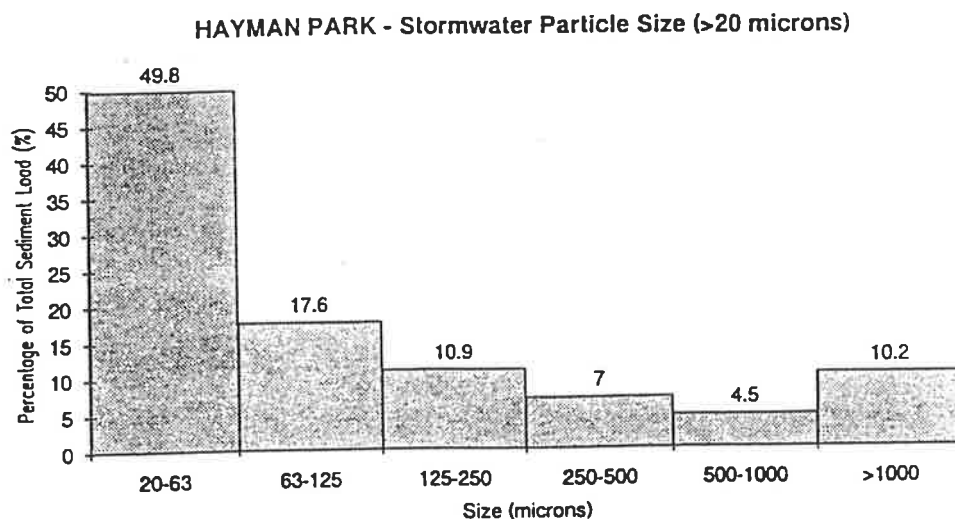


Figure 2.5 : Particle size distribution (>20 microns) at the Hayman Park site, Auckland
(Source : Leersnyder, 1993)

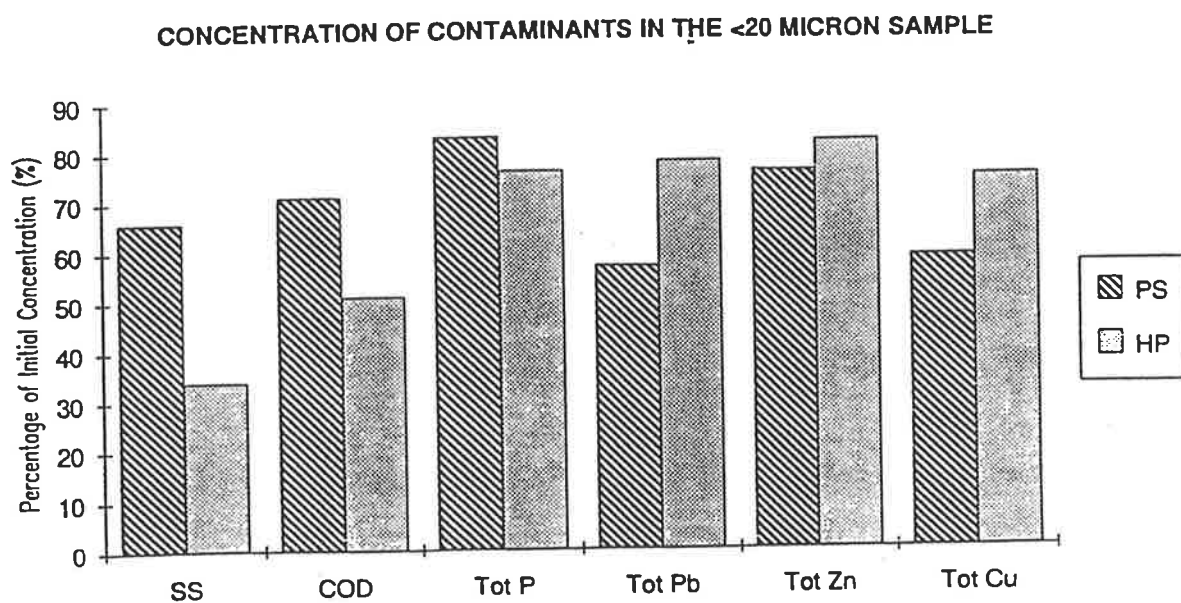


Figure 2.6 : Average percentage of contaminant concentration associated with stormwater particles less than 20 microns for all storms at Pacific Steel (PS) and Hayman Park (HP).
(Source : Leersnyder 1993).

The particle distribution results outlined for the three catchments monitored in New Zealand are similar to other findings from catchments located through different parts of the world. The general conclusion is that the contaminants in urban stormwater are associated with the finer fraction.

2.4.1.3 Effect of Land Use

The type of land use in a catchment has an effect on the distribution of particle sizes from a catchment and hence the quality of water. A sediment study on five catchments with different land uses in the Adelaide metropolitan area in South Australia outlined the variations that can be expected. Passfield and Phillips (1996, unpublished) sampled sediments in stormwater runoff at the curb inlet drain to the pipe network system in catchments with commercial, residential, construction activity and industrial land uses. The fact that the samples were collected at the entrance to the pipe network and (open channel) drainage system eliminates the effect that these both have on the particle size distribution. The results of Passfield and Phillips (1996, unpublished) give an indication of the effect of catchment land use on stormwater runoff particle size distributions and the associated water quality.

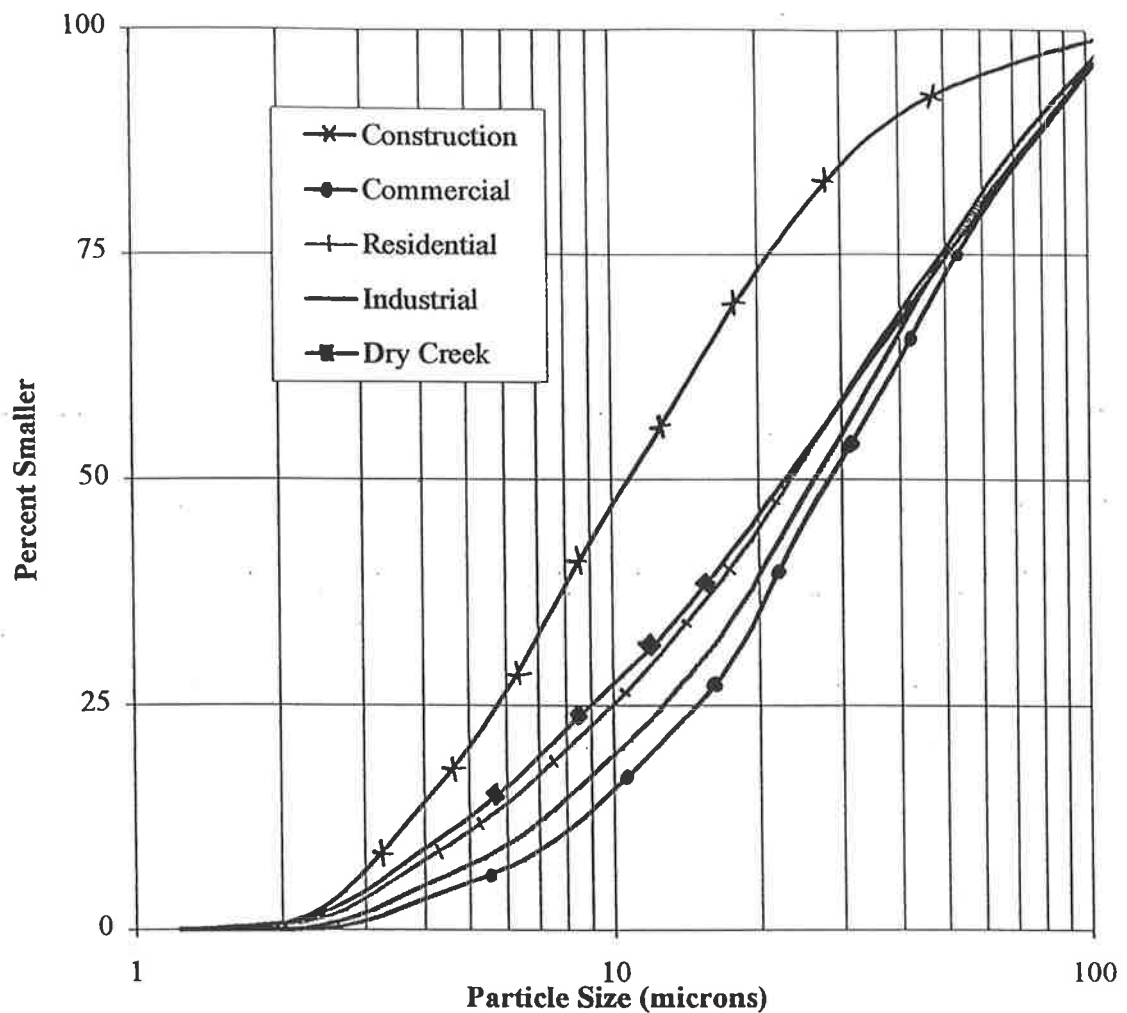


Figure 2.7 : Averaged particle size distributions (Source : Passfield and Phillips 1996, unpublished)

The catchment containing the construction activity has the largest proportion of fine particles. Approximately 95% of the particles in this catchment were less than 64 microns in size. This is due to the clay and silt particles becoming disturbed on the surface due to the construction activity. Heavy traffic during construction activity break down particles to smaller sizes, increasing the amount of finer material. The fine fraction of particles are the fraction that is easily entrained into the stormwater flow due to the small amount of energy required to move a small particle. Approximately 82% of particles in the industrial catchment were less than 64 μ m, and approximately 80% in the residential and commercial catchments.

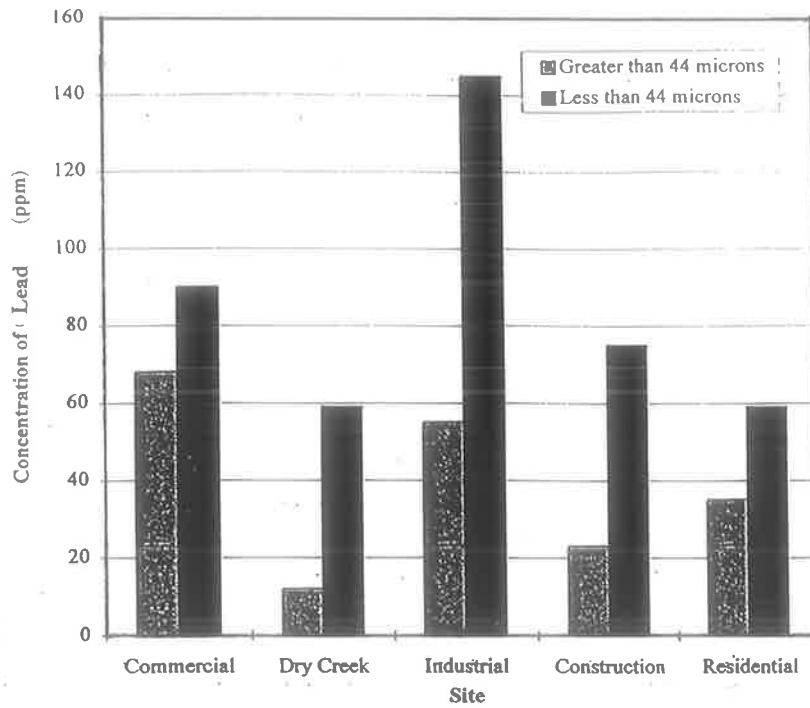


Figure 2.8 : Composite sample concentrations of Lead for particles less than and greater than $44\mu\text{m}$. (Source : Passfield and Phillips 1996, unpublished)

The association of contaminants with the smaller particles is evident in the results of Passfield and Phillips (1996). Figure 2.8 above shows result of lead concentrations associated with particle sizes less than and greater than $44\mu\text{m}$ in the different catchments. Figure 2.8 shows that more than 60% of the lead is associated with particles less than $44\mu\text{m}$ in all catchments with different land uses.

2.4.2 Turbidity

Turbidity is the measure of light penetration through water, and is expressed in Nephelometric Turbidity Units (*NTUs*). The suspended solids in water scatter the light that hits them and makes water look cloudy. The measurement of turbidity is strongly related to the amount of sediment in the water. The relationship between turbidity and Total Suspended Solids is affected by sediment particle size, shape, texture and by the sample water colour (Clark and Crawley, 1987). High levels of turbidity result from erosion, industrial discharges of dirty water and large amounts of algae.

In the past turbidity has been measured by a Secchi disc and prior to that by the Jackson Candle technique. The Jackson Candle Turbidity Units (*JTUs*) were measured by observing a candle through a water sample and comparing what was observed against a colour chart to determine the turbidity level.

A Secchi disc is a disc that is lowered into the water with the top marked in black and white sections. The disc is lowered into the water until the black and white sections become indistinguishable. This depth of water is then recorded, and is used as a measure of turbidity of the water. Recent advances in technology have provided alternative devices for measurement of turbidity of water. Nephelometric turbidimeters transmit an incident light beam (tungsten bulb) through a water sample to a light detection device. The transmitted light detector provides compensation for interferences from colour and light absorbing materials, and compensates for fluctuations in light intensity (HACH company, 1991). An accurate measurement of turbidity (*NTU*) can be obtained in the field as well as in the laboratory.

The strong relationship between turbidity and total suspended solids links it with common pollutants such as heavy metals and nutrients which are often attached to the small sediment fraction. This has led to increasing attention being given to the continuous monitoring of turbidity as an indication of the overall quality of a water body. Field monitoring of turbidity has been extensively investigated by Gippel (1989(a), 1989(b), 1994, 1995) and has proven to be an accurate and effective way of estimating total suspended solids in stormwater.

The decrease in light penetration caused by turbidity effects the instream ecology. Makepeace et al. (1995) state that an increase of 25*NTU* could reduce a river's primary biological productivity by between 13 and 50%. This monitoring study recorded mean turbidity levels during storm events of between 38*NTU* and 410*NTU* entering the Barker Inlet Wetland and a mean turbidity of 879*NTU* entering the Magazine Creek Wetland.

2.4.3 Dissolved Solids

The sum of all dissolved constituents in stormwater runoff is referred to as total dissolved solids (*TDS*). The dissolved inorganic material mostly consists of salts such as the ions of

calcium, magnesium, sodium, potassium, bicarbonate, sulphate and chloride (Smith *et al.*, 1990,91). The dissolved organic compounds contain carbon as the major constituent atom.

The unit of measurement for dissolved solids is milligrams per litre (*mg/L*) which is equivalent to parts per million (*ppm*). The world average dissolved solids concentration of fresh water is about *100mg/L* (Berner and Berner, 1987). In a literature review of the past 25 years of urban stormwater research, Makepeace *et al.* (1995) outline a range of dissolved solids concentrations found in urban stormwater throughout the world between 75.9 and *2792mg/L*, and a world mean concentration of *178mg/L*. These values can be only used as an estimated range of dissolved solid concentrations as the type of samples (eg grab, sequential, event mean concentration) were not clearly outlined by Makepeace *et al.* (1995).

The dissolved solid concentration of precipitation is lower than most fresh water bodies. The average TDS concentration of rain-water is only a few milligrams per litre. Table 2.2 shows the typical concentrations of major ions in rainfall.

TABLE 2.2 : Typical concentrations of major ions in rainfall (*mg/L*).
(Adapted from Berner and Berner, 1987).

Ion	Continental Rain	Marine and Coastal Rain
Na ⁺	0.2 - 1	1 - 5
Mg ²⁺	0.05 - 0.5	0.4 - 1.5
K ⁺	0.1 - 0.5	0.2 - 0.6
Ca ²⁺	0.2 - 4	0.2 - 1.5
NH ₄ ⁺	0.1 - 0.5	0.01 - 0.05
H ⁺	pH 4 - 6	pH 5 - 6
Cl ⁻	0.2 - 2	1 - 10
SO ₄ ²⁻	1 - 3	1 - 3
NO ₃ ⁻	0.4 - 1.3	0.1 - 0.5

The ions of sodium, potassium, calcium, magnesium and chlorine shown in Table 2.2 above are derived primarily from particles in the air, while ions of sulphate, ammonia and nitrate are derived mainly from atmospheric gases (Allan, 1995). Closer to the ocean, marine salts such

as sodium chloride (NaCl) become more important, and as one proceeds further inland the salts of CaSO_4 or $\text{Ca}(\text{HCO}_3)_2$ are important (Allan, 1995).

2.4.3.1 Sources of Dissolved Solids

The major source of dissolved solids is the dissolution of minerals naturally found in soil and rock (Smith *et al.*, 1991,92; Allan, 1995). Allan (1995) backs this statement by using the fact that the world average runoff to rainfall ratio is 0.46. This means that 46 percent of the rainfall that occurs on the continents of the earth becomes runoff. Berner and Berner (1987) showed that the concentration of ions in river water should be 2.2 times the concentration in precipitation. Allan (1995) goes on to state that because the actual differential is roughly twenty fold, rock weathering, other natural sources and anthropogenic inputs must account for the majority of dissolved ions in river water.

2.4.3.2 Electrical Conductivity

Conductivity is a measure of the electrical conductance of water, and is an approximate measure of the total dissolved ions. Electrical conductivity is usually described in micro siemens per centimetre ($\mu\text{S cm}^{-1}$) at 20°C . Older literature such as Golterman (1975) express conductivity in superseded units of $mhocm^{-1}$. In many instances there is a very strong relationship between total dissolved solids and electrical conductivity as can be seen in Figure 2.9 below.

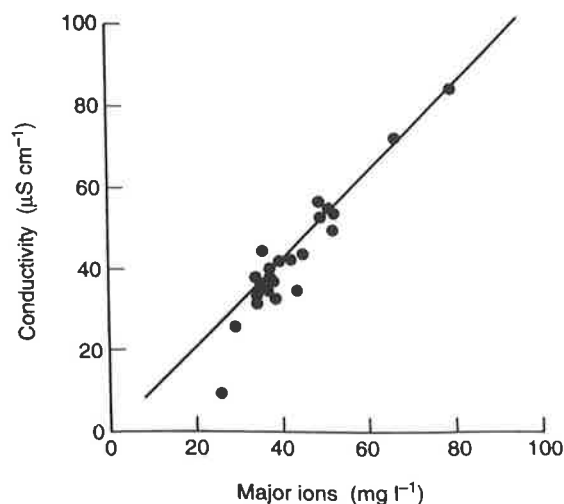


Figure 2.9 : Electrical Conductivity versus the concentration of major ions for some West African rivers. (From Grove, 1972).

The relationship between electrical conductivity and total dissolved solids is usually linear (ie $TDS = k \times EC$). The value of the constant, k , varies between 0.55 and 0.75 depending on the location (Walling, 1984). Changes in electrical conductivity are usually due to the concentrations of charged ions in solution, ionic composition and temperature.

2.4.4 Nutrients

Nutrients are essential for plant growth. The nutrient ions such as nitrate (NO_3^-) and phosphate (PO_4^{3-}) stimulate plant growth. The presence of nutrients increases the growth rate of algae and other living organisms. Nutrient levels in excess of demand, such as that which occurs when industrial or sewage waste water enters a water body, can be hazardous to the water body as algal blooms can occur and deplete the oxygen reserves of the environment.

There are many nutrients known to man, whereas only the 6 major types make up 95% of the mass of all living organisms (Miller and Armstrong, 1982). The 6 major nutrients are known as 'the macro nutrients', and are carbon, oxygen, hydrogen, phosphorus, nitrogen and sulphur (Miller and Armstrong, 1982).

Of the 6 macro nutrients the phosphorus and nitrogen levels are often the lowest required by living matter to produce. Wetzel (1983) describes this using the ratio of phosphorus to nitrogen and carbon required by macrophytes and algae. The ratio is as follows :

$$40C : 7N : 1P$$

Using this ratio and considering a hypothetical situation whereby all the micronutrients are available, then for 40 grams of algae, phosphorus can produce 40 times its weight in biomass, nitrogen 5.7 grams and carbon only 1 gram. This shows that increased levels of phosphorus to an ecosystem will result in increased productivity of that system (provided that all other macro nutrients were abundant). In conclusion the two nutrients of greatest interest to stormwater runoff are phosphorus and nitrogen.

The measurement of nutrients in urban stormwater requires the collection of water samples during storm events. The collection and analysis of grab samples over a long term period can give an indication of the range of nutrients in a system, however the determination of nutrient loads requires careful and painstaking monitoring of both flow ~~quantity~~^{some} and ~~quantity~~. The instrumentation required for such monitoring includes pressure transducers, flow measurement weir, data loggers and an automatic water sampler. The distribution and frequency of water samples collected within each event is of utmost importance to gain a true indication of the overall load of nutrients in each event. The transformation of nutrients between their various forms means that immediate retrieval and analysis of stormwater samples is required.

The nutrients of phosphorus and nitrogen and their various forms are outlined and discussed in the following sections.

2.4.4.1 Nitrogen

Nitrogen exists in many forms. Figure 2.10 presents a simplified diagram of the nitrogen cycle and shows the different nitrogen species giving a diagrammatic representation of the underlying processes that occur between the species. The Earth's atmosphere consists of 78% by volume of nitrogen gas in the form of dinitrogen, N_2 (O'Neill, 1985). Unlike oxygen (O_2) however, dinitrogen is unreactive due to strong covalent bonding, and is not directly available to the majority of living organisms. Blue-green algae and a small number of bacteria are an exception to this, as they easily absorb dinitrogen gas (Miller and Armstrong, 1982). Blue-green algae convert atmospheric dinitrogen to a more useful form (ammonia, NH_4^+), by a process called fixation. Other living organisms require nitrogen to be broken down further into other forms such as nitrate, nitrite or proteins before biomass production can occur.

TABLE 2.3 : Nitrogen forms and concentrations in stormwater
(Source : Makepeace et al., 1995)

Form of Nitrogen	Stormwater range (mg/L)
Total nitrogen	0.32 - 16
Inorganic nitrogen	0.09 - 5.44
organic nitrogen	0.32 - 16
Nitrate	0.01 - 12
Nitrite	0.02 - 1.49
Ammonia	0.01 - 4.3
Total Kjeldahl nitrogen	0.32 - 16

Table 2.3 outlines the forms of nitrogen that have been studied in urban stormwater and the respective ranges of concentrations outlined in a review by Makepeace et al. (1995). Makepeace et al. (1995) outline the sources of nitrogen in stormwater as fertilisers, industrial cleaning operations, feed lots, animal excrement and the combustion of fossil fuels. Leaves and other organic matter are also a source of nitrogen in stormwater. In Duncan's (1995) review of urban stormwater quality processes it states that the dry weight of total nitrogen in leaves is about 1%.

The interactions of nitrogen between its many forms are outlined in the following sections. The nitrogen cycle is a complex cycle consisting of a number of processes namely nitrogen fixation, nitrification, ammonification and denitrification.

2.4.4.2 Nitrogen Fixation

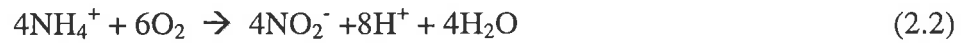
Nitrogen fixation is the process of reducing dinitrogen gas, N_2 , to ammonium ions, NH_4^+ , and can be described by equation 2.1 (O'Neill, 1985).



Nitrogen fixation releases energy (thermodynamic reaction) which is where the micro-organisms derive their energy. The nitrogen fixation process is carried out by micro-organisms which contain the enzyme nitrogenase.

2.4.4.3 Nitrification

Plant growth relies heavily on the nitrification process, the conversion of ammonium ions, NH_4^+ , to nitrite, NO_2^- , and then to nitrate ions, NO_3^- . Plants are unable to consume nitrogen in the form of ammonia or ammonium. Equation 2.2 and 2.3 explain the nitrification reaction. (O'Neill, 1985).



2.4.4.4 Ammonification

Ammonification is the process whereby organic nitrogen is returned to the inorganic form of ammonia, NH_3 (Allen and Kramer, 1972). Equation 2.4 describes the ammonification process.



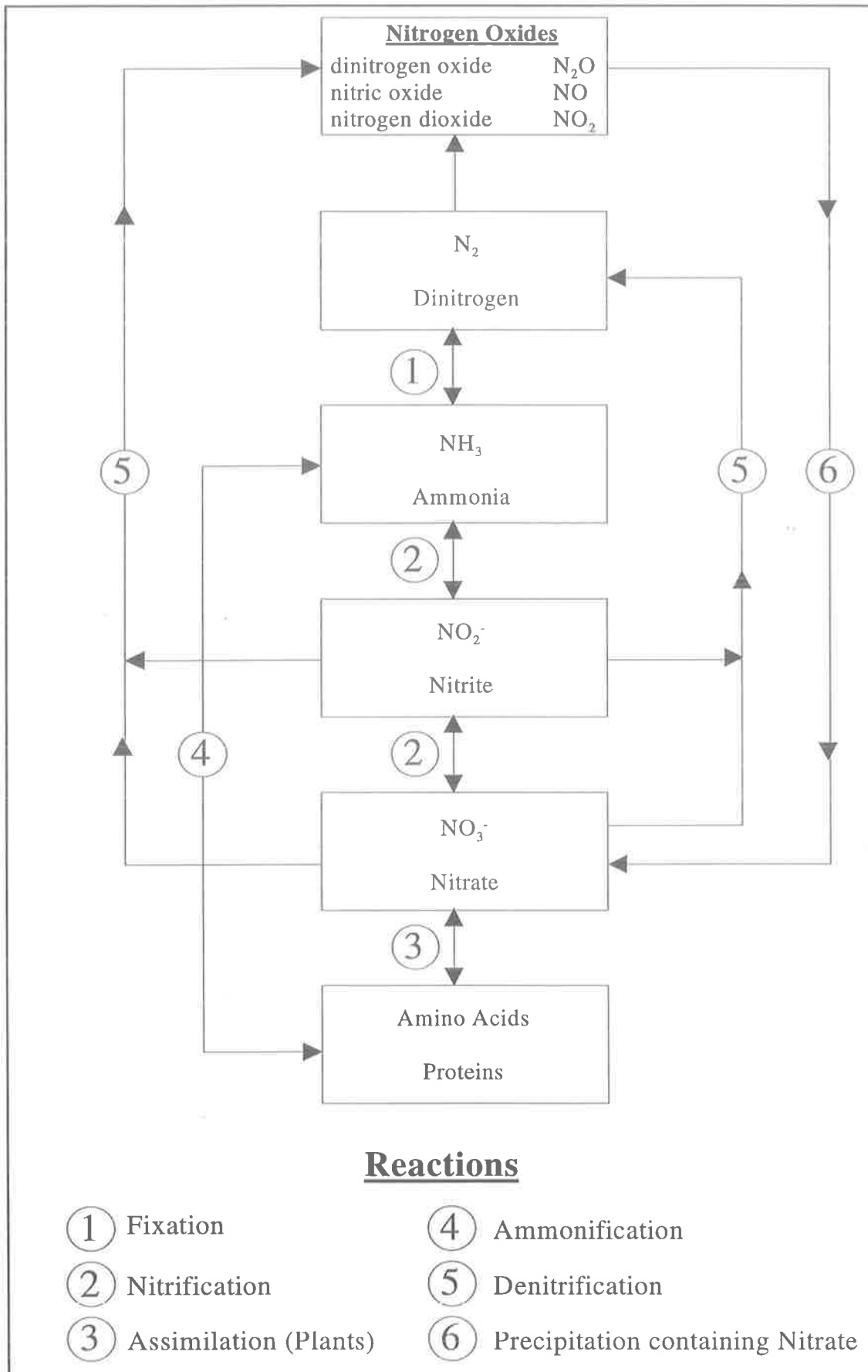


Figure 2.10 : Simplified Nitrogen Cycle. Adapted from Gamble (1997).

2.4.4.5 Denitrification

Denitrification is the regeneration of dinitrogen from nitrate. Nitrate serves as an electron acceptor for anaerobic bacteria in the absence of oxygen (Allen and Kramer, 1972). An intermediate step in denitrification is the production of nitrite. The reduction of nitrate does not always form dinitrogen. Nitrous oxides such as dinitrogen oxide (N_2O) are often formed. Dinitrogen oxide is an inert gas in the troposphere and is the second most abundant nitrogen species in the atmosphere, with a concentration of approximately 0.3ppm. Dinitrogen oxide is becoming more abundant in the atmosphere with a growth rate of 0.3% per annum (Allen and Kramer, 1972). Equation 2.5 below (Reed et al., 1995) describes the denitrification process based on methanol as the carbon source, and also assumes that all nitrogen is in the form of nitrate.



2.4.4.6 Phosphorus

Phosphorus primarily occurs as phosphate and exists either in a dissolved form incorporated in organisms, or attached to sediments. Phosphorus is usually the most important nutrient as it is usually the nutrient in shortest supply, thereby controlling the productivity of plants and the rate of eutrophication.

The most biologically available form of phosphorus is orthophosphate, (PO_4^{3-}), (ANZECC, 1992). Dissolved inorganic phosphorus is assimilated by plants and microbes and transformed into particulate organic phosphorus (O'Neill, 1985). Phosphate ions are sorbed onto charged clay sediment and charged organic particles when the dissolved inorganic phosphorus (DIP) concentrations are high, however when the DIP concentration is low, desorption of the phosphate ions will more likely occur. Under aerobic conditions dissolved inorganic and organic phosphorus forms react with metal oxides and hydroxides and form insoluble precipitates. This process is reversed under anaerobic conditions. Seasonal fluctuations of anaerobic/aerobic conditions cause fluctuations in the availability of dissolved phosphate ions (O'Neill, 1985).

Makepeace et al. (1995) outline the phosphorus ranges observed from locations throughout the world. A range of total phosphorus concentrations between 0.01 and 7.3mg/L was found with a range of mean concentrations between 0.015 and 0.82mg/L. Soluble phosphorus has been found in the range 0.038 to 3.52mg/L, and particulate phosphorus between 0.014 to 2.85mg/L.

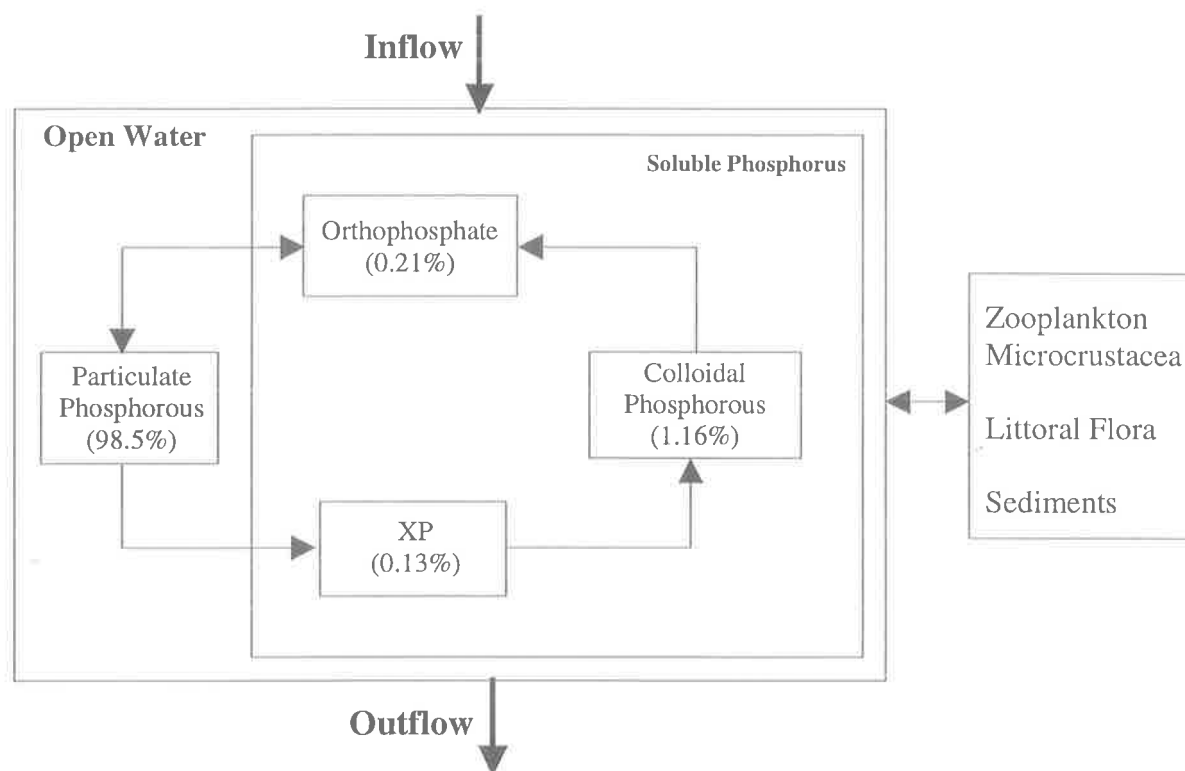


Figure 2.11 : Simplified Phosphorus Cycle. Adapted from Gamble (1997).

The ANZECC (1992) guidelines state that “it is not possible to recommend a single set of nitrogen and phosphorus concentrations that will prevent nuisance algal problems in Australian fresh water because many other factors can also limit the development of nuisance growth” and that “it is strongly recommended that site-specific studies be undertaken to determine appropriate concentrations”. The province of Alberta in Canada has a surface water quality objective of 0.15mg/L for total phosphorus.

2.4.4.7 Eutrophication

When nutrients become available in large quantities (ie when supply of nutrients outweighs demand) accelerated growth of algae and other aquatic plants can cause eutrophication.

Eutrophication is derived from the Greek word *eutrophos*, which means well nourished (Laidler, 1991).

The accelerated growth of algae and other aquatic plants on the surface of a water body restricts sunlight and hence existing subsurface plants die and sink to the bottom of the water column and decompose. The decomposing organic material on the bottom consumes dissolved oxygen in the water which in turn can kill the oxygen breathing animals in the water as well as the aerobic bacteria. The anaerobic bacteria take over the organic decaying process, producing methane, ammonia and hydrogen sulphide as byproducts which explains the characteristic smell of eutrophic waters. The remaining algae eventually die and leave the water body in an anaerobic state, barren of plant and animal life.

2.4.4.8 Blue-Green Algae

Blue-green algae is of great concern in South Australia as temperate conditions favourable to blue-green algae production cause regular outbreaks, especially in the summer months. The main algal groups influencing water quality are as follows (Mackay and Eastburn, 1990) :

- Diatoms;
- Blue-green algae (cyanobacteria);
- Flagellates (Synura); and
- Green Algae (Scenedesmus).

Blue-green algae, otherwise known as cyanobacteria, are photosynthetic bacteria with a distinctive green colour due to pigments of blue and red. The most commonly occurring species of cyanobacteria in Australia include *Microcystis*, *Anabaena*, *Nodularia*, *Cylindrospermopsis* and *Oscillatoria* (Maier and Dandy, 1994). Algal blooms are a serious problem for water bodies and users of the water as they produce toxins and produce unpleasant tastes and odour. The toxins produced by blue-green algal blooms include hepatoxins, neurotoxins and endotoxins. Table 2.4 summarises the various toxins, sources and effects.

TABLE 2.4 : Summary of various Cyanobacterial toxins and their effects (Source : Maier and Dandy, 1994)

Toxin	Toxin type	Source Organism	Effects
Microcystin	Hepatotoxin	<i>Microcystis Anabaena</i>	<ul style="list-style-type: none"> • Hepatoenteritis • Liver Damage • Tumor growth promotion
Nodularin	Hepatotoxin	<i>Nodularia</i>	<ul style="list-style-type: none"> • Hepatoenteritis • Liver damage • Tumor growth promotion
Cylindrospermopsin	Hepatotoxin	<i>Cylindrospermopsis</i>	<ul style="list-style-type: none"> • Gastroenteritis • Hepatitis • Renal malfunctioning • Haemorrhaging
Anatoxin-a Anatoxin-a (s) Saxitoxin Neosaxitoxin	Neurotoxin	<i>Anabaena circinalis</i>	<ul style="list-style-type: none"> • Muscle tremors • Staggering • Paralysis • Breathing difficulties
Lipopolysaccharides	Endotoxin	<i>Most cyanobacteria</i>	<ul style="list-style-type: none"> • Gastroenteritis • Skin irritation • Eye irritation • Allergic reactions

MDBC (1993) outline the climatic conditions and characteristics that effect the growth rate of algae :

- Nutrient levels;
- Light;
- Temperature;
- Turbidity;
- River flow; and
- The state of the aquatic ecosystem.

Creagh (1992) concluded that the actual combination of the above factors that induce algal blooms is not known, and MDBC (1993) concluded that to gain a better understanding of the triggering mechanisms of algal blooms, real-time water quality monitoring within a water body might be required.

2.4.4.9 Sources of Phosphorus

Phosphorus occurs as both point and non-point sources, and only recently the non-point sources of phosphorus are being appreciated. A study on the Lake Burley Griffin phosphorus budget (Cullen and Rosich, 1979) determined that 68% of all phosphorus entering the lake came from non-point rural sources, and only 29% from point sewage effluent. The same study found that most of the non-point source material was associated with storm event runoff. Most urban catchments such as the catchments of the Barker Inlet Wetland and the Magazine Creek Wetland receive the majority of the phosphorus from non-point sources.

The main sources of phosphorus are outlined in the following list (Golterman, 1975, O'Neill, 1985, Chapman, 1996) :

- Naturally available from the weathering of phosphorus bearing rocks;
- Decomposition of organic matter (tree leaves); *(organic wastes)*
- Wastewater discharges both domestic and industrial (including sewage effluent);
- Detergents; *(kitchen wastes)*
- Fertiliser run-off; and
- Mobilisation from organic and mineral constituents of sediments by bacteria.

Makepeace et al. (1995) adds lubricants to this list. In Australian soils the natural availability of phosphorus from the weathering of phosphorus bearing rocks is low as Australian soils tend to be deficient in phosphorus (Clark and Crawley, 1987). As a result phosphorus fertilisers are added to promote vegetation growth and so there is a build up of phosphorus in soils. This is less relevant to the urban catchments monitored in this research with the main sources of phosphorus being the decomposition of organic matter and detergents.

2.4.5 pH

pH is an abbreviation that represents the concentration of hydrogen ions in water. The concentration of hydrogen ions is a measure of the acidity or alkalinity and is measured on a scale from 1 to 14. pH is calculated by the equation :

$$\text{pH} = -\log[\text{H}^+] \quad (2.6)$$

Pure water has a neutral pH of 7, as the hydrogen ion concentration $[\text{H}^+]$ is 10^{-7} moles/L. pH values of less than 7 indicate acidic conditions, and pH above 7 is referred to as alkaline conditions. The greater the deviation from a neutral pH of 7, the more acidic or alkaline the condition is.

Sudden changes in pH are often the result of pollution discharges from industrial sources, and are detrimental to natural water ways as many organisms are very sensitive to pH levels.

The pH of water is easily measured by a pH meter. A pH meter consists of two electrodes which measure the conductivity of the water. The quantity of the current between the two electrodes is referred to as conductivity. The more hydrogen ions that are present in the water the higher the conductivity reading, and hence the lower the pH.

The pH in stormwater varies with the amount of local sulphur dioxide and nitrogen oxide emissions (Makepeace et al., 1995). The concentration of pH in precipitation is typically between 3 and 6 (Makepeace et al., 1995). Makepeace outlines the pH range of urban stormwater to be between 4.5 and 8.7. The ANZECC (1992) guidelines define a pH range of 6.5 to 9 as acceptable for the protection of aquatic ecosystems in fresh waters, which is the same range that the Canadian freshwater aquatic life guidelines recommends.

2.4.6 Dissolved Oxygen

Dissolved oxygen (DO) refers to the amount of oxygen contained in a water body. The oxygen in water is used by living organisms. The concentration of dissolved oxygen is a reliable guide to the ability of a water body to sustain and support riverine life.

Oxygen enters a water body by photosynthesis of aquatic biota and via the transfer of oxygen across the air-water interface. A turbulent water body is more rapidly aerated and is more likely to have higher DO levels than stagnant water. As the temperature of water increases, the solubility of gases into water decreases, and so water at lower temperature has a better chance of increasing its dissolved oxygen levels. Table 2.5 below shows the varying concentration of oxygen in fresh water and salt water at various temperatures.

TABLE 2.5 : The concentration of oxygen in fresh and salt water at saturation, at varying temperature. (Adapted from Laidler, 1991).

Temperature (°C)	Fresh Water (mg/L)	Salt Water (mg/L)
0	14.6	11.3
5	12.8	10.1
10	11.3	9.0
15	10.1	8.2
20	9.2	7.4
25	8.3	6.7
30	7.6	6.1
35	6.9	5.5

It is also evident from Table 2.5 that the solubility of oxygen increases with decreasing salinity. Water is said to be saturated with respect to oxygen when no more oxygen can be dissolved into it. These values are shown above in Table 2.5. Water which is turbulent has many small bubbles in it and can become supersaturated, a level of saturation that exceeds 100 percent. Water quality in terms of DO is often expressed as a percentage saturation of oxygen. This is calculated by the following equation (Laidler, 1991) :

$$\% \text{ saturation} = \left[\frac{\text{dissolved oxygen in sample}}{\text{dissolved oxygen at saturation}} \right] \times 100 \quad (2.7)$$

An indication of the water quality represented by the percentage saturation of oxygen is shown below in Table 2.6.

TABLE 2.6 : Percentage oxygen saturation and water quality. (Adapted from Laidler, 1991).

% saturation of oxygen	Water Quality
<40	Very poor
40 - 55	Poor
55 - 70	Satisfactory
70 - 85	Good
85 - 110	Excellent

Reduction in the dissolved oxygen concentration of water reduces the physiological efficiency of fish and non-breathing invertebrates (ANZECC, 1992). The effect of reduced dissolved oxygen levels on fish has been extensively researched elsewhere in the world (Alabaster and Lloyd 1982, USEPA, 1986), whereas there is little data available for Australian conditions. Koehn and O'Connor (1990) reviewed data on the effects of DO on fish found in freshwater bodies in Victoria, and suggested that DO concentrations below 5 mg/L are stressful to many species.

TABLE 2.7 : Range of Dissolved Oxygen concentrations designated for water usage. (Adapted from NCSU, 1997).

Designated Water Use	Lowest Acceptable DO level (mg/L)
Warm water fish	5.0
Cold water fish	6.0
Spawning Season	7.0
Estuarine biota	5.0
Recreational Contact	3.0

Table 2.7 shows the lowest levels of dissolved oxygen acceptable for cold and warm water fish and other estuarine biota presented by NCSU (1986).

Dissolved Oxygen can play a large role in the survival of biota in temperate lakes and wetland systems during the summer months, due to stratification. Seasonal stratification occurs due to the water density changing with changing temperature. As the water temperature increases, the density decreases. As the temperature increases in summer a layer of warm low density water forms in the top layer of water (the epilimnion). A layer of cooler water of higher

density is sent to the bottom (hypolimnion). Separating the two layers is a layer of rapid temperature change called the thermocline (Smith, 1990).

At the start of the summer season, the hypolimnion contains more dissolved oxygen due to the cooler temperatures of the lower layer of water. As time progresses, dead organisms from the epilimnion sink to the hypolimnion layer and are broken down by microorganisms. Microorganisms play a key role in the loss of oxygen from water and gradually result in an oxygen deficient hypolimnion. The stratification phenomena is accelerated if the water body is in a eutrophic state. The water body could be depleted of oxygen by the end of the summer season.

The introduction of excess organic material to a water body may result in the depletion of dissolved oxygen from that water body. Biota exposed to water with dissolved oxygen saturation levels of less than 30% for one to four days will most likely die. When oxygen requiring organisms perish, only organisms that are air-breathing and anaerobic bacteria remain (Gower, 1980). IMPACTS

Dissolved oxygen levels in stormwater are typically in the range 0 to 14mg/L (Makepeace et al. 1995). The dissolved oxygen concentration is diurnal and may vary dramatically in a 24 hour period. Sutherland (1981) found diurnal variations in DO concentrations of approximately 10 mg/L in the Yarrowee River, Victoria. Due to the diurnal nature of the dissolved oxygen concentration of water the ANZECC guideline (1992) for DO in natural river systems is specified over at least one diurnal cycle. The guideline states that the dissolved oxygen level shall not fall below 6 mg/L or 80 - 90% saturation over at least one diurnal cycle. The freshwater aquatic guidelines for Canada range from 5mg/L for warm water biota to 9.5mg/L for cold water biota (Makepeace et al. 1995).

2.4.7 Heavy Metals

The ions of some metals are essential for life, whereas others are toxic and accumulate in certain body tissues. Calcium in bones, iron in the human bloodstream and copper and zinc to a lesser extent are all essential for life.

The metallic ions found towards the bottom of the periodic table, with high atomic weights, are the more harmful of the ions. These metals are called the 'heavy metals' and include lead, mercury and cadmium. Golterman (1975) adds copper and arsenic to this list and states that one of the great dangers is the accumulation of these heavy metals in our food chain. Golterman concludes that the worst accumulation of heavy metals in the food chain are reported from Japan where fish accumulated mercury and cadmium and killed hundreds of fisherman (Minamata disease, Takeucha, 1972 and Itai-Itai disease, Kobayashi, 1971).

Heavy metals are usually transported from a catchment adsorbed to the silt fraction of the suspended particles in water (Golterman, 1975). Smaller quantities may be present in a dissolved state, being bonded to organic compounds. Heavy metals are widely used as important reagents and catalysts in many industrial processes. The main source of heavy metal pollution is from waste discharges from industrial plants.

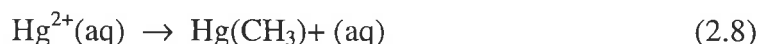
2.4.7.1 Mercury

The heavy metals exist in various chemical forms with varying residence times in the human body. Residence time is defined as the time for half of the original dose to be eliminated from the body. Inorganic ions such as Hg^{2+} and Hg_2^{2+} are water soluble and fat insoluble. These forms have a residence time of only 6 days as they are easily adsorbed in the blood and intestinal fluids and excreted from the body. Ions bonded to parts of organic molecules such as methyl mercury $\text{Hg}(\text{CH}_3)^+$ are fat soluble. This form of mercury is insoluble in aqueous solvents, but soluble in fats. Organic mercury ions can cross cell membranes and accumulate in nerve cells, with a residence time of around 70 days (Laidler, 1991). When the rate of accumulation of heavy metals is greater than the excretion rate from the body, poisoning and even death may result.

The Minamata Bay incident, 1972, in Japan alerted the world to the effects of heavy metal poisoning. Crabs in the Minamata Bay were found to contain 24 ppm of mercury, however the dead fisherman were found to have mercury levels in their kidneys of around 144 ppm.

Under anaerobic conditions inorganic mercury of short residence time can be converted into the more deadly methyl mercury. The conversion to methyl mercury is a bacteriological

conversion which involves the anaerobic methanic bacteria. The chemical equation representing this conversion is as follows (Golterman, 1975) and (Laidler, 1991):



The reaction described by equation 2.8 causes mercury adsorbed onto the silt fraction of sediment to become mobilised. This allows the mobile and deadly methyl mercury to enter the food chain and accumulate in marine animals such as fish and crabs.

The sources of mercury in stormwater runoff include emissions from the chlor-alkali industry, coal combustion, paint industry and dental amalgam (Makepeace et al. 1995). Makepeace et al. (1995) found that the concentrations of mercury throughout the world range from 0.00005 to 0.067mg/L. The ANZECC (1992) guideline for mercury to protect aquatic ecosystems in fresh water is 0.0001mg/L.

2.4.7.2 Cadmium

Cadmium is even more toxic than mercury, but in natural waters is less toxic than in distilled water because of the bonding to silt particles (Golterman, 1975) and (Reeder et al., 1979). The toxicity of cadmium to aquatic biota is affected by water hardness, pH, water temperature and the presence of organic compounds (CCREM, 1991).

The sources of cadmium include combustion, wear of tyres and brake pads, possible combustion of lubricating oils, metal-finishing industrial emissions, agricultural use of sludge, fertilisers, pesticides and corrosion of galvanised metals (Makepeace et al. 1995). Makepeace et al. (1995) found a mean concentration range of 0.0003 to 0.011mg/L. The ANZECC (1992) guideline for the protection of aquatic ecosystems in freshwater is 0.0002 to 0.002mg/L depending on the hardness of water.

2.4.7.3 Lead

Lead is often identified as the most important contaminant of concern in urban stormwater research. The main source of lead is the emissions from motor cars due to the combustion of

fuel. The trend towards vehicles that are powered by unleaded petrol, and liquid petroleum gas (LPG) is decreasing lead levels in the atmosphere, however the ever increasing world population and overall increase in the use of the automobile counteracts this decrease.

The review of stormwater quality literature by Makepeace et al. (1995) found lead concentrations of between 0.00057 and 26mg/L. The mean concentrations of lead ranged from 0.0209 to 1.558mg/L. The ANZECC (1992) guidelines suggest lead levels should be below 0.001 to 0.005 (depending on the hardness of the water) for the protection of aquatic ecosystems in fresh waters. Other heavy metal parameters that are considered an important in urban stormwater are aluminium, arsenic, chromium, copper, iron, nickel and zinc.

2.4.8 Petroleum Products

Stormwater runoff from urban catchments often has a characteristic multicoloured oil sheen on the surface, especially catchments with high percentages of industrial land uses. The source of the oil is usually engine oil that has leaked from cars on the road and then has been entrained in the runoff during a storm event. Transport yards are often a major source of oil in stormwater. Oil washed from roadways is in a dissolved form or bound to particulate matter (Snelder and Trueman, 1995). The amount of oil present in stormwater is often small with no threat to aquatic life. The more toxic components, namely soluble aromatic hydrocarbons such as benzene, phenol and naphthalene are not normally present in sump oil (Snelder and Trueman, 1995).

Polycyclic Aromatic Hydrocarbons (PAH) are present in relatively high concentrations in urban stormwater runoff, and some are highly toxic to aquatic life as they are carcinogenic. The sources of PAHs are (Snelder and Trueman, 1995) :

- Petroleum;
- Lubricating oils;
- Bitumen;
- Car exhaust fumes; and
- Decomposing organic matter emissions.

Most PAHs are insoluble and are easily sorbed onto particulate matter in stormwater. Table 2.8 outlines the range or mean and standard deviation of some polycyclic aromatic hydrocarbons as outlined by Makepeace et al. (1995).

TABLE 2.8 : Polycyclic aromatic hydrocarbons in stormwater

Polycyclic Aromatic Hydrocarbons in Stormwater

Polycyclic aromatic hydrocarbons	Range of values or mean and standard deviation (mg/l)
Anthracene	0.000009 – 0.01
Benzo(a)anthracene	0.0000003 – 0.01
Benzo(b)fluoranthene	0.0000034 – 0.0019
Benzo(k)fluoranthene	0.0000012 – 0.01
Benzo(g,h,i)perylene	0.0000024 – 0.0015
Benzo(a)pyrene	0.0000025 – 0.01
Benzo(e)pyrene	0.0004 – 0.000609
Chrysene	0.0000038 – 0.01
Dibenzo(a,h)anthracene	0.0000006 – 0.0009
Fluoranthene	0.00003 – 0.056
Fluorene	0.000096 – 0.001
Indeno(1,2,3-c,d)pyrene	0.00031 – 0.0005
Methylphenanthrenes	0.0029 ± 0.0034
2-Methylanthracene	0.00001 – 0.0016
9,10-Dimethylanthracene	0.001 ± 0.0014
Naphthalene	0.000036 – 0.0023
Perylene	0.00005 ± 0.0005
Phenanthrene	0.000045 – 0.01
Pyrene	0.000045 – 0.01
Total PAH	0.00024 – 0.013

2.4.9 Micro-organisms

Stormwater runoff contains a number of varieties of micro-organisms including viruses and bacteria, some of which cause health problems for humans. Their role in natural waterways is important for processes such as respiration of biota. Some types of bacteria respire aerobically, others are anaerobic although nearly all are heterotrophic. Algae however are autotrophic. Micro-organisms play an important role in processes such as nitrification as discussed earlier in section 2.4.4.3.

In Australia, the major sources of micro-organisms are from animal faeces washed into waterways and from untreated sewage effluent. Untreated sewage effluent is becoming less common as a source of micro-organisms in stormwater as modern day stormwater network systems are usually separate from the sewage system in Australia. Overloaded sewage systems and breakages in sewage pipes often cause temporary point source contamination of stormwater.

Makepeace et al. (1995) observed a range of mean total coliforms (TC) between 9.8×10^1 to 2.2×10^6 colony forming units (CFU)/100ml, and a range of mean fecal coliforms (FC) of between 1.6×10^2 to 2.5×10^5 CFU/100ml.

The total coliforms test indicates the presence of *Escherichia coli* (E.coli), *Citrobacter*, *Enterobacter* and *Klebsiella* (Makepeace et al. 1995), however it is not a very good indicator for evaluating the total risk to human health from microorganisms in stormwater. E.coli is the best freshwater fecal indicator even though analysis is both expensive and time consuming.

2.4.10 Pesticides

Herbicides and insecticides are common in urban stormwater (Snelder and Trueman, 1995). Herbicides including organophosphates such as *simazine*, *dalapon*, *glyphosphate* and *atrazine* are used to control plant growth. When used along-side open stormwater drains and roads they can easily find their way into stormwater. Herbicides are broken down rapidly in the aquatic environment and do not accumulate in the receiving waters. Levels of herbicides detected in stormwater pose little threat to the aquatic environment as they are about 1000 times below lethal concentration levels (Snelder and Trueman, 1995).

Insecticides however are not easily broken down in the receiving waters and provide a much greater risk to the aquatic environment. The organochlorine insecticides such as chlordane, dieldrin, DDT and lindane are quite hazardous but are now banned for household use. Polychlorinated biphenyls (PCBs) are an alternative strand of organochlorines that are also toxic.

2.5 Selection of the Water Quality Parameters for this Study

⊕ Definitely use p. 35 - Paddock 2017 info
⊕ Also Bell & Ferguson (1994)

After reviewing current literature on stormwater contamination the nutrients of nitrogen and phosphorus were decided on as the key nutrients to monitor in this study. The forms of nitrogen that were considered important include ammonium, organic, nitrate, nitrite and total nitrogen. The phosphorus forms of dissolved, particulate and total were considered important.

Various metals were identified as important to stormwater contamination and it was decided that this research project concentrate on the parameters of aluminium, arsenic, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel and zinc.

Petroleum products were identified as important to this research as oil is visibly evident on the surface of stormwater in the industrial catchments. Polycyclic aromatic hydrocarbons (PAHs) were chosen to best depict petroleum products in the stormwater.

Water quality parameters also monitored include pH, water temperature, turbidity, dissolved oxygen and electrical conductivity.

2.6 Monitoring Stormwater Quantity

A good monitoring program for urban stormwater requires both quantity and quality are measured so that pollutant loads can be determined. The previous sections have dealt with stormwater quality and the parameters that are important in the characterising stormwater runoff quality. This section discusses stormwater quantity measurement and its importance to the overall stormwater monitoring process.

2.6.1 Control Section

The choice of the control section is a very important step in measuring flow quantity. The selection of the site requires identifying a channel section with physical characteristics that will enable the flow to be stabilised so that for a given stage height the flow will always be the

same. The site should provide a good sensitivity between changes in stage height and changes in flow.

A section control can be either natural or artificial and exists at a cross section where the channel is constricted or where a downstream change in slope occurs as exists at a rock bar or the upper end of a culvert. Invariably a small weir is constructed in the channel as a control.

Of course the selection of the site is controlled by where it is necessary to monitor water quantity and quality but this necessity inherently leads to “difficult” sites. Factors affecting site selection will include (Cugley et al., 1997):

- Suitability for measuring flow. Rating tables, used to convert water depth into flow, can sometimes change considerably during the course of an event; particularly if the controlling cross section changes due to erosion or deposition of material.
- Able to meet sampling objectives. This may require expert advice, both to frame the monitoring objectives in sufficient detail, and to select sites that will provide data to meet the objectives.
- Safety of access. Safety of sampling personnel, particularly during storm events, is a key consideration.
- Whether the site can provide representative water quality data. It may be necessary to carry an initial investigative program to assess potential sites prior to establishing a permanent site.
- Security. Automatic sampling devices in highly visible locations may run an increased risk of vandalism.
- Services. The availability of power and telephone can make some sites more attractive.

2.6.2 Direct Measurement of Flow

The direct measurement of flow generally falls into four methods including :

- Artificial control;
- Volumetric measurement;
- Velocity area method; and
- Dilution gauging.

2.6.2.1 Artificial Controls

An artificial control usually consists of a weir or a flume which has a known relationship between stage height and flow rate. The stage or gauge height of water is measured from which the flow is calculated using a formula which varies according to the design of the structure. The most common precalibrated structures are weirs and flumes and both are designed to provide a known, repeatable relationship between flow and stage.

Weirs consist of a crest located across the width of an open channel (at a right angle to the direction of flow). The flow of water is impeded, causing water to overflow the crest. When the flow exceeds the capacity of the weir flow depth actually diminishes as the water approaches the weir. For this reason the height of water upstream of the weir, rather than at the weir itself, is used to calculate the flow rate. Sedimentation at the weir site may be an undesirable side effect.

Weirs for temporary measurement can be relatively inexpensive and are useful for measuring flows in natural or constructed channels because they are easily installed in irregularly shaped water courses. However in large streams or water courses might prove to be very expensive. A staff gauge can be installed at a non-turbulent point upstream of the weir crest to provide accurate and convenient stage measurement. The continuous recording of stage height can easily be accomplished by electric pressure transducers, ultrasonic transducers, shaft encoders or capacitive probes. Instrumentation for monitoring is well described in the literature (Hersch, 1978, 1985; WMO, 1981/1983, and Falkland et al., 1991). There are many standard weir shapes developed over the years which allow for the calculation of flow from a measurement of water depth at a staff gauge (Ackers et al., 1978).

Flumes are structures which force water through a narrow channel. They consist of a converging section, a throat, and a diverging section. The Parshall flume is the most common and has fixed specifications relating to geometric shape with variations only in throat and width.

2.6.2.2 Velocity Area Method

Flow or discharge (Q in m^3/s) can be measured by multiplying the area of cross section (A in m^2) by the average velocity (v in m/s) through that cross section. Velocity measurements can be made with current meters, including electromagnetic, propeller or ultrasonic types, and with floats, tracers or dyes. Generally the results from these direct methods of measurement of flow are incorporated into a stage discharge curve which is considered to be an indirect method of measurement of flow. There is now a greater range of equipment for direct measurement of flow by acoustic Doppler means in open channels and pipes. Experience with these instruments has shown that calibration of these units is essential to obtain satisfactory results. Further discussion is undertaken later on in situ devices.

2.6.2.3 Dilution Gauging Methods

Dilution gauging is a well recognised method of streamflow estimation, particularly in streams which are too turbulent for gauging by current meter. Dilution gauging is done by either constant rate injection or sudden injection of a chemical, dye or radioactive tracer into the stream at one point and measurement of the tracer at a downstream location. The technology is not new and is explained in standard manuals and textbooks (Hersch, 1985; Gordon et al., 1992).

2.6.3 Indirect Measurement of Flow

The indirect measurement of flow includes procedures where a relationship between characteristics of the channel or stream and flow are used to derive a measurement of flow.

Stage- Discharge Relationships

The development of a stage discharge relationship from many different flow gaugings for a site enables flow to be determined by simply monitoring water level. This stage discharge relationship is called a rating curve and should be checked on a regular basis for different levels of discharge. If there are changes to the downstream control section or the gauging section then the relationship between stage height and flow will change. If changes occur a new rating curve should be established. The stage is generally measured as described previously.

Slope Area Method

The estimation of peak flows from height of water marks and debris left on the banks from floods can be made. Typically Manning's equation is used. Dalrymple and Benson (1967) provide a comprehensive description of the slope -area method.

2.7 Relevant Stormwater Studies in South Australia

A number of urban stormwater studies relevant to this monitoring project have been carried out in South Australia in the past six years. The major studies include The Paddocks (Tomlinson et al., 1993), The Glenelg Quantity and Quality project (Argue and Scott, 1996), Patawalonga (MFP Australia, 1995), Greenfields (Salisbury Council), Happy Valley (Gamble, 1997; Walker et al., 1997, Jacobi and Murphy, 1996) and Dry Creek (Passfield and Phillips, 1996).

The studies outlined above have characterised the stormwater quality from a number of urban catchments in the Adelaide metropolitan area. One of the fruits from these research projects is hopefully to be able to transfer contaminant information to other urban catchments in the Adelaide metropolitan area. The 'transferability' of stormwater load information to other urban catchments in the South Australia is one of the major applications for this research. The transfer of pollutant load data between catchments between 'similar' urban catchments may not be directly feasible due to the hydrological influences on quantity measurement. Pollutant concentrations may be transferable as the concentration may be related back to the land use.

Chapter 3

Catchment Description

3.1 Introduction

The characteristics of a catchment have a direct impact on the stormwater runoff quantity and quality that is produced when rain falls upon it. Important properties of a catchment include the following :

- Catchment size;
- Degree of urbanisation;
- Land use types;
- Pipe network system;
- Open channel type;
- Soil type;
- Geology; and
- Catchment slope.

The Barker Inlet Wetland catchment is an ideal study catchment. Four main subcatchments are nestled together with varying land uses, catchment sizes and channel types with outflows

within close proximity of one another. This enables a comparison of the catchment characteristics listed above and their effect on the stormwater runoff quality.

3.2 The Barker Inlet Wetland Catchment

The Barker Inlet Wetland Catchment is a large urban catchment located in the northern suburbs of Adelaide, the capital city of South Australia. As can be seen from Figure 3.1 the upper end of the catchment extends from the edge of the suburb of North Adelaide for approximately 15 kilometres to the Barker Inlet and the suburbs of Wingfield, Gillman and Dry Creek.

The total catchment area for the Barker Inlet Wetland is 4475 hectares. The catchment for the Barker Inlet Wetland is split into four sub catchments varying in size from 223 to 2170 hectares (Williams and Daniell 1996a, 1996b) as summarised in Table 3.1.

TABLE 3.1 : Summary of Catchment and Station details

Catchment	Station No.	Area (ha)
North Arm East Drain	AU504101	2170
Hindmarsh Enfield Prospect Drain	AU504102	1300
Dunstan Road Drain	AU504103	223
South Road North Arm West Drain	AU504104	782

Before the construction of the Barker Inlet Wetland, the stormwater runoff discharged directly into the Barker Inlet and into the Gulf of St. Vincent. The Barker Inlet is a salt water estuary with dense mangroves on the banks. The Gulf of St. Vincent is abundant with fish and other marine life which rely on the Barker Inlet as an important ecosystem.

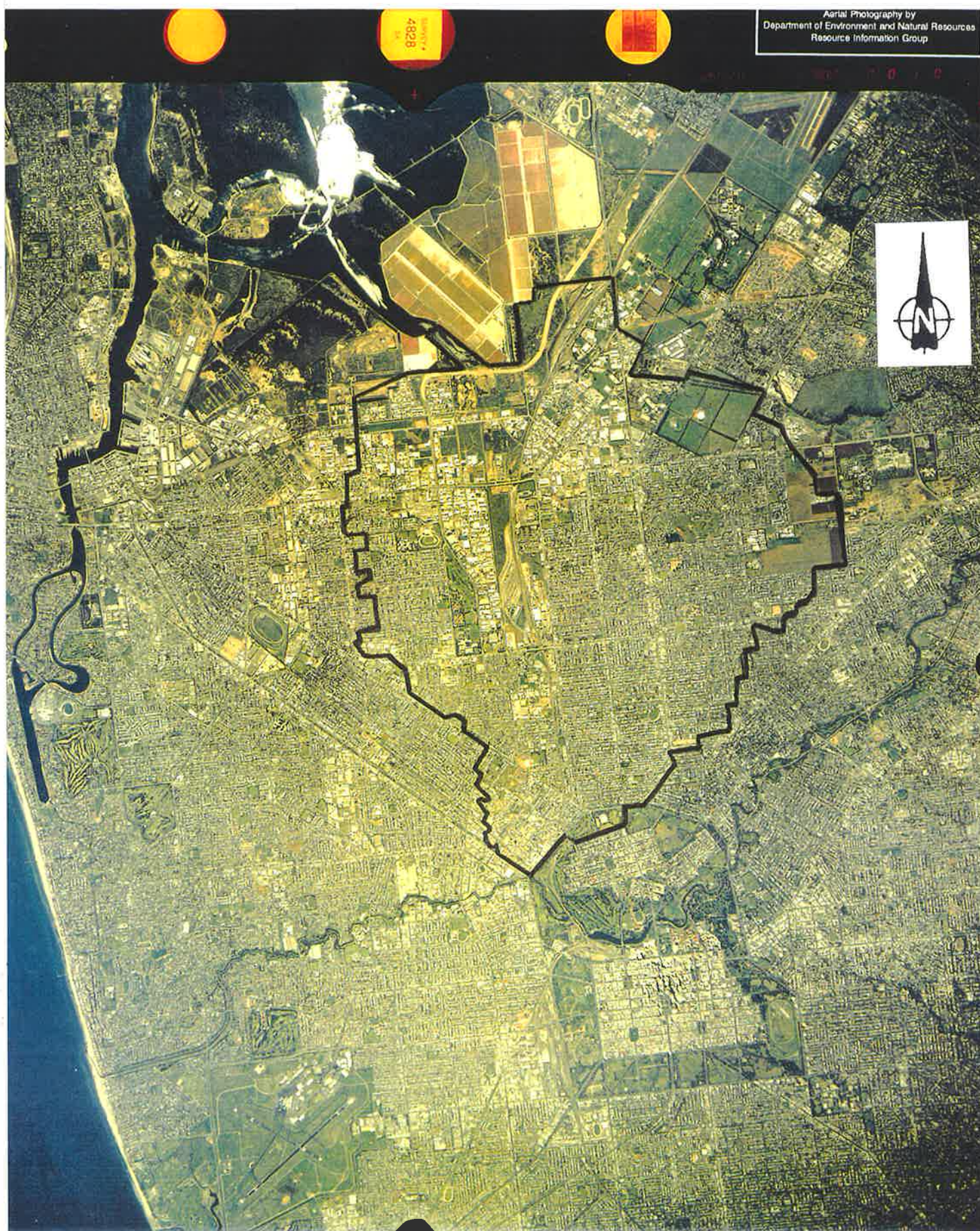


Figure 3.1 : The Barker Inlet Wetland Catchment Map

3.2.1 North Arm East Drain

The North Arm East Catchment (NAE) is the largest of the four catchments with an area of 2170 hectares (21.7 km²) of which approximately 26% is impervious (564 ha). The catchment drainage for this station is a classical "engineered" system with an open concrete lined channel at the monitoring station. The concrete channel is fed by a concrete stormwater pipe network that branches out to the limits of the catchment, with some branches including fifth order pipes.

The North Arm East Drain is a concrete lined channel of trapezoidal section, 12 metres wide at the base, 1.22 metres deep and with sidewall slopes of 45 degrees. The drain is straight for 100 metres upstream of the monitoring site and for 50 metres downstream, where it passes under a railway bridge and discharges down a one metre drop into an unlined earthen channel and discharges into the Barker Inlet Wetland. Photographs 3.1 and 3.2 show the North Arm East Drain and monitoring station.

The catchment is almost entirely urbanised, and the only significant open areas are contemplated for development in the near future. A typical residential street in the North Arm East Catchment is shown in Photographs 3.3 and 3.4. The rainfall to runoff response of the catchment is rapid, in the order of about 30 minutes. There is a significant dry weather base-flow although this is suspected to be industrial process water and garden water.

The catchment is flat with a gradual slope from south to north of approximately 1:118 (0.85%) and a slope from east to west of approximately 1:75 (1.33%).



Photograph 3.1 : The North Arm East Drain (AU504101) monitoring station



Photograph 3.2 : Upstream of the North Arm East monitoring station, facing downstream.



Photograph 3.3 : Typical residential street in The North Arm East Catchment
(facing east in Kintore Avenue, Kilburn)



Photograph 3.4 : Typical residential street in The North Arm East Catchment
(facing west in Kintore Avenue, Kilburn)

3.2.2 Hindmarsh Enfield Prospect Drain

The catchment area for the Hindmarsh Enfield Prospect Drain (HEP) is 1300 hectares (13 km²) with an estimated 31% of impervious area (403ha). The catchment is almost entirely urbanised. The monitoring station in this drain is located in a section of concrete lined trapezoidal channel 2.5 metres wide at the base, with sidewalls 2.1 metres high and at a slope of 57 degrees. The monitoring station is shown in Photographs 3.5 and 3.6.

A pipe network system within the suburbs of Prospect and Hindmarsh transfers stormwater to two small open channels. These two small channels discharge into a grass swale drain. The grass swale drain is sixty metres wide and extends for 1500m before passing under Grand Junction Road in culverts and then extends a further 1500m again as a wide grass swale. The grass swale drain has an area of approximately 18ha, which represents approximately 1.4 % of the catchment. The grass swale drain is shown in Photographs 3.7 and 3.8 during low flow and event flow.

The channel passes through culverts under Cormack Road in culverts before travelling in a wide earth lined channel for 200 metres before converging into a short section of concrete lined channel for 50 metres and discharging into the Barker Inlet Wetland.

The grassed swale acts as a detention/retention basin during storm flows and drains slowly to the discharge channel and monitoring station. The rainfall to runoff response of the catchment is very slow with runoff taking up to twelve hours to reach the monitoring station at the bottom of the catchment. The swale drains are occasionally mown and grazed by cattle. A high level of infiltration of flow occurs in the swale drain, especially during summer. The infiltration is highly variable and depends on antecedent catchment wetness.

The Hindmarsh Enfield Prospect (AU504102) catchment has a gradual slope from south to north of approximately 1:208 (0.48%) and a slope from east to west of approximately 1:100 (1.0%). Photograph 3.9 shows a typical main road in the Hindmarsh Enfield Prospect (AU504102) catchment and 3.10 depicts a typical residential street.



Photograph 3.5 : Hindmarsh Enfield Prospect Drain (AU504102) monitoring station.



Photograph 3.6 : Facing Downstream of the HEP monitoring station



Photograph 3.7 : The large swale drain upstream of the HEP Drain under low flow conditions. Facing Upstream.



Photograph 3.8 : The swale drain during a storm event. Facing Upstream.



Photograph 3.9 : Main road in The Hindmarsh Enfield Prospect Catchment
(Prospect Road facing south)



Photograph 3.10 : Typical residential street in The Hindmarsh Enfield Prospect Catchment

3.2.3 Dunstan Road Drain

The Dunstan Road catchment is the smallest of the four catchments with an area of 223 hectares (2.23 km²) of which 25.9% is estimated to be impervious (58ha). The industrial estate of Regency Park is located within the Dunstan Road catchment which is predominantly occupied by transport companies and motor vehicle agencies. The drain has a major truck park and fuelling station beside it which is shown in Photographs 3.13 and 3.14.

The drain is brick paved and is trapezoidal in cross-section, being 4775mm wide across the base and has paved side walls 875mm high at a slope of 10%. The drain is shown in Photographs 3.11 and 3.12. Upstream of the monitoring station the brick lined profile extends for one kilometre to Grand Junction Road, where the drain passes under the road in box culverts and then into a pipe network under the Regency Park Industrial Estate. There is a low flow drain and sand filter beneath the brick paving, with frequent interconnecting sumps through the bricks. Consequently very low flows pass under, rather than along the channel and so bypass the station.

Most noticeable in this drain is the presence of oil, which can be seen in any flows down the drain and trapped in sediment deposits. This is perhaps not surprising as the catchment has a large proportion of industrial properties within it.

The Dunstan Road catchment is flat with a negligible slope of less than 0.5%. The rainfall to runoff response of the catchment is rapid with runoff reaching the lower end of the catchment within forty minutes of the beginning of a storm.



Photograph 3.11 : Dunstan Road Drain (AU504103) monitoring station. Facing downstream.



Photograph 3.12 : Facing upstream of the Dunstan Road monitoring station



Photograph 3.13 : Major truck park and refuelling station in The Dunstan Road Catchment



Photograph 3.14 : Major truck park and refuelling station in The Dunstan Road Catchment

3.2.4 South Road North Arm West Drain

The catchment for South Road North Arm West Drain is 782 hectares (7.82 km^2) in size and is almost entirely urbanised. The impervious fraction of the catchment is estimated to be approximately 32.5% (254ha). The catchment is flat with a negligible slope of less than 0.5%. Two typical residential streets in the North Arm West Catchment are shown in Photographs 3.17 and 3.18.

At the monitoring station this drain is an unlined trapezoidal open channel, 12 metres wide at the base. Photographs 3.15 and 3.16 show the monitoring station in the South Road North Arm West Drain as well as part of the upstream channel. Upstream of the monitoring station a 500m shallow pool has been formed by the measuring weir and acts as a detention basin. Beyond that 300m of reed, sedge and other macrophytes have vegetated the drain. Due to the detention basin created by the weir and the extensive reed growth upstream of the monitoring station the rainfall runoff response of the catchment is slow.

Upstream the channel profile is maintained for six hundred metres where it passes through multiple box culverts under South Terrace, then under a railway bridge and through culverts under Cormack Road. South of Cormack Road it divides, with one channel passing under South Road and continuing adjacent to the eastern side of the carriageway and the other turning southwest into industrial then residential areas. The extensive growth of reeds in the channel has caused flooding concerns and was recently excavated by the local council to remove the reed growth. The reeds are gradually growing back to form the natural filtration system that they once provided.



Photograph 3.15 : The monitoring station at the North Arm West Drain (AU504104). Facing Upstream.



Photograph 3.16 : Upstream of the North Arm West Drain. Facing Downstream.



Photograph 3.17 : Typical residential street in The South Road North Arm West catchment



Photograph 3.18 : Typical residential street in The South Road North Arm West catchment

3.2.5 Land Uses within the Barker Inlet Wetland Catchments

The four subcatchments of the Barker Inlet Wetland vary in area, channel type and land use. The area and channel types have been discussed earlier in this chapter, and the land use types are summarised in Table 3.2 below.

TABLE 3.2 : Land Use in the Barker Inlet Wetland catchment

Catchment	North Arm East (AU504101)	Hindmarsh Enfield Prospect (AU504102)	Dunstan Road (AU504103)	North Arm West (AU504104)
Land use	% of catchment	% of catchment	% of catchment	% of catchment
Residential	40.0	50.6	0	37.6
Commercial	13.4	9.3	31.1	17.2
Manufacturing- Oils	1.2	4.7	1.9	5.8
Manufacturing- Organics	2.8	11.9	8.0	7.0
Manufacturing- Heavy Metals	5.0	2.5	8.8	6.9
Manufacturing- Other	5.7	1.9	8.2	5.4
Primary production-crops	0.2	0.1	0	0.2
Primary production- livestock	2.4	0.3	0	3.0
Open Space	18.7	10.8	39.2	14.1
No Valuation match	9.9	7.8	2.8	2.8
Total	100	100	100	100

The landuse in the Barker Inlet Wetland catchment is also shown in Figure 3.2. The land use information in Figure 3.2 is derived from Valuation and Cadastre supplied by the Department of Environment and Natural Resources and was current at March 1997. The 10 land use zones in Figure 3.2 were derived by grouping together hundreds of specific land use zones into these 10 broader groups that best depict the major land use types.

The percentages of land use types in the North Arm East catchment does not differ considerably from the percentages of land use in the HEP or North Arm West catchments. The Dunstan Road catchment does differ from the other three catchments.

The Dunstan Road catchment has no residential land use within it whereas the NAE, HEP and NAW catchments have 40, 50.6 and 37.6% respectively.

The Dunstan Road catchment has the largest percentage of commercial land use (31.1%). The Dunstan Road catchment also has the largest amount of open space (39.2%), however the open space in the Dunstan Road consists mostly of industrial storage yards.

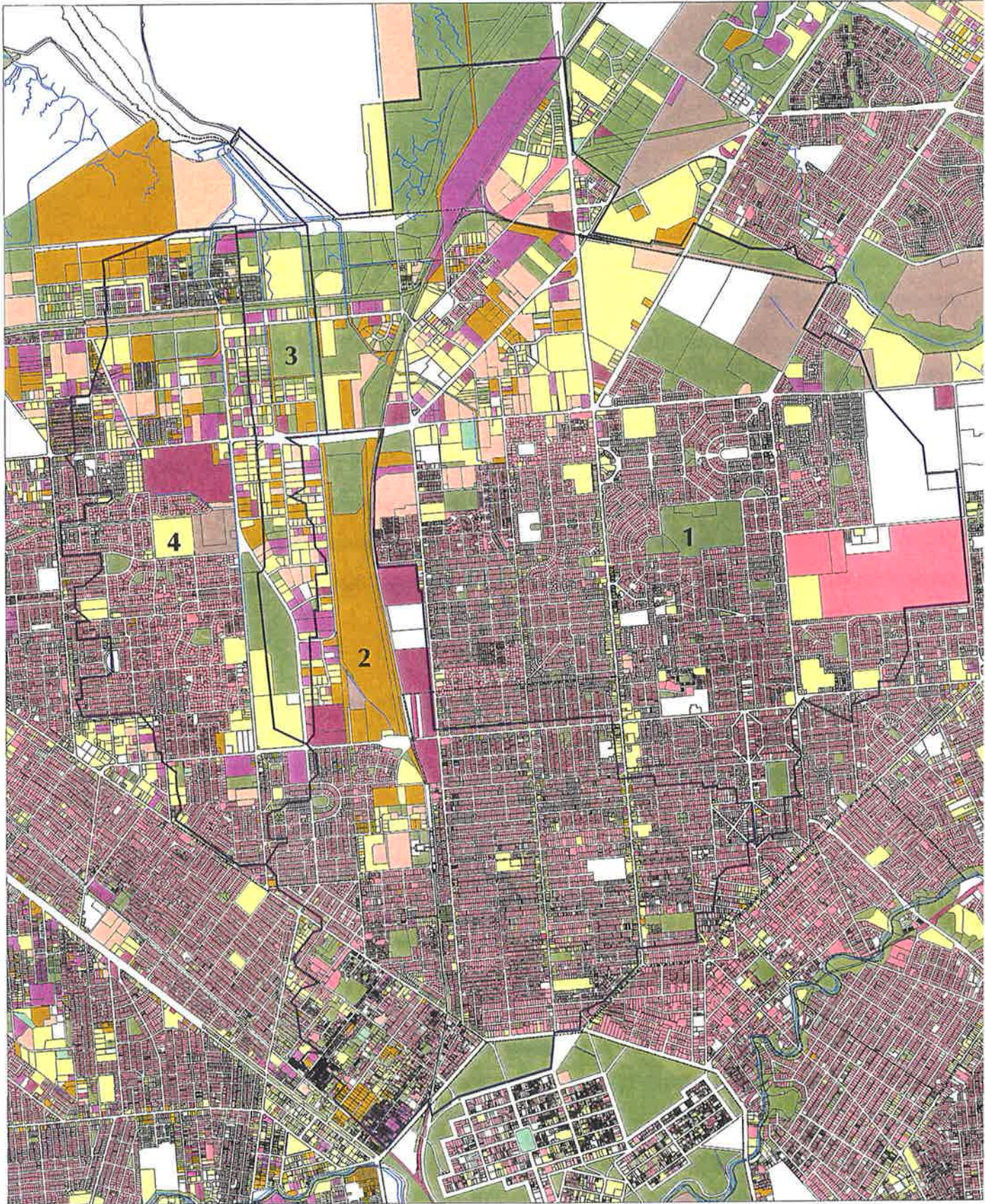
Table 3.3 combines several of the land use categories together into broader categories. The commercial/industrial land use in Table 3.3 is the sum of commercial land uses and manufacturing of oils, organic, heavy metals and other goods from Table 3.2. The Dunstan Road (AU504103) catchment has 58% of commercial/industrial land uses compared to North Arm East (AU504101) 28.1%, Hindmarsh Enfield Prospect (AU504102) 30.3% and North Arm West (AU504104) 42.3%.

TABLE 3.3 : Summary of Land Uses in the Barker Inlet Wetland Catchment

Land Use	NAE (AU504101)	HEP (AU504102)	Dunstan Rd (AU504103)	NAW (AU504104)
Residential	40	50.6	0	37.6
Commercial/ Industrial	28.1	30.3	58	42.3
Open Space	18.7	10.8	39.2	14.1
Other	13.2	8.3	2.8	6

In summary the Dunstan Road catchment has no residential area. The Dunstan Road Drain has a high proportion of industrial/commercial land uses (58%). The Dunstan Road Drain has a high percentage of open space (39.2%) compared to the other three catchments. The North Arm East (AU504101), Hindmarsh Enfield Prospect (AU504102) and North Arm West (AU504104) catchments have a high proportion of residential area. The North Arm West (AU504104) Drain also has a high percentage of commercial/industrial land uses (42.3%).

Landuse in the Barker Inlet Wetland Catchment



- Residential
- Commercial
- Manufacturing - oils
- Manufacturing - organic
- Manufacturing - heavy metals
- Manufacturing - other
- Primary production - crops
- Primary production - livestock
- Open space
- No valuation match

- Barker Inlet Wetland Catchments
 - 1 North AmI East
 - 2 Hindmarsh - Enfield - Prospect (HEP)
 - 3 Dunstan Road
 - 4 South Road - North Am West
- - - - Local Government boundary
- Drainage
- Cadastre
- Coastline



0 1.5km

Produced by INFORMATION AND DATA ANALYSIS
 Planning Division
 Department of Housing and Urban Devt
Data Source Landuse categories derived from valuation and Cadastre supplied by the Department of Environment and Nature and were current at June 1996.
Projection Transverse Mercator
Completed March 1997

* Copyright Department of Housing and Urban Development 1997. All rights reserved. Information displayed here indicates copyright for the republication of this information. It is not intended to be used for any other purpose without the written permission of the Department.
 Although every effort has been made to ensure the accuracy of the information, the Department, its agents, officers and employees make no representations or warranties, in relation to the information displayed on this map, or for any other purpose. A disclaimer of liability for loss or damage arising from reliance upon the information is available on the Department's website.

Figure 3.2 • The Barker Inlet Wetland Land Use Map.

3.2.6 Soil Types within the Catchments

Figure 3.3 is a soil association map of the Adelaide region, and outlines the different types of soils within the catchments.

The type of soil within a catchment can affect both the quantity and quality of stormwater runoff from a catchment. The quantity of pervious runoff is partly dependent on the infiltration properties of the soil in the catchment. The quality of stormwater runoff is partly dependent on the rate of erosion of the soil in a catchment. The sediment export from a catchment has a strong association with pollutants such as heavy metals and nutrients (Cullen 1980, Marsalek 1990).

The North Arm East catchment consists of brown solonised soil (BS) in the top part (south east end) of the catchment. The middle of the catchment consists of red brown or sandy clay (RB6-RB7). The bottom end of the catchment has a small percentage of estuarine muds and sands (EMS). On the eastern boundary of the NAE catchment there is a small pocket of soil consisting of black earth (BE).

The Hindmarsh Enfield Prospect catchment consists of brown solonised soil (BS) in the top half of the catchment (south-east end) while the bottom half of the catchment is red brown clay or sandy clay (RB6-RB7).

The Dunstan Road catchment consists solely of red brown or sandy clays (RB6-RB7).

The North Arm West catchment is almost all red brown or sandy clay (RB6-RB7) with only a very small pocket of estuarine muds and sand (EMS) at the bottom of the catchment.

Red brown or sandy clays (RB6-RB7) are often low in lime content and quite sandy in the lower profile (Taylor et al. 1974). Taylor et al. (1974) describe RB6 soil as having a moderate to rapid internal drainage rate and external drainage as slow. The RB7 soil is generally micaceous and low in lime content (Taylor et al. 1974) and varying physical characteristics. The internal drainage profile is rapid.

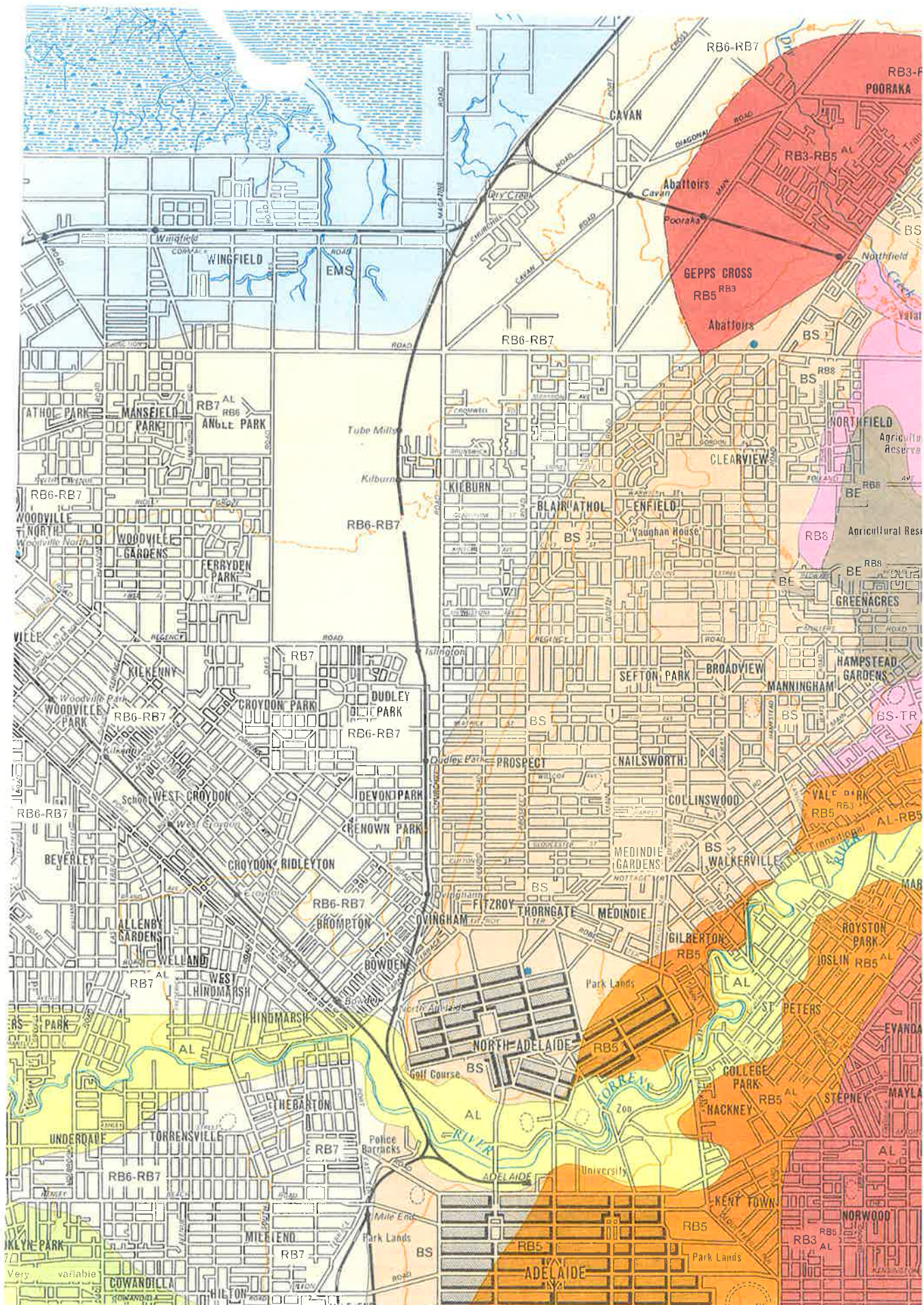


Figure 3.3 : Soil Association map of the Barker Inlet Wetland Catchment

3.2.7 The Barker Inlet Wetland

The Barker Inlet Wetland forms an integral part of a series of wetlands constructed on degraded low-lying coastal land in the northern suburbs of Adelaide in South Australia. The “green band” of wetlands combine together to intercept and treat approximately 40% of Adelaide’s stormwater runoff. The green band consists of The Greenfields, South Road Connector, Magazine Creek, Range and Barker Inlet Wetlands. Together the wetlands occupy approximately 337ha and are the world’s largest constructed Urban wetlands.

The largest of these wetlands is The Barker Inlet Wetland which is 172 hectares in size and was developed by MFP Development Corporation. The Barker Inlet Wetland receives approximately 4,500ML of polluted stormwater annually from four stormwater drains carrying industrial and urban stormwater.

The Barker Inlet Wetland represent one of the world’s southern most stands of Grey Mangroves (*Avicennia Marina*), which serve as a fish spawning area (MFP Australia, 1996). The mangroves and seagrasses are vital to the commercial and recreational fishing industry in the Barker Inlet and Spencer Gulf waters.

The wetlands act as a flood mitigation system and provide a diverse ecological habitat for flora and fauna in addition to providing an effective filtration system for urban stormwater. In the design phase of the wetland, specific consideration was given for birds, fish and other species, including breeding and nursery areas.

The planning for the Barker Inlet Wetland commenced in 1994, with contracts for construction of earthworks, structures and pipework awarded in December 1995 (MFP Australia, 1996). The construction phase commenced in January 1996 and the scope of earthworks included the excavation of some 500,000 cubic metres of earth and the importation and spreading of some 200,000 cubic metres of topsoil. The planting phase of the construction process began midway through 1996. The wetland was completed in early 1997.

A schematic diagram of the wetland is shown in Figure 3.4. The design of the wetland incorporates both deep and shallow water sections, with cells varying in water type between fresh, salt and mixed. On the southern side of the South Road connector, as outlined in Photographs 3.19 and 3.20, the wetland was designed as a deep water wetland with typical water depths of 0.6 to 0.85 metres. On the northern side of South Road connector, as outlined in Photographs 3.21 and 3.22 the wetland was designed to have shallow water depths typically in the range of 0.3m deep. A bund separates the shallow water depth part of the wetland from the inter tidal shallow water zone. Flap gates on the bund allow fresh water to flow out into the inter tidal zone but restrict salt water from entering the fresh water part of the wetland. At the northern end of the inter tidal zone a series of gates allow the water to discharge into the north arm of the Barker Inlet and then into the Gulf of St. Vincent. The stage/storage volume curves for the various cells of the Barker Inlet Wetland are outlined in Appendix A to give an indication of the storage capacities of the different cells.

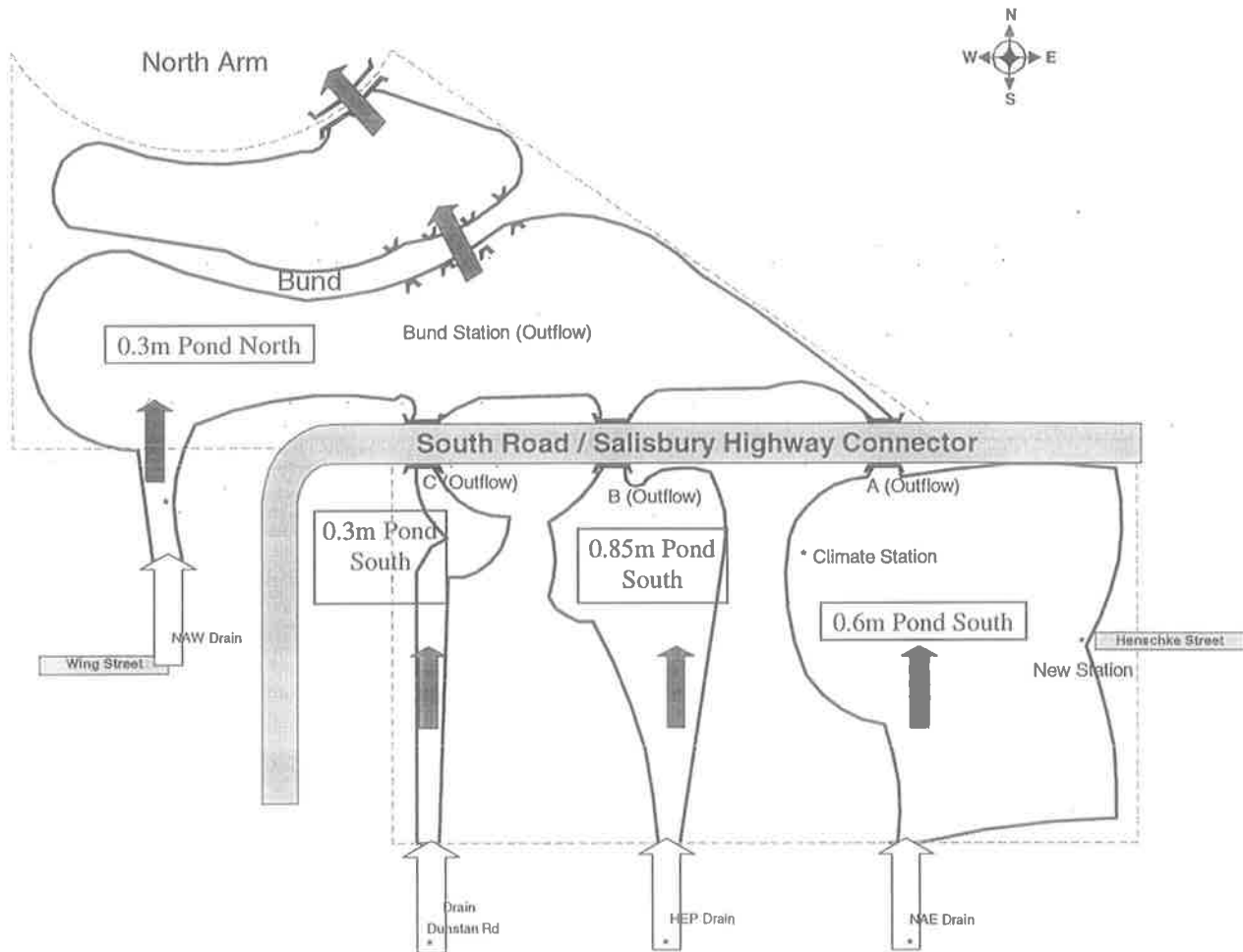


Figure 3.4 : Schematic drawing of the Barker Inlet Wetland



Photograph 3.19 : The Barker Inlet Wetland. Photograph taken from the South Road Connector facing South.



Photograph 3.20 : The Barker Inlet Wetland. Photograph taken from the South Road Connector facing South-West.



Photograph 3.21 : The Barker Inlet Wetland. Photograph taken from the South Road Connector, facing north.



Photograph 3.22 : The Barker Inlet Wetland. Photograph taken from the South Road Connector, facing North-West.

3.3 The Magazine Creek Wetland Catchment

The catchment for the Magazine Creek Wetland is approximately 1407 hectares (14.1km^2). The catchment has two subcatchments, the Jenkins Street and Eastern Parade catchments. The stormwater runoff from the Eastern Parade catchment forms part of this research project and has been monitored since the installation of a concrete weir and instrumentation in September 1996. The monitoring of runoff from the Jenkins Street Catchment is outside the scope of this phase of the monitoring project but may be investigated as part of a future research project.

3.3.1 Eastern Parade Drain

The Eastern Parade catchment has an area of 722 hectares (7.22km^2) and has been fully urbanised apart from approximately 0.9km^2 within and around the Dean Rifle Range which is currently undeveloped (Eco Management Services, 1994). The catchment includes the residential suburbs of Croydon, Rosewater and Woodville as well as some heavily industrialised areas, such as those shown in Photographs 3.25 and 3.26, within the suburbs of Gillman and Port Adelaide. The monitoring station in the Eastern Parade Drain is referred to as AU504201.

The drainage for the catchment is via underground pipes and the pipe network discharges into an open rectangular channel for several kilometres, as shown in Photographs 3.23 and 3.24, before joining the unlined Jenkins Street channel and discharging into the Magazine Creek Wetland.



Photograph 3.23 : The monitoring station at the Eastern Parade Drain (AU504201). Facing Upstream.



Photograph 3.24 : The Monitoring station at the Eastern Parade Drain (AU504201). Facing Downstream.



Photograph 3.25 : Typical industrial land use in the The Eastern Parade Catchment
(Eastern Parade facing west)



Photograph 3.26 : Typical industrial land use in the The Eastern Parade Catchment
(Eastern Parade facing East)

3.3.2 The Magazine Creek Wetland

The Magazine Creek Wetland is located to the north-west of the Dean Rifle Range. Combined with the Range Wetland it covers an area of fifty hectares. The wetlands were constructed to purify the stormwater runoff which discharges to the North Arm of the Port River. The land for the Magazine Creek and Range wetlands was acquired in 1995. Construction of the wetlands commenced in January 1996 and the total project including landscaping was completed in early 1997.

In conjunction with the Barker Inlet, Greenfields and South Road Connector wetlands the Range and Magazine Wetlands minimise the environmental damage caused by untreated urban stormwater discharging into the Barker Inlet and into the Gulf of St. Vincent.

Chapter 4

The Monitoring Network

4.1 Introduction

Monitoring stations were constructed at the bottom of the four Barker Inlet Wetland sub-catchments in 1994 with the objective of monitoring the urban stormwater from each catchment. The construction of the monitoring stations and installation of monitoring equipment for both runoff quantity and water quality was commissioned by the MFP Development Corporation. A combination of accurate velocity and flow measurement devices together with continuous water quality monitoring and event sampling equipment were installed. Pluviometers of two different types, one tipping bucket and five continuous dripping, were strategically positioned within the Barker Inlet Wetland and Magazine Creek Wetland to record rainfall.

The construction of a monitoring station in the Eastern Parade Drain to monitor stormwater into the Magazine Creek Wetland was commissioned by MFP Development Corporation and completed in September 1996.

4.2 Primary Aims of the Monitoring Project

The monitoring network must be designed and constructed in line with the study objectives. The study objectives for phase 1 of the monitoring programme are outlined in Section 1.2. The objectives are numerous but in a broad sense are to characterise the stormwater quality and quantity from the four Barker Inlet Wetland catchments and the one Magazine Creek catchment, The Eastern Parade drain.

4.3 Rainfall Measurement

Rainfall is subject to great variability both spatially and temporally. Stormwater runoff studies are often limited by insufficient rainfall data for their catchments. A priority of this study was to locate pluviometers throughout the catchments in order to obtain a good understanding of the variability of rainfall.

4.3.1 Barker Inlet Wetland Catchment

Six pluviometers were strategically placed throughout the Barker Inlet Catchment. The pluviometer locations are described in Table 4.1, and outlined in Figure 4.1. The locations were chosen to have an accurate coverage of the catchment area and also to maintain high security of the instrumentation. Five stations have Dataflow Automatic rain gauges connected to DS93 8 channel 128k loggers. Photograph 4.1 depicts one of the pluviometers in the Barker Inlet Wetland catchment.



Photograph 4.1 : Hampstead Centre (AU504114) Pluviometer in the Barker Inlet Wetland Catchment

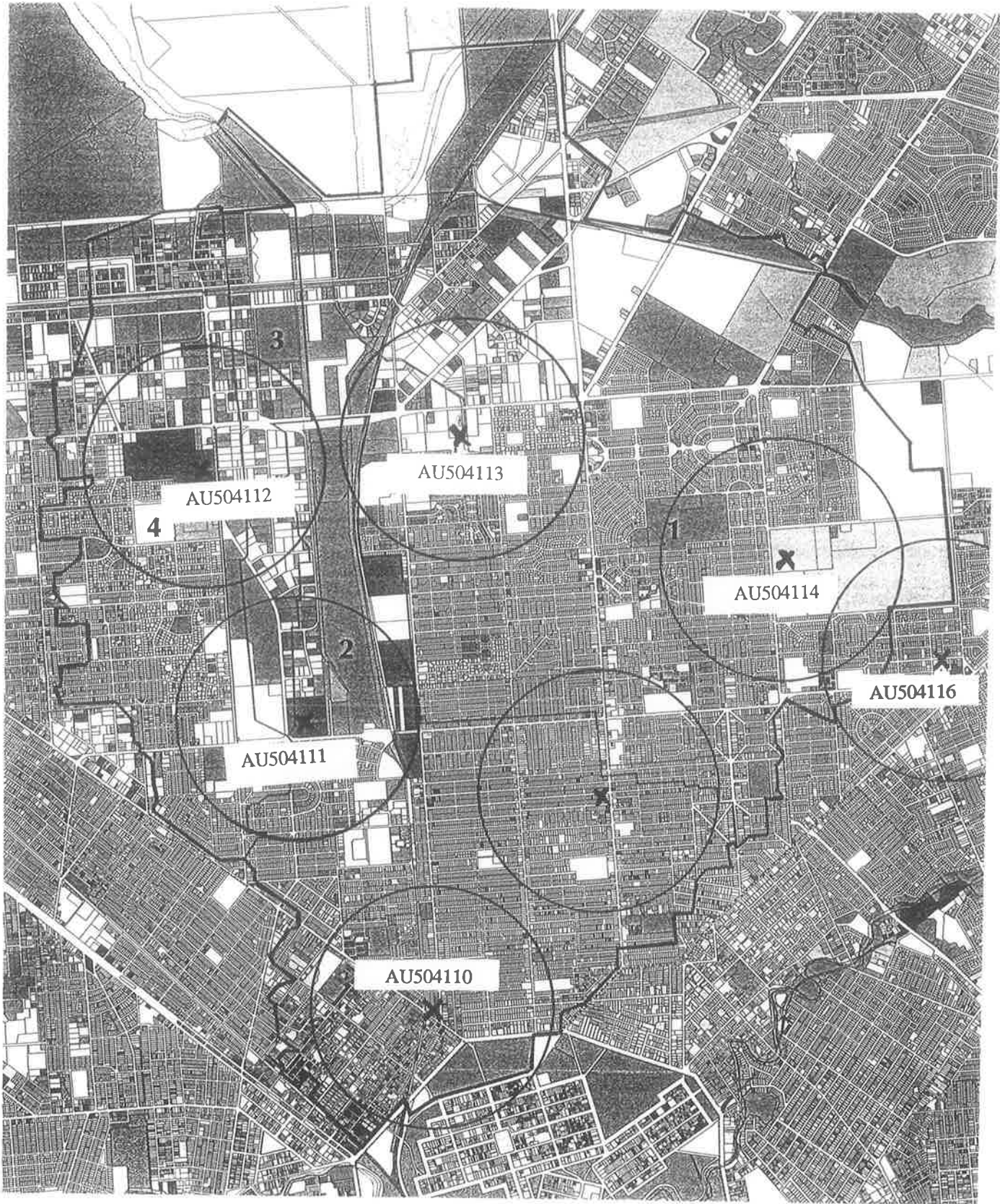


Figure 4.1 : Rain Gauge location in the Barker Inlet Wetland catchment

The location of the rain-gauges shown in Figure 4.1 was carefully planned in order to record the most accurate rainfall data possible. The design of the rain gauge network is such that each rain gauge is representative of the rainfall falling within a circular area with a 1km radius. When strategically placed in the catchment as shown in Figure 4.1 the whole catchment is accurately monitored. Sun shields have been purchased for these loggers to assist in maintaining the integrity of the logging system. The sixth pluviometer is a tipping bucket rain gauge.

TABLE 4.1 : Pluviometers located in the Barker Inlet Wetland Catchment

Station No.	Station Description
AU504110	Ovingham Depot, DRT, Churchill Road
AU504111	Regency Park STA Depot, South Road
AU504112	Angle Park ETSA Depot, Grand Jn Road
AU504113	Enfield Council Depot, Grand Junction Road, Kilburn
AU504114	Hampstead Centre, Hampstead Road, Clearview
AU504115	Prospect Council Depot, Main North Road, Prospect
AU504116	Greenacres Council Depot, Rellum Road, Greenacres

4.3.2 Magazine Creek Wetland Catchment

The rainfall that falls in the Magazine Creek Catchment is monitored by the two pluviometers that are outlined in Table 4.2.

TABLE 4.2 : Pluviometers located in the Magazine Creek Wetland Catchment

Station No.	Station Description
AU504211	Woodville High School
AU504212	Bowling Club

4.4 Stormwater Monitoring Stations

4.4.1 Barker Inlet Wetland Catchment

A monitoring station was constructed at the outlet of the four catchments described in Chapter 3. A monitoring station consists of a combination of flow measurement devices, continuous monitoring water quality probes, automatic water sampler and data loggers. The continuous water quality monitoring probes are housed in a protective cage in the centre of each channel. The data are recorded by data loggers housed in an instrumentation cabinet on the bank of the channel. The instrumentation cabinet also houses the automatic water sampler and purpose designed controller box. Photograph 4.4 shows the cage housing the continuous monitoring probes and Photograph 4.6 shows the instrumentation cabinet designed to protect the instrumentation from vandals.

4.4.1.1 Flow Measurement

The flow at each monitoring station is measured by a concrete weir measuring structure and by ultrasonic Doppler velocity probes. A pressure transducer immediately upstream of the weir measures the stage height of the water in the channel which is recorded by the data logger. The stage height is converted to flow via a stable stage/discharge relationship. A gauge plate on the channel wall is checked on the regular site inspections to make sure that any long term drift of the pressure transducer readings are taken into account.

At each station a concrete broad crested weir was constructed to measure the quantity of stormwater runoff. A cross section of the weir is outlined in Figure 4.2, and Photograph 4.3 shows the construction of the weir in the North Arm East (AU504101) drain.

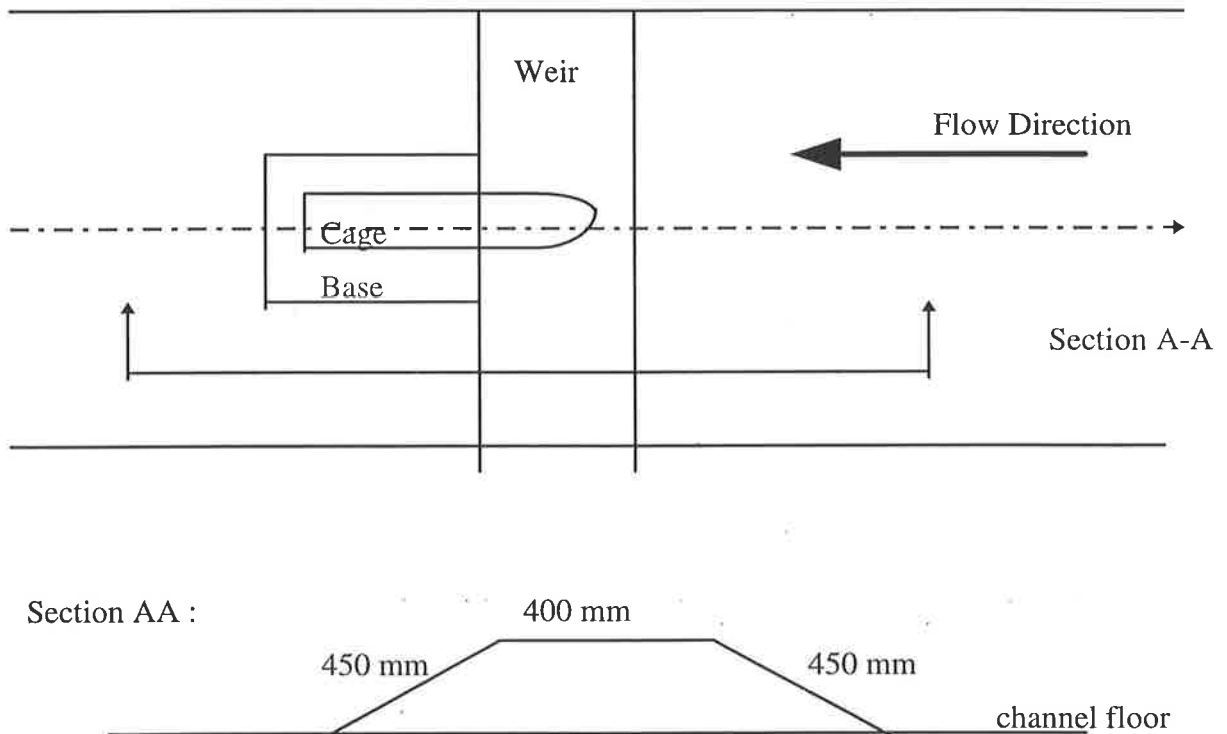


Figure 4.2 : Broad Crested Weir

The top of the weir is a 400 mm wide flat and horizontal section with 450 mm wide flat sections at a 1-in-4 slope on either side. The weir crest is at most only 175 mm above the channel floor. The weir crest height varies between stations depending on the dimensions and relative heights of the channels.

In the centre of the weir is the instrument cage base. This consists of a 2.1m wide by 3.0m long concrete slab. The top has a 50mm fall from the outer edges, which are level with the crest of the weir, to the centre giving a low flow path through the centre of the weir to the sensors. A 100mm deep trough through the centre of the instrument cage base allows low flows to be channelled through the continuous monitoring probes.

4.4.1.2 Instrumentation Cage

The instrument cage is a vandal and debris resistant structure some 3 metres long, 500 mm wide and 1.2 metres high. It has a 45 degree sloped leading edge debris guard and then a steel mesh sided instrument cage. Inside the cage is a support post for the linkage that carries the sensor enclosure and trailing float. In a low flow situation the sensor heads lie in a 100 mm

deep trough that is partially closed by the float thus ensuring that the sensor heads remain submerged but in flowing water. The construction of the instrument cage is shown in Photograph 4.3. The float is designed to rise with increasing stage height which places the monitoring probes in a position that best represents the flow for that height (approximately 60% of the total depth from the bed of the channel). The float has a capacity to rise to a stage height of approximately one metre before it is constrained by its lever arm and the top of the instrument cage. The instrument cage at the North Arm East drain is shown in Photograph 4.4, taken during a storm event.



Photograph 4.2 : Construction of the North Arm East Drain Weir



Photograph 4.3 : Construction of the instrument cage.

4.4.1.3 Continuous Monitoring Probes

The continuous monitoring probes were installed to monitor important stormwater parameters such as turbidity, electrical conductivity, pH, dissolved oxygen and water temperature. The probes are protected inside the instrument cage. The sensor heads protrude below the streamlined sensor enclosure and are placed in the following order from the leading edge (right to left) as shown in Photograph 4.5 :

- Turbidity sensor;
- Electrical conductivity probe;
- pH sensor;
- Intake tube for the water sampler; and
- Dissolved Oxygen and Temperature sensor.

Table 4.3 outlines the brand and model number of each of the continuous monitoring probes along with the range of values and units that it measures.

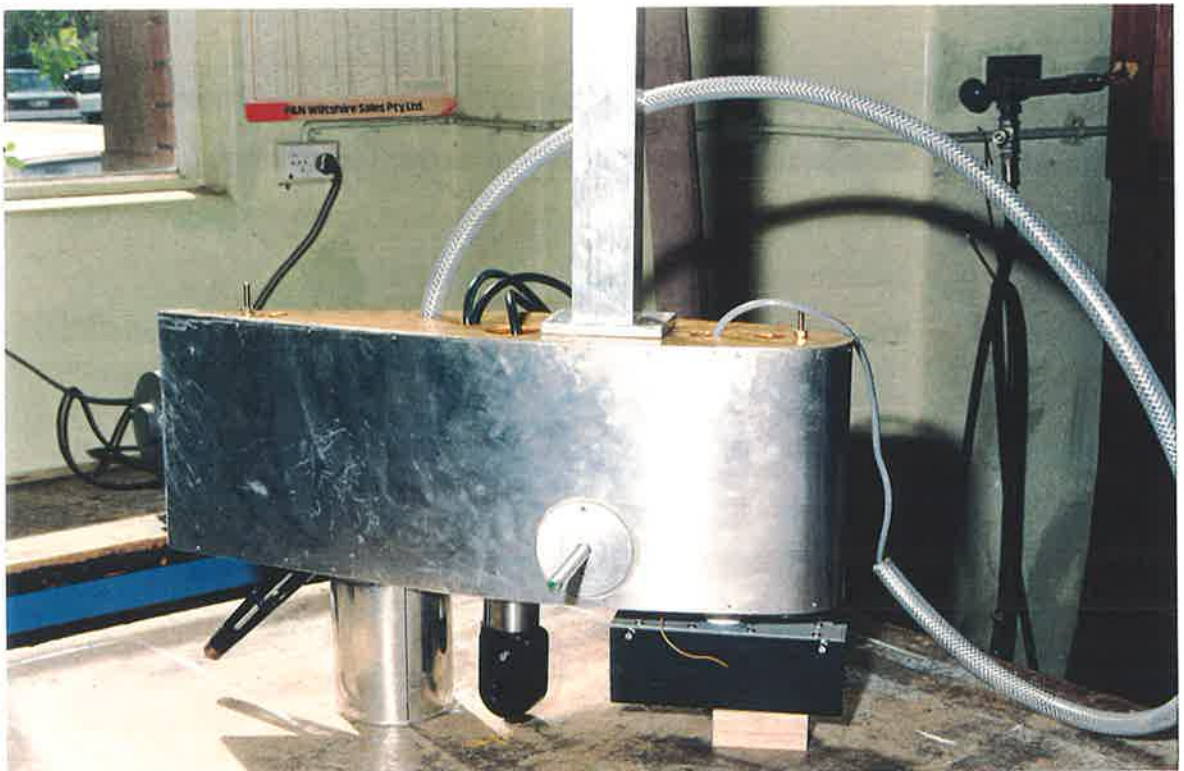
TABLE 4.3 : Details of continuous monitoring probes

Probe	Scale/units	Brand/model no.
pH	0 - 14 <i>units</i>	Greenspan PH100
temperature	0 - 50 <i>degrees Celsius</i>	Greenspan
electrical conductivity	0 - 2000 <i>micro Siemens</i>	Greenspan EC200
turbidity	0 - 2000 <i>units</i>	Tain
dissolved oxygen	0 - 20 <i>ppm</i>	Greenspan DO100
water velocity	(-4) - 4 <i>m/s</i>	Mace HVQ
stage height	0 - 2.5 <i>m</i>	Greenspan PS200

A steel channel acts as a cable cover and extends from the front face of the weir for 3 metres upstream and branches right to a pressure sensor housed in a steel case on the channel bottom.



Photograph 4.4 : Instrumentation cage in the North Arm East Drain



Photograph 4.5 : Continuous monitoring probes during construction.

Cable ducts within the weir and behind the channel wall lead to a steel vandal resistant instrument cabinet on the bank. The instrument cabinet on the bank of the channel houses the data loggers, controllers, batteries and an automatic water sampler. The cabinet is shown in Photograph 4.6.

4.4.1.4 Data Logger and Controller

The instrument cabinet on the bank of the channel houses a UNIDATA model 7000 logger that records all of the measurements from the continuous monitoring probes at predetermined time increments. The logger is shown in Photograph 4.7 (left hand side).

An electronic controller was designed by the department of Civil & Environmental Engineering at The University of Adelaide. The controller is shown in Photograph 4.8 (right hand side). The controller determines the time increment at which the logger records as well as determining when the automatic water sampler is to take samples. The data collector can adjust the values that the controller uses via computer software, Sterm, designed by Department of Civil & Environmental Engineering at The University of Adelaide. The values that can be input into the controller are as follows:

- Log Active Interval : The increment of time (minutes) that the logger will record values at stage heights that are greater than the 'Log threshold'.
- Log threshold : The stage height (m) that when exceeded forces the logger to log in increments of the 'Log Active Interval'.
- Sample threshold : The stage height (m) that when exceeded forces the automatic water sampler to activate.
- Log Period : The increment of time (minutes) that the logger will record values at stage heights that are less than the 'Log threshold'.
- Sample Period : The maximum time increment (minutes) that can expire between two consecutive water samples while the 'Height Variance' and 'Turbidity Variance' have not been exceeded.



Photograph 4.6 : Instrumentation cabinet at the North Arm East Drain.



Photograph 4.7 : Data logger and controller.

Turbidity Variance : The increment of turbidity units which when exceeded after initialisation of the automatic water sampler will induce another sample to be taken.

Height Variance : The increment of stage height (m) units which when exceeded after initialisation of the automatic water sampler will induce another sample to be taken.

Currently a stage height thresh-hold value is used to trigger the automatic water sampler, but changes in the operating software of the controller can allow other instrument values, such as turbidity, to be used instead of or in conjunction with the water height value. As it stands, a change in the water height greater than the selectable 'variation value' will cause the controller to tell the UNIDATA logger to save all the installed sensor values. Furthermore, the UNIDATA logger is programmed to record the instrument values on the hour, regardless of any events.

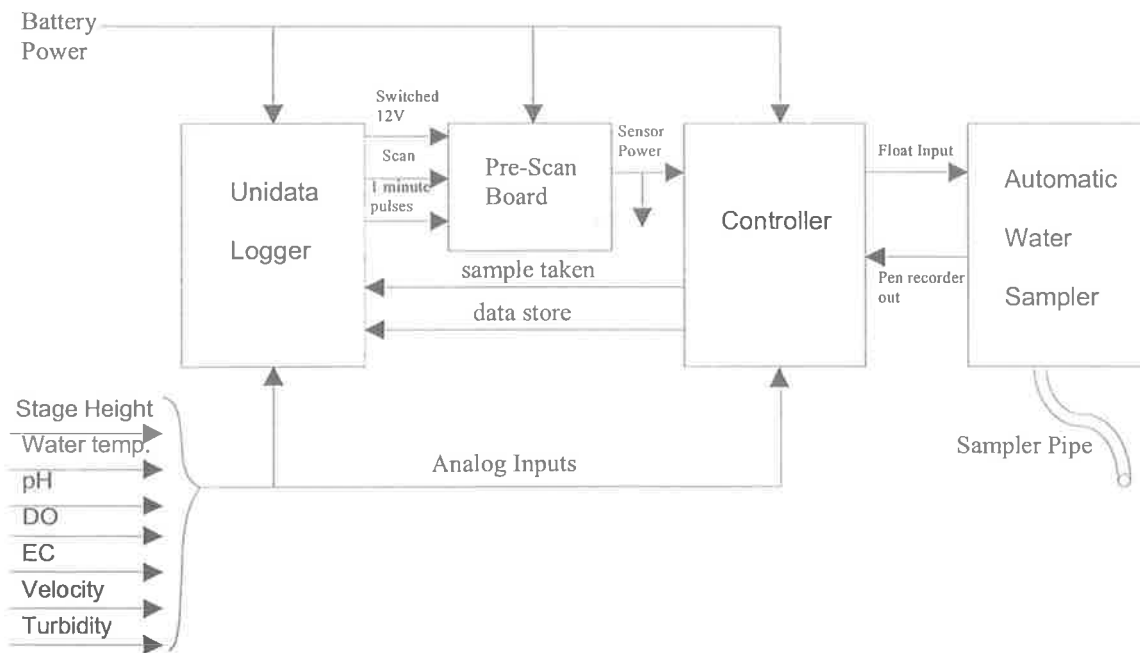


Figure 4.3 : Block diagram of Instrumentation

increase/decrease increments of stage height and/or turbidity values. The sampling frequency is extremely important so that adequate samples are taken during the rise and fall of the hydrograph. The frequency of samples during the rising limb is typically higher than the frequency during the falling limb due to the sharp increase in flow rate early in each event.

After a storm event the water samples are collected and then returned to the laboratory. The sequential samples are tested for total suspended solids, turbidity and total phosphorus concentrations.

A composite sample is made up from the stormwater sequential samples (up to 24 samples) and is taken to The State Water Laboratory to be tested for nutrient and metal concentrations. The composite sample is carefully made up from the individual samples using a 'flow weighted' method. The composite sampling method is explained in Section 4.6.

4.4.1.6 Trash Racks

Trash racks have been installed downstream of three of the monitoring stations in the Barker Inlet Wetland catchment and upstream of the fourth station, North Arm West Drain. The trash racks are shown in Photographs 4.8 and 4.9. The recent construction of trash racks has created backwater problems in the channels during storm events as they fill with litter early in most events and drain slowly, detaining the flow. The trash racks collect gross litter which consists of organic plant material, plastic containers, bottles, and plastic bags. The plant material intercepted by the trash racks makes up the largest proportion (typically about 80%) of material trapped in the racks.

Utilising continuously recorded velocity data both before and after the construction of trash racks in the North Arm East (AU504101) drain it was determined that the trash racks reduce the flow rate in the channel by approximately 30 to 40% depending on the amount of litter accumulated in the racks.



Photograph 4.8 : Construction of trash racks at the HEP Drain.



Photograph 4.9 : Trash racks at the North Arm East Drain

Backwater problems occur in the other three stations where the trash racks are downstream of the monitoring stations. The water backs up on the upstream side of the trash racks which reduce channel velocities to a near stand still. This creates further problems as the automatic water sampler is controlled by stage height.

The trash rack in North Arm West Drain (AU504104) was constructed upstream of the monitoring station. The trash rack backs up flow and slowly releases it, dramatically reducing the peak flows with a similar effect to that of a ponding basin.

The trash racks need to be emptied on a regular basis in order to minimise disruption to the flow regime of the channel as well as avoiding possible flooding of the drains. The maintenance of the trash racks is the responsibility of the local council authority which is the City of Port Adelaide and Enfield. The cost of maintaining pollutant traps such as these is very high. Increased community awareness of the high maintenance costs of such systems funded by their council rates would hopefully reduce the quantity of gross pollutants disposed of in the stormwater. This would decrease the frequency and costs of maintaining the trash racks.

4.4.2 Magazine Creek Wetland Catchment

Construction of the monitoring station in the Eastern Parade monitoring station was completed in September 1996. The Eastern Parade monitoring station differs from the Barker Inlet monitoring stations due to accessibility to the drain being difficult.

4.4.2.1 Flow Measurement

Flow measurement in the Eastern Parade (AU504201) is reliant on a flat-V triangular weir and maintaining a stable stage/discharge relationship for it. A velocity probe upstream of the weir is used in conjunction with the weir to measure flow. A pressure transducer upstream of the weir continuously measures the stage height and a second pressure transducer downstream of the weir monitors any backwater effects that may occur. Backwater problems have not been encountered in the Eastern Parade drain thus far.

4.4.2.2 Continuous Probes

As discussed earlier, poor accessibility to the Eastern Parade drain along with budget constraints have forced the continuous probes to be scaled down to the two pressure transducers (upstream and downstream of the weir) and a velocity probe. Water quality is still a priority with an automatic water sampler included in the monitoring station setup on the bank of the channel.

4.4.2.3 Data Loggers and Controller

The data logger and controller are the same as for the Barker Inlet Wetland monitoring stations. The electronic controller designed by the Department of Civil and Environmental Engineering is still the driving force behind the data logging increment and automatic sampler control.

4.4.2.4 Automatic Water Sampler

A Gamet automatic water sampler is housed in the instrumentation cabinet on the bank of the Eastern Parade Drain. The sampler is controlled by the electronic controller and is triggered by the stage height sampler threshold. Subsequent samples are taken with changes in stage height and/or turbidity values as determined by values stored in the Sterm software.

4.5 Field Visit Procedures

In any stormwater monitoring program it is important to have a set of clearly defined field visit procedures. This minimises the potential for loss of data. When clearing and resetting data loggers it is important that correct procedures are followed. If the correct procedures are not followed and the loggers are set up incorrectly data loss can occur. It is important that the electronic controller values are checked on every site visit. This makes sure that the data loggers log at the correct time intervals and that the sample and log thresholds are all set correctly. The site visit procedures to the Barker Inlet Wetland monitoring stations are outlined in Appendix B, and include the following procedures :

- General Procedures;
- Equipment Checklist;
- Data Download Procedure;
- Battery Check/Change Procedure;
- Clear and Reprogram Logger Procedure;
- Storm Controller Procedure; and
- Water Sample Collection Procedure.

In conjunction with following the correct site visit procedures it is imperative that site sheets are filled out on each site visit.

4.5.1 Station Site Sheets

Station site sheets are filled out on each site visit so that information is recorded and filed to describe the condition of that site on the specific day and information regarding the data downloaded. The information that is recorded on the site sheet includes the following; date time, station, downloaded file name and size (bytes), continuous probe readings before and after cleaning the probes (used for calibration), battery levels (old and replacement batteries), storm controller values and any other relevant notes. The Station Site Sheets are shown in Appendix B.

4.6 Composite Sample Preparation

Each monitoring station is equipped with a Gamet automatic water sampler as mentioned in Section 4.4. The samples collected during storm events are combined into a composite sample so that event mean concentrations can be determined. The composite samples are combined on the basis of flow to provide a representative mass loading of the discharge that the wetland receives for the period sampled.

A computer program named 'H2OSAMP' was designed by the Department of Civil and Environmental Engineering at Adelaide University to assign weightings to each of the sequential samples during an event. The composite sample was then prepared using the weightings determined by H2OSAMP.

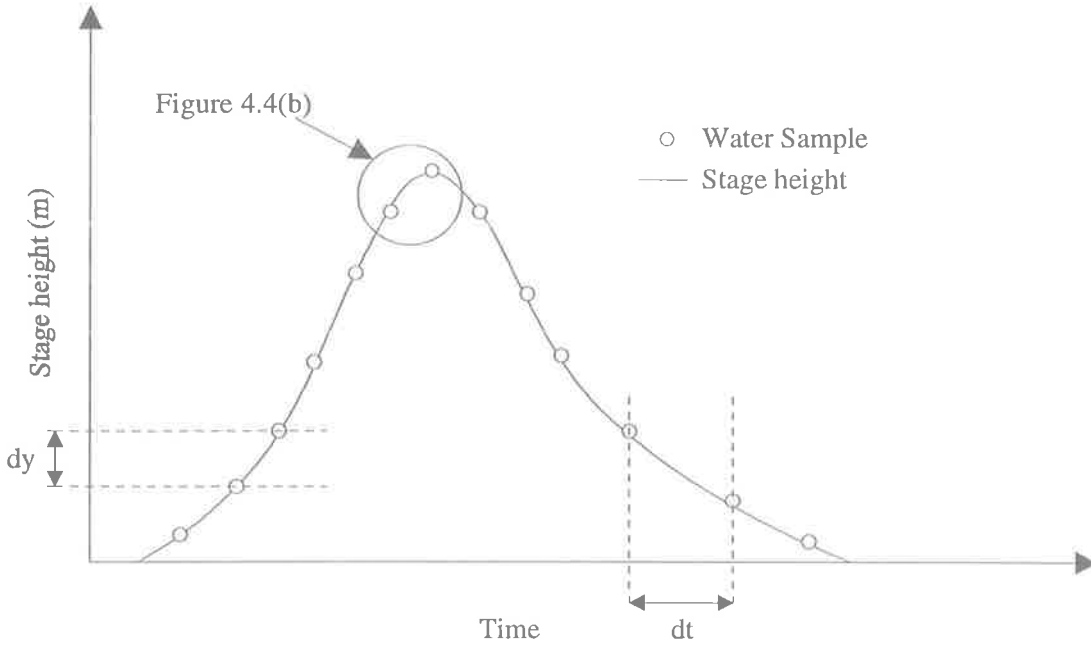


Figure 4.4(a) : Sequential samples during a storm event

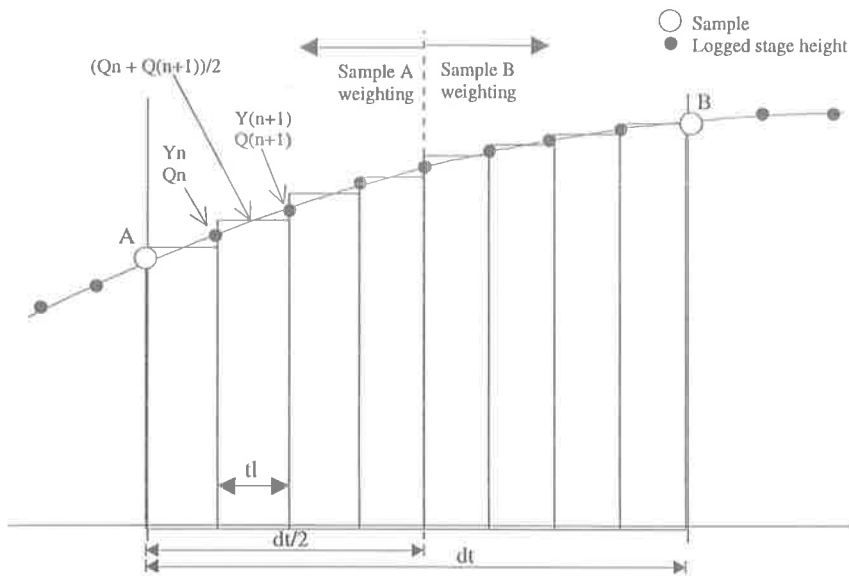


Figure 4.4(b) : Calculating flow weighting for composite sample

The procedure by which H2OSAMP distributes a weighting to each sample is summarised in Figures 4.4 (a) and (b). Considering samples A and B outlined in Figure 4.4 (b), separated by a time dt . The volume of runoff within the time increment dt is distributed such that the first $dt/2$ runoff fraction is distributed to sample A and the second $dt/2$ fraction to sample B. H2OSAMP converts the recorded stage heights, Y_n , to flows, Q_n , using a rating table. It then averages the two flow points Q_n and $Q_{(n+1)}$ to determine the average flow rate for the logged time increment, t_1 . The average flow rate $(Q_n + Q_{(n+1)})/2$ in cumecs is multiplied by the

logged time increment t_l . This determines the volume of flow for the time t_l in cubic metres. The volumes of flow are summed for all time increments t_l within the $dt/2$ fraction. This $dt/2$ volume plus the $dt/2$ volume prior to the sample divided by the total flow volume for the event determines the flow weighting for sample A. H2OSAMP repeats this calculation for all samples within the defined start and finish times for the event to determine the weightings to produce the composite sample.

4.7 Water Sample Quality Testing

Automatically controlled Gamet samplers are employed to sample storm events along with periodic grab samples indicative of low flow. The storm event samples are combined into a composite sample and sent to an external water laboratory for determination of event mean concentrations (EMC) of nutrients and metals. The EMC values indicate the mean concentration of pollutants for a storm event, and when combined with storm volumes provide information on the total load of pollutants discharging from the catchment in that event.

As well as testing the composite samples, each individual sample is tested in the environmental laboratory at the University for TSS, turbidity, total phosphorous and when time permits, electrical conductivity and pH. This gives an indication of the changes in the parameters during the storm event, which assists in developing a picture of the underlying processes taking place.

4.7.1 Water Sample Storage

Immediate collection of stormwater samples after each storm event, cold storage in a laboratory refrigerator and immediate laboratory testing provide the most accurate water quality information. These procedures are in accordance with the findings of Kachka *et al.* (1994).

Automatic water samplers with in-built field refrigeration are ideal for water sample preservation but could not be considered due to budget constraints. A large chest style refrigerated storage was purchased and modified for this research project to preserve the water

inbetween sample collection and laboratory testing. The refrigerator was designed to store the samples at temperatures between 1 and 4°C.

Kachka *et al.* (1994) investigated the time that water samples can be held in refrigeration before changes in the nutrient concentrations would occur (ie Nitrate to Ammonia). The conclusion from their study was that the samples could be stored for no longer than 18 hours. Using the findings of Kachka *et al.* (1994) as a guide, the samples were collected, refrigerated and tested in the laboratory within the 18 hour period wherever possible.

Delivering the composite sample to the State Water Laboratory within the 18 hour period was a high priority as these results included a breakdown of the nutrient forms, and heavy metals.

4.7.2 Water Quality Parameters of Interest

The pollutant parameters that are present in stormwater runoff were discussed earlier in Chapter 2. The conclusion was that the parameters that were important to continuously monitor in the field were:

- Turbidity;
- Electrical conductivity;
- pH;
- Dissolved Oxygen; and
- Water Temperature.

The parameters that were considered important for laboratory testing were:

- Nutrient Concentration;
- Metal Concentration; and
- Poly Aromatic Hydrocarbons (PAH).

4.7.3 Palintest System

In the early stages of the research program nutrient concentration testing was performed using the Palintest photometer kit. The Palintest Interface Photometer 7000 was used in 1994 and the first few months of 1995. The Palintest system proved to be inadequate for the

number of samples required to be tested for this project. With four water samplers in operation there was a chance of 96 water samples needing to be tested from any large storm event. In early 1995 funding became available to upgrade to the HACH spectrometer system which would save on time and increase the accuracy of results.

4.7.4 Hach System

The DR/2000 HACH Spectrophotometer was purchased to take over from the Palintest System for the testing of nutrient concentrations. The HACH system improved accuracy as well as sample test efficiency by utilising batch testing. HACH Test'N' Tube™ procedures have many advantages over other procedures, namely safety, efficiency, use smaller concentrations of reagents, minimal waste generation and accuracy. Using a HACH COD reactor up to 25 samples can be digested simultaneously. Two COD reactors were purchased for the research program and so up to 50 samples could be digested within 30 minutes. Batch testing using a predetermined time schedule, the DR/2000 HACH Spectrophotometer on a continuous read mode, and using a distilled water blank (results adjusted accordingly) allowed the testing of maximum samples in minimum time with a high level of accuracy. In this research project the HACH Spectrophotometer was used to test total phosphorus although it has the capability of testing 120 common water quality parameters.

4.8 In House Laboratory Testing

Individual water samples were tested in the laboratory for each storm event. Prompt collection of the sequential samples from the field, cold storage and immediate laboratory testing were a high priority for this research project as discussed in Section 4.6.1 earlier.

4.8.1 Total Suspended Solids Testing

Each individual sample was tested for total suspended solids (TSS) to give an indication of the changes of sediment concentration during a storm event. Samples were stored in a chest refrigerator and tested as soon as possible after being collected. The cold temperature from storage in the refrigerator is counter productive to sediment testing, and so the samples were

allowed to adjust to room temperature before testing. This proved to give a more stable and accurate total suspended solids reading.

All samples were thoroughly mixed by a standard mixing procedure carried out on each and every sample to create continuity and accuracy across all storm events. Each sample was aggressively inverted exactly 30 times before immediately filtering a representative of the volume of sample. The TSS tests were conducted by filtering the water sample through a standard $0.45\mu\text{m}$ glass fibre filter using a Nalgene filtration device. Deionised water was used to clean both the measuring beaker and Nalgene filtration apparatus to make sure that no cross contamination of samples occurred. The filter papers were placed on petri dishes and dried in an oven at 104°C for sufficient time (at least 1-2 hours) to allow evaporation of all moisture from the filter paper. Tweezers were used on transfer of the filter paper from the scales, filtration apparatus, petri dish and back to the scales to make sure that other substances were neither removed from or deposited on the filtered sample.

4.8.2 Turbidity Testing

A HACH 2100P Portable Turbidimeter was used to conduct turbidity tests on each water sample. The turbidimeter has a range of 0 to 999NTU and a claimed accuracy of $\pm 0.5\text{NTU}$. Each individual sample was tested for turbidity to give an indication of the changes of turbidity levels during each storm event. As with the total suspended solids tests, it was important to let the samples adjust to room temperature before testing. Sufficient mixing of the sample to give the most accurate turbidity reading was carried out on each sample. The outside of the glass sample vials were cleaned with a supplied gel to remove moisture and any marks that would influence the turbidity reading.

4.8.3 Total Phosphorous Testing

As mentioned in Section 4.7.4 the Total Phosphorous concentrations were determined using a HACH Spectrometer for each sequential sample. The HACH 'Test'n' tube' procedures were followed. An adjustment to the procedures was to use a distilled water blank to enable batch sampling. It was important to allow the reagents to digest for exactly ten minutes as required by the HACH 'Test'n' tube' procedures, as the accuracy of the total phosphorus reading is sensitive to reaction time. A time schedule was implemented to take advantage of the batch

sampling procedure so that a maximum number of samples could be tested in the minimum time, with maximum accuracy. This was implemented due to the large number of sequential samples that are collected from the five drains from each event.

4.9 External Testing

Each composite sample was delivered to the Australian Water Quality Centre at Bolivar in South Australia after each event to determine event mean concentrations of nutrients, heavy metals and polyaromatic hydrocarbons. The event mean concentration results are presented in Chapter 7.

4.9.1 Nutrients

The following nutrient parameters were tested at the Australian Water Quality Centre :

- Ammonia as N;
- TKN as Nitrogen;
- Nitrate + Nitrite as N;
- Filterable Reactive Phosphorus as P; and
- Total Phosphorus.

4.9.2 Metals

The following heavy metal parameters were tested at the Australian Water Quality Centre :

- Aluminium;
- Arsenic;
- Cadmium;
- Chromium,
- Copper;
- Iron;
- Lead;
- Manganese;

- Mercury;
- Nickel; and
- Zinc.

4.9.3 Polycyclic Aromatic Hydrocarbons

Event composite samples were also analysed to determine the concentration of polycyclic aromatic hydrocarbons. The following polycyclic aromatic hydrocarbon parameters were tested at the Australian Water Quality Centre :

- Naphthalene;
- Acenaphthylene;
- Acenaphthene;
- Fluorene;
- Phenanthrene;
- Anthracene;
- Fluoranthene;
- Pyrene;
- Chrysene;
- Benzo (A) Anthracene;
- Benzo (B) Fluoranthene;
- Benzo (K) Fluoranthene;
- Benzo (A) Pyrene;
- Indeno (123-CD) Pyrene;
- Dibenzo (AH) Anthracene; and
- Benzo (GHI) Perylene.

4.10 Archiving Data

4.10.1 Hydsys Database

The data recorded in the field are downloaded from loggers onto a laptop computer before being returned to the University to be entered into HYDSYS, a hydrometric archiving and retrieval system. The data are then checked for irregularities and verified before final

archiving. The HYDSYS database is stored on the University computer network so data are automatically backed up each day. A copy of the data files is also stored on floppy disks, the hard drive of a desk top computer and manually backed up onto tape using a tape drive. With all of these procedures in place the chance of a loss of data due to computer malfunctions is minimised. The advantage of storing the data in a real time database such as HYDSYS is the ease by which operators can access and manipulate data. The data are also easily exported to external programs such as Microsoft Excel for further manipulation and presentation.

4.10.2 Excel Spreadsheets

Event mean composite sample results are archived both as a hard copy in folders as well as into Microsoft Excel spreadsheets. The Excel data are stored on the desktop hard drive as well as being backed up onto the University network daily. The sequential sample results are similarly stored as a hardcopy and in Excel spreadsheets.

4.11 Problems - Data Collection 'Gremlins'

The task of water quality and quantity data collection in the unpredictable field environment is usually plagued with problems. These problems are affectionately referred to as data collection 'Gremlins'. This section describes numerous problems that were encountered during the monitoring programme and more importantly outlines the solutions that were implemented. The data collection 'Gremlins' are associated with a number of aspects of the monitoring programme including such things as instrumentation, human error, vandalism, weather effects, water samplers, water sample analysis and continuous monitoring probes.

The Tain continuous turbidity probes have proven to be a handful at each of the monitoring stations. The two biggest problems associated with the Tain turbidity probes are the sudden and gradual fouling of the lenses. The sudden fouling of the turbidity probes occurs when a cluster of organic material such as algae mat becomes lodged in the turbidity measurement path length. This sends the turbidity reading to maximum which is approximately 1500 Tain turbidity units (a Tain turbidity unit is a non-dimensional unit which is then calibrated against NTU units), and in turn creates a large increase in voltage drawn by the turbidity meter. This increase in voltage created an incorrect turbidity reading, but even more damaging affected the

readings of the other continuous probes. This problem was solved by installing voltage limiters on the turbidity channel at each monitoring station, as well as modifying the turbidity lenses so that the flow dislodges the blockages more easily. The gradual fouling of the turbidity lens due to build up of sediment and algae was also a problem. The turbidity lenses by design are recessed and the screws holding the lenses in place protrude outwards and create low velocity regions increasing the deposition of sediment on the lens. This problem was reduced by modifying the lenses of the probes by attaching an external flat perspex lens over the top of the existing lens and attaching it with countersunk screws, and recalibrating the probe. It is important the perspex does not become scratched so cleaning is performed with a soft bristled tooth brush.

Chapter 5

Channel Hydrology

5.1 Introduction

The measurement of stormwater quantity from a catchment forms an integral part of any monitoring program. Flow rate measurement in the past has relied on measurement weirs and maintaining stable stage/discharge relationships. Ultrasonic Doppler velocity probes offer an alternative method of flow measurement (Daniell and Williams 1997, Daniell et al.1997). The importance of accurate flow measurement cannot be underrated as ~~The importance of accurate flow measurement cannot be underrated as~~ the flow rate and event runoff volumes directly affect the determination of event water quality loads (Williams and Daniell 1997). Gauged runoff is also important in the process of calibrating rainfall runoff routing models.

5.2 Flow Measurement

The stormwater runoff exits the Barker Inlet Wetland and Magazine Creek Wetland catchments via a pipe network system before discharging into open channel flow. Weir measurement structures in the open channels were constructed to monitor flow quantity. A

pressure transducer upstream of the weir continuously measures the stage height of the water in the channel which is recorded in a data logger. The stage height is converted to flow via a stage/discharge relationship. A gauge plate on the channel wall is checked regularly and compared to recorded stage height to make sure that any drift of the stage height readings are taken into account.

The North Arm East Drain (AU504101), Hindmarsh Enfield Prospect (AU504102), Dunstan Road (AU504103) and Eastern Parade Drain (AU504201) also have ultrasonic velocity probes installed in the channel base, which provide an alternative flow measurement device.

5.2.1 Broad Crested Weir Equations

The measurement weirs constructed in the four Barker Inlet Wetland channels and the Eastern Parade drain were designed in accordance with broad crested weir specifications outlined by Bos (1989). Bos (1989) outlined a range of H_1/L values that determine whether the weir is broad or sharp crested. H_1 is the height of the weir and L is the length of the weir crest in the direction of flow. The range of H_1/L ratios as determined by Bos (1989) is :

$$\text{Broad Crested Weir : } 0.08 \leq H_1/L \leq 0.50$$

According to Bos (1989) the broad crested weir equations are applicable to the weir measuring structures used in this study.

The broad crested weirs constructed in the four Barker Inlet Wetland channels are of similar design but with varying dimensions. The weir cross section was outlined earlier in Figure 4.2. A shallow v-notch was constructed in the centre of each weir to channel low flows through a 100mm deep trough housing the continuous monitoring probes. The dimensions of the v-notch is 50mm deep and 2.1m wide. The only variation between the four Barker Inlet channels is that in the Hindmarsh Enfield Prospect (AU504102) drain the v-notch spans the whole channel due to the narrow width of the channel (4.1m).

The calculation of flow for each channel is broken into two parts. The first 50mm of flow above cease to flow (CTF) level must be calculated by a v-notch broad crested weir equation, whereas at heights above this the equation for a broad crested weir with trapezoidal control

section must be used. The calculation of the flows for the Hindmarsh Enfield Prospect (AU504102) channel vary due to the v-notch spanning the whole channel base, however the two stage calculation for the stage/discharge rating curve still applies.

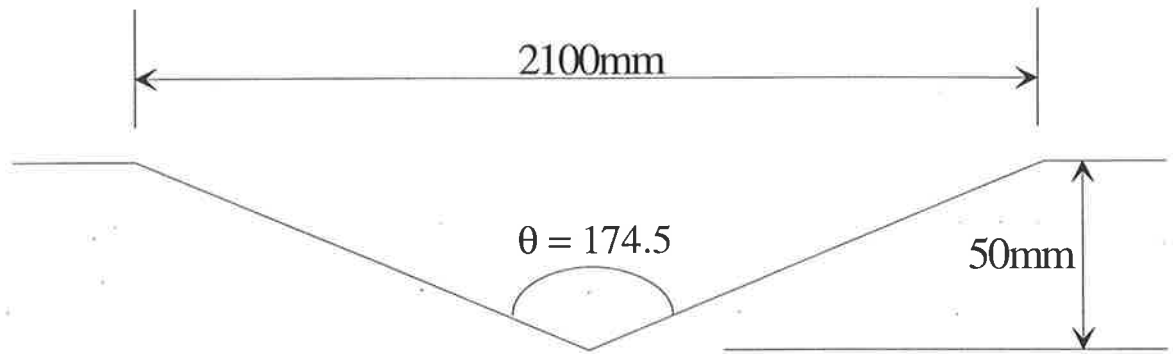


Figure 5.1 : Dimensions of shallow V-notch weir section

The cross section dimensions of the v-notch are outlined in Figure 5.1. Bos (1989) derives the equation for a v-notch broad crested weir as :

$$Q = C_d \times C_v \times \frac{16}{25} \times \left(\frac{2}{5} \times g\right)^{0.5} \times \tan\left(\frac{\theta}{2}\right) \times H_1^{2.5} \quad (5-1)$$

Where : Q = Discharge (m^3/s)

$$H_1 = 5/4 * y_c$$

C_d and C_v are coefficients introduced to obtain a practical head-discharge equation

θ is the angle created at the bottom of v-notch

At stage heights greater than 50mm above the CTF level the weir flow becomes a broad crested weir with trapezoidal control section as outlined in Figure 5.2.

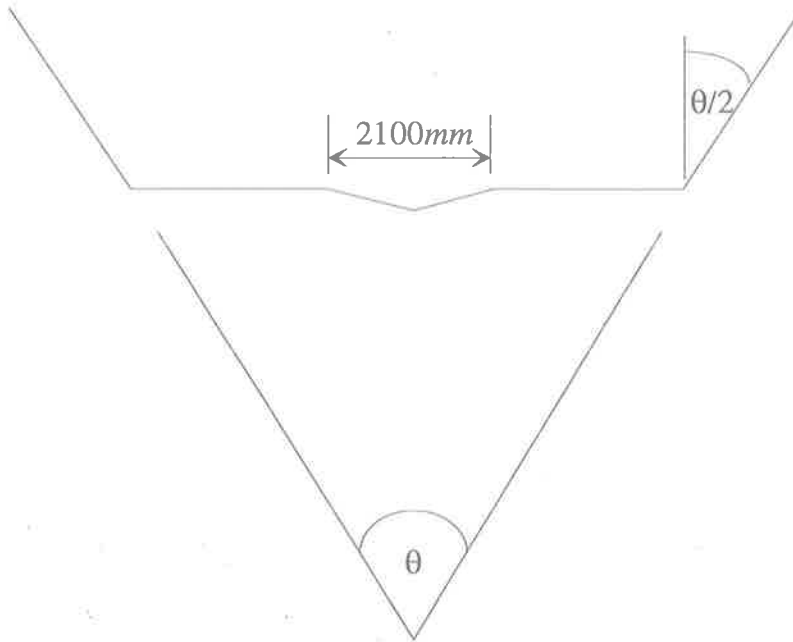


Figure 5.2 : Broad Crested weir with Trapezoidal control section

The equation for a broad crested weir with trapezoidal control section is Bos (1989):

$$Q = Cd(b \times y_c + m \times y_c^2) \times [2 \times g(H_1 - y_c)]^{0.5} \quad (5-2)$$

Where : Q = Discharge (m^3/s)

$$m = \tan\left(\frac{\theta}{2}\right)$$

y_c/H_1 ratio varies as the H_1/b ratio varies, and is determined by Table C-6 in Appendix C.

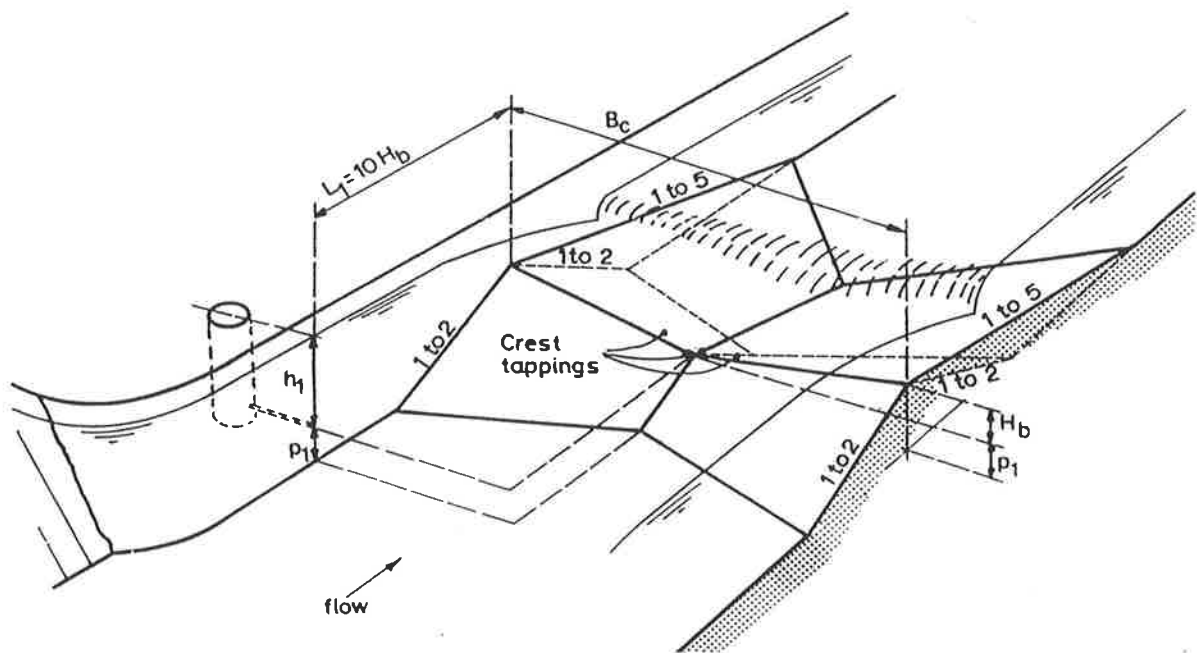
C_d is the discharge coefficient and is determined using actual velocity data as outlined section 5.8.

The cease to flow stage height levels vary at each of the four monitoring stations due to different relative heights of the weir crests. The cease to flow (CTF) levels are outlined in Table 5.1.

TABLE 5.1 : Cease to flow levels in of the monitored open channels

Station Number	CTF level (m)
AU504101	0.105
AU504102	0.130
AU504103	0.215
AU504104	0.280
AU504201	0.250

The weir in the Eastern Parade (AU504201) drain is dissimilar to the four Barker Inlet Wetland drains. The weir in the Eastern Parade (AU504201) is a 'Triangular profile flat-V weir' weir with slopes of 1:2 upstream and 1:5 downstream. The cross-slopes of the flat-V weir are 1:20. The basic layout of the flat-V weir is outlined in Figure 5.3 below, and a photograph of the weir in the Eastern Parade (AU504201) channel is outlined in Photographs 3.23 and 3.24.



(Source: Bos, 1989)

Figure 5.3 : Triangular profile flat-V weir

The flat-V weir has the advantage of providing a wide opening at high flows so that it causes no excessive backwater effects, whereas at low flows its opening is reduced so that the

sensitivity of the structure remains acceptable. According to Bos (1989) the discharge for a 'short crested flat-V weir' is determined by Equation 5-3.

$$Q = C_r C_d C_v \frac{4}{15} \sqrt{2g} \frac{B_c}{H_b} \left[h_e^{2.5} - (h_e - H_b)^{2.5} \right] \quad (5-3)$$

Where :

- Q = Discharge (m³/s)
- C_d and C_v are coefficients introduced to obtain a practical head-discharge
- B_c is the width of the channel
- C_r is the ratio of trapezoidal cross sectional area divided by vertical side cross sectional area.

Equation 5-3 is for a 'short crested flat-V weir' with vertical sides however the Eastern Parade (AU504201) channel has slightly trapezoidal sides. This was taken into account by introducing a coefficient (C_r) to represent the ratio of the trapezoidal cross section divided by the vertical side cross section which is slightly greater than one. The use of well calibrated velocity-area curves should be used in the first instance so that backwater conditions caused by any downstream control can be accurately monitored.

5.3 Stage/Discharge Rating Tables

The stage/discharge rating tables are calculated using Equations 5.1, 5.2 and 5.3 as outlined in Section 5.2. The channel dimensions are outlined in Appendix C along with the stage/discharge rating curves for each of the Barker Inlet Wetland drains as well as the Eastern Parade drain.

5.4 Backwater Problems

Measuring the quantity of stormwater runoff has in the past relied mainly on measurement weirs and maintaining stage/discharge relationships using current meters. At high flows or under backwatered conditions these methods can be inaccurate and invalid. At high flows, discharge measurement weirs can become drowned out as the flow tends towards channel

flow rather than weir flow, and it is often difficult to define this point in time. Another major problem is that downstream controls such as trash racks, vegetation growth, tidal influence or wetland pond depth backwater the weir measurement structure. Any of these situations influencing downstream stage height may make the stage/discharge relationship invalid.

5.4.1 Trash Racks

Trash racks are a popular retrofitting tool on the downstream end of many urban catchments to improve the quality of stormwater runoff from a catchment. Gross pollutants and floatables including discarded milk carton containers, plastic bags and plant debris dislodged in the flow are quite effectively caught in the racks. Photographs 5.1 and 5.2 show the trash racks during a storm event. After trash racks were installed downstream of the measurement weirs in January 1996, most events became backwatered. Trash racks were installed downstream of the monitoring stations North Arm East Drain (AU504101), Hindmarsh Enfield Prospect Drain (AU504102) and Dunstan Street Drain (AU504103) in January 1996. At North Arm West Drain (AU504104) the trash racks were installed upstream of the monitoring station.

Photograph 5.4 shows clearly the effect of the full trash racks on the flow in the channel. The water has come to a near standstill due to the backwatering caused by the trash racks. In contrast Photograph 5.3 shows a free flowing channel prior to the construction of trash racks. The head drop over the weir is quite noticeable whereas there is no head drop in Photograph 5.4 due to such low velocities.

The velocity of the flow upstream of the trash racks is reduced as the trash racks become full. The theoretical Equation 5-1 for the flow over the weir becomes invalid as the flow is controlled now by the trash rack downstream. The stage height values cannot be converted to flow with the stage/discharge rating curve without severely overestimating the flow values.

The theoretical rating curve cannot be relied on as the only measure of stormwater flow. An improved system taking into account the effect of the trash racks on the velocity of the stormwater flow needed to be implemented. The system incorporating ultrasonic velocity probes was originally installed to do an automatic rating of the weir. It then became of paramount importance for the backwatered station.



Photograph 5.1 : Trash racks in the North Arm East Drain



Photograph 5.2 : Trash rack basket full of gross pollutants



Photograph 5.3 : Storm event prior to the installation of trash racks. No backwater



Photograph 5.4 : Storm event after installation of trash racks. Backwatered

5.5 Ultrasonic Velocity Probes

Ultrasonic Doppler probes offer an alternative method of flow measurement. Doppler probes have the potential to reduce the capital costs of installing monitoring stations and to reduce the field maintenance required. Velocity probes can be used in open channels, streams, culverts and sewers to directly measure water velocity.

5.5.1 Doppler Theory

Doppler theory dates back to 1843 when Christian Doppler established a theory that there is a change in the frequency of wave motion (sound, light and radio) as a function of motion. When a source of sound is in motion relative to its surrounding medium the frequency of the signal differs from that of a stationary source.

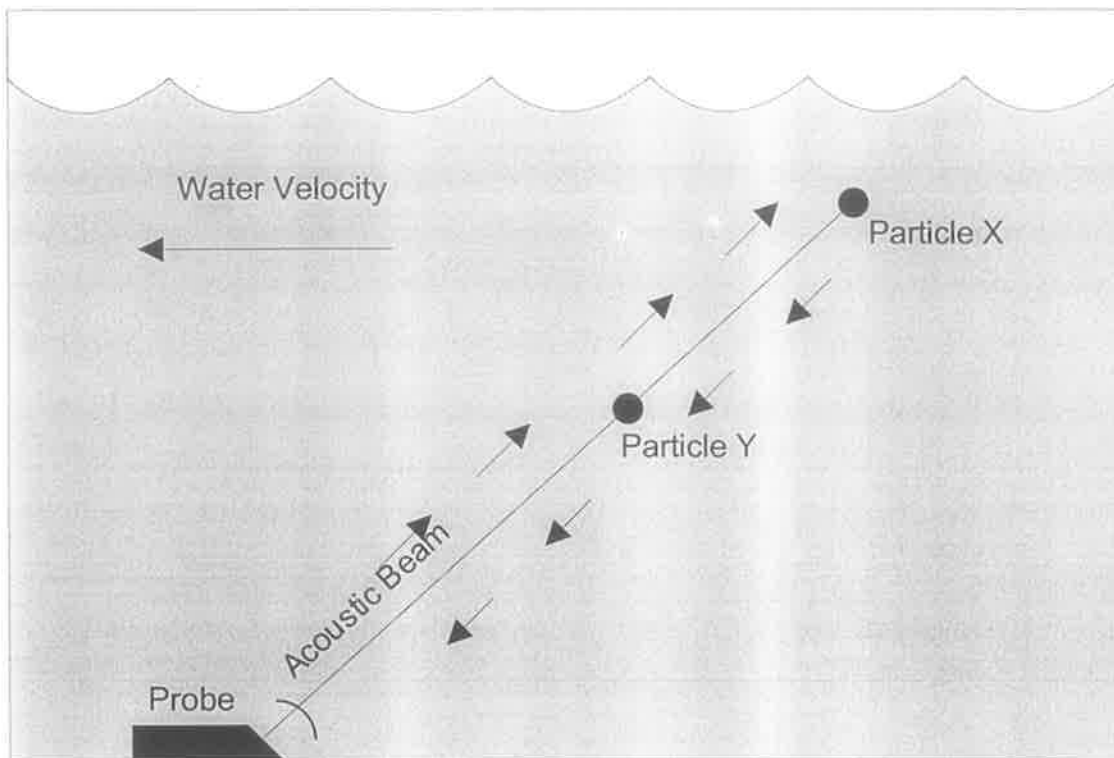


Figure 5.4 : Diagrammatic representation of Ultrasonic Velocity Probe

This principle is utilised by the Doppler probes to measure the velocity of water flowing in the open channel. The medium (water) is in motion relative to the source of the sound (Doppler

and is reflected back to it by a suspended particle moving in the water. A receiver inside the Doppler listens for a returning signal and a measuring circuit measures the Doppler shift. A processing system analyses the Doppler shifts experienced by the returning signals and calculates a mean Doppler shift, from which it determines the velocity of the medium into which it sent its signal. The formula used to convert the mean Doppler shift to a velocity is :

$$V_{\text{water}} = f_{\text{shift}} \times \frac{c}{2} \times f_c \times \cos \theta \quad (\text{m/s}) \quad (5-4)$$

Where V_{water} = Velocity of water (m/s)

f_{shift} = Doppler shift

f_c = carrier frequency

c = speed of sound in water

θ = beam angle

5.5.2 Unidata Doppler Probe

The Unidata Starflow ultrasonic Doppler instrument measures velocity, depth and temperature during each scan interval. The water velocity is measured acoustically by Doppler shift theory, the water depth above the Unidata Starflow is measured by a pressure transducer, and the temperature is measured to refine the acoustic recordings. Equation 5-4 shows that the calculated velocity of water (V_{water}) is directly proportional to the speed of sound in water. The speed of sound in water varies with changes in water density. The most significant influence on water density is the water temperature. The UNIDATA STARFLOW Doppler probe measures water temperature and adjusts the velocity of sound in water appropriately in accordance with Table 5.2.

TABLE 5.2 : Velocity of sound in water (m/s) at atmospheric pressure
(Source: Unidata Starflow User's Manual (Revision A 1994) MEA Australia)

Temperature (°C)	Fresh Water (m/s)	Sea Water (m/s)
0	1402	1449
5	1426	1471
10	1447	1490
15	1466	1507
20	1482	1521
25	1497	1534
30	1509	1545
35	1520	1555

Table 5.2 indicates the variation of the velocity of sound in water with variation in salinity.

5.6 Flume Testing

The reliability and accuracy of ultrasonic velocity probes was investigated before field application was considered. The accuracy of Doppler probes is often reported to be $\pm 1\%$. The UNIDATA STARFLOW velocity probe is claimed to have an accuracy of $\pm 2\%$ of measured velocity and a stage height accuracy of $\pm 0.25\%$. The range of velocities that can be measured by the STARFLOW probe is 20mm/s up to 5m/s . These claims are all based on tow tank testing under ideal conditions. Uncontrolled field conditions are far from the conditions during tow tank testing however flume testing of the probes was more representative of open channel flow.

Testing of the probes was carried out in the hydraulics laboratory in the Department of Civil & Environmental Engineering at The University of Adelaide. The flume used to test the Doppler probes was rectangular in cross section and measured 915mm wide, 450mm deep and 15 metres long. The depth of flow was constrained to approximately 450mm due to the depth of the flume and the capacity of the water pump.

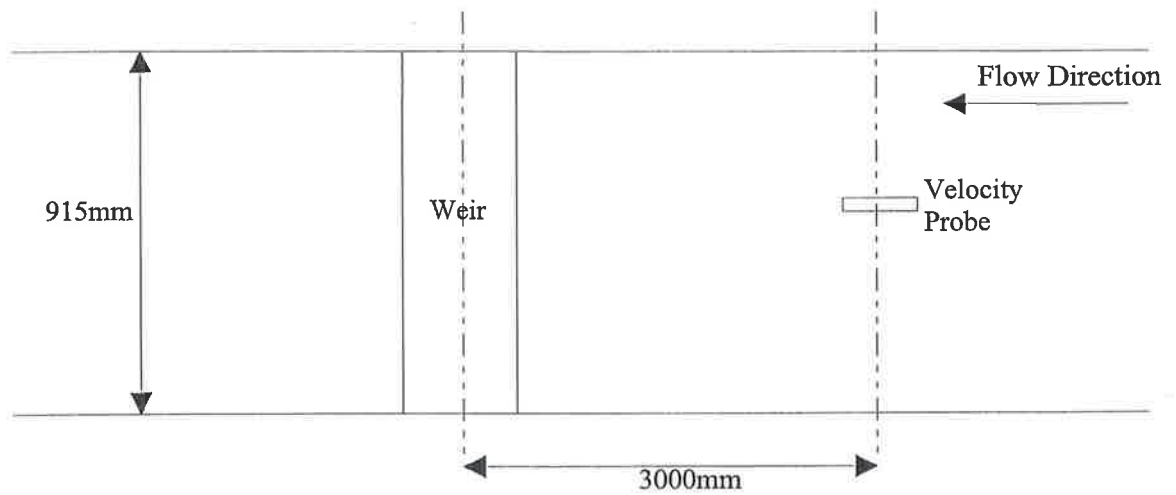
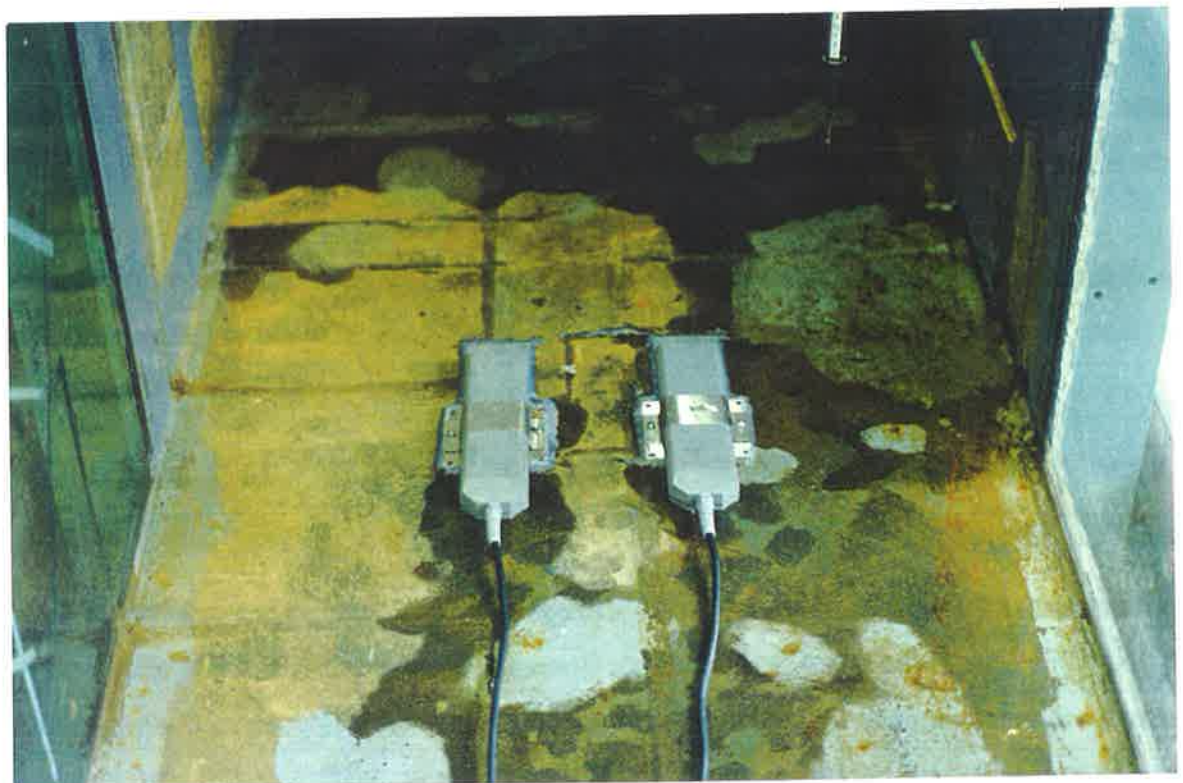


Figure 5.5 : Velocity Test Layout in Adelaide University Flume

The Doppler probes were extensively tested during the months July and August 1995. A 1:1 scale model of the actual field weir was constructed out of timber and installed in the flume to replicate conditions that would likely to be experienced in the field. The probes were tested for accuracy and consistency facing both upstream and downstream. No literature could be found to determine which is the superior direction for the probes to face for best possible results. Photograph 5.5 shows the flume that the velocity probes were tested in.



Photograph 5.5 : The Adelaide University flume with velocity probe

5.6.1 Test Procedure

Two brands of ultrasonic velocity probes were tested in the Adelaide University flume to investigate their accuracy. The two velocity probes tested were the Unidata Starflow probe outlined in Section 5.5.2 and the Mace HVQ probe.

The probes were tested at a variety of depths and flow rates. The flow rates ranged from low flows at around $0.01\text{m}^3/\text{s}$ to a maximum of $0.3\text{m}^3/\text{s}$ which was the maximum capacity of the flume. The range of stage heights was between 100mm (CTF of the weir) and 350mm .

The first tests were run with the probes facing upstream. Tests were carried out at 25mm intervals starting at low flows and ending at high flows. At each level of stage height the flume was left for at least 15 minutes to allow the flow to normalise. The frequency of velocity readings was preset to 15 second intervals. The velocity of each probe was recorded every 15 seconds for 10 minutes. The velocities were then averaged to determine a single velocity reading for the stage height.

The actual flow rate in the flume was then determined by closing the valve in the storage tank at the base of the flume. The accumulated volume of water was measured during a time period and hence converted to flow rate. This was repeated several times and averaged to gain an accurate flow rate. The flow rate could then be divided by the cross sectional area at the velocity probe location to determine the actual average velocity. This was repeated at 25mm intervals up to a maximum of 350mm . The test was repeated three times to give an indication of the repeatability of the results.

The direction of the probes was reversed so that the probes facing were facing downstream. The tests were once again conducted at stage heights from 100mm to 350mm at 25mm increments. These tests were again repeated three times.

5.6.2 Test Results

The test results from flume testing the two ultrasonic velocity probes are outlined in Figures 5.6 and 5.7 which show one test run in each direction. Both the Mace and Unidata velocity probes gave more accurate velocity results when they were facing upstream. Facing upstream, the errors recorded by the Mace velocity probe ranged from 1.3% to 4.5% with an average

error of 3.1% over the three tests. The errors recorded by the Unidata Starflow probe when facing upstream ranged from 1.1% to 4.9%, but averaged out at 3.3%.

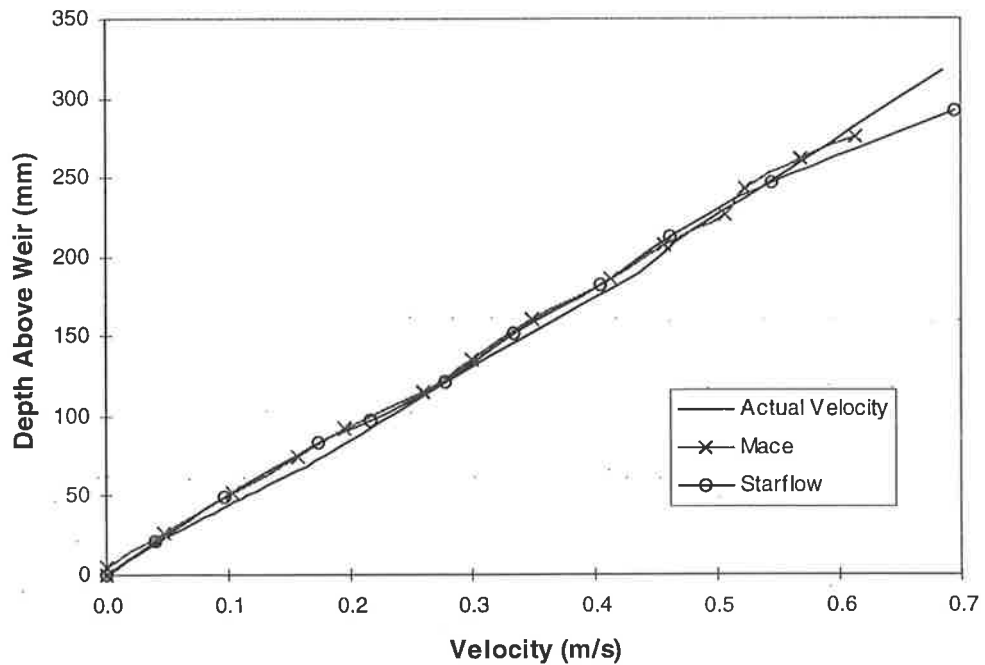


Figure 5.6 : Ultrasonic Velocity probes facing upstream

When facing downstream, the errors recorded by the Mace velocity probe ranged from 1.1% to 5.5% with an average error of 4.2% over the three tests. The errors recorded by the Unidata Starflow probe when facing downstream ranged from 1.2% to 5.9%, but averaged out at 4.4%.

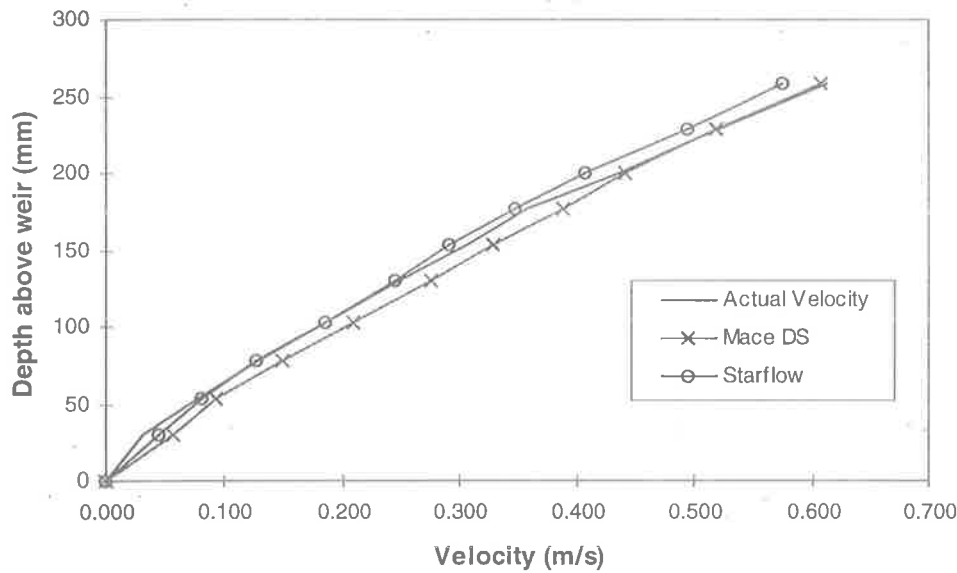


Figure 5.7 : Ultrasonic Velocity probes facing downstream

The accuracy of the pressure transducer in the Unidata Starflow probe was good with stage height errors ranging from 0.28% to 1.42% and averaging out at 0.94% over the six tests. The average errors recorded by the velocity probes of about 3.2% facing upstream and 4.3% facing downstream were considered acceptable as the conditions were far more turbulent than tow tests performed by the manufacturers. The results were deemed acceptable for the field application and considered more accurate than relying on stage/discharge relationships only.

5.7 Field Application

Given the extensive testing of the ultrasonic velocity probes in a controlled environment, the next step was to install velocity probes in the field to see how they performed under uncontrolled conditions. Three Mace QVT probes were installed approximately five metres upstream of the weir at North Arm East Drain placed facing downstream. The probes were installed across the cross section so that the variation of velocity across the cross section could be determined. The location of the probes across the cross section is outlined in Figure 5.8.

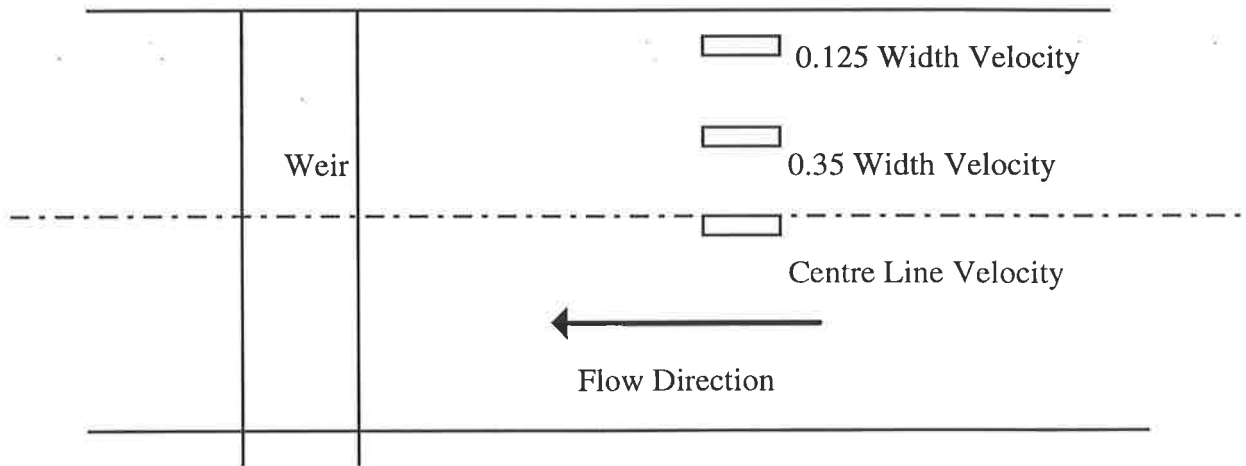


Figure 5.8 : Location of the velocity probes across the cross section of North Arm East Drain.

The objective of the three velocity probes was to calibrate the flow across the channel at the monitored cross section. This did not go according to plan as all three velocity probes never worked at the same time. The problem was later traced to a faulty controller box housed in the instrumentation cabinet on the bank of the channel, and not to faults in the velocity probe head units. This problem meant that the centre line velocity was not measured during any of the storms which were used to calibrate the flow of the cross section.

5.7.1 Cross Section Velocity Variation

Velocity data were analysed for a number of storm events that occurred during 1995 and 1996. Three typical storm events are depicted in Figure 5.9, 5.10 and 5.11. The three series

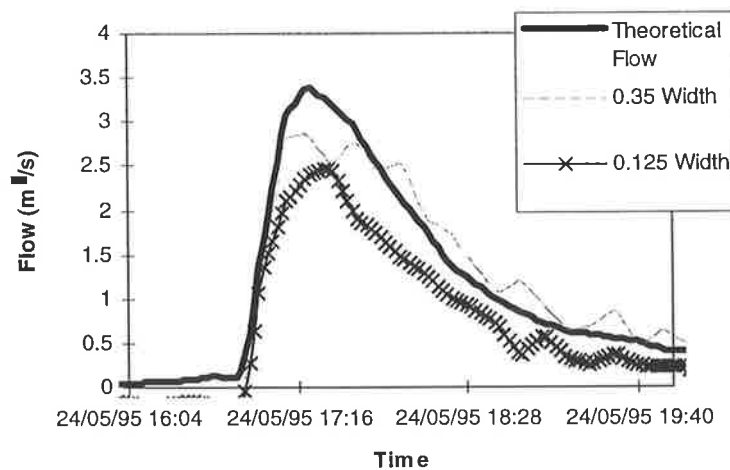


Figure 5.9 : AU504101, North Arm East Drain storm event 24/5/95

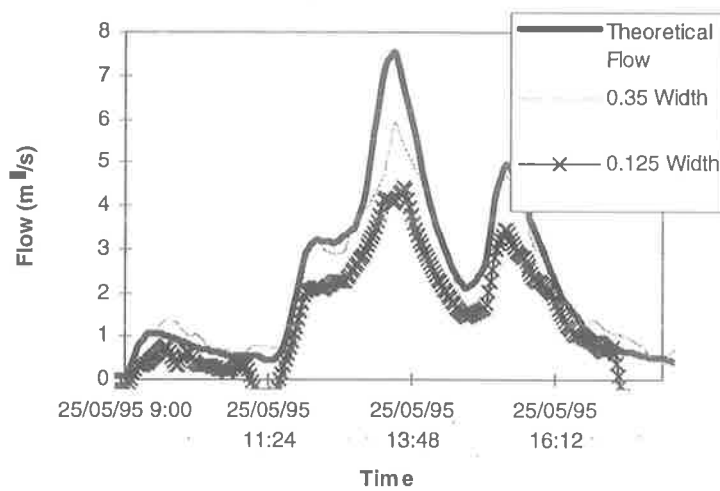


Figure 5.10 : AU504101, North Arm East Drain storm event 25/5/95

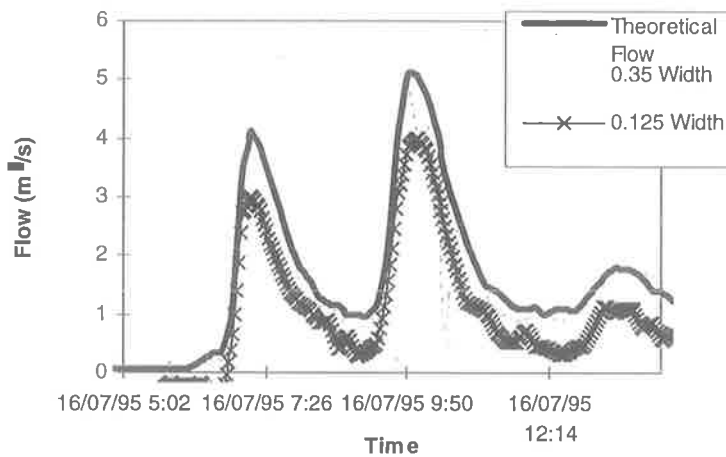


Figure 5.11 : AU504101, North Arm East Drain storm event 16/7/95

depicted in Figures 5.9 to 5.11 are the 'theoretical flow' derived from the stage/discharge relationship for the weir and the continuous velocity data at the 0.35 and 0.125 widths multiplied by the cross sectional area of the channel to give flow. The centre line velocity is notably absent due to a faulty controller box. It must be noted that an assumption has been made when converting the raw velocity data to flow that the velocity probe is indicative of the whole cross section of the channel. This is assumed to allow a direct comparison between the actual flows and the theoretical flows so that the velocity variation across the channel can be determined.

It is apparent from Figures 5.9 to 5.11 that the 0.125 width velocity is less than the 0.35 width. This was expected due to the frictional effects of the channel walls. The velocity distribution across the channel was expected to look similar to the one depicted Figure 5.12 below.

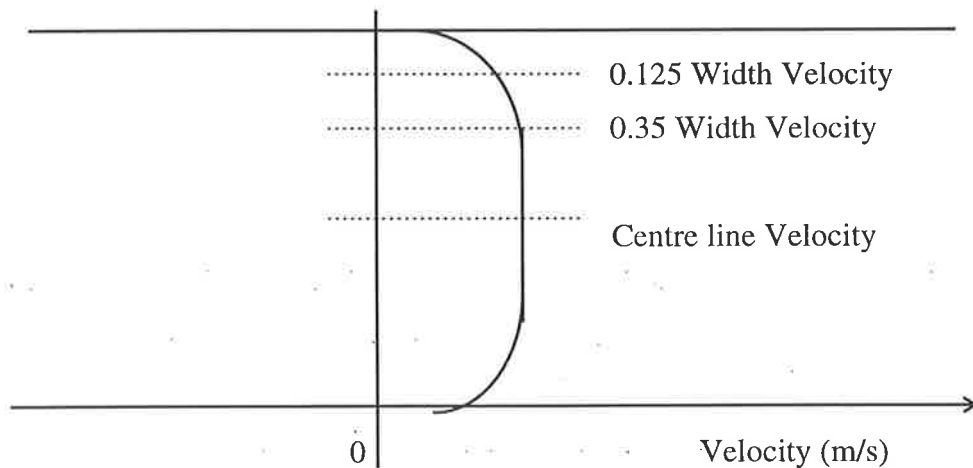


Figure 5.12 : Expected Velocity Variation across the channel cross section

Data from a number of storms during 1995 were analysed to determine the difference between velocity measured at the 0.125 width to that at the 0.35 width. The result from this analysis was that the velocity at 0.125 width was approximately 20% less than the velocity measured at 0.35 width. Although data for the centre line velocity was unavailable it was expected that the centre line velocity would have been approximately 5-10 % greater than the velocity measured at 0.35 width, as the centre line velocity is often the location of the maximum velocity.

Taking these results into account it was concluded that the 0.35 width estimated the flow accurately. For future events the 0.35 width velocity was used for flow measurement in conjunction with the stage/discharge rating curves.

5.8 Improving Stage/discharge Rating Curves

In Sections 5.6 and 5.7, ultrasonic velocity probes have proven to be an effective way of measuring stormwater flow in open channels. Given the acceptable performance of the velocity probes in the flume and the field, a means of improving stage/discharge rating curves using the continuous velocity record in the field was investigated.

Using the North Arm East Drain (AU504101) data, instantaneous velocity was plotted versus stage height for all the storm events with velocity data prior to the trash racks being installed in January 1996. This indicates a velocity distribution of the North Arm East Drain, and can be seen in Figure 5.13.

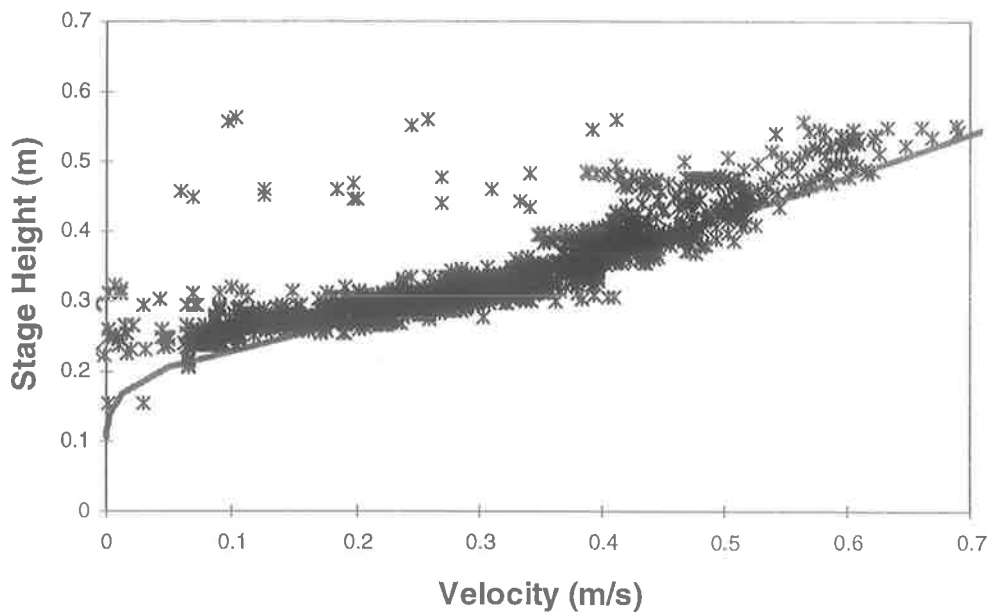


Figure 5.13 : Velocity Distribution A before the construction of trash racks in the North Arm East (AU504101) Drain.

Figure 5.13 indicates that the velocity distribution for the North Arm East Drain forms a well defined velocity band prior to the installation of trash racks. The theoretical stage/discharge rating curve was converted to a stage/velocity relationship and plotted against the velocity distribution on Figure 5.13 to give an indication of its validity. This is evident in Figure 5.13 and suggests that the theoretical stage/discharge rating curve is valid for all stage heights in 1994 and 1995 prior to the installation of trash racks.

The theoretical stage/discharge curve depicted by the stage/velocity curve outlined in Figure 5.13 was derived from Equations 5-1 and 5-2 outlined in Section 5.2.1. Figure 5.13 was used to determine the coefficients used in the calculation of theoretical flow. The theoretical stage/discharge curve for the North Arm East (AU504101) drain was converted to a stage/velocity curve by dividing by the cross sectional area. The theoretical stage/velocity curve was then plotted on the same graph as the actual velocity distribution, as seen in Figure 5.13. The fact that the theoretical stage/velocity curve falls within the distribution band of actual velocities implies that a coefficient of 1.0 can be used for the theoretical calculation of flow, at least up to a velocity of 0.7m/s. Utilising actual velocity data is a more accurate way of determining the coefficients for Equations 5-1 and 5-2 than using tabulated coefficients determined from other channels.

The instantaneous velocity data for events in the North Arm East (AU504101) drain after the installation of trash racks were then plotted and can be seen in Figure 5.14. The velocity distribution again forms a well defined band of velocities in the North Arm East (AU504101) channel after the construction of trash racks. A line of best fit was plotted through the velocity distribution, as outlined in Figure 5.14.

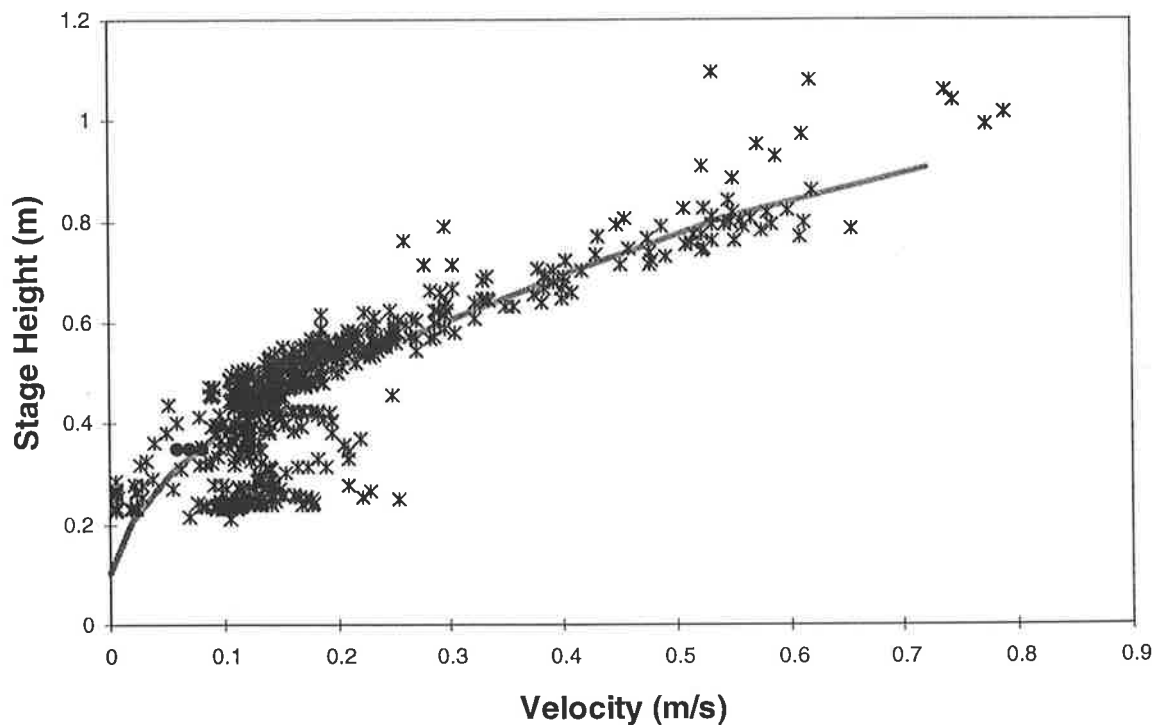


Figure 5.14 : Velocity Distribution B after the construction of trash racks in the North Arm East (AU504101) Drain.

The line of best fit can be converted into a stage/discharge velocity curve by multiplying by the cross-sectional area. The stage/discharge relationship forms a dynamic rating curve and can be used for flow measurement of events occurring after the installation of trash racks.

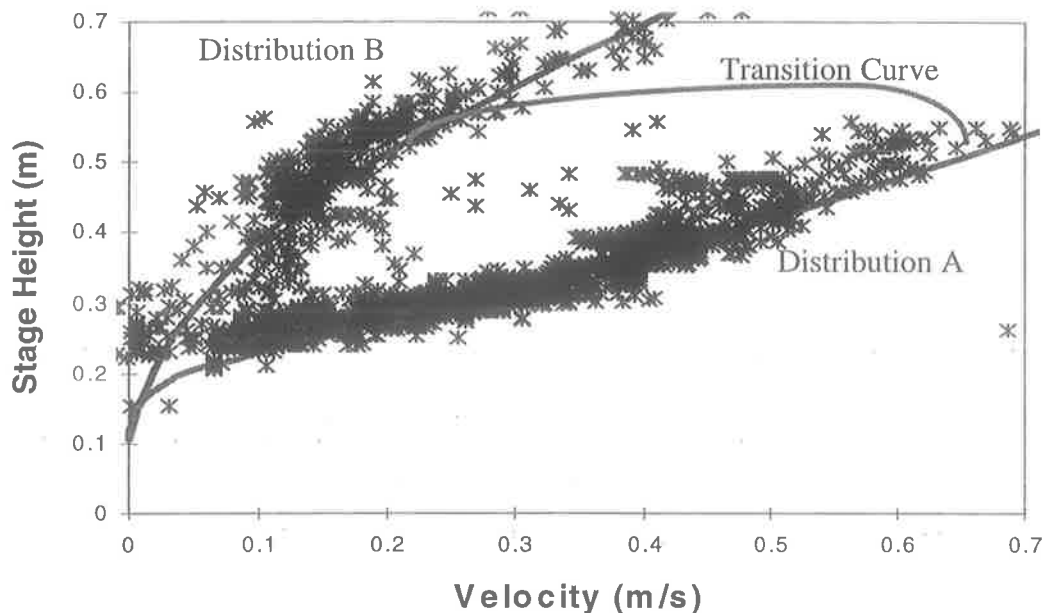


Figure 5.15 : Velocity Distributions A and B before and after the construction of trash racks in the North Arm East Drain (AU504101).

The velocity distributions before and after the installation of trash racks are presented on the same figure, Figure 5.15. Overlaying the velocity distributions before and after the construction of the trash racks gives a good indication of the reduction in velocities caused by the trash racks.

Not all events occurring after the installation of trash racks in the North Arm East (AU504101) drain fall totally within velocity distribution B. By analysing the velocity data of the events occurring after the installation of trash racks it was determined that the rising limb of each event was often not backwatered. The trash racks are usually empty at the beginning of each event and so the flow becomes backwatered later in the event as the trash rack fills with gross pollutants. This is indicated by the stage height record of event 13/4/96 outlined in Figure 5.16. The rising limb of the hydrograph is not backwatered and follows velocity distribution A until it reaches the hydrograph peak, point 1. The flow then goes through a transition period as the trash rack accumulates rubbish, until the trash rack becomes

full when it reaches point 2. From point 2 onwards the flow is backwatered and follows velocity distribution B.

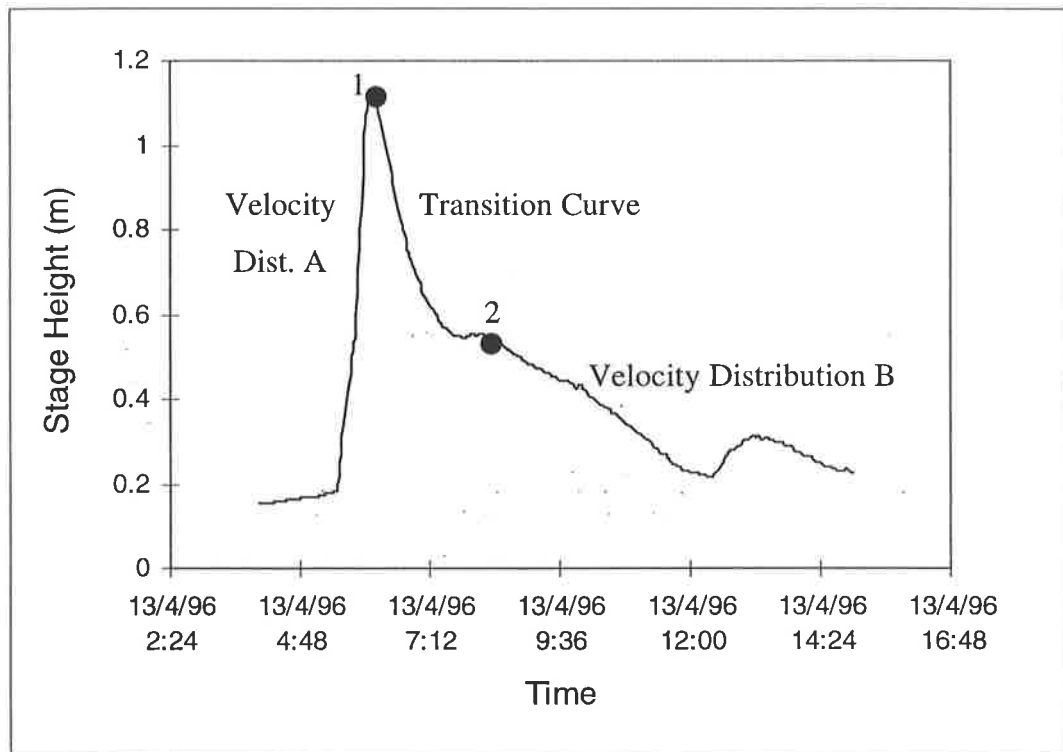


Figure 5.16 : Stage Height record for event 13/4/96 in the North Arm East (AU504101) Drain

This forms a hysteresis loop which is evident in the velocity distributions outlined in Figure 5.15. The three velocity distributions form a loop which is followed in an anti-clockwise direction.

The best indication of the success of the 3-pronged rating curve procedure for events occurring after the installation of trash racks is the runoff coefficient for the catchment. Analysis of events prior to the installation of trash racks determined an average runoff coefficient of 0.27 for the North Arm East (AU504101) catchment. Analysis of events occurring after the installation of trash racks using the 3-pronged rating curve procedure proved that the runoff coefficient is consistent at an average of around 0.27. This confirms that the 3-pronged rating curve procedure is valid for events occurring after the installation of trash racks.

Ideally the velocity data should be used on an individual event basis to give the most accurate flow measurement. The 3-pronged velocity distribution procedure utilising velocity

distributions A and B as well as the transition curve is merely a fall back procedure to be used in the case of velocity probe failures.

5.9 Summary of North Arm East Flow Measurement

Due to the construction of trash racks part way through stage 1 of the monitoring program the derivation of flow in the North Arm East Drain is split into two methods. The first method is valid prior to the construction of trash racks, and involves converting the stage height to flow using the stage/discharge rating curve outlined by Equations 5-1 and 5-2 and is valid up until January 30 1996. The second method is valid from February 1 1996 onwards (after the construction of trash racks) and is dependent on the three velocity distributions outlined in Figure 5.15.

5.10 Flow Measurement in the Hindmarsh Enfield Prospect Drain

The flow for the Hindmarsh Enfield Prospect (AU504102) drain has been reliant on the theoretical stage/discharge rating table calculated by equations 5-1 and 5-2. The stage/discharge rating curve for the Hindmarsh Enfield Prospect (AU504102) drain prior to the installation of trash racks is outlined in Appendix C.

A Mace ultrasonic velocity probe was installed in the Hindmarsh Enfield Prospect (AU504102) drain in September 1996. The probe was installed facing upstream in accordance with the conclusions from flume testing of velocity probes, that they are more accurate facing upstream. As the velocity probe was not installed until September 1996 (8 months after the installation of trash racks) the theoretical stage/discharge rating curve cannot be directly verified by actual velocity data. However the velocity distribution of events after the installation of trash racks can be determined and hence a dynamic rating curve can be derived for the Hindmarsh Enfield Prospect (AU504102) drain.

The instantaneous velocity values were plotted against stage height for a number of storms occurring after September 1996. This is shown in Figure 5.17.

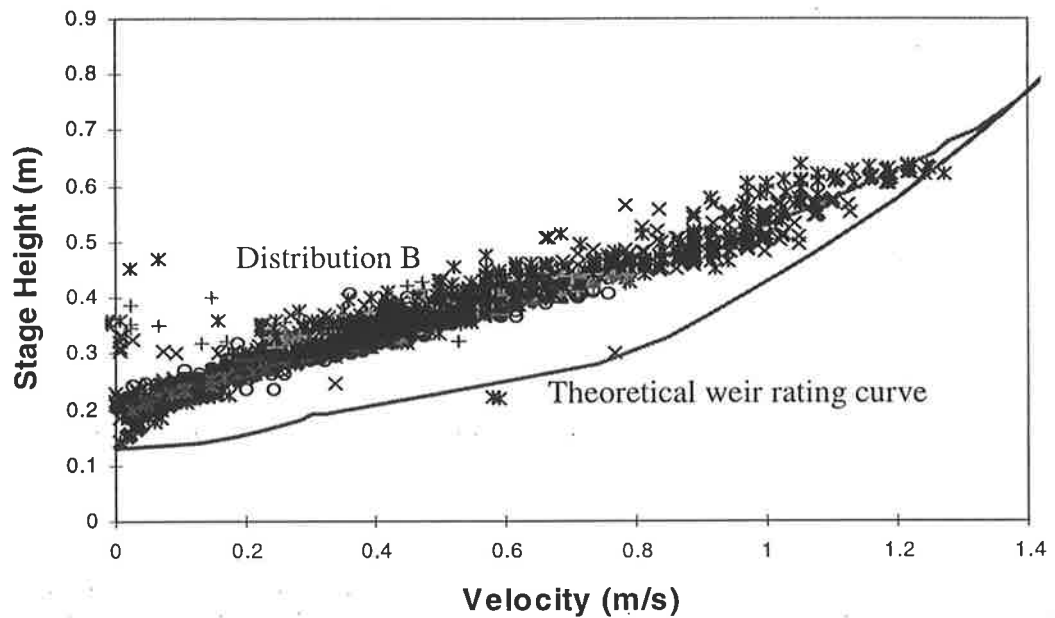


Figure 5.17 : Velocity Distribution B after the construction of trash racks in the HEP Drain (AU504102).

The theoretical stage/discharge rating curve has been converted to stage/velocity and included in Figure 5.17 as a comparison. It must be noted that the curves are representative of two different area cross sections, and so a true comparison cannot be made until the stage velocities are converted to stage/discharges as outlined in Figure 5.18.

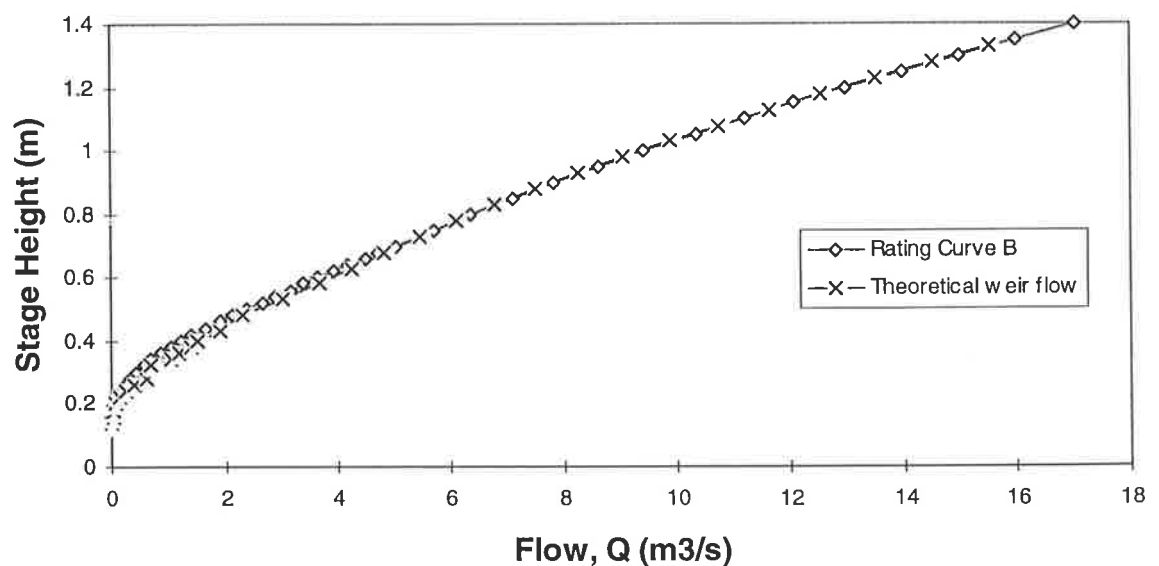


Figure 5.18 : Flow rating curves, Hindmarsh Enfield Prospect (AU504102) Drain

Figure 5.18 clearly shows that the actual flow in the Hindmarsh Enfield Prospect (AU504102) drain recorded by the Mace velocity probe is the same as the predicted theoretical weir flow. This shows that theoretical stage/discharge is valid and that the trash racks do not create a backwater effect on the runoff in the Hindmarsh Enfield Prospect (AU504102) drain. The determination of flow both before and after the installation of trash racks can therefore be determined by the theoretical stage/discharge rating curve. The velocity data still should be used as a more accurate measurement of flow so that any backwatered effects are monitored.

In the event of a large storm it is likely that the pond level downstream of the monitoring station in the Hindmarsh Enfield Prospect (AU504102) drain may be elevated to a level that will affect the flow of the weir. This was evident in an event that occurred on 6 February 1997 in the Hindmarsh Enfield Prospect (AU504102) drain. The velocity data for the event on 6/2/97 are outlined in Figure 5.19.

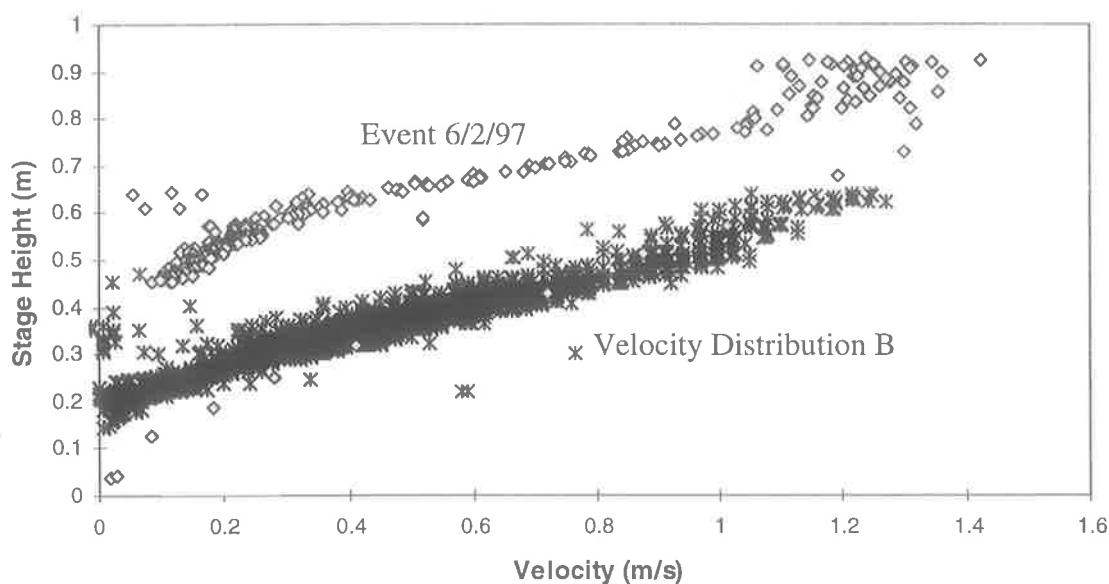


Figure 5.19 : Velocity distribution of event 6/2/97 compared to velocity distribution B in the Hindmarsh Enfield Prospect (AU504102) Drain

The rising limb of the event 6/2/97 is weir flow as it closely follows 'Velocity Distribution B', however the velocity distribution of the falling limb does not follow the same distribution. The velocity data on the falling limb of event 6/2/97 are far less which indicates that there is some kind of downstream influence on flow. The flow rate for event 6/2/97 was therefore

determined by converting the velocity data to flow. The total event volume was calculated to be approximately 73ML. The volume of flow that the pond downstream of the Hindmarsh Enfield Prospect (AU504102) monitoring station (0.85m pond, South) can store is approximately 55ML at a depth of 1.3m as outlined in Appendix A. This indicates that the pond became full during the 6/2/97 event and that the downstream water level had an influence on flow. A large event on 22/1/97 also contributed to elevated pond levels as its volume was approximately 69ML. The data from event 6/2/97, the largest monitored event during this monitoring phase, highlights the import role that the velocity probes play in monitoring any backwater effects in the channels.

The overall accuracy of flow measurement of stormwater in the channels has been improved with the use of ultrasonic Doppler velocity probes as an alternative method of flow measurement.

The determination of the dynamic stage/discharge rating curves in the North Arm East (AU504101) and Hindmarsh Enfield Prospect (AU504102) drains increases the accuracy of flow measurement from the two catchments.

The continuous record of velocity data for the drains is extremely important. Two methods for the calculation of flow from continuous stage height have been outlined. One method is valid when the trash racks are empty, the other is valid under backwatered conditions when the trash racks are full. The continuous velocity data needs to be examined after each event to determine which rating curve is appropriate.

Often events occur that begin as weir flow when the trash racks are empty then revert to backwatered conditions as the trash racks become full. The continuous velocity record for the event becomes even more important as it can be directly converted to flow by multiplying by the cross-sectional area to give flow.

Chapter 6

Runoff Routing Model

6.1 Introduction

As an extension to the field monitoring of stormwater quality and quantity a runoff routing model was produced for the North Arm East (AU504101) catchment. The North Arm East catchment was chosen as it is by far the largest of the five monitored catchments and produces the largest quantity of stormwater runoff that enters the Barker Inlet wetland. A number of modelling programmes are available such as RORB, Hydrol and ILSAX, however the RAFTS-XP runoff routing program was chosen due to the author's familiarity with the program.

6.2 Data Availability

The available data stored in the HYDSYS database was exported in the RAFTS-XP format as required. A continuous record of Rainfall and Runoff was available for the North Arm East Catchment for the period April 1994 to July 1997. As discussed in Chapter 5 the installation of trash racks in January 1996 introduced a downstream control on the downstream stage

height, backwatering most events. This has a large effect on flow and hence effects the modelling of the catchment in the runoff routing model. It was decided that the best approach to modelling the North Arm East catchment was to calibrate the model on storms that occurred prior to the installation of trash racks. After the model was calibrated and verified on events prior to the construction of trash racks, with no downstream control, it could then be applied to events after January 1996 to investigate the backwater effect that the trash racks introduced. Effectively the modelling was broken into two stages.

The data available for stage 1 (the calibration and verification of the model on events prior to the installation of trash racks) includes April 1994 to January 30 1996. The data available for stage 2 (the effect of the trash racks on the flow) included February 1996 to July 1997.

6.2.1 Stage 1

The events chosen to calibrate the RAFTS-XP model on are shown in Table 6.1 below, and the verification events are shown in Table 6.2

TABLE 6.1 : Events Modelled in Stage 1

Storm N°	Start Time/Date	Finish Time/Date
1	01:00 12/7/94	06:00 12/7/94
2	21:00 8/6/95	02:00 9/6/95
3	00:00 3/5/95	24:00 3/5/95
4	06:00 25/5/95	20:00 25/5/95
5	15:00 21/7/95	21:00 21/7/95

TABLE 6.2 : Verification Events for Stage 1

Storm N°	Start Time/Date	Finish Time/Date
Ver 1	11:00 7/6/95	19:00 7/6/95
Ver 2	15:00 26/6/95	22:00 26/6/95
Ver 3	11:00 4/4/95	18:00 4/4/95
Ver 4	00:00 2/4/95	05:00 2/4/95

6.2.2 Stage 2

The events occurring after January 1996 that were input into the RAFTS-XP model and used to determine the effect of the trash racks are described in Table 6.3 below.

TABLE 6.3 : Storms modelled in Stage 2

Storm N°	Start Time/Date	Finish Time/Date
Back 1	04:00 13/4/96	12:00 13/4/96
Back 2	03:00 31/7/96	12:00 31/7/96
Back 3	05:00 6/12/96	09:30 6/12/96
Back 4	02:00 4/7/96	13:00 4/7/96

6.3 Rainfall Distribution

There are six pluviometers in the Barker Inlet Wetland Catchment as described in Chapter 4. The North Arm East Catchment is a large urban catchment with an area of 2170 ha (21.7km^2) so it was important to incorporate all of the available rainfall data. The program *Surfer*[®] for *Windows* was employed to produce an isohyetal rainfall distribution across the catchment for each storm event. From the isohyetal rainfall distributions an average depth of rainfall was determined. *Surfer*[®] for *Windows* could be used to calculate the rainfall volume that fell on the catchment and hence dividing by the catchment area the average rainfall depth for each event. A problem with the *Surfer*[®] for *Windows* package was found when calculating the average rainfall depth over the catchment. This led to manually calculating the average rainfall depth from rainfall distributions. The average rainfall depth could then be distributed using the temporal pattern from one of the pluvio records for the event.

The isohyetal rainfall distributions for calibration events 1-5 (stage 1), verification events 1-4 (stage 1) and for stage 2 events 1-4 are shown in Appendix D.

6.4 Event Volumes

Once the average rainfall depth over the catchment was determined for each event the total rainfall volume for each event was determined. The stormwater runoff volumes were obtained from the HYDSYS database by extracting the cumulative runoff volume for each event. The total rainfall and runoff volumes for calibration events 1 to 5 are shown in Table 6.4 below.

TABLE 6.4 : Rainfall Depth, Volume and Runoff Volume

Event No.	Avg Rainfall Depth (mm)	Rainfall Volume (ML)	Runoff Volume (ML)
1	4.8	104.16	16.52
2	5.9	128.03	22.84
3	18	390.60	97.50
4	12.8	277.76	78.04
5	7.8	169.26	50.08
6	9	195.30	77.29

To determine the runoff coefficient for the North Arm East catchment a graph of the total runoff volume versus rainfall volume for each event was produced and is shown in figure 6.1. A line of best fit was drawn through the six events. The slope of the line of best fit was calculated to be 0.26, which could then be used as the initial guess for the impervious percent (26%) of the North Arm East catchment in the RAFTS-XP model.

The 26% initial guess for the impervious proportion in the North Arm East (AU504101) Catchment seems reasonable compared to other published data elsewhere in the Adelaide metropolitan area. Williams and Smythe (1994) found the urban catchment of Minkara Creek catchment at Happy Valley in Adelaide to be 22%. Kemp (1995) modelled the Glenelg and the Paddocks catchments, two other urban catchments in Adelaide, and found that they both have impervious proportions of 27%. An extensive survey of the Glenelg catchment estimated that the impervious proportion was 29%.

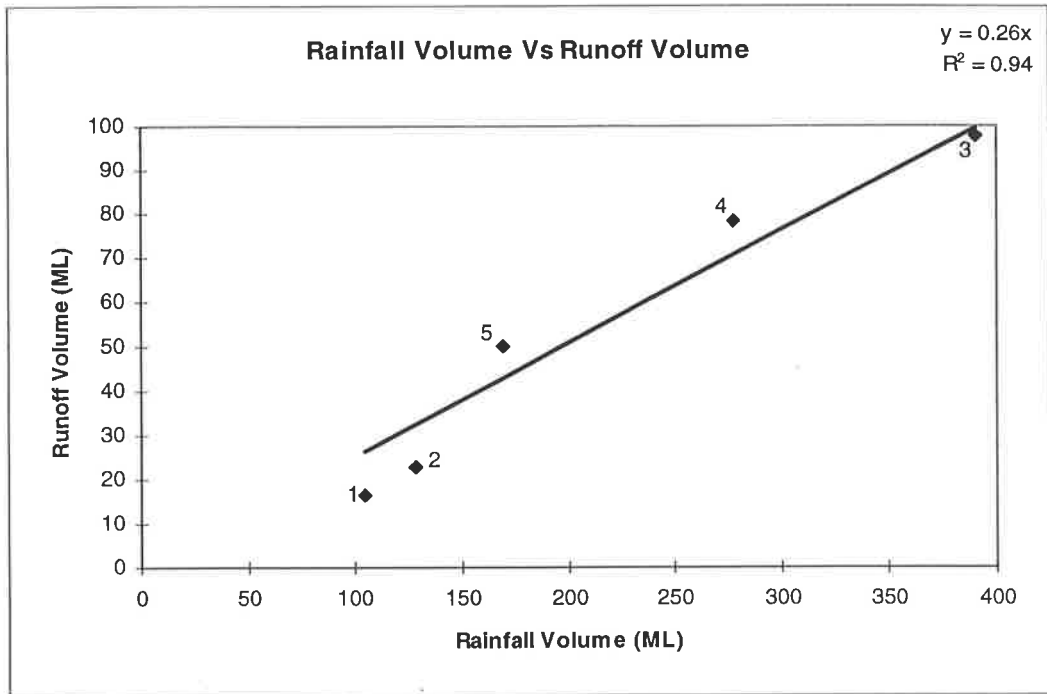


Figure 6.1 : Rainfall Volume Vs Runoff Volume

6.5 RAFTS-XP Program

The RAFTS-XP (1996) user manual has a detailed description of the RAFTS-XP model. The model was originally developed by both Willing and Partners Pty Ltd. and the Snowy Mountains Engineering Corporation (Goyen and Aitken 1976). The model was originally called the 'Regional Stormwater Drainage Model'. In the early 80s Willing and Partners Pty Ltd. further developed the model which is now known as the RAFTS-XP model.

The RAFTS-XP model consists of five major modules :

- The Library Module;
- The Hydrograph Generation Module;
- Rainfall Loss Module;
- Reservoir Routing Module;
- River-Channel Routing Module.

The Library module is used in the overall program management and operation. The Library module communicates with the other four modules and controls the data, computation and

program output. The Hydrograph generation module controls the generation of the output hydrograph from the RAFTS-XP model.

A single catchment one node model is split into two subcatchments. Each subcatchment is divided into ten sub-areas divided by isochrones (lines of equal travel time from the catchment boundary to subcatchment outlet) through which the excess rainfall is routed. The routed excess rainfall is summed using a non-linear storage. The generated hydrographs are manipulated by the link network to the outlet of the catchment via the routing module. The subcatchments can be connected via a channel, pipe or time lag. The storage relationship for each sub-area is described by equation 6-1:

$$s = B.q^{(n+1)} \quad (6-1)$$

where :

- s is the volume storage (hrs × m³/s)
- B is the storage delay time coefficient
- q is the instantaneous rate of runoff (m³/s)
- n is the non standard storage exponent

The rainfall loss module controls the loss of rainfall to processes such as infiltration and evapotranspiration. The rainfall loss can be modelled by the Phillip's infiltration equations or simply by initial and continuing loss.

The Reservoir routing module can handle ponding basins and other major storage areas. The module requires data on the stage-storage and stage-discharge relationships for the storage areas as well as spillway dimensions and levels (if required).

The River/Channel routing module utilises the Muskingum-Cunge routing procedure. In this study a time lag on the output hydrograph was used instead.

6.6 Modelling the Events Using RAFTS-XP

Stage 1 of the modelling process involved modelling the events described in Table 6.1. A one node RAFTS-XP model was produced with the first subcatchment representing the impervious area in the catchment, and the second subcatchment representing the pervious

area. This solves the problem of using RAFTS-XP in the Adelaide area where the model does not allow for the paved areas to be treated separately to pervious areas. This is due to the model development occurring in Canberra where the roofs and other paved areas are directly connected to the main stormwater drainage system.

The historical storms were calibrated with the accuracy of the fit based on the examination of the hydrograph by eye. Each step of the calibration procedure is outlined below.

6.6.1 The Calibration Approach

- The largest event, event 3, was calibrated first.
- The initial guess for the impervious area was taken from figure 6.1 as 26 percent, which represents an impervious area of 564 hectares.
- The initial loss was set to ensure the start of the rise of the gauged flow hydrograph was modelled accurately.
- The impervious area was adjusted to match the volume of the gauged flow hydrograph.
- The pervious area was adjusted to maintain the total area of 2170 hectares.
- The value of the non standard storage (n) exponent was set at -0.2. This is equivalent to a Rorb $k=0.8$.
- The continuing loss (proportional) was adjusted, however the pervious area usually had no runoff and hence no effect on the output hydrograph.
- The value of the storage delay coefficient (B) was adjusted to best fit the shape of the gauged flow hydrograph.
- If required, an appropriate time lag (x-shift) was introduced to match the time frame of the gauged runoff hydrograph.

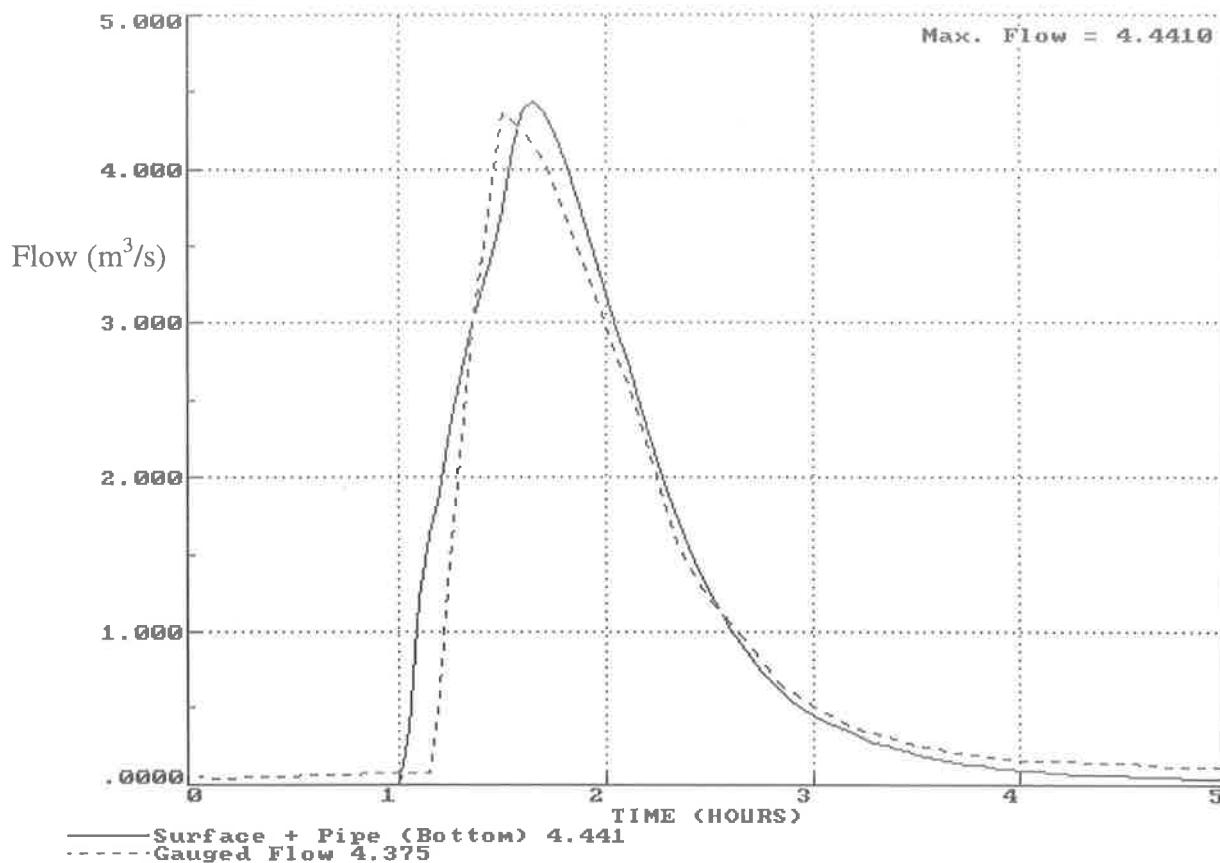
6.6.2 Calibrated Model Parameters

Each of the five events were calibrated using the above procedure. The parameters determined for the five events are outlined below in Table 6.5.

TABLE 6.5 : Calibrated Model Parameters for Stage 1.

Event #	Type	time	Initial	Contin.	Area	DSC	NSSE
	Area	lag	loss	loss (P)	(ha)	B	N
1	imperv.	25	1.6	0	550	0.135	-0.2
	pervious		5.5	0.93	1620	0.1	-0.2
2	imperv.	30	1.6	0	550	0.147	-0.2
	pervious		5.5	0.93	1620	0.1	-0.2
3	imperv.	40	1.2	0	580	0.095	-0.2
	pervious		5.5	0.93	1590	0.1	-0.2
4	imperv.	35	1	0	550	0.125	-0.2
	pervious		5.5	0.93	1620	0.1	-0.2
5	imperv.	25	2	0	570	0.11	-0.2
	pervious		5.5	0.93	1600	0.1	-0.2

The calibrated hydrographs are outlined in Figures 6.2 to 6.6. From Figures 6.4 and 6.6 it looks as though there may be slow flow on the receding limbs from the pervious area.

**Figure 6.2** : Calibrated event 1, 12/7/94

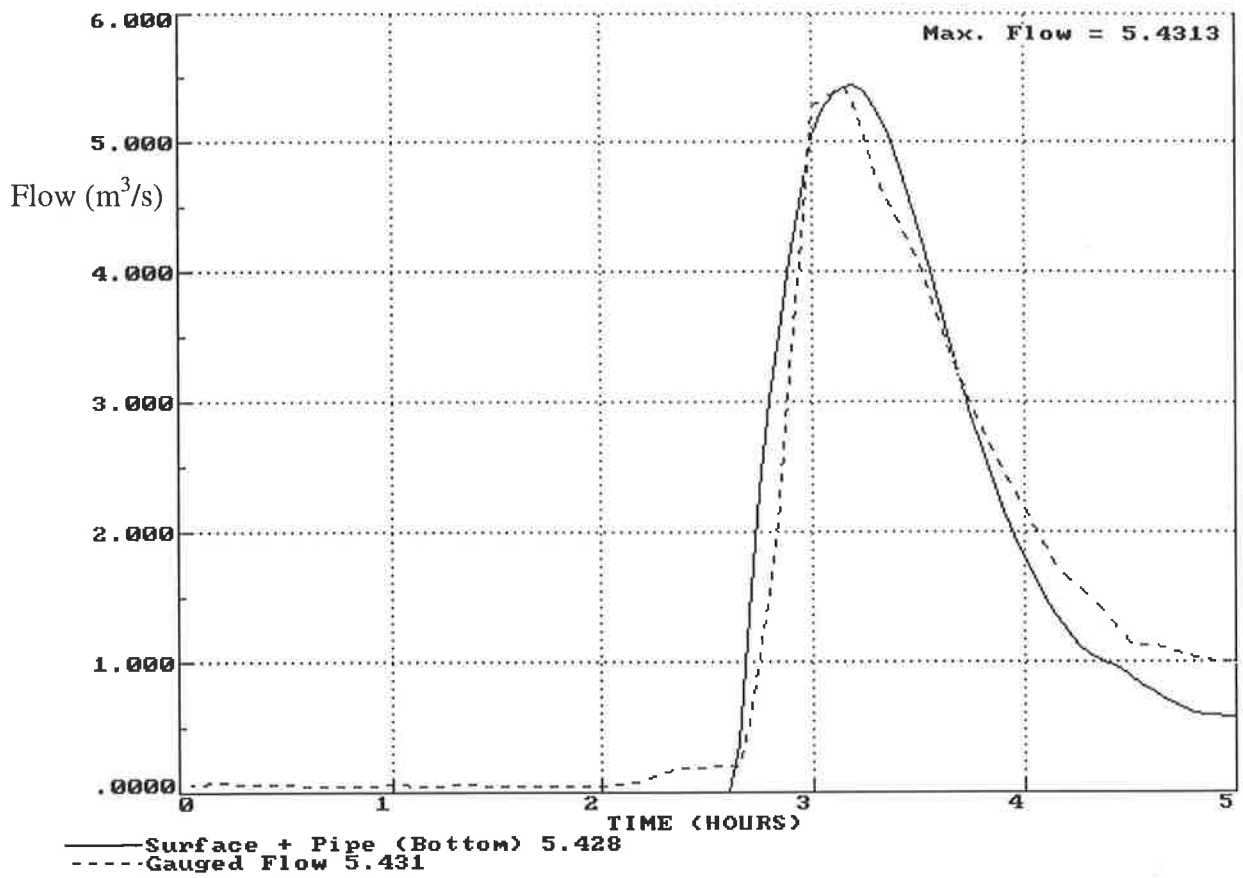


Figure 6.3 : Calibrated event 2, 8-9/6/95

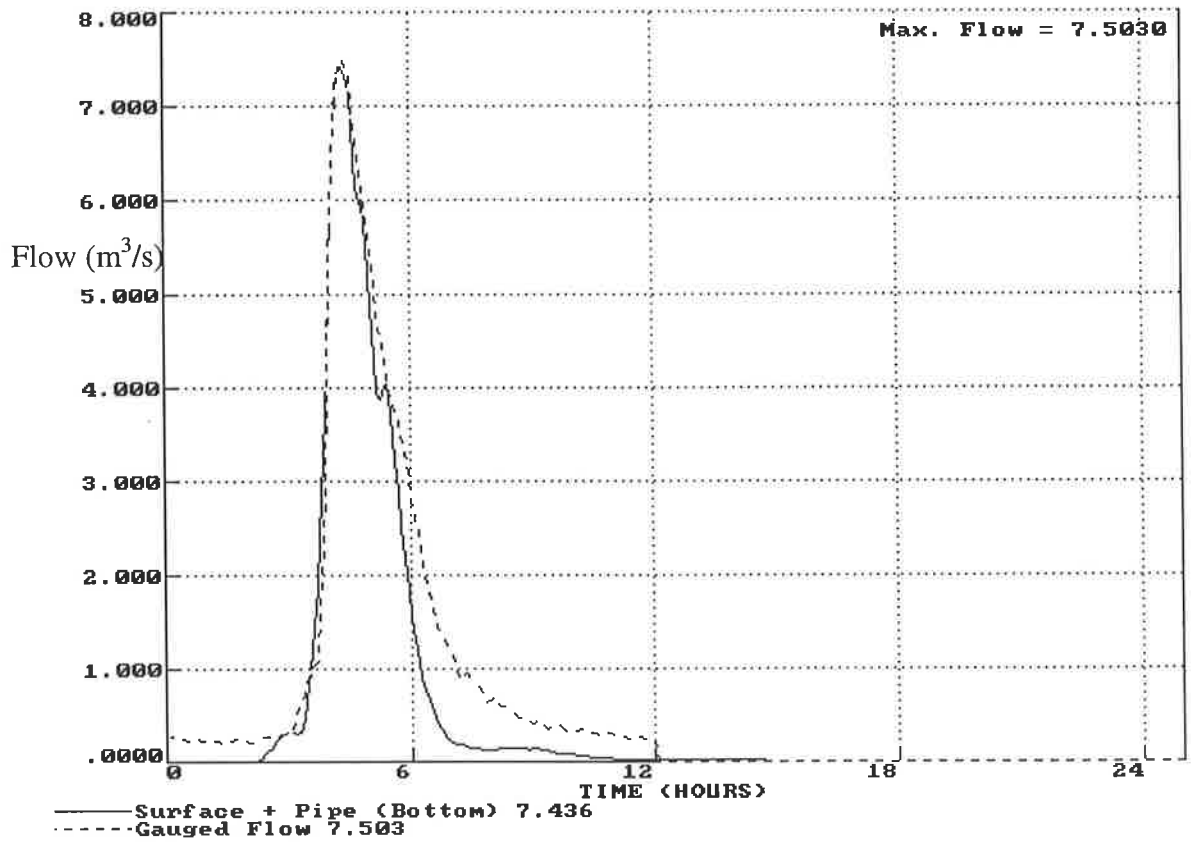


Figure 6.4 : Calibrated event 3, 3/5/95

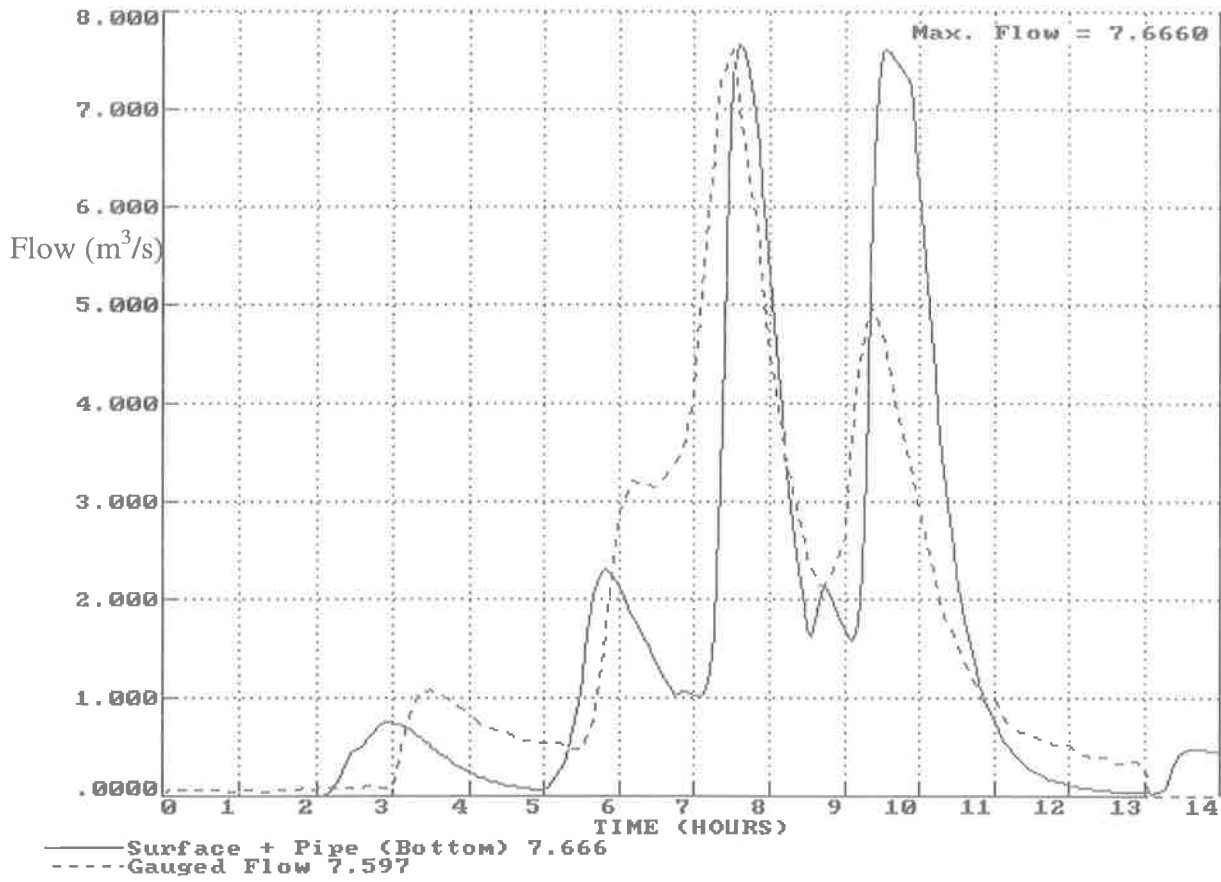


Figure 6.5 : Calibrated event 4, 25/5/95

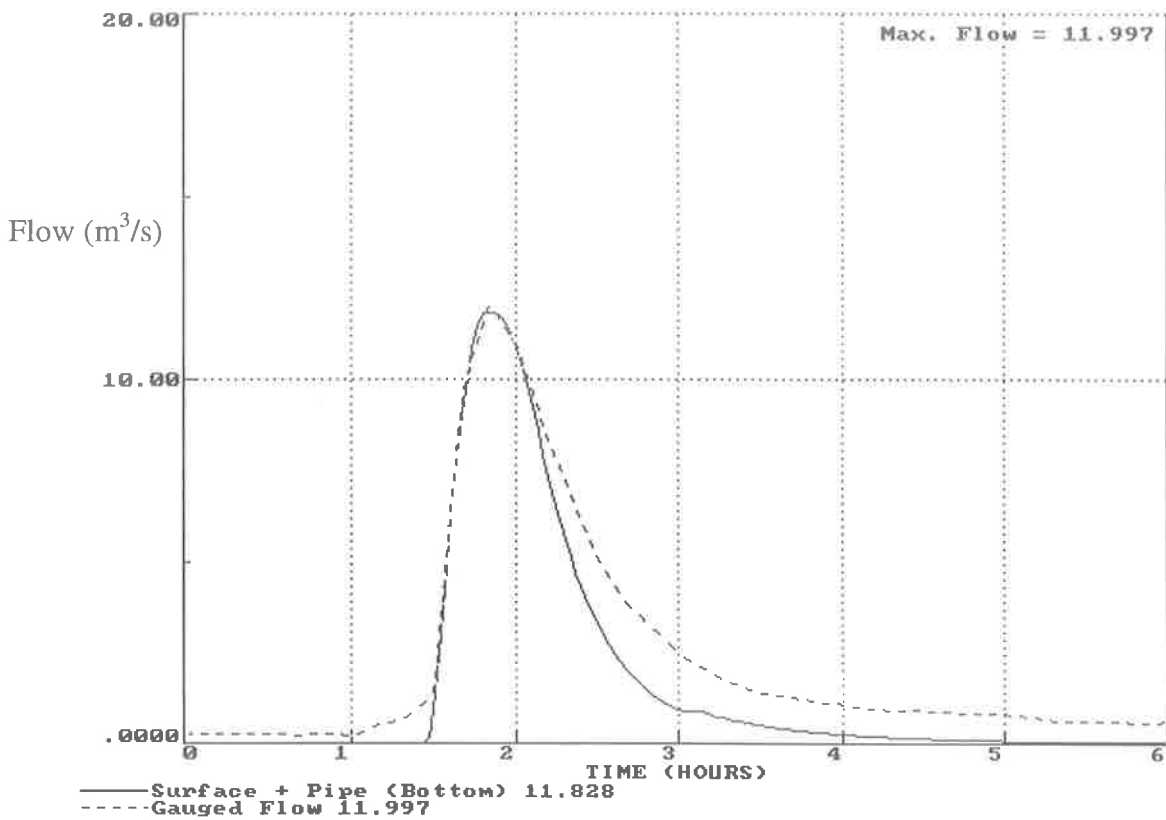


Figure 6.6 : Calibrated event 5, 21/7/95

6.6.3 Parameter Selection Technique

There are a number of simple parameter selection techniques available in order to find a single set of parameters to best suit the historical storm data. The methods rely on the operator fitting the event as near as possible to the gauged flow hydrograph. This includes trying to match the shape as well as the peak flow for each event. An objective approach was preferred over the many subjective techniques available.

All of the techniques require a weighting be allocated to the set of parameters for each event. The weightings vary depending on the type of parameter selection technique that is used. Equation 6-2 below was used to extract a parameter set from the parameters of the calibrated historical storms.

$$P_t = \frac{1}{\sum_{i=1}^n R_i} \sum_{i=1}^n R_i P_i \quad (6-2)$$

where :

- n = The number of storms (6)
- P_t = The single parameter value obtained from weighting and combining the 6 calibrated event parameters. This is repeated for all of the parameters required for the RAFTS-XP model.
- R_i = The individual ranking given to each event parameter by the parameter selection technique.
- P_i = The calibrated parameters for each storm.

The parameter selection technique used in the research was the Peak Difference Weighting Technique, Williams and Smythe (1994).

6.6.4 Peak Difference Weighting Technique

The Peak Difference Weighting Technique uses the difference between the RAFTS-XP model peak flow and the gauged peak flow. The difference between the two peaks is expressed as a percentage error of the RAFTS-XP model peak flow. The percentage error in peak flow prediction determines the weighting factor to be given to the calibrated parameters for that

event. Table 6.6 outlines the weighting given to different percentage errors in peak flow prediction.

The errors in the predicted peak flow values of the calibrated events range from 0.5 to 1.5 % as outlined in Table 6.7. Table 6.7 also outlines the weighting to each set of calibration parameters as allocated by the peak difference weighting technique.

TABLE 6.6 : Weight given to Percentage Error in Peak Flow Prediction

% Error	Weight Given to Event
0 - 0.5	12
0.5 - 1.0	11
1.0 - 2.0	10
2.0 - 3.0	9
3.0 - 4.0	8
4.0 - 5.0	7
5.0 - 6.0	6
6.0 - 7.0	5
7.0 - 8.0	4
8.0 - 9.0	3
9.0 - 10.0	2
> 10.0	1

TABLE 6.7 : Weighting calibrated events by parameter selection technique

Event #	RAFTS-XP Peak	Gauged Peak	% error	weightin g	Coeff.
1	4.375	4.441	1.5	10	0.185
2	5.431	5.428	-.05	12	0.222
3	7.503	7.436	-0.9	11	0.204
4	7.597	7.666	0.9	11	0.204
5	11.997	11.828	-1.4	10	0.185
Total				54	1

6.6.5 North Arm East Catchment Model Parameters

After careful calibration of the selected events and using the parameter peak difference parameter selection technique, a single set of parameters were produced for the North Arm East catchment. The parameters are outlined in Table 6.8.

TABLE 6.8 : The North Arm East Catchment Parameters.

Area Type	Area (ha)	Time Lag	Initial loss (mm)	Continuing loss (Prop.)	DSC B	NSSE n
Impervious	560	31	1.47	0	0.123	-0.2
Pervious	1600	31	5.5	0.93	0.1	-0.2

6.6.6 Parameter Verification

The final RAFTS-XP model parameters outlined in Table 6.8 require verification. First the calibration storms were run through the model using the final parameter set. The results are shown in Appendix E, Figures E1-E5. The accuracy of the peak flows was calculated to indicate the success of the model parameters. The errors which are outlined in Table 6.9 ranged from 4.2 to 22.4% which was accepted as a reasonable result.

TABLE 6.9 : RAFTS-XP parameters re-applied to calibration events.

Event	RAFTS-XP Peak	Gauged Peak	% error
1	5.2283	4.375	16.3
2	7.0021	5.431	22.4
3	6.423	7.503	-16.8
4	7.9269	7.597	4.2
5	11.503	11.997	-4.3

Figure 6.7 outlines the result of re-applying the RAFTS-XP model to the calibration event 3, 3/5/95.

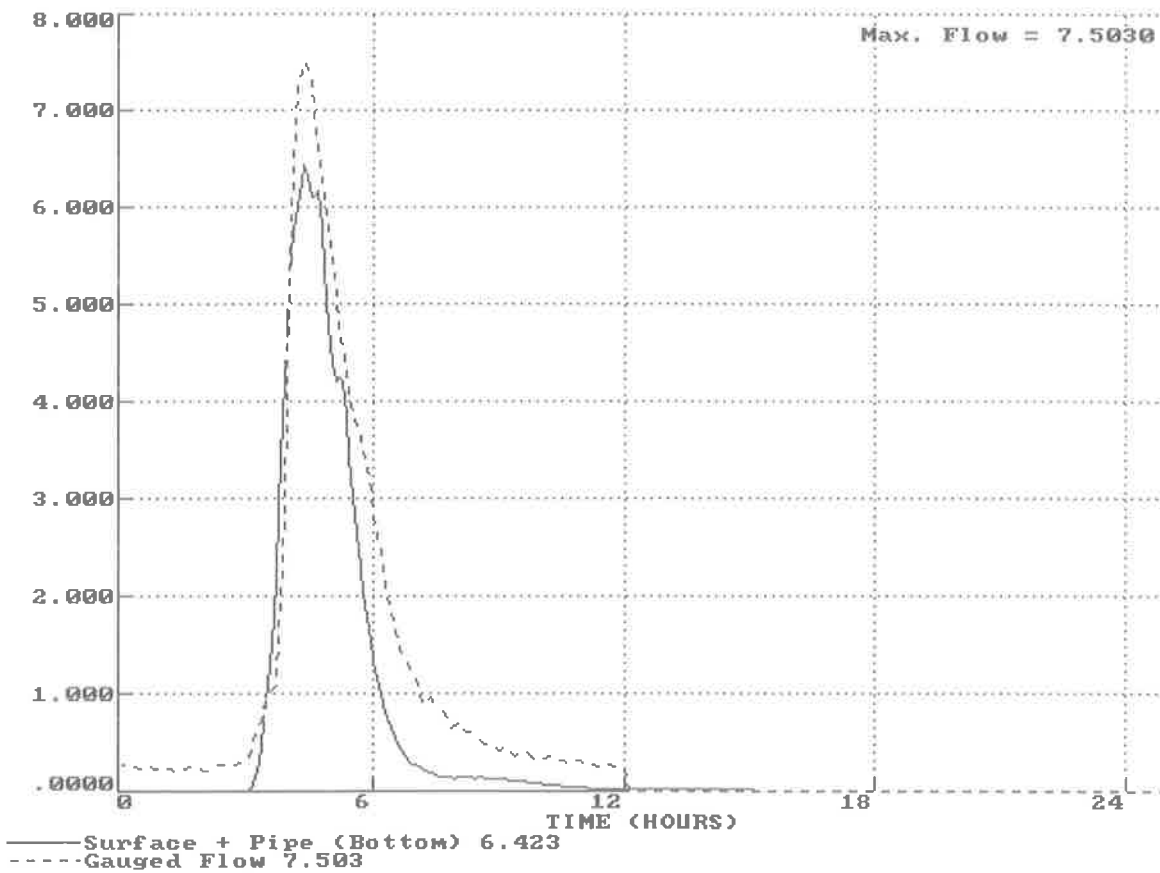


Figure 6.7 : RAFTS-XP model re-applied to calibration Event 3, 3/5/95

The model was then verified on storm events outside of the calibration set. The verification events were earlier outlined in Table 6.2. The results of the verification are shown in Appendix E, Figures E6-E9, and the percentage errors in estimated peak flow outlined in Table 6.10. Percentage errors were determined and ranged between 2.7 and 27.7% and the model was accepted on this basis.

TABLE 6.10 : RAFTS-XP parameters applied to verification events.

Event	RAFTS-XP Peak	Gauged Peak	% error
Ver 1	1.921	2.199	-14.5
Ver 2	2.373	2.438	-2.7
Ver 3	5.7981	4.26	26.5
Ver 4	6.8186	4.932	27.7

Figure 6.8 outlines the result of applying the RAFTS-XP model to the verification event 3, 4/4/95.

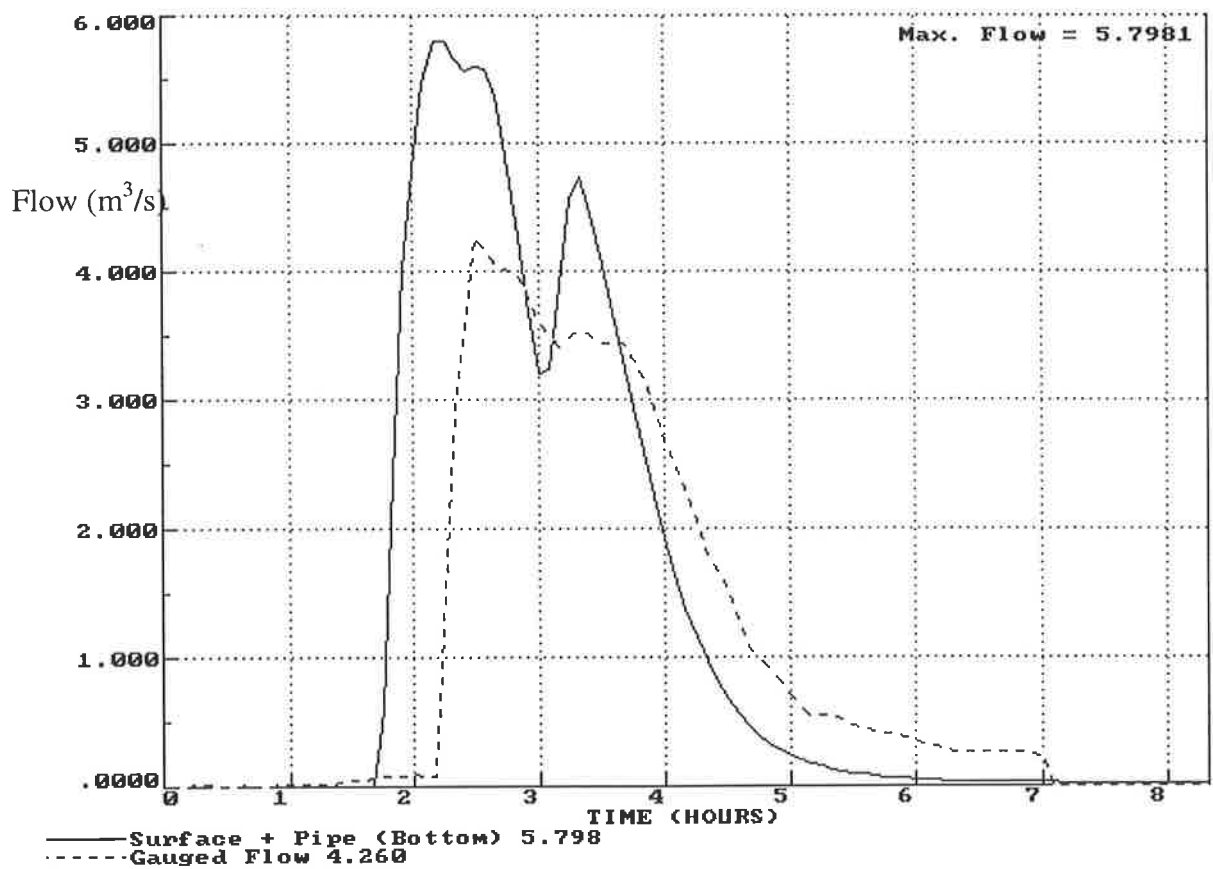


Figure 6.8 : RAFTS-XP model applied to calibration Verification Event 3, 4/4/95

6.7 New Years Eve Storm

After the RAFTS-XP model was calibrated and verified it was applied to a rainfall collected from a large storm event on New Years Eve 1995. This was the largest event that occurred within this research project. Unfortunately the gauged flow for this event was not recorded in the North Arm East drain as the logger buffer filled up just prior to the event. Rainfall data were collected from the pluviometers in the catchment, and so the RAFTS-XP model can be used to estimate the runoff that would have occurred.

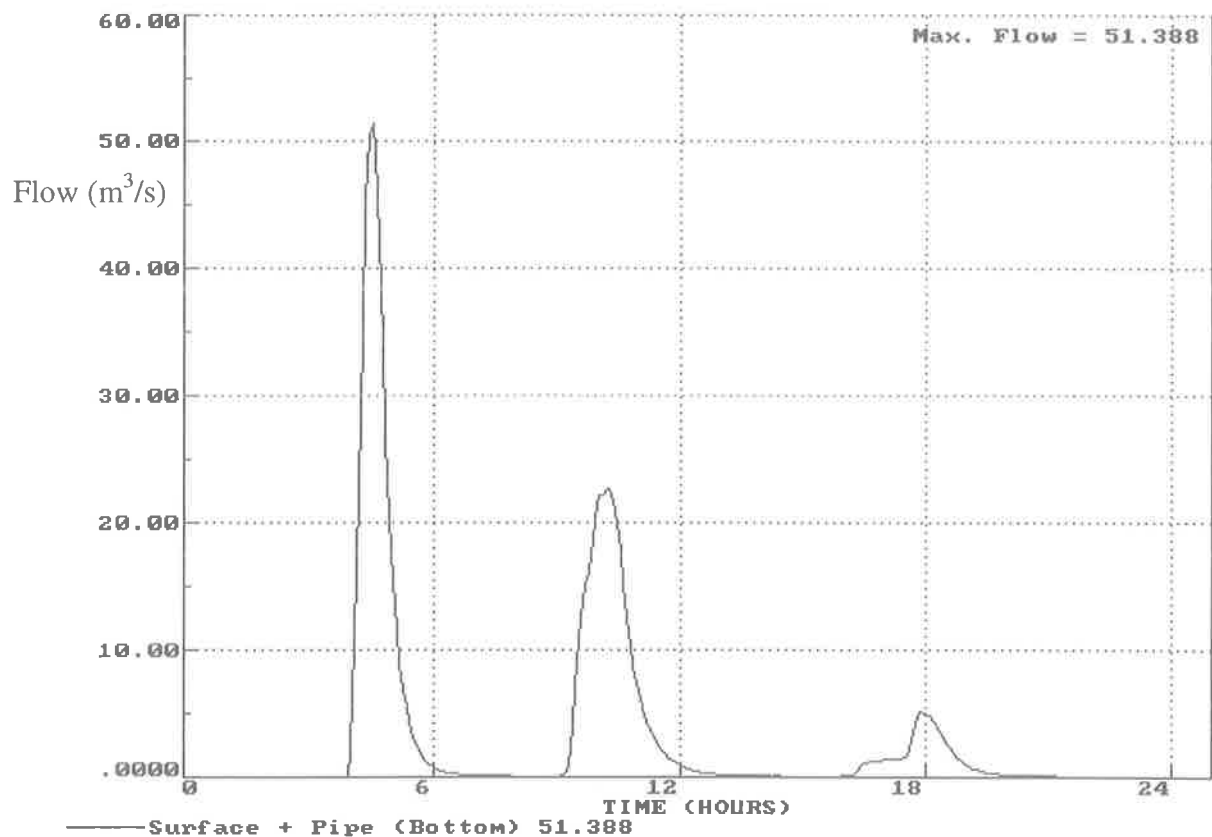


Figure 6.9 : Predicted runoff from the 1995 New Years Eve event

The rainfall distribution for the 1995 New Years Eve event is outlined in Appendix D, Figure D-11. The average rainfall for the event was 45mm, and a maximum gauging of around 50mm. The rainfall for the event was very intense with the majority occurring during a 45 minute period. The intensities recorded at the pluviometers were equivalent to between a 20 year and a 50 year average recurrence interval (ARI). The RAFTS-XP model predicted a peak flow of $51.4\text{m}^3/\text{s}$ as outlined in Figure 6.9. On a site visit to the North Arm East drain on New Years day 1996, debris marks were observed up to a stage height of approximately 1.3m. Substituting this stage height into the weir equation (Bos, 1979) produces an estimated flow of $30\text{m}^3/\text{s}$. However such a high flow would have drowned out the weir, and flow would have tended towards channel flow. Calculating the expected channel flow at a stage height of 1.3m by Manning's equation a peak flow of $46\text{m}^3/\text{s}$ was estimated. The RAFTS-XP peak flow prediction of $51.4\text{m}^3/\text{s}$ is within 10% of the predicted peak flow using Manning's equation.

6.8 Investigation Into the Backwater Effect

Applying the calibrated and verified RAFTS-XP model to events occurring after the installation of trash racks gives an indication of the effect that the trash racks have on the stormwater runoff. The model was applied to four events occurring after January 1996, with the results outlined in Figures 6.10 to 6.13.

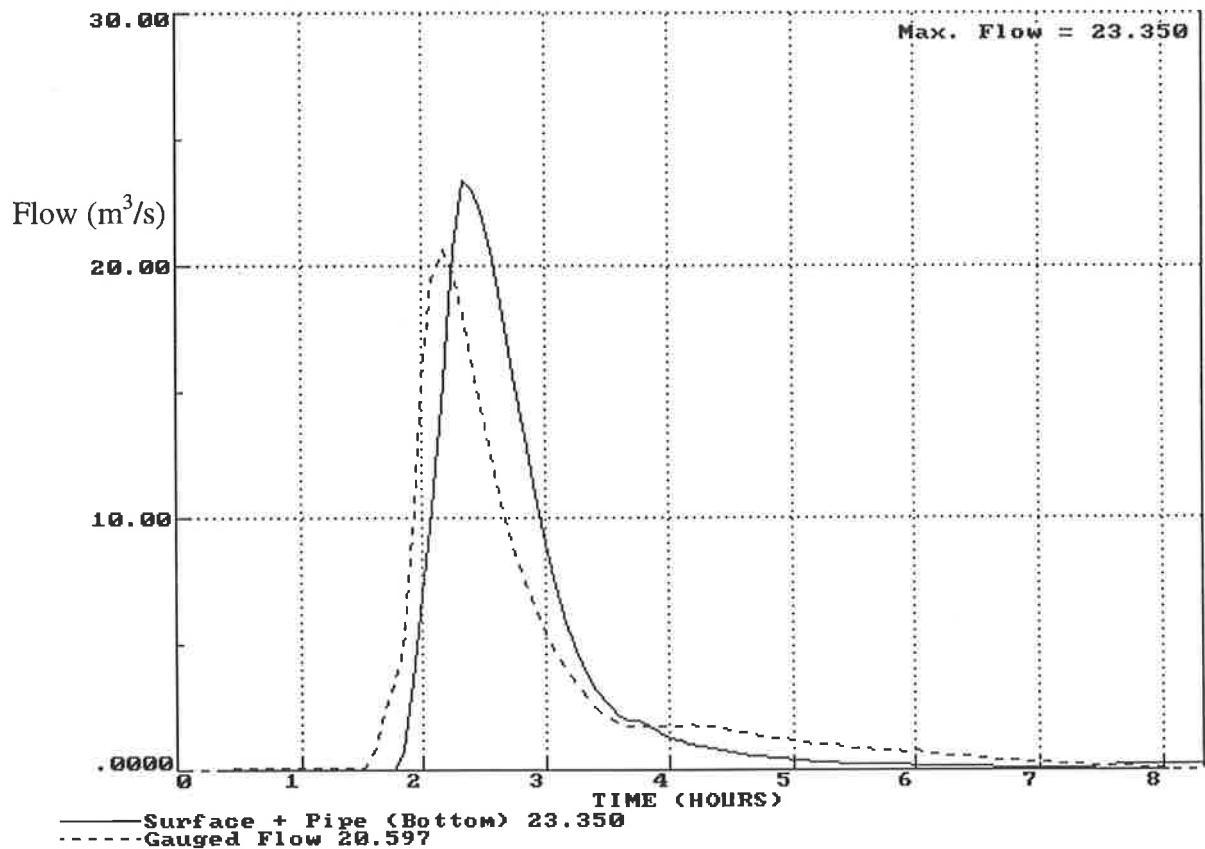


Figure 6.10 : Backwatered event 1, 13/4/96

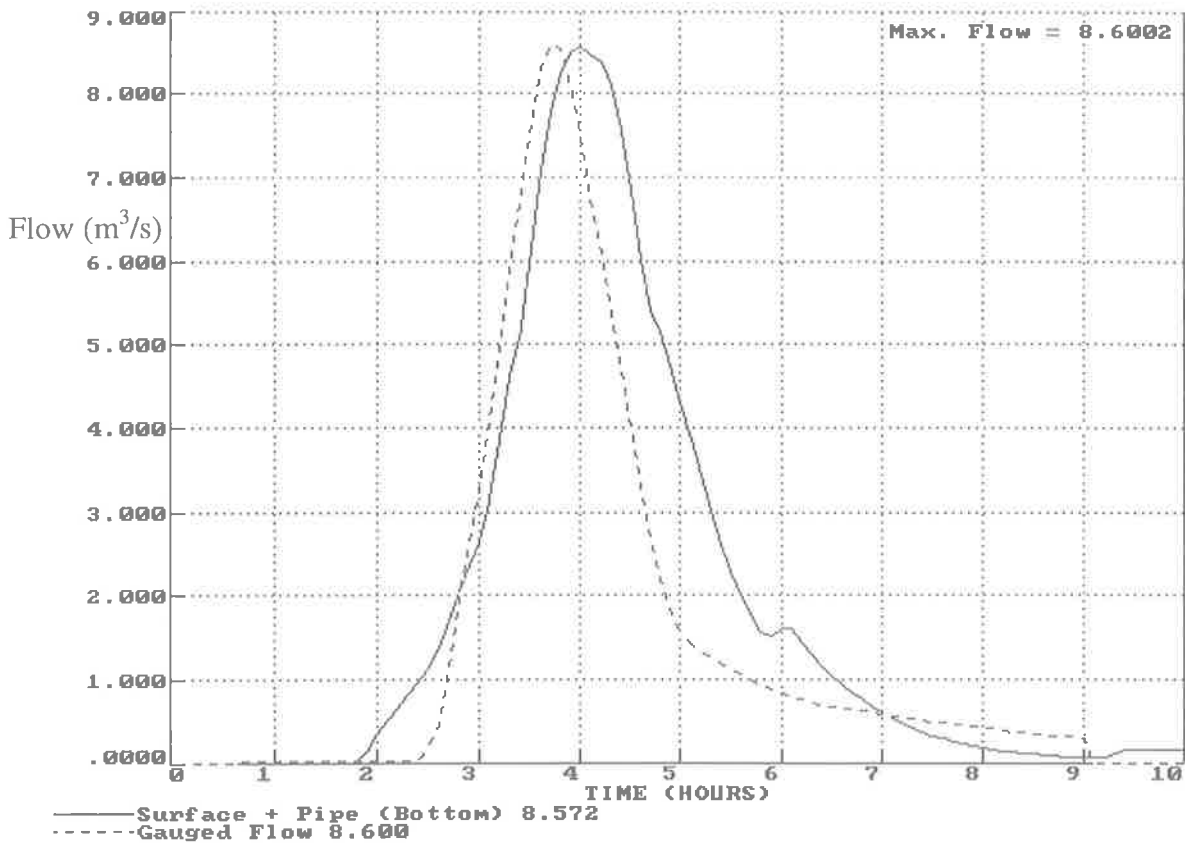


Figure 6.11 : Backwatered event 2, 31/7/96

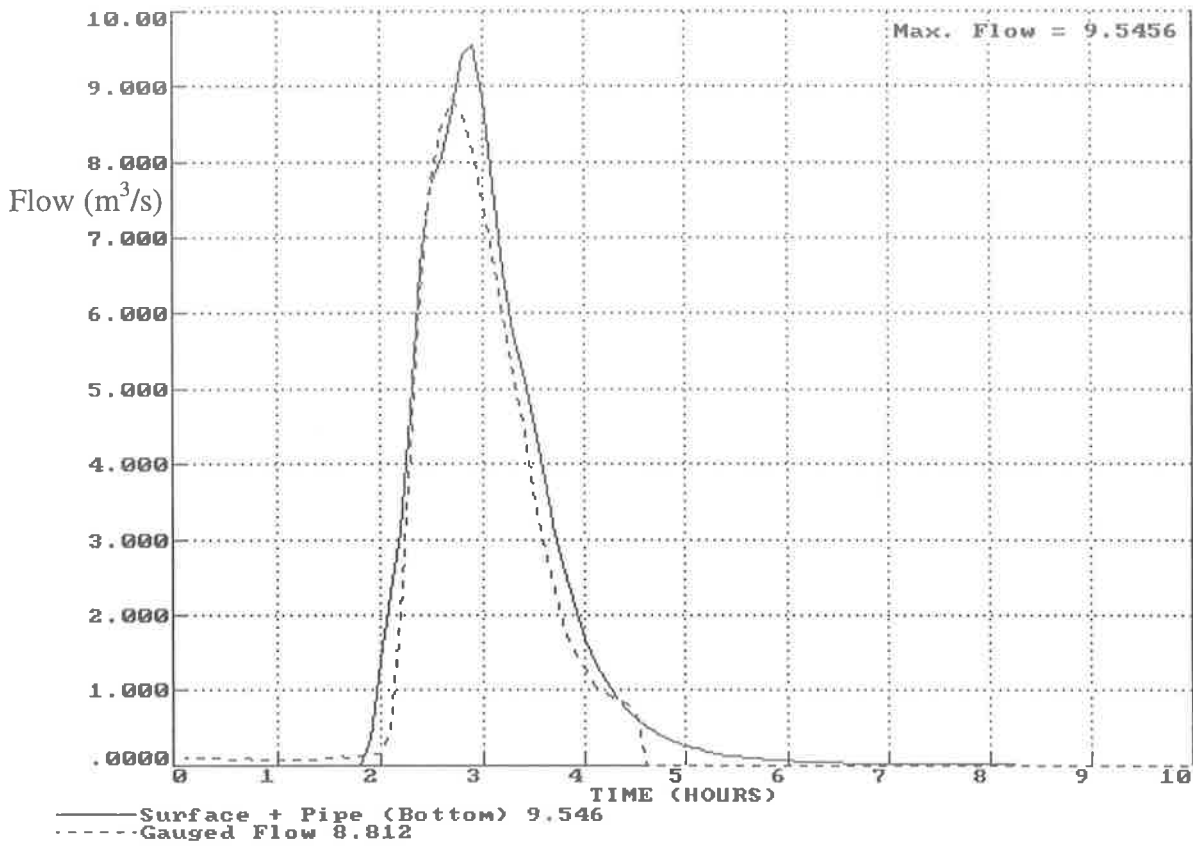


Figure 6.12 : Backwatered event 3, 6/12/96

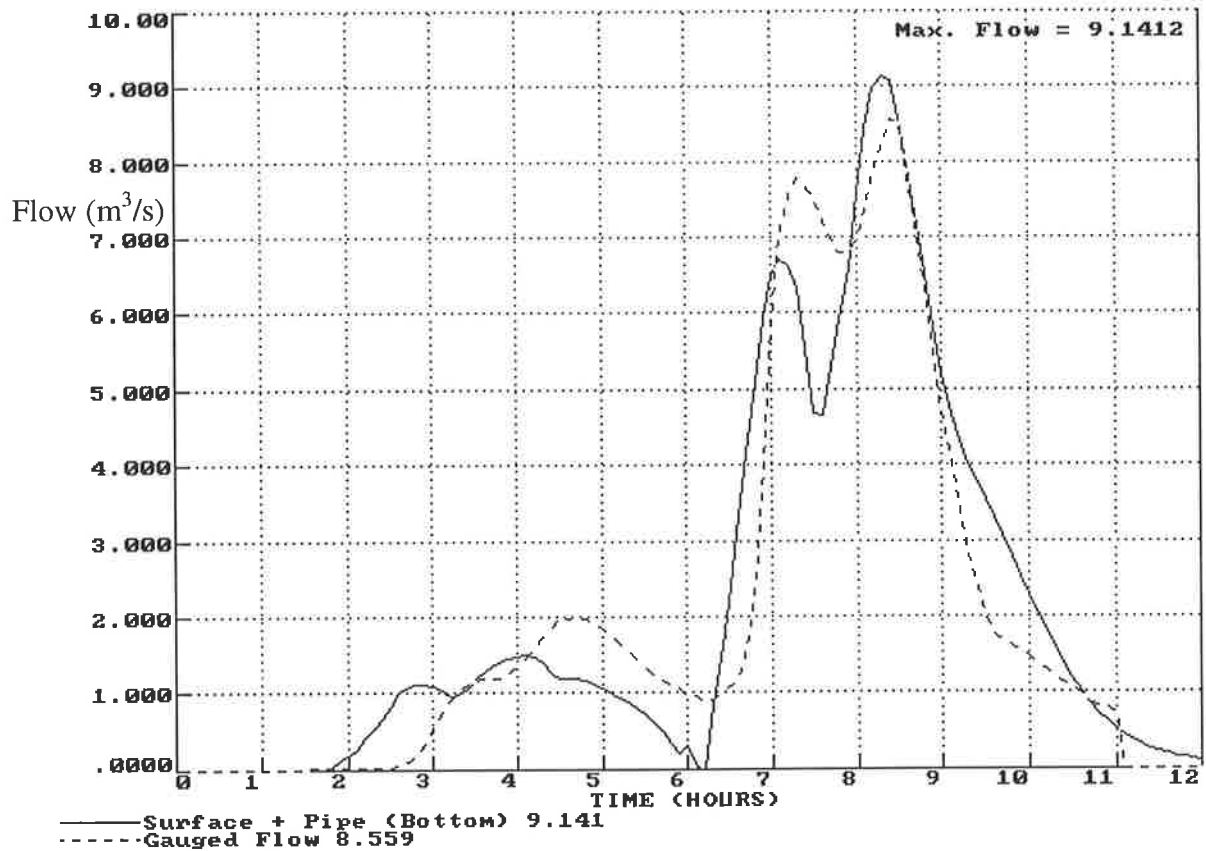


Figure 6.13 : Backwatered event 4, 4/7/96

The gauged flows that are outlined in Figures 6.10 to 6.13 were determined by a three pronged rating curve procedure as outlined in Sections 5.8 and 5.9. The RAFTS-XP model correlates very well with the gauged flow, which indicates that the three pronged rating curve procedure is a reasonable compromise solution to the backwatering problem.

Chapter 7

Water Quality Results

7.1 Introduction

This chapter presents the results of the stormwater monitoring program on inflows to the Barker Inlet and Magazine Creek wetlands. The results presented in this chapter form phase one of the monitoring program and include inflow data from five catchments collected during the period April 1994 to June 1997. The data presented in this chapter include rainfall and runoff data, sequential sample results, composite sample results and continuous real-time monitoring data.

7.2 Rainfall and Runoff Characteristics

Adelaide is the driest capital city in Australia and is located in the driest state or territory in Australia, South Australia. The climate in Adelaide is typically hot and dry in the summer months with occasional thunderstorms, yielding the majority of rainfall in winter during the months of June, July and August. Historically the average yearly rainfall for the Barker Inlet Wetland Catchment area ranges from approximately 440mm on the western boundary to 500mm on the eastern boundary, with the overall catchment average of approximately 470mm per year. The increase in yearly rainfall from west to east is due to the Adelaide foothills in the east producing more rainfall than the flatter plains in the west.

The pluviometers that measure the rainfall in the Barker Inlet Wetland Catchment were described earlier in Table 4.1 and by Figure 4.1. The rainfall data outlined in Appendix D contains data for the period April 1994 - June 1997. The yearly rainfall recordings during the monitoring program are outlined in Table 7.1.

TABLE 7.1 : Rainfall during monitoring program

Year of record	Recorded Rainfall (mm)
1994 (1 May - December 31)	280
1995	400
1996	490
1997 (1 January - 1 July)	180

The rainfall recorded in 1995 was below average with approximately 400mm falling on the catchment. 1996 improved with an above average recording of 490mm which yielded the majority of water quality data for this report. During 1997 the rainfall was below average up until July with a recording of approximately 180mm up until the 1st of July.

TABLE 7.2 : Average rainfall to runoff time lag in each Catchment

Catchment	Station No	Lag time (minutes)
North Arm East	AU504101	40
Hindmarsh Enfield Prospect	AU504102	720
Dunstan Road	AU504103	30
North Arm West	AU504104	120
Eastern Parade	AU504201	30

The catchments have varying runoff response times to the onset of rain due to the differences in pipe network systems and channel types. The lag times for the catchments are outlined in Table 7.2. The North Arm East (AU504101), Dunstan Road (AU504103) and Eastern Parade (AU504201) Catchments have rapid rainfall runoff responses in the order of 30 to 40 minutes whereas the Hindmarsh Enfield Prospect (AU504102) Catchment is slow, with a typical lag of twelve hours. The slow response of the Hindmarsh Enfield Prospect (AU504102) Catchment is due to the long grass swale drain, however this will be variable depending on the magnitude of the event.

The quantity of runoff from the catchments varies depending on the rainfall distribution, catchment area, impervious/pervious proportions and antecedent catchment conditions of each event. The range of event runoff volumes for each of the four Barker Inlet wetland Catchments is outlined in Figure 7.1.

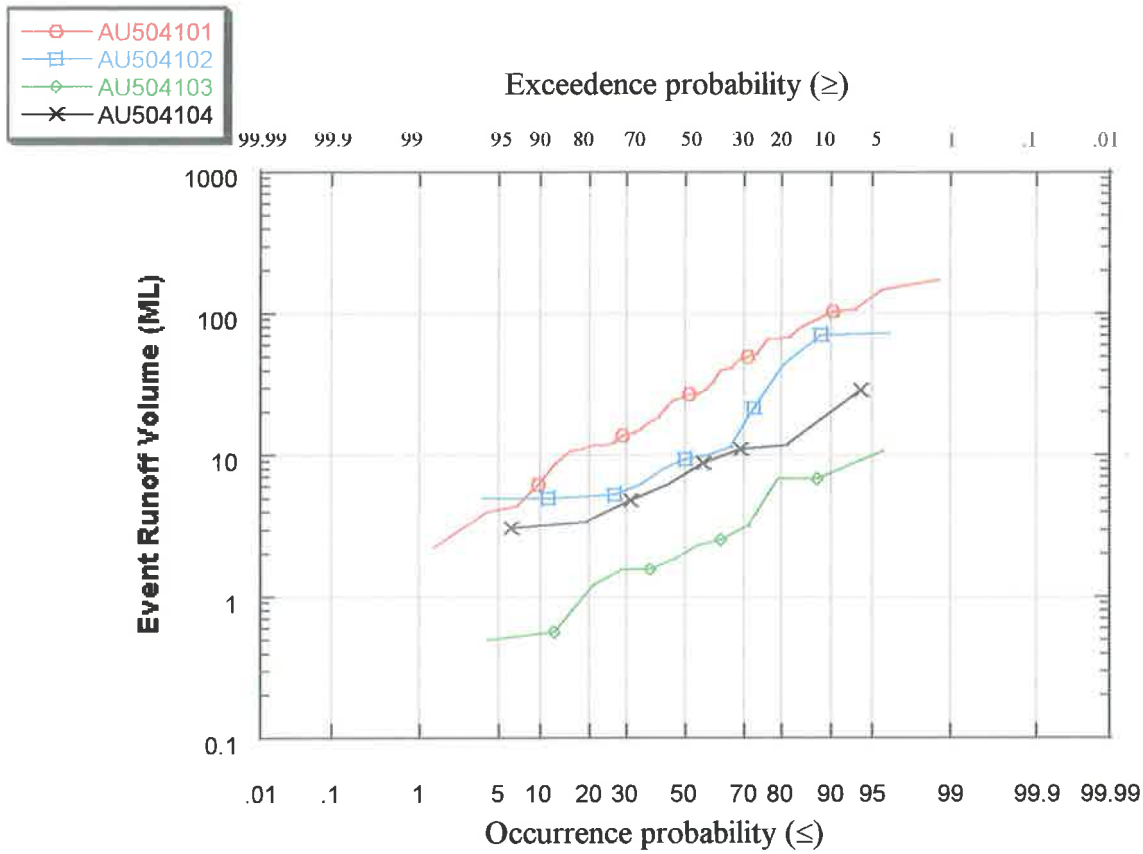


Figure 7.1 : Event runoff volume (ML) probability curves

Event runoff volumes ranged from approximately 0.5 to 118 megalitres which indicates the diverse nature of stormwater runoff quantity from the catchments that enters the wetlands. Figure 7.2 indicates the event runoff volumes recorded in the North Arm East (AU504101) Catchment for the period of record. Using the ARR estimated rainfall average recurrence intervals and a runoff coefficient of 0.26 (determined in Chapter 6) the theoretical one hour duration runoff volumes for the North Arm East (AU504101) Catchment are compared.

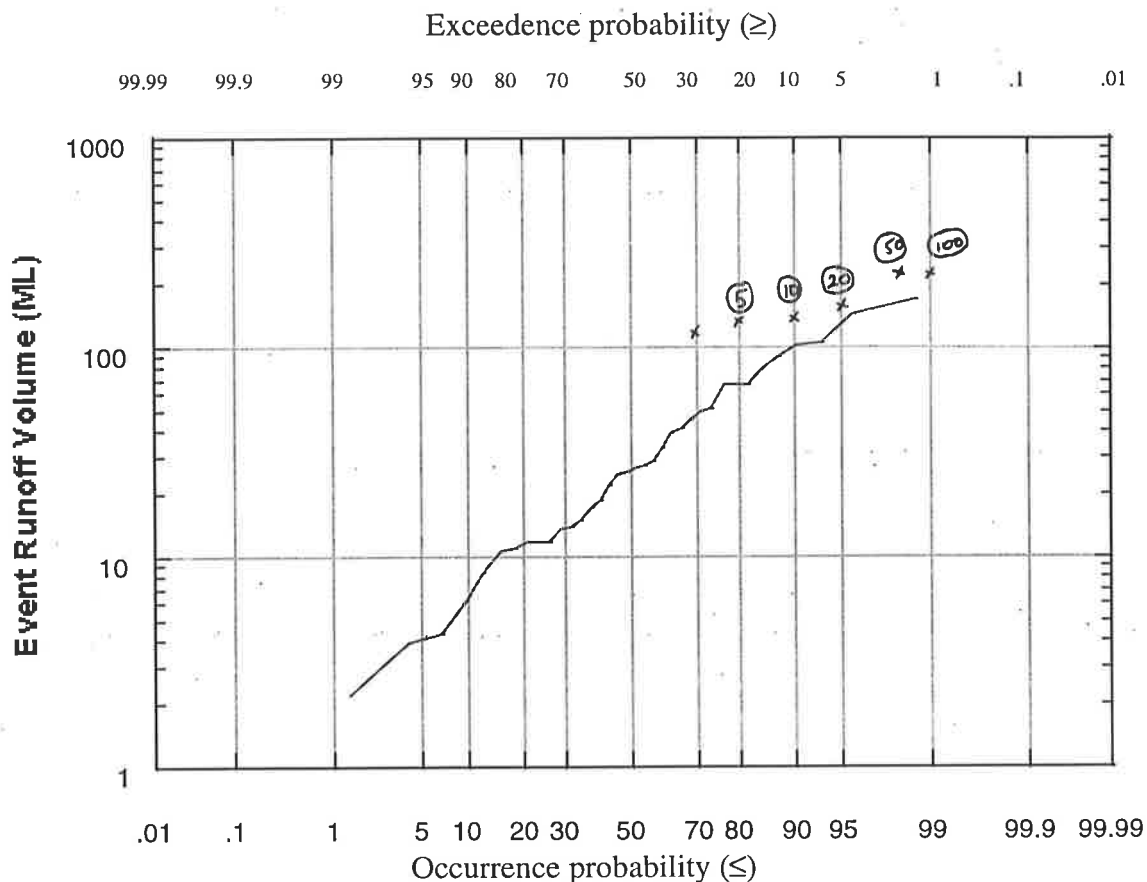


Figure 7.2 : Probability curve for event runoff volumes from the North Arm East (AU504101) Catchment (ML)

Notes on Figure 7.2 :

The design event runoff volumes for the North Arm East (AU504101) Catchment were calculated using a runoff coefficient of 0.26. (This was determined in Chapter 6).

The points plotted all have a duration of 1 hour.

The points represent Average Recurrence Intervals (ARI). ie 5 represents a 5 year ARI with a 1 hour duration.

7.3 Sequential Samples

Sequential samples were automatically collected during storm events to give an indication of the stormwater quality and how it changes during each event. Sequential samples provide water quality information at a single point in time during an event and when combined can give an indication of the runoff contamination processes.

7.3.1 Sequential Sample Results

Sequential samples were automatically collected during each event and promptly tested for total phosphorus, total suspended solids and turbidity concentrations. The results for each catchment are summarised in Tables 7.3 to 7.7.

TABLE 7.3 : Sequential sample results from North Arm East Catchment (AU504101)

	Number of samples	Minimum	Maximum	Mean	Median
Total suspended solids (mg/L)	297	1	1359	159	97
Turbidity (NTU)	297	8	1372	148	114
Total phosphorus (mg/L)	297	0.03	3.60	0.32	0.32

TABLE 7.4 : Sequential sample results from Hindmarsh Enfield Prospect Catchment (AU504102)

	Number of samples	Minimum	Maximum	Mean	Median
Total suspended solids (mg/L)	86	3	459	44	13
Turbidity (NTU)	86	8	390	38	22
Total phosphorus (mg/L)	86	0.01	1.38	0.33	0.34

TABLE 7.5 : Sequential sample results from Dunstan Road Catchment (AU504103)

	Number of samples	Minimum	Maximum	Mean	Median
Total suspended solids (mg/L)	47	86	2246	472	249
Turbidity (NTU)	47	110	1898	410	233
Total phosphorus (mg/L)	47	0.18	3.12	0.92	0.75

TABLE 7.6 : Sequential sample results from North Arm West Catchment (AU504104)

	Number of samples	Minimum	Maximum	Mean	Median
Total suspended solids (mg/L)	48	22	1137	256	127
Turbidity (NTU)	37	33	334	148	123
Total phosphorus (mg/L)	37	0.04	0.73	0.35	0.40

TABLE 7.7 : Sequential sample results from Eastern Parade Catchment (AU504201)

	Number of samples	Minimum	Maximum	Mean	Median
Total suspended solids (mg/L)	19	20.6	15853	1535	375
Turbidity (NTU)	11	63.4	3030	879	516
Total phosphorus (mg/L)	11	0.55	5.40	3.36	3.08

7.3.1.1 Total Suspended Solids

The two residential catchments North Arm East (AU504101) and North Arm West (AU504104) recorded similar concentrations of total suspended solids with median values of 97mg/L and 127mg/L respectively. The other residential catchment of Hindmarsh Enfield Prospect (AU504102) recorded low concentrations of suspended solids relative to the other three catchments with a mean of only 13mg/L. The low concentration of total suspended solids in the Hindmarsh Enfield Prospect (AU504102) Catchment is likely due to sedimentation occurring in the large grass swale upstream of the monitoring station.

The industrial catchment of Dunstan Road (AU504103) recorded significantly higher total suspended solid concentrations than the other three Barker Inlet wetland Catchments with a mean of 249mg/L. The other industrial catchment, Eastern Parade (AU504201) recorded a very high median suspended solids concentration of 375mg/L.

7.3.1.2 Turbidity

The turbidity concentration results correlate closely to the total suspended solid results. The North Arm East (AU504101) and North Arm West (AU504104) Catchments recorded median concentrations of 114NTU and 123NTU respectively. Similar to the total suspended solids result the North Arm West turbidity concentration is slightly higher than the North Arm East concentration. The Hindmarsh Enfield Prospect (AU504102) Catchment recorded a median of only 22NTU whereas the industrial catchment of Dunstan Road (AU504103) recorded

233NTU, significantly higher than the other catchments. The industrial catchment of Eastern Parade recorded an extremely high median turbidity level of 516mg/L, however this must be observed with caution from such a small data set.

7.3.1.3 Total Phosphorus

The three residential catchments of North Arm East (AU504101), Hindmarsh Enfield Prospect (AU504102) and North Arm West (AU504104) recorded similar median total phosphorus concentrations of 0.32, 0.34 and 0.40mg/L respectively. Unlike the total suspended solids and turbidity results the concentration of total phosphorus in the Hindmarsh Enfield Prospect (AU504102) does not conform to the other catchment results. This could be due to the breakdown of total phosphorus between its dissolved and particulate forms. The grass swale is unlikely to have much of an effect on the dissolved phosphorus fraction whereas the particulate phosphorus fraction would be affected during sedimentation. The breakdown of phosphorus forms was not investigated for sequential samples however the event mean concentrations later in this chapter will outline the proportions of different forms of phosphorus.

The industrial catchment of Dunstan Road (AU504103) recorded a high median concentration of 0.75mg/L and Eastern Parade recorded a high median total phosphorus concentration of 3.08mg/L which is approximately 8 times that of the residential catchments.

7.3.2 Probability Curves

Water quality data presented in tabular form does not give a true picture of the whole data set, as you only get an indication of the range between minimum and maximum values, and a mean and/or median value for the data set. The contaminant probability curves presented in this section and later sections give a better indication of the whole data set as well as providing valuable probability statistics.

The probability curves are derived from the whole data set. The y-axis outlines the contaminant concentration. The x_1 -axis outlines the 'occurrence probability', which is the probability of a contaminant concentration occurring (equal to or less than the contaminant concentration outlined on the y-axis). The x_2 -axis outlines the 'exceedence probability', which

is the probability of a contaminant concentration not occurring (greater than the contaminant concentration outlined on the y-axis). Figure 7.3 outlines the sequential sample probability curve for total suspended solid concentrations.

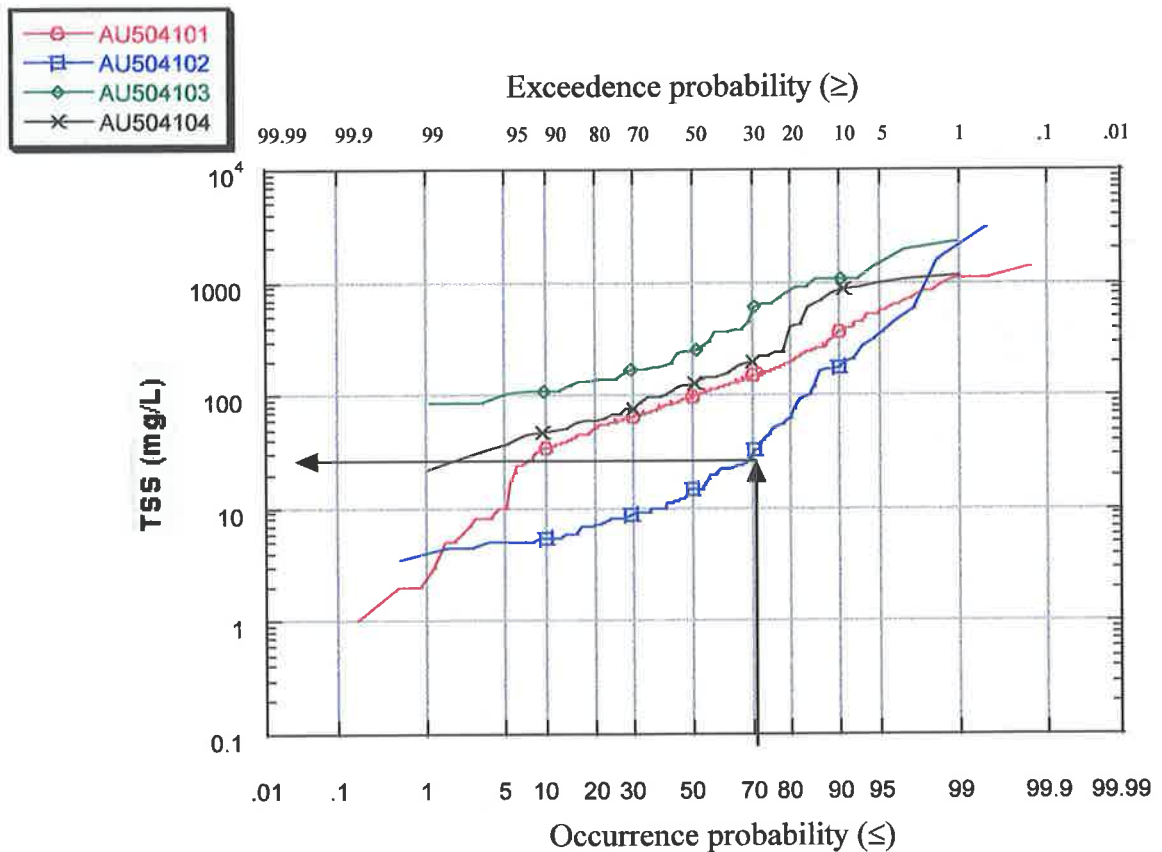


Figure 7.3 : Sequential sample total suspended solids (mg/L) probability curves

An example of how to use the probability curves is outlined in Figure 7.3. You can enter the graph from any of the three axis depending on the information that you are trying to determine. In this example the graph is entered from the x_1 -axis at a 70% occurrence probability. Move in a vertical direction from the x_1 -axis until you intersect the catchment that you are interested in. The Hindmarsh Enfield Prospect Drain (AU504102) is used in this example. Once the catchment line has been intersected the contaminant concentration can be read off of the y-axis. In this example there is a 70% probability of a total suspended solids concentration equal to or less than 23mg/L occurring in a sequential sample during an event. Conversely this means that there is a 30% probability that a total suspended solids concentration of 23mg/L will be exceeded in any sequential sample during an event in the Hindmarsh Enfield Prospect (AU504102) Catchment.

The differences of the sequential sample concentrations between the four catchments are more clearly illustrated by the probability curves. It is evident in Figure 7.3 that the suspended solid concentrations are greatest in the industrial Dunstan Road (AU504103) Catchment. The concentrations in the North Arm West (AU504104) and North Arm East (AU504101) Catchments are similar although the North Arm West has slightly higher concentrations over the broad band of concentrations. The North Arm East Catchment however, recorded a slightly higher maximum concentration of 1359mg/L. The concentrations in the Hindmarsh Enfield Prospect (AU504102) Catchment are significantly lower than the other three catchments.

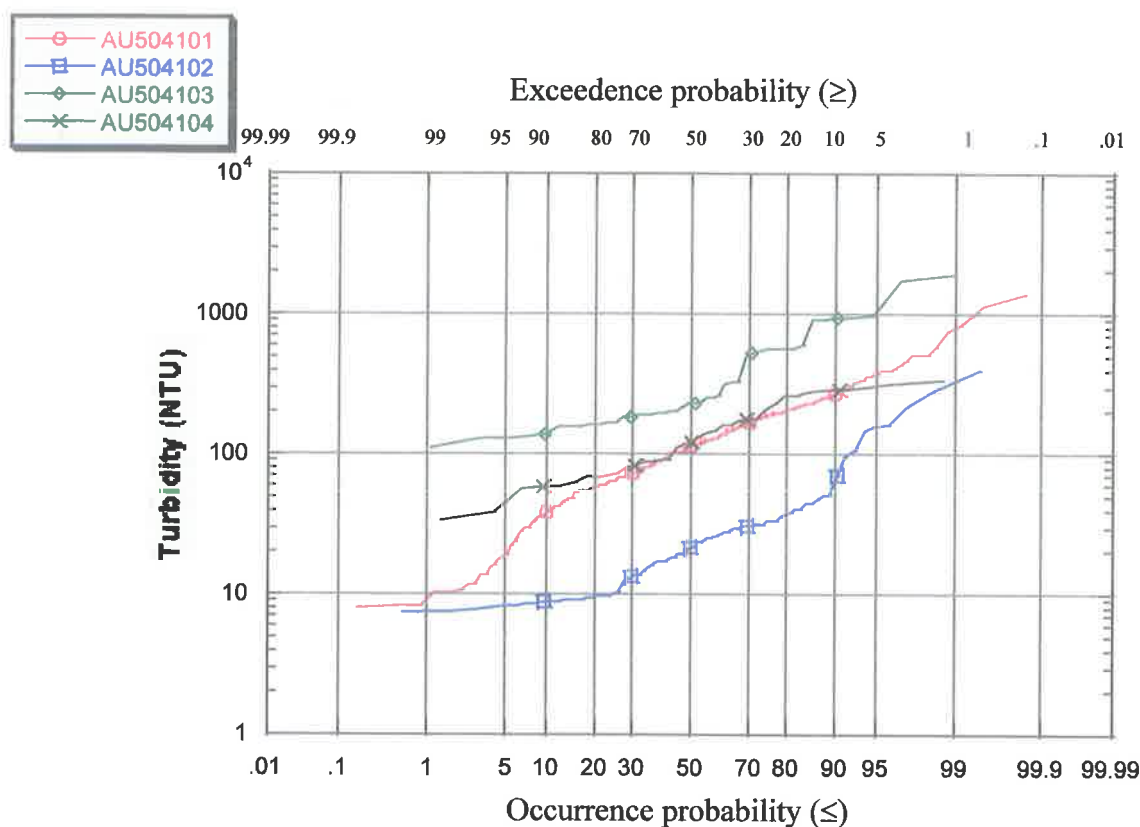


Figure 7.4 : Sequential sample turbidity (NTU) probability curves

The turbidity results outlined in Figure 7.4 show the same trends as the total suspended solid results. The highest turbidity recordings are from the industrial Dunstan Road (AU504103) Catchment, the lowest from the Hindmarsh Enfield Prospect (AU504102) Catchment and the two residential catchments of North Arm East (AU504101) and North Arm West (AU504104) recording similar turbidity levels.

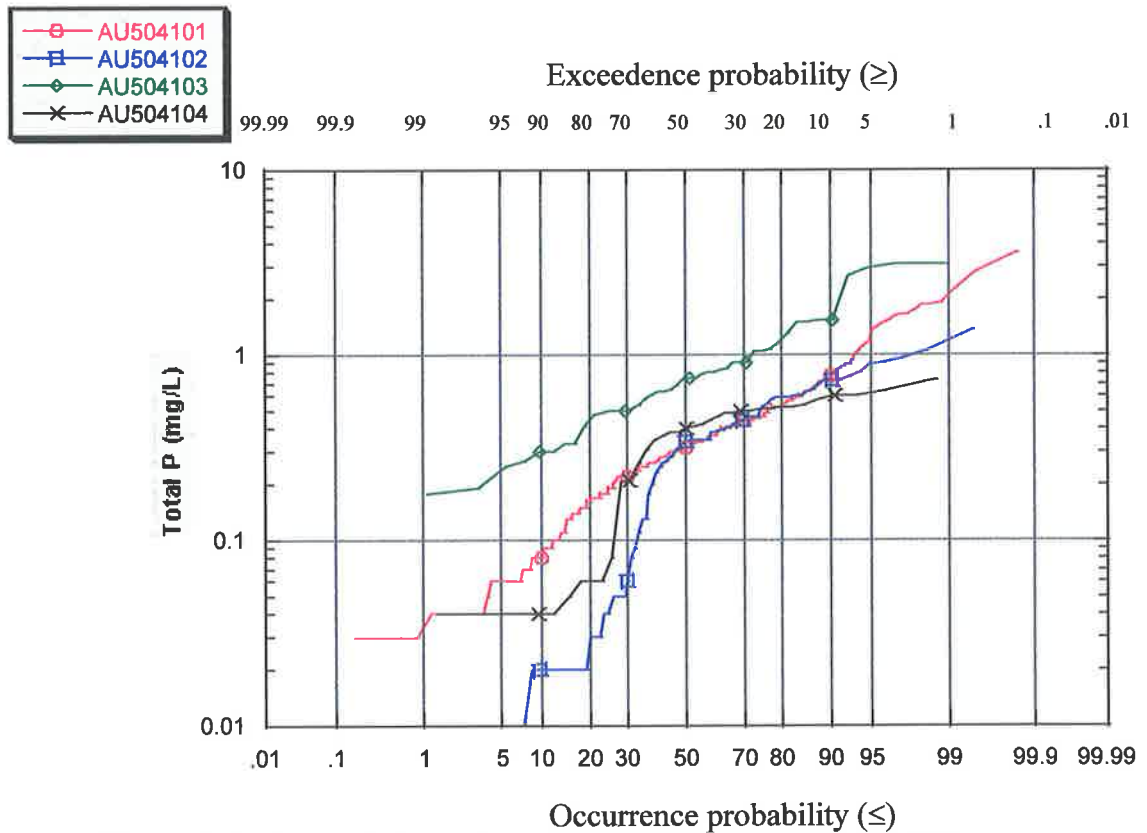


Figure 7.5 : Sequential sample total phosphorus (mg/L) probability curves

The total phosphorus probability curves in Figure 7.5 indicates what Tables 7.3 to 7.7 already outlined. The total phosphorus levels in the Dunstan Road (AU504103) Catchment are significantly greater than the other three catchments. Similar levels of total phosphorus were recorded in the North Arm East (AU504101), Hindmarsh Enfield Prospect (AU504102) and North Arm West (AU504104) Catchments.

7.3.3 Sequential Sample Parameter Correlations

There are some inter relationships of contaminants in urban stormwater. Correlations are often the result of contaminants occurring from the same source in a catchment or that the contaminants are transported by the same means such as adsorbed to particulate matter. Correlations between contaminants are important for a number of reasons. Contaminant relationships can provide a clearer picture of the sources of pollution in a catchment, and they can also be used to extend or improve data sets. The usefulness of correlations is mostly dependent on the reliability and accuracy of a relationship between two parameters. The correlation must also be determined from a large enough data set before it can be relied on for future predictions between parameters.

Include this in my discussion

the correlation must be based

If the correlation between two parameters is reliable and accurate it can be used to reduce the number of monitored parameters to save time and costs. The following sections outline the relationships between the sequential sample parameters of turbidity, total suspended solids and total phosphorus.

7.3.3.1 Turbidity Vs Total Suspended Solids

This section investigates the relationship between turbidity and total suspended solids. The correlations between total suspended solids and turbidity over the whole sequential sample data set for the four Barker Inlet Wetland Catchments are outlined in Figures 7.6 to 7.9. The correlations in the Eastern Parade Catchment were not investigated due to such a small number of samples in the data set.

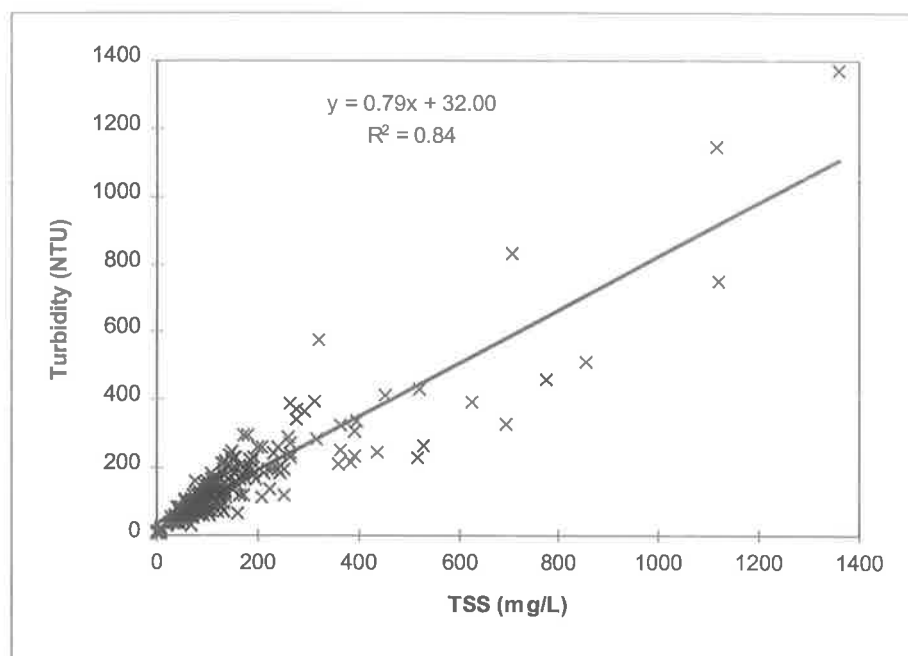


Figure 7.6 : Correlation between total suspended solids and turbidity for all sequential sample data from the North Arm East Catchment (AU504101)

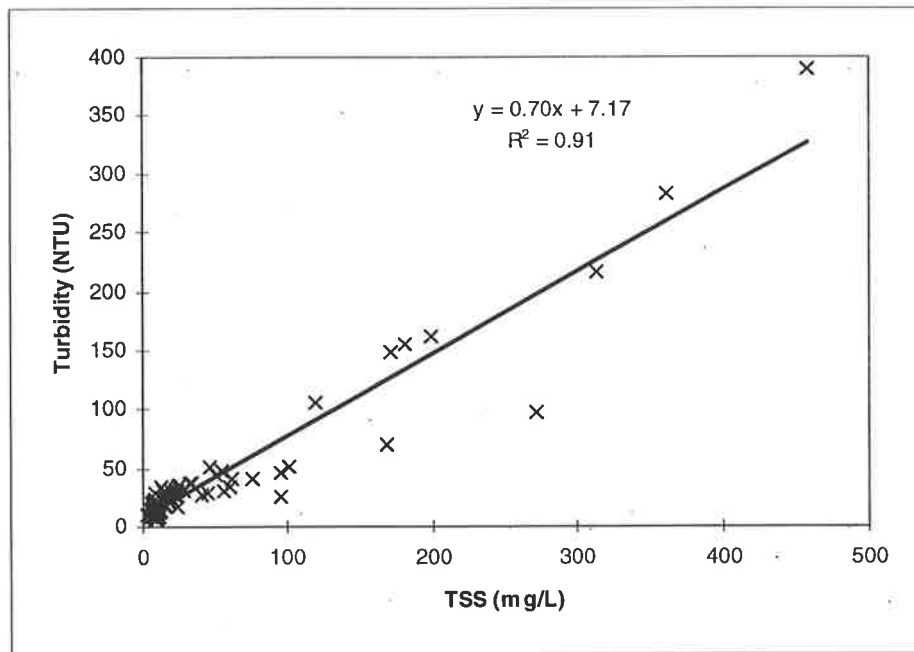


Figure 7.7 : Correlation between total suspended solids and turbidity for all sequential sample data from the Hindmarsh Enfield Prospect Catchment (AU504102)

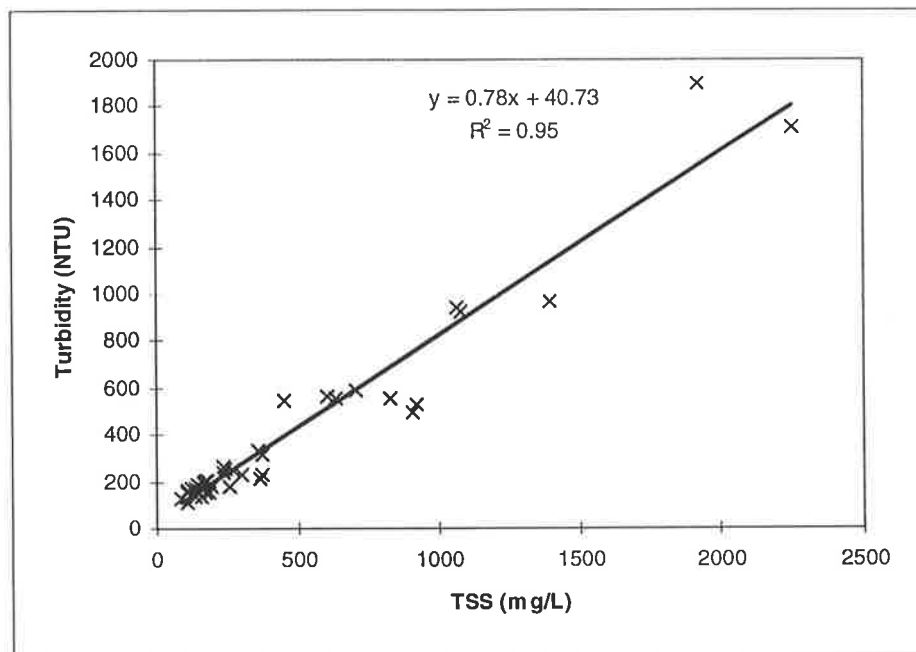


Figure 7.8 : Correlation between total suspended solids and turbidity for all sequential sample data from the Dunstan Road Catchment(AU504103)

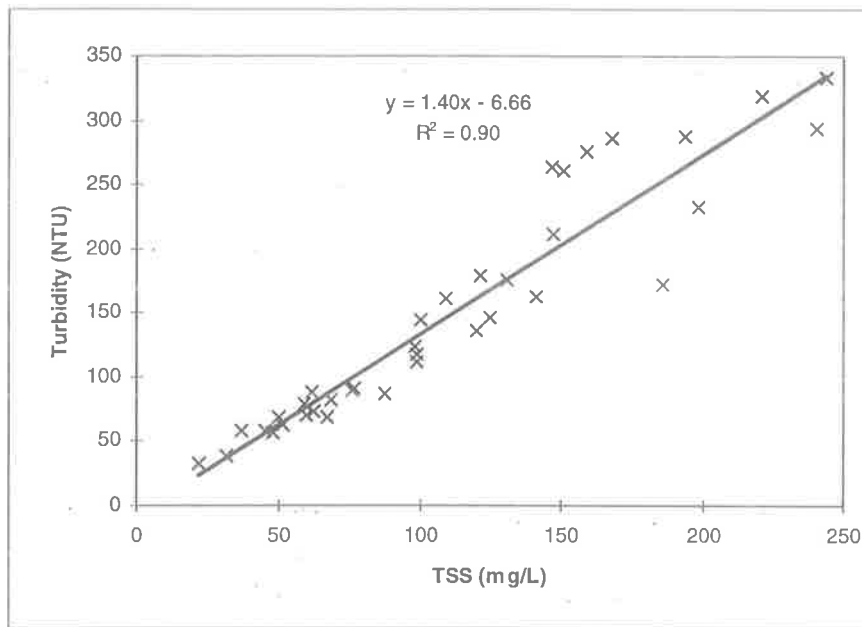


Figure 7.9 : Correlation between total suspended solids and turbidity for all sequential sample data from the North Arm West Catchment (AU504104)

The correlations found between total suspended solids and turbidity are significant with r^2 values in the North Arm East (AU504101), Hindmarsh Enfield Prospect (AU504102), Dunstan Road (AU504103) and North Arm West (AU504104) Catchments of 0.84, 0.91, 0.95 and 0.90 respectively. The relationships are summarised in Table 7.8 below along with a comparison to the findings of Gipple (1995) on two different catchments Eden and Latrobe. The Eden Catchment is a small forested catchment 0.8km^2 in area near Eden, New South Wales, Australia (Gipple, 1989a; 1989b). The Latrobe River Catchment is in Victoria, Australia.

TABLE 7.8 : Relationships between turbidity and total suspended solids

Catchment	Equation	r^2 value
North Arm East (AU504101)	turbidity = $(0.79) \times \text{TSS} + 32.0$	0.84
Hindmarsh Enfield Prospect (AU504102)	turbidity = $(0.70) \times \text{TSS} + 7.17$	0.91
Dunstan Road (AU504103)	turbidity = $(0.78) \times \text{TSS} + 40.73$	0.95
North Arm West (AU504104)	turbidity = $(1.40) \times \text{TSS} - 6.66$	0.90
Eden (Gipple, 1995)	turbidity = $(0.84) \times \text{TSS} + 4.62$	0.80
Latrobe (Gipple, 1995)	turbidity = $(0.85) \times \text{TSS} - 1.97$	0.88

Notes on Table 7.2:

The unit of turbidity for drains AU504101, AU504102, AU504103 and AU504104 is NTU.

The unit of turbidity for Eden and Latrobe (Gipple, 1995) is FAU.

Gipple (1995) stated that an r^2 variance of at least 80% is desirable for a predictive model between turbidity and total suspended solids, which has been well exceeded by four relationships found in this study.

Gipple (1995;1993) outlines the difficulties of turbidity measurement both in the laboratory and in the field and states that “the relationship between turbidity and suspended solids concentrations is potentially confounded by variations in particle size, particle composition and water colour.”

The positive intercept value in the equations outlined in Table 7.8 is due to turbidity caused by dissolved substances (Gipple, 1995). For instance the positive intercept of 7.17 found for the Hindmarsh Enfield Prospect (AU504102) Catchment is due to a turbidity caused by colloids and dissolved matter that are not recorded in the total suspended solids concentration as they pass through the standard $0.47\mu\text{m}$ glass filter. The negative intercept of -6.66 and -1.97 in the North Arm West (AU504104) and Latrobe Catchments respectively has no meaning (Gipple, 1995).

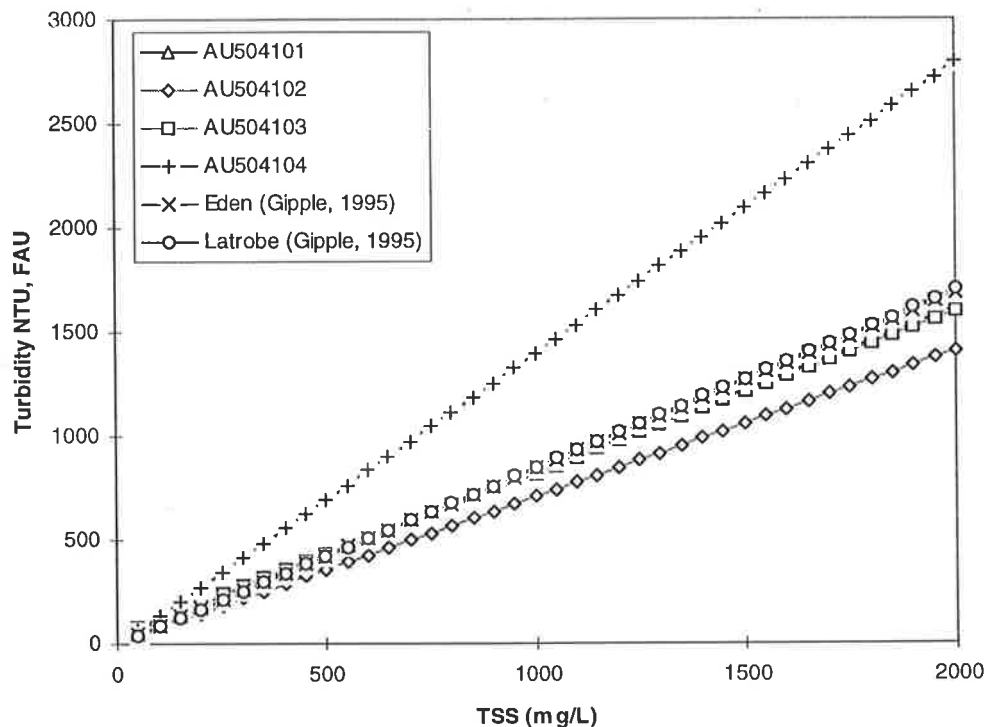


Figure 7.10 : Comparison of correlations between TSS and turbidity

Figure 7.10 gives an indication of the differences between the turbidity-total suspended solids relationships determined in the four catchments of this study compared to those of Gippel (1995). The relationships found by Gippel (1995) for Eden and Latrobe are very similar to the North Arm East (AU504101) and Dunstan Road (AU504103) relationships. The Hindmarsh Enfield Prospect (AU504102) is not all that different whereas the North Arm West (AU504104) relationship is an outlier. There is no reason why the relationships derived in this study should match the findings of Gippel (1995) due to the differences between urban and rural catchments and the differences in particle size distribution between catchments, such as fine sizes versus coarse.

7.3.3(1.1) Turbidity Vs Total Phosphorus

The relationships between turbidity and total phosphorus were found to be insignificant. The best correlation was found in the North Arm West (AU504104) Catchment with an r^2 value of 0.57 as outlined in Figure 7.11. A summary of the relationships found in the four Barker Inlet wetland Catchments is outlined in Table 7.9.

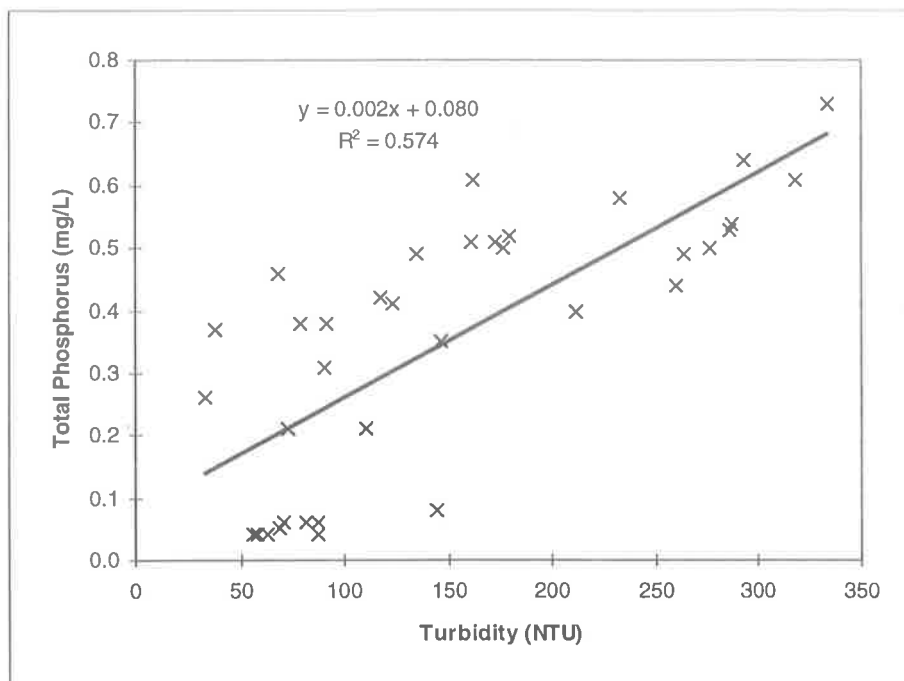


Figure 7.11 : Correlation between turbidity and total phosphorus for all sequential sample data from the North Arm West Catchment (AU504104)

TABLE 7.9 : Summary table of relationships between turbidity and total phosphorus

Catchment	Equation	r ² value
North Arm East (AU504101)	Tot. P = (0.04) × turbidity ^(0.44)	0.29
Hindmarsh Enfield Prospect (AU504102)	Tot. P = (0.047) × turbidity ^(0.401)	0.06
Dunstan Road (AU504103)	Tot. P = (0.021) × turbidity ^(0.623)	0.45
North Arm West (AU504104)	Tot. P = (0.002) × turbidity + 0.08	0.57

Techniques other than a linear relationship were investigated such as power, exponential, and quadratic relationships. A power relationship increased the correlation in three of the catchments marginally over a linear relationship. The introduction of a third degree was investigated such as introducing flow to try and improve the relationship however this was unsuccessful. Dividing the samples or whole events into categories defined by parameters such as rising/falling limb of hydrograph or wet/dry catchment conditions was also unsuccessful.

Some events had a strong correlation between turbidity and total phosphorus such as those outlined in Table 7.10.

TABLE 7.10 : Individual events with good correlations between turbidity and total phosphorus in the North Arm East (AU504101) Catchment

Event Date	r ²
22/6/96	0.97
5-6/7/96	0.97
28-29/7/96	0.96
23/6/96	0.88
28/6/96	0.84
19/7/96	0.80

Figure 7.12 is an example of a significant correlation between turbidity and total phosphorus. It is important to understand the reason why some events such as those in Table 7.10 have significant correlations and why some events have insignificant correlations. An investigation into all the individual event correlations outlined in Appendix G was undertaken to try to identify the reason behind this but none was found. A comparison was made between the

events with good correlations and those with poor correlations for event flow volumes, average event rainfall depths, rainfall intensities, time between events for build up, range of turbidity levels, range of total phosphorus levels and position of samples in events (ie rising or falling limb), however to no avail.

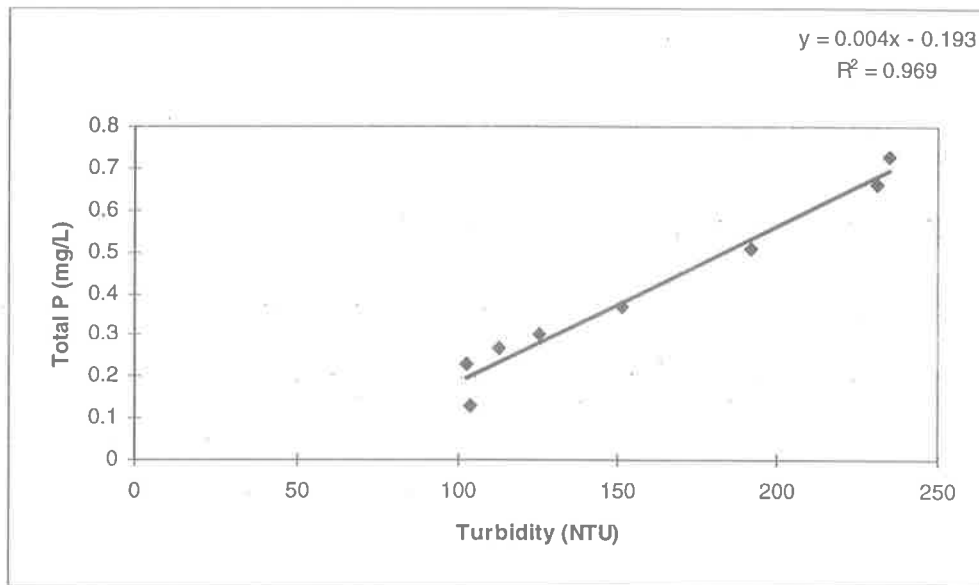


Figure 7.12 : Correlation between turbidity and total phosphorus for sequential samples during event 5-6/7/96 in the North Arm East Drain (AU504101)

The author feels that the correlation between turbidity and total phosphorus is dependent on the particle size distribution of each event and the percentage of contaminants absorbed to each fraction. This aspect of water quality was outside the scope of this research and it is recommended that this be investigated in future research.

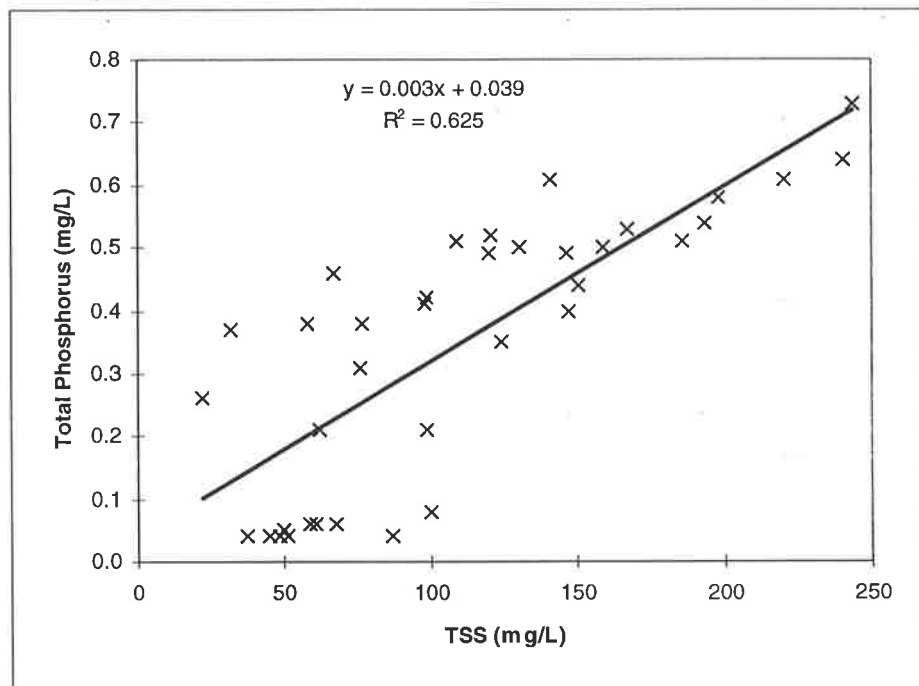
7.3.3.1.2 Total Suspended Solids Vs Total Phosphorus

Similarly to the total phosphorus-turbidity relationship, no significant correlation could be found between total suspended solids and total phosphorus.

TABLE 7.11 : Summary table of relationships between total suspended solids and total phosphorus

Catchment	Equation	r ² value
North Arm East (AU504101)	Tot. P = (0.0008) × TSS + 0.254	0.35
Hindmarsh Enfield Prospect (AU504102)	Tot. P = (0.068) × TSS ^(0.303)	0.06
Dunstan Road (AU504103)	Tot. P = (0.026) × TSS ^(0.581)	0.57
North Arm West (AU504104)	Tot. P = (0.002) × TSS + 0.039	0.63

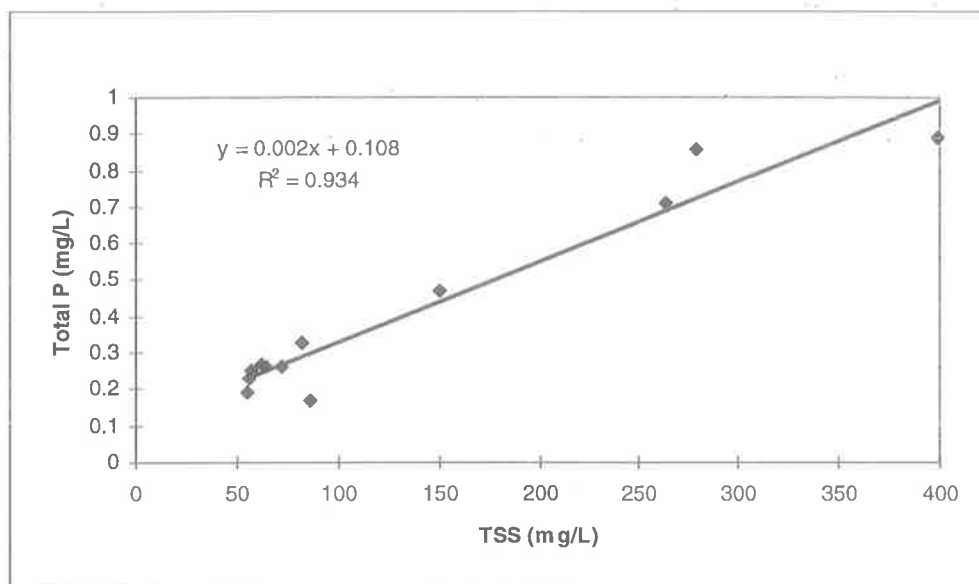
The best correlation was found in the North Arm West (AU504104) Catchment with an r² value of 0.63 as outlined in Figure 7.13. A summary of the relationships found in the four Barker Inlet Wetland catchments is outlined in Table 7.11.

**Figure 7.13** : Correlation between total suspended solids and total phosphorus for all sequential sample data from the North Arm West Catchment (AU504104)

Similar to the total suspended solids and total phosphorus results a good correlation was observed in some events and poor correlations in others. Table 7.12 outlines six events with significantly high correlations between total suspended solids and total phosphorus. Figure 7.14 outlines the relationship between total phosphorus and total suspended solids in the North Arm East (AU504101) Catchment for event 28-29/7/96.

TABLE 7.12 : Individual events with good correlations between total suspended solids and total phosphorus in the North Arm East (AU504101) Catchment

Event Date	r^2
28-29/7/96	0.93
22/6/96	0.89
25/4/96	0.82
23/6/96	0.82
28/6/96	0.81
5-6/7/96	0.81

**Figure 7.14 :** Correlation between total suspended solids and total phosphorus for sequential samples during event 28-29/7/96 in the North Arm East Drain (AU504101)

The sequential sample correlations for each event are outlined in Appendix G.

7.3.4 Water Quality Changes During Events

The main objective behind collecting and analysing sequential samples is to determine the changes in water quality within each event. Appendix H presents the sequential sample results for each event. The parameters of total phosphorus, turbidity and total suspended solids are plotted along with the hydrograph of each event. The rainfall is also included in the results. An example of the results obtained from sequential sample analysis is shown in Figure

total suspended solids and turbidity and Figure 7.16 for total phosphorus obtained during an event on 13 April 1996 in the North Arm East Drain (AU504101).

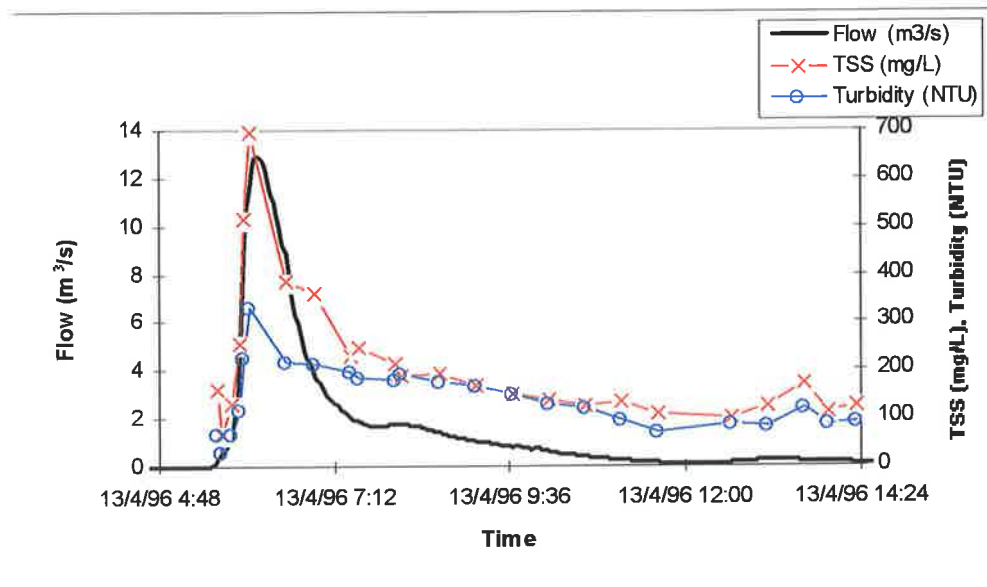


Figure 7.15 : Total suspended solids and turbidity concentration changes during event 13/4/97 in the North Arm East Drain (AU504101)

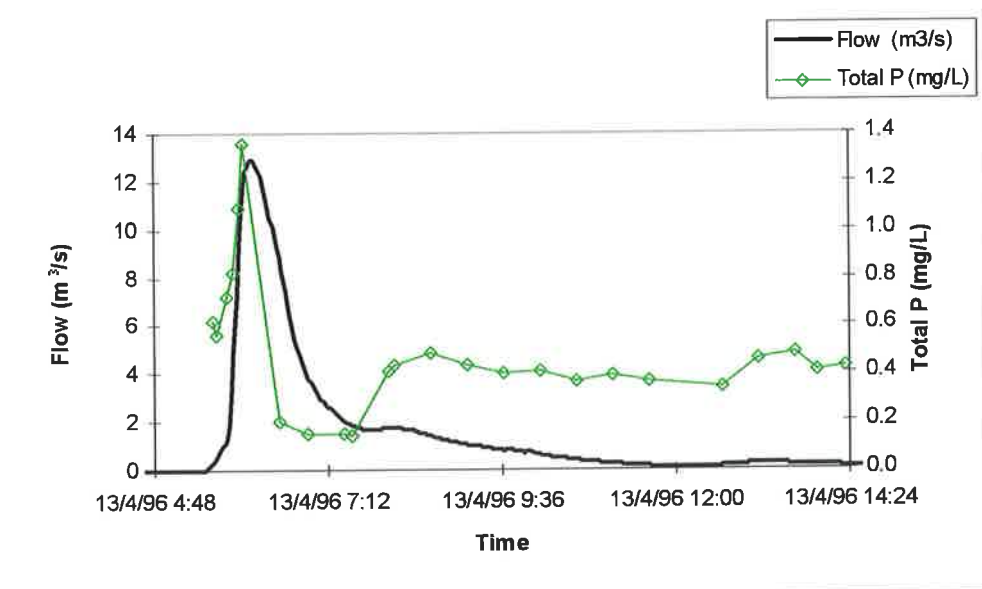


Figure 7.16 : Total phosphorus concentration changes during event 13/4/97 in the North Arm East Drain (AU504101)

From the onset of rainfall in the North Arm East (AU504101) Catchment it takes approximately 40 to 60 minutes before the rising limb of the hydrograph is observed at the monitoring station. The rising limb of the hydrograph in the North Arm East (AU504101) Catchment is typically steep. In the North Arm East (AU504101) Catchment the

concentration of turbidity, total suspended solids and total phosphorus are usually low at the very beginning of the event which is evident in the events on 13/4/96, 12/5/96, 17/6/96, 18/6/96, 22/6/96, 29/6/96, 4/7/96, 16/7/96, 31/7/96 and 6/2/97. The concentrations of the three parameters increase abruptly during the rising limb of the hydrograph and sometimes, but not always, peak before the hydrograph peaks.

The pattern of concentration changes for total suspended solids and turbidity is usually very similar, which is expected due to the strong correlation between the two parameters outlined in Section 7.3.3.1 previously. The concentration changes of total phosphorus is sometimes similar to total suspended solids and turbidity but not always. This is indicative of the correlation results outlined in Sections 7.3.3.2 and 7.3.3.3 previously which stated that the overall correlation between total phosphorus and total suspended solids or turbidity was insignificant however on an event basis it was sometimes strong.

The concentrations of total suspended solids, turbidity and total phosphorus in the North Arm East (AU504101) Catchment usually decrease during the falling limb of the hydrograph. The falling limb of the hydrograph decreases in energy as the limb decreases. The fallout of previously entrained sediments in the flow increases as the limb decreases in flow rate and energy. The sediment that is deposited in the channel during the falling limb of the hydrograph is often entrained early in the following event or a multiple peak of the same event and is a probable cause of the phenomenon known as first flush.

7.3.4.1 First Flush Phenomenon

As discussed earlier in Chapter 2, the phenomena of 'first flush' in urban stormwater has been observed by many authors such as Yaziz et al. (1989), Niemczynowicz (1992;1993) and Vorreiter et al. (1994). A first flush of total suspended solids, turbidity and total phosphorus was often observed in the four Barker Inlet Wetland Catchments, but not always. The first flush observed in the North Arm East (AU504101), Hindmarsh Enfield Prospect (AU504102), Dunstan Road (AU504103) and North Arm West (AU504104) Drains is likely to be due to channel flush and not catchment flush.

7.3.4.2 Hysteresis Plots

The hysteresis plots of sequential sample concentrations were plotted for each event to gain a better understanding of the washoff process for the catchments. The hysteresis plots' direction of rotation, width of loop, cross overs, and start and finishing points all give an indication of the processes occurring during washoff from each event. Clark et al. (1987) stated that the looping effect of hysteresis plots are "usually explained as being evidence of the flushing effect". An example of a hysteresis plot is outlined in Figure 7.17 for total phosphorus in the North Arm East (AU504101) Drain during an event on the 13 April 1996. The hysteresis plots of all of the other events for total suspended solids, turbidity and total phosphorus are outlined in Appendix I.

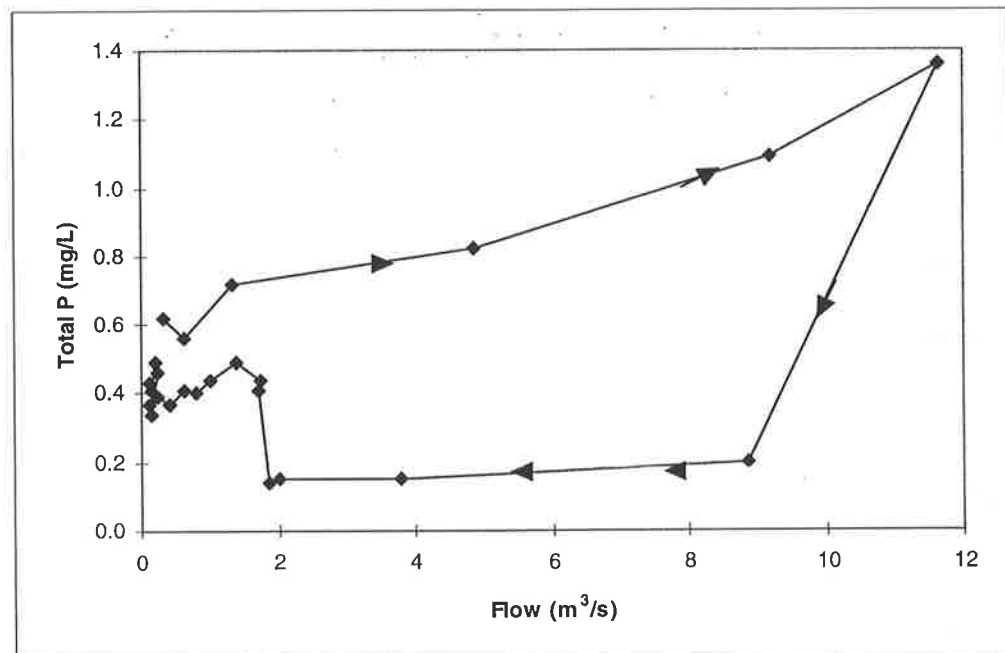


Figure 7.17 : Hysteresis plot of total phosphorus during event 13/4/97 in the North Arm East Drain (AU504101)

The hysteresis plot in Figure 7.17 is evidence of a first flush of total phosphorus in the North Arm East (AU504101) Catchment during the event on 13/4/97. The starting point of the hysteresis loop is at a greater concentration than the finishing point and the direction of rotation for the loop is clockwise

No significant trends arose from the analysis all of the hysteresis plots in Appendix I. Each event has its own characteristic hysteresis plot which is often different to the events both preceding and following it. Some events rotate clockwise, some anticlockwise, some start at a

concentration greater than they finish, and some do not. This is due to the complexity of the washoff process with so many determining factors such as build up load, antecedent catchment conditions, rainfall intensity, stormwater runoff velocities, particle size distribution and street sweeping frequency to name a few.

7.4 Event Mean Concentrations

The sequential samples automatically collected from each storm event were combined into a composite sample. Combining the sequential samples into a composite sample is based on a flow weighting technique which was described earlier in Section 4.6 of Chapter 4. The composite samples were analysed by an external body, the Australian Water Quality Centre, at Bolivar in South Australia to determine the event mean concentrations of various contaminants for each event. The event mean concentration is indicative of the average concentration over the whole storm event.

Event loads of the various contaminants in the stormwater are determined by multiplying the event mean concentrations by the event runoff volume for each event. The contaminant loads are investigated in the following section (Section 7.5).

7.4.1 Event Mean Concentration Results

The composite samples were analysed for nutrient and metal concentrations. Nitrogen and phosphorus are the two nutrients investigated in this monitoring program. The analysis of nitrogen investigated the various forms which include ammonia, organic form, total Kjeldahl nitrogen (summation of various nitrogen forms), nitrate, nitrite and total nitrogen. The analysis of phosphorus investigated the dissolved, particulate and total forms.

The metals that the composite samples were analysed for include aluminium, arsenic, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel and zinc. The event mean concentration results for the four Barker Inlet wetland Catchments are outlined in Tables 7.13 to 7.16 and the results for the Eastern Parade Catchment are outlined in Table 7.17.

TABLE 7.13 : North Arm East Drain (AU504101) Event Mean Concentrations (mg/L)

NUTRIENTS (mg/L)	No°	Min	Max	Mean	Median
Ammonia as N	35	0.02	1.10	0.22	0.15
Organic Nitrogen	35	0.34	7.19	1.92	1.36
TKN as Nitrogen	35	0.44	8.05	2.15	1.55
Nitrate + Nitrite as N	35	0.01	0.59	0.32	0.31
Total Nitrogen	35	0.69	8.15	2.46	1.93
Filt. Reactive Phosphorus as P	35	0.02	0.34	0.10	0.08
Particulate Phosphorus	35	0.07	1.60	0.32	0.23
Phosphorus (Total as P)	35	0.12	1.94	0.42	0.34
METALS (mg/L)					
Aluminium (Al)-Total	36	0.42	5.53	2.47	2.30
Arsenic (As)- Inorganic	36	0.001	0.005	0.003	0.003
Cadmium (Cd)-Total	36	0.0002	0.002	0.001	0.001
Chromium (Cr)-Total	36	0.005	0.04	0.01	0.01
Copper (Cu)- Total	34	0.02	0.09	0.04	0.04
Iron (Fe)- Total	36	0.47	6.36	2.48	2.19
Lead (Pb) - Total	36	0.04	0.36	0.15	0.12
Manganese (Mn)- Total	36	0.03	0.27	0.09	0.07
Mercury (Hg)- Total	36	0.0001	0.003	0.0003	0.0002
Nickel (Ni)- Total	36	0.003	0.03	0.01	0.01
Zinc (Zn)- Total	36	0.22	1.01	0.51	0.44
Total suspended solids (mg/L)	28	27.1	632	161	123

TABLE 7.14 : HEP Drain (AU504102) Event Mean Concentrations (mg/L)

NUTRIENTS (mg/L)	No°	Min	Max	Mean	Median
Ammonia as N	12	0.02	4.20	0.61	0.15
Organic Nitrogen	12	0.53	5.70	1.72	1.26
TKN as Nitrogen	12	0.55	9.90	2.32	1.38
Nitrate + Nitrite as N	12	0.01	0.41	0.11	0.04
Total Nitrogen	12	0.61	9.91	2.43	1.47
Filt. Reactive Phosphorus as P	12	0.01	0.34	0.19	0.17
Particulate Phosphorus	12	0.07	10.27	0.29	0.16
Phosphorus (Total as P)	12	0.22	1.14	0.48	0.39
METALS (mg/L)					
Aluminium (Al)-Total	13	0.12	3.01	1.02	0.65
Arsenic (As)- Inorganic	13	0.001	0.02	0.005	0.004
Cadmium (Cd)-Total	13	0.0002	0.002	0.001	0.001
Chromium (Cr)-Total	13	0.005	0.02	0.01	0.01
Copper (Cu)- Total	12	0.02	0.31	0.06	0.04
Iron (Fe)- Total	13	0.18	2.94	1.05	0.58
Lead (Pb) - Total	13	0.008	0.07	0.04	0.04
Manganese (Mn)- Total	13	0.01	0.63	0.09	0.05
Mercury (Hg)- Total	13	0.0001	0.0005	0.0002	0.0001
Nickel (Ni)- Total	13	0.002	0.03	0.01	0.01
Zinc (Zn)- Total	13	0.08	0.38	0.20	0.21
Total suspended solids (mg/L)	9	5.8	265	64.2	20.6

TABLE 7.15 : Dunstan Road Drain (AU504103) Event Mean Concentrations (mg/L)

NUTRIENTS (mg/L)	No°	Min	Max	Mean	Median
Ammonia as N	11	0.01	5.90	0.97	0.31
Organic Nitrogen	11	0.45	58.20	8.98	2.61
TKN as Nitrogen	12	0.46	64.10	9.58	3.25
Nitrate + Nitrite as N	12	0.01	0.48	0.27	0.30
Total Nitrogen	12	0.74	64.11	9.86	3.62
Filt. Reactive Phosphorus as P	12	0.07	3.93	0.51	0.16
Particulate Nitrogen	12	0.01	6.77	1.47	0.49
Phosphorus (Total as P)	12	0.16	10.70	1.98	0.76
METALS (mg/L)					
Aluminium (Al)-Total	12	0.005	12.4	6.28	5.71
Arsenic (As)- Inorganic	12	0.002	0.01	0.005	0.005
Cadmium (Cd)-Total	12	0.0003	0.008	0.002	0.001
Chromium (Cr)-Total	12	0.005	0.05	0.02	0.02
Copper (Cu)- Total	12	0.005	0.29	0.09	0.05
Iron (Fe)- Total	12	0.005	12.0	6.53	6.62
Lead (Pb) - Total	12	0.07	0.58	0.21	0.15
Manganese (Mn)- Total	12	0.005	0.64	0.20	0.14
Mercury (Hg)- Total	12	0.0001	0.002	0.0004	0.0001
Nickel (Ni)- Total	12	0.004	0.15	0.03	0.02
Zinc (Zn)- Total	12	0.005	2.05	0.79	0.59
Total suspended solids (mg/L)	10	105	1232	540	408

TABLE 7.16 : North Arm West Drain (AU504104) Event Mean Concentrations (mg/L)

NUTRIENTS (mg/L)	No°	Min	Max	Mean	Median
Ammonia as N	8	0.02	0.49	0.16	0.15
Organic Nitrogen	8	0.76	2.56	1.55	1.32
TKN as Nitrogen	8	0.90	2.80	1.70	1.48
Nitrate + Nitrite as N	8	0.04	0.70	0.29	0.29
Total Nitrogen	8	1.13	2.92	1.99	1.90
Filt. Reactive Phosphorus as P	8	0.01	0.12	0.07	0.08
Particulate Phosphorus	8	0.16	0.57	0.30	0.27
Phosphorus (Total as P)	8	0.18	0.62	0.37	0.35
METALS (mg/L)					
Aluminium (Al)-Total	8	0.005	9.95	3.08	2.54
Arsenic (As)- Inorganic	8	0.001	0.01	0.004	0.004
Cadmium (Cd)-Total	8	0.0005	0.002	0.001	0.001
Chromium (Cr)-Total	8	0.005	0.06	0.03	0.03
Copper (Cu)- Total	8	0.005	0.07	0.04	0.04
Iron (Fe)- Total	8	0.005	13.0	3.62	2.67
Lead (Pb) - Total	8	0.02	0.09	0.05	0.05
Manganese (Mn)- Total	8	0.005	0.27	0.11	0.09
Mercury (Hg)- Total	8	0.0001	0.0018	0.0004	0.0001
Nickel (Ni)- Total	8	0.007	0.05	0.02	0.02
Zinc (Zn)- Total	8	0.005	0.60	0.32	0.32
Total suspended solids (mg/L)	5	54.5	681	219	132

TABLE 7.17 : Eastern Parade Drain (AU504201) Event Mean Concentrations (mg/L)

NUTRIENTS (mg/L)	No ^o	Min	Max	Mean	Median
Ammonia as N	5	0.08	1.48	0.64	0.33
Organic Nitrogen	5	1.72	56.0	25.16	17.24
TKN as Nitrogen	5	1.80	56.10	25.80	18.72
Nitrate + Nitrite as N	5	0.01	0.12	0.05	0.03
Total Nitrogen	5	1.88	56.13	28.86	18.73
Filt. Reactive Phosphorus as P	5	0.13	1.05	0.71	0.91
Particulate Phosphorus	5	0.03	13.29	7.14	8.93
Phosphorus (Total as P)	5	0.50	14.20	7.85	9.85
METALS (mg/L)					
Aluminium (Al)-Total	6	0.46	41.3	14.59	7.0
Arsenic (As)- Inorganic	6	0.001	0.01	0.003	0.003
Cadmium (Cd)-Total	6	0.001	0.026	0.01	0.007
Chromium (Cr)-Total	6	0.005	0.23	0.10	0.08
Copper (Cu)- Total	6	0.04	1.23	0.48	0.23
Iron (Fe)- Total	6	1.30	102	30.1	11.2
Lead (Pb) - Total	6	0.10	4.2	1.55	0.66
Manganese (Mn)- Total	6	0.09	1.73	0.65	0.35
Mercury (Hg)- Total	6	0.0001	0.001	0.0005	0.0003
Nickel (Ni)- Total	6	0.006	0.15	0.05	0.017
Zinc (Zn)- Total	6	0.59	54.4	14.3	2.88
Total suspended solids (mg/L)	5	126	1605	551	423

Appendix J outlines the total event mean concentration data set for each catchment.

The Tables 7.13 to 7.17 also show the mean and median values of concentration. The number of events that were analysed is included to give an indication of the size of the data set for each catchment. Table 7.18 presents a summary of the event mean concentration results from the five catchments.

TABLE 7.18 : Summary of event mean concentration results, median values (mg/L)

	AU504101 NAE	AU504102 HEP	AU504103 Dunstan	AU504104 NAW	AU504201 Eastern P.
Number of Events	36	13	12	8	6
NUTRIENTS (mg/L)					
Ammonia as N	0.15	0.15	0.31	0.15	0.33
Organic Nitrogen	1.36	1.26	2.61	1.32	17.24
TKN as Nitrogen	1.55	1.38	3.25	1.48	18.72
Nitrate + Nitrite as N	0.31	0.04	0.30	0.29	0.03
Total Nitrogen	1.93	1.47	3.62	1.90	18.73
Filt. Reactive Phosphorus as P	0.08	0.17	0.16	0.08	0.91
Particulate Phosphorus	0.23	0.16	0.49	0.27	8.93
Phosphorus (Total as P)	0.34	0.39	0.76	0.35	9.85
METALS (mg/L)					
Aluminium (Al)-Total	2.30	0.65	5.71	2.54	7.0
Arsenic (As)- Inorganic	0.003	0.004	0.005	0.004	0.003
Cadmium (Cd)-Total	0.001	0.001	0.001	0.001	0.007
Chromium (Cr)-Total	0.01	0.01	0.02	0.03	0.08
Copper (Cu)- Total	0.04	0.04	0.05	0.04	0.23
Iron (Fe)- Total	2.19	0.58	6.62	2.67	11.2
Lead (Pb) - Total	0.12	0.04	0.15	0.05	0.66
Manganese (Mn)- Total	0.07	0.05	0.14	0.09	0.35
Mercury (Hg)- Total	0.0002	0.0001	0.0001	0.0001	0.0003
Nickel (Ni)- Total	0.01	0.01	0.02	0.02	0.017
Zinc (Zn)- Total	0.44	0.21	0.59	0.32	2.88
Total suspended solids (mg/L)	123	20.6	408	132	423

7.4.2 EMC Probability Curves

Similar to the sequential sample results it is hard to compare the event mean concentrations between catchments in its tabular form. Probability curves were produced for each parameter to aid in the comparison of water quality between the catchments. The probability curves for the event mean concentrations are outlined in Appendix K. The zinc event mean

concentration probability curves for the Barker Inlet Wetland Catchments are outlined in Figure 7.18.

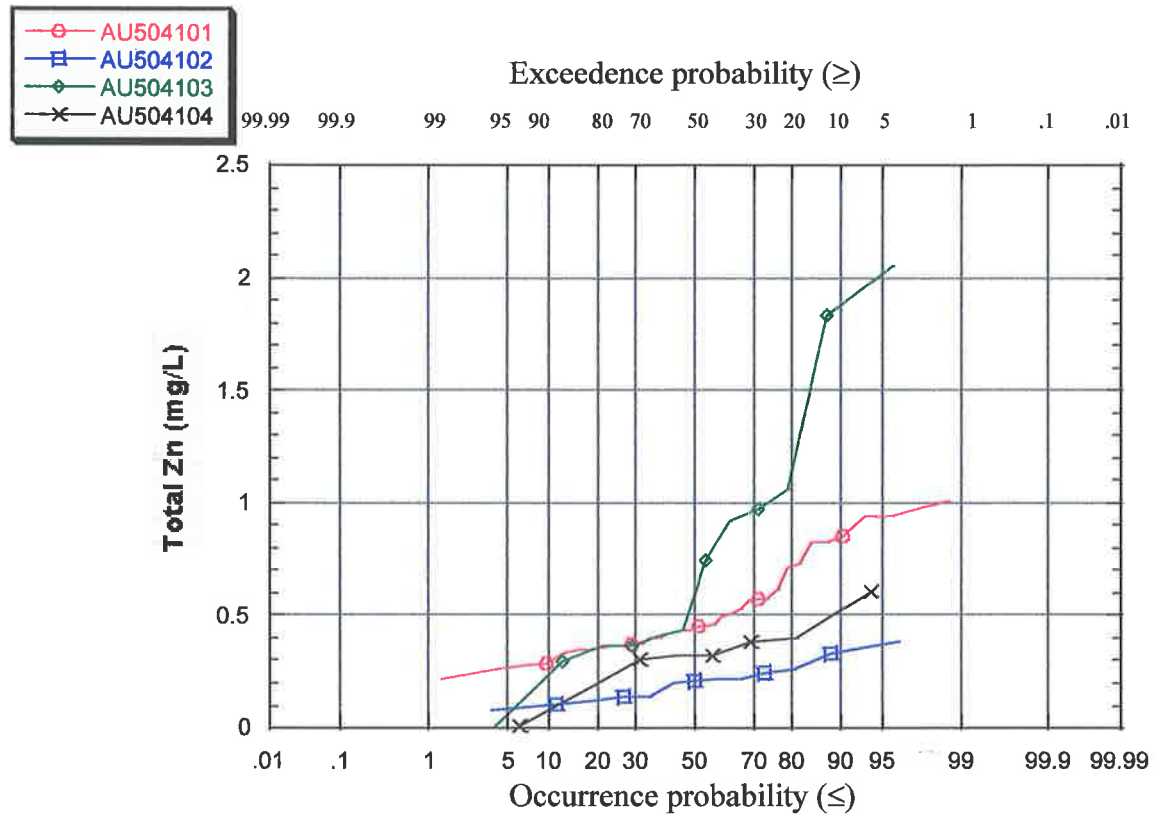


Figure 7.18 : Total zinc event mean concentration (mg/L) probability curves

7.4.3 Relative Contaminant Proportions

The proportions of each contaminant in stormwater relative to the total concentration of contaminants gives an indication of the pollutants that are most abundant. This is important as the contaminants causing the most problems can be identified.

TABLE 7.19 : Nutrient proportions (%) in urban stormwater

Station	AU504101 NAE	AU504102 HEP	AU504103 Dunstan	AU504104 NAW	AU504201 East.
No. Events	35	12	12	8	5
All Nitrogen forms	84.9	79	82.7	84.4	65.5
All Phosphorus forms	15.1	21	17.3	15.6	34.5
Total %	100	100	100	100	100
Nitrogen breakdown	-	-	-	-	-
Ammonia as N	8.2	10.1	9.6	8.6	1.9
Organic Nitrogen	74.6	87.4	81.2	75.1	98
Nitrate + Nitrite	17.2	2.5	9.2	16.3	0.1
Total %	100	100	100	100	100
Phosphorus breakdown	-	-	-	-	-
Dissolved P	26	50.4	25.2	22.5	9.2
Particulate P	74	49.6	74.8	77.5	90.8
Total %	100	100	100	100	100

Table 7.19 outlines the proportions of nutrients and their various forms in stormwater from the five monitored catchments. The proportions in Table 7.19 are determined as a percentage of the nutrient forms monitored in this study. Obviously other nutrients and different forms are present in the stormwater however to give an indication of the breakdown of the monitored nutrient forms these were ignored. Table 7.20 outlines the proportions of metals in the catchments. Similar to the determination of nutrient proportions the metal proportions in Table 7.20 are a percentage of the monitored metals only and not of every metal present in the stormwater.

TABLE 7.20 : Metal proportions (%) in urban stormwater entering the Barker Inlet Wetland

Station	AU504101 NAE	AU504102 HEP	AU504103 Dunstan	AU504104 NAW	AU504201 East.
No. Events	36	13	12	8	6
Aluminium (Al)	44.5	41.3	42.9	44.14	31.2
Arsenic (Ar)- Inorganic	0.06	0.25	0.04	0.06	0.01
Cadmium (Cd)	0.02	0.03	0.01	0.01	0.03
Chromium (Cr)	0.19	0.51	0.18	0.48	0.35
Copper (Cu)	0.68	2.25	0.35	0.70	1.02
Iron (Fe)	42.3	36.9	49.7	46.3	50.0
Lead (Pb)	2.29	2.28	1.14	0.84	2.9
Manganese (Mn)	1.25	2.98	1.07	1.50	1.56
Mercury (Hg)	0.003	0.006	0.001	0.002	0.001
Nickel (Ni)	0.14	0.32	0.13	0.35	0.07
Zinc (Zn)	8.57	13.1	4.45	5.61	12.8
Total %	100	100	100	100	100

Due to the high concentrations of aluminium, iron and to a lesser extent zinc depicted by the high proportions in Table 7.20 the heavy metal proportions with low concentrations (that are often more toxic to life forms in the receiving water body) are hard to compare. Table 7.21 excludes aluminium, iron and zinc from the proportion calculation so that a better comparison can be made between the heavy metals found in lower concentrations.

TABLE 7.21 : Low concentration heavy metal proportions (%) in urban stormwater entering the Barker Inlet Wetland

Station	AU504101 NAE	AU504102 HEP	AU504103 Dunstan	AU504104 NAW	AU504201 East.
No. Events	36	13	12	8	6
Arsenic (Ar)- Inorganic	1.26	2.94	1.29	1.54	0.2
Cadmium (Cd)	0.33	0.37	0.32	0.29	0.6
Chromium (Cr)	4.18	5.88	6.07	12.13	5.8
Copper (Cu)	14.7	26.1	12.13	17.6	17.1
Lead (Pb)	49.6	26.5	39.0	21.4	49.1
Manganese (Mn)	27.0	34.5	36.8	38.1	26.0
Mercury (Hg)	0.06	0.07	0.03	0.04	0.02
Nickel (Ni)	2.93	3.67	4.39	8.82	1.2
Total %	100	100	100	100	100

7.4.4 Event Mean Concentration Parameter Correlations

Correlations between contaminant parameters are common and can be attributed to a common source or mode of transportation such as sorbed to sediment matter. The correlation between total suspended sediment and turbidity is strong for the sequential samples as presented earlier in Section 7.3.3. This section investigates the correlation between the nutrient and metal contaminants using the event mean concentration results.

The correlation between any two contaminants from the event mean concentration results was investigated by plotting every combination of two parameters that appear in Tables 7.13 to 7.18. The significant correlations that were found are outlined in Table 7.22. The correlation between Iron and Aluminium in the North Arm East Catchment was the strongest correlation. The association between sediment particles and pollutants was evident and Figure 7.19 outlines one of the relationships of most interest which is between total suspended solids and lead.

TABLE 7.22 : Correlations between parameter EMC in the North Arm East Catchment (AU504101)

Parameters	Correlation, r^2
Iron & Aluminium	0.94
Total Suspended Solids & Iron	0.91
Total Suspended Solids & Aluminium	0.82
Total Suspended Solids & Lead	0.80
Lead & Iron	0.76
Total Suspended Solids & Manganese	0.74
Zinc & Manganese	0.69
Lead & Aluminium	0.65
Dissolved P & Ammonia as N	0.65
Total Suspended Solids & Particulate Phosphorus	0.61
Total Suspended Solids & Mercury	0.56
Manganese & TKN as N	0.56
Total Suspended Solids & Nickel	0.54
Chromium & Copper	0.54
Manganese & Particulate Phosphorus	0.52
Arsenic & Aluminium	0.52

The correlations between parameters was well summarised by pH environment (1995), "Correlations between metals and metals could indicate a common source in industry or land use. Correlations between metals and organic matter are more likely to reflect the potential of organic surfaces to absorb and transport metals. Correlations between metals and nutrients may be a result of the total nitrogen content of organic matter, but correlations between nutrients would probably indicate a common source".

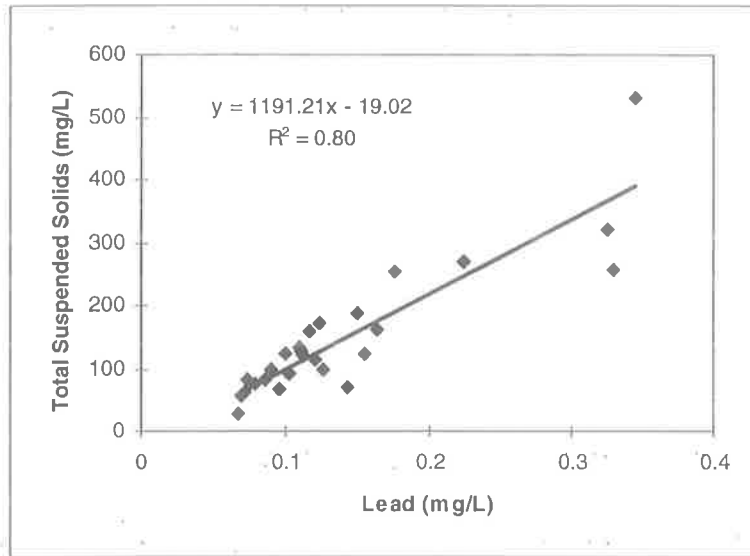


Figure 7.19 : EMC correlation between Total Suspended Solids and Lead in the North Arm East Drain (AU504101)

7.4.5 Discussion of Event Mean Concentration Results

This section compares event mean concentrations between the five catchments by drawing on the sequential sample results, event mean concentration tabulated results, event mean concentration probability curves and contaminant proportions outlined in the previous sections. The event load results and discussion which are considered even more important than concentration results are outlined in Sections 7.5 and 7.6 respectively.

7.4.5.1 Nutrients

The two macronutrients of nitrogen and phosphorus were monitored in this study. The nitrogen forms monitored in this study were ammonia, organic nitrogen, total Kjeldahl nitrogen (summation of various nitrogen forms), and dissolved nitrate and nitrite. The phosphorus forms were dissolved reactive phosphorus and particulate phosphorus.

The observed concentrations of the two macronutrients indicates that the majority of nutrients in the stormwater entering the Barker Inlet Wetland are the nitrogen forms. On average the stormwater inflow to the Barker Inlet Wetland contains a nutrient breakdown of 83% nitrogen to 17% phosphorus (ignoring other forms of nutrients). The proportion of nitrogen entering the Magazine Creek Wetland from the Eastern Parade Catchment (AU504201) was smaller with 65.5% as nitrogen and 34.5% as phosphorus. The data set is very small for the Eastern

Parade Catchment as only 5 events had been monitored, so the proportions need to be observed with caution.

Ammonia is very toxic to aquatic organisms (Makepeace, 1995) especially in its undissociated form, NH_3 , (ANZECC, 1992). The main sources of ammonia are from domestic sewage and industrial land uses (ANZECC, 1992) and as the sewage systems are separate to the stormwater systems in these catchments industrial land uses are the main source. It is therefore not unexpected that the concentrations of ammonia in the industrial catchments of Dunstan Road (AU504103) and Eastern Parade (AU504201) are much higher than the three residential catchments. The industrial catchment of Dunstan Road (AU504103) recorded a median EMC concentration of 0.31mg/L which is similar to the median of 0.33mg/L found in the industrial catchment of Eastern Parade (AU504201). The residential catchments of North Arm East (AU504101), Hindmarsh Enfield Prospect (AU504102) and North Arm West (AU504104) all recorded the same lower median EMC ammonia concentration of 0.15mg/L . The proportions of ammonia to other nitrogen forms was fairly consistent in the Barker Inlet Wetland Catchments, ranging from 8.2% in the North Arm East (AU504101) Catchment to 10.1% in the Hindmarsh Enfield Prospect (AU504102) Catchment.

Organic nitrogen makes up the majority of the nitrogen forms entering the Barker Inlet and Magazine Creek Wetlands. 74.6% of nitrogen recorded in the North Arm East (AU504101) catchment as organic nitrogen, 87.4% in the Hindmarsh Enfield Prospect (AU504102), 81.2% in the Dunstan Road (AU504103), 75.1% in the North Arm West (AU504104) Catchment. The Eastern Parade (AU504201) Catchment recorded 98% of nitrogen forms as organic. The organic nitrogen concentrations were highest in the industrial catchments with a median EMC concentration of 2.61mg/L recorded in the Dunstan Road (AU504103) Catchment and 17.24mg/L in the Eastern Parade Catchment (AU504201). Much of organic nitrogen is associated with the larger particle sizes as decomposing plant material, bacteria and algae ((McKergow 1994, Leersnyder, 1993) which explains the high total suspended solid and turbidity concentrations recorded in the Dunstan Road and Eastern Parade Catchments. The three residential catchments of North Arm East (AU504101), Hindmarsh Enfield Prospect (AU504102), and North Arm West (AU504104) recorded similar median organic nitrogen concentrations of 1.36, 1.26, and 1.32mg/L respectively.

Nitrate (NO_3^-) formed from nitrite (NO_2^-) by the nitrification process is one of the most bioavailable forms of nitrogen for plant growth. The proportion of nitrate and nitrite to the other forms of nitrogen varies between the five catchments. The three residential catchments of North Arm East (AU504101), Hindmarsh Enfield Prospect (AU504102) and North Arm West (AU504104) recorded nitrate + nitrite proportions of 17.2, 9.2, and 16.3% respectively and relatively similar median EMC concentrations of 0.31, 0.30 and 0.29mg/L. The Hindmarsh Enfield Prospect (AU504102) Catchment recorded only 2.5% of nitrogen forms as nitrate and nitrite with a low median EMC nitrate + nitrite concentration of 0.04mg/L. This is likely to be due to the chemical reduction of nitrate to nitrite, and then to ammonia in the large grass swale, thereby explaining the elevated proportion of ammonia (87.4% of all nitrogen forms). The grass swale delays flows by up to twelve hours and has such a large grass surface area (18ha) that it is not unreasonable for this to occur. The ammonia proportion in the Hindmarsh Enfield Prospect (AU504102) Catchment is high, however the ammonia median concentration relatively low, but this is likely due to the low proportion of industrial land uses within the catchment. The industrial catchment of Eastern Parade also recorded a small proportion of nitrate and nitrite compared to other forms of nitrogen (0.1%), and a low median concentration of 0.03mg/L. The abundance of algae and organic material in the Eastern Parade Drain indicate that the nitrate may have been reduced to nitrite and then to ammonia in the channel, which could explain the highest ammonia median concentration of the five catchments (0.33mg/L).

Total nitrogen levels were greatest in the industrial catchment of Eastern Parade (AU504201) which recorded an EMC median concentration of 18.7mg/L with the other industrial catchment of Dunstan Road (AU504103) recorded a concentration of 3.62mg/L. The total nitrogen concentrations recorded in the Dunstan Road (AU504103) Catchment are approximately 90% higher than those recorded in the residential catchments of North Arm East (AU504101) and North Arm West (AU504104) which recorded EMC median concentrations of 1.93 and 1.90mg/L respectively. The Hindmarsh Enfield Prospect (AU504102) Catchment recorded the lowest total nitrogen EMC median concentration of 1.47mg/L.

Similar total phosphorus EMC median concentrations were recorded in the residential catchments of North Arm East (AU504101), Hindmarsh Enfield Prospect (AU504102) and North Arm West (AU504104) with values of 0.34, 0.39 and 0.35mg/L respectively. The

industrial catchment of Dunstan Road (AU504103) recorded a EMC median total phosphorus concentration of 0.76mg/L , over double that of the residential catchments, and the Eastern Parade catchment recorded an order of magnitude higher with 9.85mg/L . The median concentration in the Eastern Parade Drain is biased towards high concentration 'first channel flush' samples early in the flow hydrographs, due to such a small data set.

The proportions of dissolved and particulate phosphorus vary significantly between the catchments. The North Arm East (AU504101) Catchment recorded a median dissolved phosphorus concentration of 0.08mg/L which represented 26% of total phosphorus. The particulate fraction of 74% was recorded with a median concentration of 0.23mg/L . The Hindmarsh Enfield Prospect (AU504102) Catchment recorded a median dissolved phosphorus concentration of 0.17mg/L (50.4% proportion), and a concentration of 0.16mg/L particulate phosphorus. The low particulate phosphorus concentration in the Hindmarsh Enfield Prospect Catchment is probably due to the grass swale upstream of the monitoring station inducing sedimentation. The industrial catchment of Dunstan Road (AU504103) recorded 74.8% of phosphorus in the particulate form with a median concentration of 0.49mg/L and 25.2% in dissolved reactive form (0.16mg/L). The North Arm West (AU504104) Catchment's results are almost identical to the North Arm East (AU504101) Catchment with 77.5% particulate phosphorus at a concentration of 0.27mg/L and 25.5% dissolved at 0.08mg/L . The majority of phosphorus in the Eastern Parade Catchment is particulate (90.8%) recording a median concentration of 0.93mg/L , with only 9.2% dissolved (0.91mg/L).

7.4.5.2 Metals

Aluminium and iron are by far the two most abundant metals entering the Barker Inlet and Magazine Creek Wetlands.

Of the metals monitored entering the Barker Inlet Wetland, aluminium contributes to 43% on average and iron 44%. Zinc is the third most abundant metal consisting on average of 8% of metal inflows to the Barker Inlet Wetland. The remaining 18% of metal inflows is broken down into proportions outlined in Table 7.21 between the metals of cadmium, arsenic, chromium, copper, lead, manganese, mercury and nickel.

Similarly in the Magazine Creek Wetland aluminium and iron make up 31% and 50% respectively of the metal inflows from the Eastern Parade (AU504201) Catchment. Zinc contributes a further 12.8%. The breakdown of the remaining 6.2% of metal inflows to the Magazine Creek Wetland is outlined in Table 7.21.

A number of metal concentrations recorded in the five catchments show similar trends when comparing the quality between the catchments. The metals of aluminium, cadmium, iron, lead, manganese and zinc all recorded maximum median EMCs in the catchments with the highest proportion of industrial land uses. These same metals also recorded the minimum median EMCs in the residential Hindmarsh Enfield Prospect (AU504102) Catchment. The high concentration of these metals is due to the processing and manufacturing of heavy metals in the Dunstan Road (AU504103) and Eastern Parade (AU504201) Catchments. The low concentration of these metals observed in the Hindmarsh Enfield Prospect (AU504102) Catchment is likely due to sedimentation in the grass swale upstream of the monitoring station (Williams et al. 1997). The metals are likely to be attached to the suspended sediment, and as the sediment falls out of the flow during sedimentation in the grass swale so do the adsorbed metals.

This is evident in the aluminium event mean concentration results which were greatest in the two industrial catchments with median EMC's of 5.71mg/L and 7.0mg/L in the Dunstan Road (AU504103) and Eastern Parade (AU504201) Catchments respectively. The residential catchments of North Arm East (AU504101) and North Arm West (AU504104) recorded median EMC's of 2.3mg/L and 2.54mg/L respectively. The Hindmarsh Enfield Prospect (AU504102) Catchment recorded the lowest concentration of 0.65mg/L . This same trend is evident for median EMC results of cadmium, iron, lead, manganese and zinc with the concentrations summarised in Table 7.18.

The median EMCs of arsenic and mercury are similar between all five catchments, mainly due to their low detection concentrations.

7.4.6 Polycyclic Aromatic Hydrocarbons

The presence of oil on the water surface of stormwater in the Dunstan Road (AU504103) Drain during site visits prompted an investigation into the concentrations of Polycyclic Aromatic Hydrocarbons (PAHs). The investigation determined and compared PAH levels between the North Arm East (AU504101) and Dunstan Road (AU504103) Catchments. The comparison was made between these two catchments as it gives a direct comparison between a residential catchment, North Arm East (AU504101), and an industrial catchment, Dunstan Road (AU504103).

Eight event composite samples from the North Arm East (AU504101) Catchment and six from the Dunstan Road (AU504103) Catchment were tested for PAH levels. A seventh composite sample was tested from the Dunstan Road (AU504103) Catchment which was from low base flow. The results are outlined in Table 7.23 for the North Arm East (AU504101) Catchment and Table 7.24 for the Dunstan Road (AU504103) Catchment. The event PAH concentrations in both catchments were low with most concentrations less than $0.5\mu\text{g/L}$, which is the detection limit. Low PAH levels were expected in the North Arm East (AU504101) Catchment due to the low percentage of industrial/commercial activity in the catchment.

The low PAH levels found in the Dunstan Road (AU504103) Catchment were unusual due to the amount of oil visibly present in the drain. The composite samples tested were from event flow and not base flows which tends to indicate that the oil visibly present in the Dunstan Road (AU504103) Catchment was confined to base flows and not event runoff. The event runoff from the catchment appears to be low in PAH levels which means that the petroleum hydrocarbons are not being washed off the catchment surface. It could be speculated that at the beginning of each event there is a first flush of high PAH concentration and that during the rest of the event the PAH levels are low. This could be determined by collecting and analysing samples early in an event as well as the base flow preceding the event. The base flow composite sample that was tested from the Dunstan Road (AU504103) Catchment shows high levels of PAHs as outlined by the maximum column in Table 7.24. This confirms that the PAHs are mainly associated with base flows and that the event runoff is low in PAHs.

TABLE 7.23 : PAH event mean concentrations in the North Arm East (AU504101) Catchment

Parameter	Minimum (µg/L)	Maximum (µg/L)	Median (µg/L)
Naphthalene	<0.5	0.5	<0.5
Acenaphthylene	<0.5	<0.5	<0.5
Acenaphthene	<0.5	0.7	<0.5
Fluorene	<0.5	0.6	<0.5
Phenanthrene	<0.5	0.7	<0.5
Anthracene	<0.5	0.6	<0.5
Fluoranthene	<0.5	1.5	<0.5
Pyrene	<0.5	1.4	<0.5
Chrysene	<0.5	<0.5	<0.5
Benzo (A) Anthracene	<0.5	0.6	<0.5
Benzo (B) Fluroanthene	<0.5	<0.5	<0.5
Benzo (K) Fluoranthene	<0.5	<0.5	<0.5
Benzo (A) Pyrene	<0.5	<0.5	<0.5
Indeno (123-CD) Pyrene	<0.5	<0.5	<0.5
Dibenzo (AH) Anthracene	<0.5	<0.5	<0.5
Benzo (GHI) Perylene	<0.5	<0.5	<0.5

TABLE 7.24 : PAH event mean concentrations in the Dunstan Road (AU504103) Catchment

Parameter	Minimum (µg/L)	Maximum (µg/L)	Median (µg/L)
Naphthalene	<0.5	30.0	<0.5
Acenaphthylene	<0.5	5.0	<0.5
Acenaphthene	<0.5	11.0	<0.5
Fluorene	<0.5	17.0	<0.5
Phenanthrene	<0.5	16.0	<0.5
Anthracene	<0.5	5.4	<0.5
Fluoranthene	<0.5	5.1	<0.5
Pyrene	<0.5	11.0	<0.5
Chrysene	<0.5	<2.5	<0.5
Benzo (A) Anthracene	<0.5	<2.5	<0.5
Benzo (B) Fluoranthene	<0.5	<2.5	<0.5
Benzo (K) Fluoranthene	<0.5	<2.5	<0.5
Benzo (A) Pyrene	<0.5	3.0	<0.5
Indeno (123-CD) Pyrene	<0.5	<2.5	<0.5
Dibenzo (AH) Anthracene	<0.5	<2.5	<0.5
Benzo (GHI) Perylene	<0.5	<2.5	<0.5

7.5 Event Contaminant Loads

The contaminant load entering the Barker Inlet Wetland is arguably the most important aspect of this phase of monitoring. The inflow loads outline the quantity of contaminants that are entering the wetland as opposed to the quality which was determined by the sequential sample and event mean concentration results.

The important aspect of the overall monitoring project during future research phases is to determine what happens to this inflow load of contaminants once it enters the Barker Inlet Wetland. What improvement is there between outflow loads compared to inflow loads? What happens to the contaminant load that remains in the wetland, where and how is it distributed? Which parts of the wetland are more efficient than others at improving

stormwater quality? The answers to these questions will hopefully become clearer from future research phases.

TABLE 7.25 : Summary of event loads entering the Barker Inlet Wetland, median values (kg)

	AU504101 NAE	AU504102 HEP	AU504103 Dunstan	AU504104 NAW
Catchment Area (ha)	2170	1300	223	782
Estimated impervious area (ha)	564	403	58	254
Number of Events	36	13	12	8
NUTRIENTS (kg)				
Ammonia as N	3.52	2.01	0.47	0.64
Organic Nitrogen	33.3	13.0	6.38	12.8
TKN as Nitrogen	40.0	17.4	6.74	13.8
Nitrate + Nitrite as N	7.83	0.53	0.49	1.52
Total Nitrogen	51.8	17.5	7.54	17.1
Filt. Reactive Phosphorus as P	1.94	1.88	0.31	0.45
Particulate Phosphorus	6.28	2.79	1.60	2.55
Total Phosphorus	9.02	4.69	1.90	2.98
METALS (kg)				
Aluminium (Al)-Total	55.9	8.29	14.5	10.2
Arsenic (As)- Inorganic	0.067	0.03	0.01	0.03
Cadmium (Cd)-Total	0.02	0.004	0.003	0.005
Chromium (Cr)-Total	0.32	0.09	0.04	0.20
Copper (Cu)- Total	0.90	0.50	0.14	0.26
Iron (Fe)- Total	55.2	10.5	14.2	11.4
Lead (Pb) - Total	2.99	0.28	0.46	0.29
Manganese (Mn)- Total	1.80	0.77	0.30	0.77
Mercury (Hg)- Total	0.005	0.001	0.0004	0.001
Nickel (Ni)- Total	0.20	0.06	0.05	0.12
Zinc (Zn)- Total	12.9	1.98	1.49	1.76
Total Suspended Solids	3410	124	1385	1669

This section outlines the contaminant inflow loads entering the Barker Inlet Wetland, which are determined by applying total event runoff volumes to the event mean concentrations. A summary of the median event contaminant loads entering the Barker Inlet Wetland is outlined in Table 7.25.

The event loads are affected by two main factors. Contaminant concentration is one factor and the other is stormwater runoff volume, which is directly proportional to the impervious area of the catchment for small and medium events. The high concentrations of contaminants in the industrial catchment of Dunstan Road (AU504103) are counteracted by the small impervious area, estimated to be only 58 hectares. This reduces the overall contaminant load from the catchment compared to the residential catchment of North Arm East (AU504101) which had lower contaminant concentrations but a much larger estimated impervious area of 564 hectares.

Similar to the presentation of the sequential samples and event mean concentration results the best comparison between the catchments is using the probability curves. The event load probability curves are presented in Appendix M. To give a true comparison between the catchments the loads have been normalised to give an indication of load per unit squared of catchment (mg/m^2).

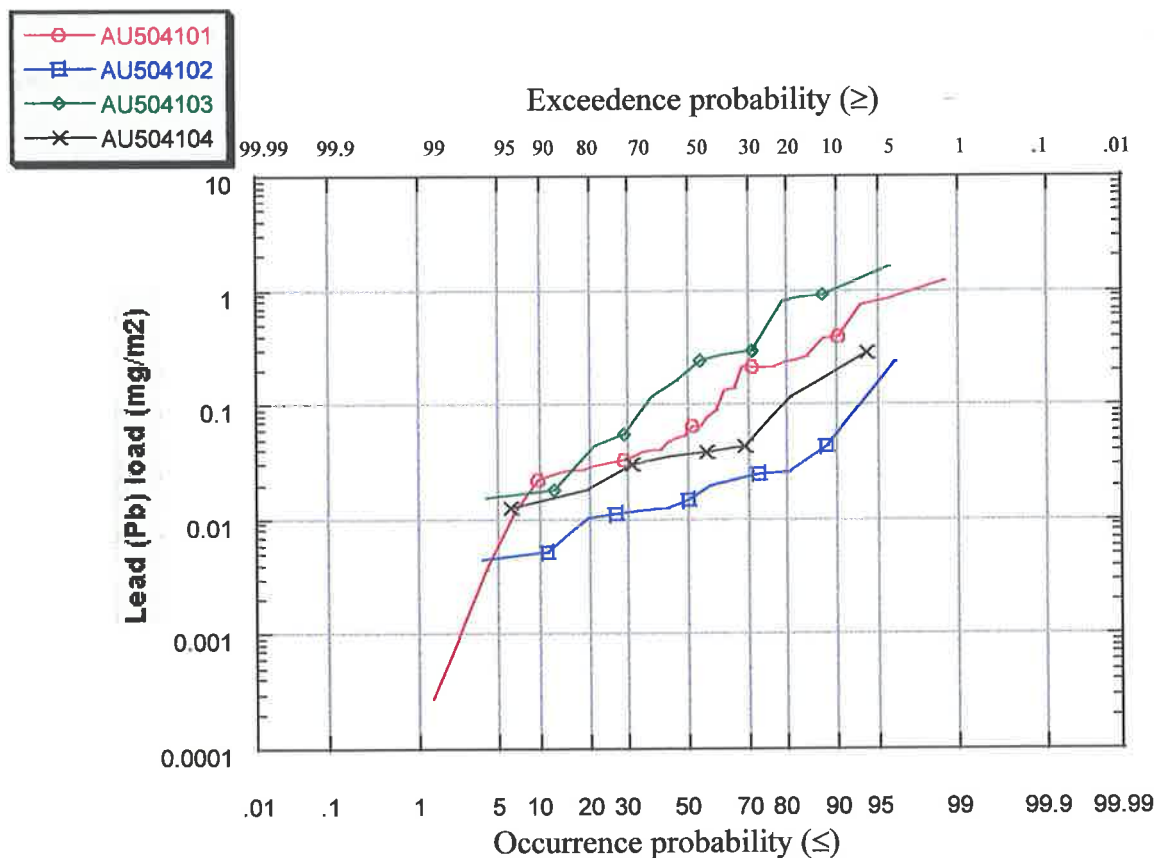


Figure 7.20 : Lead (Pb) event load per unit area (mg/m^2) probability curves

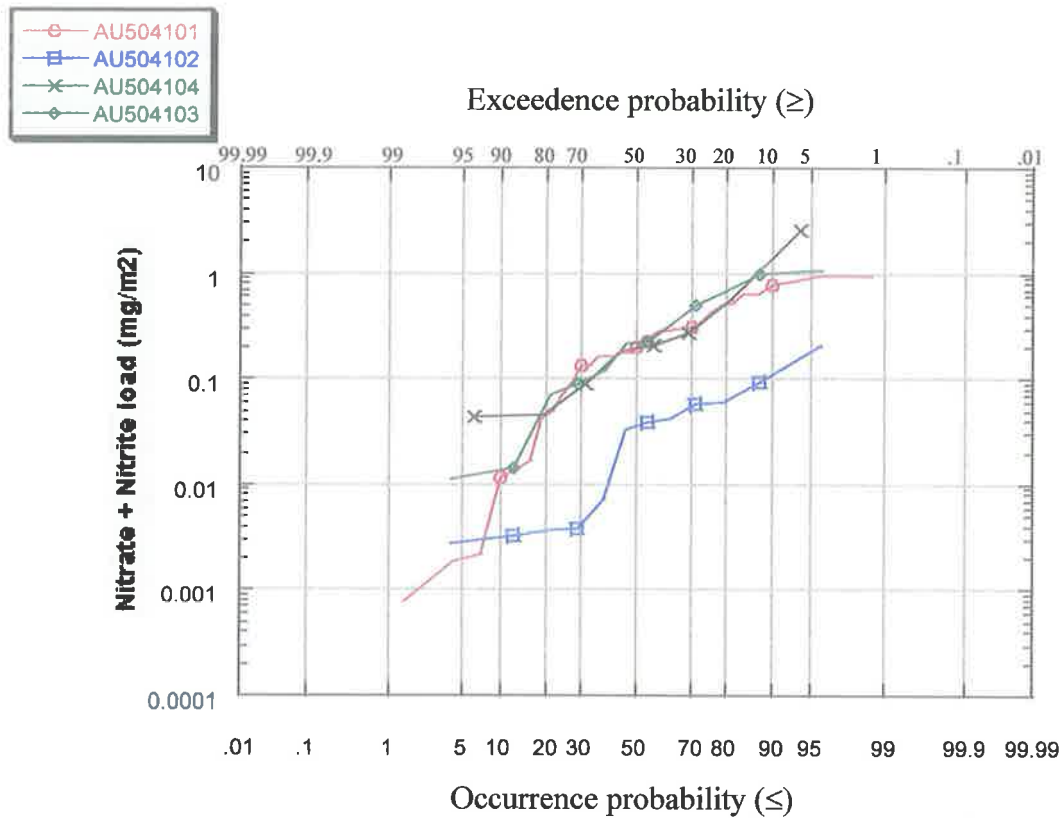


Figure 7.21 : Nitrate + Nitrite Event Load Probability Curve (mg/m²)

Figure 7.20 outlines the event load probability curves for lead (Pb) entering the Barker Inlet Wetland, and Figure 7.21 outlines the Nitrate + Nitrite event load probability curve (mg/m²).

7.6 Annual Pollutant Loads

The annual catchment yield of heavy metals is outlined in Table 7.26. The values are an estimation determined from two years of data collection. The continuation of the monitoring programme in the future will produce revised estimates based on a larger data set.

The estimated annual pollutant loads presented have been normalised by dividing by the catchment which produces a unit of mg/m². This enables a better comparison of the pollutant yield between the catchments with varying land uses and channel types. Multiplying the values outlined in Tables 7.26 and 7.27 by the catchment area in square kilometres will produce an estimated annual load in kilograms.

TABLE 7.26 : Estimated Annual Yield of Heavy Metals (mg/m²)

Catchment	AU504101	AU504102	AU504103	AU504104
	NAE	HEP	Dunstan	NAW
Catchment Area (km ²)	21.7	13.0	2.23	7.82
Aluminium (Al)-Total	190	30.9	260	71.8
Arsenic (Ar)- Inorganic	0.23	0.14	0.18	0.09
Cadmium (Cd)-Total	0.06	0.02	0.1	0.02
Chromium (Cr)-Total	0.83	0.24	1.0	0.45
Copper (Cu)- Total	2.95	1.24	4.29	0.77
Iron (Fe)- Total	184	30.4	281	82.1
Lead (Pb) - Total	10.4	0.95	9.02	1.18
Manganese (Mn)- Total	6.04	1.56	8.21	2.10
Mercury (Hg)- Total	0.02	0.01	0.01	0.01
Nickel (Ni)- Total	0.55	0.16	0.79	0.37
Zinc (Zn)- Total	32.9	5.70	34.3	6.83

It is evident from the normalised annual yield of heavy metals outlined in Tables 7.26 that the industrial Dunstan Road (AU504103) Catchment has the highest pollutant load except for arsenic, lead and mercury.

When the normalised values of annual heavy metal yield are multiplied by the catchment areas however, the highest proportion of heavy metals entering the Barker Inlet Wetland comes from the North Arm East (AU504101) Catchment as it is the largest. 67% of the annual total copper load that enters the Barker Inlet Wetland and 84% of the annual total lead load is from the North Arm East (AU504101) Catchment. The input loads of the other heavy metal parameters are also mainly sourced from the North Arm East (AU504101) Catchment.

If a catchment management plan was to be implemented to try to reduce the input load of heavy metals to the Barker Inlet Wetland and hence the Barker Inlet and St Vincent's Gulf the resources should be directed to the North Arm East (AU504101) Catchment.

TABLE 7.27 : Estimated Annual Yield of Nutrients (mg/m²)

Catchment	AU504101	AU504102	AU504103	AU504104
	NAE	HEP	Dunstan	NAW
Catchment Area (km ²)	21.7	13.0	2.23	7.82
Ammonia as N	10.2	6.93	33.7	2.79
Organic Nitrogen	100	31.7	319	29.9
TKN as Nitrogen	110	38.6	355	32.7
Nitrate + Nitrite	18.8	2.28	8.61	7.93
Total Nitrogen	129	40.9	364	40.7
Dissolved Phosphorus	4.72	4.0	17.9	1.56
Particulate Phosphorus	17.5	4.77	69.2	6.32
Total Phosphorus	22.2	8.77	87.2	7.88

The normalised annual yield of nutrients is outlined in Table 7.27. With the exception of nitrate and nitrite which is highest in the North Arm East (AU504101) Catchment, the industrial catchment of Dunstan Road (AU504103) has the highest normalised annual yield.

When the catchment areas are taken into account approximately 63% of total nitrogen and 57% of total phosphorus annual load entering the Barker Inlet Wetland is from the North Arm East (AU504101) Catchment and the area is 21.7km².

7.7 Distribution of Annual Contaminant Load

The annual contaminant load that enters the Barker Inlet and Magazine Creek Wetlands is distributed between a number of storm events. These events range from small runoff volumes to quite large volumes. It is important to know how much of the annual load is distributed in the large runoff volume events compared to the medium and smaller events.

Using the North Arm East (AU504101) Catchment as an example this section graphs the distribution of a number of contaminants for all of the 36 events that were monitored during the eighteen month sampling period for this research. These events range in event runoff volume from 170ML in the 6/2/97 event down to 2.23ML in the 6/7/96 event. Figure 7.22 outlines the distribution of the event runoff volumes which have been ranked from the largest

volume (6/2/97) to the smallest (6/7/97). It is evident that 52% of the total runoff volume for these 36 events comes from the largest 7 events and hence the other 29 events make up the remaining 48% of total runoff volume.

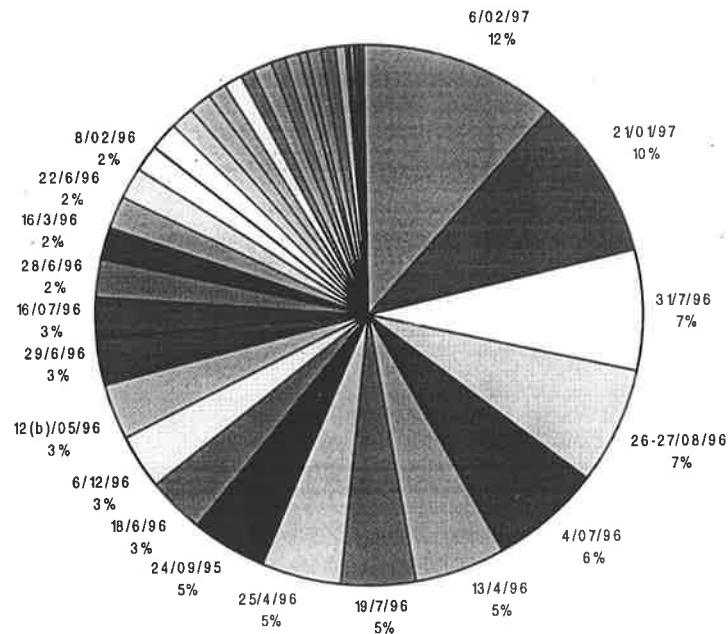


Figure 7.22 : Distribution of event runoff volumes in the North Arm East (AU504101) Catchment for the 18 month period to 6/2/97

The distribution of the annual total nitrogen load is outlined in Figure 7.23. The 36 events are again ranked from largest to smallest event runoff volume, with the largest event on the left end of the x-axis to the smallest on the right end. The graph rises steeply and then gradually flattens out which indicates that a high percentage of the annual pollutant load comes from the large runoff volume events.

It is evident from Figure 7.23 that 62% of the annual total nitrogen load comes from 25% of the events. This indicates that the few large events by volume that occur make up a large proportion of the total annual contaminant load. If the wetland cannot handle these large events then a large proportion of the annual load will bypass the wetland purification process and discharge into the Barker Inlet with effectively a zero days retention time.

Figure 7.24 outlines the distribution of the total phosphorus annual load. 53% of the annual total phosphorus load is from only 25% of the events.

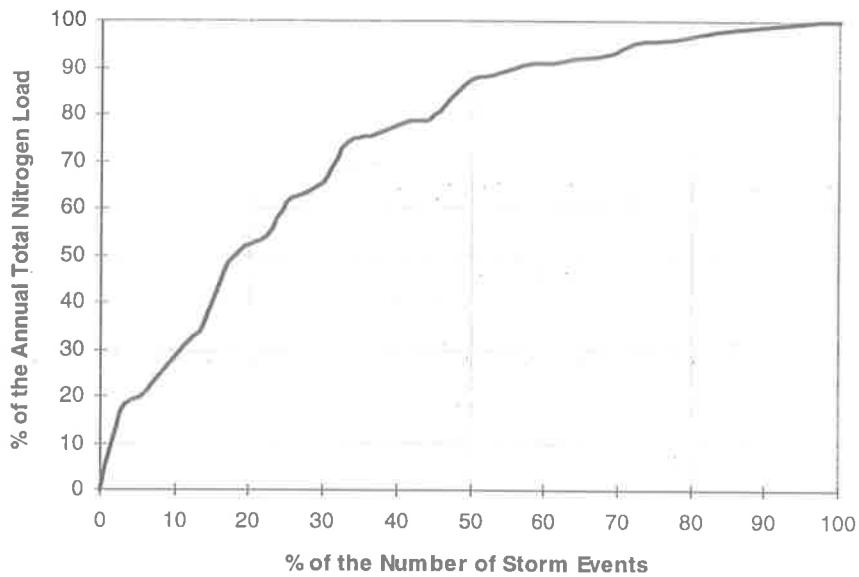


Figure 7.23 : Distribution of total nitrogen event loads in the North Arm East (AU504101) Catchment

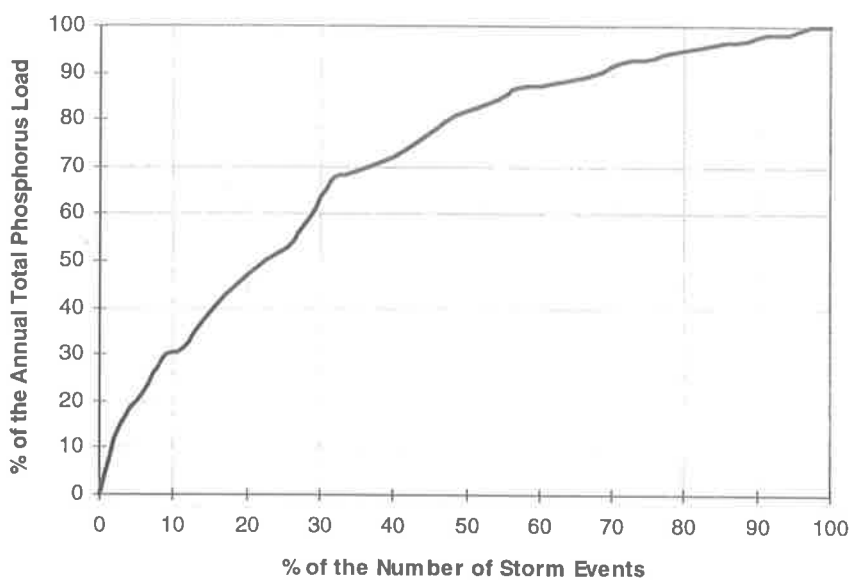


Figure 7.24 : Distribution of total phosphorus event loads in the North Arm East (AU504101) Catchment

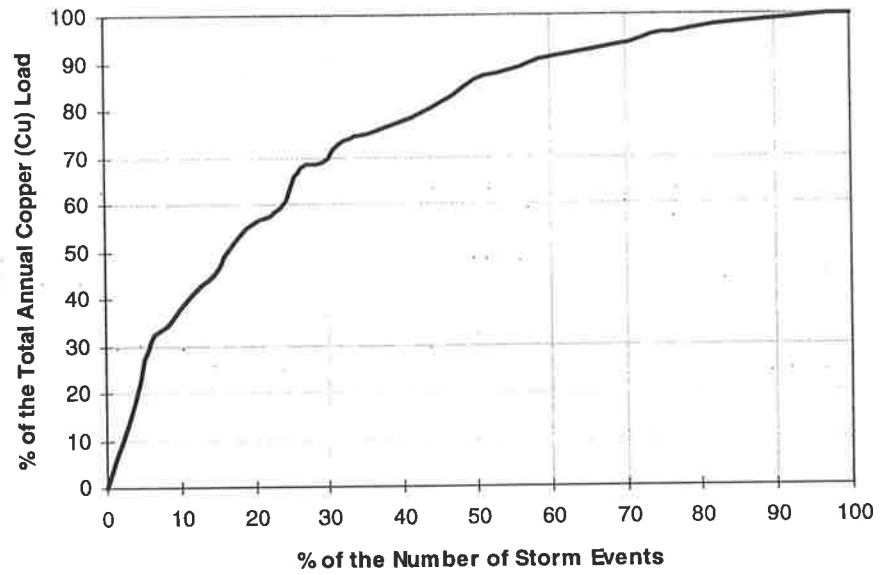


Figure 7.25 : Distribution of copper (Cu) event loads in the North Arm East (AU504101) Catchment

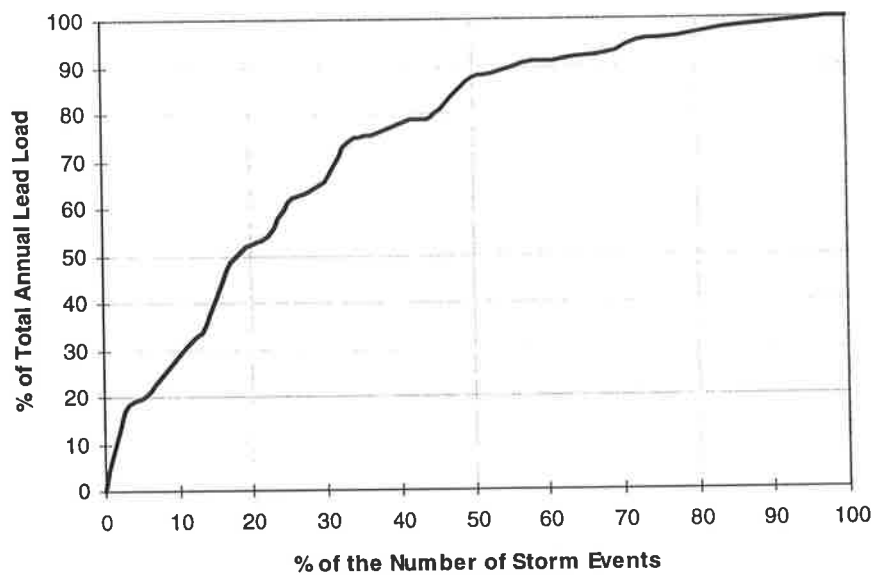


Figure 7.26 : Distribution of lead (Pb) event loads in the North Arm East (AU504101) Catchment

Figure 7.25 outlines the distribution of the annual copper load. It is evident 62% of the annual copper load comes from only 25% of the events. Figure 7.26 shows the distribution of the annual lead load. 61% of the annual lead load is from only 25% of the events.

In summary this section shows that a large proportion of the total annual contaminant load is from a small proportion of events. The largest 9 events (25% of the total number of monitored events) contribute to between 53% and 62% of the total annual load of nitrogen, phosphorus, lead and copper.

There are a number of interventions that effect the distribution of annual pollutant load. The size of the event, frequency of street sweeping and construction activity in the catchment can affect the pollutant load in each event. The length of dry period before each event can be directly related to the build up of pollutants. Table 7.28 outlines the build up time of each event in the North Arm East (AU504101) Catchment as well as the concentration of particulate phosphorus that was recorded (event mean concentration, *mg/L*) from each event. The average event mean concentration from events with less than 7 days build up time is 0.25*mg/L* particulate phosphorus. The average event mean concentration from events with between 7 and 14 days build up time is 0.30*mg/L* particulate phosphorus. The average event mean concentration from events with more than 14 days build up time is 0.51*mg/L* particulate phosphorus.

Although it has been demonstrated that the build up time between events can affect the concentration of pollutants, the effect of washoff also has an effect. The pollutant concentrations at the bottom of the catchment are reliant on both build up and washoff processes, and the effect each has is often hard to separate from the other (Duncan, 1995). If build up was the only variable that affected the pollutant runoff concentration then you would expect that the fourth column in Table 7.28, the concentration of particulate phosphorus, would range from the maximum concentration at the top of the table to the minimum concentration at the bottom the same as the build up column. It does not, which shows that other influences such as the washoff process also play a part in the overall contamination of urban stormwater.

TABLE 7.28 : Build up time for each event in the North Arm East (AU504101) Catchment

Storm date	Time since last event (days)	Runoff Volume (ML)	Particulate Phosphorus EMC (mg/L)	Particulate Phosphorus Load (kg)
2/05/97	80	3.9	1.60	6.28
6/12/96	60	49.4	0.56	27.53
14/01/97	38	6.3	0.56	3.49
16/3/96	37	28.8	0.22	6.40
17-18/6/96	35	15.1	0.17	2.49
26-27/08/96	26	103.1	0.22	22.27
24/01/96	24	13.8	0.73	10.03
6-7/04/96	20	25.5	0.20	5.00
12(a)/05/96	17	11.9	0.36	4.27
6/02/97	14	170.1	0.37	62.75
8/02/96	14	27.0	0.51	13.80
25/4/96	12	66.5	0.23	14.97
16/07/96	10	39.2	0.15	5.73
28-29/7/96	9	14.2	0.27	3.87
13/4/96	6	79.3	0.35	27.42
30/09/95	6	24.9	0.30	7.42
28/6/96	5	32.9	0.22	7.08
22/6/96	4	27.4	0.37	10.14
31/7/96	3	105.6	0.24	25.46
4/07/96	3	90.9	0.07	5.91
6/05/97	3	10.7	0.17	1.86
2/10/95	2	18.5	0.15	2.70
18/7/96	2	11.1	0.35	3.84
1/07/96	2	4.4	0.18	0.76
19/7/96	1	67.3	0.30	20.32
18/6/96	1	50.6	0.15	7.54
12(b)/05/96	1	45.9	0.75	34.18
29/6/96	1	40.9	0.13	5.44
2-3/5/97	1	21.9	0.33	7.11
23/6/96	1	17.3	0.13	2.20
9/02/96	1	12.0	0.19	2.27
3(b)/5/97	1	11.8	0.31	3.63
5-6/07/96	1	8.5	0.19	1.61
6(b)/07/96	1	2.2	0.11	0.24

7.8 Continuous Real Time Monitoring

This report has presented results from laboratory analysis of samples collected during event flows which has highlighted the variability of urban stormwater quality both between and during storm events.

The continuous real time monitoring of various water quality parameters at each monitoring station includes all or some of the following parameters; stage height, water velocity, dissolved oxygen, pH, turbidity, temperature and electrical conductivity. The emphasis of this report has been on the collection and measurement of storm event samples, however the following sections briefly investigate some trends and results observed from the continuous real time monitoring to date.

7.8.1 Overview of the Continuous Real Time Data Set

The length of the continuous real time data sets varies between each of the catchments depending on when instrumentation was installed at the monitoring stations. Table 7.29 below outlines the length of the continuous real time data set for each monitoring station.

TABLE 7.29 : Continuous Probe Data Set

Station	Catchment	Recorded Data Set
AU504101	North Arm East Drain	April 1994 - July 1997
AU504102	HEP Drain	January 1995 - July 1997
AU504103	Dunstan Road Drain	September 1994 - July 1997
AU504104	North Arm West Drain	July 1994 - July 1997
AU504105	Eastern Parade Drain (Gillman)	September 1996 - July 1997

The continuous probe data sets from the four catchments monitoring inflows to the Barker Inlet Wetland contain continuous probes monitoring stage height, water velocity, turbidity, electrical conductivity, pH, dissolved oxygen and temperature. The real time monitoring data set for the Eastern Parade (AU504105) station monitoring inflows to the Magazine Creek Wetland contains data for the probes of upstream and downstream stage height and water velocity only. Appendix N outlines the whole continuous real time data set for each catchment.

7.8.2 Electrical Conductivity

The electrical conductivity is typically high during periods of low flow but decreases as stormwater events pass. This is clearly indicated by the continuous electrical conductivity data presented in Figure 7.27 recorded in the North Arm East (AU504101) Drain during a

storm event on the 21/7/95. The electrical conductivity is relatively high at the beginning of the event with a concentration of around $650\mu\text{S}/\text{cm}$. As the first peak of the storm passes the electrical conductivity decreases to around $350\mu\text{S}/\text{cm}$.

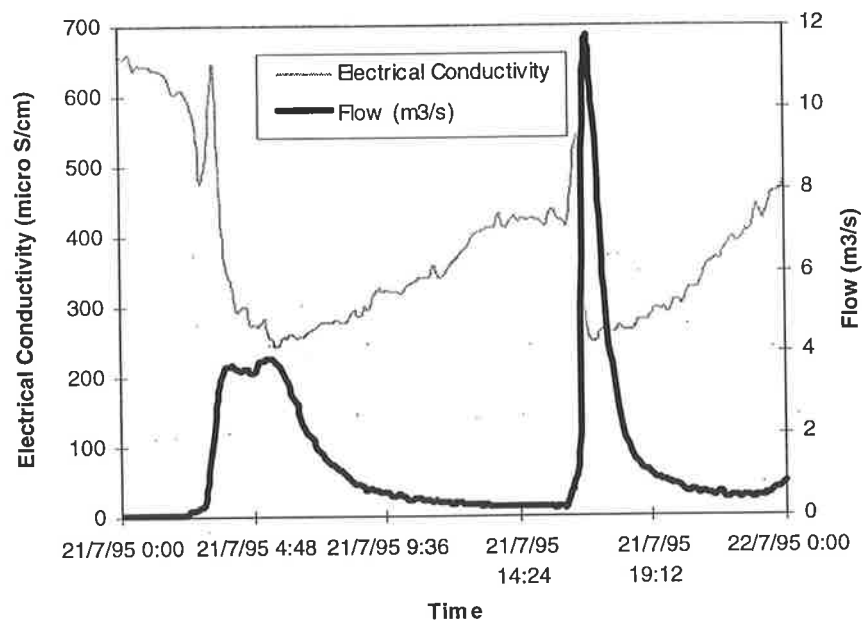


Figure 7.27 : Continuous electrical conductivity and flow during event 21/7/95 in the North Arm East (AU504101) Drain

The electrical conductivity gradually increases back up to around $500\mu\text{S}/\text{cm}$ before the second peak of the event arrives and the electrical conductivity decreases back down to approximately $250\mu\text{S}/\text{cm}$. After the second hydrograph peak passes the electrical conductivity increases again.

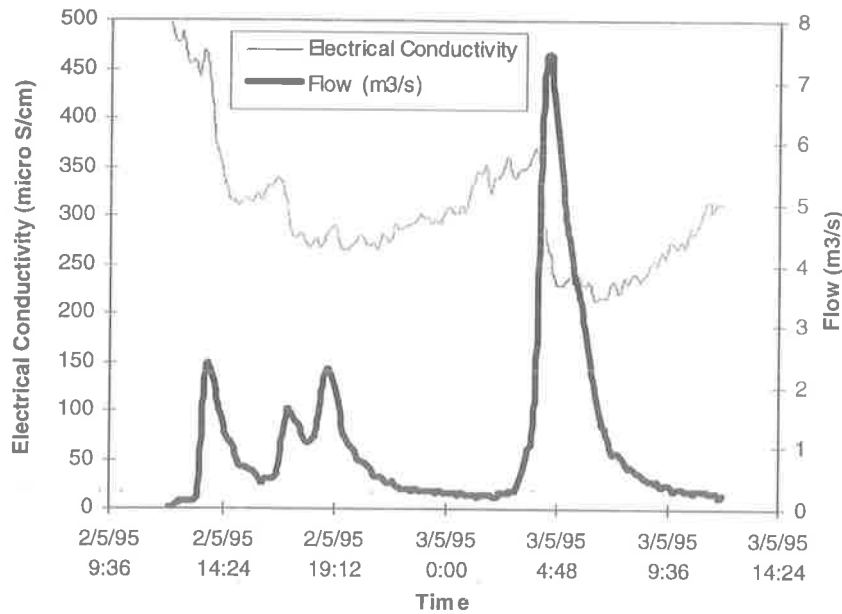


Figure 7.28 : Continuous electrical conductivity and flow during event 2-3/5/95 in the North Arm East (AU504101) Drain

The same trend is observed in Figures 7.28 and 7.29. Figure 7.28 outlines the decreasing electrical conductivity concentrations during hydrograph peaks in an event on the 2-3/5/95 in the North Arm East (AU504101) Catchment.

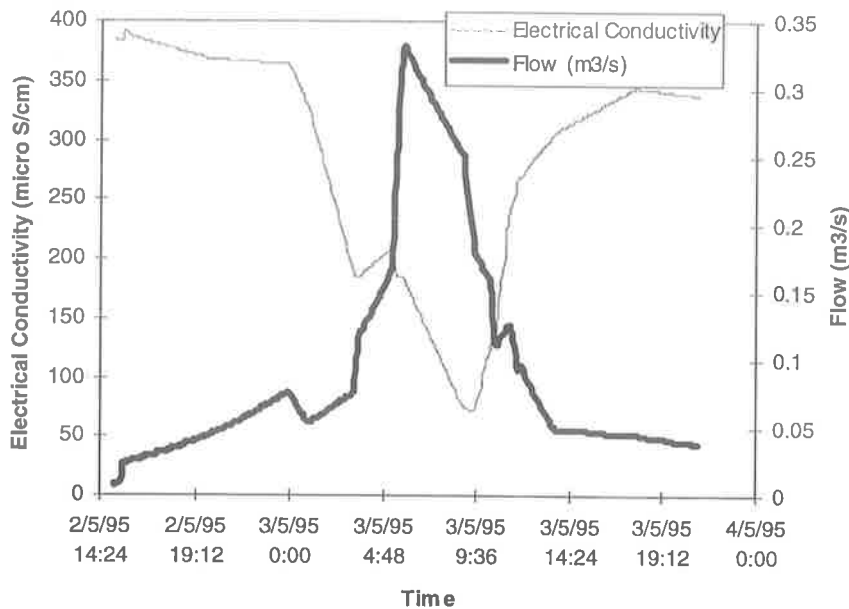


Figure 7.29 : Continuous electrical conductivity and flow during event 2-3/5/95 in the North Arm West (AU504104) Drain

Figure 7.29 outlines electrical conductivity in the North Arm West (AU504104) Drain decreasing from about $400\mu\text{S}/\text{cm}$ to around $60\mu\text{S}/\text{cm}$ during and the same event on the 2-3/5/95

7.8.3 pH

The continuously monitored pH levels are most often within the range of 7 to 9 in all of the monitored channels. The ANZECC (1992) guidelines specify an acceptable range of 6 to 9 for protection of a fresh water ecosystem. Some point discharges have been recorded with peaks of over 9 which are likely to be associated with industrial discharges as they most often do not coincide with rainfall events. The pH often decreases to around 8 during a storm event in the North Arm East (AU504101) Catchment which indicates that the level of pH in storm events is near neutral. This is shown in Figure 7.30.

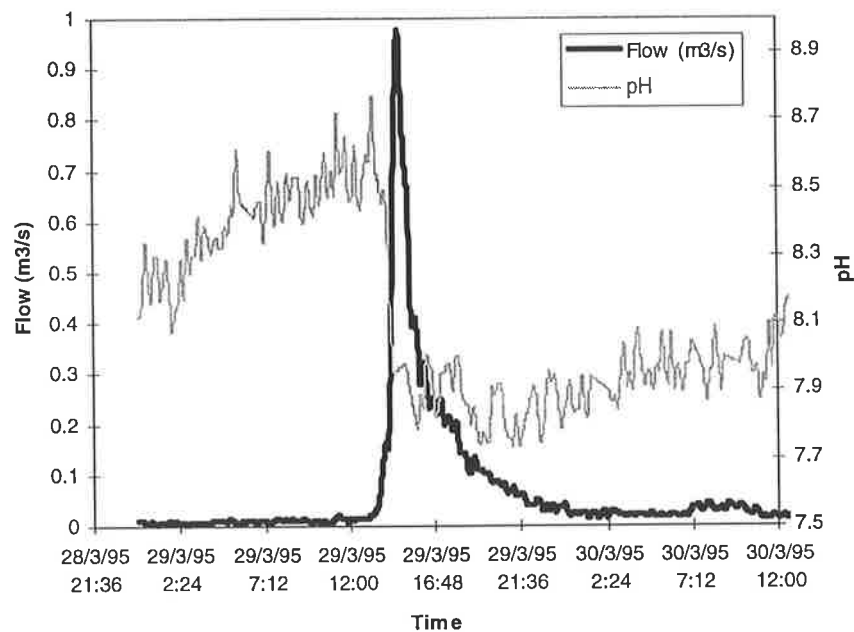


Figure 7.30 : pH level in event 29/3/95 in the North Arm East (AU504101) Catchment

7.8.4 Dissolved Oxygen

Dissolved oxygen typically increases during a storm event such as that outlined in Figure 7.31. The rapidly moving water in the channel is aerated during a storm event and is more likely to have higher dissolved oxygen levels than stagnant water.

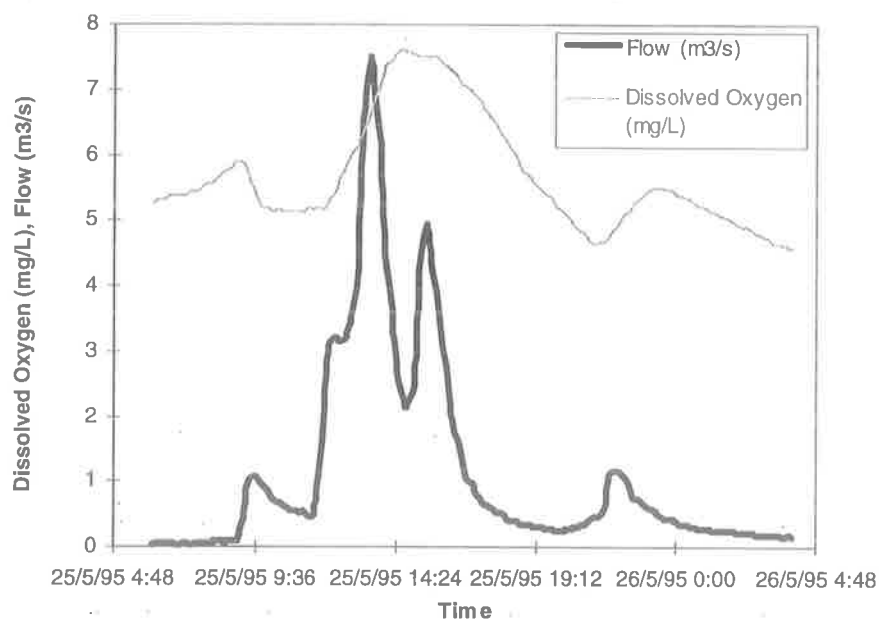


Figure 7.31 : Continuous dissolved oxygen and flow during event 25/5/95 in the North Arm East (AU504101) Drain

7.8.5 Water Temperature

The water temperature is an important parameter to measure as the readings of other parameters such as electrical conductivity are temperature dependent. The typical daily fluctuations of water temperature are shown in Figure 7.32. The low temperature of water entering the wetland system has been observed during numerous storm events. Figure 7.33 outlines the drop in water temperature during the 6/2/97 event in the North Arm East (AU504101) Drain.

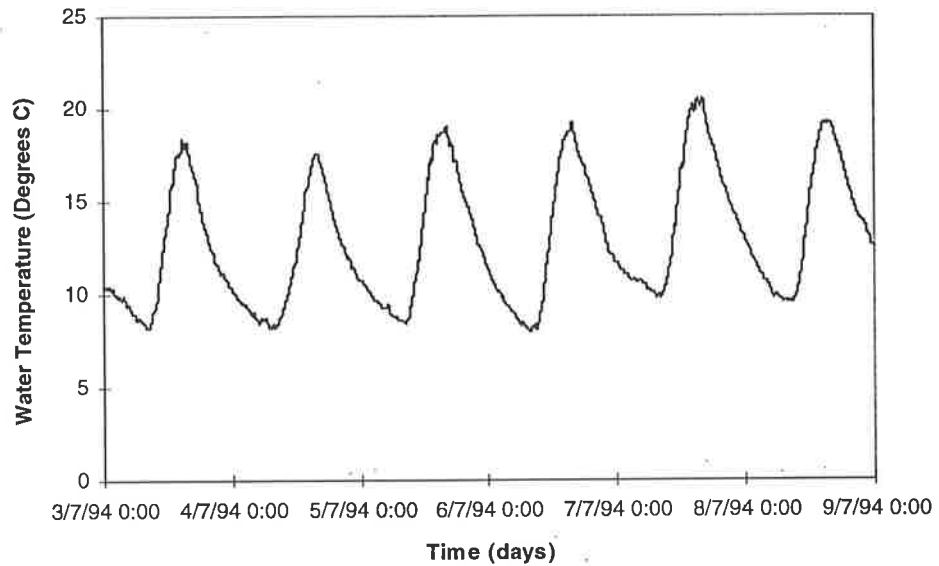


Figure 7.32 : Daily water temperature fluctuations in the North Arm East (AU504101) Drain

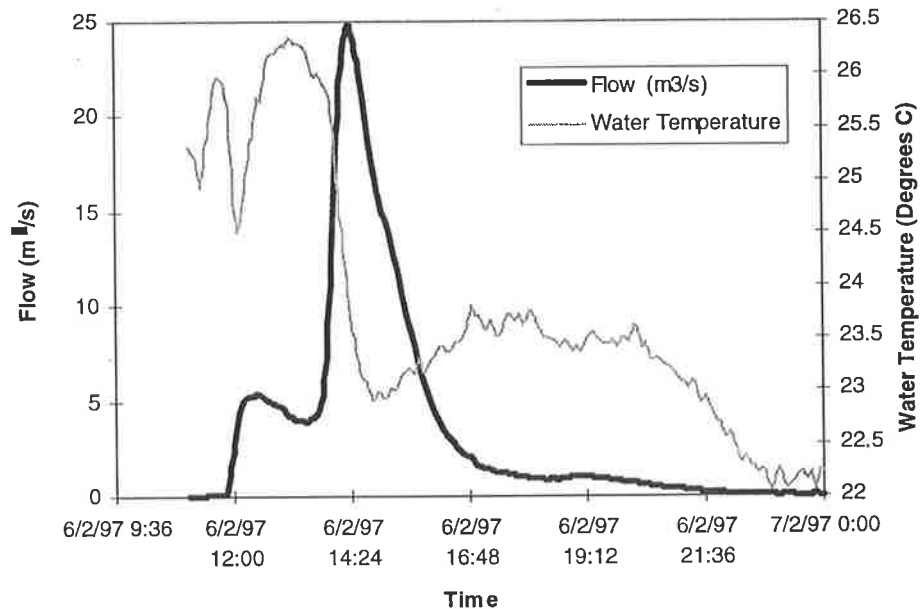


Figure 7.33 : Low water temperature entering the wetland system from event 6/2/97 in the North Arm East (AU504101) Drain

Seasonal fluctuations are evident with average summer water temperatures greater than winter which is to be expected.

7.8.6 Turbidity

Contaminants in stormwater are often associated suspended sediment as they can be adsorbed onto the finer sized particles (Leersnyder, 1993; McKergow, 1994; Passfield and Phillips,

1996 unpublished). Section 7.3.3.1 earlier outlined the strong association between total suspended solids and turbidity in the four Barker Inlet Wetland Catchments. Continuous real time monitoring of turbidity can therefore act as a reasonable indicator of water quality. The direct correlation between turbidity and other water quality parameters was found by Tomlinson et al. (1993) from The Paddocks Catchment.

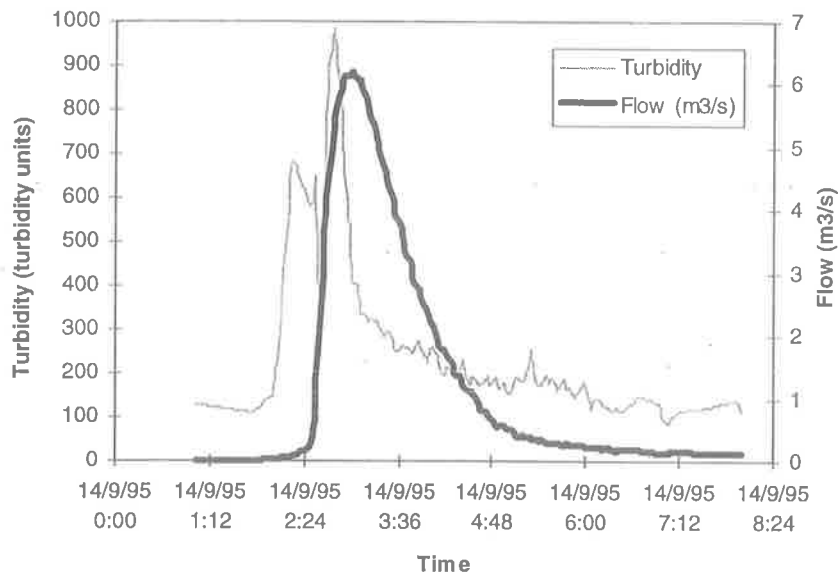


Figure 7.34 : Continuous turbidity and flow during event 14/9/95 in the North Arm East (AU504101) Drain

The continuous real time monitoring of turbidity in the North Arm East (AU504101) Catchment is outlined in Figure 7.34 and 7.35 for events on the 14/9/95 and 25/5/95 respectively. The continuous turbidity peaks before the hydrograph peaks indicating a first flush of sediment in both events.

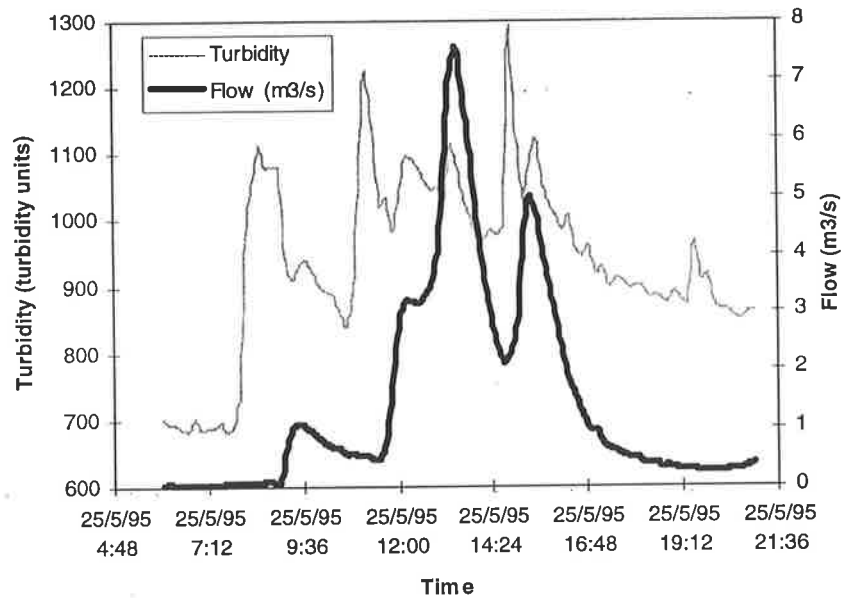


Figure 7.35 : Continuous turbidity and flow during event 25/5/95 in the North Arm East (AU504101) Drain

Using continuous real time turbidity as an indication of water quality appears to be an obvious solution and short cut for stormwater quality measurement, however it is highly dependent on the reliability and accuracy of the turbidity probe. The reliability of continuous turbidity data during this monitoring program has been poor. The fouling of turbidity probes either by algal growth or accumulated sediment on the lens occurred often, even though dual path turbidity probes were used in this study.

Relying on automatic water samples collected during storm events to indicate contaminant concentration changes during an event often fails to capture the turbidity “first flush”. This is one of the advantages of continuously monitored turbidity and is highlighted in Figure 7.38. The automatic water samples are triggered by stage height and so in Figure 7.38 the samples are taken on the rising and then falling limb of the hydrograph. There is a sharp “first flush” turbidity peak approximately 15 minutes before the rising limb of the hydrograph which the automatic water samples missed as the stage height was still below the sample threshold. The continuous turbidity probe was successful in monitoring this phenomena.

Gippel (1989(a), 1989(b), 1994, 1995) extensively investigated the use of turbidity for measuring the transport of suspended solids in natural streams as well as in stormwater from various catchments in New South Wales and Victoria. Gippel found a strong correlation between turbidity and suspended solids which was outlined earlier in Section 7.3.3.1. The

relationship between continuous real time measurement of turbidity and turbidity measured in the laboratory was investigated and is outlined in the following section.

7.8.6.1 Relationship Between Continuous and Laboratory Turbidity

The real time continuous turbidity measurements and the laboratory measurement of turbidity for four events in the North Arm East (AU504101) Drain are outlined in Figures 7.36 to 7.43.

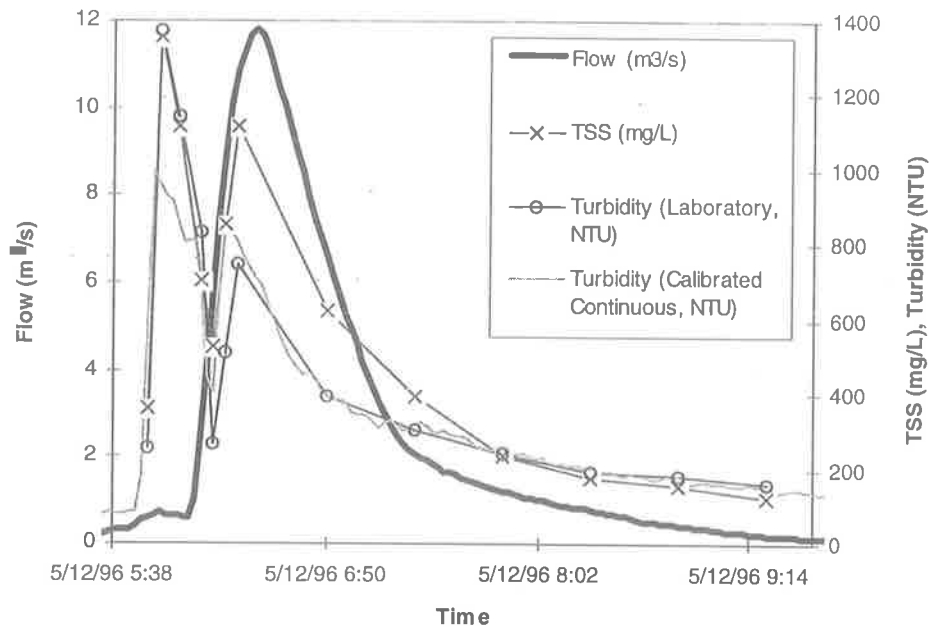


Figure 7.36 : Continuous turbidity and laboratory TSS and turbidity during event 12/5/96 in the North Arm East (AU504101) Drain

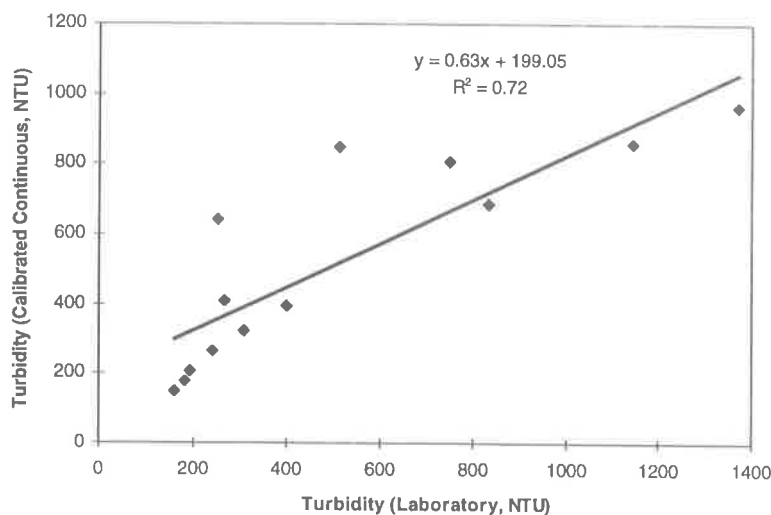


Figure 7.37 : Relationship between continuous turbidity and laboratory measured turbidity during event 12/5/96 in the North Arm East (AU504101) Drain

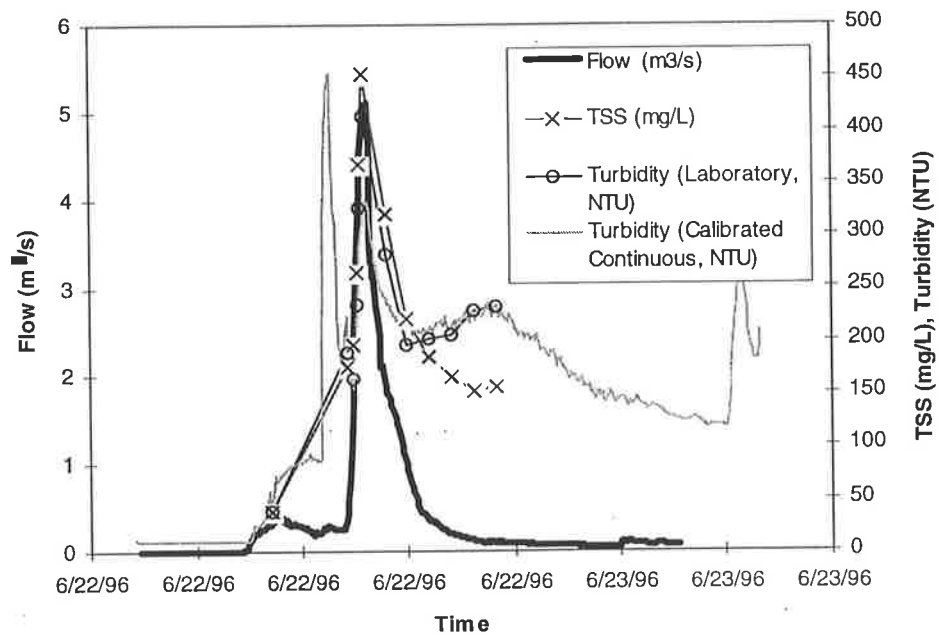


Figure 7.38 : Continuous turbidity and laboratory TSS and turbidity during event 22/6/96 in the North Arm East (AU504101) Drain

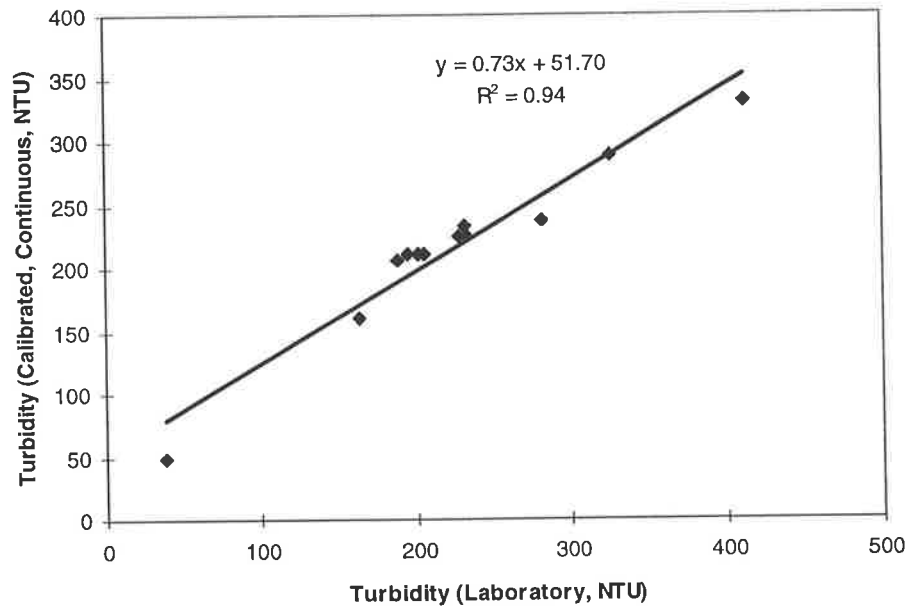


Figure 7.39 : Relationship between continuous turbidity and laboratory measured turbidity during event 22/6/96 in the North Arm East (AU504101) Drain

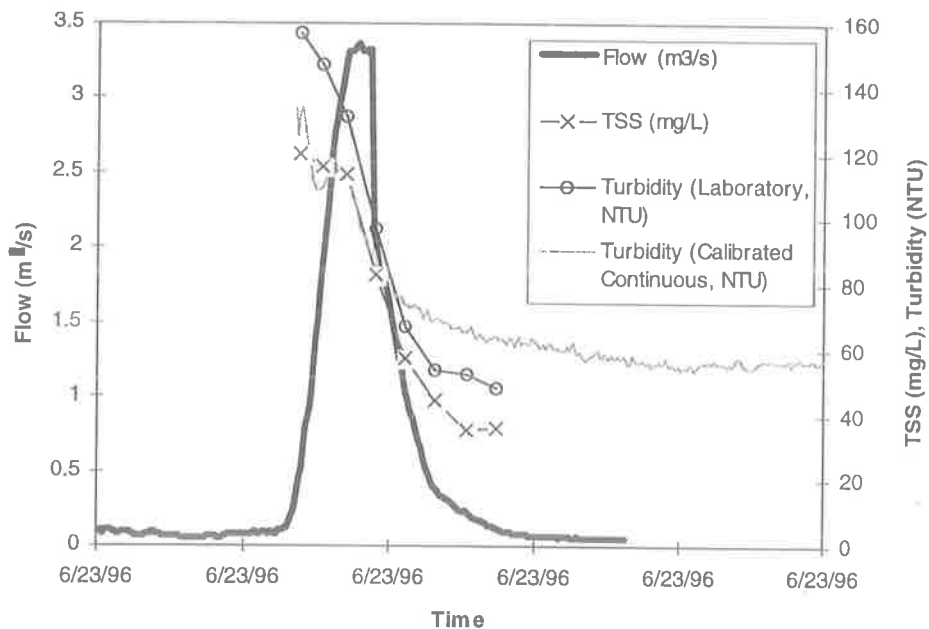


Figure 7.40 : Continuous turbidity and laboratory TSS and turbidity during event 23/6/96 in the North Arm East (AU504101) Drain

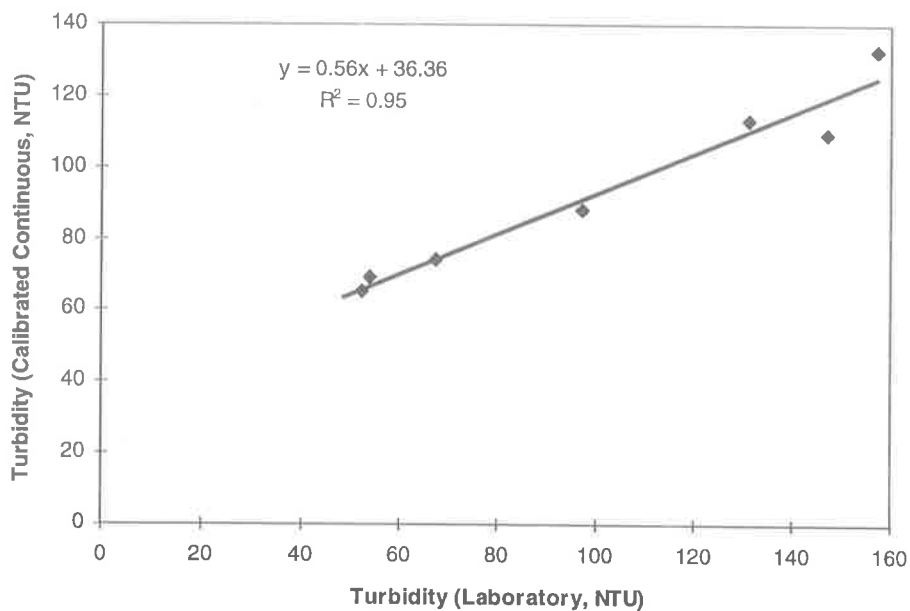


Figure 7.41 : Relationship between continuous turbidity and laboratory measured turbidity during event 23/6/96 in the North Arm East (AU504101) Drain

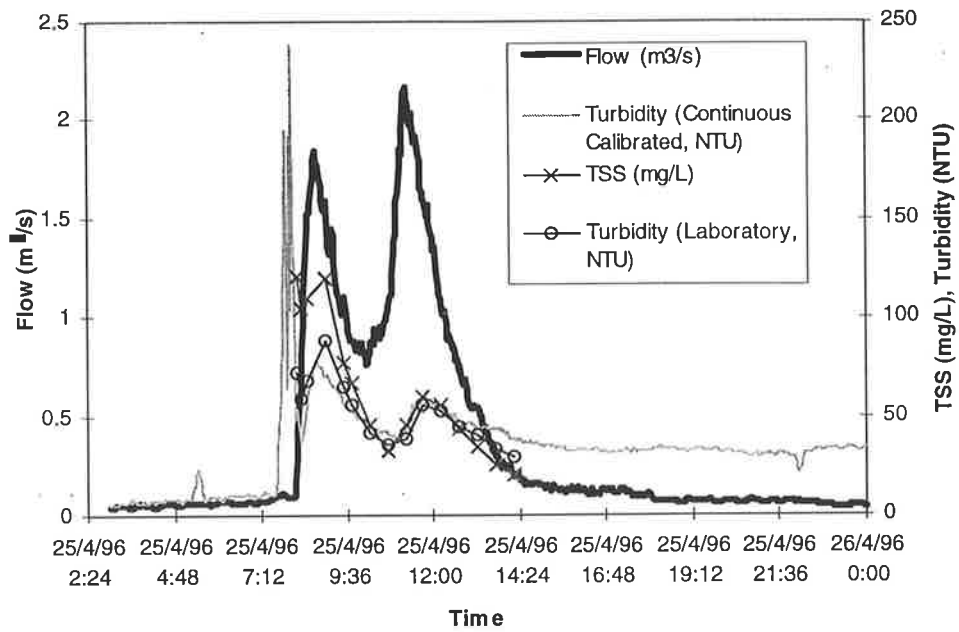


Figure 7.42 : Continuous turbidity and laboratory TSS and turbidity during event 25/4/96 in the North Arm East (AU504101) Drain

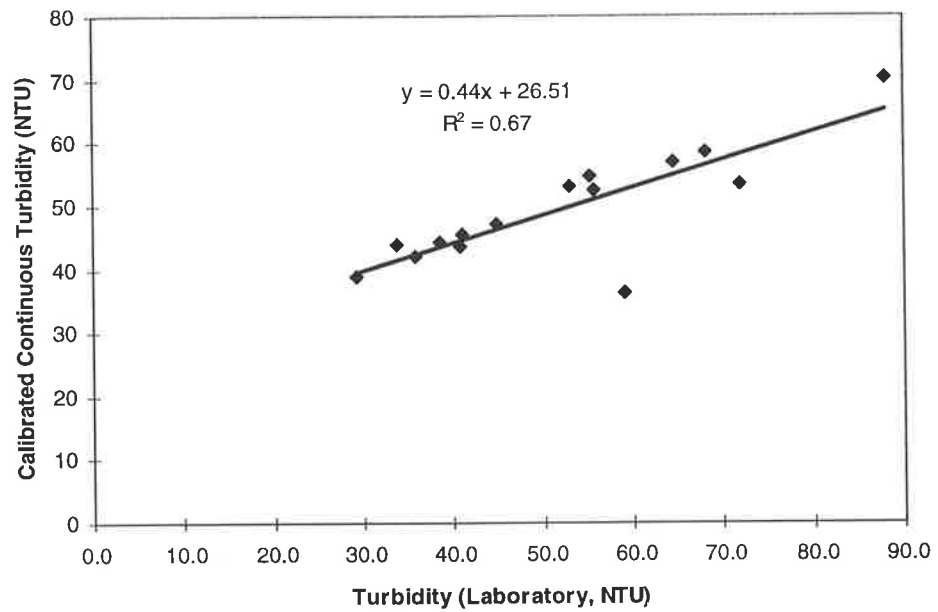


Figure 7.43 : Relationship between continuous turbidity and laboratory measured turbidity during event 25/4/96 in the North Arm East (AU504101) Drain

The relationship between continuous turbidity and laboratory measured turbidity was found to be relatively strong for the four events with R^2 values of 0.72, 0.94, 0.96 and 0.67 observed. This shows that the accurate continuous measurement of turbidity can be an excellent indication of total suspended solids and to a lesser extent other water quality parameters such as nutrients and heavy metals.

The Tain continuous turbidity probes need to be calibrated against laboratory measurement of turbidity which in turn needs careful calibration against known formazine standards. This is evident in Figures 7.34, 7.36 and 7.38.

The results outlined in this section and the results outlined by Gippel (1994, 1995, 1989a, 1989b) show continuous probes have proven to be an accurate measurement of turbidity. The main problem with the continuous measurement of turbidity in the field is the reliability of the probes.

Chapter 8

Conclusions and Recommendations

8.1 Conclusions

The water quality entering the Barker Inlet and Magazine Creek Wetlands varies significantly in each catchment. High variability between different storm events in the same catchment was evidenced by the range of composite sample results, and the sequential sample results outlined the high variability of contaminants during storm events.

A large variation of water quality between different catchments with varying land uses was observed. The contaminant concentrations in the industrial catchments of Dunstan Road (AU504103) and Eastern Parade (AU504201) were generally higher than the residential catchments. The type of open channel in a catchment had a significant effect on water quality as the discharge from the grass swale in the Dunstan Road (AU504103) catchment had low contaminant concentrations compared to the other four catchments. This was evident by the total suspended solids results as well as the contaminants associated with sediment such as heavy metals.

The input load of nutrients to the Barker Inlet Wetland from the four catchments is in the proportion of 83% nitrogen and 17% phosphorus. The nutrient load entering the Magazine Creek Wetland from the Eastern Parade (AU504201) drain is approximately 66% nitrogen and 34% phosphorus. Of the various forms of nitrogen entering the Barker Inlet Wetland approximately 80% is in the organic form, with 98% of the nitrogen entering the Magazine Creek Wetland being organic.

The metals in stormwater entering the Barker Inlet and Magazine Creek Wetlands mainly consists of aluminium and iron and to a lesser extent zinc. 43% of the metals entering the Barker Inlet Wetland consists of aluminium, 44% as iron and 8% as zinc. Of the remaining heavy metals approximately 34% is lead.

The range of total suspended solids concentrations entering the Barker Inlet Wetland was determined from analysis of sequential samples to be from 1mg/L to 2246mg/L. The concentrations of total suspended solids entering the Magazine Creek Wetland ranged from 20.6mg/L to 15853mg/L.

The range of turbidity concentrations entering the Barker Inlet Wetland was determined from analysis of sequential samples to be from 8NTU to 1898NTU. The concentrations of turbidity entering the Magazine Creek Wetland ranged from 63.4NTU to 3030NTU.

The range of total phosphorus concentrations entering the Barker Inlet Wetland was determined from analysis of sequential samples to be from 0.01mg/L to 3.12mg/L. The concentrations of total phosphorus entering the Magazine Creek Wetland ranged from 0.55mg/L to 5.40mg/L.

The concentration ranges of the other forms of nutrients were determined on an event mean concentration basis. The metal contaminants were also determined as event mean concentrations. These results were outlined for each catchment in Tables 7.5 to 7.7 and they are summarised in Table 8.1.

TABLE 8.1 : Summary of event mean concentration results, median values (mg/L)

	AU504101 NAE	AU504102 HEP	AU504103 Dunstan	AU504104 NAW	AU504201 Eastern P.
Number of Events	36	13	12	8	6
NUTRIENTS (mg/L)					
Ammonia as N	0.15	0.15	0.31	0.15	0.33
Organic Nitrogen	1.36	1.26	2.61	1.32	17.24
TKN as Nitrogen	1.55	1.38	3.25	1.48	18.72
Nitrate + Nitrite as N	0.31	0.04	0.30	0.29	0.03
Total Nitrogen	1.93	1.47	3.62	1.90	18.73
Filt. Reactive Phosphorus as P	0.08	0.17	0.16	0.08	0.91
Particulate Phosphorus	0.23	0.16	0.49	0.27	8.93
Phosphorus (Total as P)	0.34	0.39	0.76	0.35	9.85
METALS (mg/L)					
Aluminium (Al)-Total	2.300	0.652	5.705	2.540	7.000
Arsenic (As)- Inorganic	0.003	0.004	0.005	0.004	0.003
Cadmium (Cd)-Total	0.0008	0.0005	0.0013	0.0007	0.0074
Chromium (Cr)-Total	0.010	0.008	0.024	0.028	0.078
Copper (Cu)- Total	0.035	0.036	0.047	0.040	0.230
Iron (Fe)- Total	2.190	0.582	6.615	2.665	11.225
Lead (Pb) - Total	0.119	0.036	0.151	0.049	0.660
Manganese (Mn)- Total	0.065	0.047	0.143	0.087	0.350
Mercury (Hg)- Total	0.0002	0.0001	0.0001	0.0001	0.0003
Nickel (Ni)- Total	0.007	0.005	0.017	0.020	0.017
Zinc (Zn)- Total	0.443	0.207	0.592	0.323	2.884
Total suspended solids (mg/L)	122.9	20.6	407.5	131.7	422.5

The contaminant loads entering the Barker Inlet Wetland are summarised in Table 8.2. The highest proportion of the heavy metal load entering the Barker Inlet Wetland comes from the North Arm East (AU504101) catchment as it has the largest area. 67% of the annual total copper load that enters the Barker Inlet Wetland and 84% of the annual total lead load is from the North Arm East (AU504101) catchment. The input loads of the other heavy metal parameters are also mainly sourced from the North Arm East (AU504101) catchment. Approximately 63% of the total nitrogen load and 57% of total phosphorus annual load entering the Barker Inlet Wetland are from the North Arm East (AU504101) catchment.

TABLE 8.2 : Estimated annual yield of nutrients and heavy metals (mg/m²)

Catchment	AU504101	AU504102	AU504103	AU504104
	NAE	HEP	Dunstan	NAW
Catchment Area (km ²)	21.7	13.0	2.23	7.82
Ammonia as N	10.2	6.93	33.7	2.79
Organic Nitrogen	100	31.7	319	29.9
TKN as Nitrogen	110	38.6	355	32.7
Nitrate + Nitrite	18.8	2.28	8.61	7.93
Total Nitrogen	129	40.9	364	40.7
Dissolved Phosphorus	4.72	4.0	17.9	1.56
Particulate Phosphorus	17.5	4.77	69.2	6.32
Total Phosphorus	22.2	8.77	87.2	7.88
Aluminium (Al)-Total	190	30.9	260	71.8
Arsenic (Ar)- Inorganic	0.23	0.14	0.18	0.09
Cadmium (Cd)-Total	0.06	0.02	0.1	0.02
Chromium (Cr)-Total	0.83	0.24	1.0	0.45
Copper (Cu)- Total	2.95	1.24	4.29	0.77
Iron (Fe)- Total	184	30.4	281	82.1
Lead (Pb) - Total	10.4	0.95	9.02	1.18
Manganese (Mn)- Total	6.04	1.56	8.21	2.10
Mercury (Hg)- Total	0.02	0.01	0.01	0.01
Nickel (Ni)- Total	0.55	0.16	0.79	0.37
Zinc (Zn)- Total	32.9	5.70	34.3	6.83

It was found that when the contaminant loads are normalised as they are in Table 8.2 that the highest pollutant load is from the industrial Dunstan Road (AU504103) catchment.

The distribution of the estimated annual event load is such that a few large storms each year contribute to a large proportion of the total annual load. The largest 9 events by event volume (25% of the total 36 events) contribute 62% of the annual total nitrogen load. The same 9 events contribute 53% of the total phosphorus annual load, 62% of the annual copper load and 61% of the annual lead load.

Table 7.28 in the previous chapter outlined the effect of dry periods between events on the concentration of particulate phosphorus in the North Arm East (AU504101) catchment. On average, events with a longer build up period recorded higher concentrations of pollutants.

A runoff routing model developed for the North Arm East (AU504101) catchment using the RAFTS-XP program. The model was calibrated on gauged runoff data and a parameter selection technique was used to determine a single parameter set. The final parameter set was then verified on a number of events outside the calibration set. The model parameters are outlined in Table 8.3.

TABLE 8.3 : The North Arm East Catchment Parameters for the RAFTS-XP model

Area Type	Area (ha)	Time Lag	Initial loss (mm)	Continuing loss (Prop.)	DSC B	NSSE n
Impervious	560	31	1.47	0	0.123	-0.2
Pervious	1600	31	5.5	0.93	0.1	-0.2

The data set presented in this thesis is very valuable in light of the conclusions of Pandit and Gopalakrishnan (1997). There is very little long term annual pollutant load data available for urban stormwater and the following paragraph is an extract from their journal paper which highlights the problem with computer based annual pollutant load estimates.

“Although, ideally, simulated results should be verified by comparison with measured data, this could not be done because continuous long-term (one year or more) annual pollutant load data simply do not exist since it is very expensive to monitor the water quality of every single storm event during the year.” (Pandit and Gopalakrishnan, 1997).

The annual pollutant loads presented in this thesis fill the void that Pandit and Gopalakrishnan (1997) were referring to and are based on 18 months of continuous water quality monitoring. Almost every single storm event during this period was monitored, the few events that were missed were a result of equipment malfunction.

8.2 Recommendations

The findings of this study have highlighted a number of areas in which further investigation could complement the results of this research.

The scope of this research project was restricted to the investigation and analysis of inflow stormwater quality and quantity to the Barker Inlet Wetland. Stormwater quality and quantity at the outflow end of the wetland is an unknown quantity. As a result the effectiveness of the Barker Inlet Wetland to improve stormwater quality before it enters St. Vincent Gulf is not known. Outflow monitoring is now proceeding and is the subject of a separate study. Monitoring of quality at strategic points in the wetland should be investigated to give an indication of the effectiveness of the various cells within the wetland to improve stormwater quality.

It is recommended that future monitoring of outflow stormwater quality from the Barker Inlet Wetland and the subsequent determination of the wetlands performance be compared to the findings of Duncan (1995). Duncan (1995) investigated the treatment of stormwater by wetlands and sedimentation basins at 51 locations in four countries throughout the world. A statistical overview of wetland outflows compared to inflows was published and currently forms a good bench mark for comparison purposes.

This study has developed an understanding of the concentrations and loads of various contaminants from five different catchments during storm events. The variation of total phosphorus during storm events closely followed suspended solids behaviour. The distribution of particles and their various sizes was outside the scope of this research. Further study needs to be dedicated to investigating the particle size distribution of stormwater from each of the catchments monitored in this study. Other monitoring studies such as those by Leersnyder (1993) and McKergow (1994) generally found an increase in pollutants with decreasing particle size, and it will be interesting to see if the sediments in the catchments monitored in this study behave the same way. An analysis of particle size distributions from the various catchments will provide a sounder foundation for comparison of water quality results.

The stormwater quality from the Hindmarsh Enfield Prospect (AU504102) catchment was generally lower in contaminant concentration than the other four catchments. Although the Hindmarsh Enfield Prospect (AU504102) catchment has the highest proportion of residential land use of the five catchments, and one of the lowest percentages of commercial and industrial land uses it has been suggested that the low contaminant concentrations is mainly due to the effect of the large grass swale in the catchment. It is recommended that the effect of the grass swale be investigated more closely in future research. This can only be achieved by the construction of a monitoring station at the upstream end of the swale. A direct comparison between the inflows and outflows to the swale could then be made. Is the grass swale a source or sink for contaminants? If the quality of stormwater is vastly improved by the grass swale as it is proposed then what happens to the contaminants that are removed from the passing stormwater. Sediment core samples taken throughout the swale could shed more light on what happens to the contaminants in the grass swale.

The pollutant concentration in storm events was found to be related to the dry period between events. It is recommended that the effect of the build up and washoff processes on pollutant concentrations be more extensively investigated for the data set presented in this thesis. Ideally the build up and washoff processes should be isolated so that the effect of each one can be quantified.

This report presents the results of the first three years of stormwater monitoring from 1994 to July 1997 however the majority of the data is from 1996 and 1997. The establishment of more accurate annual contaminant yields from the catchments can only be achieved from a continuous longer data set. It is strongly recommended that this monitoring program be continued for as long as it is financially viable.

The monitoring network however could be substantially improved with the implementation of telemetric data transfer. Telemetry would decrease the turnover time between the collection and analysis of water samples which would lead to an improvement in the data quality from the monitoring programme. The 'lost time' due to instrumentation failure could be substantially reduced due to its early detection. The efficient time management of site visits based on the need for instrument cleans, sample collection and battery replacement would free up more time for analysis of current data, computer modelling and report writing.

There is a need to revise the values outlined in this report in the context of the continuing data collection programme. The average and median sequential sample and event mean concentrations need to be updated over a larger data set to increase their confidence level.

8.3 Current and Future Research Phases

Two additional research projects commenced early in 1997. The two projects, both involving Master of Engineering Science students, are investigating some of the aspects recommended in the previous section.

The first of these research projects forms phase 2 of the overall monitoring project and aims to investigate the effectiveness of the Barker Inlet Wetland to improve stormwater quality. Monitoring stations at the outflow from cell A and at the Bund (outlined in Figure 3.4) in the Barker Inlet Wetland were constructed during the early months of 1997. An additional station monitoring another inflow to cell A, the Henschke Street Drain, was also constructed.

The monitoring of the North Arm East (AU504101) and Henschke Street inflows to cell A in conjunction with outflows from cell A will be used to investigate the capacity of the wetland to reduce nutrient and sediment levels. The breakdown of nutrient forms at the inflow and outflow to cell A as well as intermediate locations will be monitored to indicate the transformations occurring within the cell. The scope of this research project will include the development of a mathematical model simulating the hydrological and ecological processes in the wetland with particular consideration given to the nutrient transformations such as nitrogen cycling and biomass productivity. The model developed in this research will be calibrated and validated on data collected from cell A of the Barker Inlet Wetland.

The second research project will involve an intensive investigation of the suspended sediment that is washed off of the four Barker Inlet Wetland Catchments. Particular attention will be given to the particle size distributions in each catchment and the concentration of pollutants associated with the different particle sizes.

The project aims to build on the results presented in this research to gain a better understanding of the generation processes and rates within the catchments. An investigation

will be undertaken into the variation of particle sizes during a storm event, and the effect that this has on the pollutant carrying capacity of stormwater. A water quality model such as SWMM will be calibrated on field data to predict the build up and washoff of pollutants within each catchment.

References

- Ackers, P., White W. R., Perkins J. A., Harrison A. J. M. (1978). Weirs and Flumes for Flow Measurement. Chichester, Wiley.
- Alabaster, J. and Lloyd R. (1982). Water Quality Criteria for Freshwater Fish. London, Butterworths. 2nd Edition.
- Allan, D. J. (1995). Stream Ecology : Structure and Function of Running Waters, Chapman & Hall. 1st Edition. 388pp.
- Allen, H. E. and Kramer J. R. E.(1972). Nutrients in Natural Waters. New York, John Wiley. 457pp.
- ANZECC (1992). Australian Water Quality Guidelines For Fresh and Marine Waters. 205pp.
- Argue, J. R. and Scott P.(1996). Residential Stormwater : Non-Gross Pollution. Adelaide, Urban Water Resources Centre. Progress Report, May - July 1996.
- ARR (1989). Australian Rainfall and Runoff : A Guide to Flood Estimation. Canberra, The Institution of Engineers, Australia. Vol 1(2) 375pp. Revised Edition.
- Baca, E., Bedient P. B., Olsen R. (1982). "Urban Impacts of Water Supply Reservoir." Journal of the Environmental Engineering Division, Proceedings of the American Society of Civil Engineers **108**(EE1): 73-87.
- Berner, E. K. and Berner R. A.(1987). The Global Water Cycle. Englewood Cliffs, New Jersey, Prentice-Hall.
- Bos, M. G. (1989). Discharge Measurement Structures. The Netherlands, ILRI. 3rd Revised Edition, 401pp.

CCREM (1991). Canadian Water Quality Guidelines. Ottawa.

Chapman, D. (1996) A guide to the use of biota, sediments and water in environmental monitoring. Chapman and Hall. London.

Clark, R. D. S. and Crawley P. D. (1987). The Development of a Methodology for the Calculation of Daily Loads and Concentrations of Nitrogen, Phosphorus and Turbidity Transported in Rivers in the Mt Lofty Ranges of South Australia. Adelaide, EWS. August 1987, Ref 87/16.

Cordery, I. (1977). "Quality Characteristics of Urban Stormwater in Sydney, Australia." *Water Resources Research* **13**(1): 197-201.

Cowen, W. F. and Lee G. F. (1973). "Leaves as Source of Phosphorus." *Environmental Science and Technology* **7**(9): 853-854.

Creagh, C. (1992). What Can Be Done About Toxic Algal Blooms ? *Ecos*, Vol 72, pp.14-19.

Cugley, J., Suter P., Ockenden A., Fisher G., Carter J., Daniell T. M. (1997). Monitoring Catchment Water Quality Draft Guidelines for EPA.

Cullen, P. and Rosich, R.S. (1979). A phosphorus budget for Lake Burley Griffin and management implications for urban lakes. Canberra, AWRC Technical Paper No 31.

Cullen, P. (1980). Sources of Nutrients to Aquatic Ecosystems. Proceedings of the Eutrophication Workshop, Canberra, Australian Government Publishing Service. pp.44-57.

Dally, L. K. (1984). Urban Storm Drainage Detention Facilities for Runoff and Water Quality Control. Proceedings of the Third International Conference on Urban Storm Drainage, Goteborg, Sweden. Vol 1(4) pp.47-56.

- Dalrymple, T. and Benson M. A. (1967). Measurement of Peak Discharge by the slope-area method US Geological Survey Techniques of Water Resources Investigations. Washington DC, USGS. **Book 3:** Chapter A2.
- Daniell, T.M. and Williams, B.G (1997) Determination of Urban Runoff Pollutant Load - Both Quality and Quantity of Flow are Important, Workshop on Local Scale Hydrological Processes in Islands, Highlands and Urban Areas in Malaysia: Needs for Future Direction, 12-14 November 1997, Kuala Lumpur, IHP Malaysia and Unesco.
- Daniell, T.M., Williams, B.G., Fisher, G. (1997) Monitoring Stormwater Quantity - Some Hints and Pitfalls, Stormwater in the next millennium, Hydrological Society of South Australia, 23rd October 1997, Adelaide, South Australia.p 1-7.
- Dempsey, B. A., Tai Y. L., Harrison, S.G. (1993). "Mobilization and Removal of Contaminants Associated with Urban Dust and Dirt." *Water Science and Technology* **28**(3-5): 225-230.
- Dorney, J. R. (1986). "Leachable and Total Phosphorus in Urban Street Tree Leaves." *Water, Air and Soil Pollution* **28**: 439-443.
- Duncan, H. P. (1995). A Review of Urban Storm Water Quality Processes. Melbourne, Cooperative Research Centre for Catchment Hydrology. 38pp.
- Eco Management Services (1994). Magazine Creek and Range Wetlands (At Gillman) Technical Feasibility Study. Adelaide, MFP Development Corporation. 50pp.
- Ellis, J. B. (1977). The Characterization of Particulate Solids and Quality of Water Discharged from an Urban Catchment. Effects of Urbanization and Industrialization on the Hydrological Regime and on Water Quality, Proceedings of the Amsterdam Symposium. pp.283-291.
- Falkland, A. C., Daniell T. M., Johns, I.A., Malone, D.C., White, I. (1991). Hydrological Instrumentation : A Review of Recent Developments in Australia. International Hydrology and Water Resources Symposium 1991. pp.151-164.

- Ferrara, R. A. and Witkowski P. (1983). "Stormwater Quality Characteristics in Detention Basins." *Journal of Environmental Engineering* **109**(2): 428-447.
- Gamble, S. (1997). *Monitoring the Nutrient Inflows and Outflows of a Constructed Urban Wetland*. Civil & Environmental Engineering. Adelaide, The University of Adelaide.
- Gippel, C. J. (1989a). The use of turbidity instruments to measure upstream water suspended sediment concentration. Canberra, ACT, Department of Geography and Oceanography, University College, Australian Defence Force Academy. 204pp.
- Gippel, C. J. (1989b). "The use of turbidimeters in suspended sediment research." *Hydrobiologia* **176/177**: 465-480.
- Gippel, C. J. (1994). "Monitoring Turbidity of Stream Water." *Australian Journal of Soil and Water Conservation* **7**(No. 4, November 1994).
- Gippel, C. J. (1995). "Potential of Turbidity Monitoring for Measuring the Transport of Suspended Solids in Streams." *Hydrological Processes* **9**: 83-97.
- Golterman, H. L. (1975). *Physical Limnology : An Approach to the Physiology of Lake Ecosystems*. New York, Elsevier Scientific Publishing Company. 489pp.
- Gordon, N. D., McMahon T. A., Finlayson, B. (1992). *Stream hydrology : an introduction for ecologists*. Chichester, John Wiley. 526pp.
- Gower (1980). "<http://h2osparc.wq.ncsu.edu/info/do.html>."
- Goyen, A. G. and Aitken, A. P. (1976). *A Regional Stormwater Drainage Model*. Hydrology Symposium, 1976, Institution of Engineers, Aust. National Conference Publication 76/2.

- Grizzard, T. J., Randall C. W., Weand, B.L., Ellis, K.L. (1986). Effectiveness of Extended Detention Ponds. Urban Runoff Quality - Impact and Quality Enhancement Technology, Proceedings of an Engineering Foundation Conference, New Hampshire, ASCE. pp 323-337.
- Grove, A. T. (1972). The dissolved and solid load carried by some West African rivers :. *Hydrol. N. Senegal, Benue and Shari, J*: 16, 277-300.
- HACH Company (1991). Model 2100P Portable Turbidimeter Instrument and Procedure Manual. 70pp.
- Halverson, H. G., DeWalle D. R., Sharpe, W.E. (1984). "Contribution of Precipitation to Quality of Urban Storm Runoff." *Water Resources Bulletin* **20**(6): 859-864.
- Herschy, R. W. (1978). *Hydrometry, principles and practices*, John Wiley and Sons. 511pp.
- Herschy, R. W. (1985). *Streamflow measurement*. London and New York, Elsevier Applied Science Publishers Ltd. 553pp.
- Jacobi, D. and Murphy S. (1996). *Evaluation of an Urban Stormwater Wetland*. Adelaide, Department of Civil & Environmental Engineering, The University of Adelaide. 167pp.
- Katchka, A. M., Mackay S. M., Simeone, M.A. (1994). *Sampling Methodology for the Assessment of Nutrient and Bacterial Loads in Stormwater*. Water Down Under 94, International Hydrology and Water Resources Symposium, Adelaide 21-25 November 1994.
- Kemp, D. (Pers. Com., 1997). *Personal Communication*. Department of Transport, Adelaide, South Australia.
- Kluesener, J. W. and Lee G. F. (1974). "Nutrient Loading from a Separate Storm Sewer in Madison, Wisconsin." *Journal of the Water Pollution Control Federation* **46**(5): 920-936.

Kobayashi, J. (1971). Relation between the "Itai-Itai" disease and the pollution of river water by cadmium from a mine. *Adv. Water Pollut. Res. Proc. Int. Conf.*, 5th, San Fransisco and Hawaii. 1, I25 : 1-7.

Koehn, J. D. and O'Connor, W. D. (1990). Biological information for management of native freshwater fish in Victoria. Melbourne, Department of Conservation & Environment.

Konno, H. and Nonomura, S.(1981). Sediment Discharge on Land Grading Areas in Kohoku, Japan. *Urban Stormwater Quality, Management, and Planning, Proceedings of the Second International Conference on Urban Storm Drainage*, Urbana, Illinois, Water Resources Publications, Colorado. pp.209-217.

Laidler, G. (1991). *Environmental Chemistry : An Australian Perspective*. Melbourne : Longman Cheshire, 1991, 233pp.

Lawrence, I. (1986). Source and Fate of Urban Runoff Constituents and their Management. *Stormwater Quality in Urban Areas*, Wollongong, Water Research Foundation of Australia. 2-1 - 2-11.

Leersnyder, H. (1993). The Performance of Wet Detention Ponds for the Removal of Urban Stormwater Contaminants in the Auckland (NZ) Region. Auckland, University of Auckland: 118.

Mackay, N. and Eastburn, D. Eds. (1990) "The Murray", The Murray Darling Basin Commission, Canberra, Australia, 393pp.

Maier, H. R. and Dandy, G. C. (1994). Blue Green Algae in the River Murray. Adelaide, The University of Adelaide, Department of Civil and Environmental Engineering. December 1994, G25.

Makepeace, D. K., Smith D. W., Stanley, S.J. (1995). *Urban Stormwater Quality : Summary of Contaminant Data*. Critical Reviews in Environmental Science and Technology, CRC Press Inc. 139pp.

- Malmquist, P. and Svensson, G. (1977). Urban Storm Water Pollutant Sources. Effects of Urbanization and Industrialization on the Hydrological Regime and on Water Quality, Proceedings of the Amsterdam Symposium. pp31-38.
- Marsalek, J. (1990). PAH Transport by Urban Runoff from an Industrial City. Proceedings of the Fifth International Conference on Urban Storm Drainage, Osaka, Japan. Editors Iwasa, Y., Sueishi, T. 1(3) pp 481-486.
- Marsalek, J. (1992). Overview of Sediment Issues in Urban Drainage. International Symposium on Urban Stormwater Management, Sydney. pp.30-37.
- McCuen, R. H. (1989). Hydrologic Analysis and Design. Englewood Cliffs, New Jersey, Prentice Hall pp 6
- McKergow, L. (1994). Urban Stormwater Quality. Auckland, Auckland Regional Environment Council. Rep. No. 49.pp.45.
- MDBC (1993). Algal Management Strategy for the Murray-Darling Basin (Draft). Canberra.
- Menzies (1997). Design and Cleaning of Gross Pollutant Traps. Stormwater in the Next Millennium : Exportable Innovations in Stormwater Management, Adelaide, South Australia.
- Meybeck M. (1982). "Carbon, nitrogen and phosphorus transport by world rivers." : 401-450.
- MFP Australia (1995). Revised Initial Patawalonga Catchment Management Plan. Adelaide, Patawalonga Catchment Water Management Board. August 1995, 59pp.
- MFP Australia (1996). "Annual Review."
- Miller, G. T. J. and P. Armstrong (1982). Living in the Environment : concepts, problems and alternatives. Belmont, California, Wadsworth International Group. International Edition.

- NCSU (1997). Dissolved Oxygen Levels, <http://h2osparc.wq.ncsu.edu/info/do.html>.
- O'neil, P. (1985). Environmental Chemistry. London, Chapman & Hall. 2nd Edition, 268pp.
- Pandit, A. and Gopalakrishnan, G. (1997). "Estimation of Annual Pollutant Loads Under Wet-Weather Conditions." *Journal of Hydrologic Engineering*, October 1997: pp 211-217.
- Passfield, G. R. A. and Phillips, S. C. (1996). Suspended Sediment Characteristics, Dry Creek Catchment, South Australia. Civil & Environmental Engineering. Adelaide, University of Adelaide: 103. November 1996, Final Year Research Project.
- pH Environment (1995). Patawalonga Catchment Sediment Quality. A survey of silts in the Subdrains. pH environment, 58pp.
- Prasad, D., Henry, J. G., Kovacko, R. (1980). Pollution Potential of Autumn Leaves in Urban Runoff. Proceedings of the International Symposium on Urban Storm Runoff, Lexington, Kentucky. Editors : Meadows, M.E., DeVore, R.W., pp.197-202.
- RAFTS-XP (1996). Runoff Analysis and Flow Training Simulation with XP Graphical Interface, User's Manual. Version 5. 169pp.
- Randall, C. W., Grizzard T. J., Helsel, D.R., Griffin, D.M. (1981). Comparison of Pollutant Mass Loads in Precipitation and Runoff in Urban Areas. Urban Stormwater Quality, Management, and Planning, Proceedings of the Second International Conference on Urban Storm Drainage, Urbana, Illinois, Water Resources Publications, Colorado. pp29-38.
- Randall, C. W., Ellis K., Grizzard, T.J , Knocke, W.R. (1982). Urban Runoff Pollutant Removal by Sedimentation. Stormwater Detention Facilities - Planning, Design, Operation, and Maintenance, Henniker, New Hampshire, ASCE. pp.205-219.

- Reed, S., Mitchell C., Maslin, P. (1995). *Artificial Wetlands : Principles, Design and Management*, IWES, International Winter Environmental School. 26-30 June 1995.
- Reeder, S. W., Demayo A., Taylor, M.C. (1979). Cadmium. In *Inorganic chemical substances*, Vol. 1 of *Guidelines for surface water Quality*. Ottawa, Environment Canada.
- Rolfe, G. L., Akhtar M. A. , Arnold, M.E. (1978). "Nutrient Fluxes in Precipitation, Throughfall, and Stemflow in an Oak-Hickory Forest." *Water Resources Bulletin* **14**(5): 1220-1226.
- Sartor, J. D. and Boyd G. B. (1972). *Water Pollution Aspects of Street Surface Contaminants*. Washington, D.C., United States Environmental Protection Agency. November 1972, EPA-R2-72-O81.
- Shaheen, D. G. (1975). *Contributions of Urban Roadway Usage to Water Pollution*. Washington, D.C., United States Environmental Protection Agency. March 1975. EPA-600/2-75-004.
- Sharpin, M. G. (1992). *Non-point source nutrients in the Canberra region*. Department of Civil and Maritime Engineering, University College, University of New South Wales, Australian Defence Force Academy. **1**(2) 120pp+App.
- Smith (1990). "<http://h2osparc.wq.ncsu.edu/info/do.html>."
- Smith, S. D., Wellington A. B., Nacklinger, J.L., Fox, C.A. (1991). "Functional responses of riparian vegetation to streamflow diversion in the eastern Sierra Nevada." *Ecol. Appl.* **1**, 89-97.
- Spangberg, A. and Niemczynowicz J. (1992). "High Resolution Measurements of Pollution Wash-Off from an Asphalt Surface." *Nordic Hydrology* **23**: 245-256.
- Spangberg, A. and Niemczynowicz J. (1993). *Measurements of Pollution Wash-off from an Asphalt Surface*. Proceedings of the Sixth International Conference on Urban Storm Drainage Niagara Falls, Ontario, Canada.

- Sutherland, P. D. (1981). Significance of sewage lagoon algae in receiving waters. Proc. Ninth Federal Convention, Aust. Water & Wastewater Assoc., Canberra.
- Takeuchi, T. (1972). Distribution of mercury in the environment of Minamata Bay and the inland Ariaka Sea. Environmental Mercury Contamination. R. H. a. B. D. D. (Editors). Mich., Science Publishers: 79-81.
- Taylor, J.K, Thompson, B.P, Shepherd, R.G. (1974). The Soils and Geology of the Adelaide Area. Bulletin 46, Geological Survey of South Australia. Department of Mines. 90pp.
- Tomlinson, G. W., Fisher A. G., Clark, R.D.S. (1993). The Paddocks : Stormwater, a Community Resource. Adelaide, EWS. September 1993, Rep. 93/11.
- Unidata (1995). Unidata Starflow Ultrasonic Doppler Instrument User's Manual. Australia, Lynn MacLaren Publishing. Revision A, September 23 1994, 76pp.
- ~~USEPA~~ (1983). Results of the Nationwide Urban Runoff Program. Washington, US Environmental Protection Agency, Water Planning Division. 440/5-87-001.
- ~~USEPA~~ (1986). Methodology for Analysis of Detention Basin for Control of Urban Runoff Quality. Washington DC, US Environmental Protection Agency, Water Planning Division.
- Vorreiter, L. and Hickey, C. (1994). Incidence of the First Flush Phenomenon in Catchments of the Sydney Region. Water Down Under 94, Adelaide, SA Vol.3, pp 359-364.
- Walker, D. J. and Gamble S. (1995). Minkara Wetland Water Quality Assessment Preliminary Report. Adelaide, Department of Civil & Environmental Engineering, The University of Adelaide. 44pp.
- Walker, D. J., Murphy S., Gamble, S. (1997). Minkara Wetland. Adelaide, Department of Civil & Environmental Engineering, The University of Adelaide.

- Walling, D.E. and Hadley, R.F. Eds. (1984). *Erosion and Sediment Yield : Some Methods of Measurement and Modelling*. Norwich, England : Geo Books. 218pp.
- Wetzel, R. G. (1983). *Limnology, Second Edition*. New York., W.B. Saunders Company.
- Whipple, W. and Hunter J. V. (1981). "Settleability of Urban Runoff Pollution." *Journal of the Water Pollution Control Federation*. Vol 53(No. 12): 1726-1731.
- Whiteley, H. R., Licsko Z. J., Corsi, R.L. (1993). Quality of Stormwater from Residential Areas in Guelph, Ontario, Canada. *Proceedings of the Sixth International Conference on Urban Storm Drainage, Niagara Falls, Ontario, Canada*. 1(2) pp.531-536.
- WHO (1980). Recommended health-based limits in occupational exposure to heavy metals. Geneva, World Health Organisation. Technical Report Series No.647.
- WHO (1984). Health criteria and other supporting information. Geneva, World Health Organisation. Volume 2 of Guidelines for drinking water quality No.647.
- Williams, B.G., Daniell, T.M., (1996a) Characterisation of Stormwater Runoff, Wingfield, South Australia. *Advanced Technology in the Environmental Field, IASTED International Conference, Gold Coast 1996*.
- Williams, B.G., Daniell, T.M., (1996b) Characterisation of Stormwater Runoff, Entering the MFP Wetland, Wingfield, South Australia. *International Conference on Water Resources and Environment Research: Towards the 21st Century, October 29-31, Kyoto, Japan*, p 61-68.
- Williams, B.G., Daniell, T.M., (1997) Ultrasonic Velocity Probes, An Aid to Development of Rating Curves, *24th Hydrology and Water Resources Symposium 24-28 November 1997, Waiwhenua, Auckland New Zealand*. p 550.

- Williams, B.G., Daniell, T.M. and Manning, P (1997) Improving Wetland Design, Documenting Inflow Loads and Tracking Pollutants, 24th Hydrology and Water Resources Symposium 24-28 November 1997, Wai-Whenua, Auckland New Zealand , p 137-142.
- Williams, B. G. and Smythe C. (1994). Modelling Rainfall Flows into Urban Wetlands at Happy Valley, South Australia, using RAFTS-XP. Adelaide. Final Year Report. Department of Civil & Environmental Engineering, The University of Adelaide. pp67.+App.
- Willing & Partners Pty Ltd. (1996). "RAFTS-XP Version 5.0 User Manual."
- WMO (1981). Measurement of River Sediments. WMO Operational Hydrology Report 16, World Meteorological Organisation, Geneva, 61pp.
- Wu, J. S., Holman R., Dorney, J. (1988). Water Quality Study on Urban Wet Detention Ponds. Design of Urban Runoff Quality Controls, Proceedings of an Engineering Foundation Conference on Current Practice and Design Criteria for Urban Quality Control, Missouri, ASCE. pp280-289.
- Yaziz, M. I., Gunting H., Sapari, N., Ghazali, A.W. (1989). "Variations in Rainwater Quality from Roof Catchments." *Water Research* 23(6): 761-765.
- Yousef, Y. A., Wanielista M. P., Harper, H.H. (1986). Design and Effectiveness of Urban Detention Basins. Urban Runoff Quality - Impact and Quality Enhancement Technology, Proceedings of an Engineering Foundation Conference, New Hampshire, ASCE. pp338-350.

Appendix A

Wetland Pond Volumes

Summary

Appendix A outlines the storage volume curves for the Barker Inlet Wetland. The storage volume curves are courtesy of Geocomp Systems (Victoria). A schematic drawing of the Barker Inlet Wetland is outlined in figure 3.2.

The first storage volume curve is for the 0.6m pond, south, which receives runoff from the North Arm East drain (AU504101).

The second storage volume curve is for the 0.85m pond, south, which receives runoff from the Hindmarsh Enfield Prospect drain (AU504102).

The third storage volume curve is for the 0.3m pond, south, which receives runoff from the Dunstan Road drain (AU504103).

The fourth and final storage volume curve is for the 0.3m pond, south, which receives runoff from the North Arm West drain (AU504104), plus the overflow from the 0.6m pond south, the 0.85m pond south and the 0.3m pond south.

Flood Volumes for the 0.6 Pond, South at 0.1 metre intervals

(Receives stormwater from the North Arm East (AU504101) catchment)

Table A-1 : Pond level/volume relationship

Level (m)	Cum. Vol (kL)
0.3	41.7
0.4	114.3
0.5	254.4
0.6	258.0
0.7	11664.9
0.8	24601.9
0.9	39109.9
1	54475.9
1.1	70447.0
1.2	86880.5
1.3	103719.1

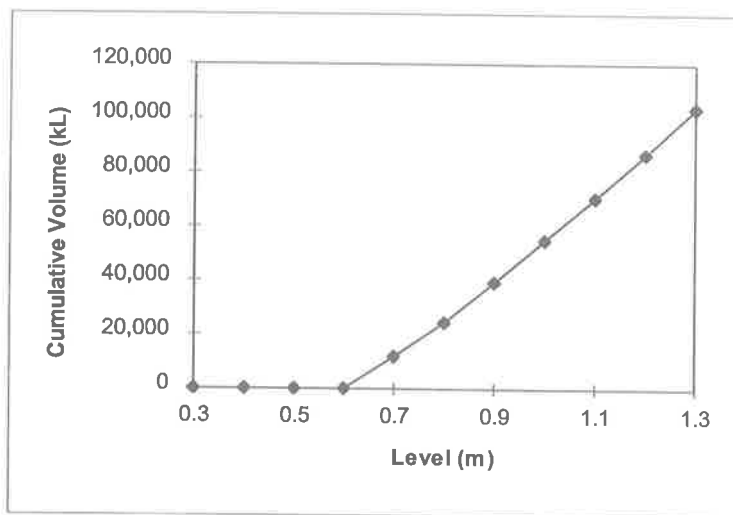


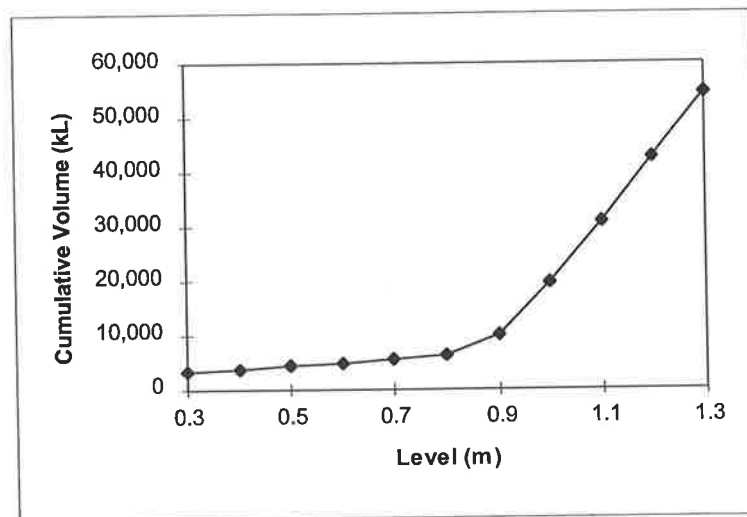
Figure A-1 : Flood Volumes in the 0.6 Pond, South

Flood Volumes for the 0.85 Pond, South at 0.1 metre intervals

(Receives stormwater from the Hindmarsh Enfield Prospect (AU504102) catchment)

Table A-2 : Pond level/volume relationship

Level (m)	Cum. Vol (kL)
0.3	3231.0
0.4	3748.4
0.5	4297.7
0.6	4879.5
0.7	5496.7
0.8	6198.3
0.9	10058.9
1	19556.3
1.1	30921.4
1.2	42614.3
1.3	54614.5

**Figure A2 : Flood Volumes in the 0.85 Pond, South**

Flood Volumes for the 0.3 Pond, South at 0.1 metre intervals

(Receives stormwater from the Dunstan Road (AU504103) catchment)

Table A-3 : Pond level/volume relationship

Level (m)	Cum. Vol (kL)
0.3	217.4
0.4	2688.2
0.5	5517.3
0.6	8541.8
0.7	11724.1
0.8	15028.8
0.9	18437.5
1	21962.8
1.1	25649.7
1.2	29444.6
1.3	33333.2

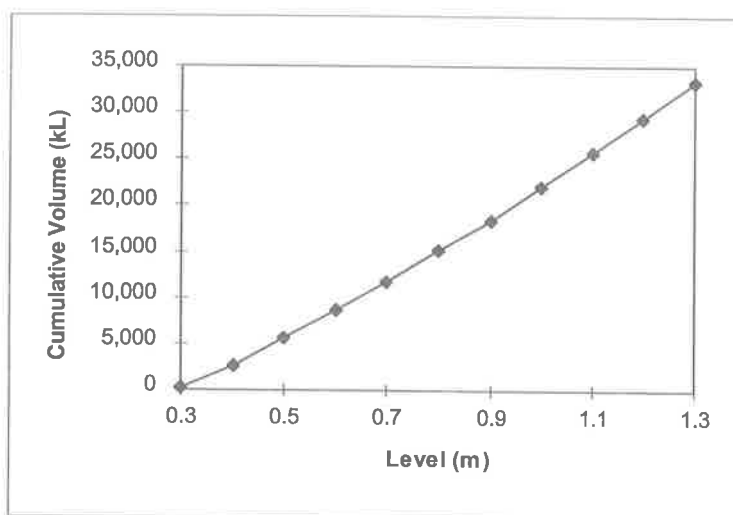


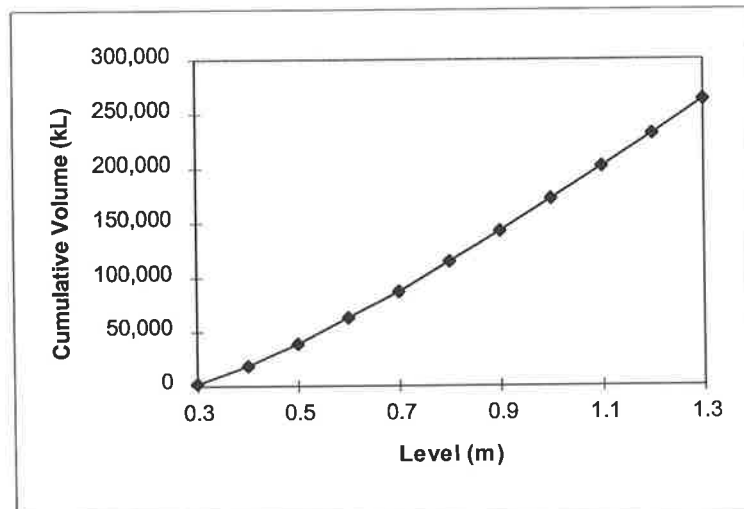
Figure A3 : Flood Volumes in the 0.3 Pond, South

Flood Volumes for the 0.3 Pond, North at 0.1 metre intervals

(Receives stormwater from the North Arm West (AU504104) catchment as well as the outflow from the 3 south ponds)

Table A-4 : Pond level/volume relationship

Level (m)	Cum. Vol (kL)
0.3	1734.2
0.4	18611.3
0.5	39035.8
0.6	62074.4
0.7	87647.9
0.8	114489.9
0.9	142514.4
1	171527.2
1.1	201379.1
1.2	231606.2
1.3	262184.7

**Figure A4 : Flood Volumes in the 0.3 Pond, North**

Appendix B

Field Site Sheets and Procedures

Summary

Appendix B includes a sample site sheet that is filled out in the field on each visit. On each site visit it is important to record data such as the date and time of visit, the downloaded filename and size, the old and new battery voltages on both the loggers and sampler, water quality before and after data download when applicable, hand held water quality values for calibration of probes, staff stage height reading to calibrate the pressure upstream transducer, number of samples, stern controller parameters and any other relevant notes.

Also included in this appendix are field procedures for data downloading, battery check and change, water sample collection, clearing and resetting the logger, controller parameter check and equipment checklist.

SITE # 1 AU504101 : North Arm East Drain

DATE :	
TIME :	

Download Filename :	.dmp	File Size :	(bytes)
---------------------	------	-------------	----------

OLD BATTERY VOLTAGE :	V
REPLACEMENT BATTERY VOLTAGE :	V
GAMET BATTERY VOLTAGE :	V
REPLACEMENT VOLTAGE :	V

	Logger Before Clean	Logger After Clean	Hand Held
pH :			
Temp :	°C	°C	°C
EC :	µS/cm	µS/cm	ppm
Turbidity :	NTU	NTU	NTU
U/S Depth :	m	m	
D/S Depth :	m	m	
Flow :	m/s	m/s	

Staff Reading : (m)

Stern Controller Check :

Log Active Interval :	2	
Log Threshold :	0.2	
Log Period :	10	
Sample Period :	60	
Turbidity Variance :	100	
Sample Threshold :	0.25	
Height Variance :	0.1	

Other Notes :

**** HAVE YOU RESET THE LOGGER AND SAMPLER ?? ** :**

A. GENERAL PROCEDURES

- A.1 Book a Departmental vehicle in advance.
- A.2 For safety reasons you are required to have at least 1 other person with you and the mobile phone.
- A.2 Equipment checklist (make sure that you pack the required tools).
- A.3 Take out a site sheet for each station.
- A.4 You must notify the laboratory manager on your destination and likely visit duration.

B. EQUIPMENT CHECKLIST

- laptop computer
- mobile phone
- blank site sheets
- pen
- keys (to open all site enclosures)
- RS232 - download cable
- stern controller - download cable
- multimeter
- batteries -Fully charged site car batteries
- batteries -Fully charged Gamet autosampler batteries
- alligator clips (to run a 2nd battery in parallel if battery is flat)
- voltage inverter (to run the laptop computer when its battery runs out)
- cleaning apparatus
 - bucket
 - 2 x toothbrushes
 - 1 x general purpose brush
 - claw
 - broom
- instrument cage opener (general purpose tool)
- clean sample bottles (to refill Gamet- if it has rained recently)
- protective clothing
 - rubber boots
 - gloves
 - hat
 - suncream
 - wet weather gear (if applicable)
- large container full of tap water (or distilled water)
- water calibration dish (plastic lunchbox)
- turbidity calibration lenses
- instrument testing/fixing tools (if applicable)

C. DATA DOWNLOAD PROCEDURE

- C.1 Turn the laptop computer on. (The computer will load DOS and prompt 'C:\>')
- C.2 Type 'cd pdl' to access the pdl directory. (ie 'C\PDL:\>')
- C.3 Type 'pdl' which to execute the STARLOG program.
- C.4 The main menu will appear on the screen : ***MAIN MENU***
Use a Scheme
Maintain Schemes
Maintain Instruments
Maintain MACRO Loggers
System Defaults
Test a Logger
QUIT
- C.5 Choose option 'Use a Scheme' and press 'Enter'.
- C.6 The program will provide a list of schemes for you to choose from. Choose the site at which you are present and press 'Enter'.
 There are four programmed schemes to choose from; MFP1, MFP2, MFP3, MFP4
- C.7 The scheme menu will appear on the screen once you have chosen the scheme.
Scheme : MFPI
List all Unload files
Display an Unload file
Delete an Unload file
Program Logger with Scheme
Unload data from Logger
Display Scheme Information
Print Scheme Information
Scheme Test mode
Incremental Unload
- C.8 Choose option 'Unload data from Logger' and press 'Enter'.
- C.9 The screen will prompt: ***** Connect logger now *****
 Press a key when ready . . .
- C.10 Connect the RS232 cable between the logger and the laptop and press 'Enter'.
- C.11 The screen will show 'Check scan rate of 6 seconds', and then 'Enter information for data'
- C.12 Information to identify the download file needs to be entered.
 Enter the following information: Station number, Date, Time, and then 'Enter'.
ie MFP1, 31/12/95 @ 14:30.
- C.13 The laptop will then download the data to a file. (This may take a while).
 Once the file has been downloaded a message on the screen will let you know. To continue just press 'Enter'.
- C.14 You need to exit the STARLOG program and get into DOS to check that the file has been downloaded properly without any errors. Do this by pressing the 'Escape' key from the Scheme menu. This will take you back to the Main menu.
- C.15 Chose the 'QUIT' option in the main menu. This will take you back to DOS. You will automatically be in the pdl directory.
- C.16 To check the download file you need to get into the directory where the dump files are stored, and type 'dir *.dmp'. This will provide a list of all the dump files for that station.

- C.17 Check that the last dump file on the list (the one that you have just downloaded) has the correct date and time prescribed to it, and that the file is the correct size.
- C.18 Record the file name, and size on the site sheet.
- C.19 To return to the STARLOG program after checking that the file has been downloaded properly simply follow procedures C.1 and C.2.
- C.20 If the battery is very low (ie <11 volts) a 2nd battery will have to be run in parallel to it using alligator clips. This will increase the voltage to an acceptable level to download.
** Do not change the battery before the data has been downloaded or loss of data may occur **

D. BATTERY CHECK/CHANGE PROCEDURE

****** Do not change the battery before data has been downloaded. If the current battery is low, disconnecting the battery will lose all of the recorded data. If you download first you eliminate the risk of losing data due to low battery voltage ******

- D.1 Using the multimeter, check the voltage of the '12V logger battery'. (Supplying power to the logger).
- D.2 Record the observed voltage on the site sheet.
- D.3 If the voltage is below 12V then it needs replacing. If the voltage is low enough to justify changing it before your next site visit then change it also.
- D.4 To replace the flat battery with a new charged battery wait for the l.e.d. light in the enclosure to come on. This stays on for approximately 6 seconds (the logger is recording values from the probes). As soon as the led goes off, disconnect the flat battery and connect the new charged battery.
- D.5 Record the voltage of the replacement battery on the site sheet if the battery is changed. If it has not been changed then write NA on the site sheet
- D.6 Repeat procedures D.1 to D.6 for the 'Gamet Sampler 12V battery'.

****** Avoid disconnecting the battery while the led light is on or the values that are being read from the probes will not be stored in the logger ******

E. CLEAR AND REPROGRAM LOGGER PROCEDURE

- E.1 This procedure can be carried out after completing procedures C and D.
- E.2 Type 'cd pdl' to access the pdl directory. (ie 'C:\PDL:>')
- E.3 Type 'pdl' which to execute the STARLOG program.
- E.4 The main menu will appear on the screen : ***MAIN MENU***
Use a Scheme
Maintain Schemes
Maintain Instruments
Maintain MACRO Loggers
System Defaults
Test a Logger
QUIT
- E.5 Choose option 'Use a Scheme' and press 'Enter'.
- E.6 The program will provide a list of schemes for you to choose from. Choose the site at which you are present and press 'Enter'.

There are four programmed schemes to choose from; MFP1, MFP2, MFP3, MFP4

E.7 The scheme menu will appear on the screen once you have chosen the scheme.

Scheme : MFPI

List all Unload files

Display an Unload file

Delete an Unload file

Program Logger with Scheme

Unload data from Logger

Display Scheme Information

Print Scheme Information

Scheme Test mode

Incremental Unload

E.8 Choose option 'Program Logger with scheme' and press 'Enter'.

E.9 The screen will prompt a warning message:

*** Clear & Program Logger. Are you sure? (Y/N) ***

If you have followed procedures C and D correctly type 'Y' and 'Enter'

E.10 The screen will prompt: *** Connect logger now ***

Press a key when ready . . .

E.11 Connect the RS232 cable between the logger and the laptop and press 'Enter'.

E.12 The computer will do several checks :

Configure MACRO logger

Check logger firmware

The screen will prompt: "Logger firmware is version-1 , version 30 expected.
continue (Y/N) :-"

type 'Y' and 'enter'

E.13 Once the logger has been cleared and reset it will return you to the Scheme Menu. Press 'escape' to exit this. The computer will now go to the Main Menu. Choose the Quit option and return to the Dos environment.

F. STERM CONTROLLER PROCEDURE

STERM

The sterm controller needs to be checked as the final procedure to make sure that the data download, battery change and logger reset has not altered any of the prescribed values. The values that need to be checked are outlined below:

Current Values =	The last value that the controller read
Stored Values =	The last value that the logger logged (stored in memory)
Log Active Interval =	The interval (minutes) that the logger will store values once the Log threshold value has been exceeded.
Log threshold =	The threshold (stage height metres) that when exceeded forces the logger to log at the 'Log Active Interval'.
Sample threshold =	The threshold (stage height metres) that when exceeded forces the automatic water sampler to take samples.
Log Period =	The interval (minutes) that the logger will store values when the Log threshold value has not been exceeded.
Sample period =	The maximum time that can expire between samples once the Sample threshold has been exceeded.
Log count =	Records the number of minutes since the logger last logged (stored) a value.

Sample period count = Records the number of minutes since the last sample was taken.

This value is only activated when the 'Sample threshold' has been exceeded.

Turbidity Variance = The increment of turbidity units that when exceeded after the automatic water sampler has been initialised will induce a water sample to be taken. (Only if 4 or greater minutes have expired since the last sample was taken).

Height Variation = The increment of stage height that when exceeded after the automatic water sampler has been initialised will induce a water sample to be taken. (Only if 4 or greater minutes have expired since the last sample was taken).

- F.1 You need to be in the root directory ('C:\>')
- F.2 Type 'stern b' and 'enter'
- F.3 The interface screen for the stern controller will appear.
- F.4 Press 'F3' (this runs the Terminal)
- F.5 If all is well the screen will prompt "ready"
- F.6 Press 'Enter' - The parameters and their corresponding values will appear on the screen.
- F.7 Check that the values are the same as shown on the site sheet.

G. WATER SAMPLE COLLECTION

- G.1 Download the data file first by following C.1 - C.13
- G.2 Turn the Gamet Automatic Sampler off.
- G.3 Carefully remove the lid from the autosampler
- G.4 Remove the round bottle support and rubber bands
- G.5 Place lids on all of the sample bottles that have samples in them
- G.6 Be careful that the samples are identified carefully by legible numbers on the lids of the samples.
- G.7 Remove the sample bottles
- G.8 Replace the bottles with empty sample bottles
- G.9 Replace the round bottle support and rubber bands.
- G.10 Replace the lid to the autosampler
- G.11 Turn the autosampler back on
- G.12 Answer 'Yes' to exit
- G.13 Answer 'No' to set parameters
- G.14 Answer 'No' to
- G.15 Answer 'No' to Float Mode
- G.16 Answer 'Yes' to LP Float Mode

Appendix C

Stage/Discharge Rating Curves

Summary

Appendix C outlines the stage/discharge rating curves for each monitored drain. The cross section dimensions for each channel were determined by surveying the drains.

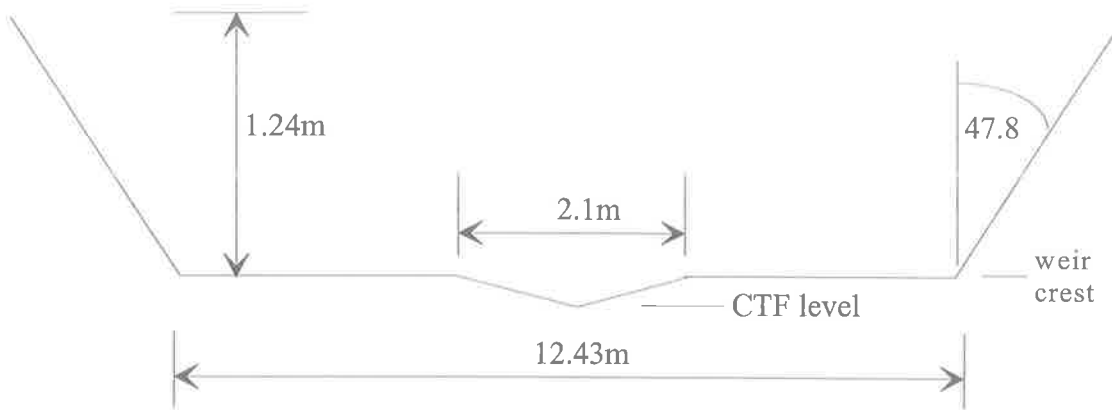


Figure C-1 : North Arm East drain dimensions (AU504101)

Other Properties

Channel slope : 0.0024

Cease to flow (CTF) stage height : 0.105m

Weir crest level : 0.155m

Downstream trash rack bottom level : 0.286m below weir crest

Downstream trash rack top level : 0.255m above weir crest

TABLE C-1 : Dynamic Stage/Discharge rating Table for the North Arm East (AU504101) weir. (Valid 1st February 1996 onwards, ie valid for backwatered events)

Stage Height (m)	Discharge (m ³ /s)
0.105	0.0000
0.115	0.0003
0.125	0.0015
0.135	0.0041
0.145	0.0085
0.155	0.0149
0.205	0.0529
0.305	0.22
0.405	0.58
0.505	1.26
0.605	2.39
0.705	3.84
0.805	5.84
0.905	8.76
1.205	14.97
1.505	19.13

TABLE C-2 : Stage/Discharge Rating Table for the North Arm East (AU504101) weir.
(Valid up until January 30 1996, ie valid for non-backwatered events)

Stage Height (m)	Discharge (m³/s)
0.105	0.0000
0.115	0.0003
0.125	0.0015
0.135	0.0042
0.145	0.0085
0.155	0.0149
0.165	0.0234
0.168	0.0265
0.205	0.129
0.305	1.06
0.355	1.72
0.405	2.47
0.455	3.32
0.505	4.24
0.555	5.24
0.605	6.32
0.655	7.46
0.705	8.66
0.755	9.93
0.805	11.26
0.855	12.64
0.905	14.09
0.955	15.58
1.005	17.13
1.055	18.74
1.105	20.39
1.155	22.10
1.205	23.85
1.255	25.66
1.305	27.51

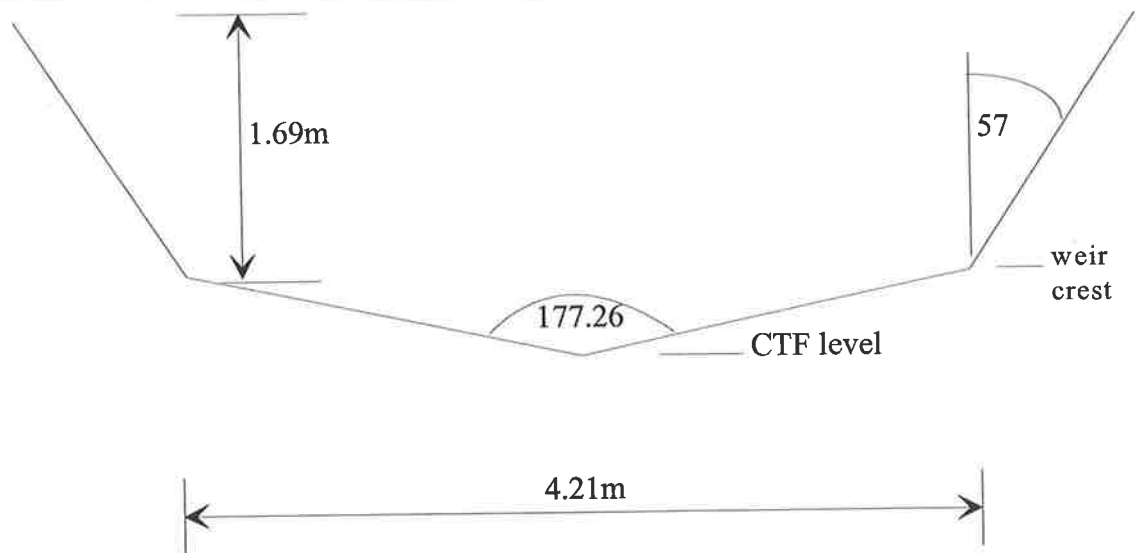


Figure C-2 : Hindmarsh Enfield Prospect drain dimensions (AU504101)

Other Related Properties

Channel slope : 0.00084

Cease to flow (CTF) stage height : 0.13m

Weir crest level : 0.18m

Downstream trash rack bottom level : 0.136m below weir crest

Downstream trash rack top level : 0.384m above weir crest

TABLE C-3 : Stage/Discharge Rating Table for the HEP (AU504102) weir

Stage Height (m)	Flow (m ³ /s)
0.13	0
0.14	0.001
0.15	0.003
0.16	0.008
0.17	0.017
0.18	0.030
0.19	0.047
0.193	0.053
0.23	0.122
0.28	0.293
0.33	0.513
0.38	0.774
0.43	1.07
0.48	1.41
0.53	1.79
0.58	2.19
0.63	2.63
0.68	3.11
0.73	3.62
0.78	4.16
0.83	4.73
0.88	5.34
0.93	5.98
0.98	6.65
1.03	7.35
1.08	8.09
1.13	8.86
1.18	9.67
1.23	10.50
1.28	11.37
1.33	12.27

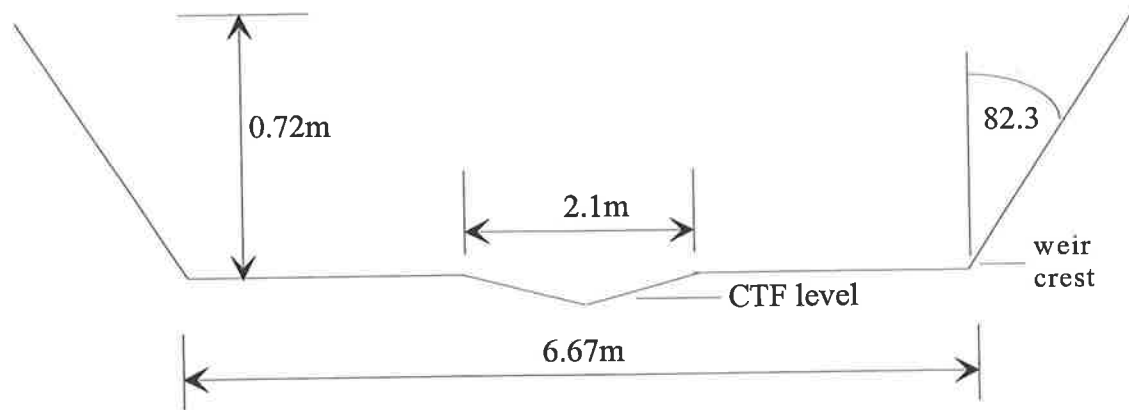


Figure C-3 : Dunstan Road drain dimensions (AU504103)

Other Related Properties

Channel slope : 0.0011

Cease to flow (CTF) stage height : 0.215m

Weir crest level : 0.265m

Downstream trash rack bottom level : 0.423m below weir crest

Downstream trash rack top level : 0.112m above weir crest

TABLE C-4 : Stage/Discharge Rating Table for the Dunstan Road (AU504103) weir

Stage Height (m)	Flow (m ³ /s)
0.14	0.000
0.15	0.000
0.16	0.002
0.17	0.004
0.18	0.009
0.19	0.015
0.2	0.023
0.203	0.027
0.24	0.114
0.29	0.374
0.34	0.731
0.39	1.17
0.44	1.70
0.49	2.30
0.54	2.98
0.59	3.73
0.64	4.56
0.69	5.47
0.74	6.46
0.79	7.53
0.84	8.68
0.89	9.92
0.94	11.23
0.99	12.63
1.04	14.11
1.09	15.69
1.14	17.34
1.19	19.09
1.24	20.93
1.29	22.86
1.34	24.88

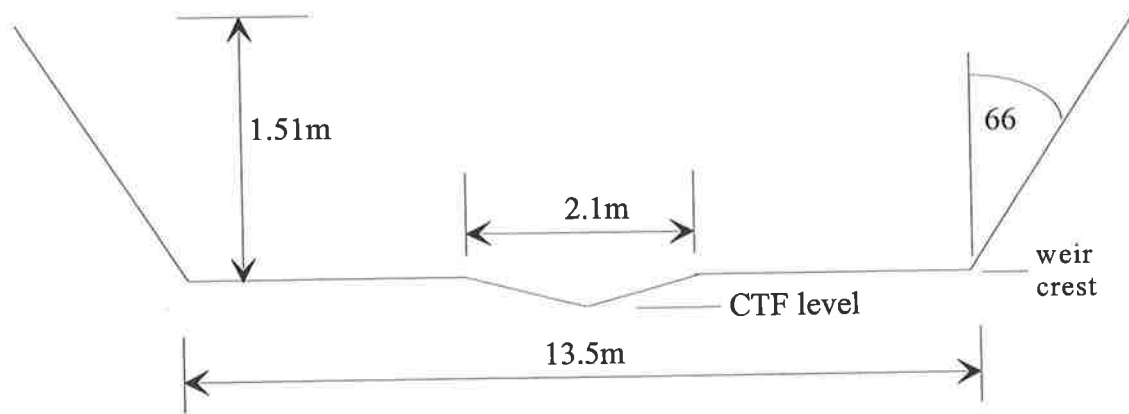


Figure C-4 : North Arm West drain dimensions (AU504104)

Other Related Properties

Channel slope : 0.00035

Cease to flow (CTF) stage height : 0.28m

Weir crest level : 0.33m

Downstream trash rack bottom level : 0.275m below weir crest

Downstream trash rack top level : 0.235m above weir crest

TABLE C-5 : Stage/Discharge Rating Table for the North Arm West (AU504104) weir

Stage Height (m)	Flow (m ³ /s)
0.28	0.000
0.29	0.000
0.30	0.002
0.31	0.004
0.32	0.009
0.33	0.015
0.34	0.023
0.34	0.027
0.38	0.137
0.43	0.564
0.48	1.16
0.53	1.89
0.58	2.74
0.63	3.70
0.68	4.75
0.73	5.91
0.78	7.15
0.83	8.49
0.88	9.91
0.93	11.42
0.98	13.01
1.03	14.68
1.08	16.44
1.13	18.27
1.18	20.19
1.23	22.18
1.28	24.26
1.33	26.41
1.38	28.64
1.43	30.94
1.48	33.33

Appendix D

Isohyetal Rainfall Distributions

Summary

Appendix D outlines a number of isohyetal rainfall distributions for selected events occurring in the North Arm East catchment. The rainfall distributions were determined for a number of events used for calibrating and verifying the runoff routing model setup for the North Arm East catchment. The average rainfall depth over the catchment was determined from the isohyetal rainfall distributions.

Figures D2 - D6 are the isohyetal rainfall distributions for Events 1-5 modelled by the RAFTS-XP runoff routing model.

Figures D7 - D10 are the isohyetal rainfall distributions for Verification Events 1-4 used to verify the RAFTS-XP runoff routing model.

Figure D11 is the isohyetal rainfall distribution of the 1995 New Years Eve event.

Figures D12 - D13 are the isohyetal rainfall distributions for Backwatered Events 1 and modelled by the RAFTS-XP runoff routing model.

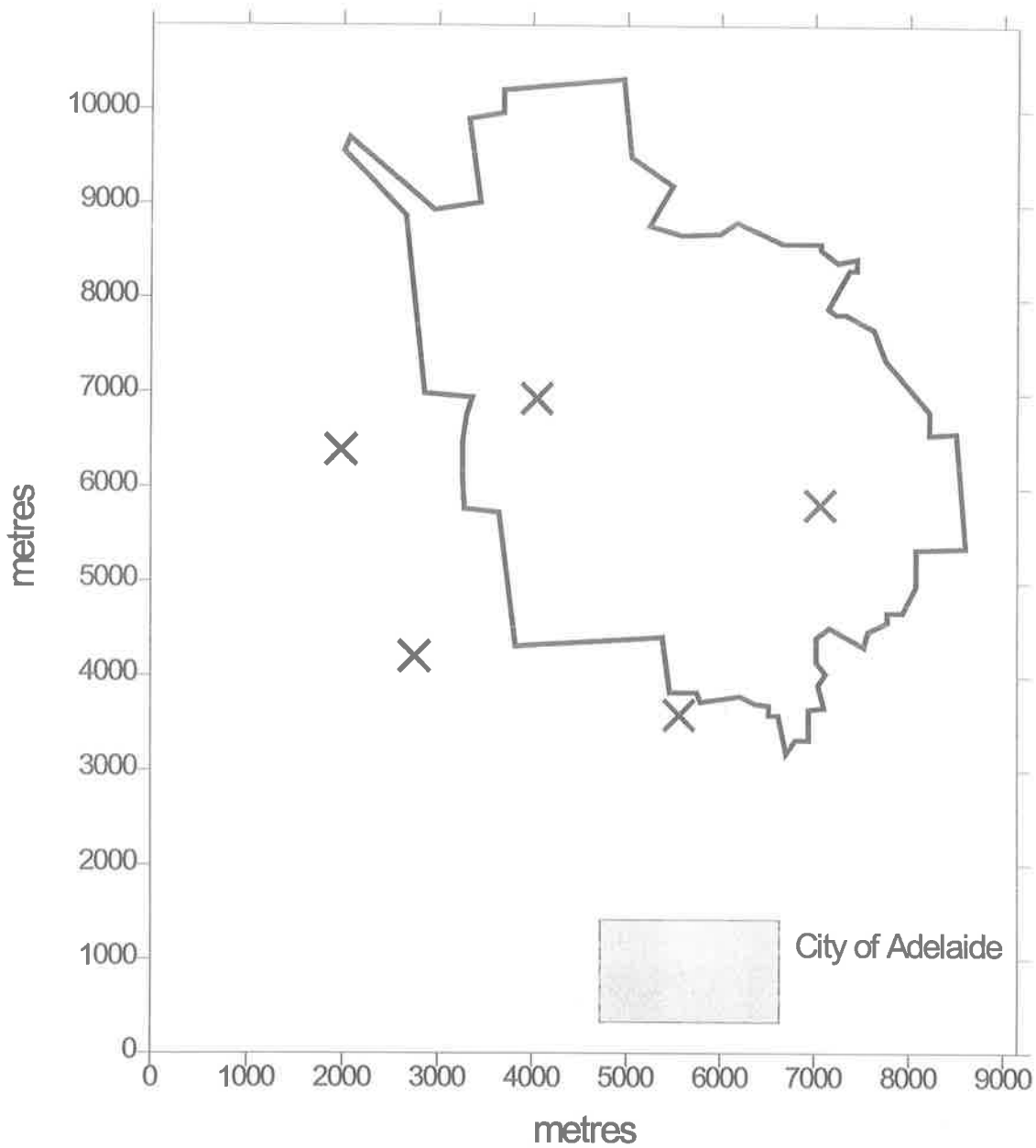


Figure D-1 : Location of raingauges and the North Arm East Catchment relative to the City of Adelaide

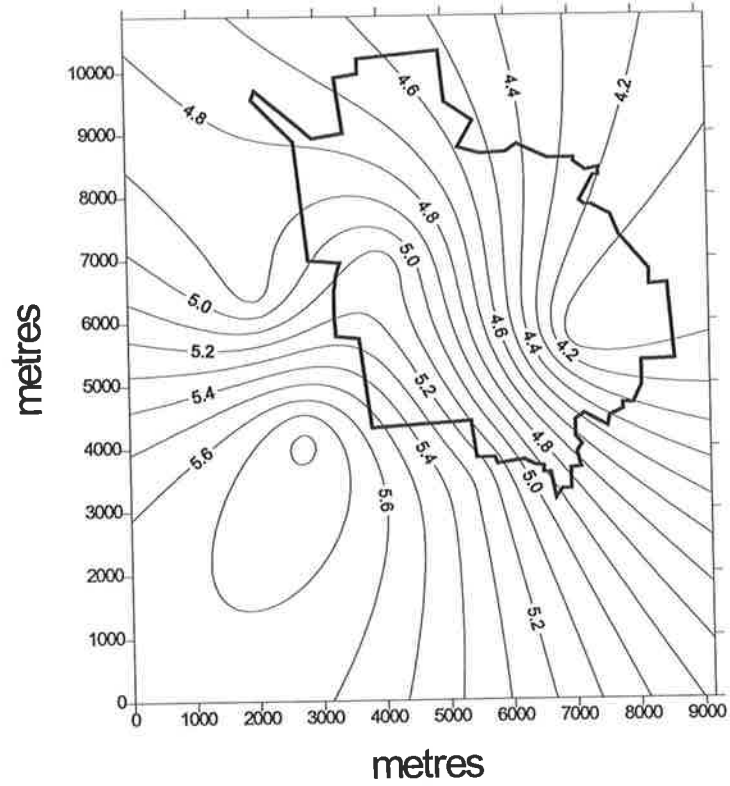


Figure D-2 : Event 1, 5 hours to 06:00 12 July 1994

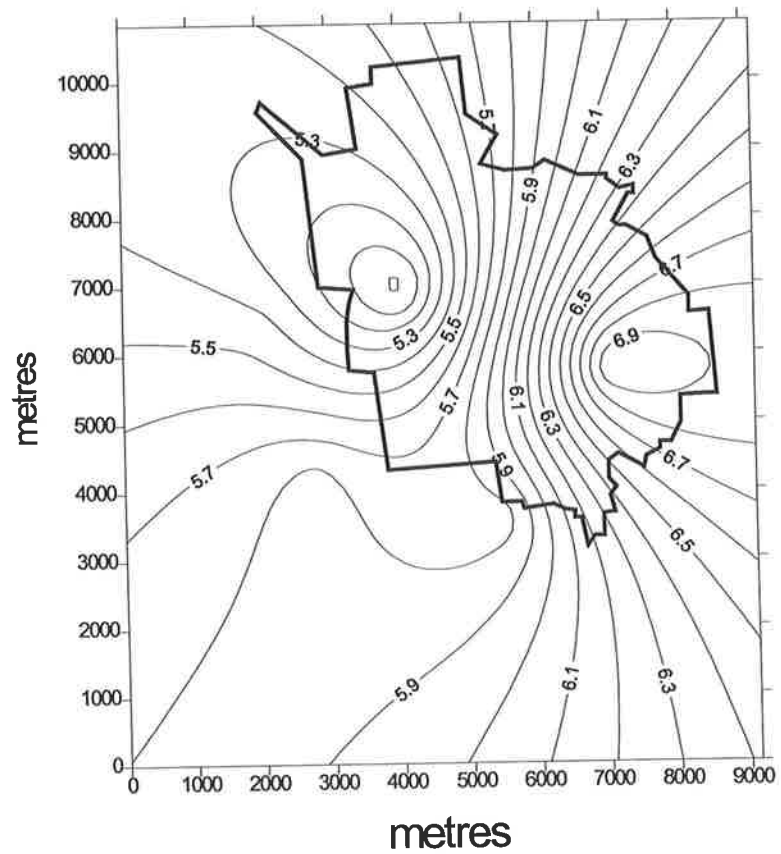


Figure D-3 : Event 2, 5 hours to 02:00 9 June 1995

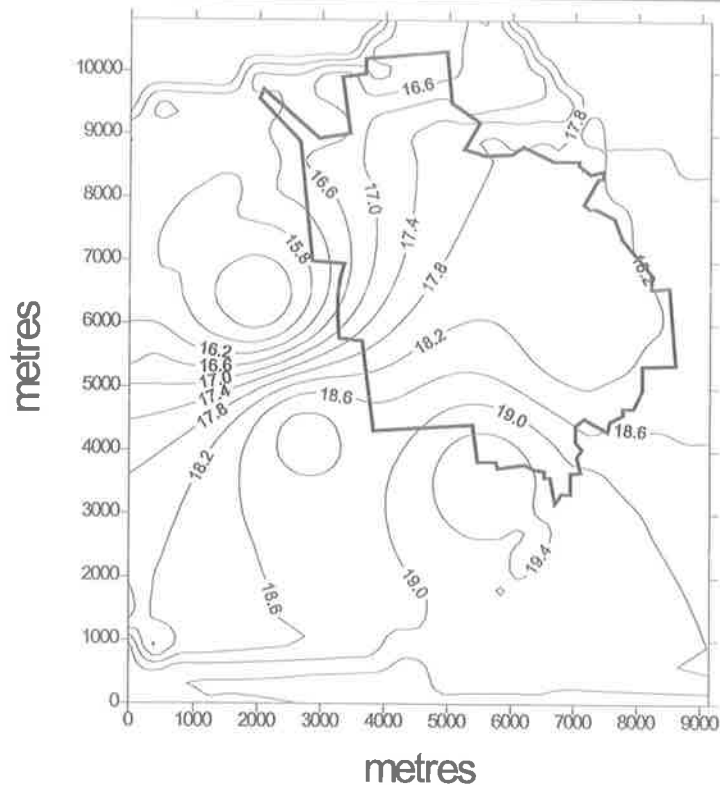


Figure D-4 : Event 3, 25 hours to 12:00 3 May 1995

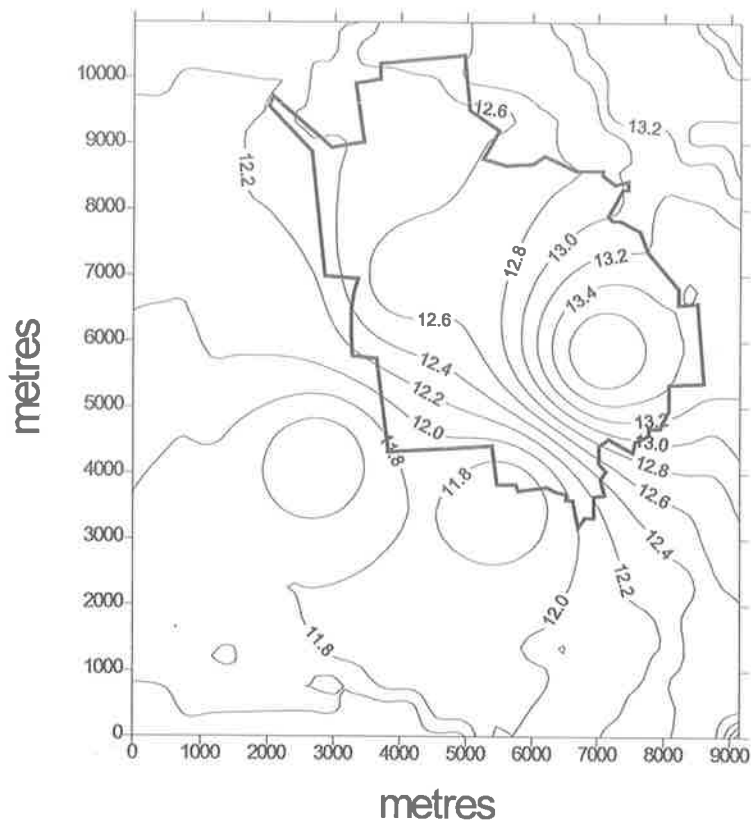


Figure D-5 : Event 4, 13 hours to 19:00 25 May 1995

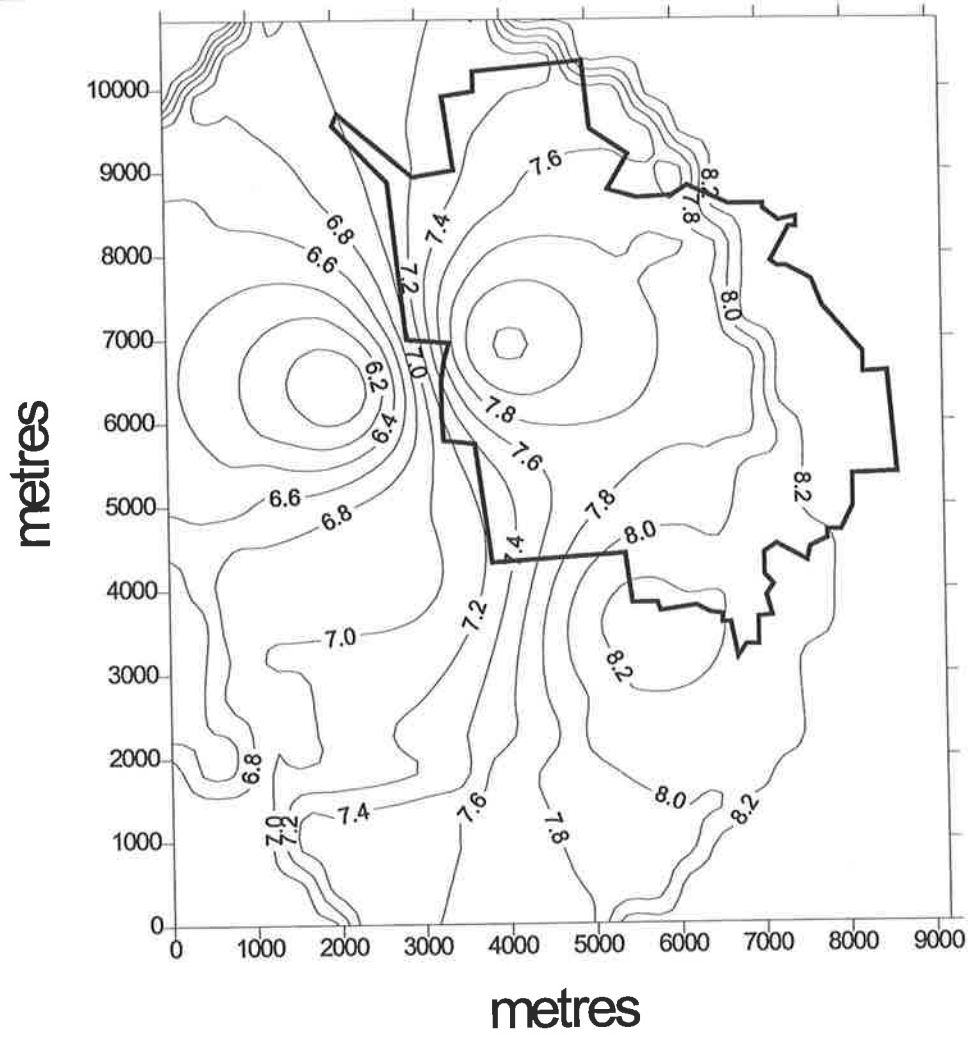


Figure D-6 : Event 5, 6 hours to 21:00 21 July 1995

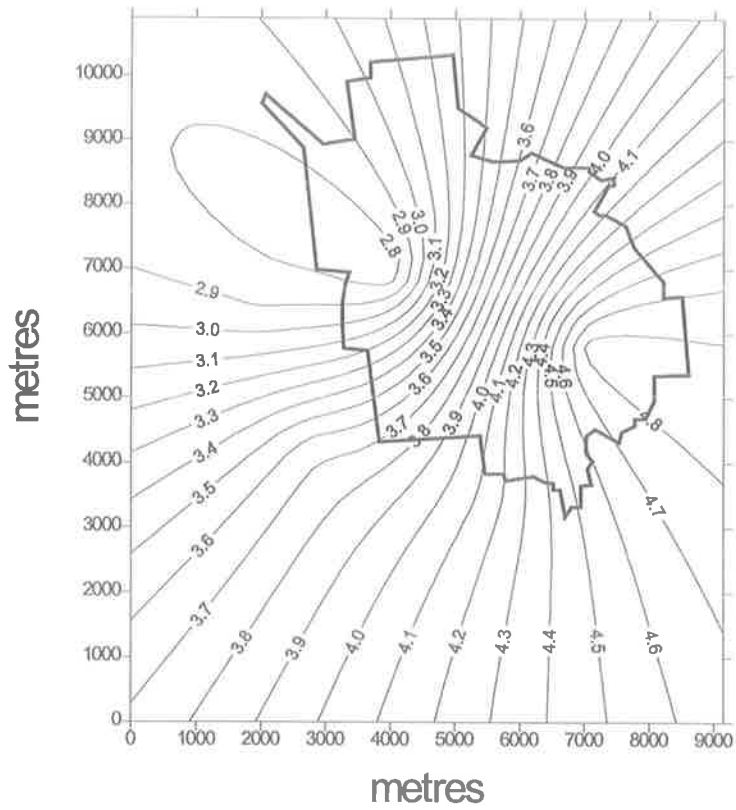


Figure D-7 : Verification Event 1, 7 June 1995

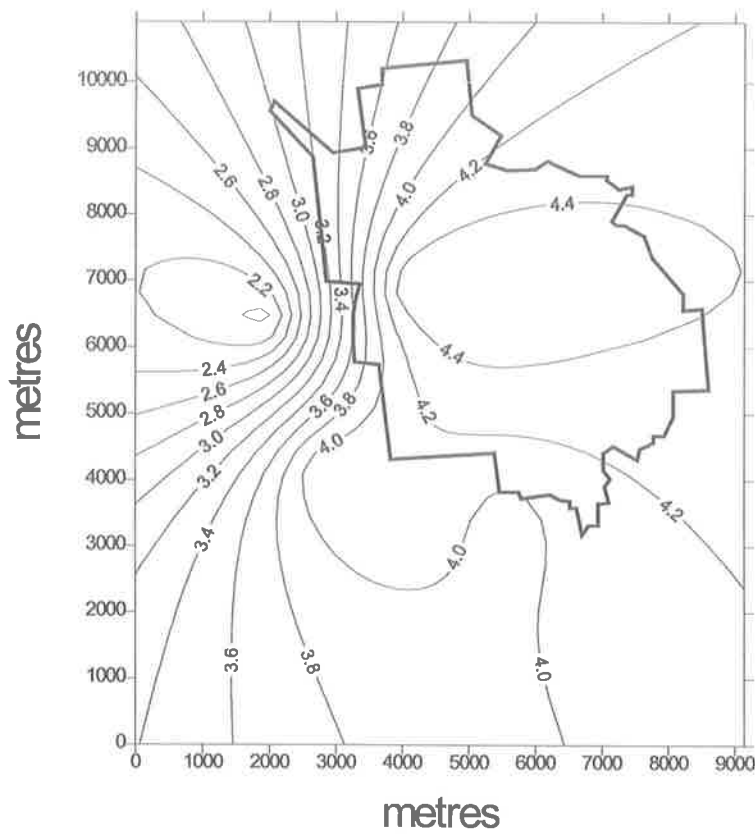


Figure D-8 : Verification Event 2, 26 June 1995

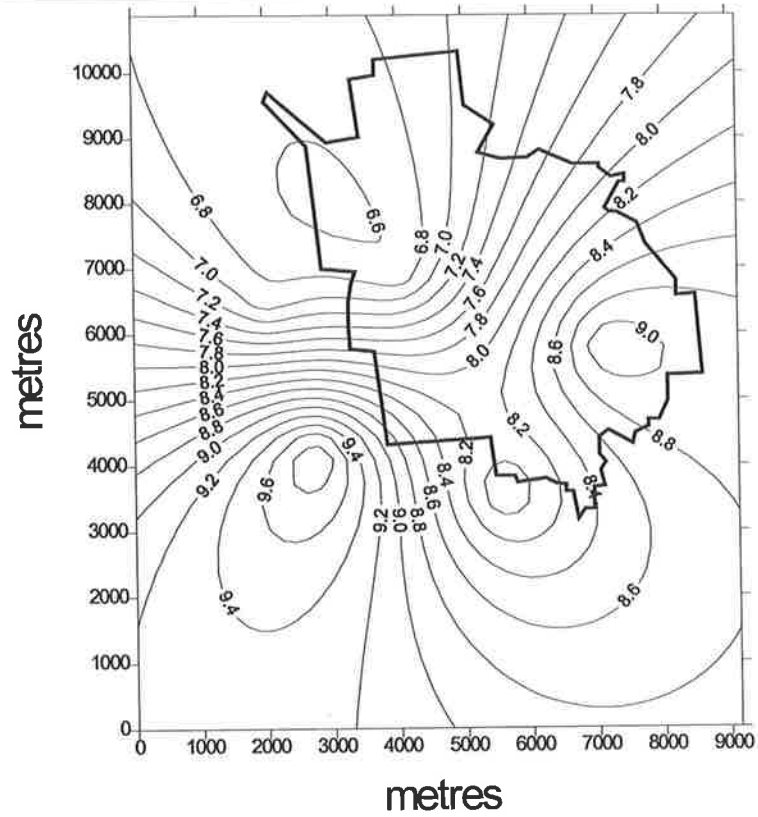


Figure D-9 : Verification Event 3, 4 April 1995

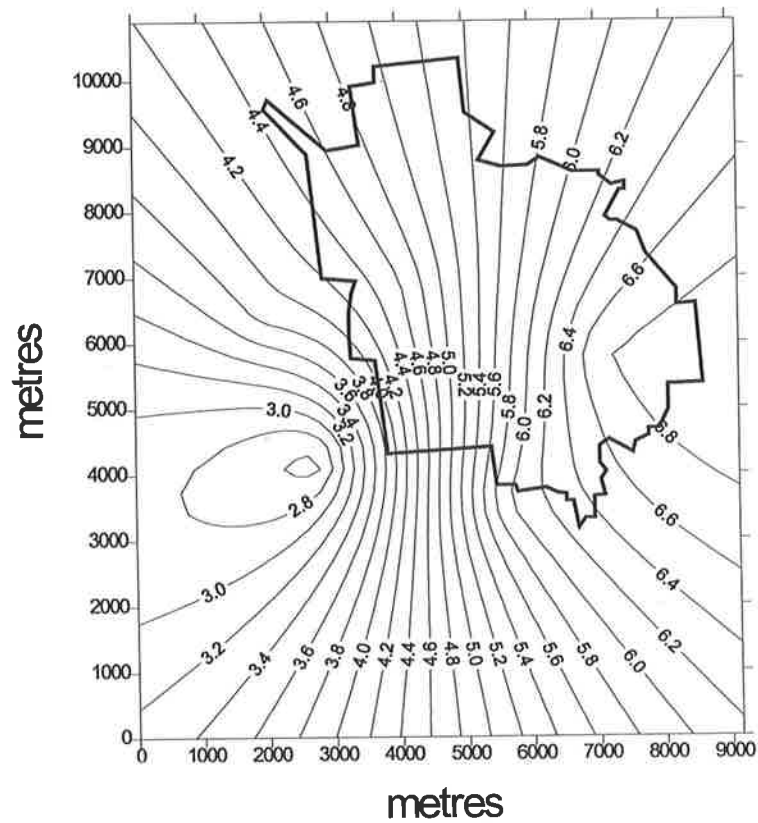


Figure D-10 : Verification Event 4, 2 April 1995

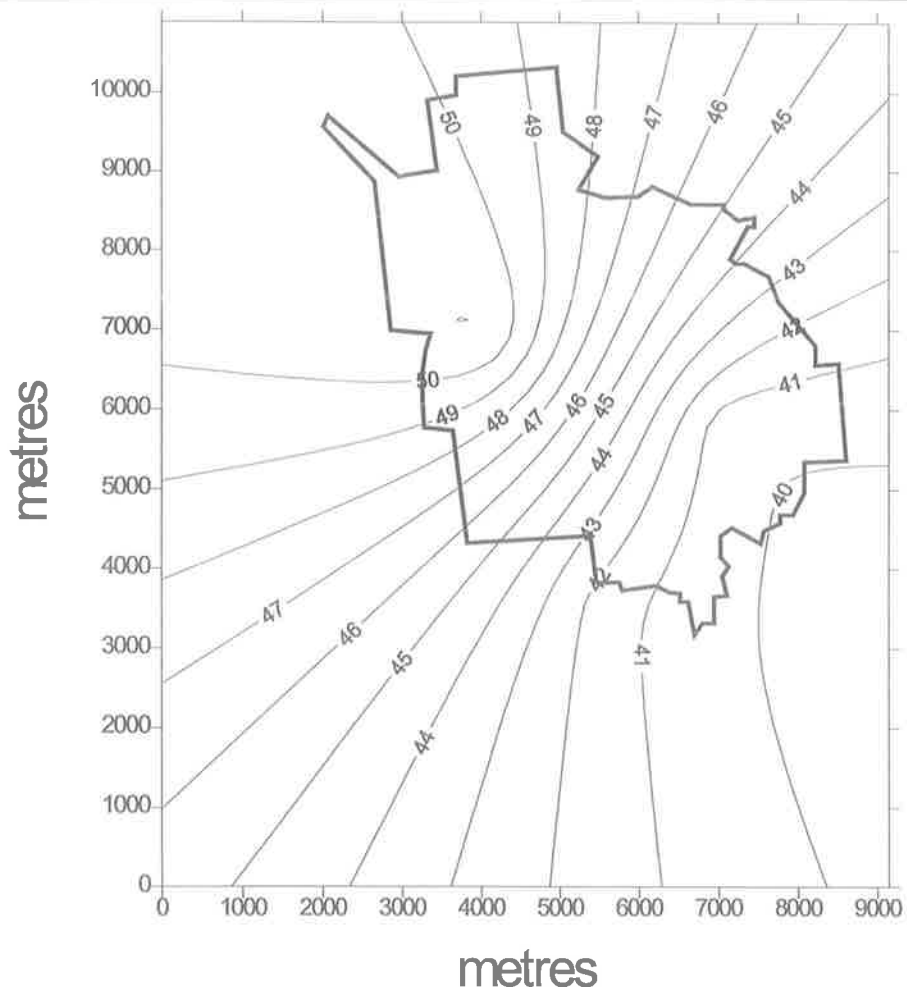


Figure D-11 : New Years Eve Storm, 31 December 1995

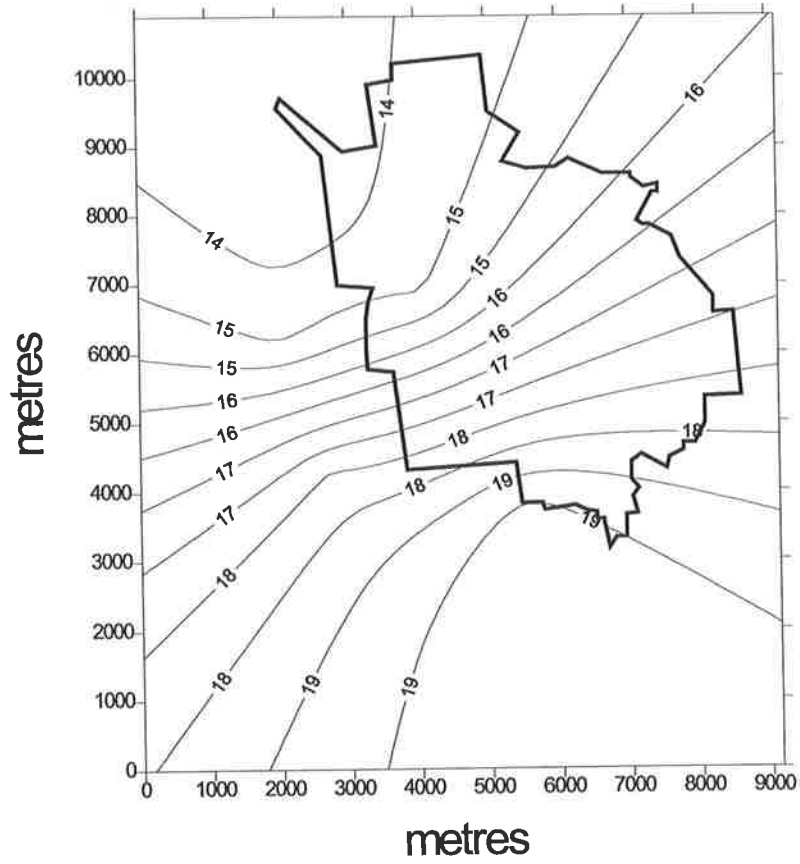


Figure D-12 : Backwatered Event 1, 13 April 1996

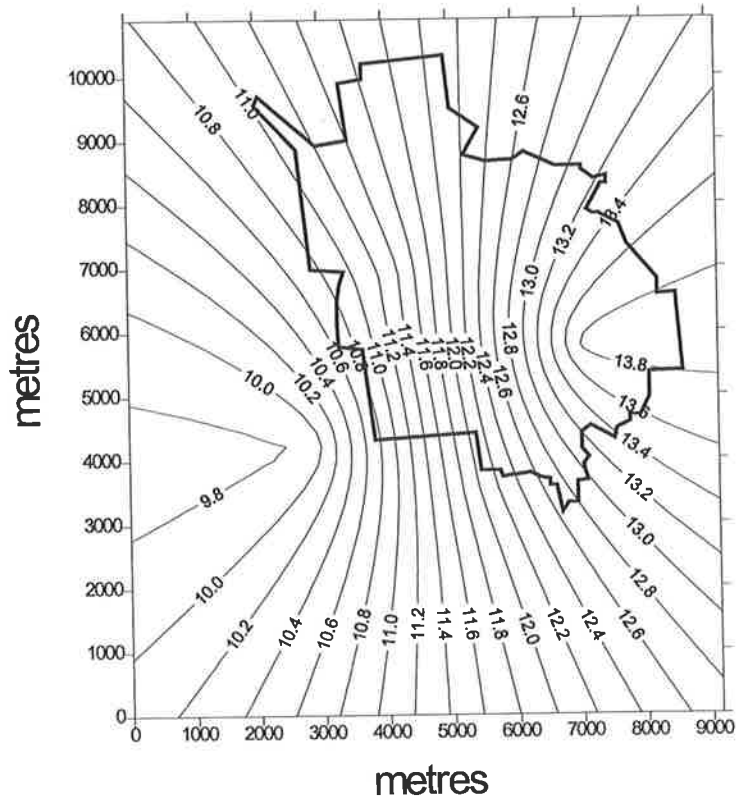


Figure D-13 : Backwatered Event 2, 31 July 1996

Appendix E

RAFTS-XP Model Outputs

Summary

Appendix E outlines the verification results of the North Arm East catchment RAFTS-XP model.

Figures E1-E5 show the verification results by re-applying the RAFTS-XP model to the calibration events.

Figures E6-E9 show the verification results by applying the RAFTS-XP model to the verification events, outside the calibration set.

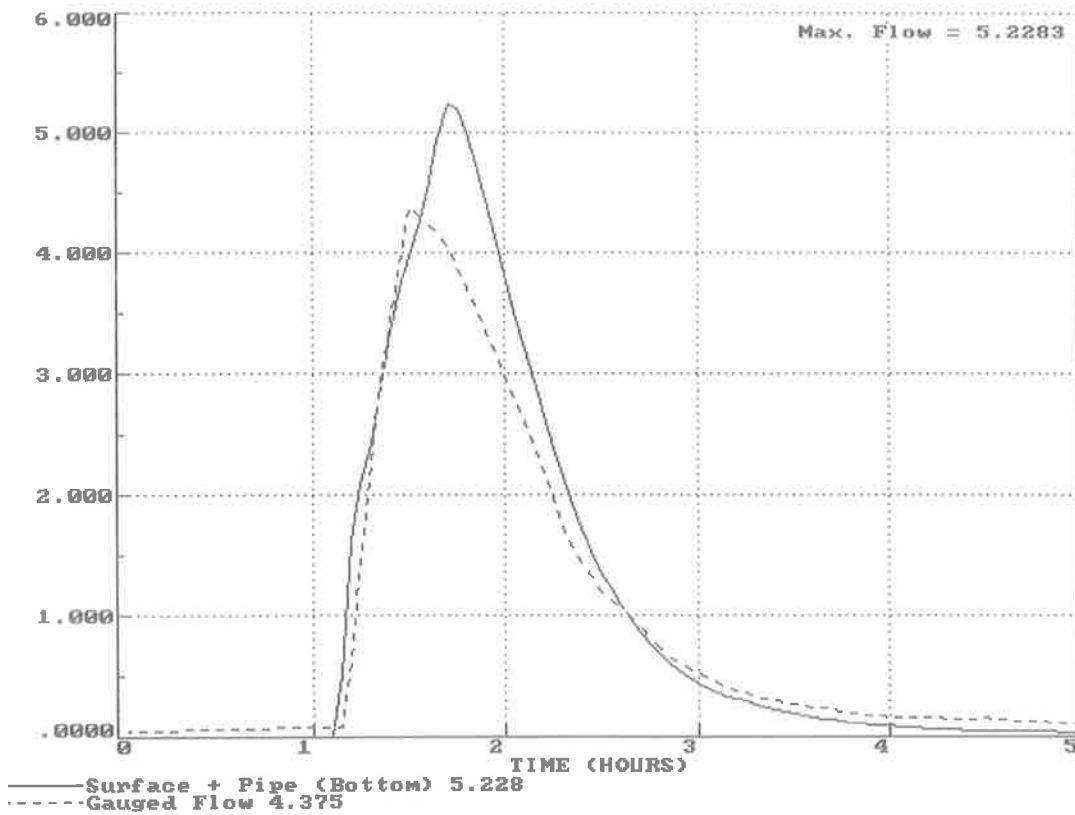


Figure E-1 : RAFTS-XP model re-applied to calibration Event 1

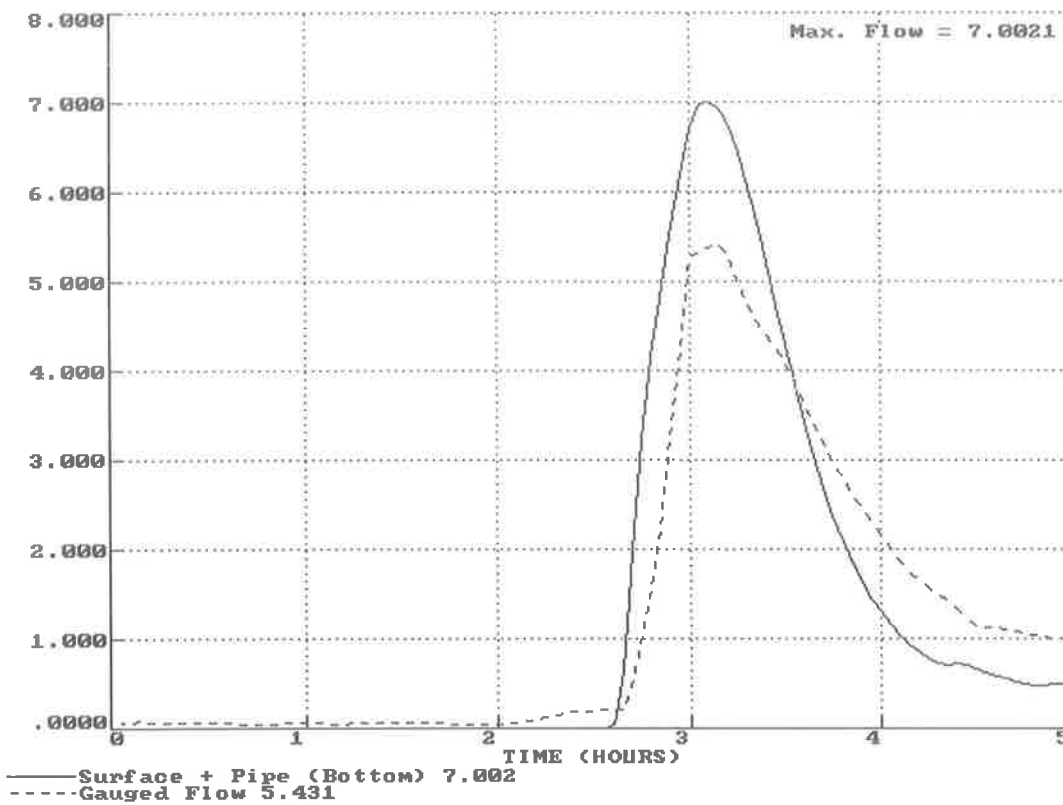


Figure E-2 : RAFTS-XP model re-applied to calibration Event 2

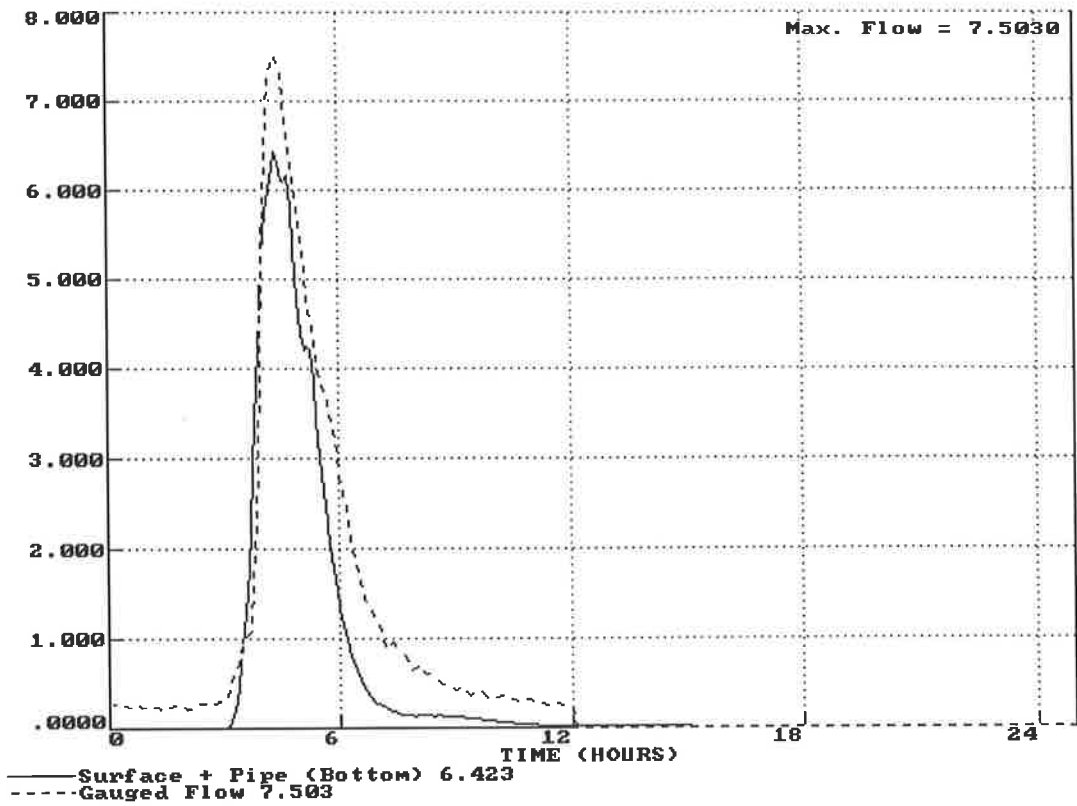


Figure E-3 : RAFTS-XP model re-applied to calibration Event 3

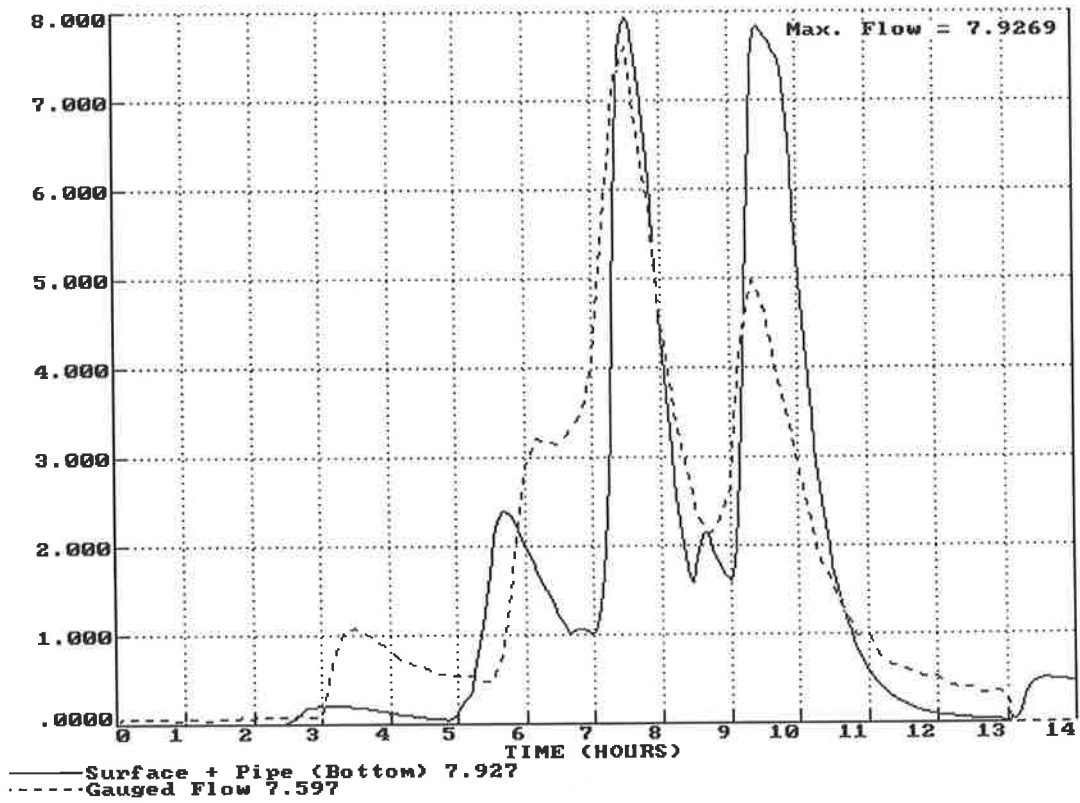


Figure E-4 : RAFTS-XP model re-applied to calibration Event 4

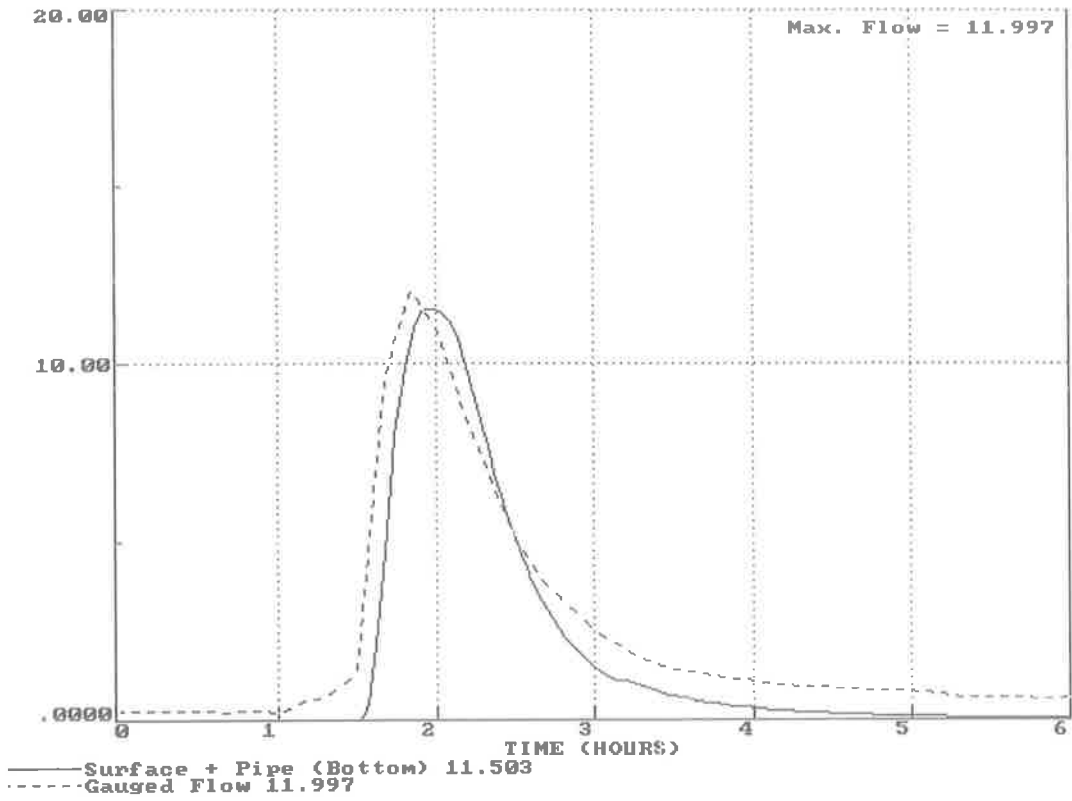


Figure E-5 : RAFTS-XP model re-applied to calibration Event 5

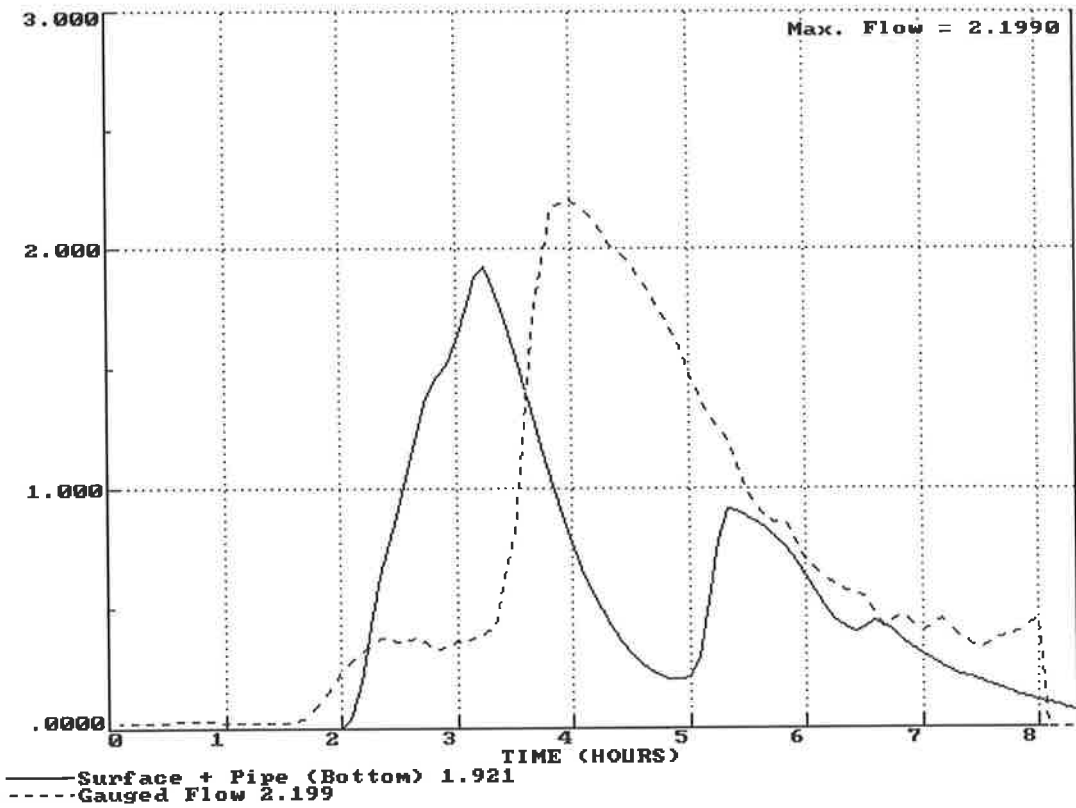


Figure E-6 : RAFTS-XP model applied to calibration Verification Event 1

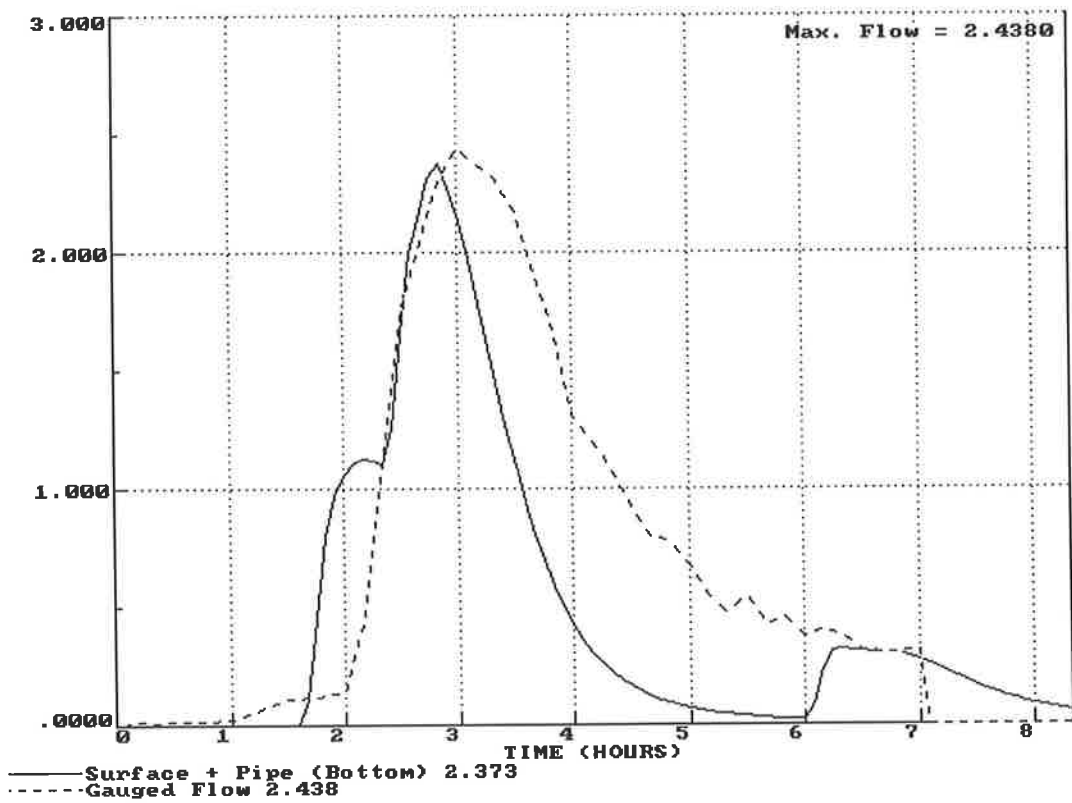


Figure E-7 : RAFTS-XP model applied to calibration Verification Event 2

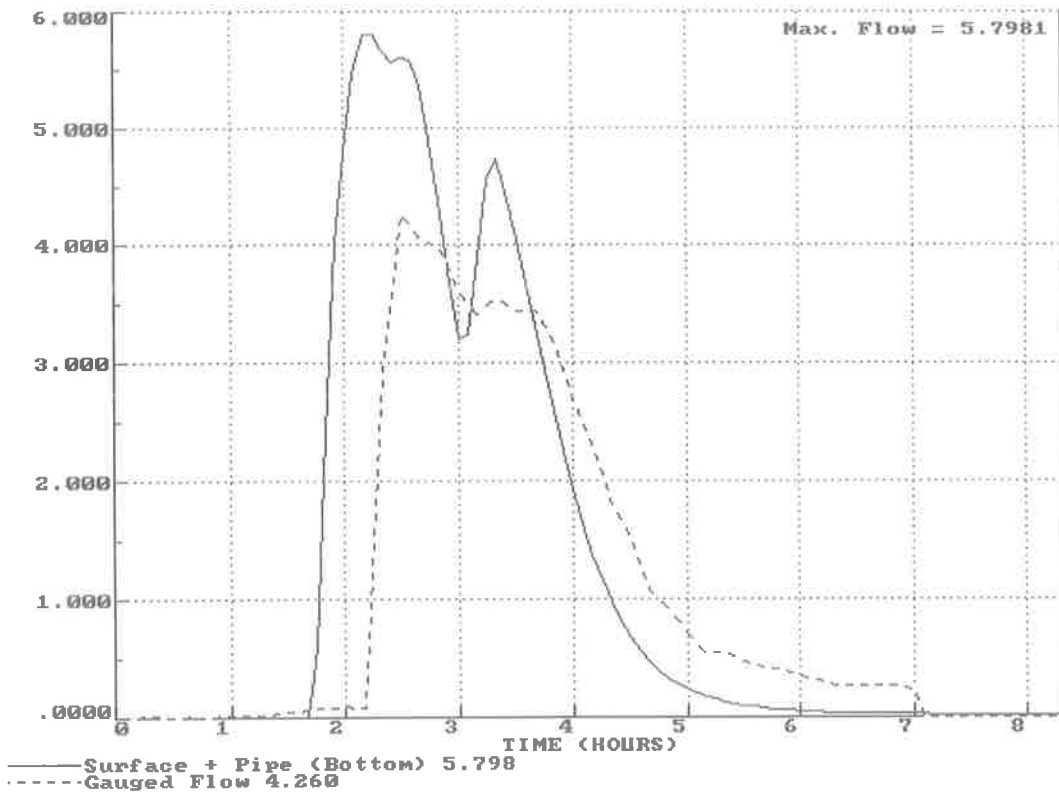


Figure E-8 : RAFTS-XP model applied to calibration Verification Event 3

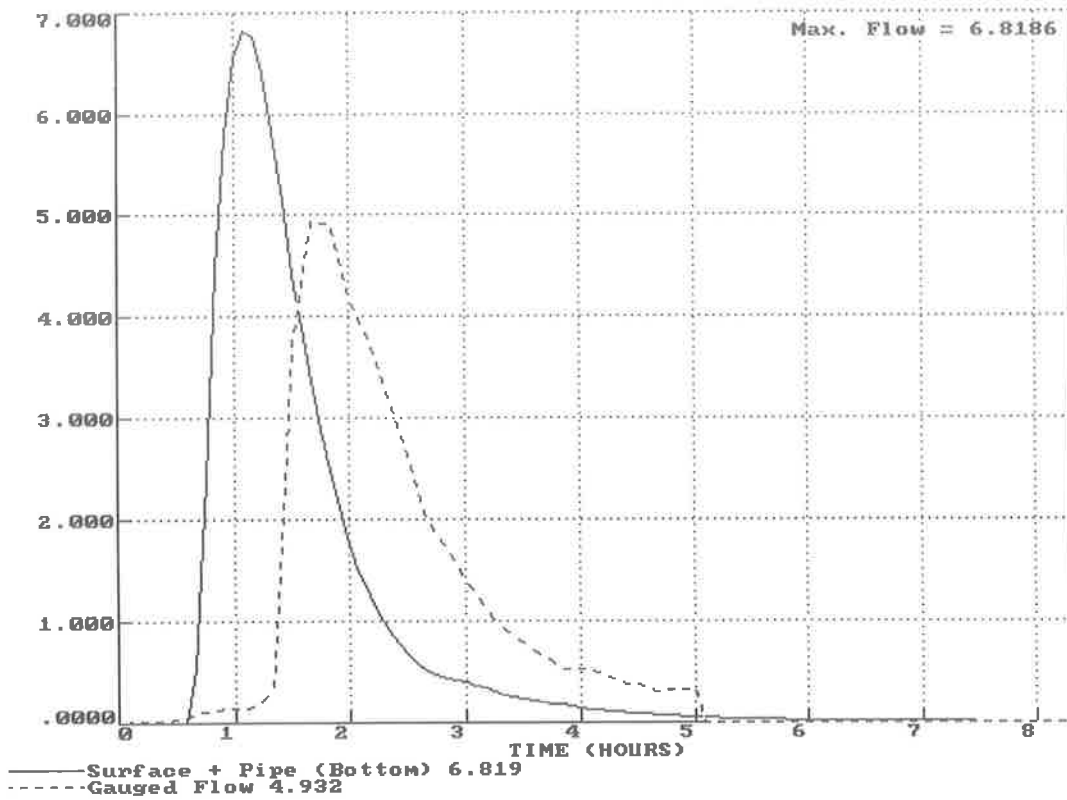


Figure E-9 : RAFTS-XP model applied to calibration Verification Event 4

Appendix F

Pluviometer Data Set

Summary

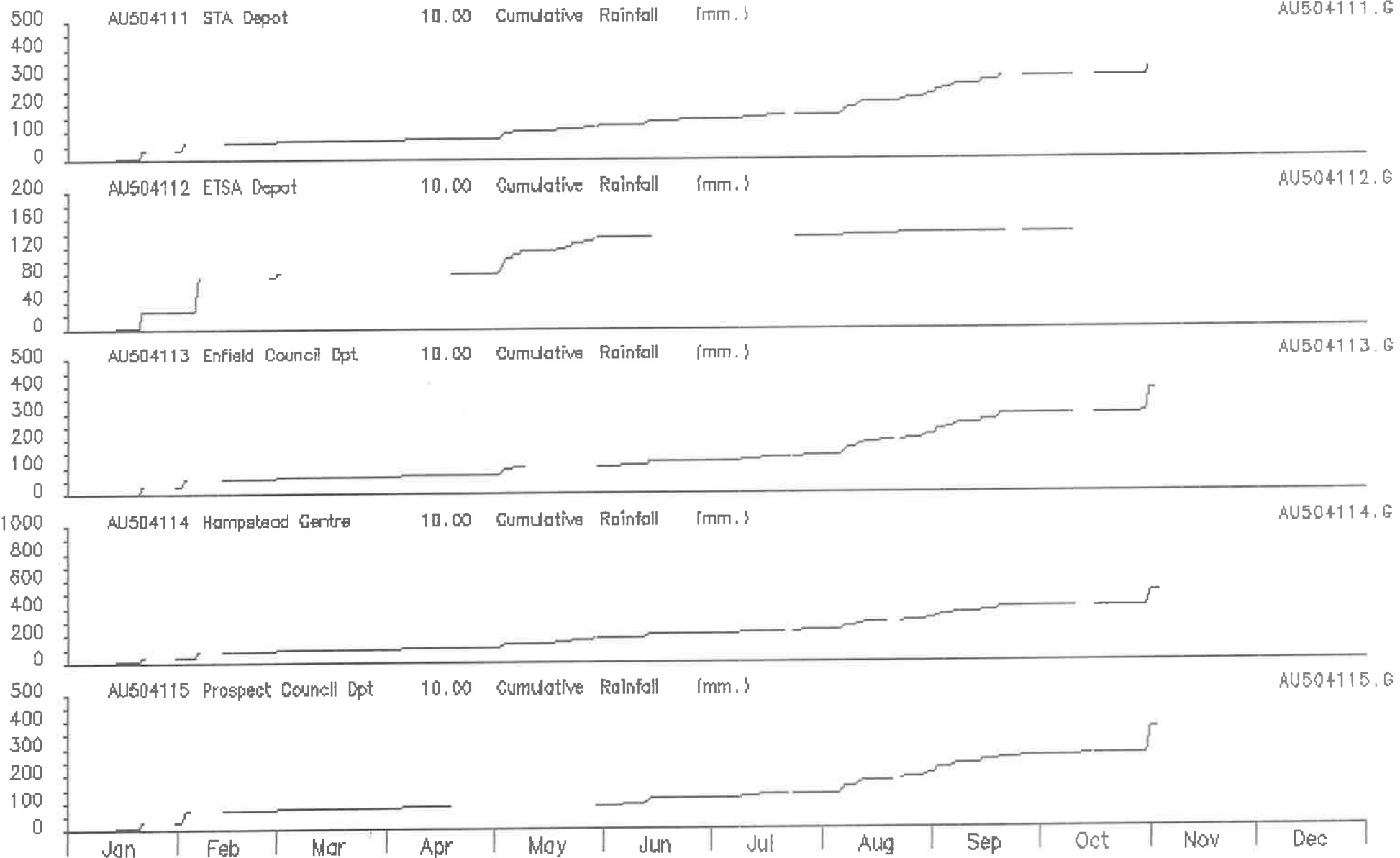
Appendix F outlines the pluviometer data set from 1994 to 1997.

Civil Engineering, Adelaide University

HYPL0T V74 Output 21/11/1987

Period 1 Year Plot Start 00:00_01/01/1987
 Interval 12 Hour Plot End 00:00_01/01/1988

1987



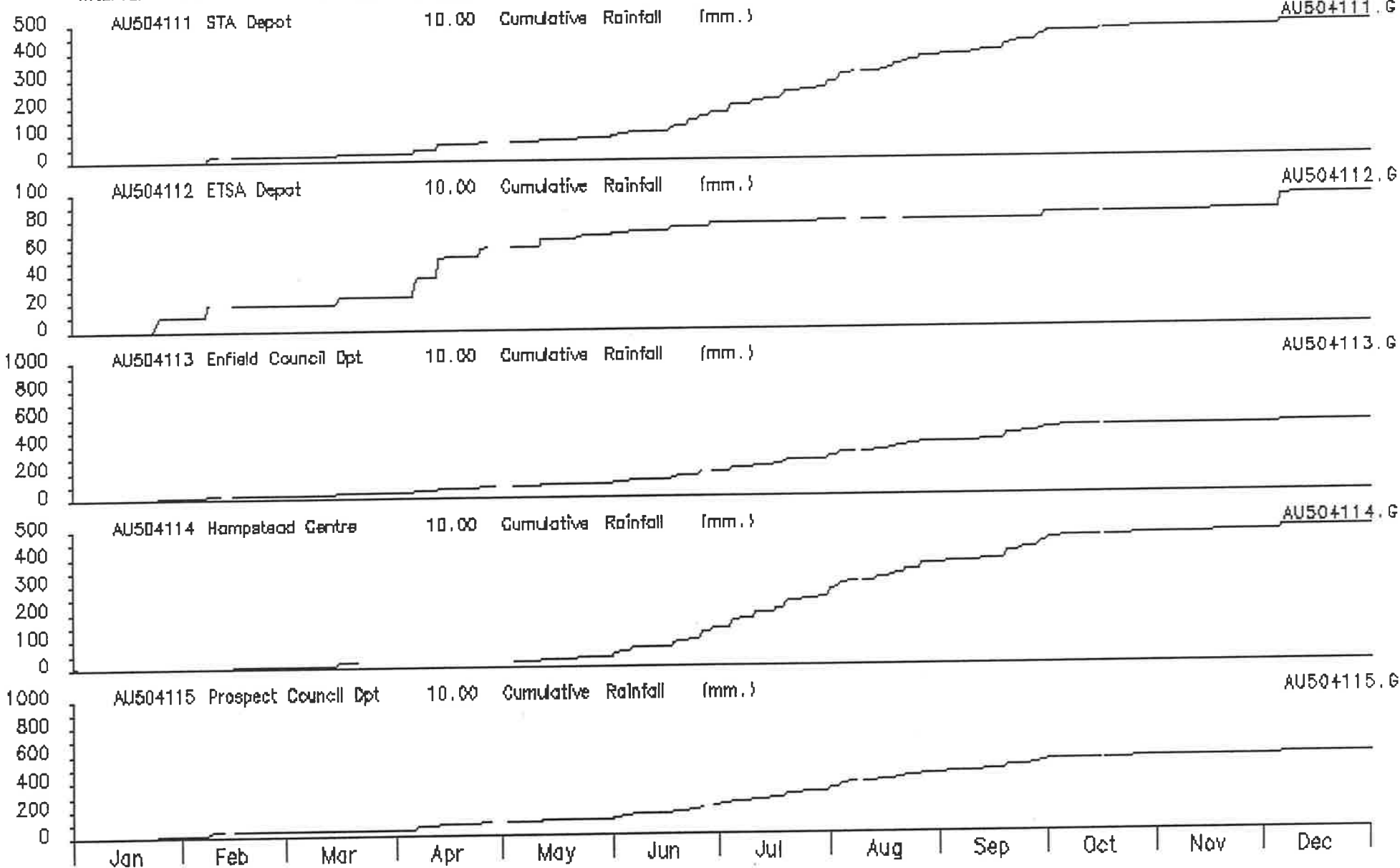
Civil Engineering, Adelaide University

HYPLOT V74 Output 21/11/1997

1996

Period 1 Year Plot Start 00:00_01/01/1996

Interval 12 Hour Plot End 00:00_01/01/1997



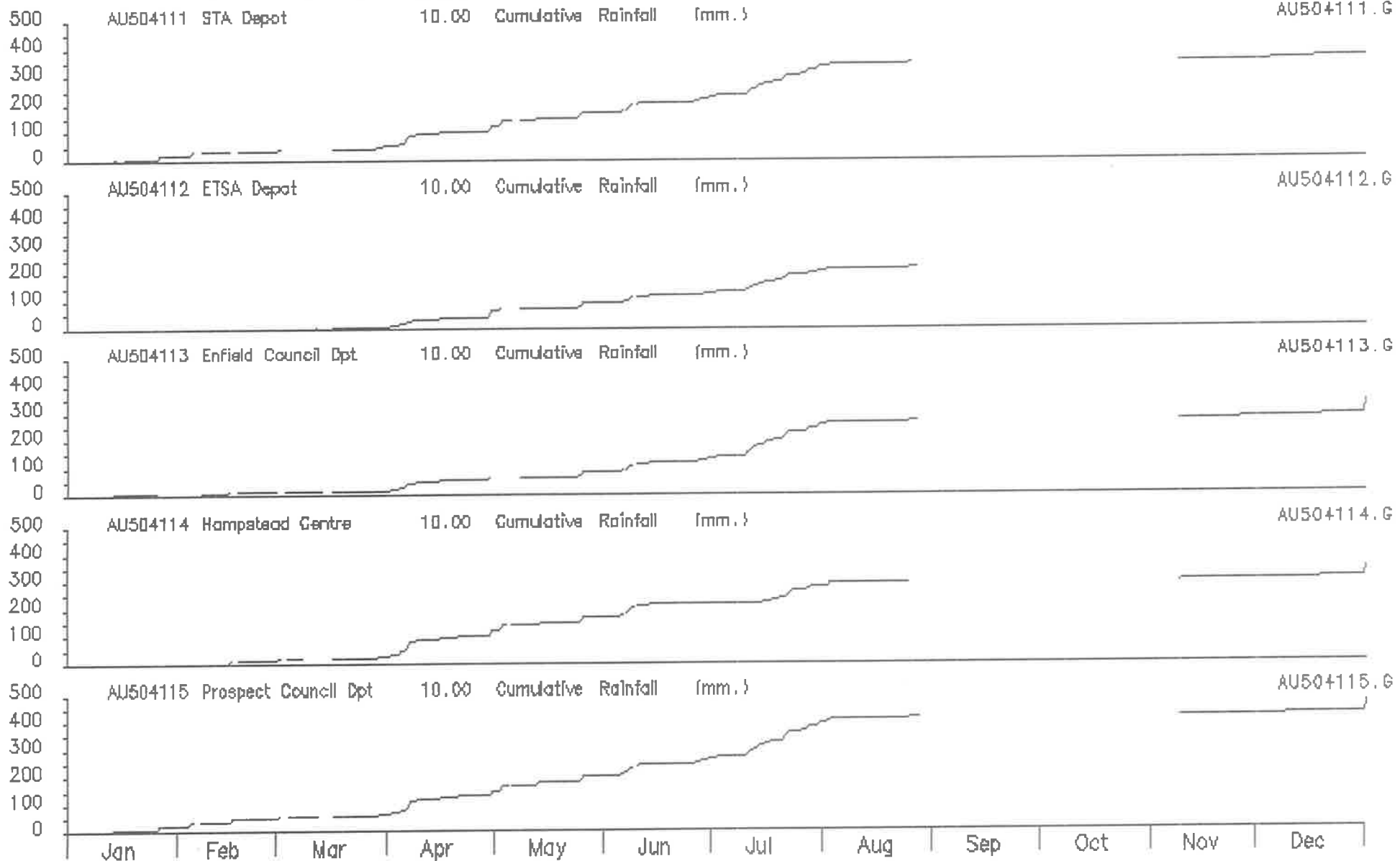
Civil Engineering, Adelaide University

HYPL0T V74 Output 21/11/1987

1995

Period 1 Year Plot Start 00:00_01/01/1995

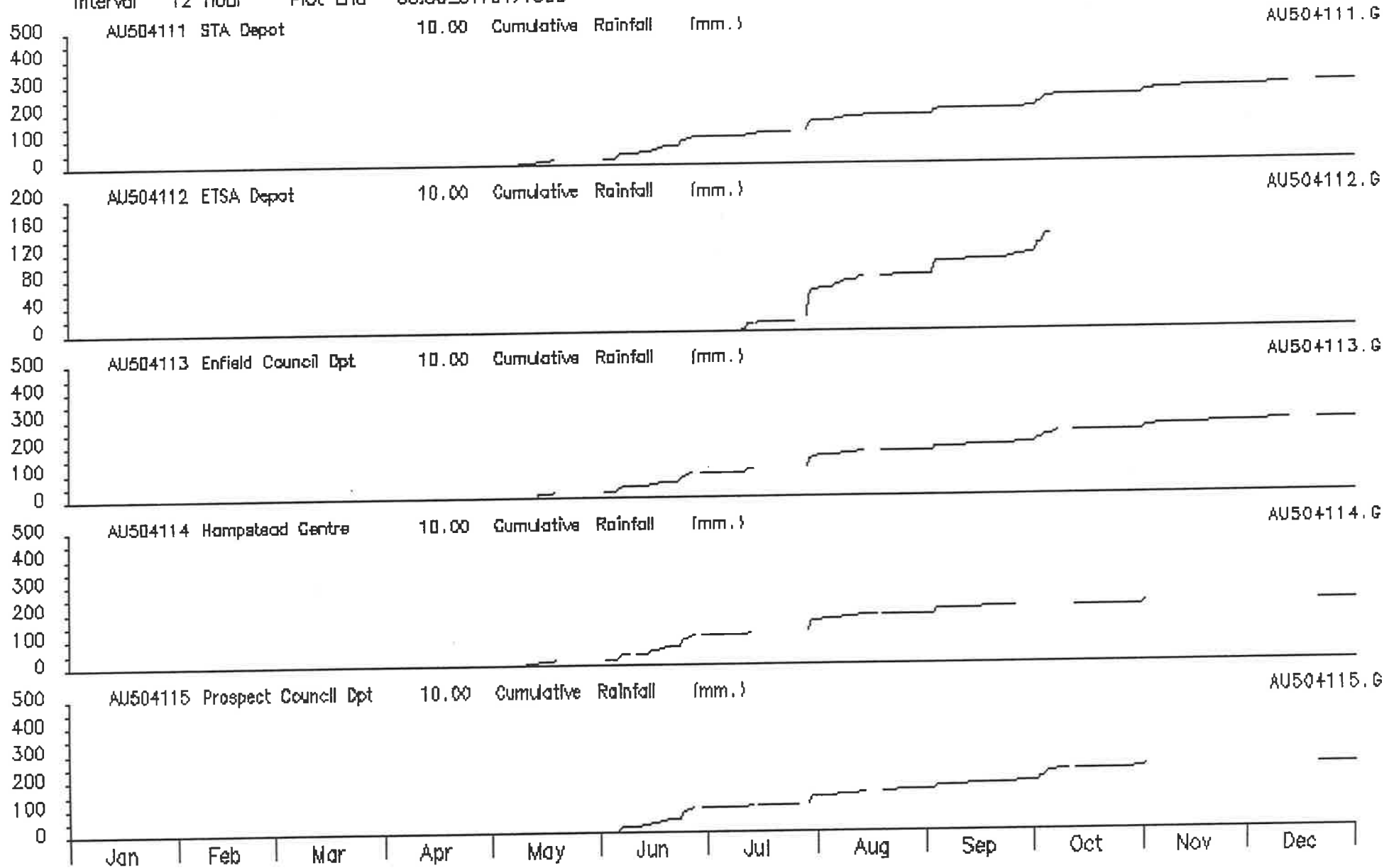
Interval 12 Hour Plot End 00:00_01/01/1996



Civil Engineering, Adelaide University

HYPLOT V74 Output 21/11/1997
1994

Period 1 Year Plot Start 00:00_01/01/1994
Interval 12 Hour Plot End 00:00_01/01/1995



Appendix G

Sequential Sample Parameter Correlations

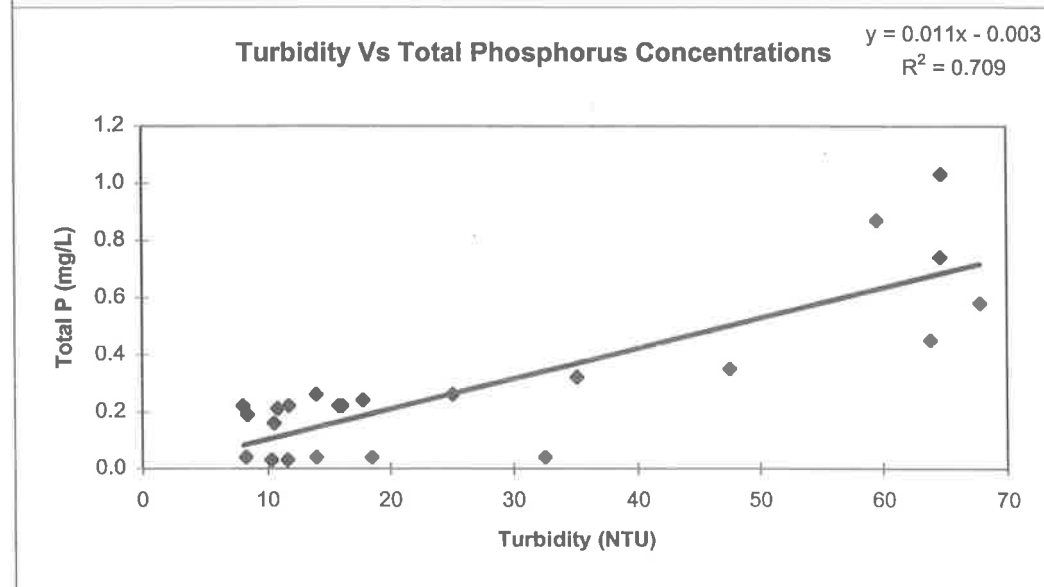
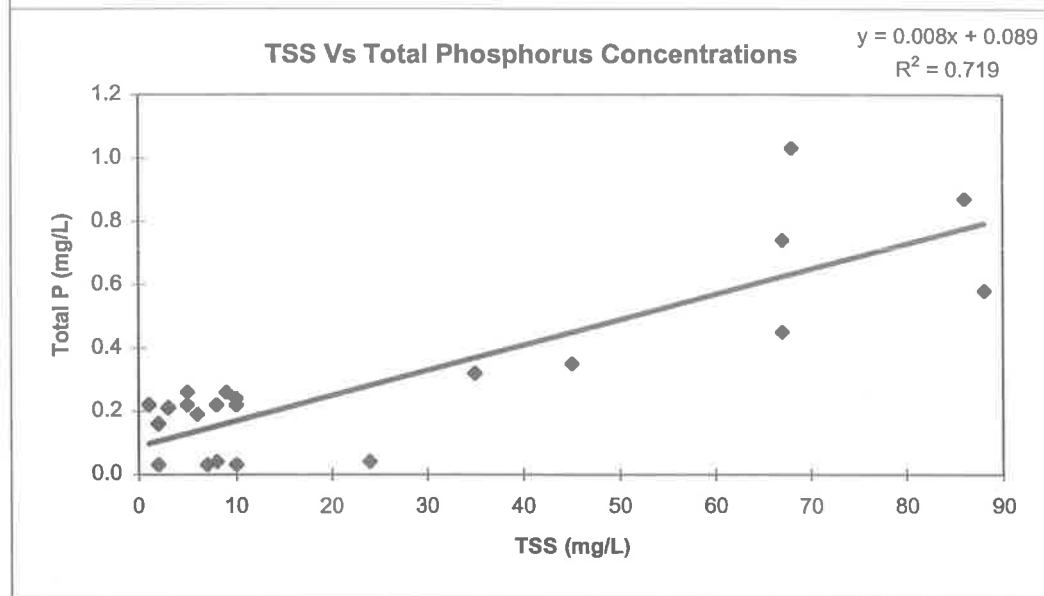
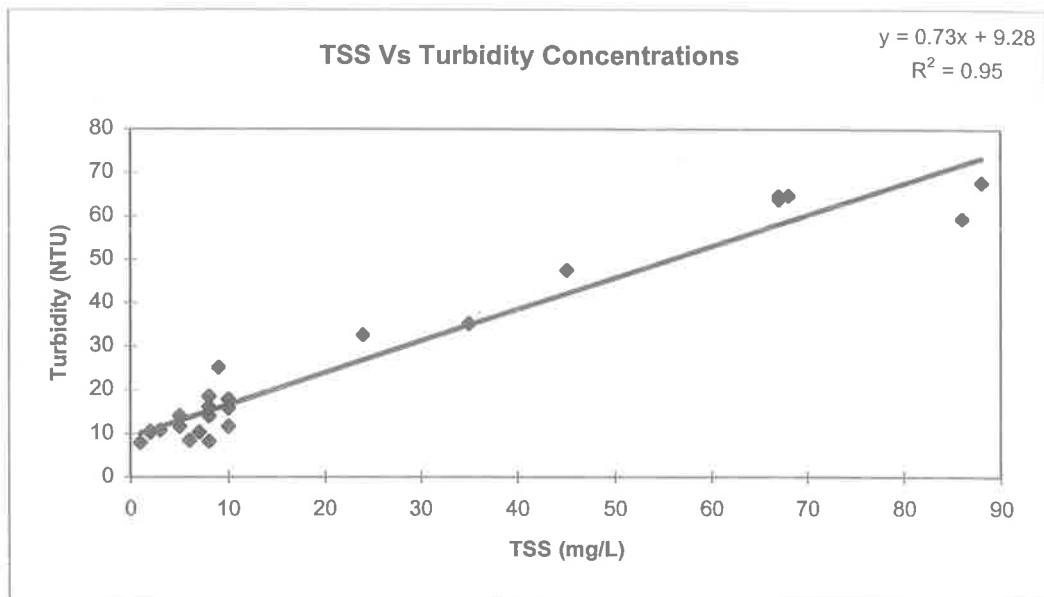
Summary

Appendix G presents the correlations between the sequential sample parameters of total suspended solids, turbidity and total phosphorus. The 3 correlations investigated were :

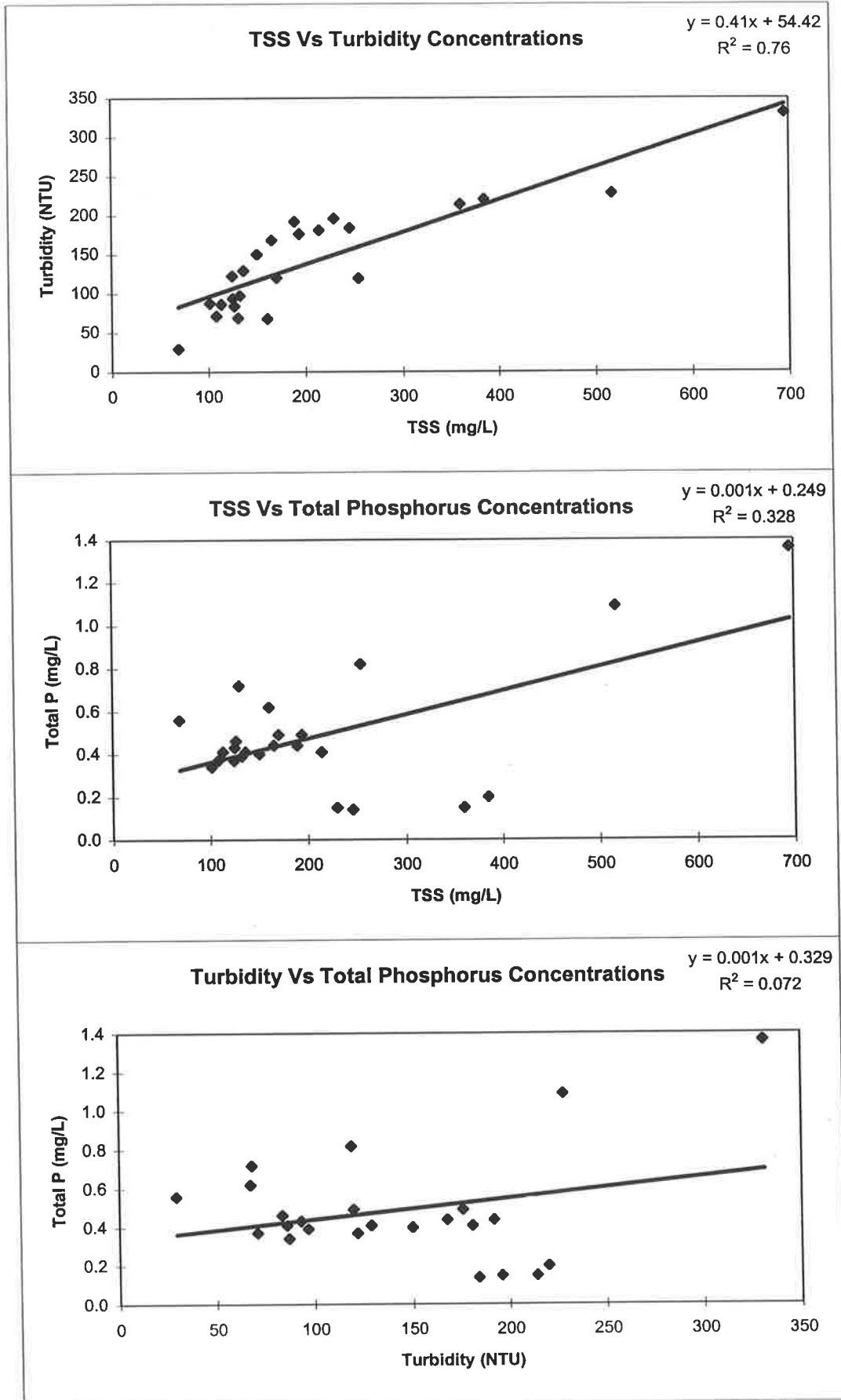
- Turbidity Vs Total Suspended Solids;
- Total Phosphorus Vs Total Suspended Solids; and
- Total Phosphorus Vs Turbidity.

North Arm East Drain (AU504101)

Storm Date : 6-7/4/96

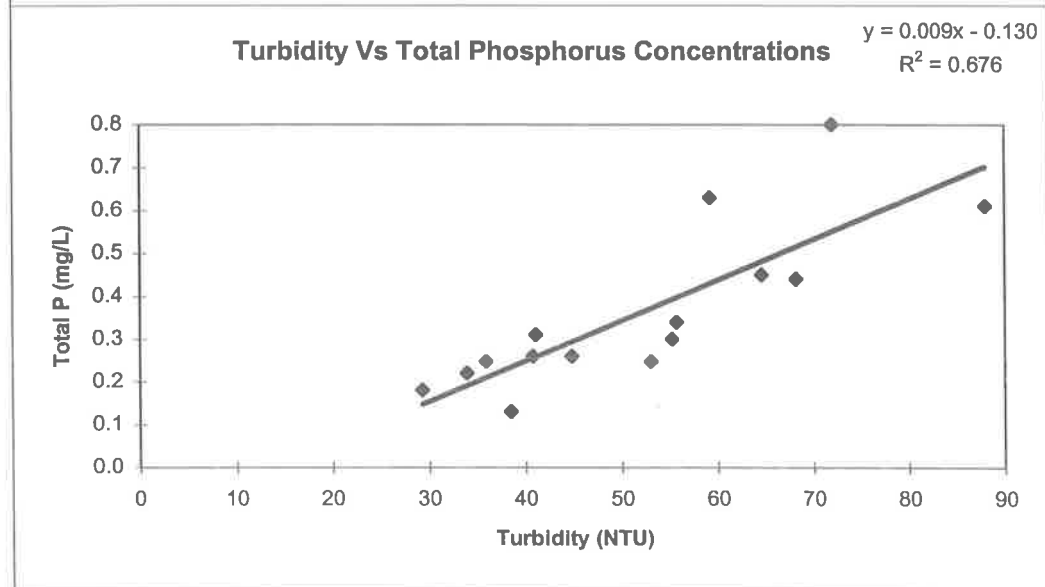
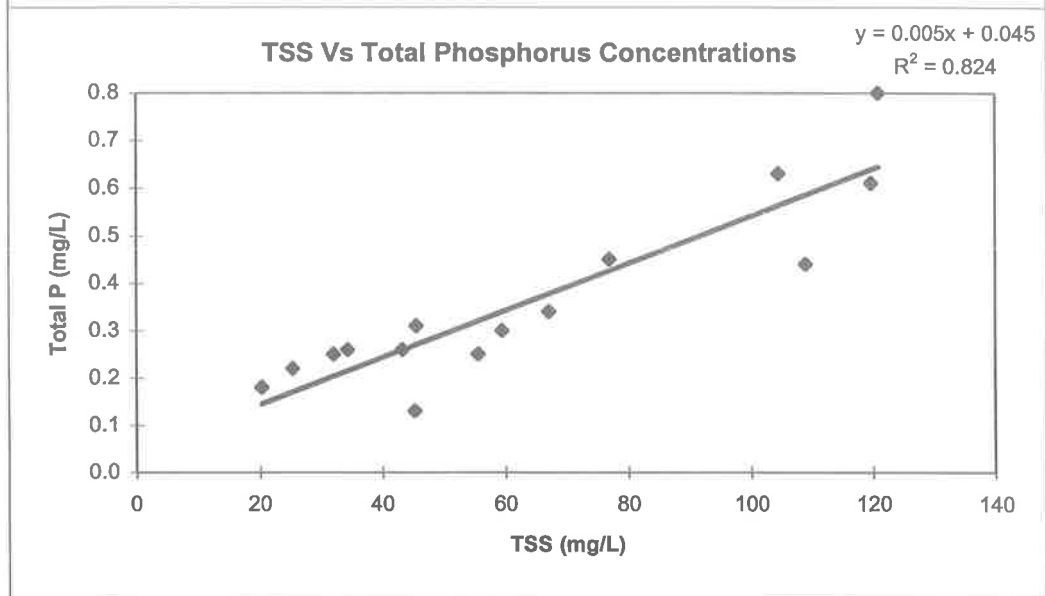
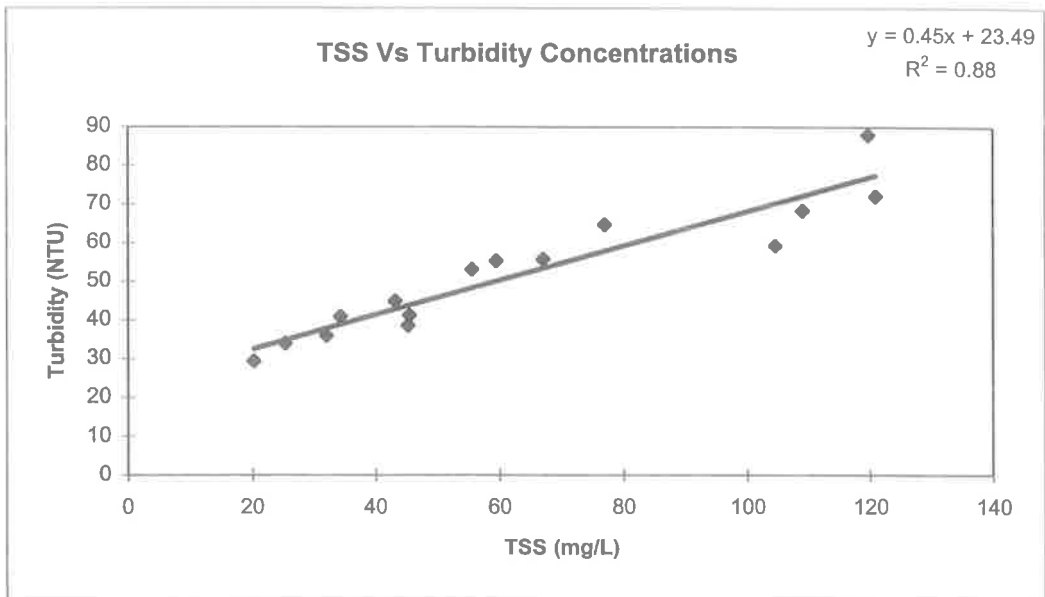


North Arm East Drain (AU504101)
Storm Date : 13/04/96

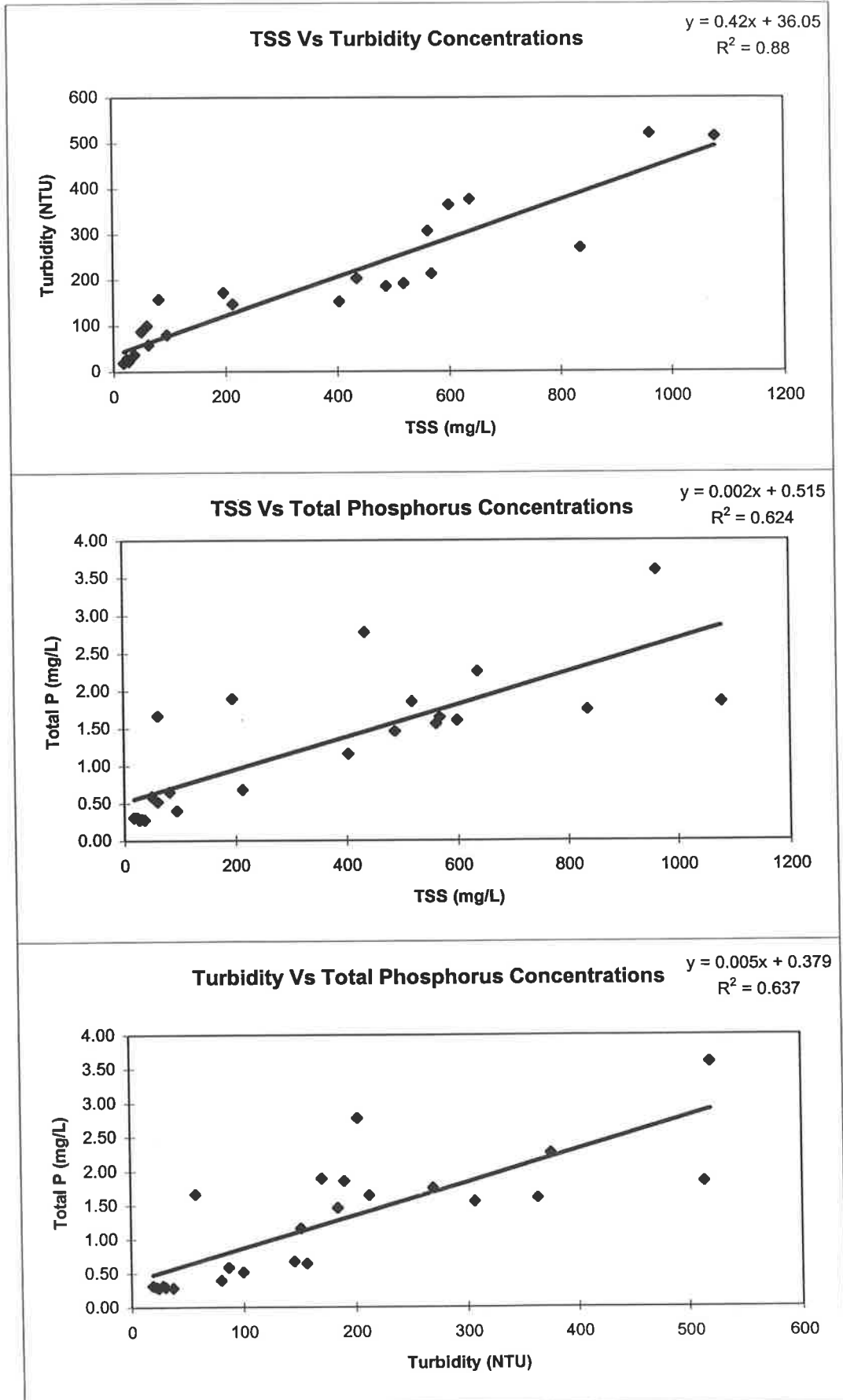


North Arm East Drain (AU504101)

Storm Date : 25/04/96

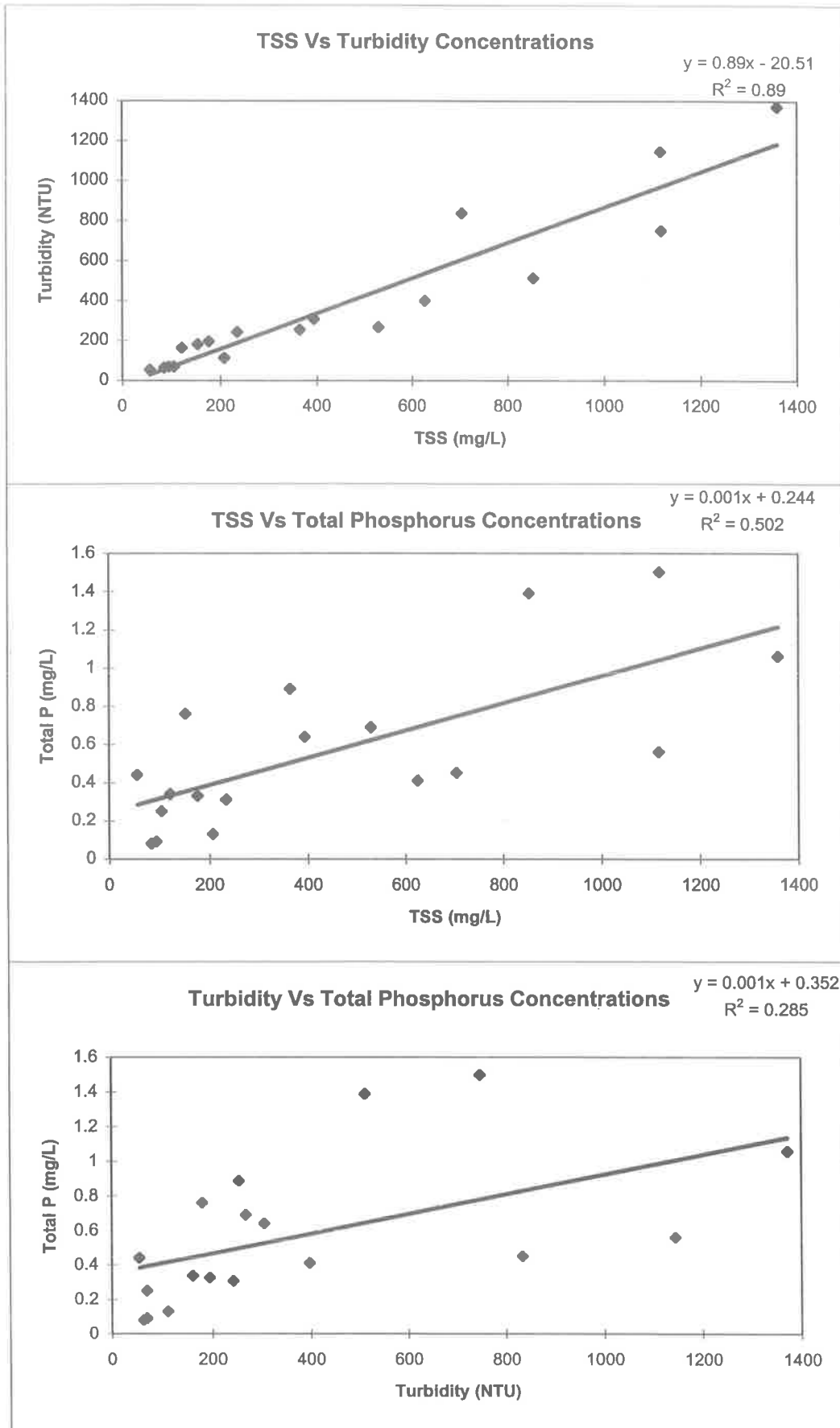


North Arm East Drain (AU504101)
Storm Date : 2-5/5/97

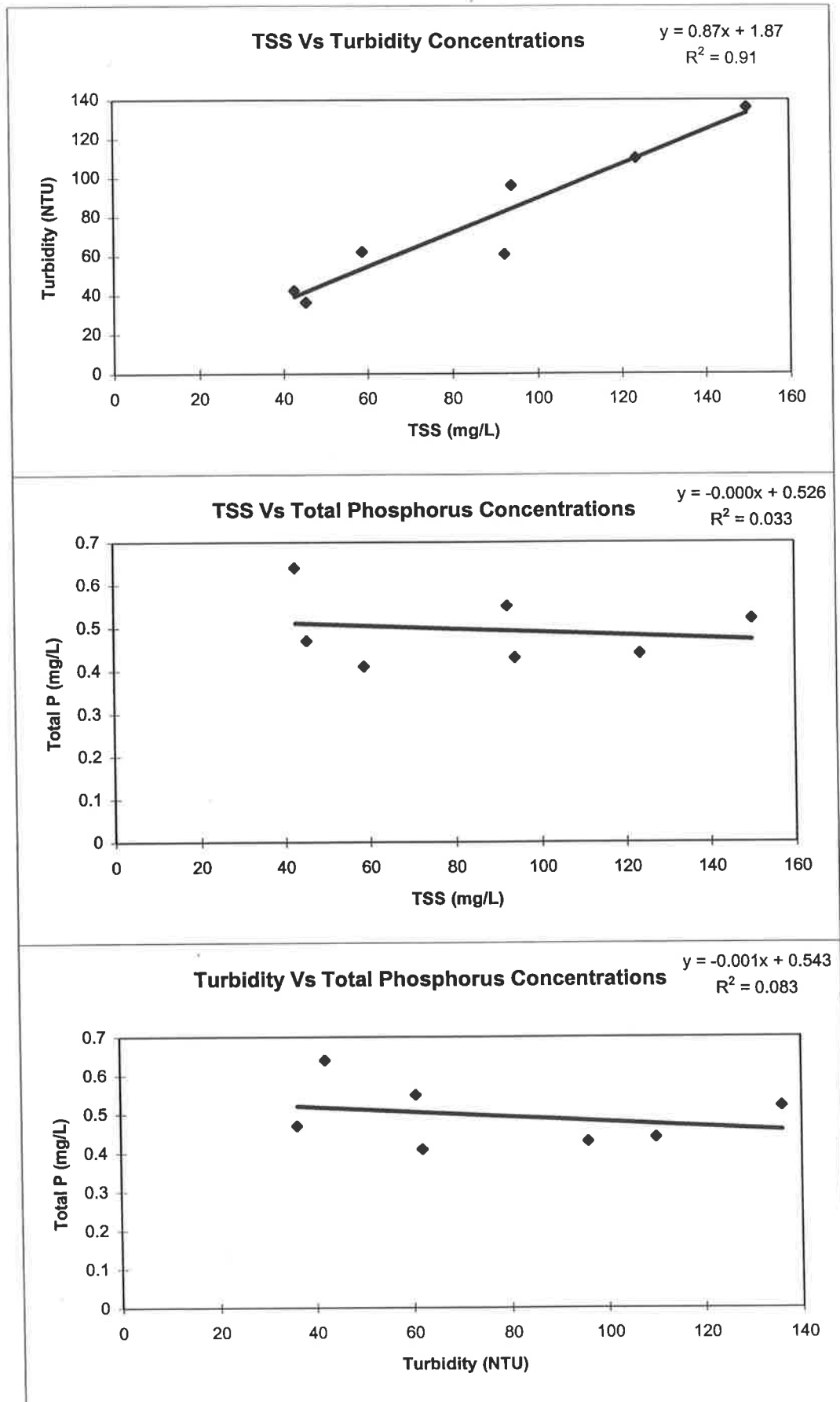


North Arm East Drain (AU504101)

Storm Date : 12/05/96

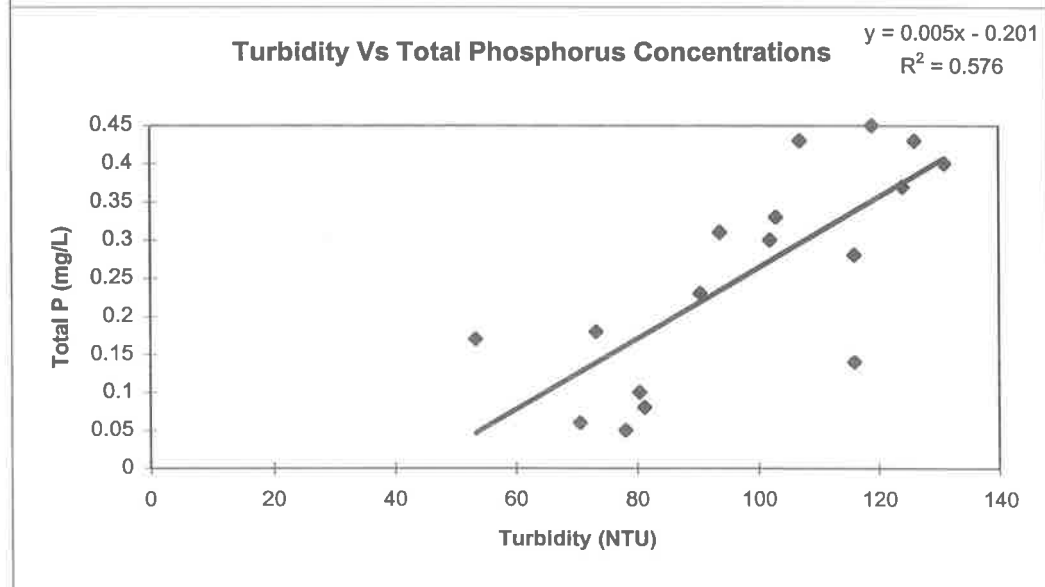
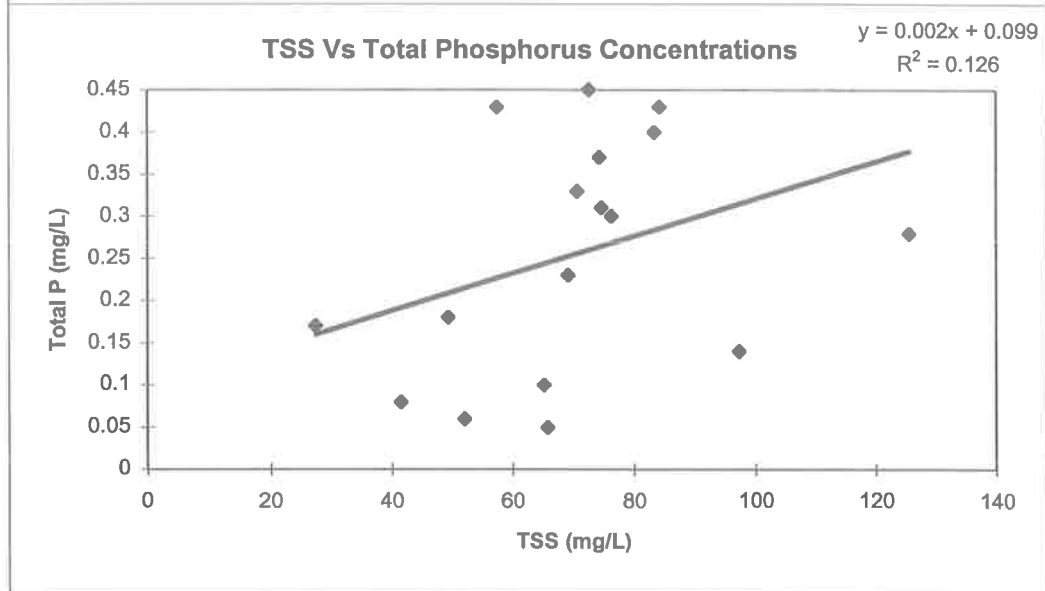
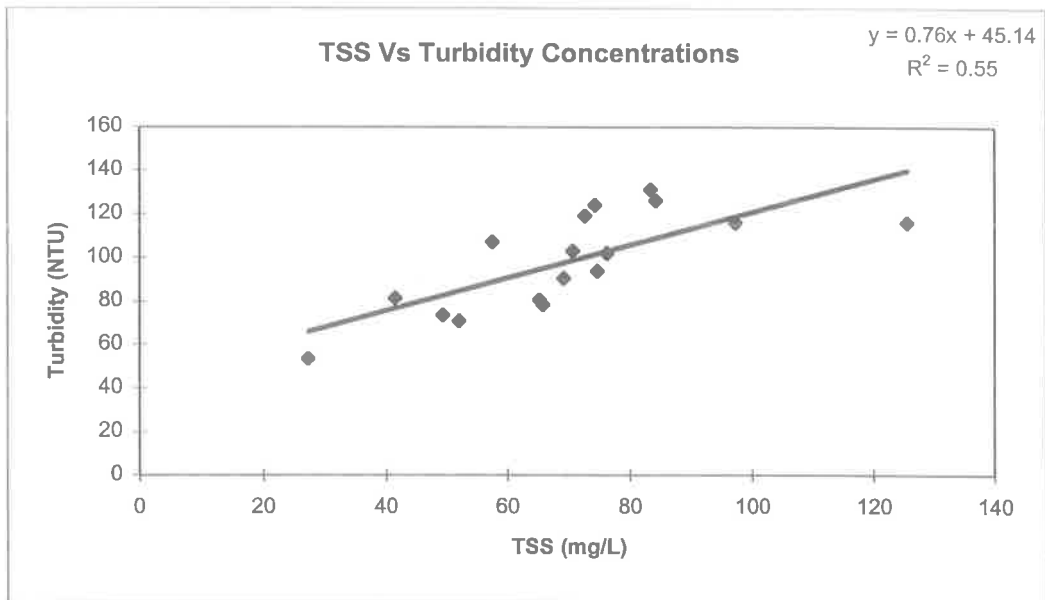


North Arm East Drain (AU504101)
Storm Date : 17/06/96

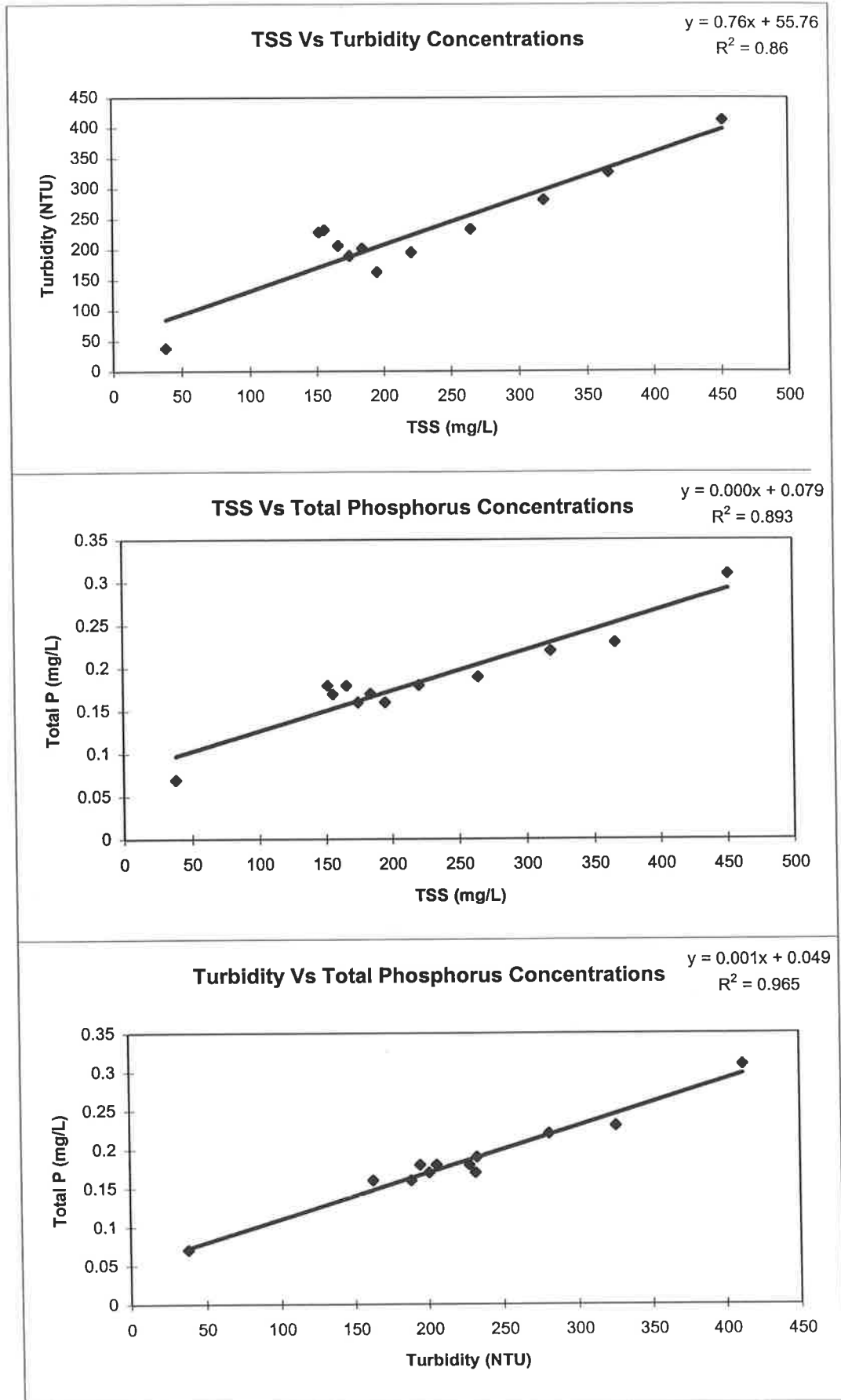


North Arm East Drain (AU504101)

Storm Date : 18/06/96

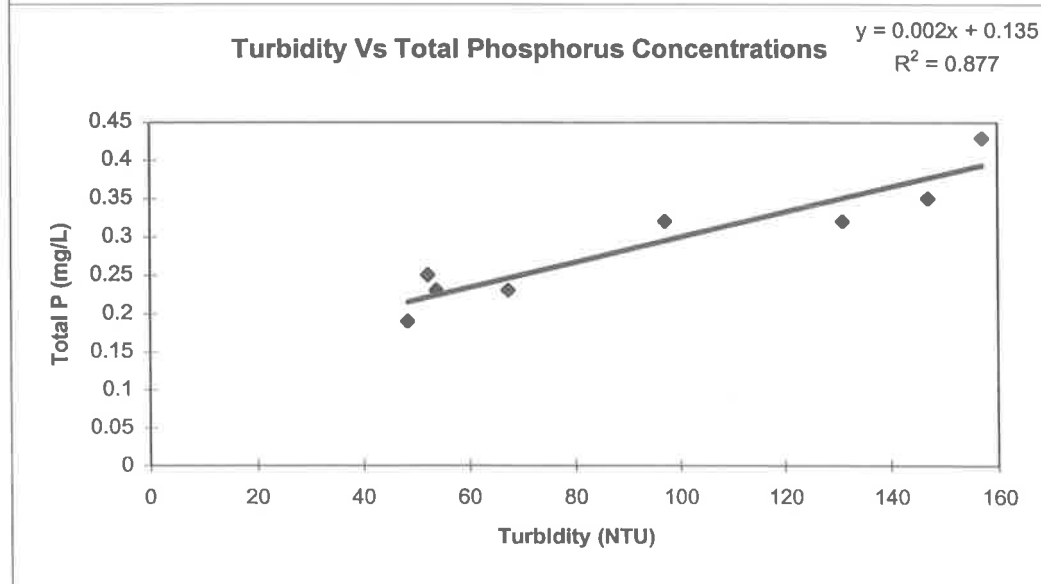
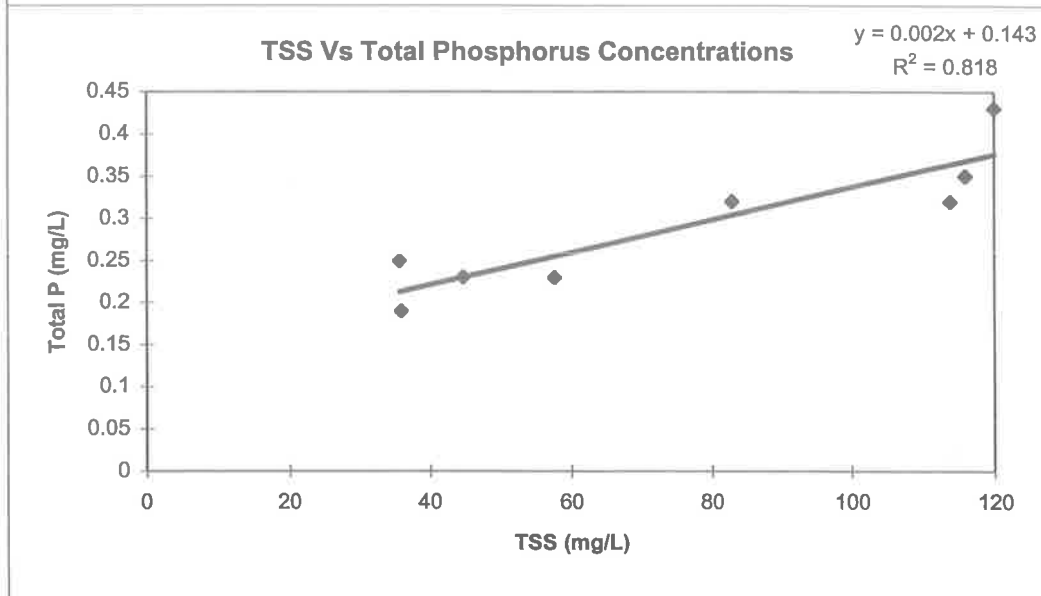
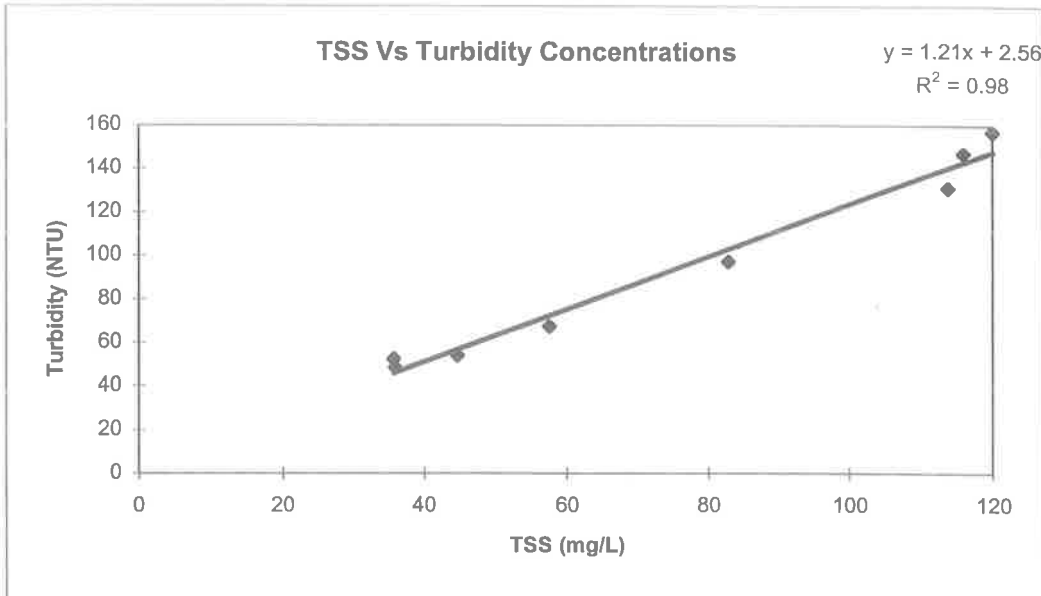


North Arm East Drain (AU504101)
Storm Date : 22/06/96



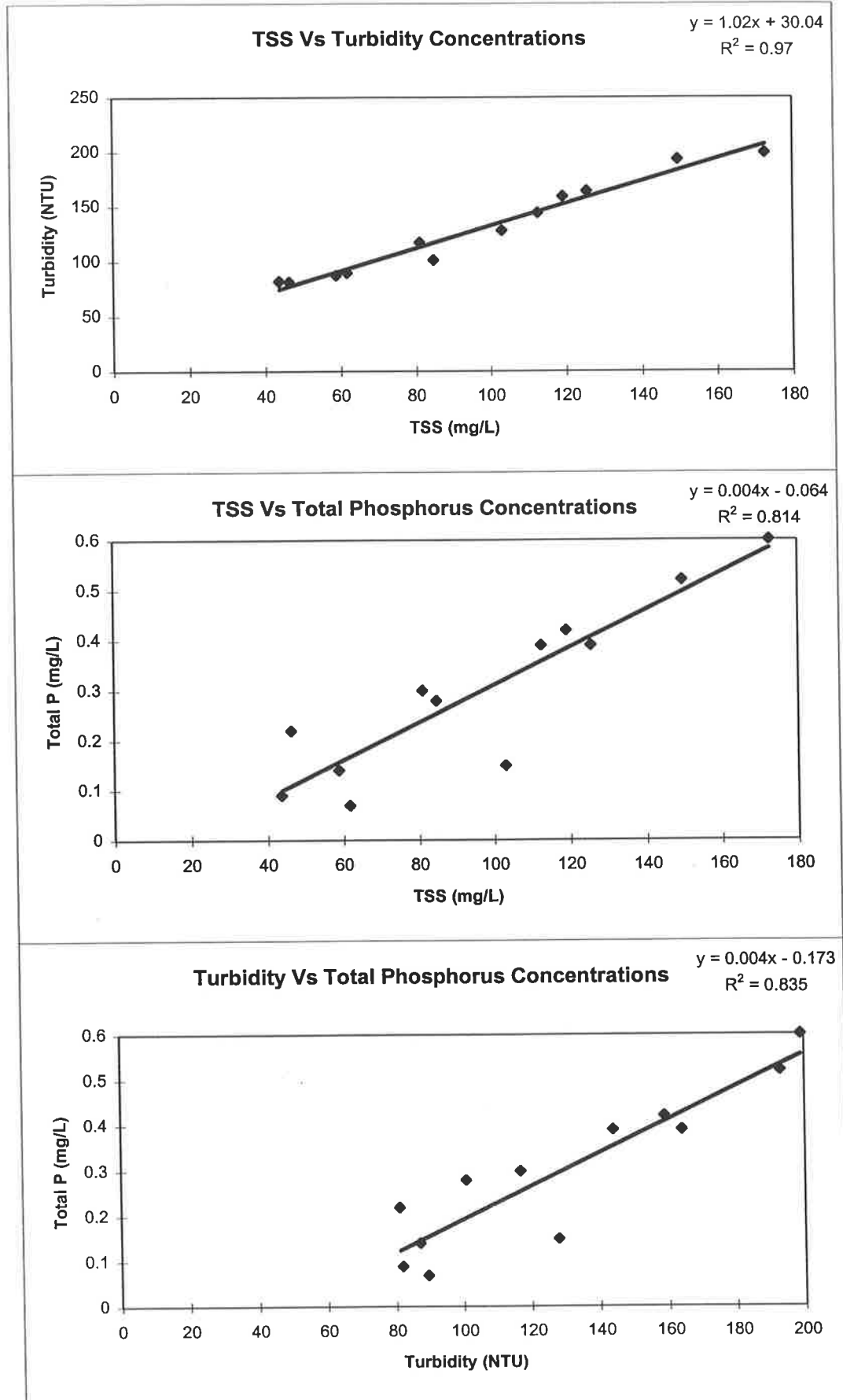
North Arm East Drain (AU504101)

Storm Date : 23/06/96



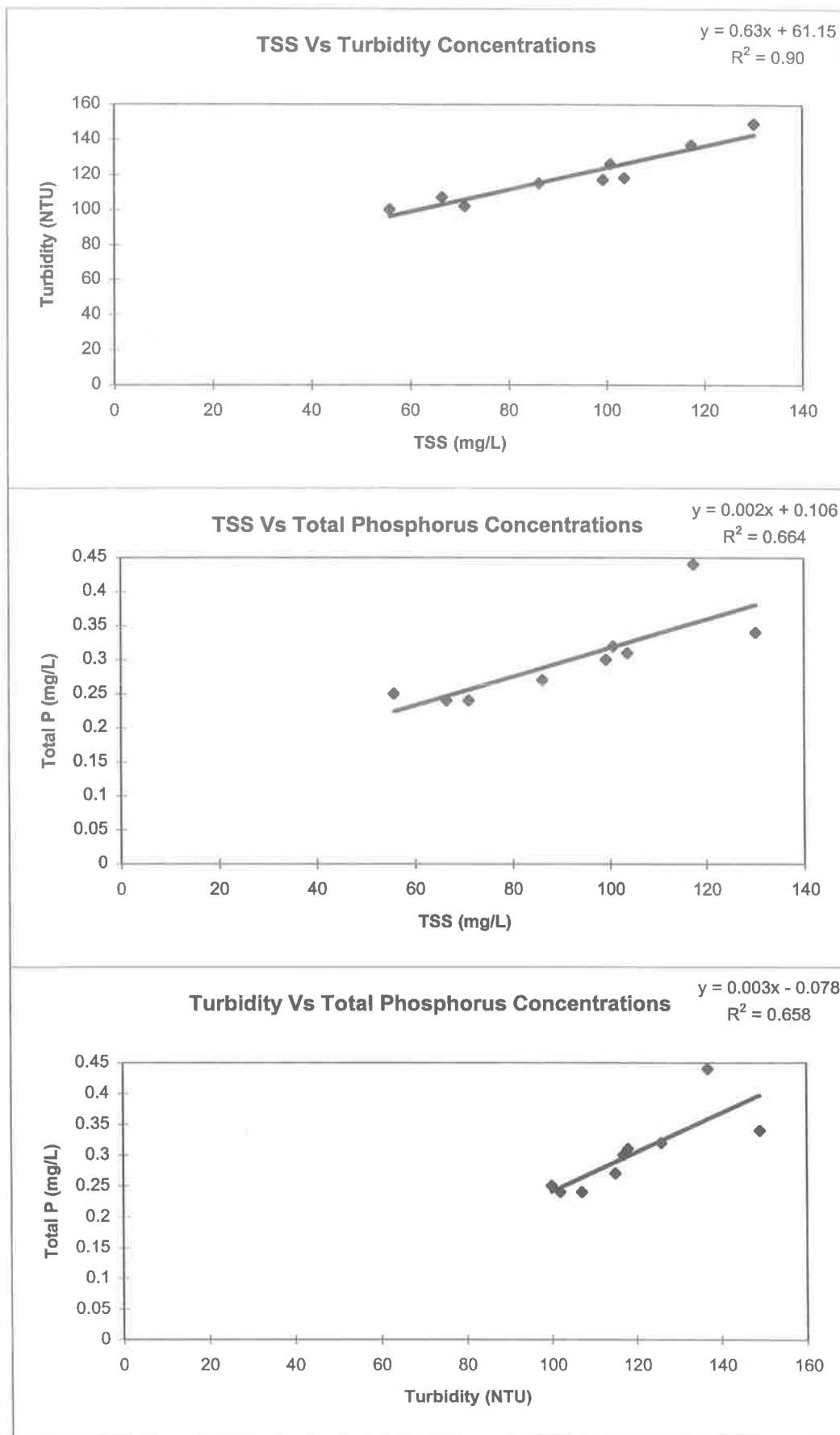
North Arm East Drain (AU504101)

Storm Date : 28/06/96



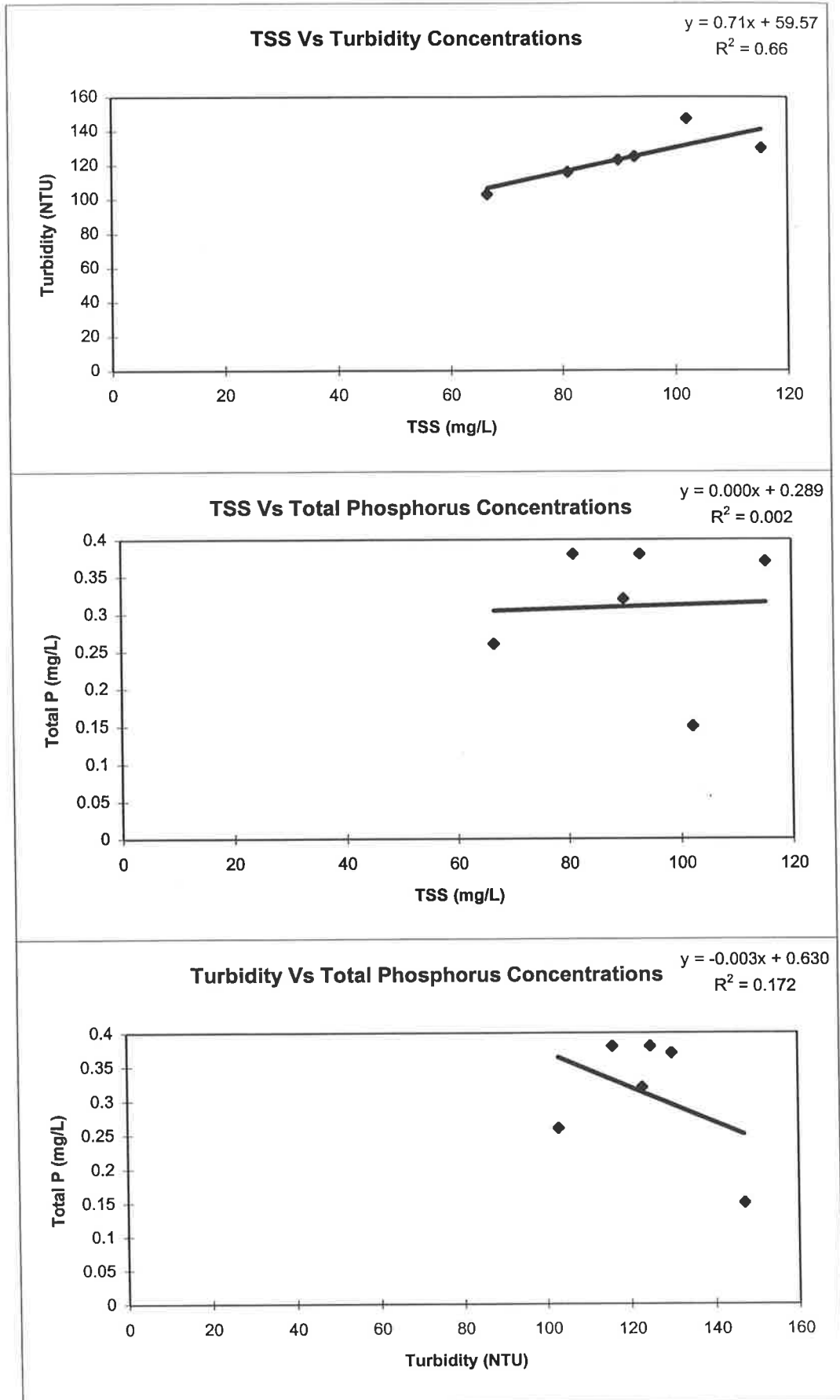
North Arm East Drain (AU504101)

Storm Date : 29/06/96



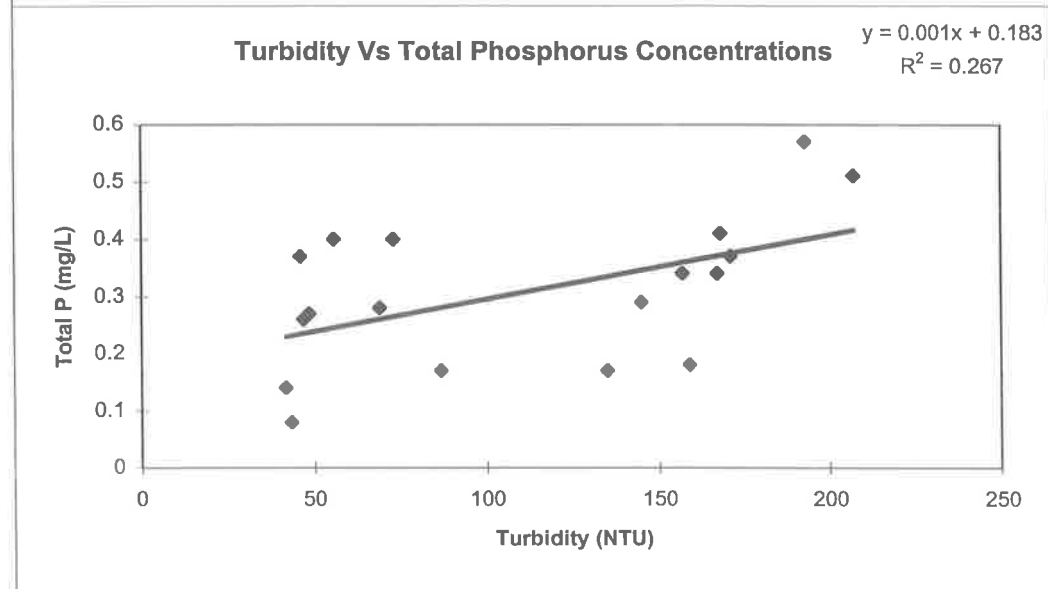
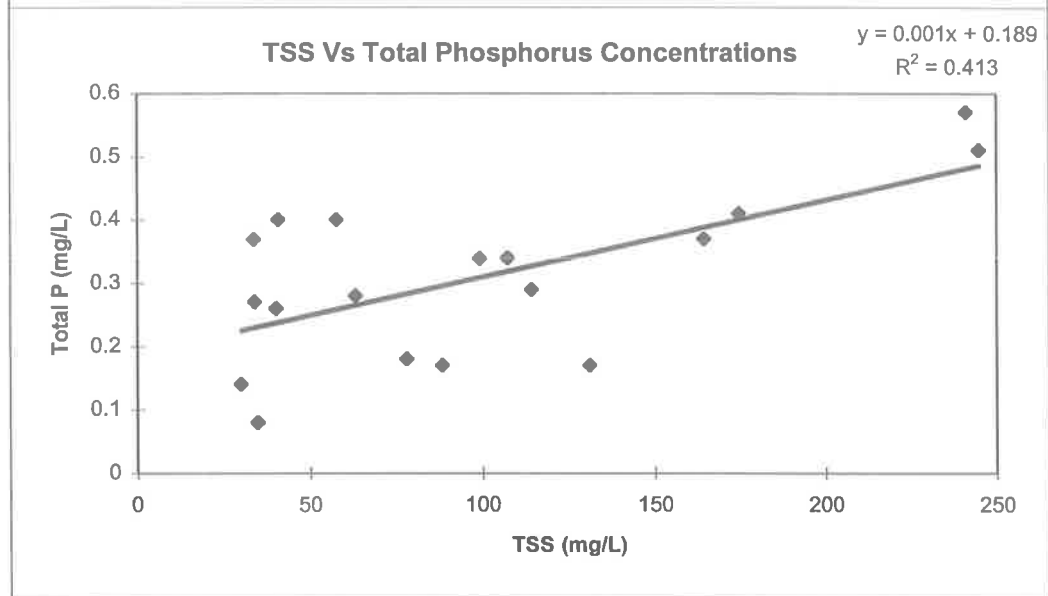
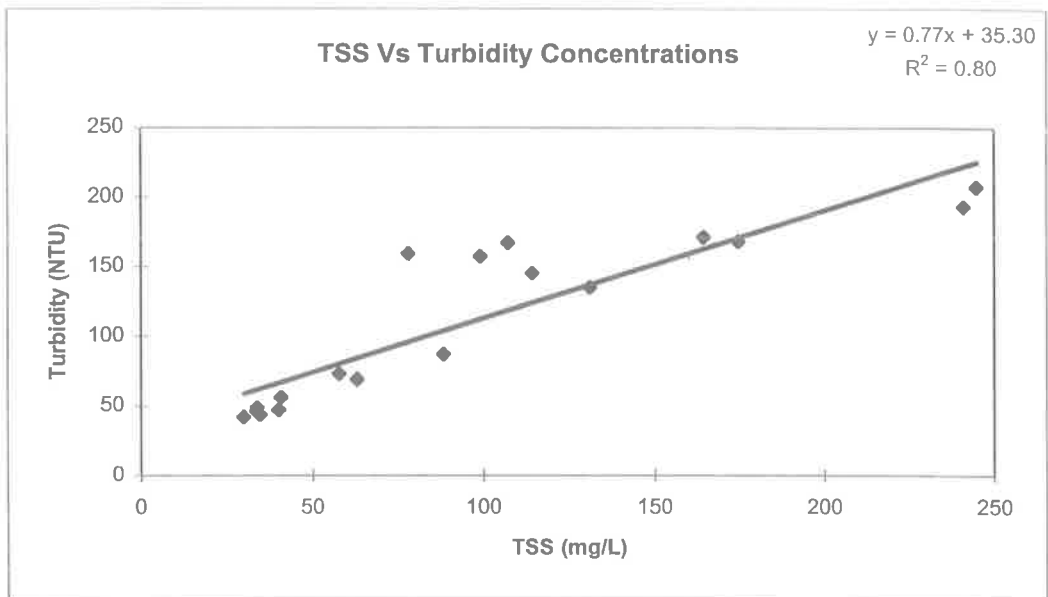
North Arm East Drain (AU504101)

Storm Date : 1/07/96



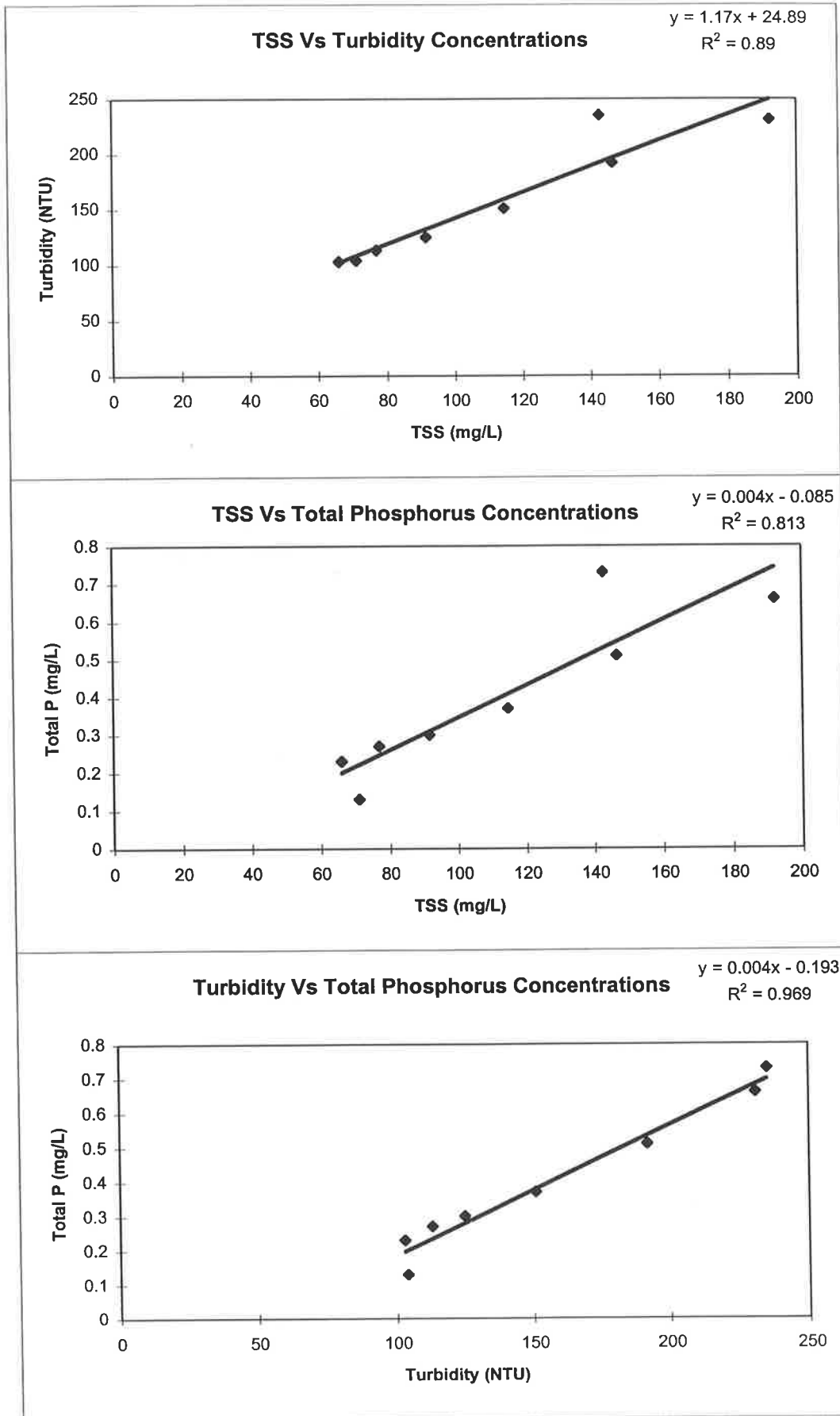
North Arm East Drain (AU504101)

Storm Date : 4/07/96



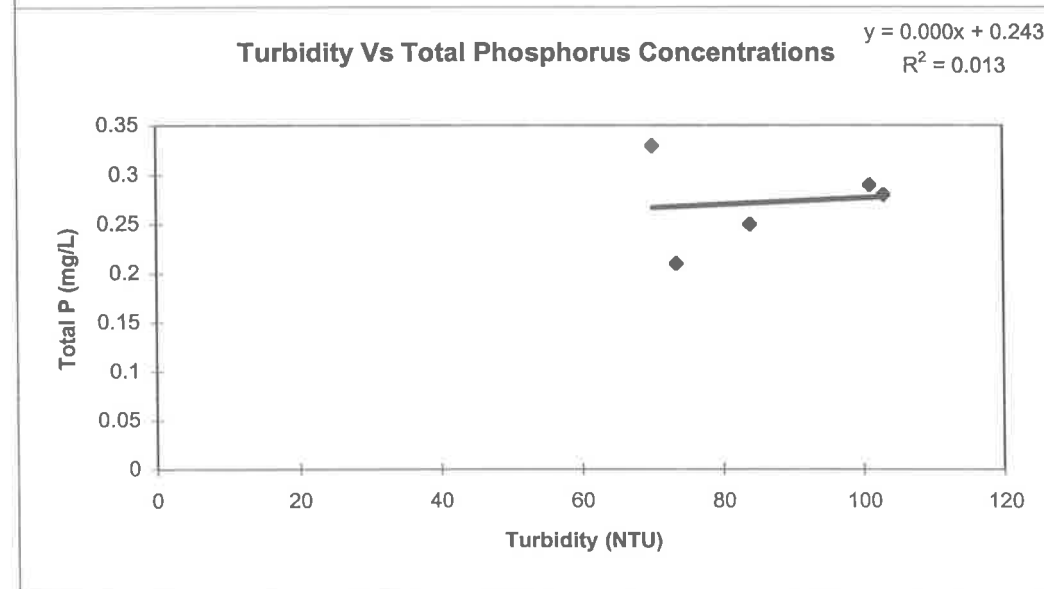
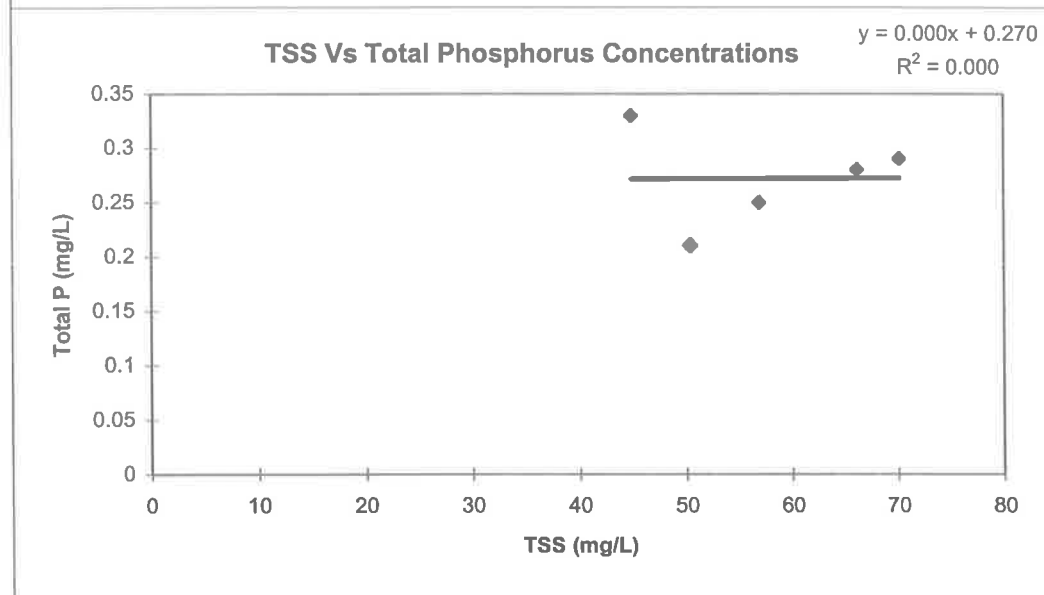
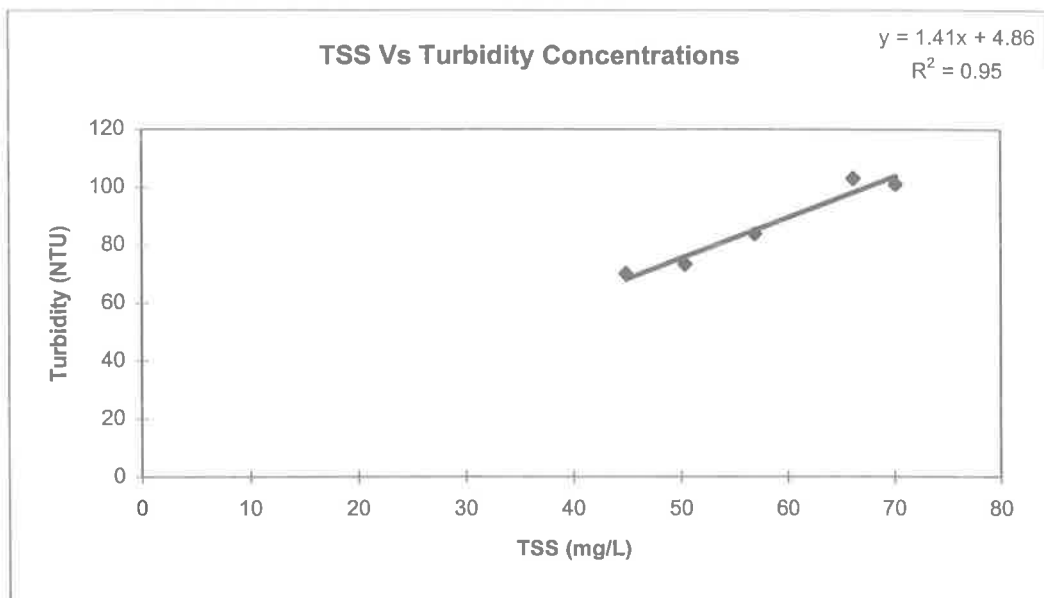
North Arm East Drain (AU504101)

Storm Date : 5-6/7/96



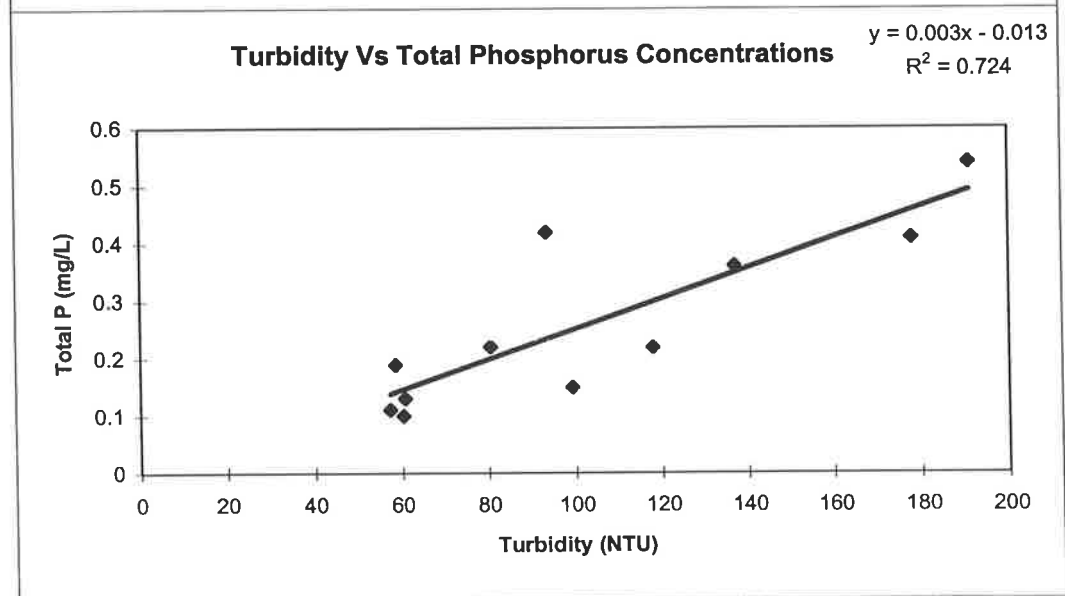
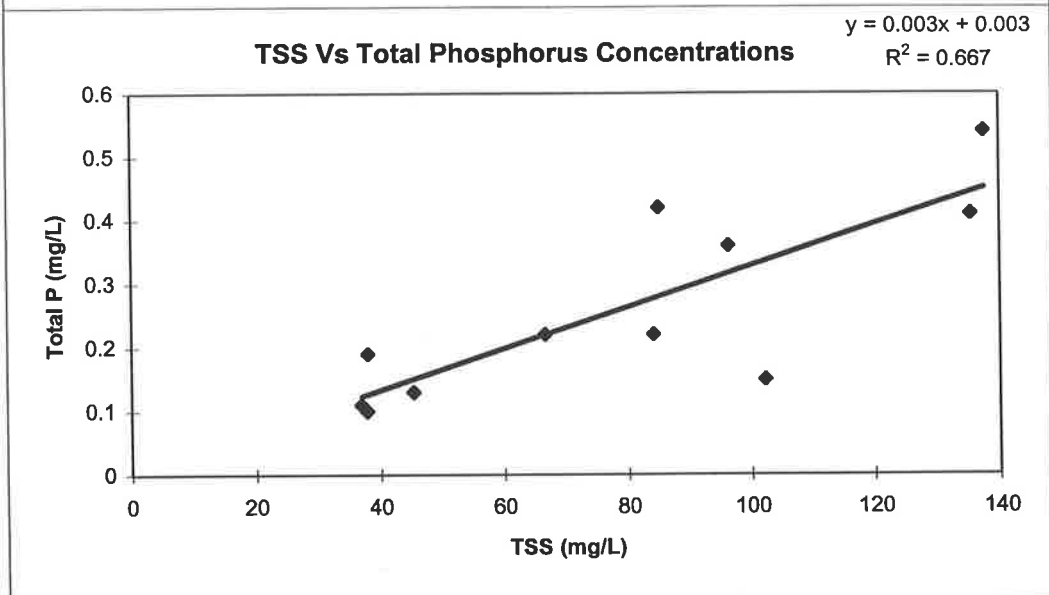
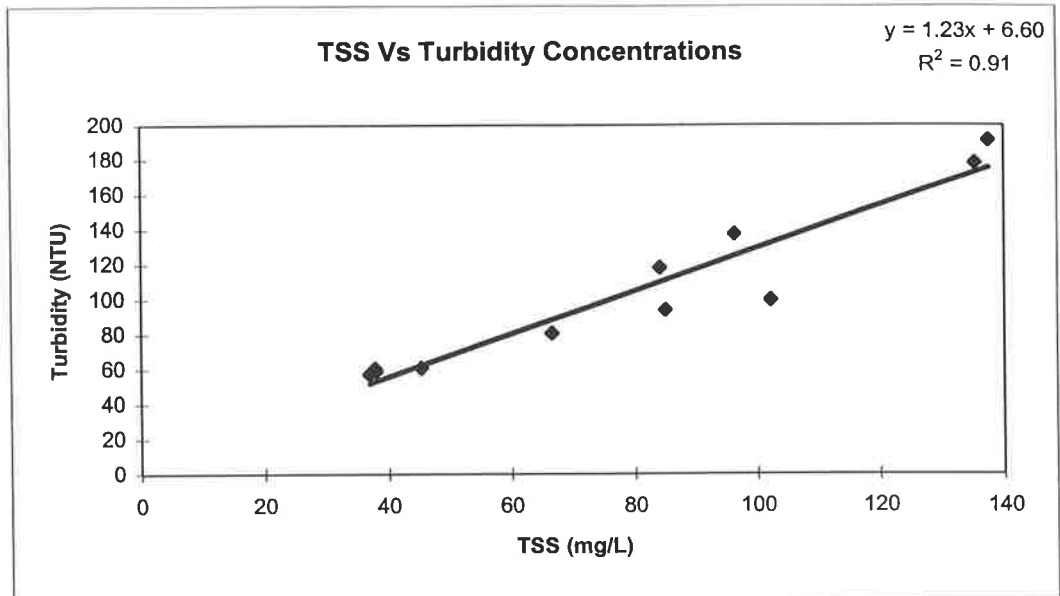
North Arm East Drain (AU504101)

Storm Date : 6/07/96



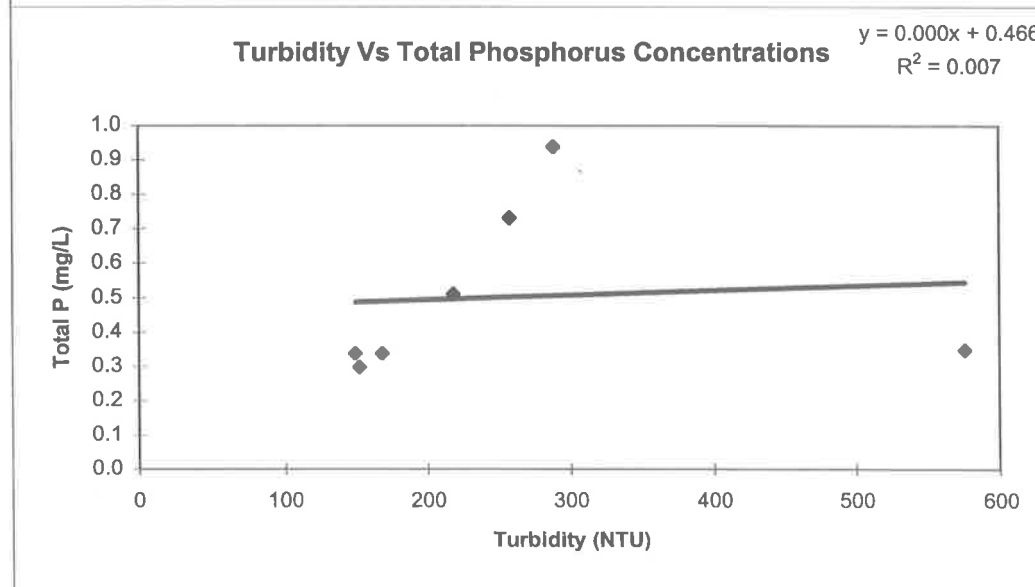
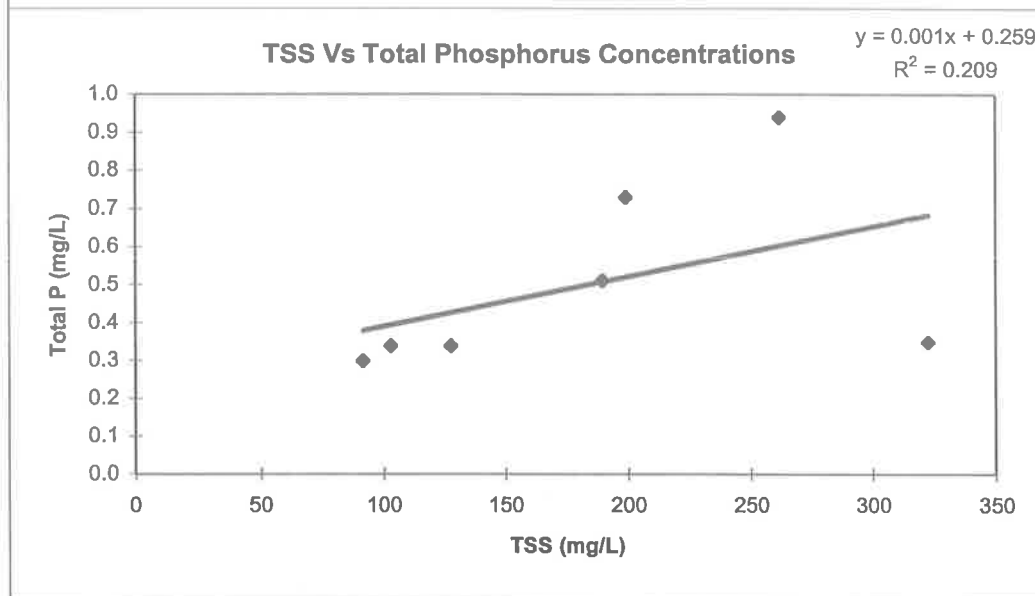
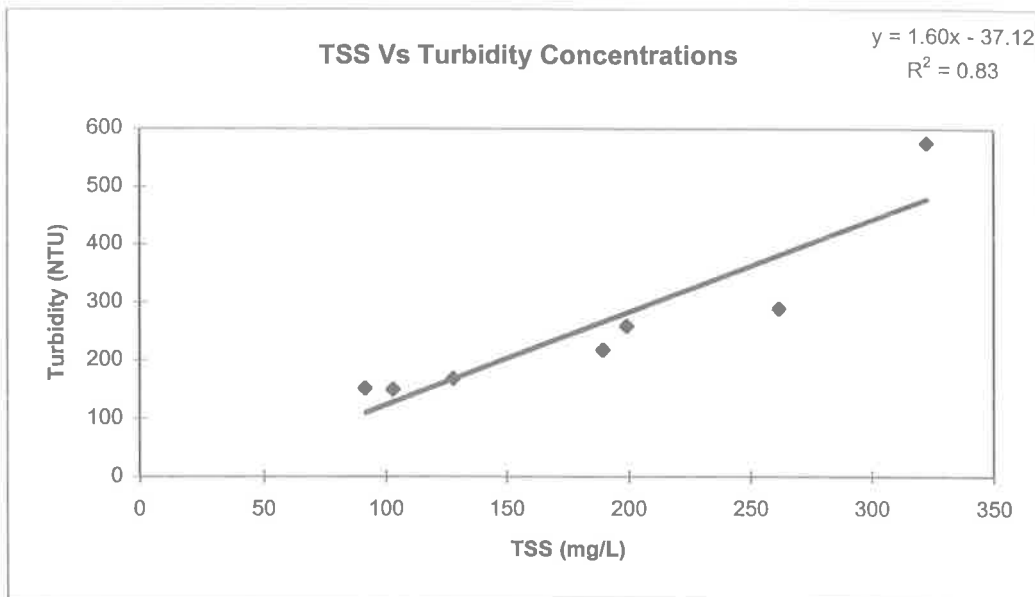
North Arm East Drain (AU504101)

Storm Date : 16/07/96



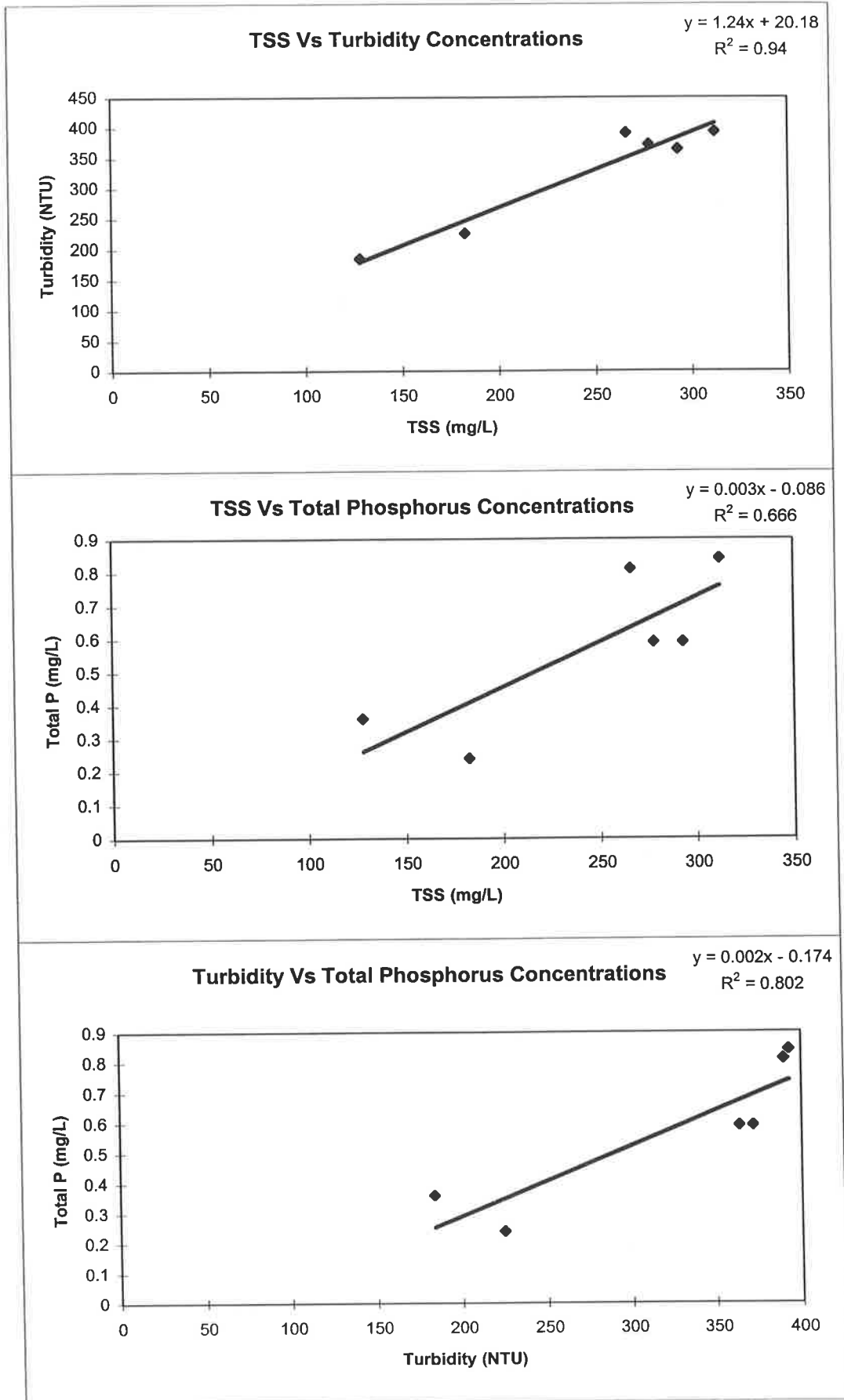
North Arm East Drain (AU504101)

Storm Date : 18/07/96

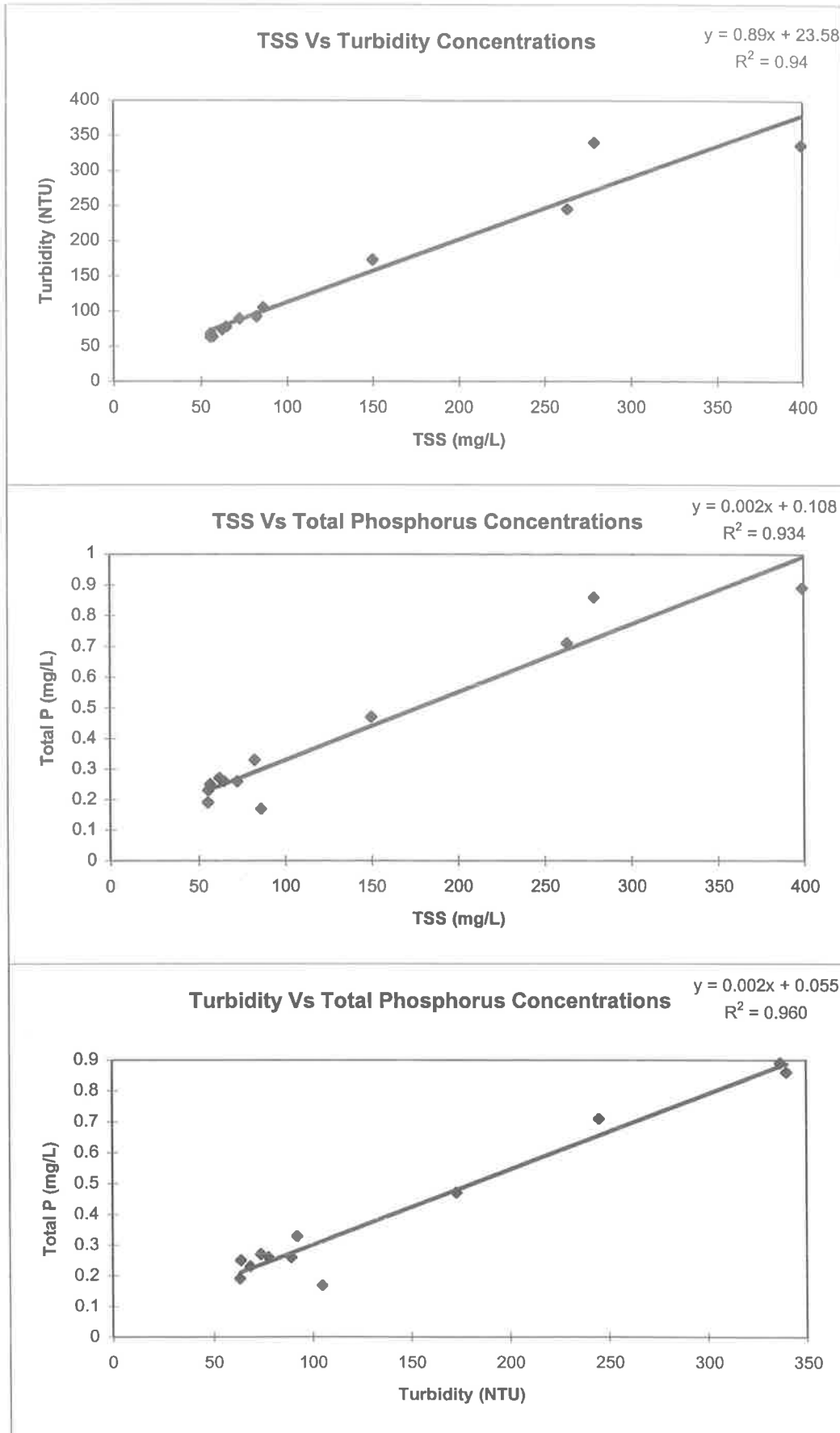


North Arm East Drain (AU504101)

Storm Date : 19/07/96

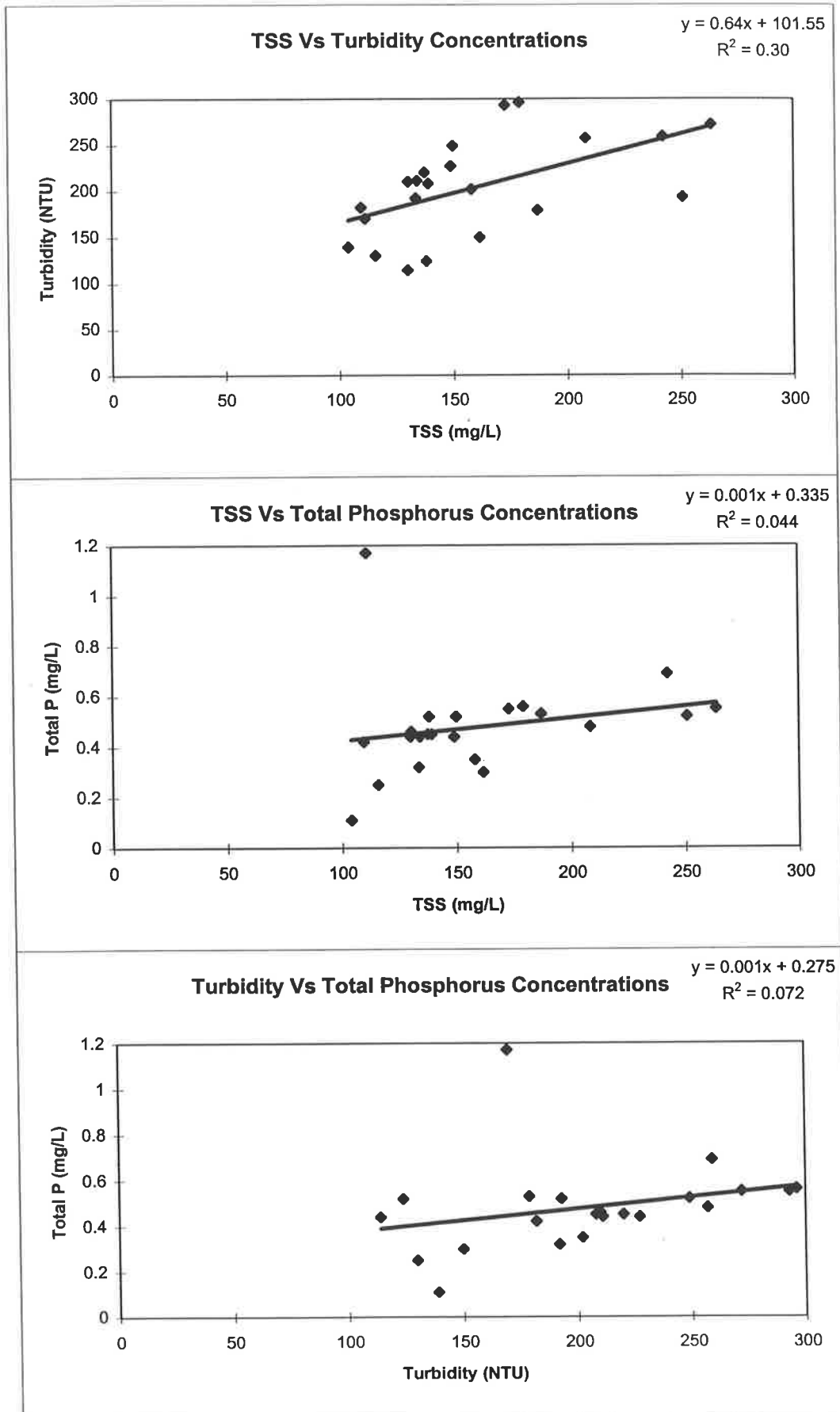


North Arm East Drain (AU504101)
Storm Date : 28-29/7/96



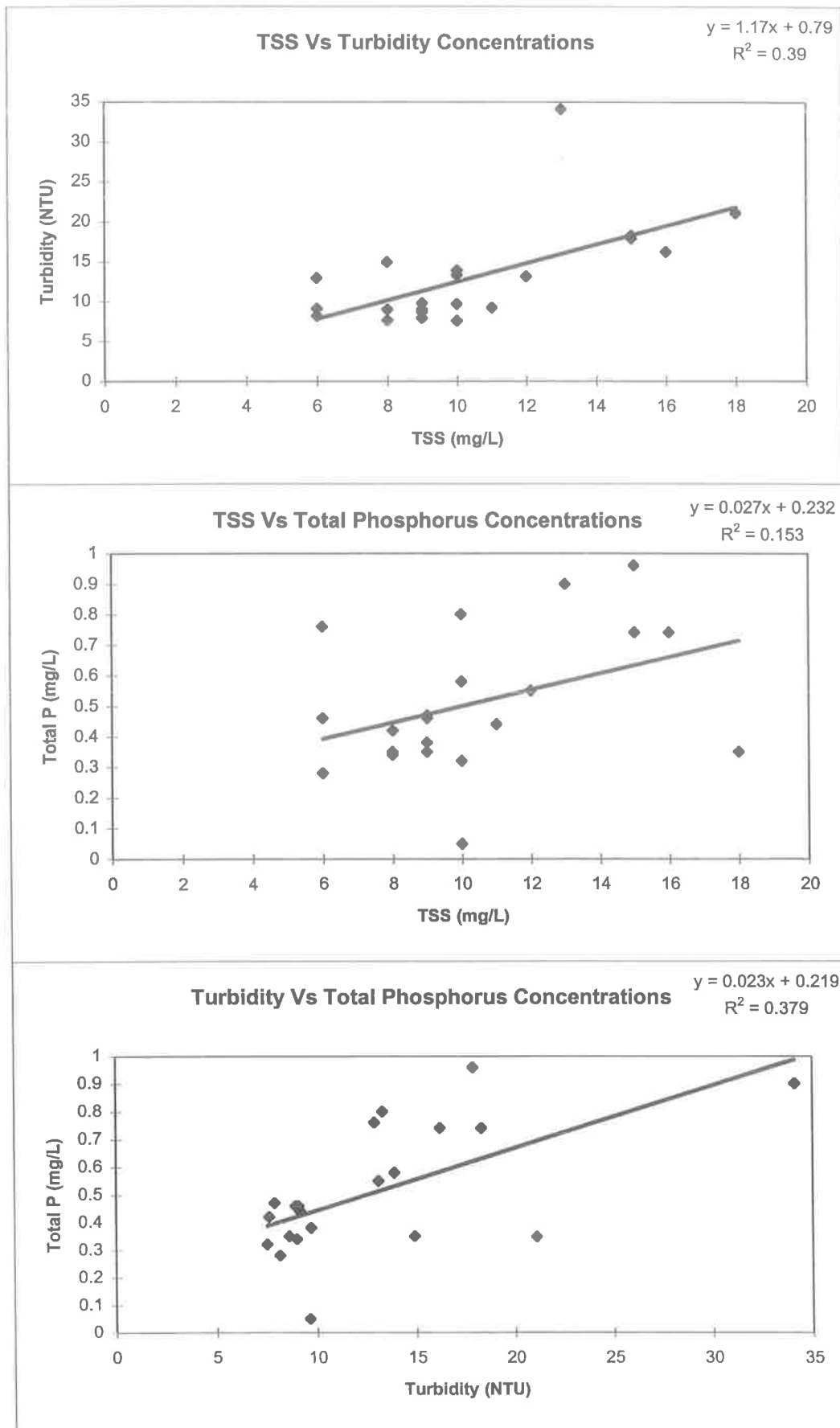
North Arm East Drain (AU504101)

Storm Date : 31/07/96



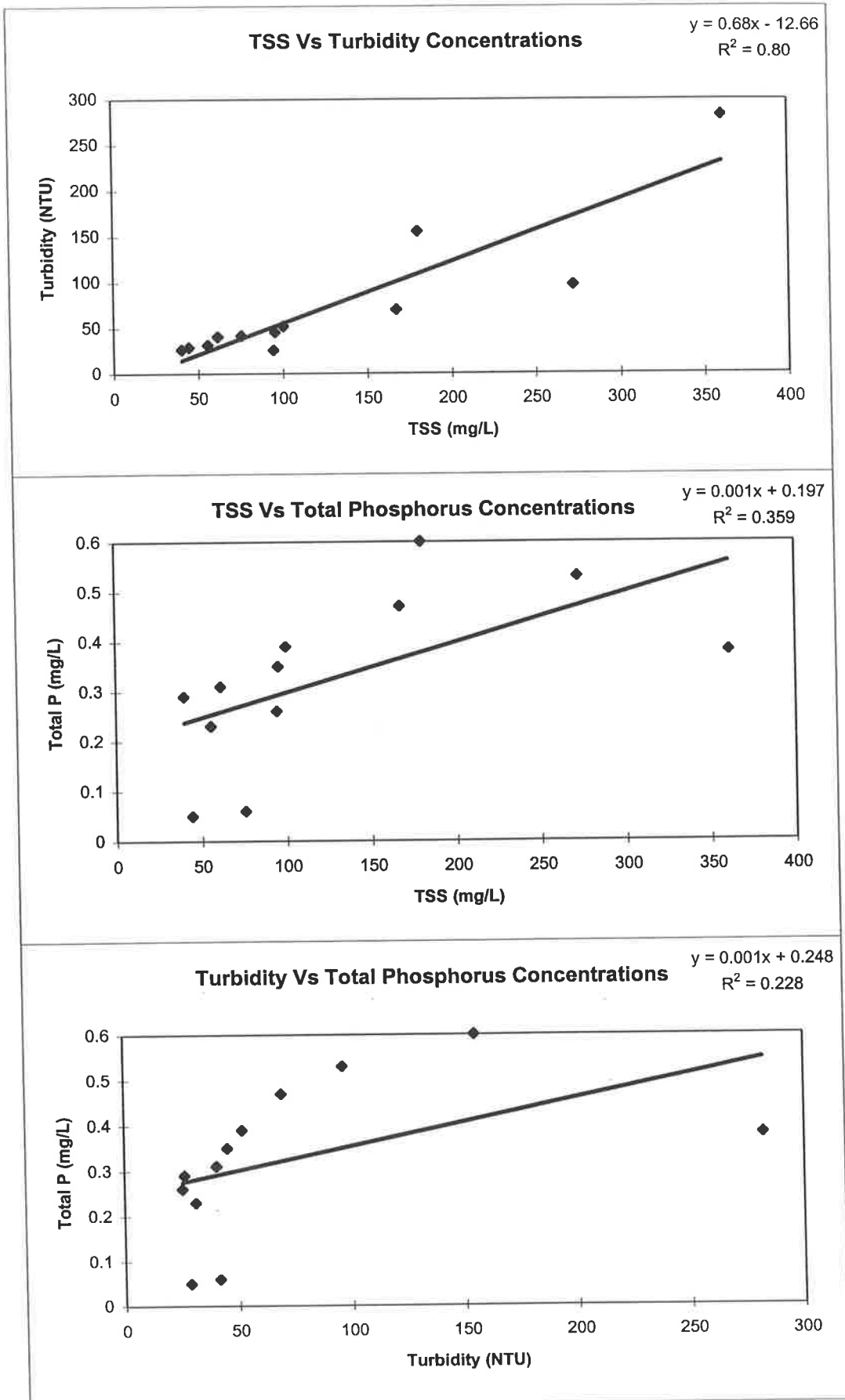
Hindmarsh Enfield Prospect Drain (AU504102)

Storm Date : 7/04/96



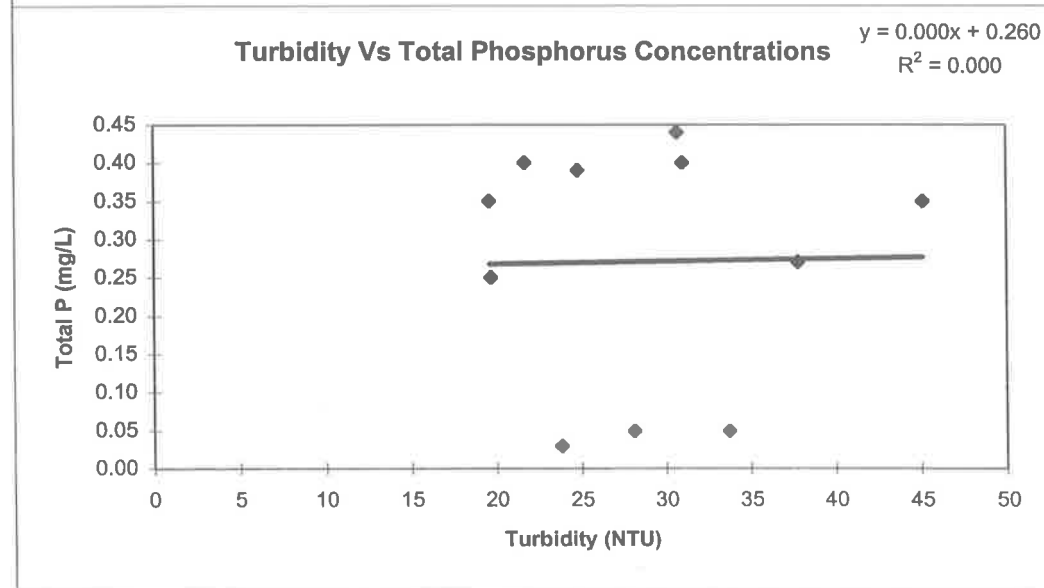
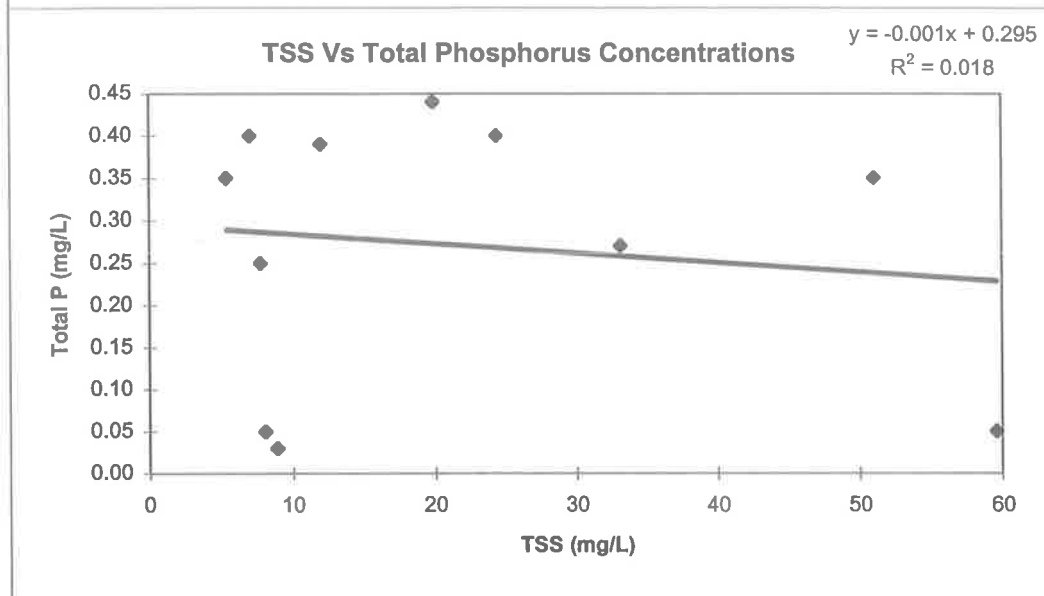
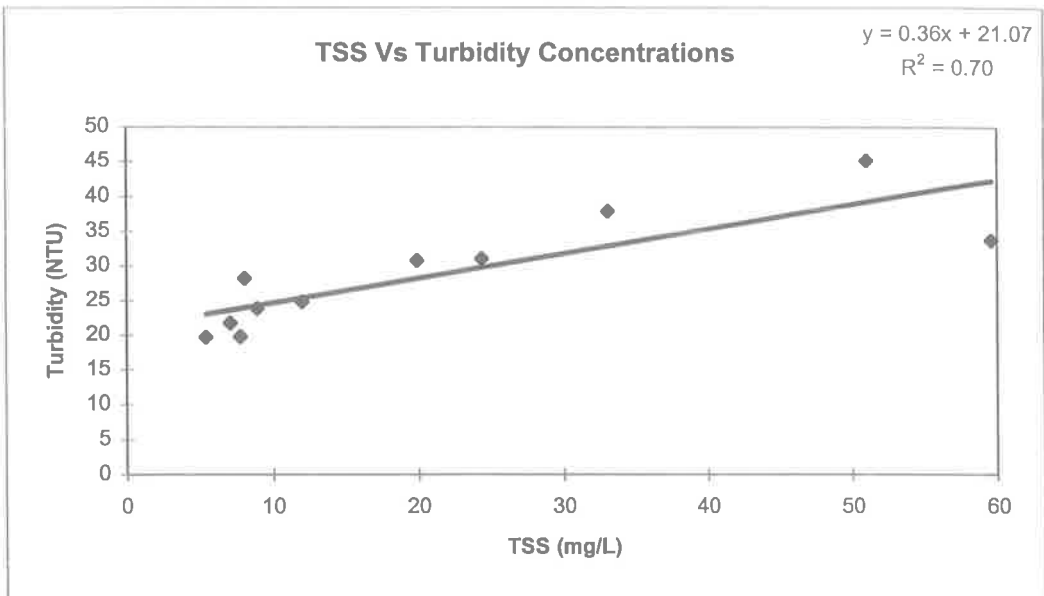
Hindmarsh Enfield Prospect Drain (AU504102)

Storm Date : 13/04/96



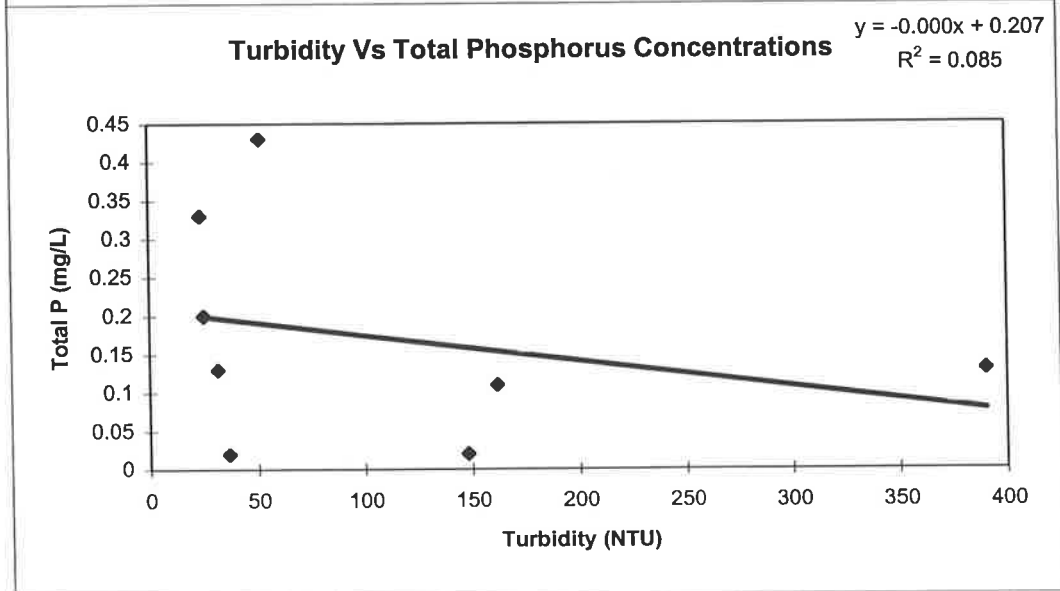
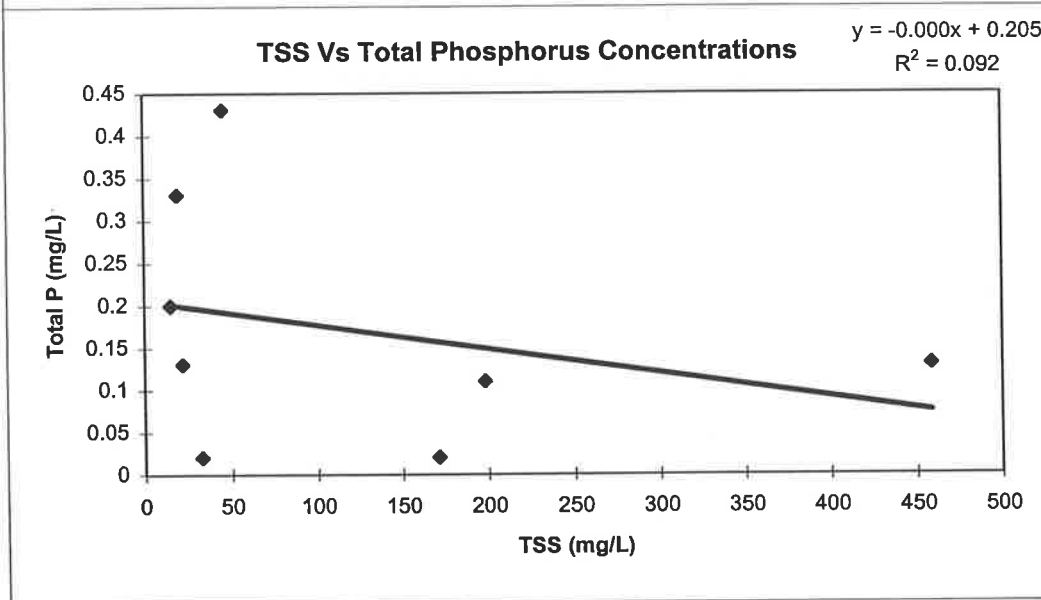
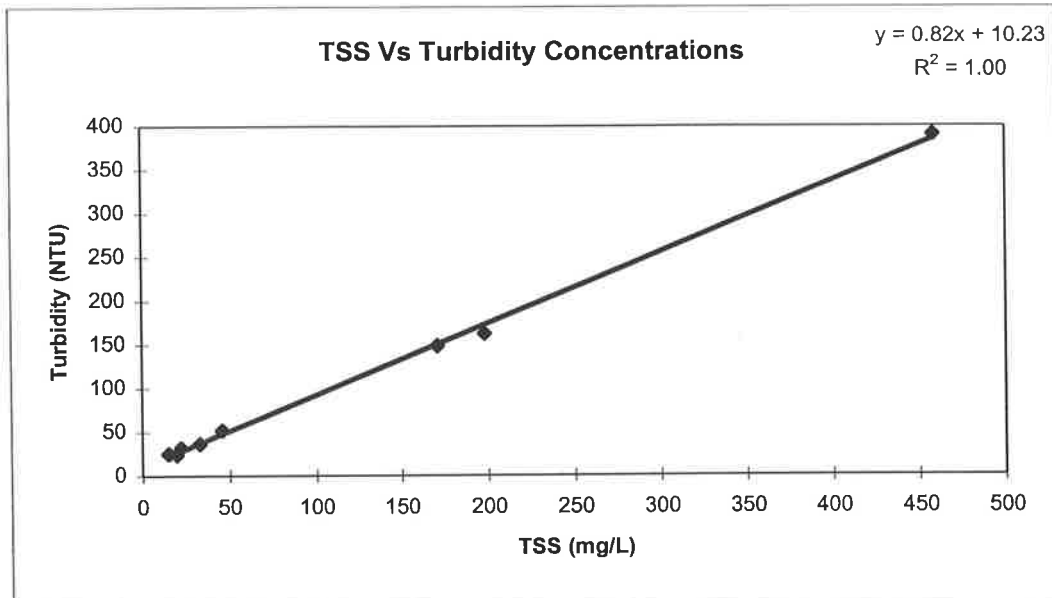
Hindmarsh Enfield Prospect Drain (AU504102)

Storm Date : 12/05/96

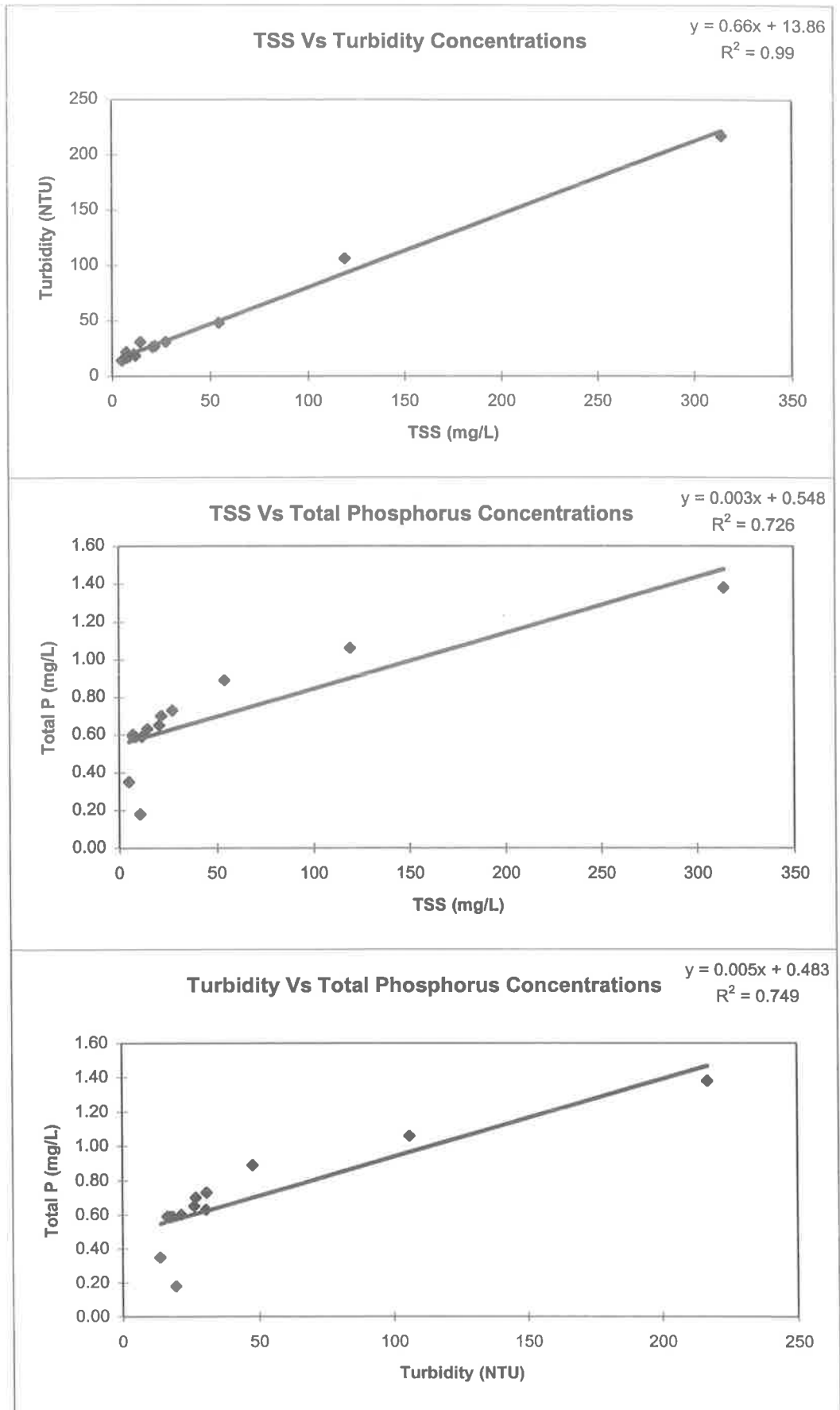


Hindmarsh Enfield Prospect Drain (AU504102)

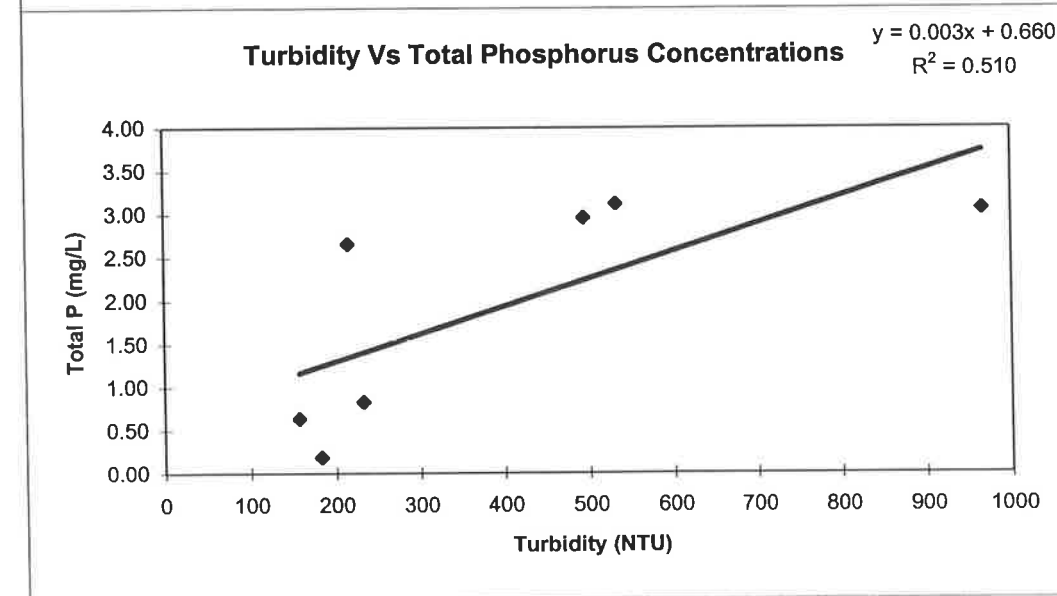
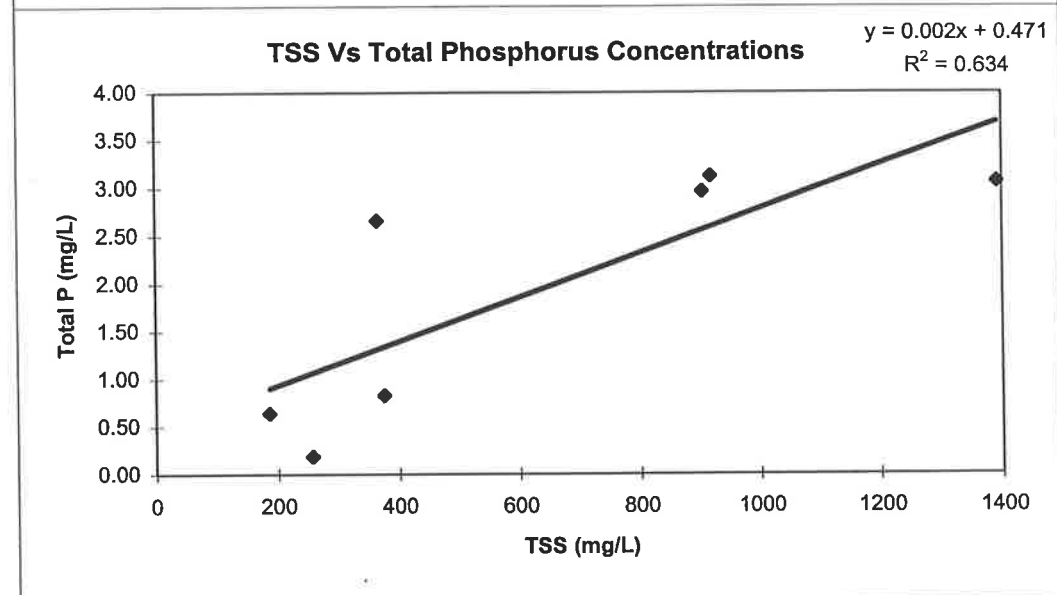
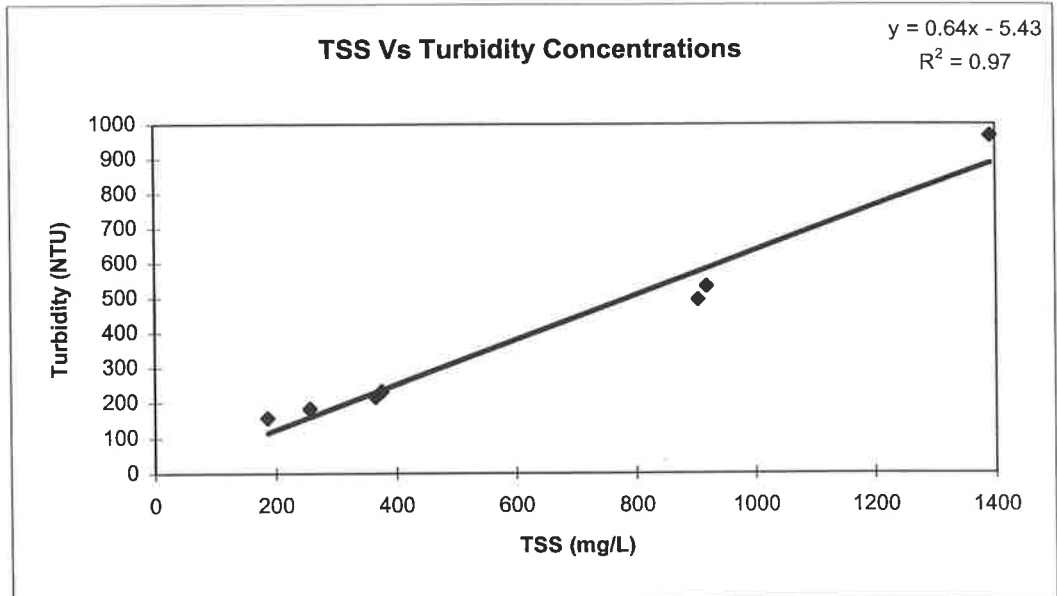
Storm Date : 1/06/96



Hindmarsh Enfield Prospect Drain (AU504102)
Storm Date : 6-7/12/1996

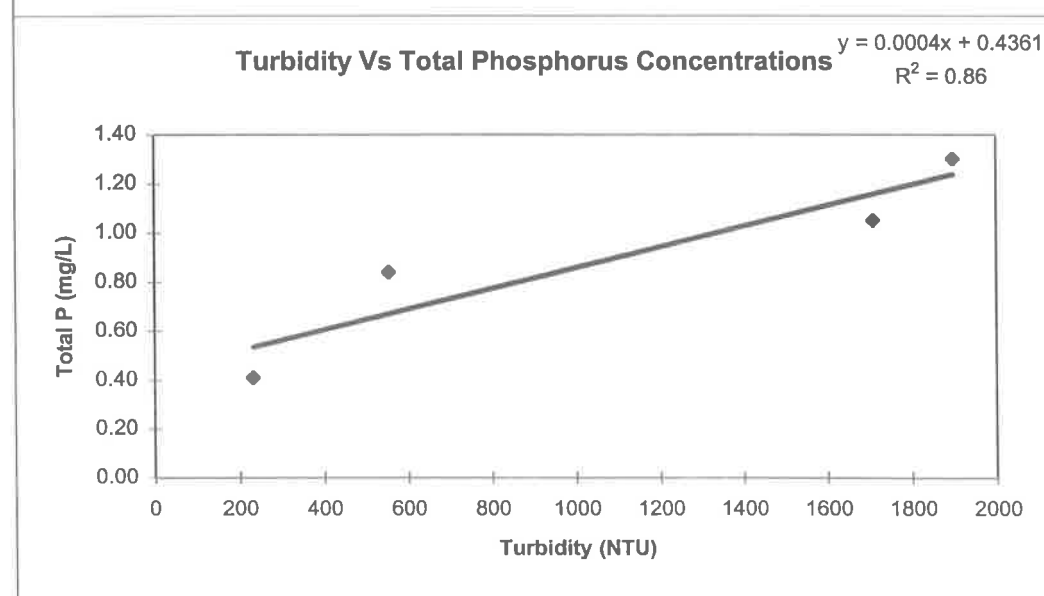
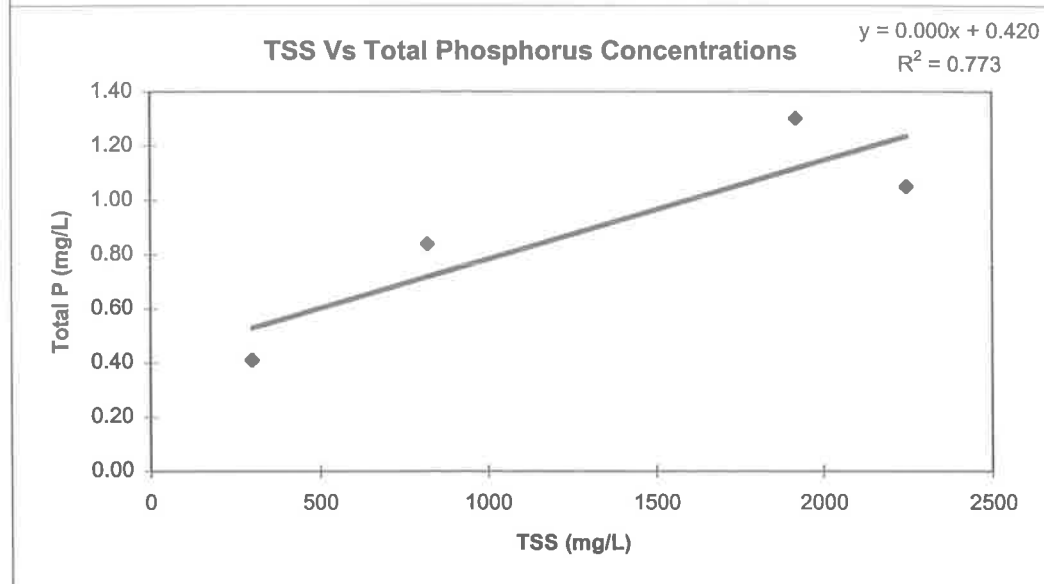
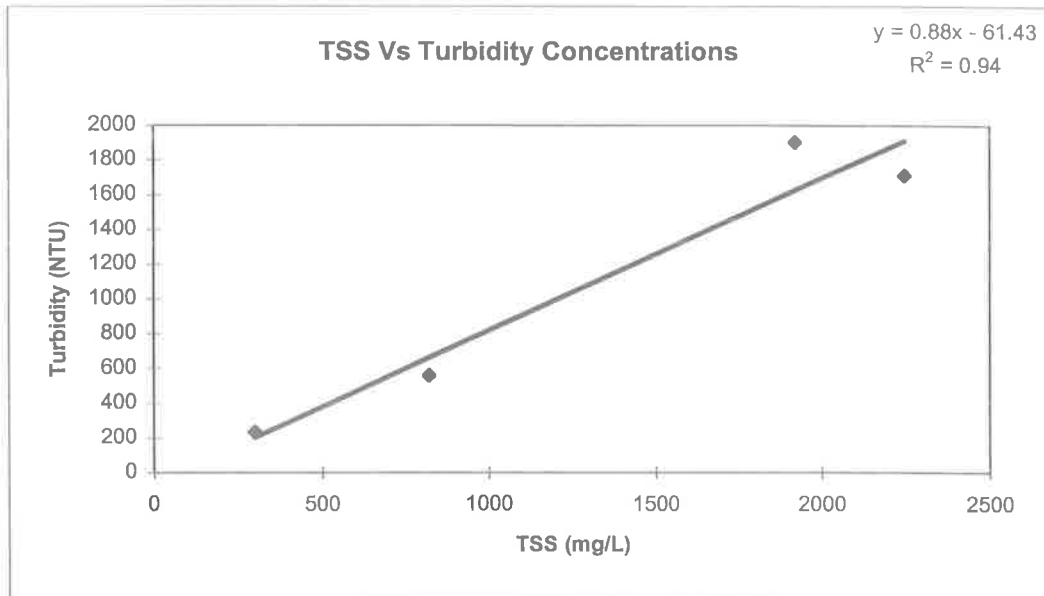


Dunstan Road Drain (AU504103)
Storm Date : 13/04/96

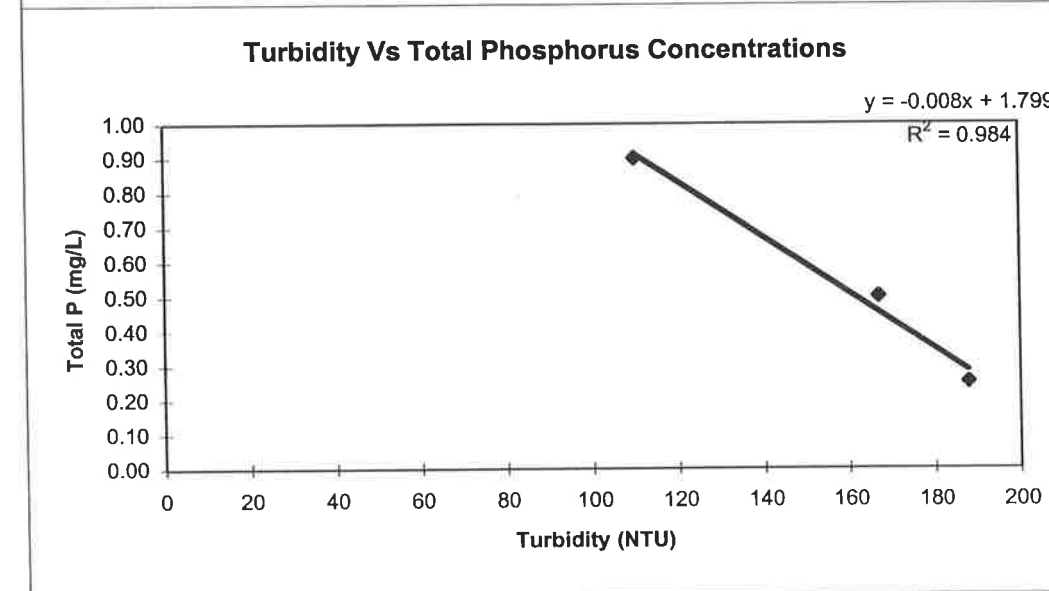
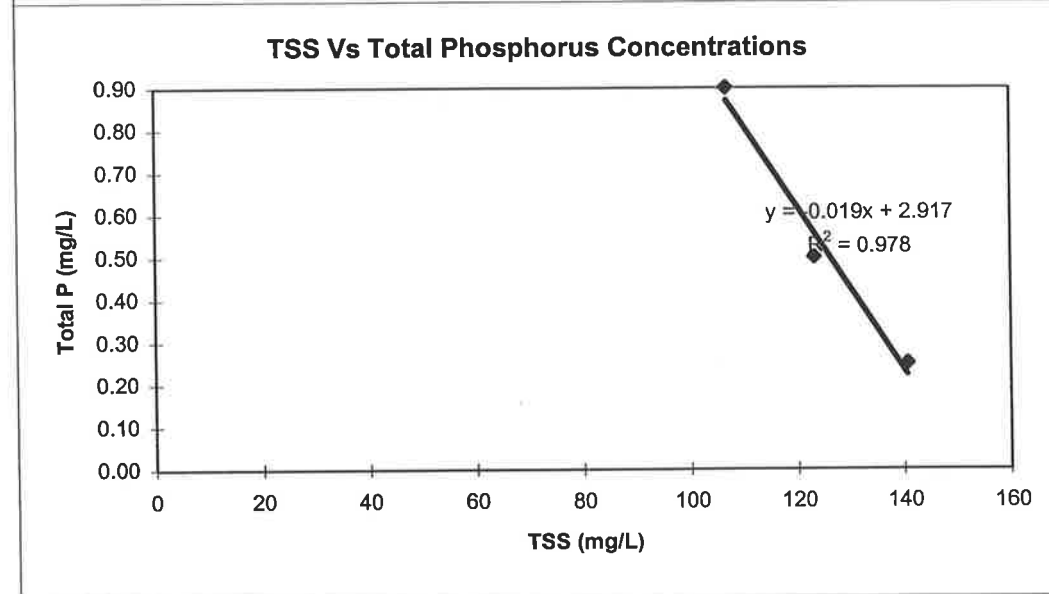
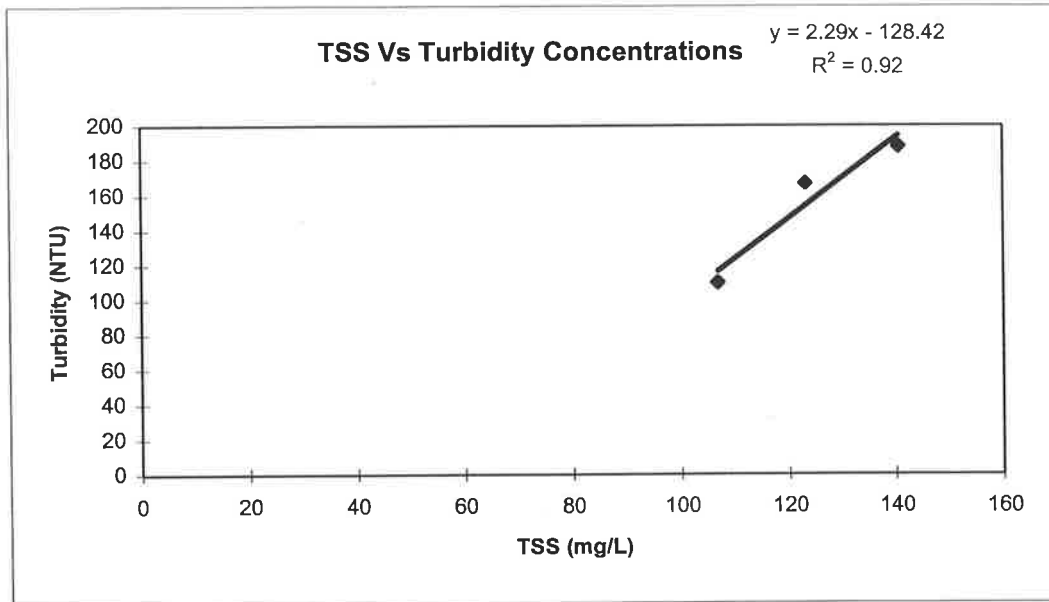


Dunstan Road Drain (AU504103)

Storm Date : 12/05/96

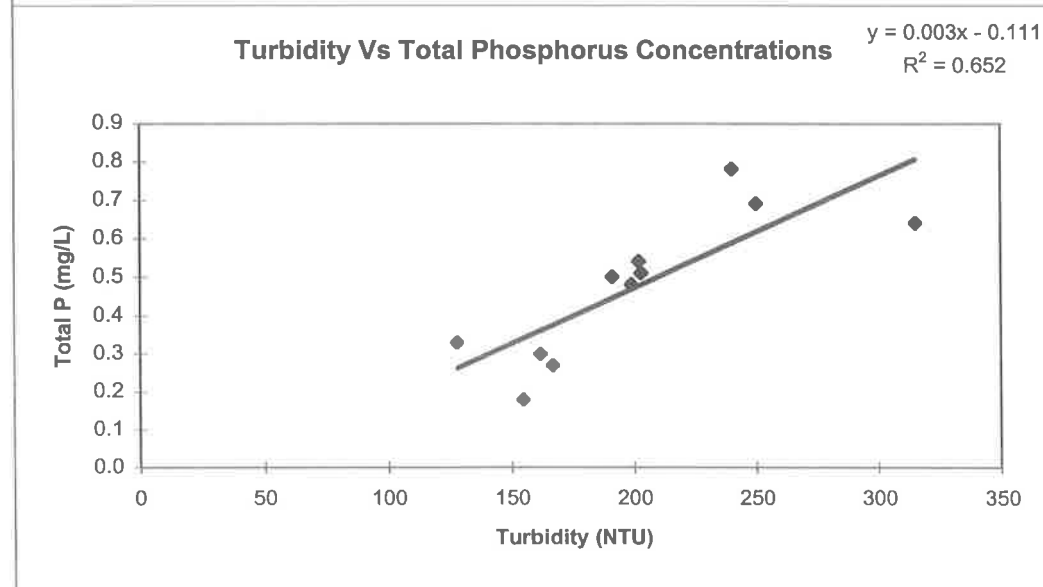
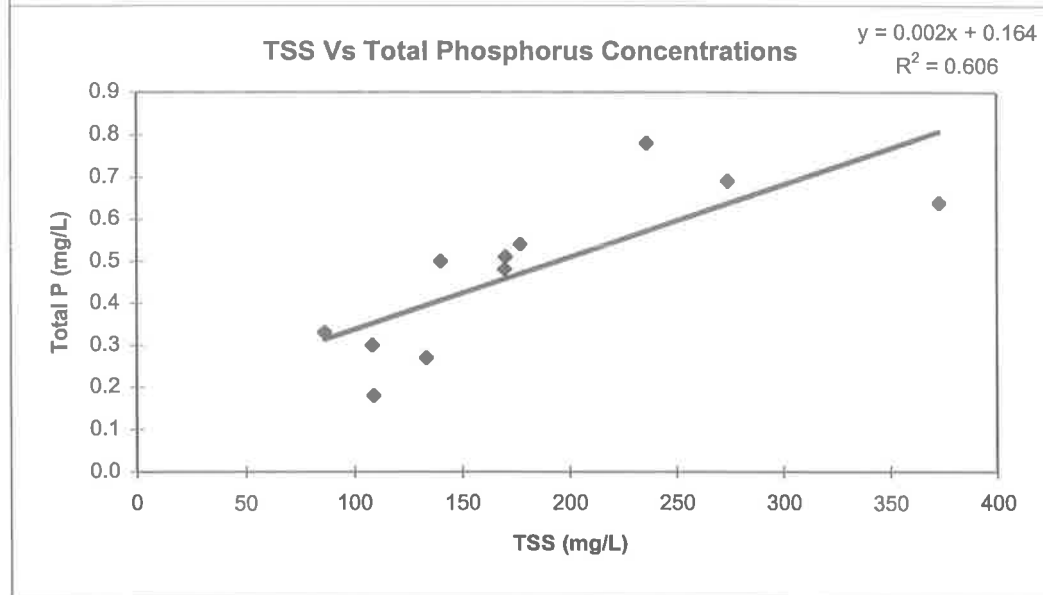
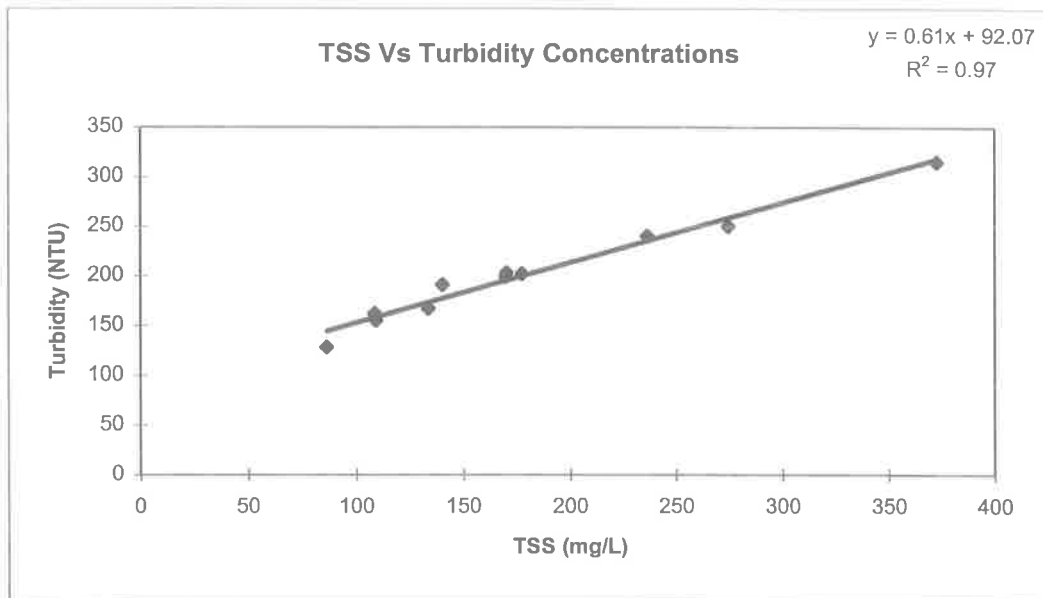


Dunstan Road Drain (AU504103)
Storm Date : 28/06/96

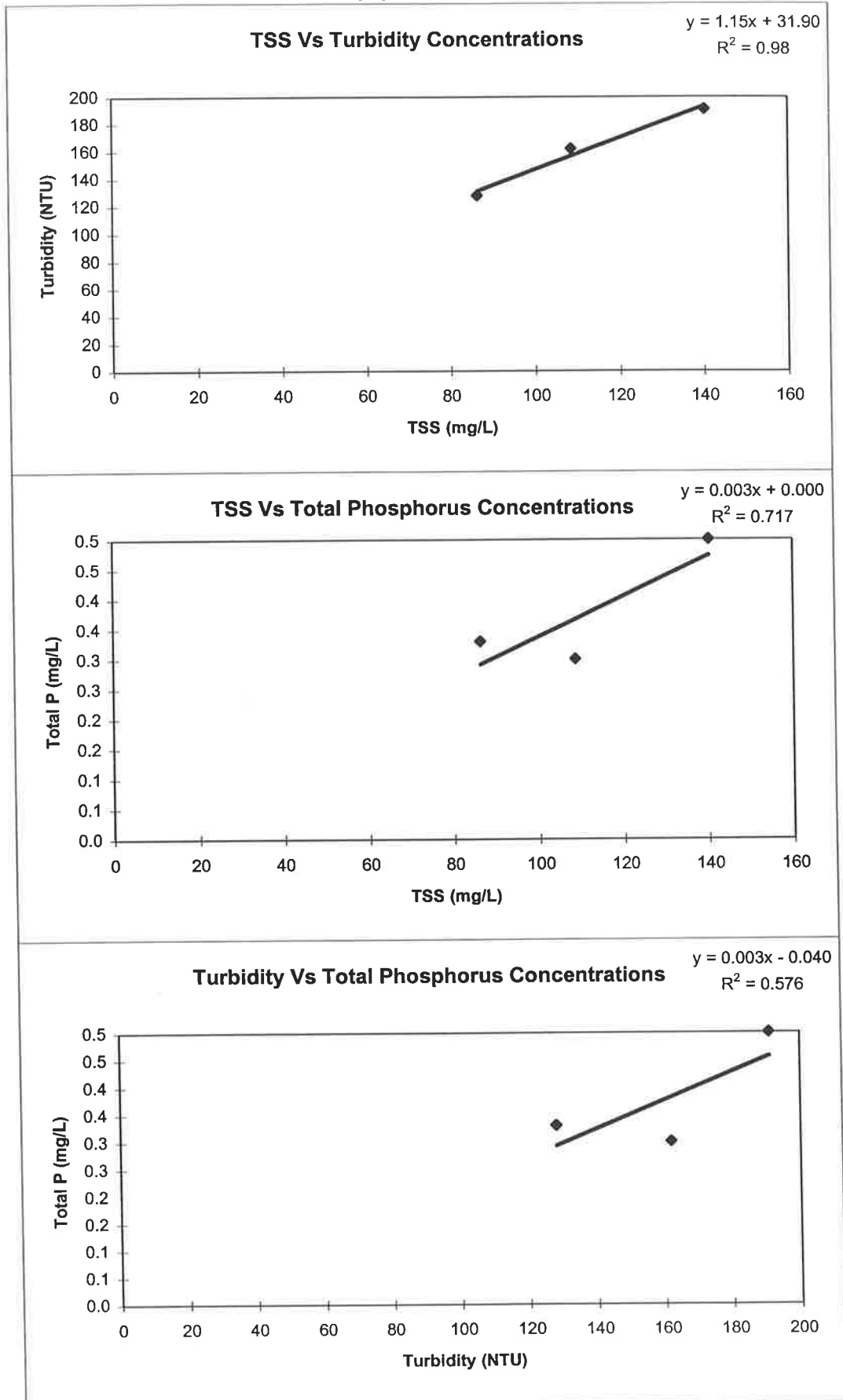


Dunstan Road Drain (AU504103)

Storm Date : 4/07/96

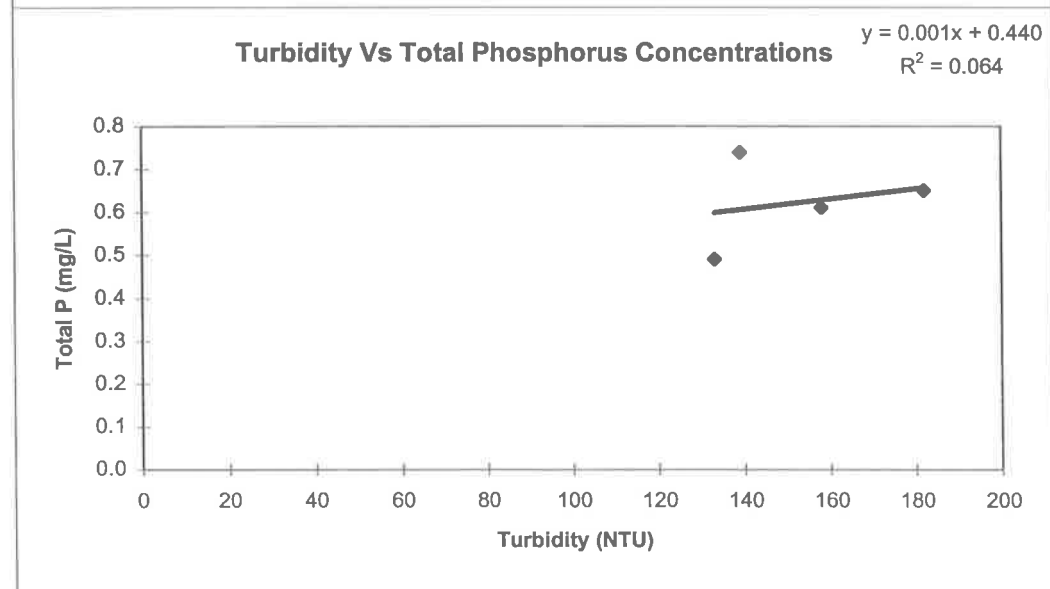
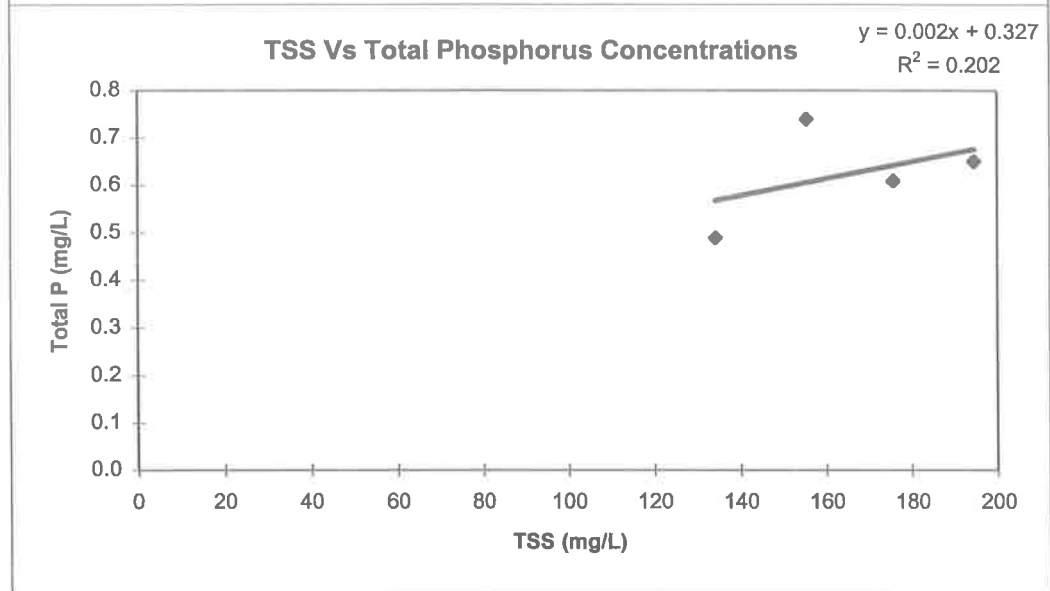
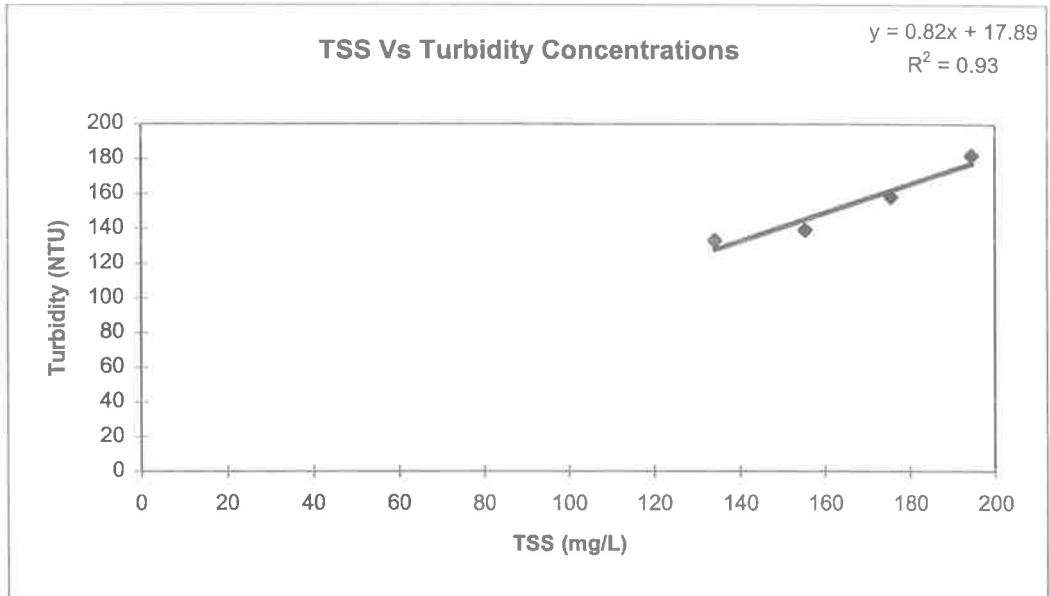


Dunstan Road Drain (AU504103)
Storm Date : 4(b)/7/1996

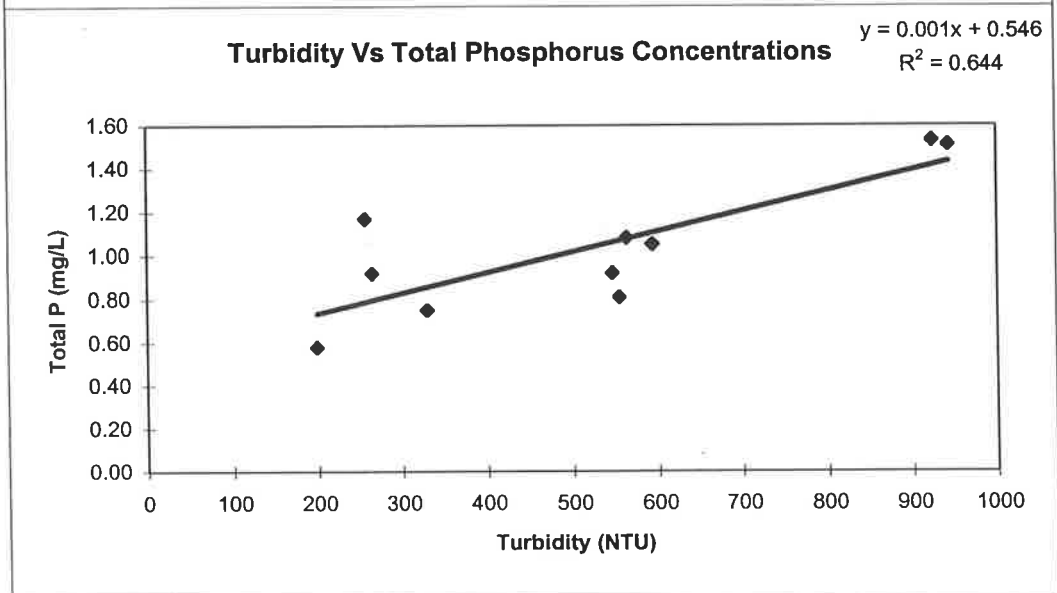
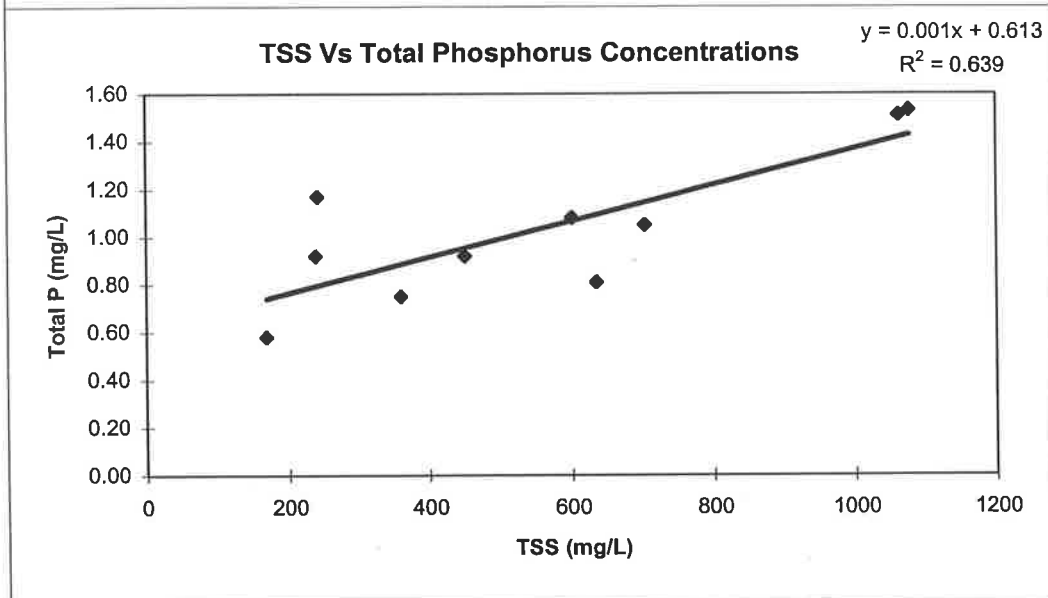
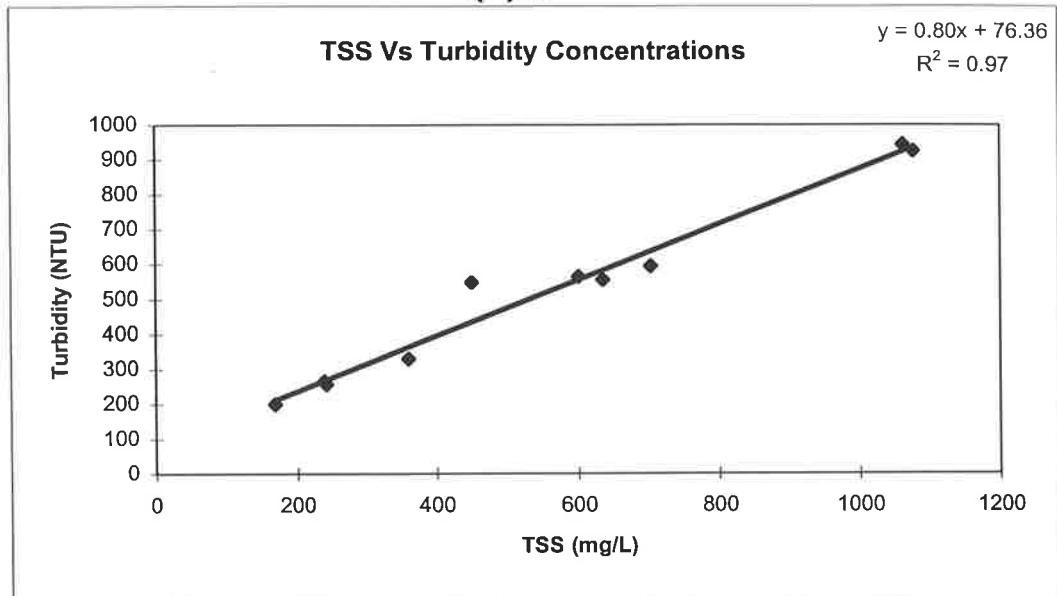


Dunstan Road Drain (AU504103)

Storm Date : 10/07/96

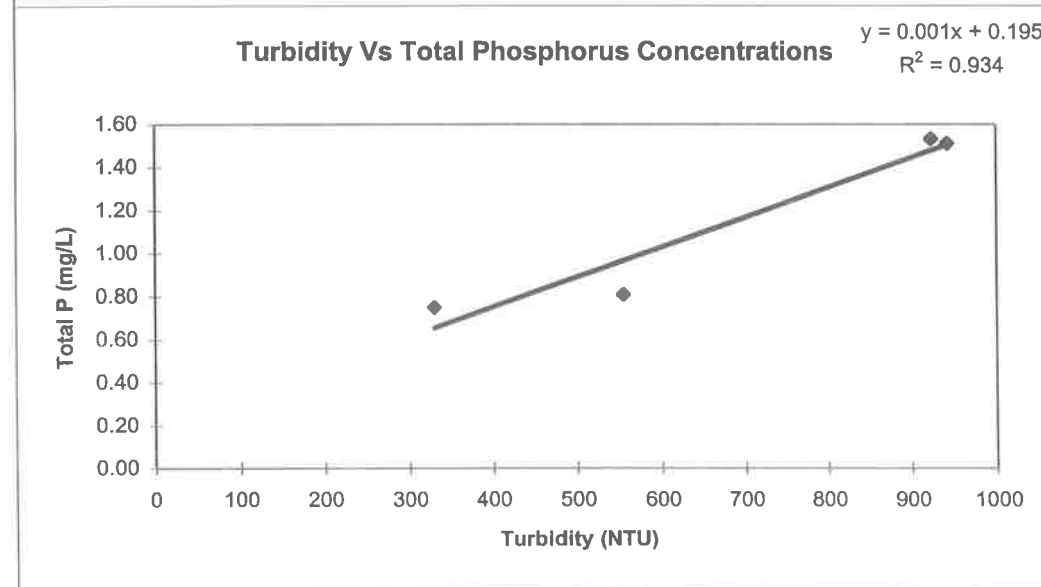
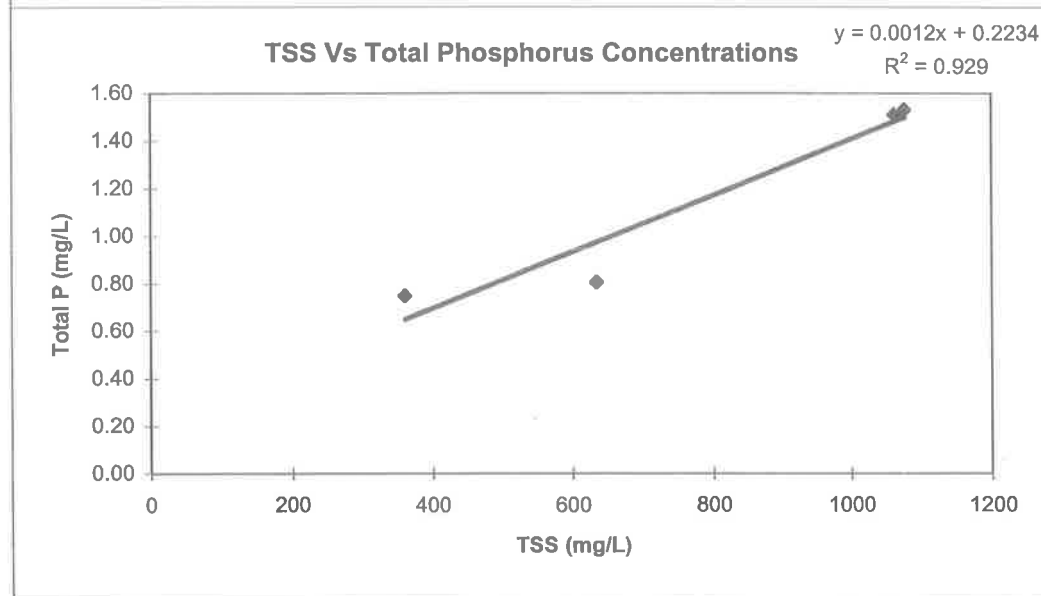
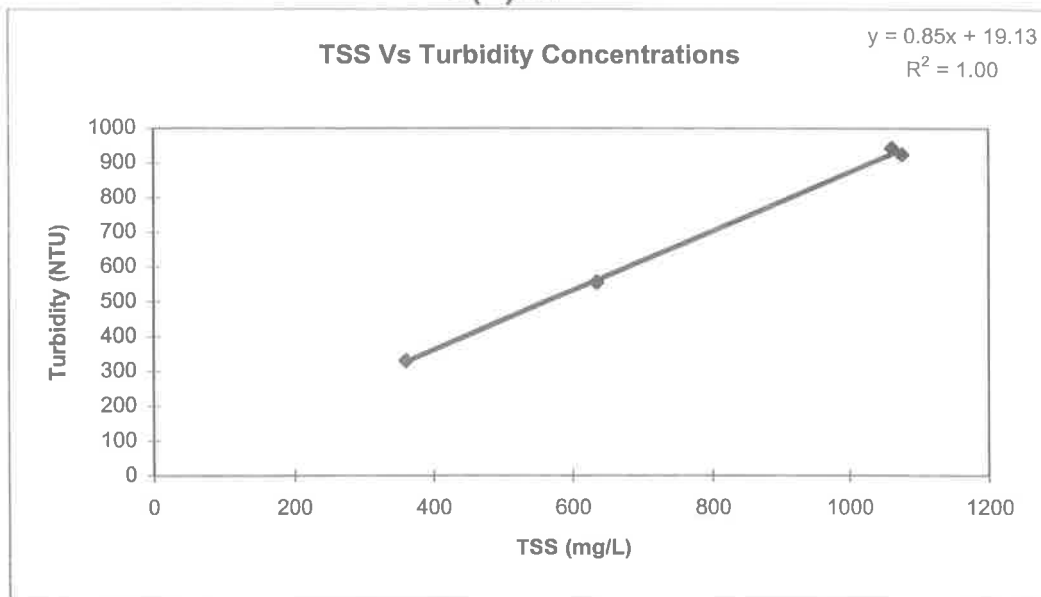


Dunstan Road Drain (AU504103)
Storm Date : 19(a)/07/1996



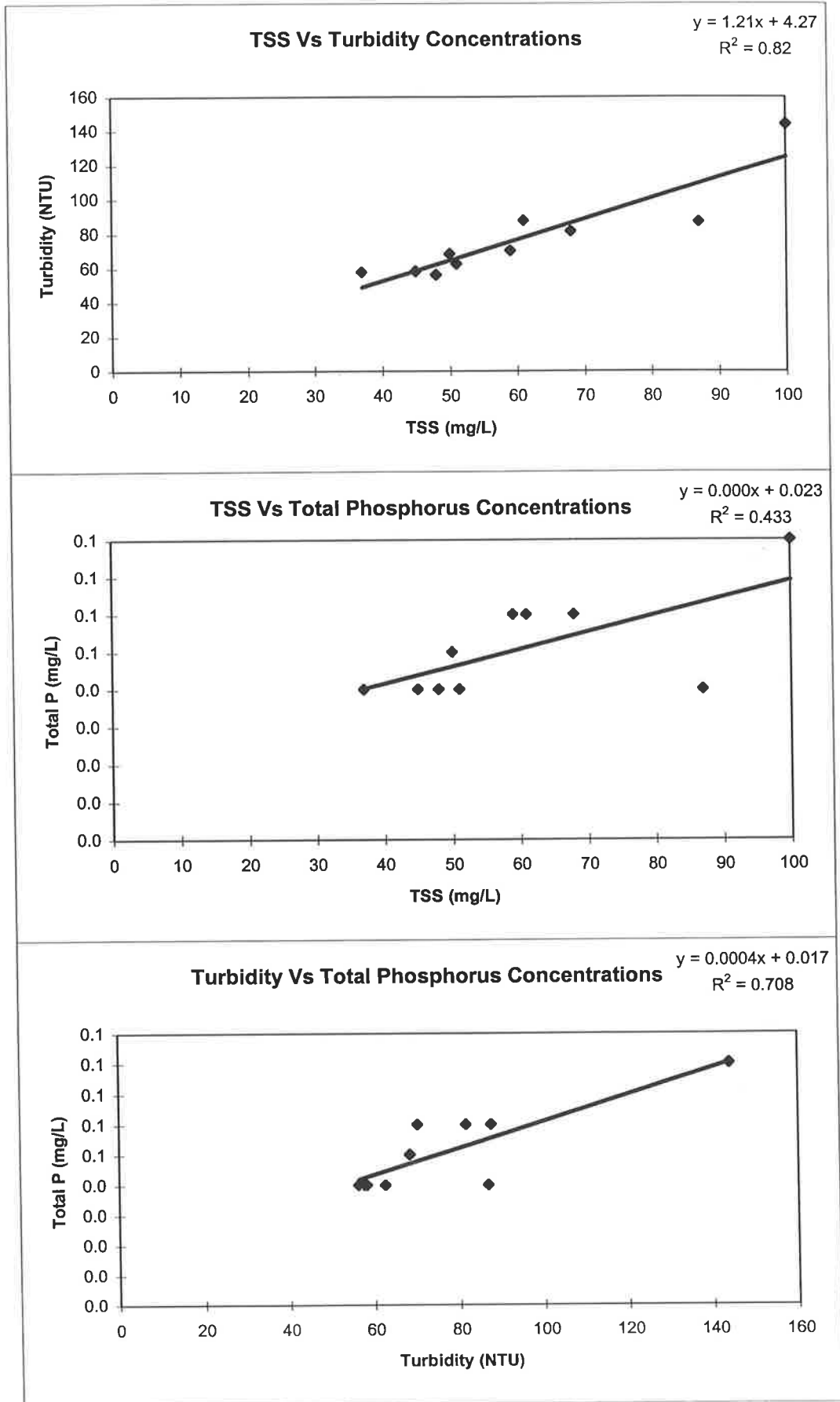
Dunstan Road Drain (AU504103)

Storm Date : 19(b)/07/1996



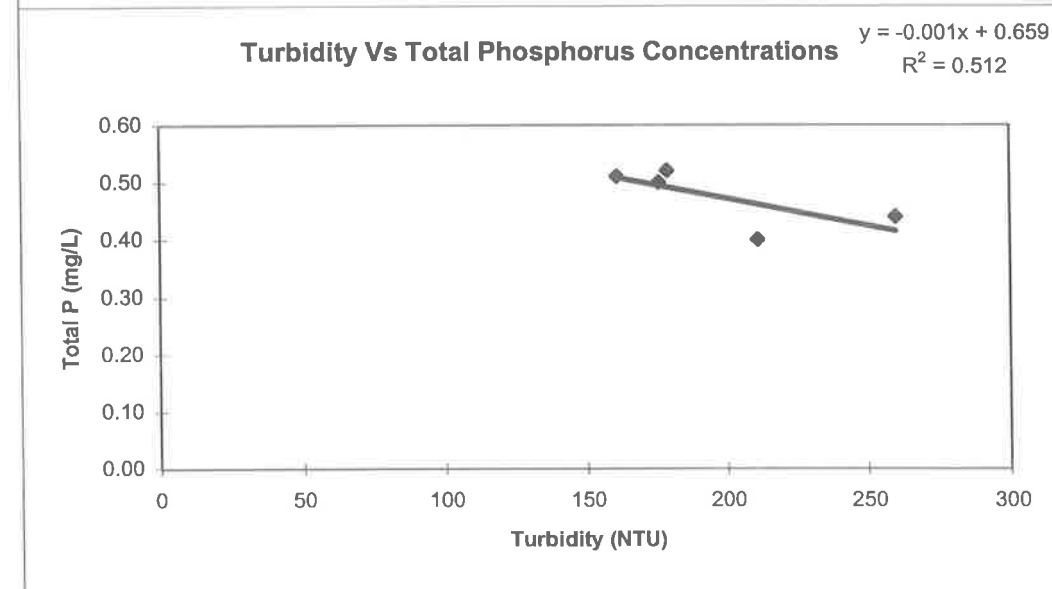
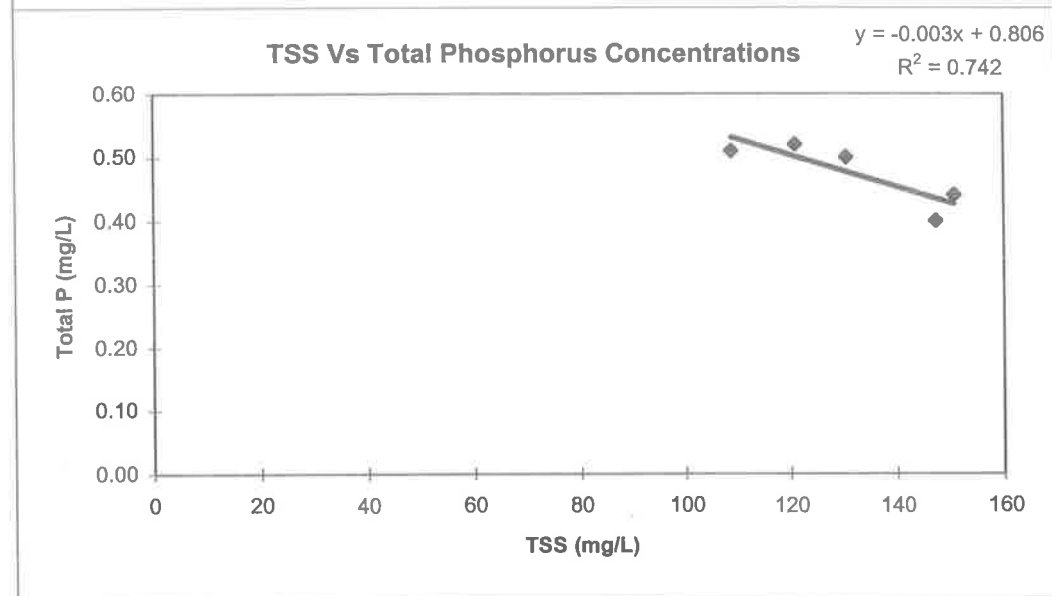
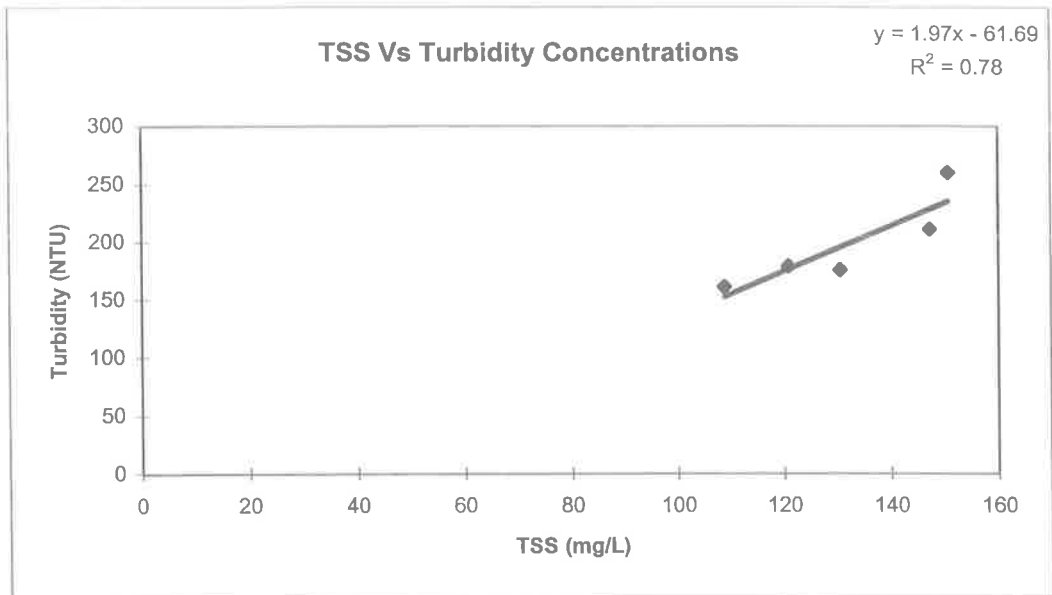
North Arm West Drain (AU504104)

Storm Date : 8/02/96



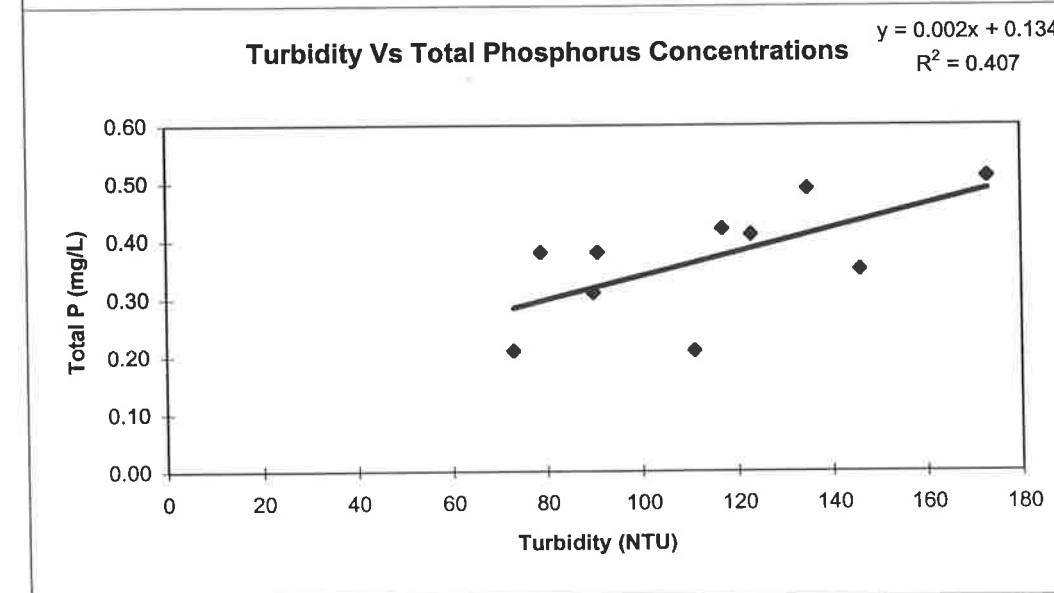
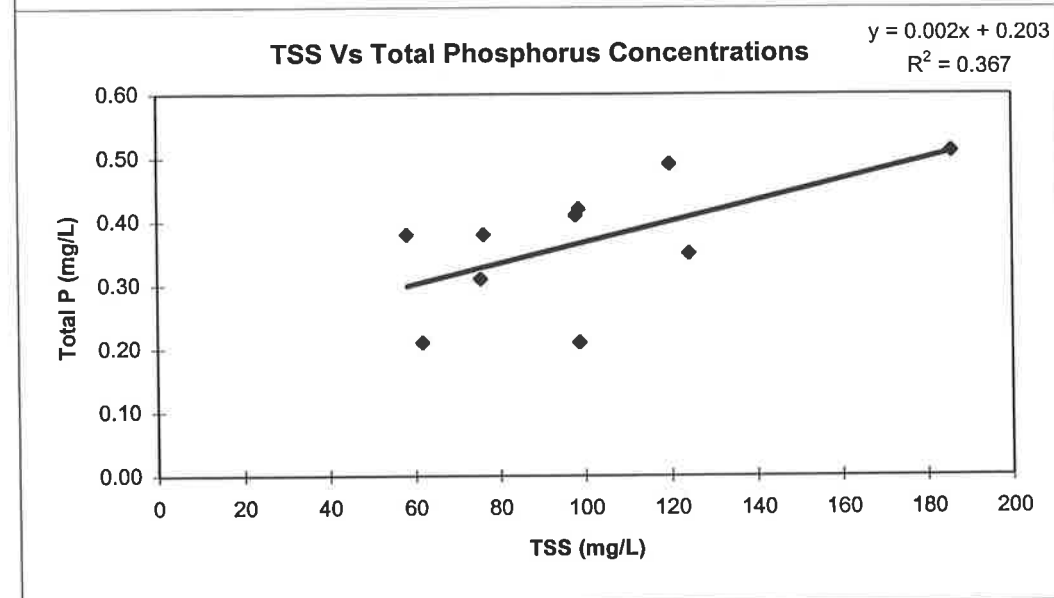
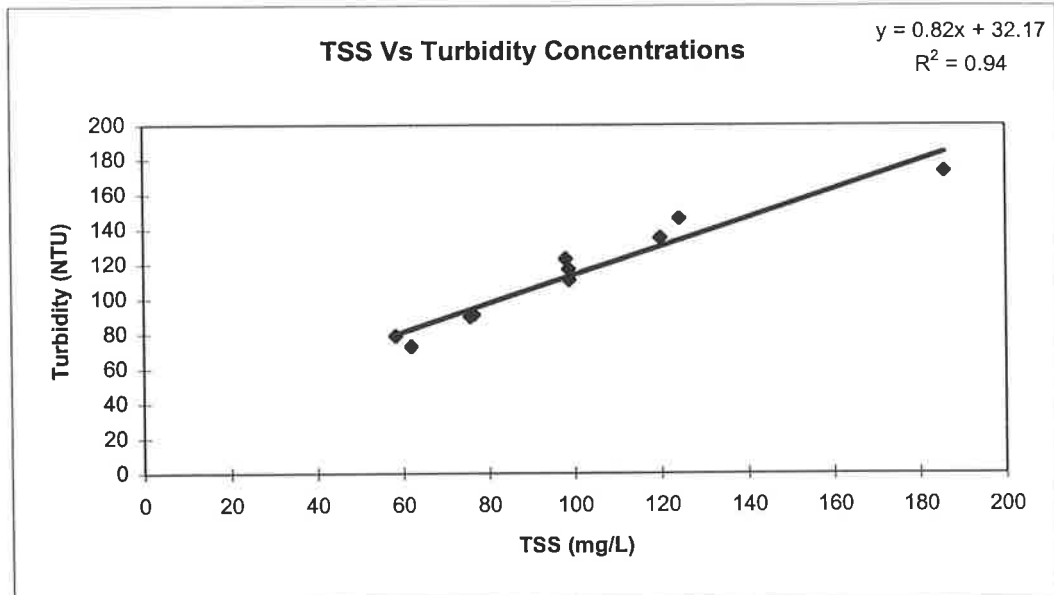
North Arm West Drain (AU504104)

Storm Date : 19/07/96



North Arm West Drain (AU504104)

Storm Date : 4/05/97



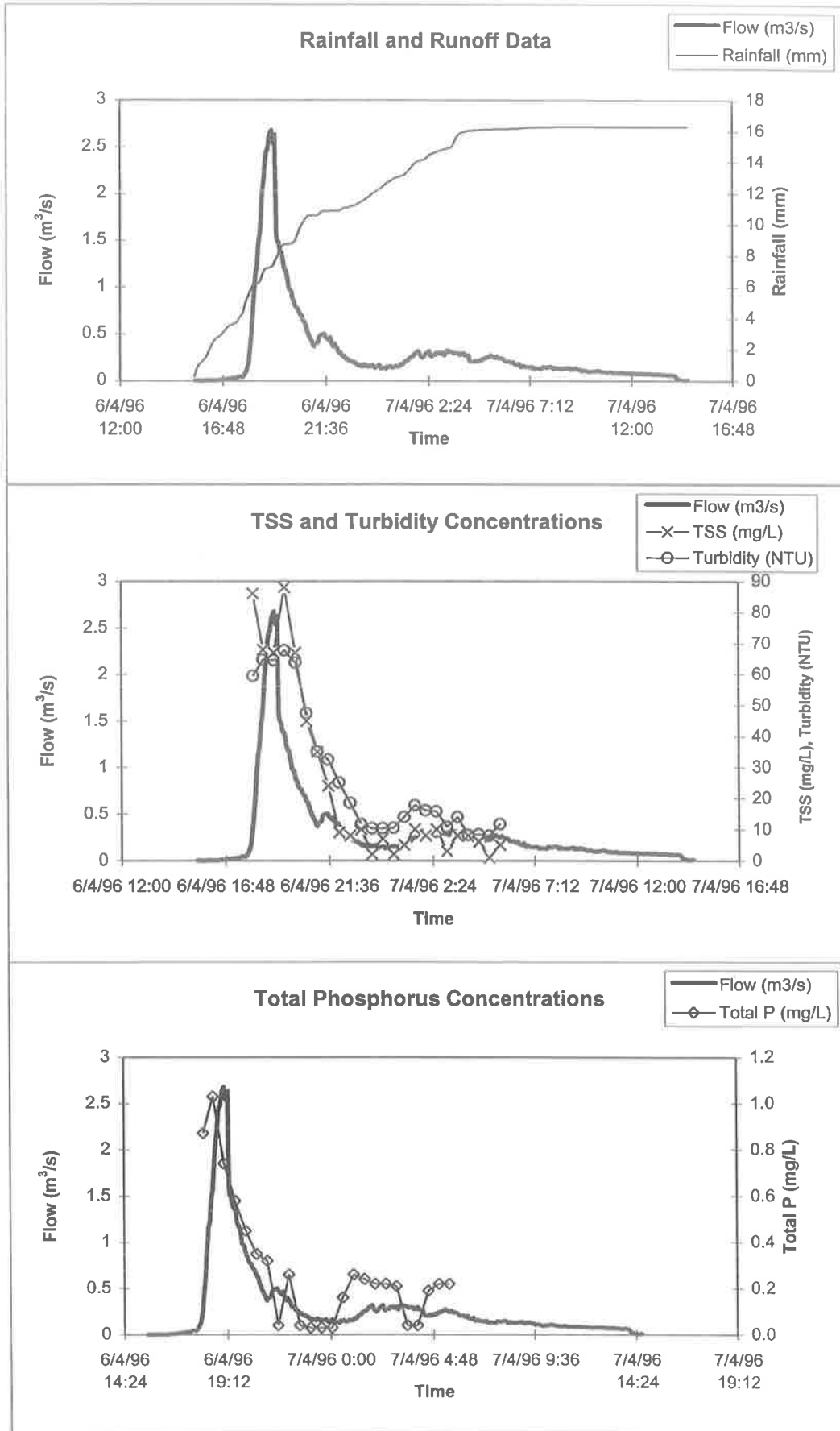
Appendix H

Sequential Sample Results

Summary

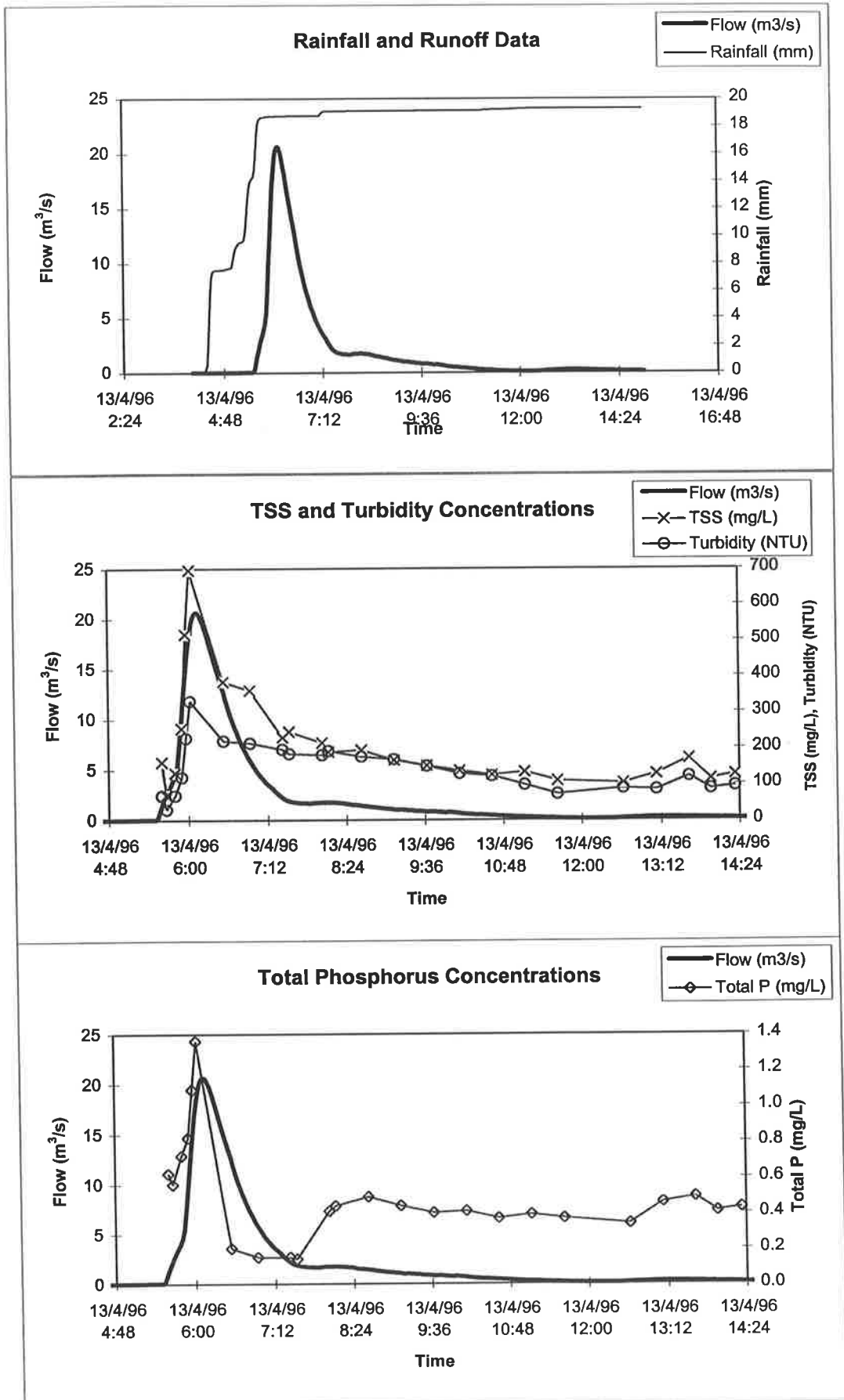
Appendix H outlines the results from the testing of sequential sample water quality. The results include the parameters of total suspended solids (TSS), turbidity and total phosphorus. The rainfall and runoff for each event are also included.

North Arm East Drain (AU504101)
Storm Date : 6-7/4/96

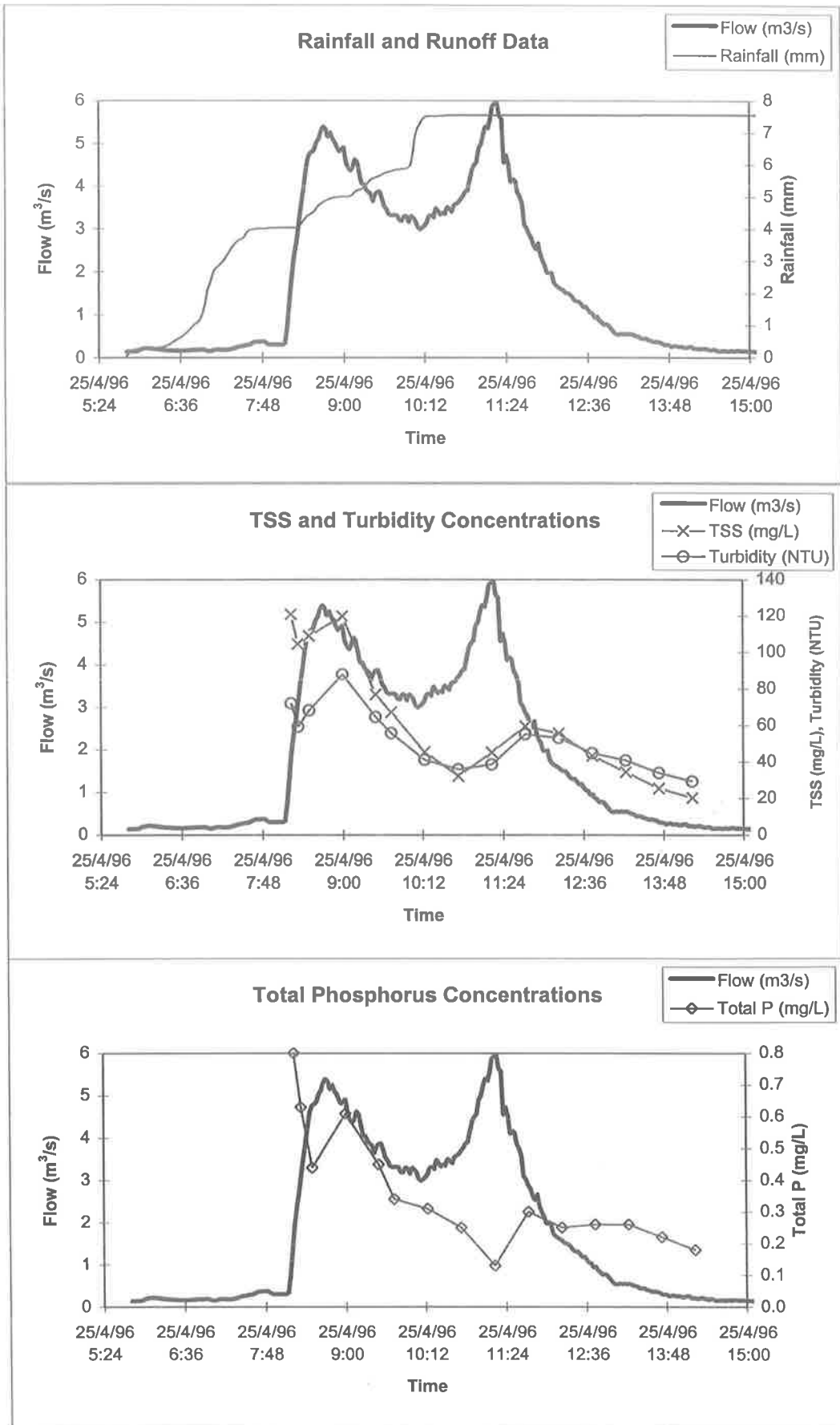


North Arm East Drain (AU504101)

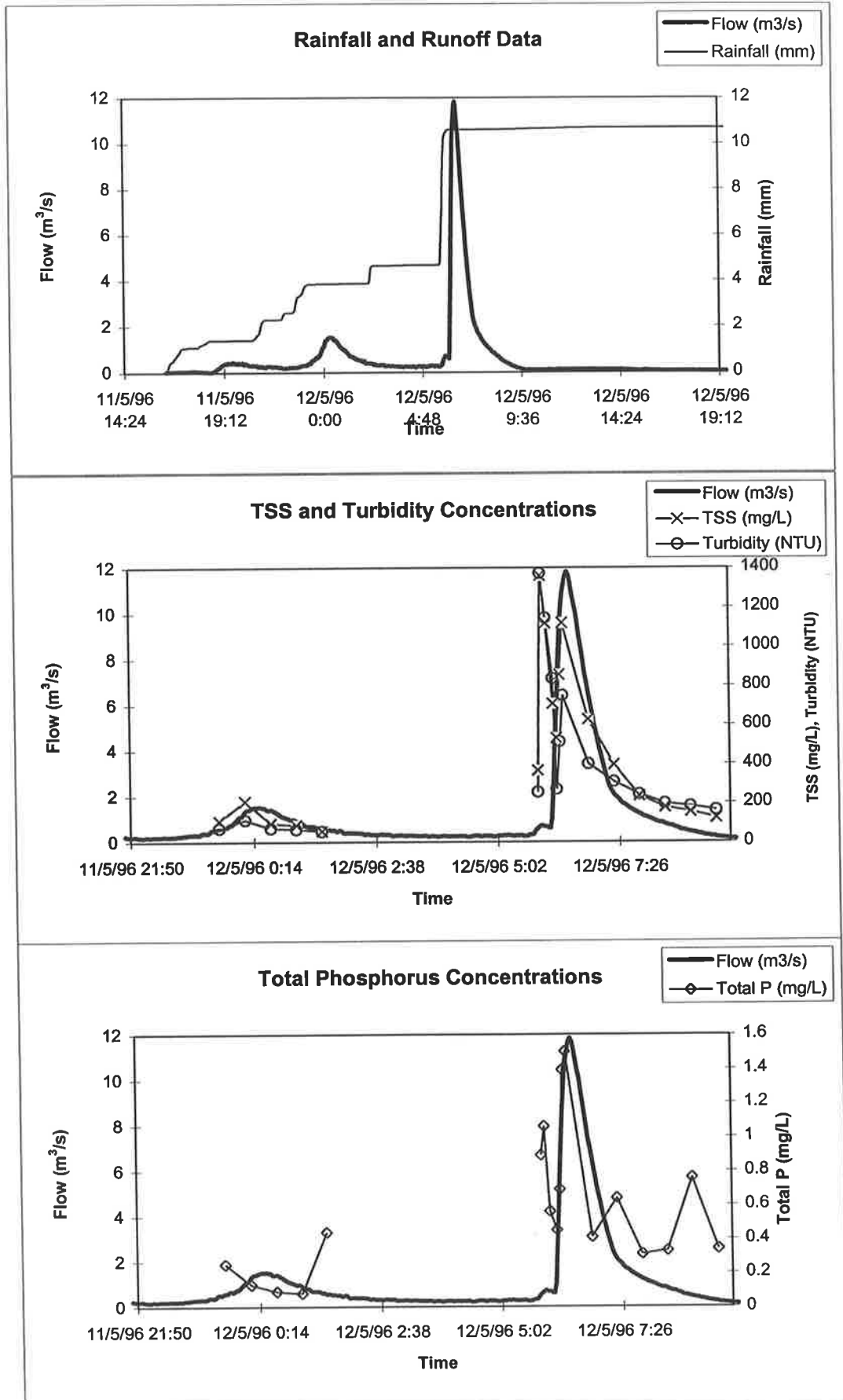
Storm Date : 13/04/96



North Arm East Drain (AU504101)
Storm Date : 25/04/96

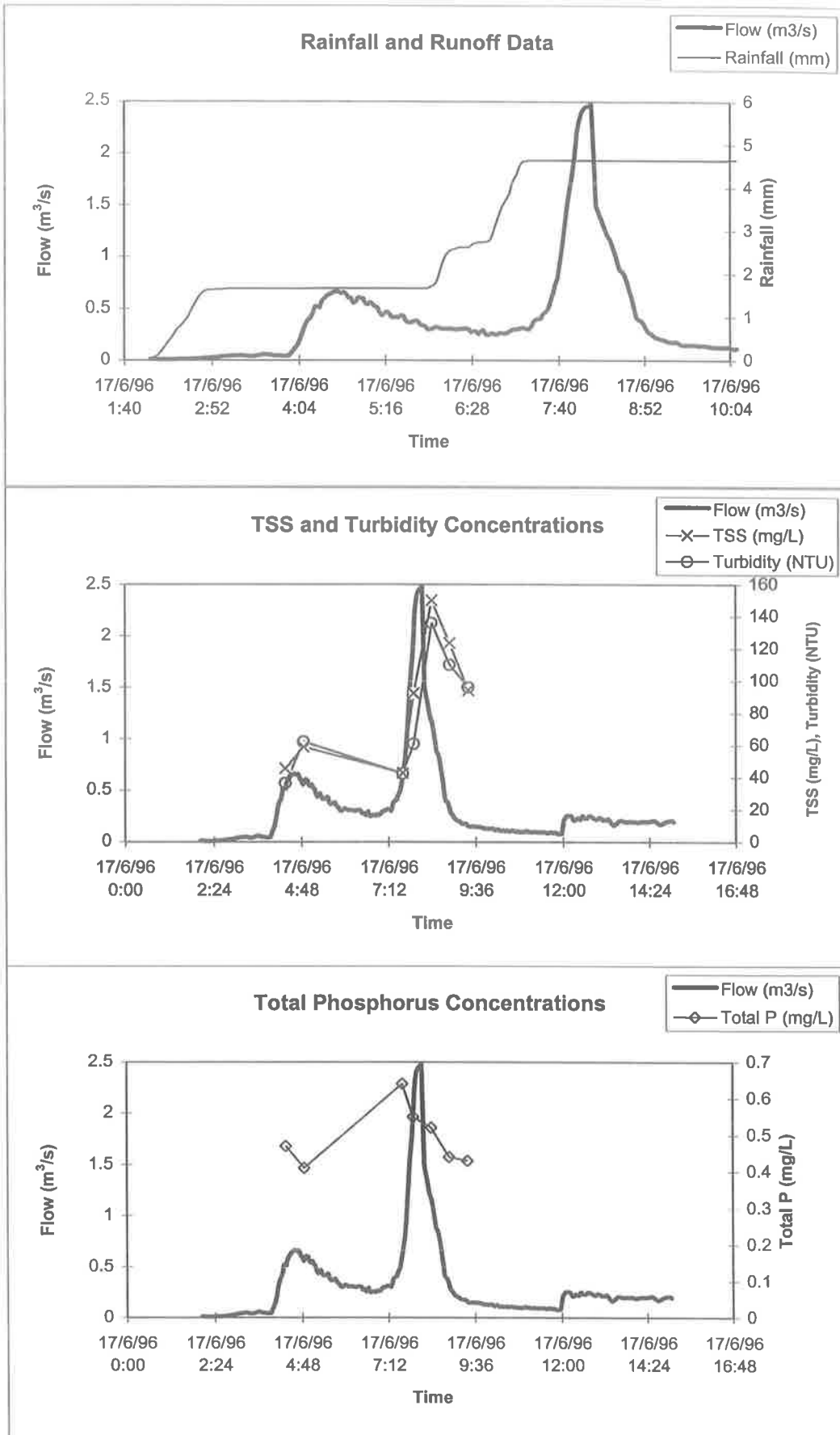


North Arm East Drain (AU504101)
Storm Date : 12/05/96

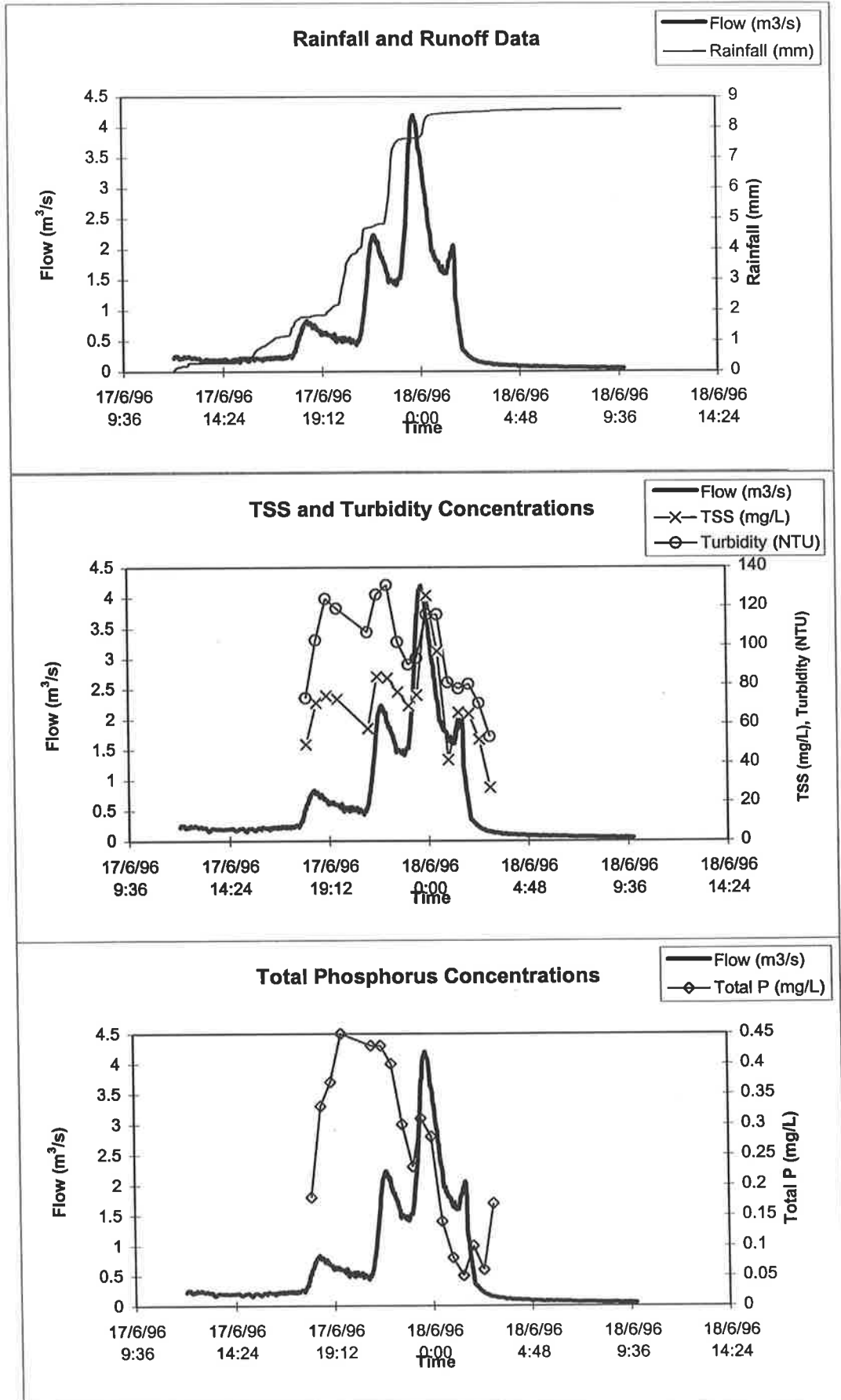


North Arm East Drain (AU504101)

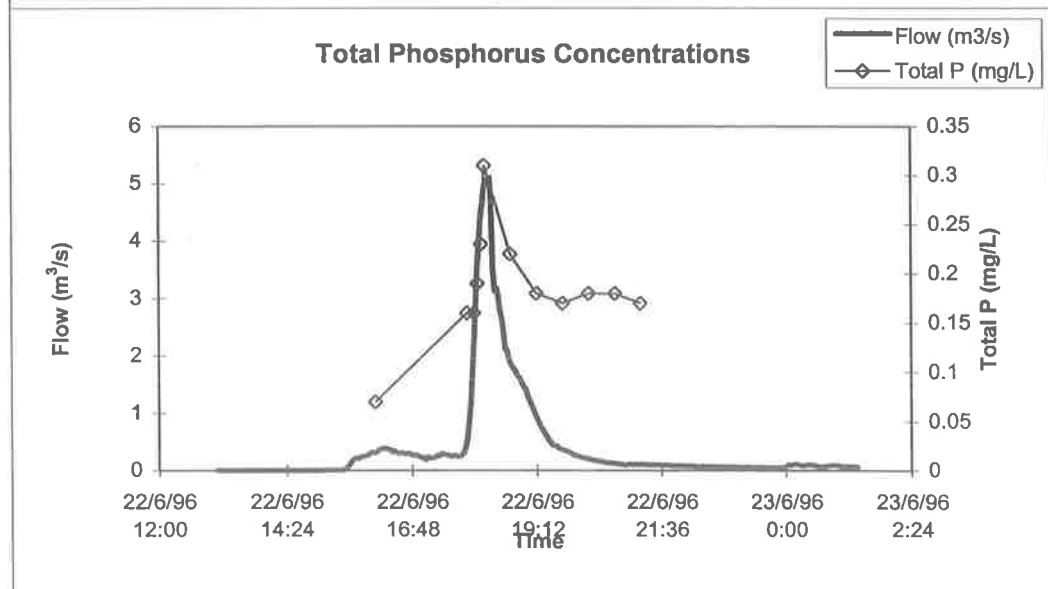
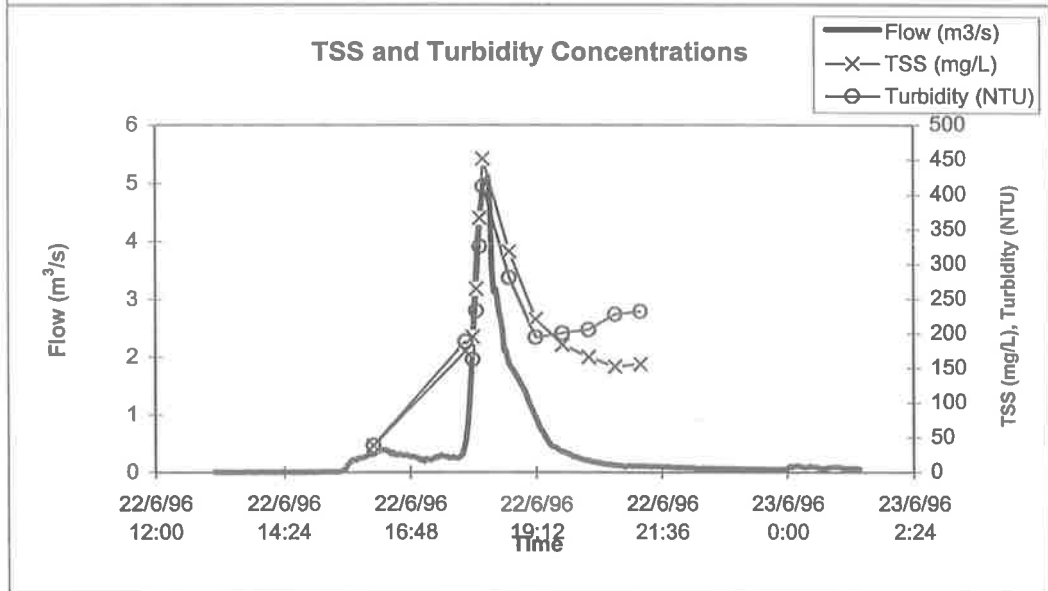
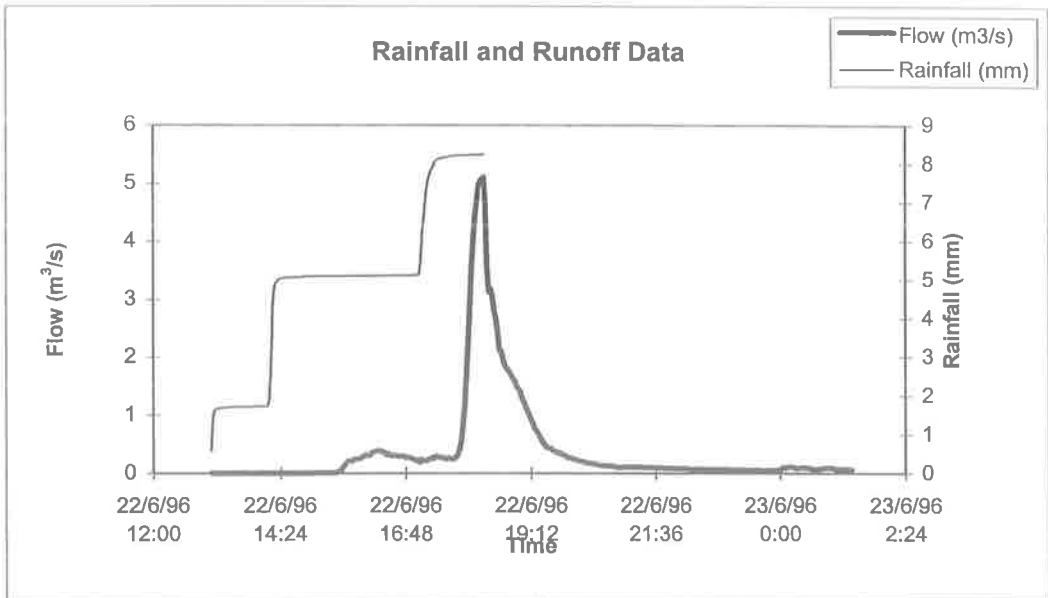
Storm Date : 17/06/96



North Arm East Drain (AU504101)
Storm Date : 18/06/96

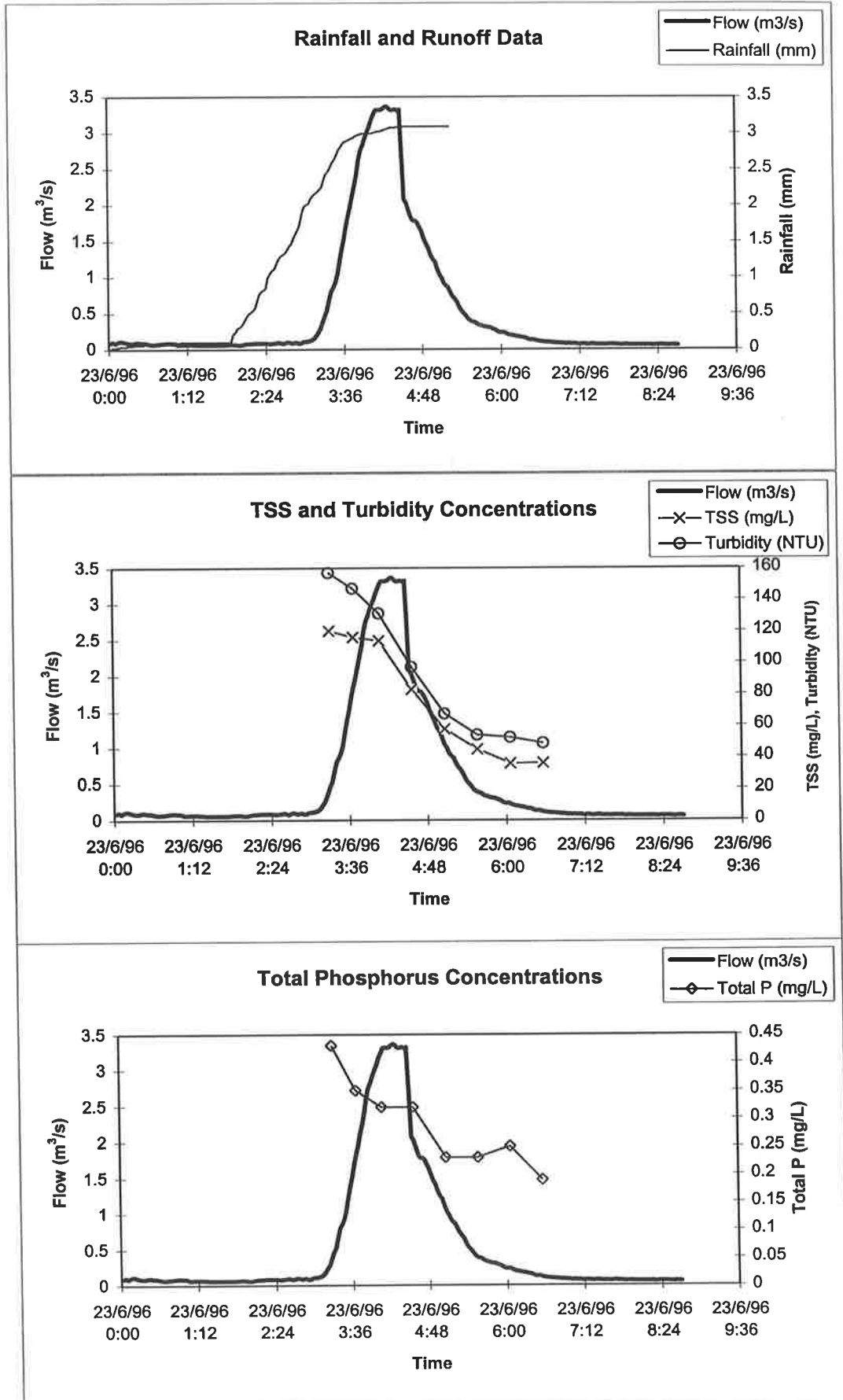


North Arm East Drain (AU504101)
Storm Date : 22/06/96



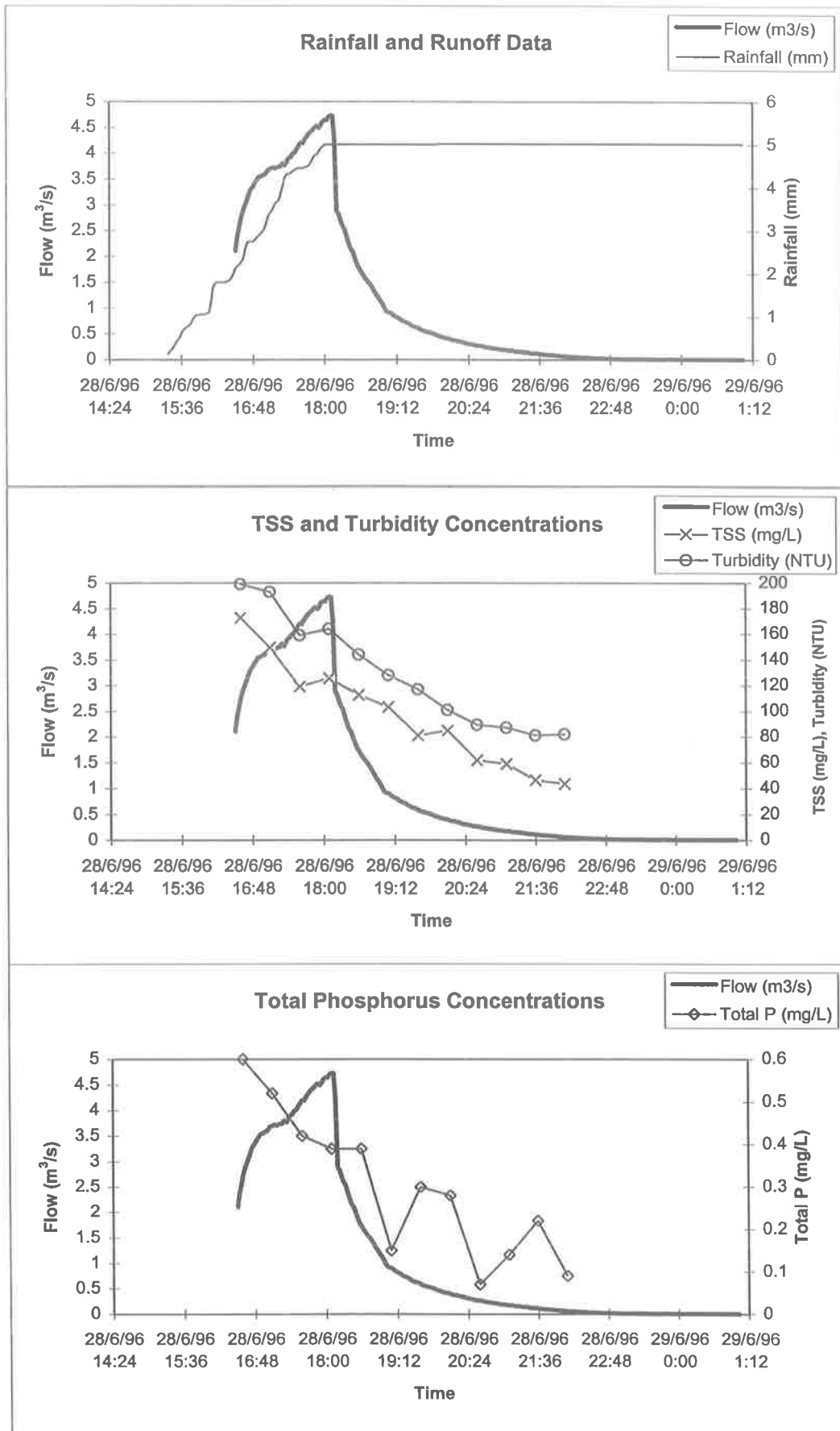
North Arm East Drain (AU504101)

Storm Date : 23/06/96



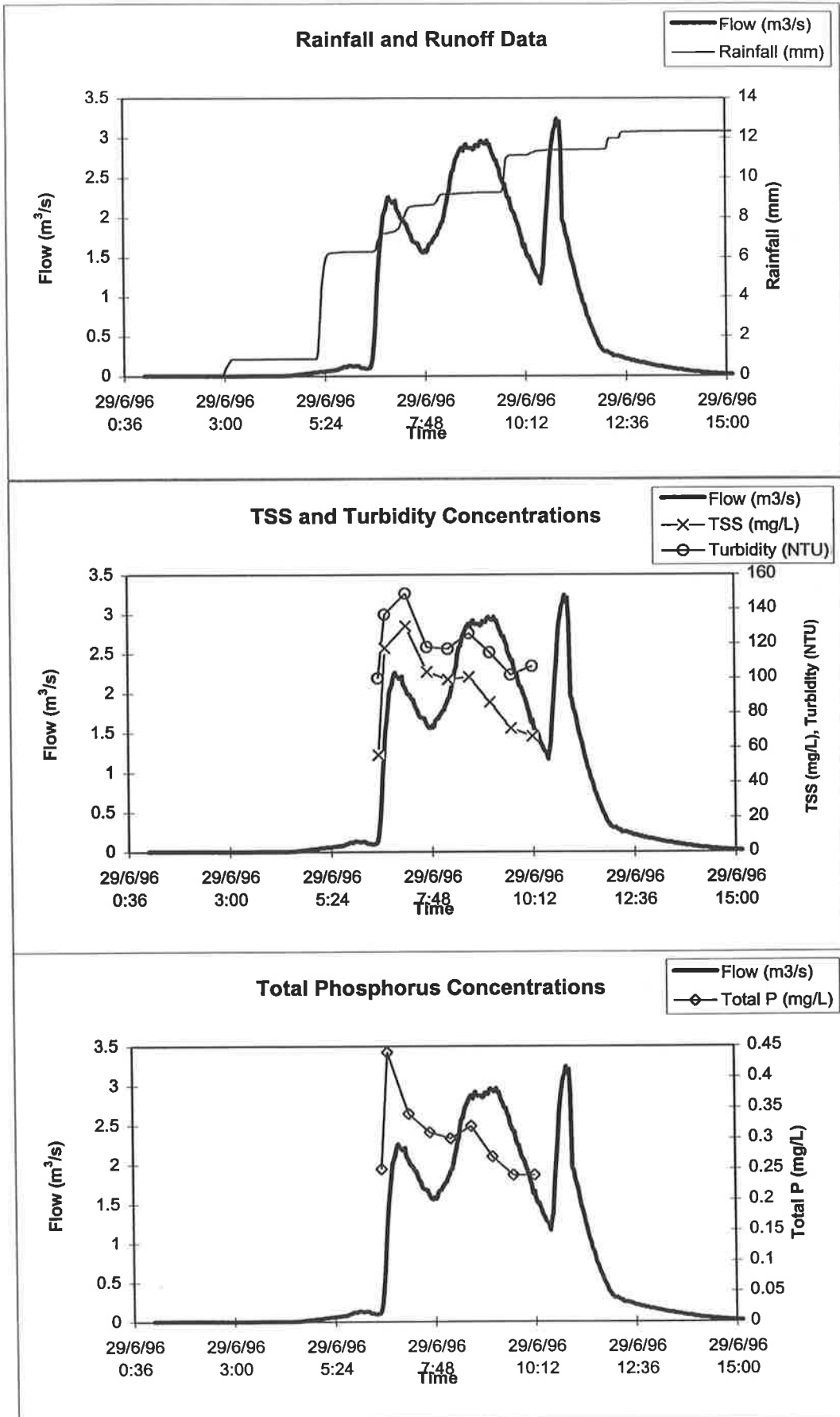
North Arm East Drain (AU504101)

Storm Date : 28/06/96



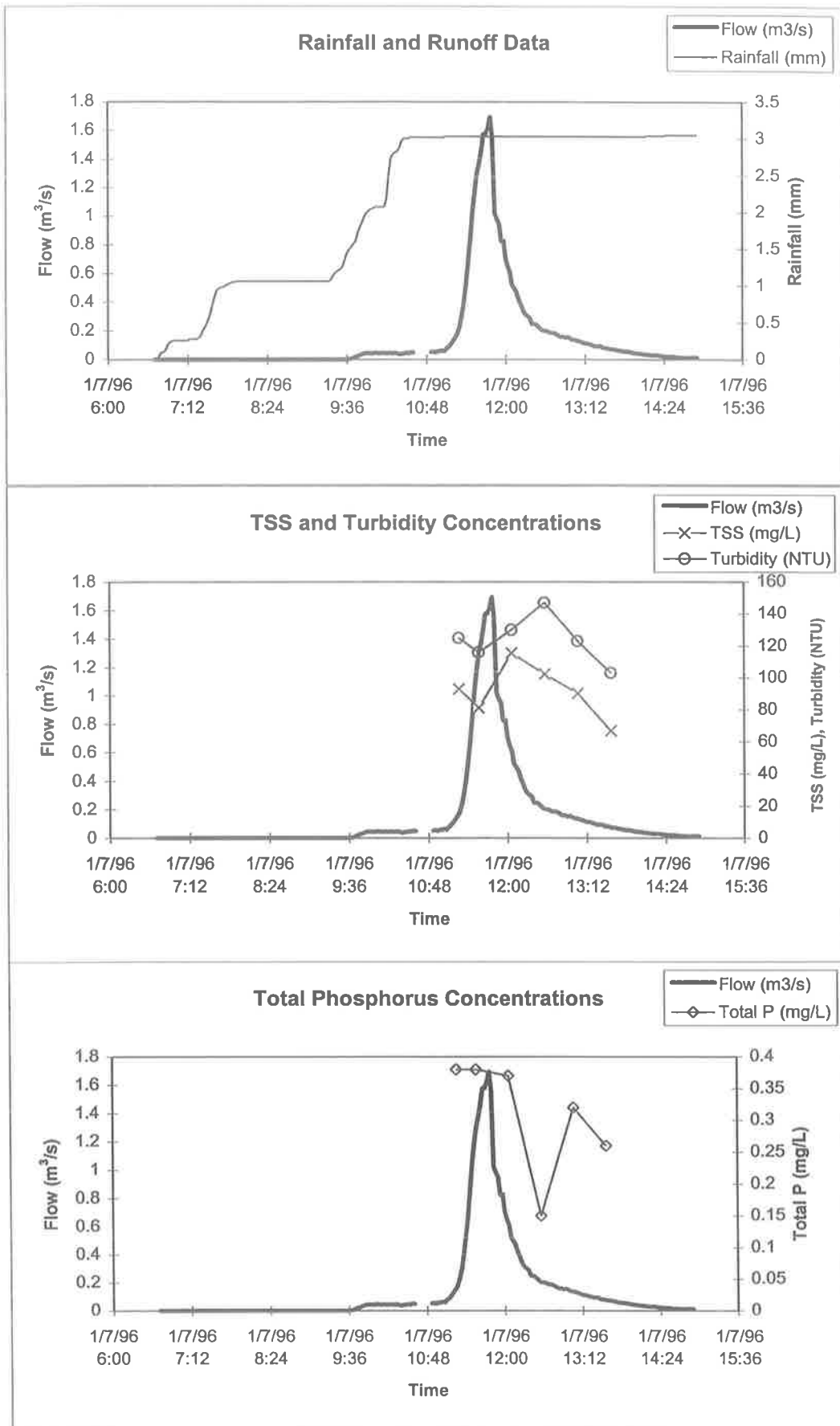
North Arm East Drain (AU504101)

Storm Date : 29/06/96

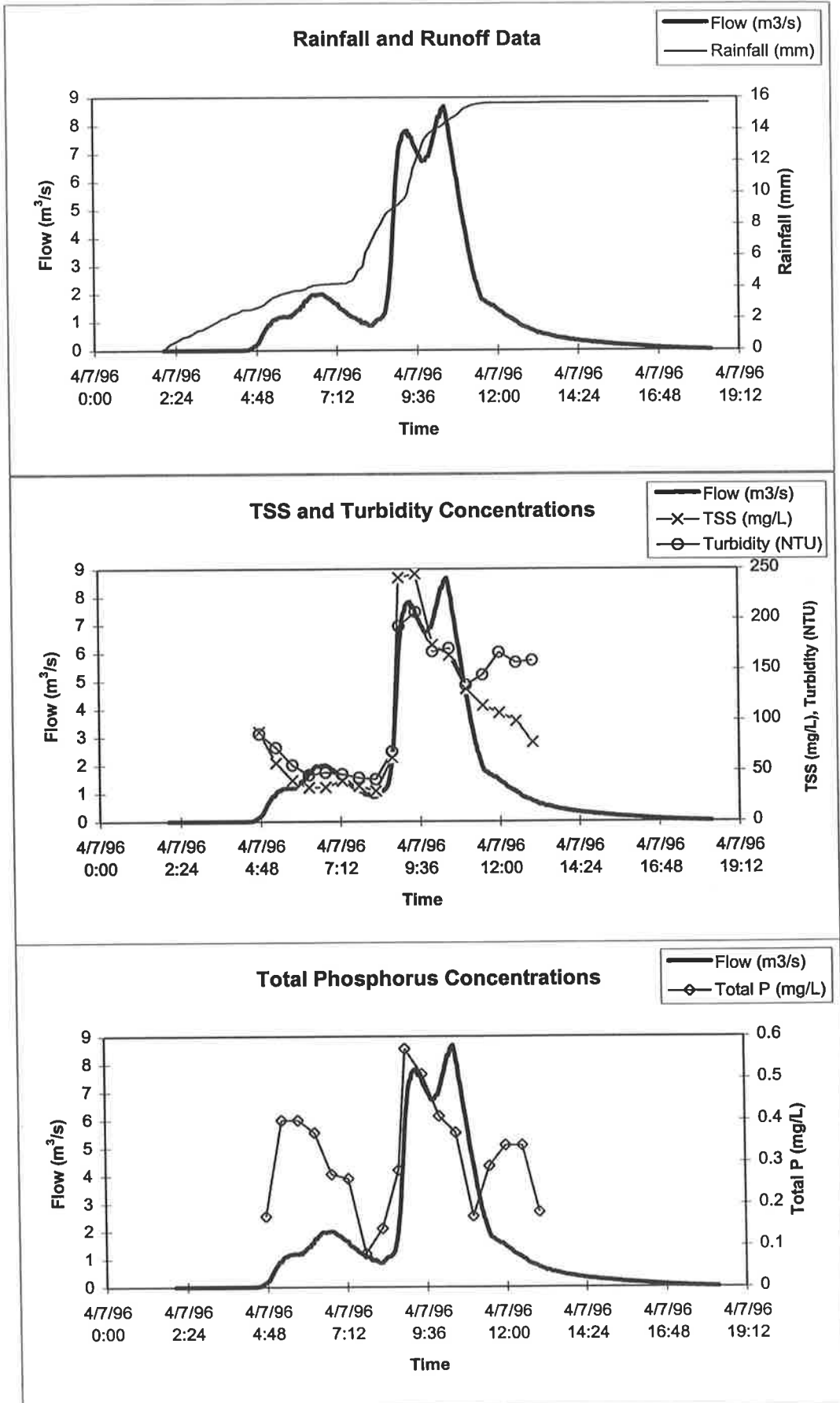


North Arm East Drain (AU504101)

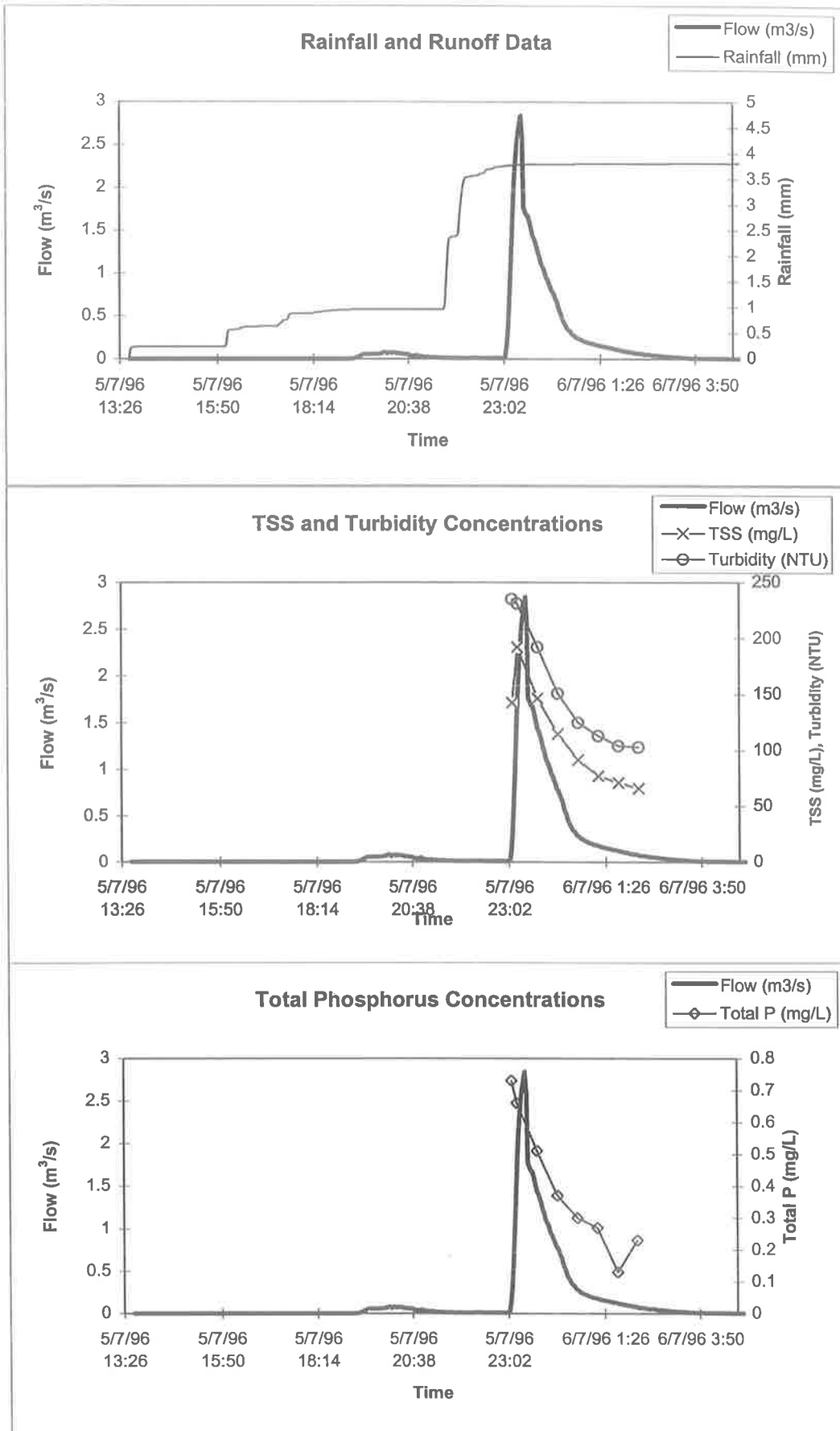
Storm Date : 1/07/96



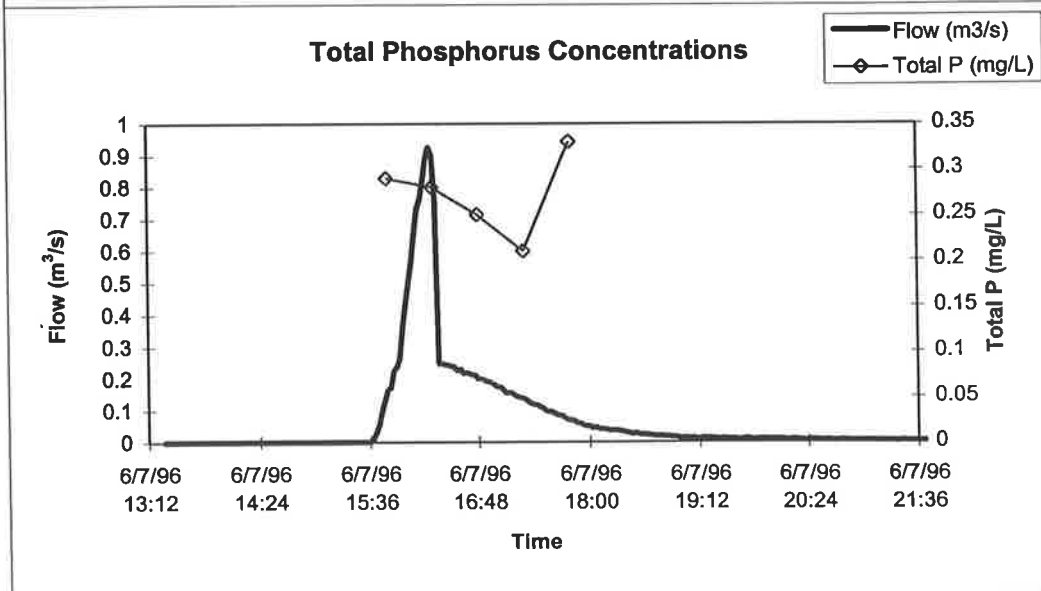
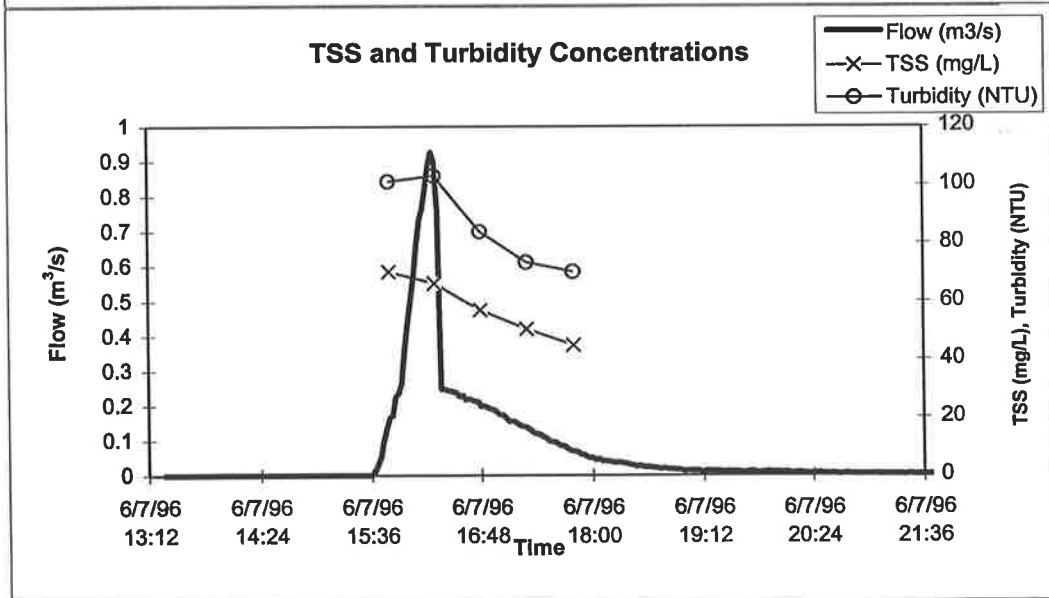
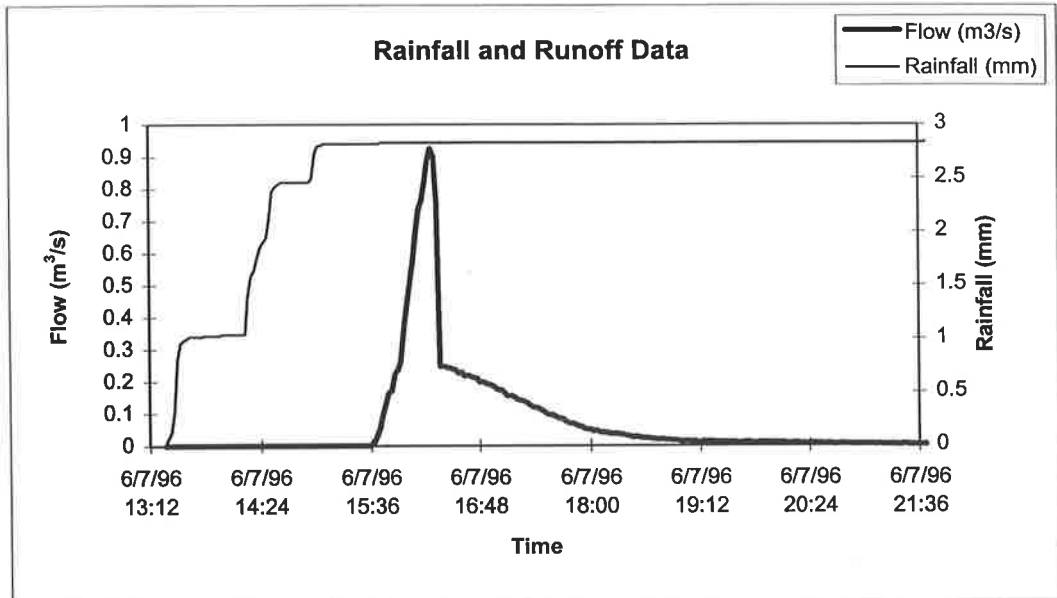
North Arm East Drain (AU504101)
Storm Date : 4/07/96



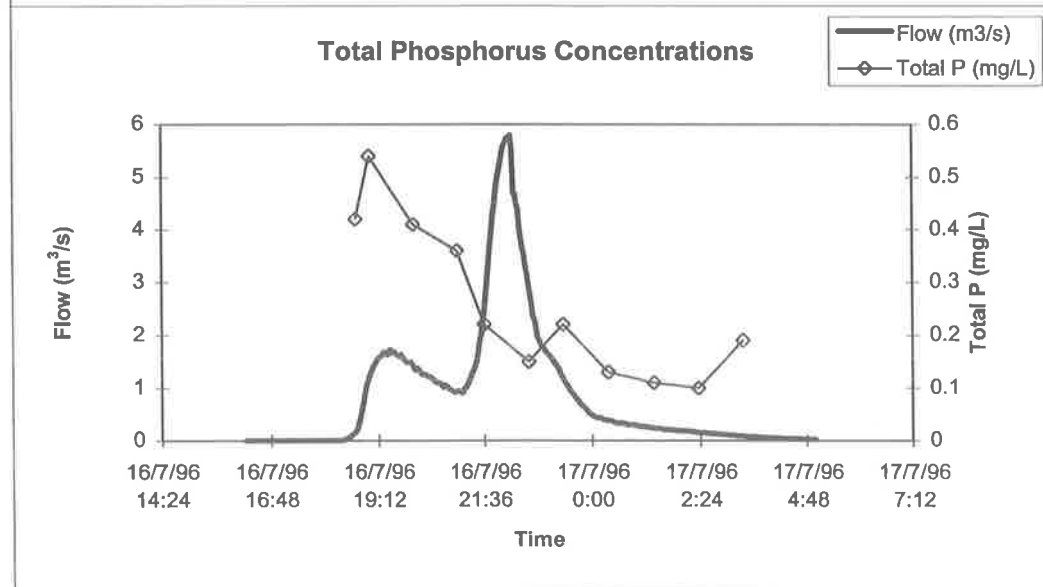
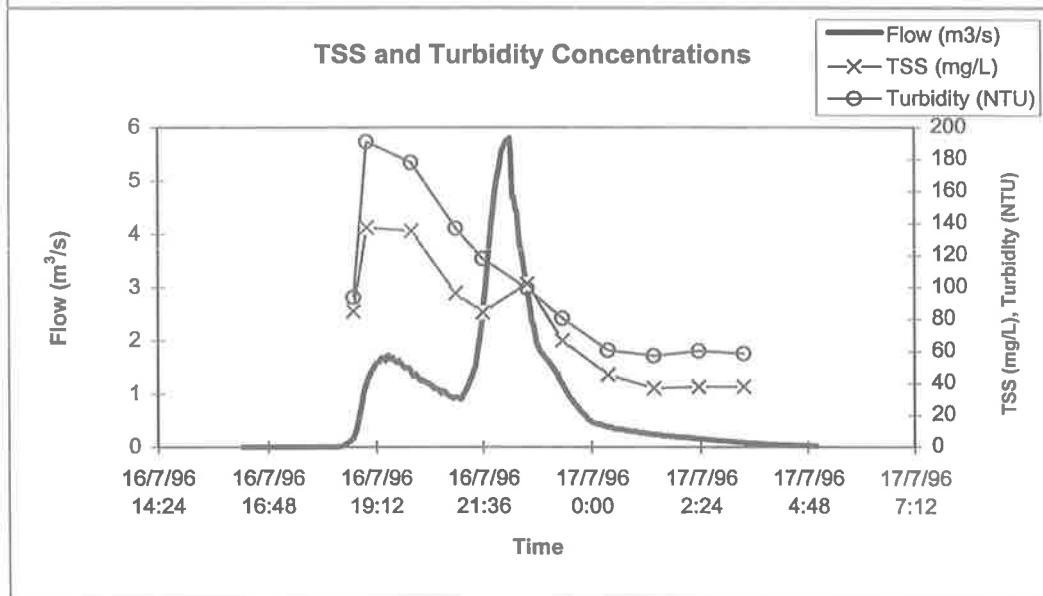
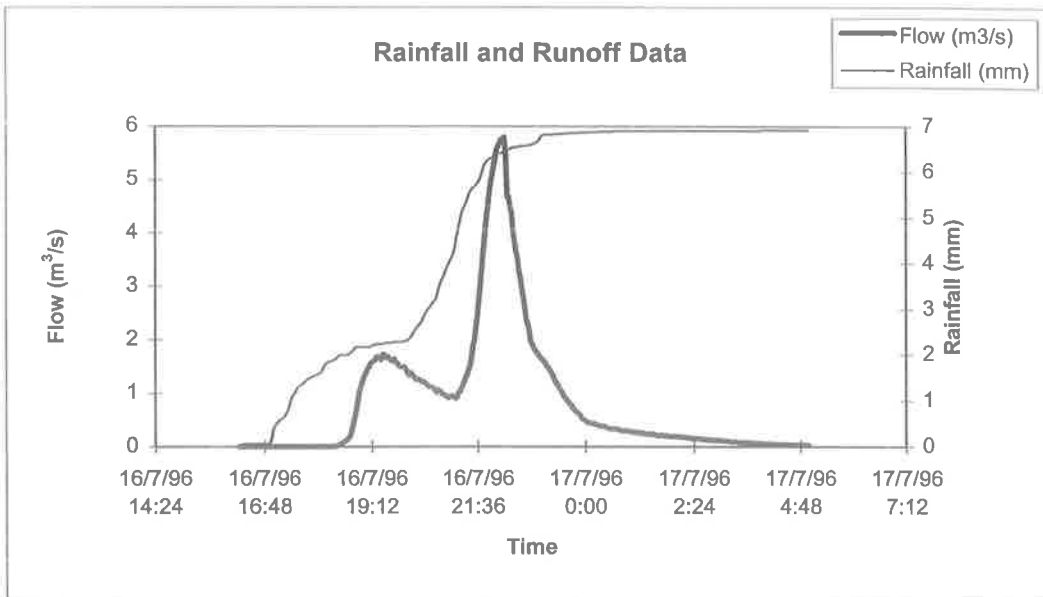
North Arm East Drain (AU504101)
Storm Date : 5-6/7/96



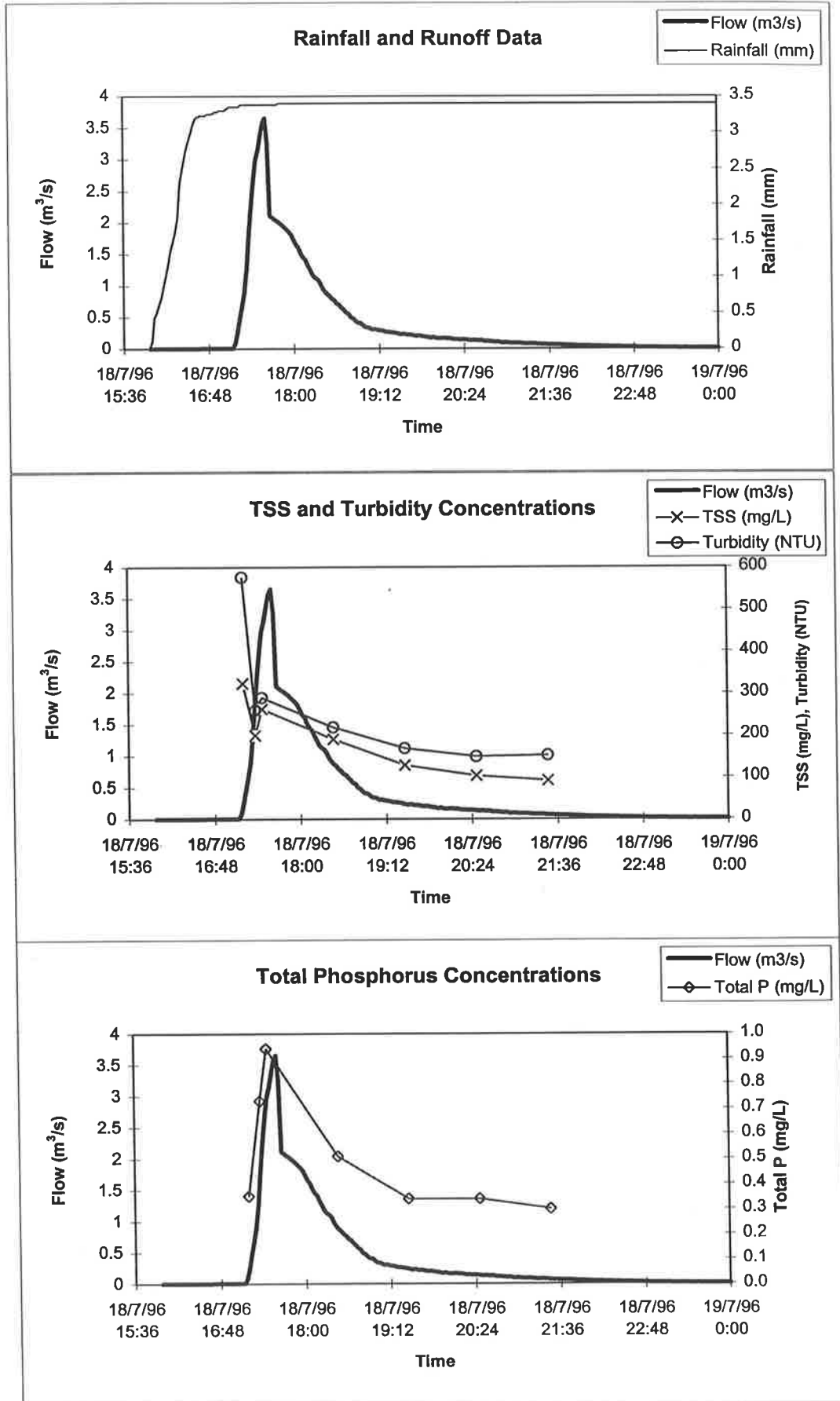
North Arm East Drain (AU504101)
Storm Date : 6/07/96



North Arm East Drain (AU504101)
Storm Date : 16/07/96

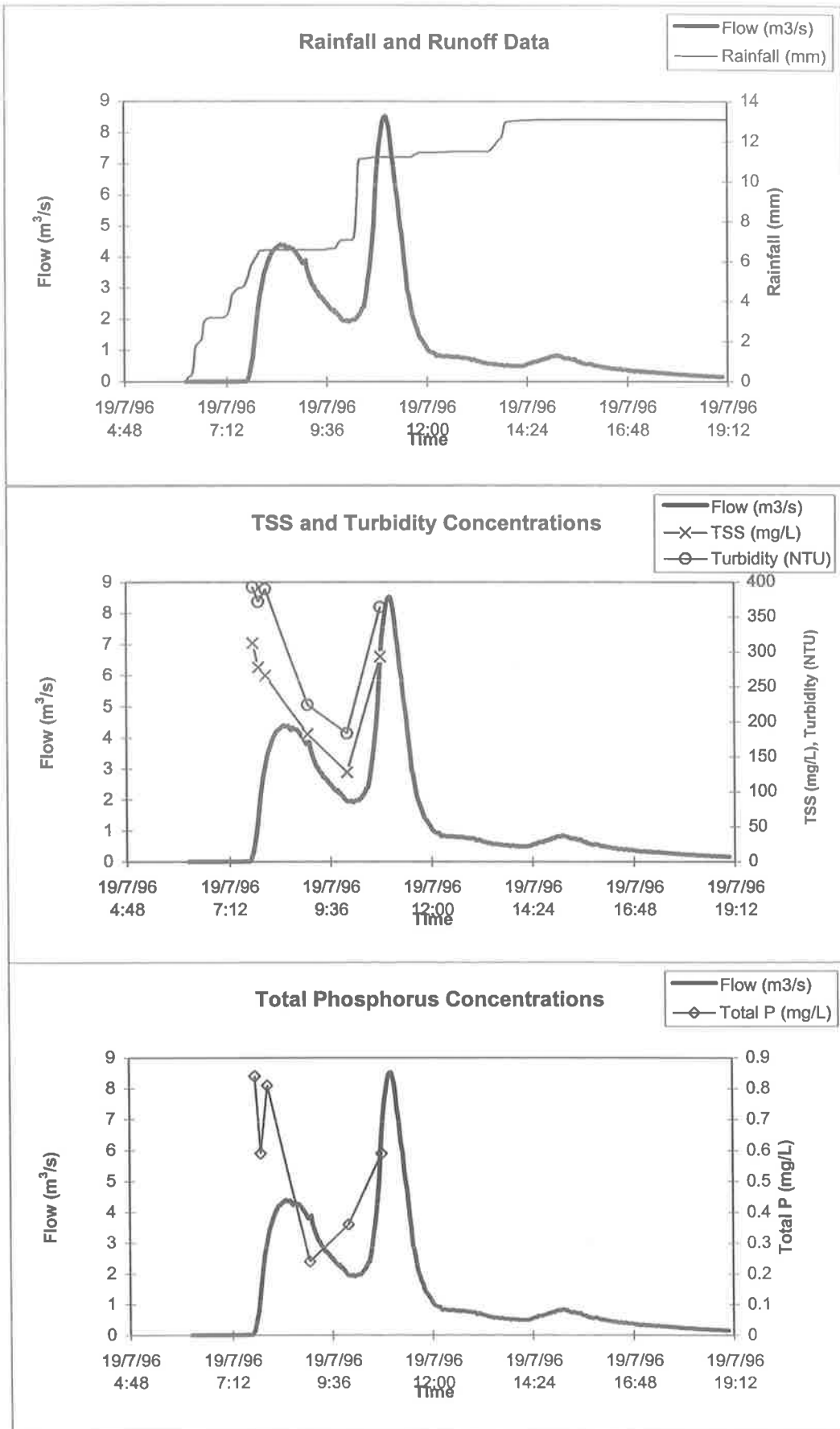


North Arm East Drain (AU504101)
Storm Date : 18/07/96



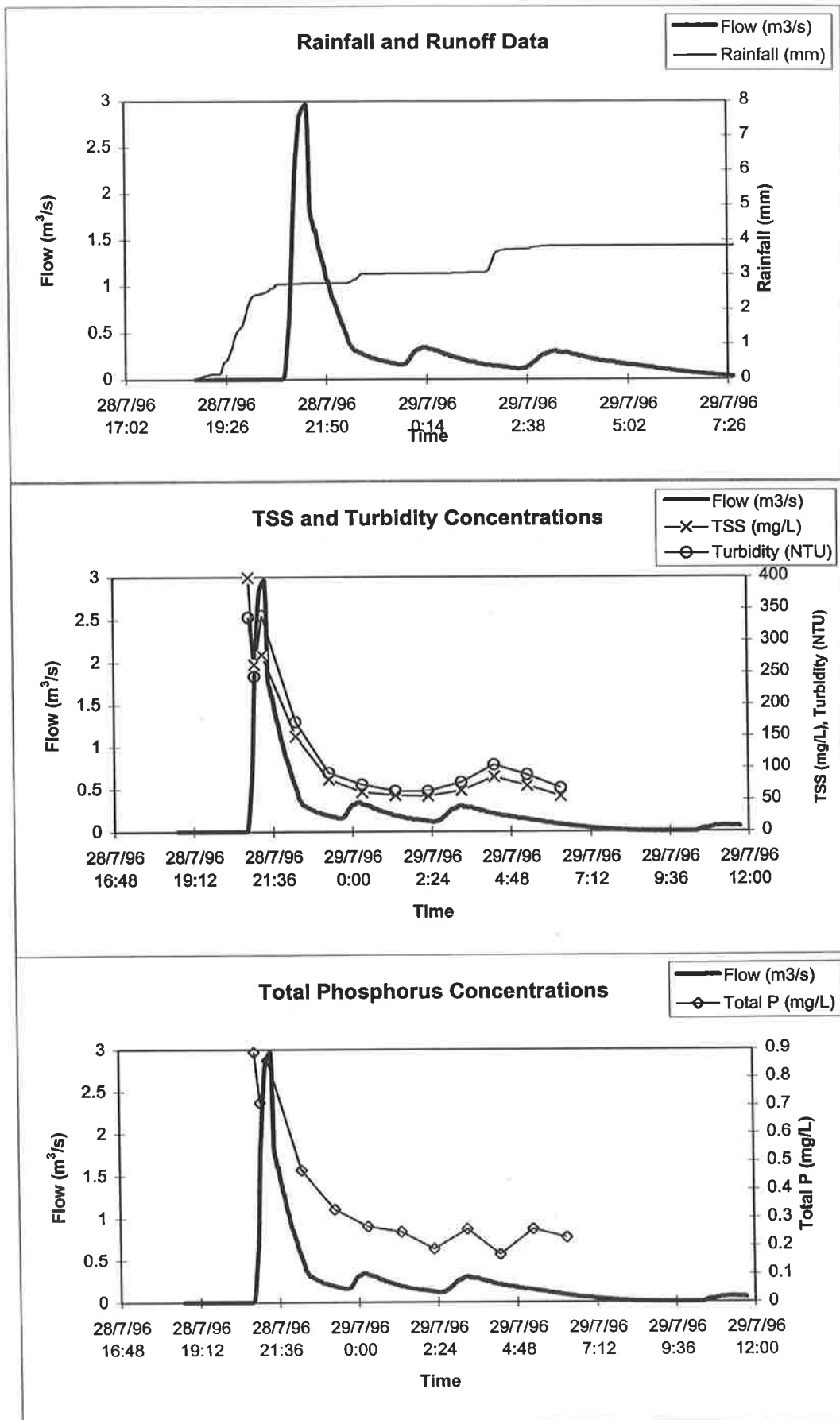
North Arm East Drain (AU504101)

Storm Date : 19/07/96



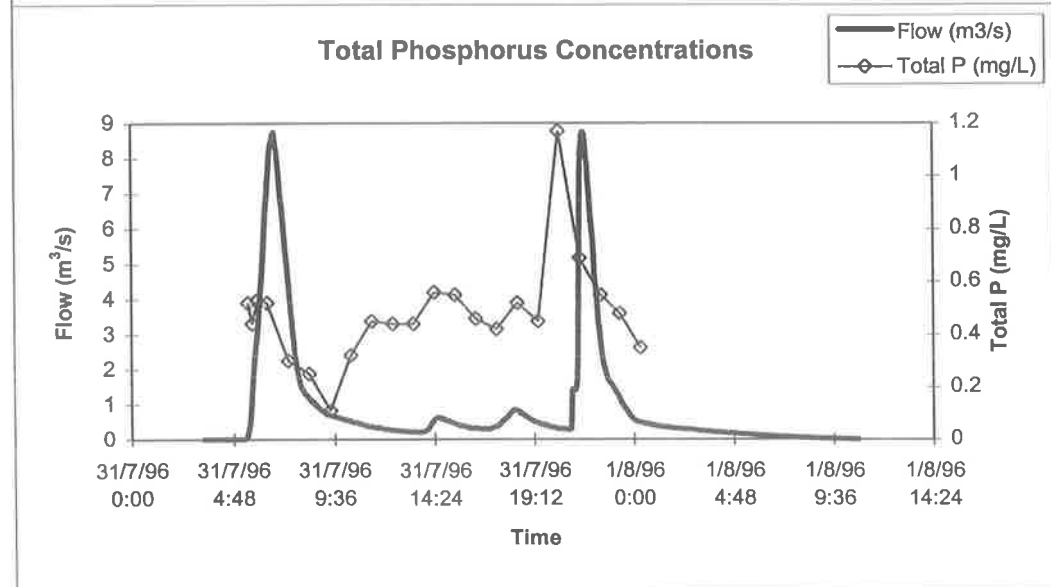
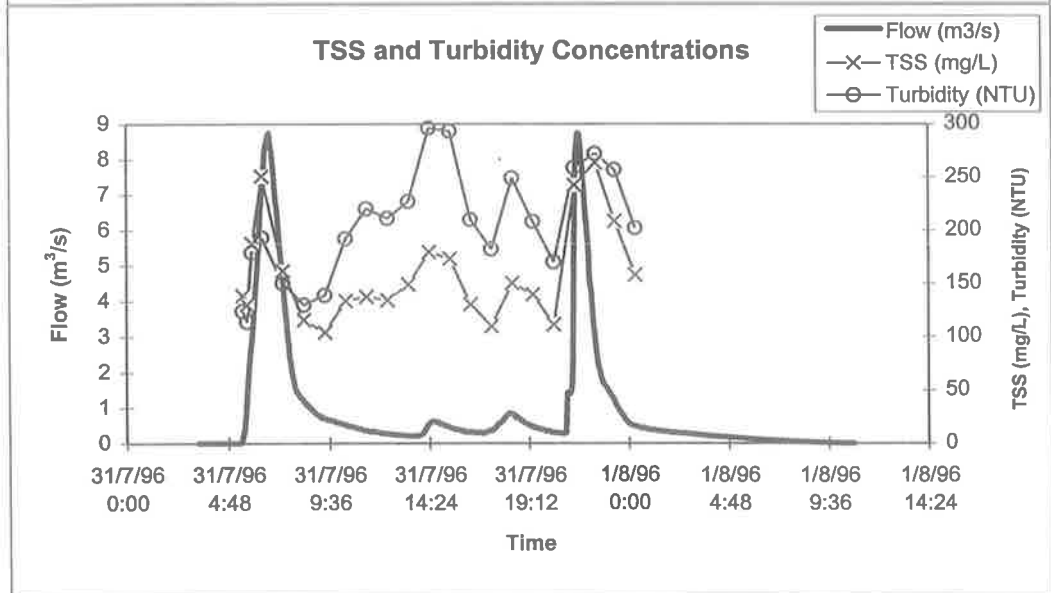
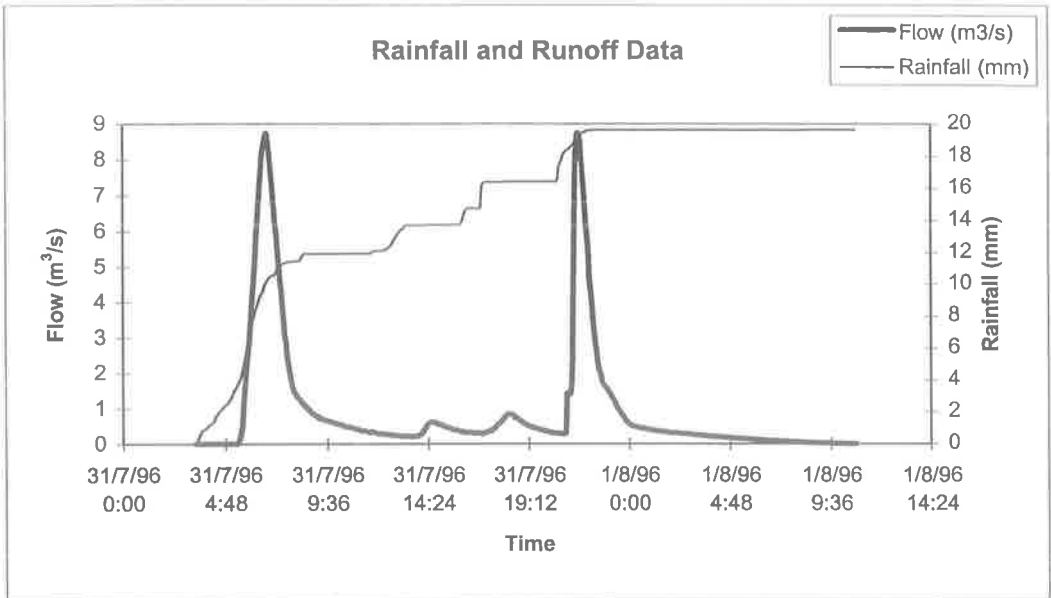
North Arm East Drain (AU504101)

Storm Date : 28-29/7/96

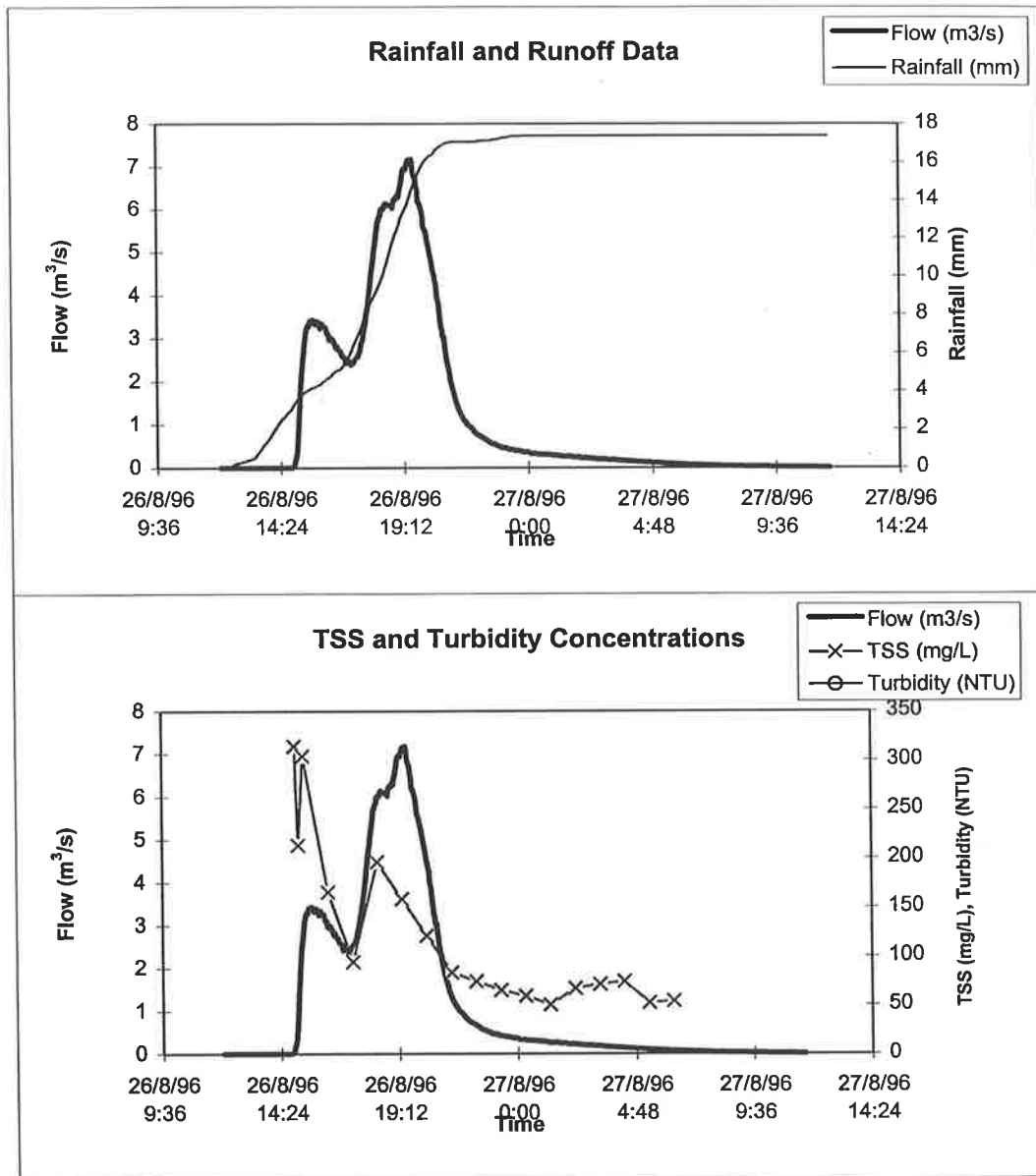


North Arm East Drain (AU504101)

Storm Date : 31/07/96

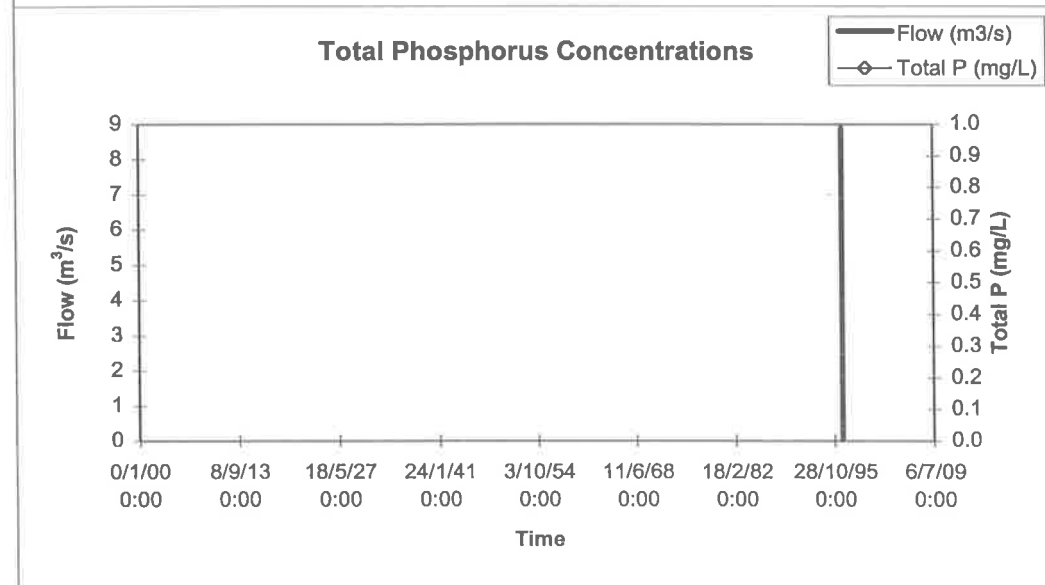
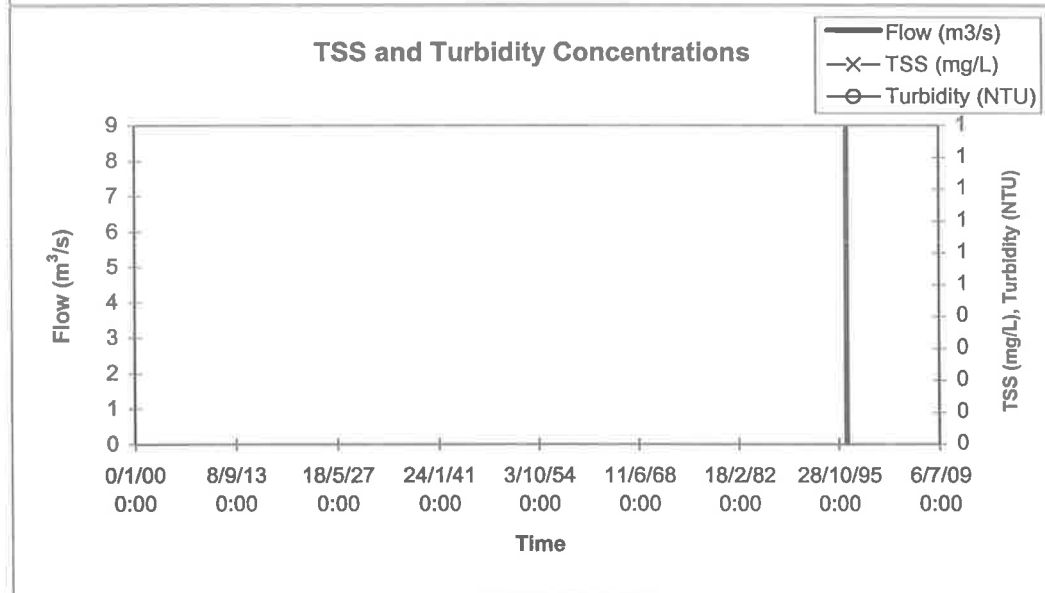
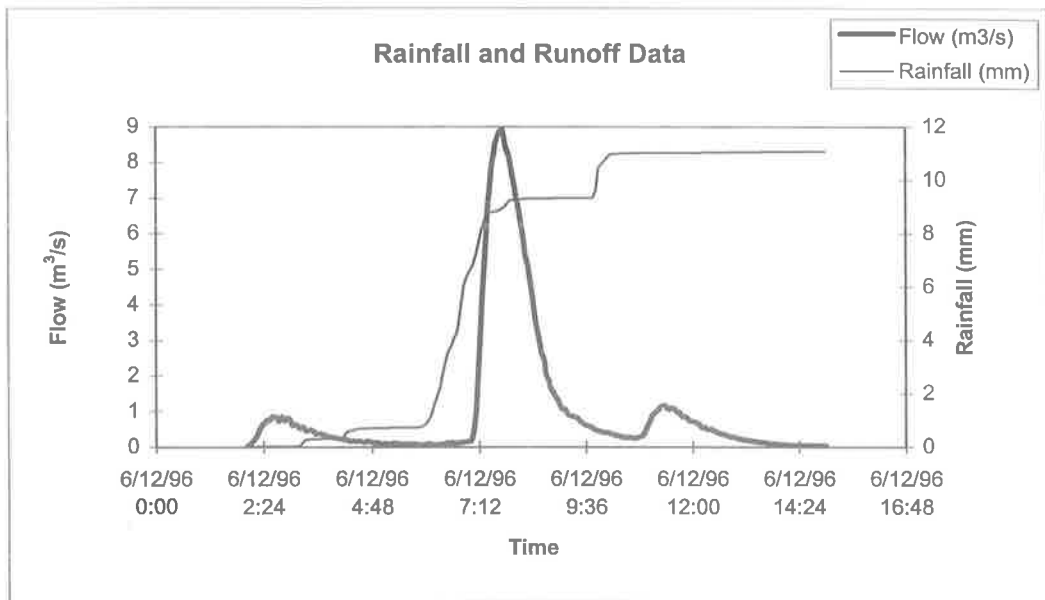


North Arm East Drain (AU504101)
Storm Date : 26-27/8/96

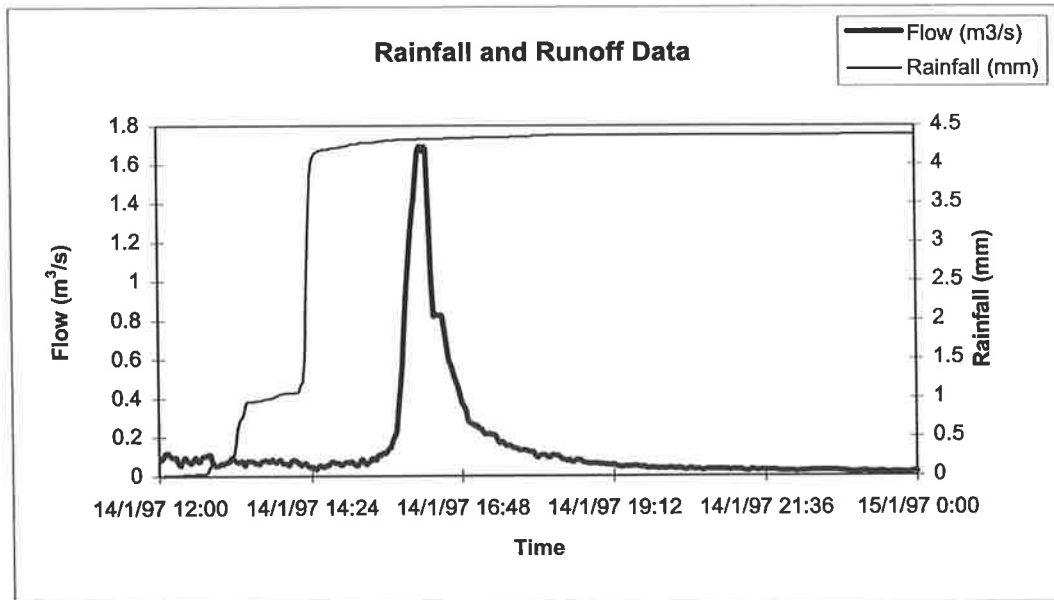


North Arm East Drain (AU504101)

Storm Date : 6/12/96

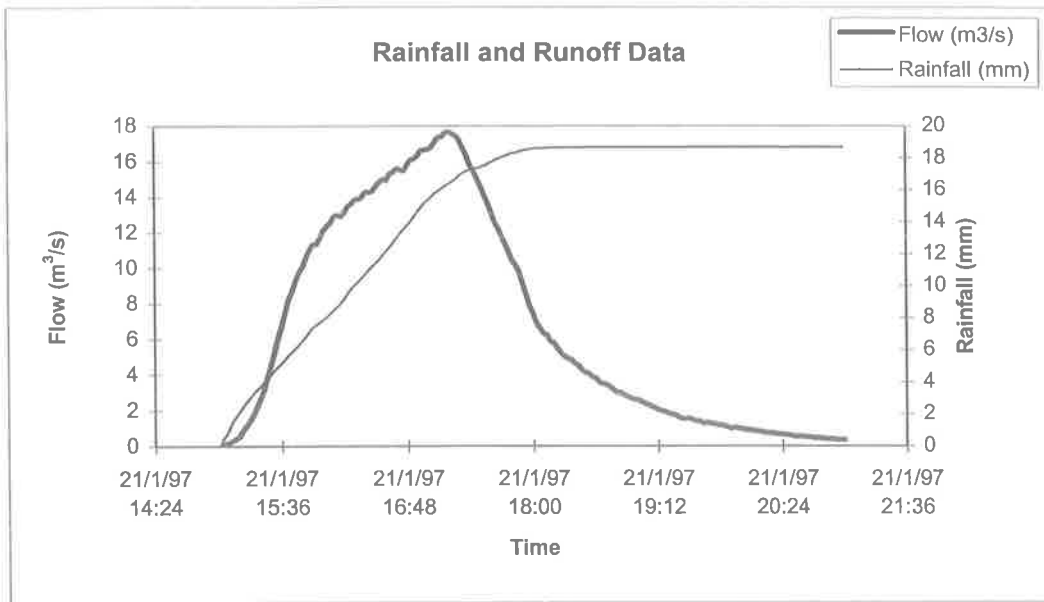


North Arm East Drain (AU504101)
Storm Date : 14/01/97

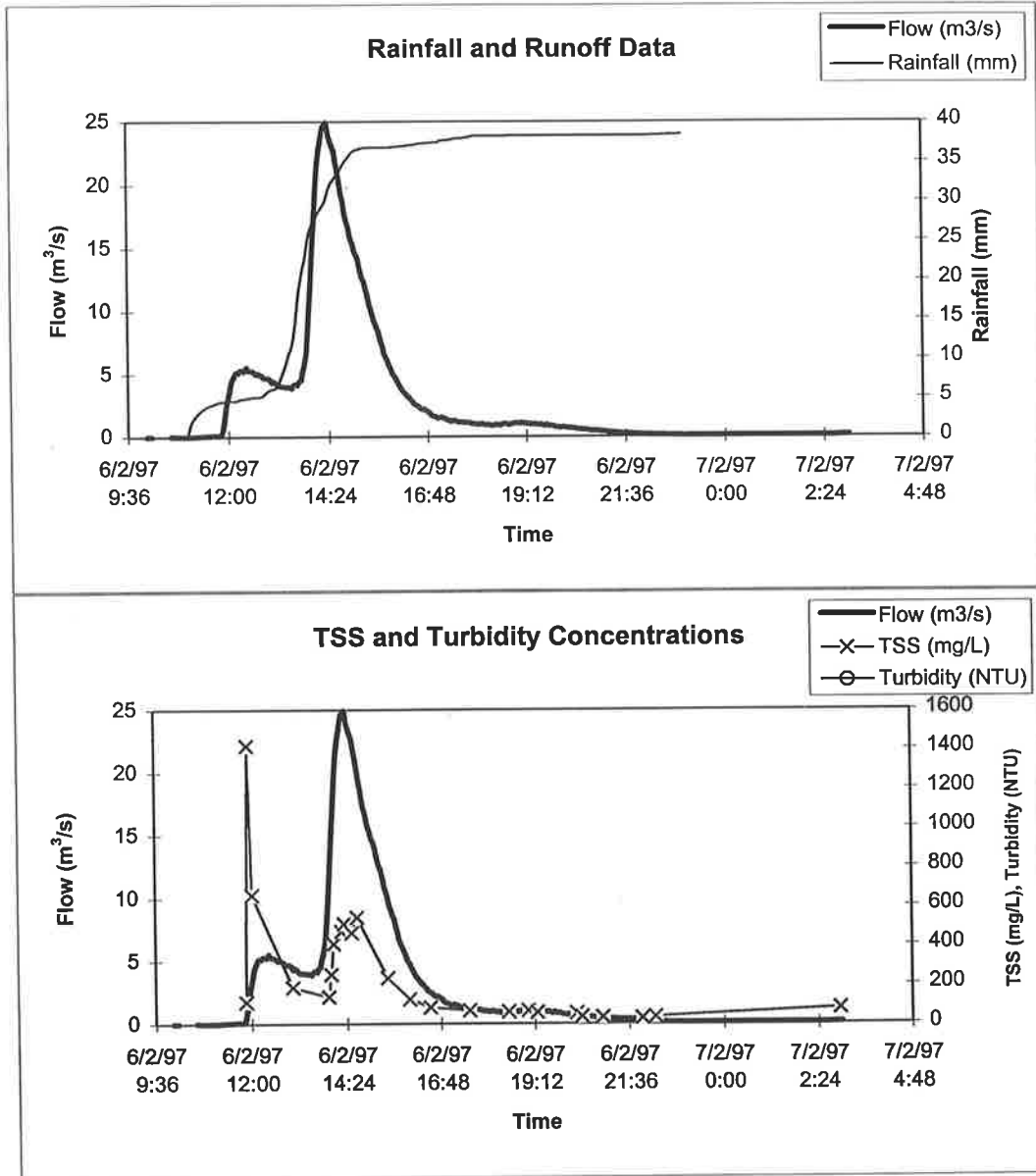


North Arm East Drain (AU504101)

Storm Date : 21/01/97

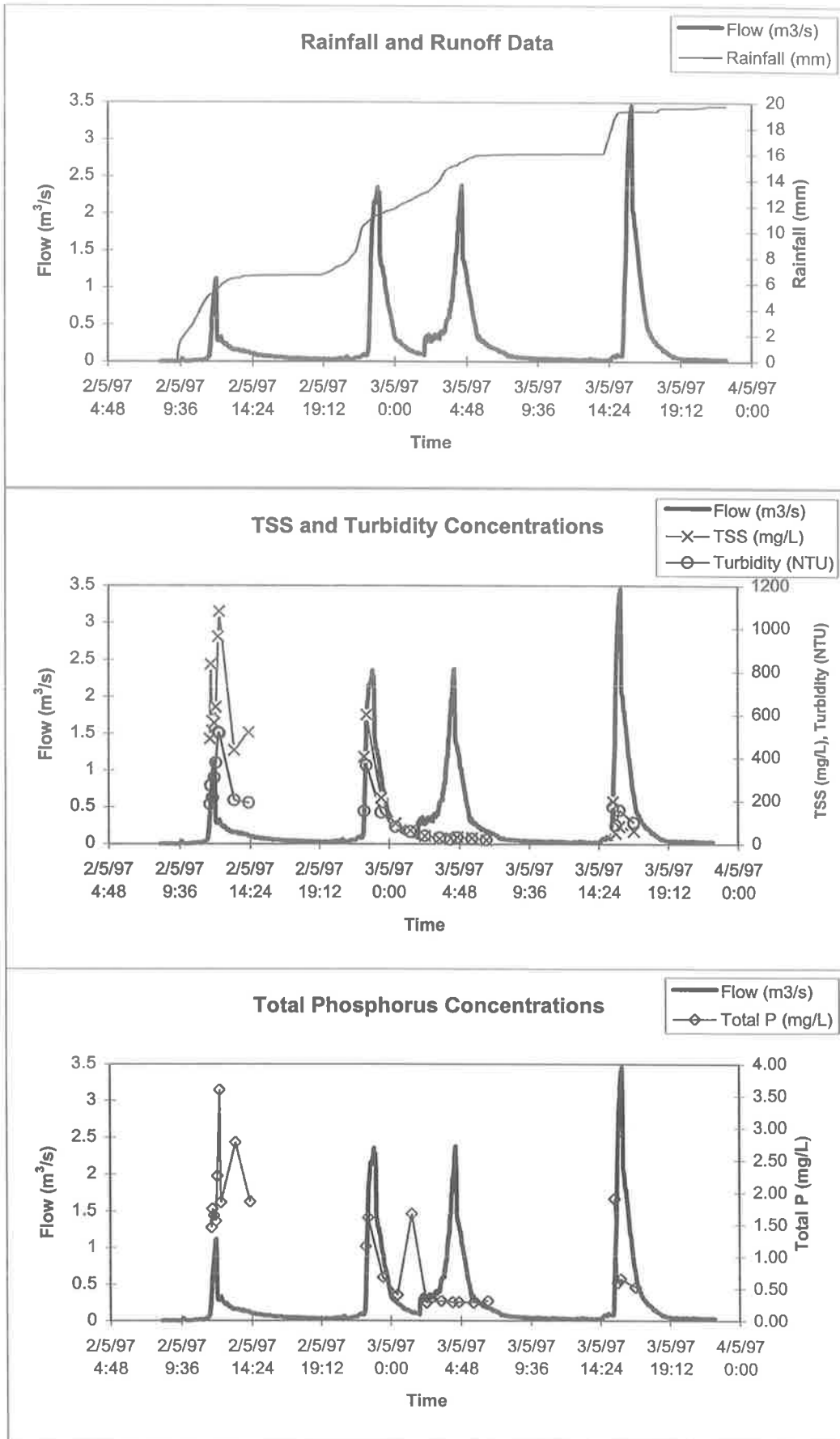


North Arm East Drain (AU504101)
Storm Date : 6/02/97



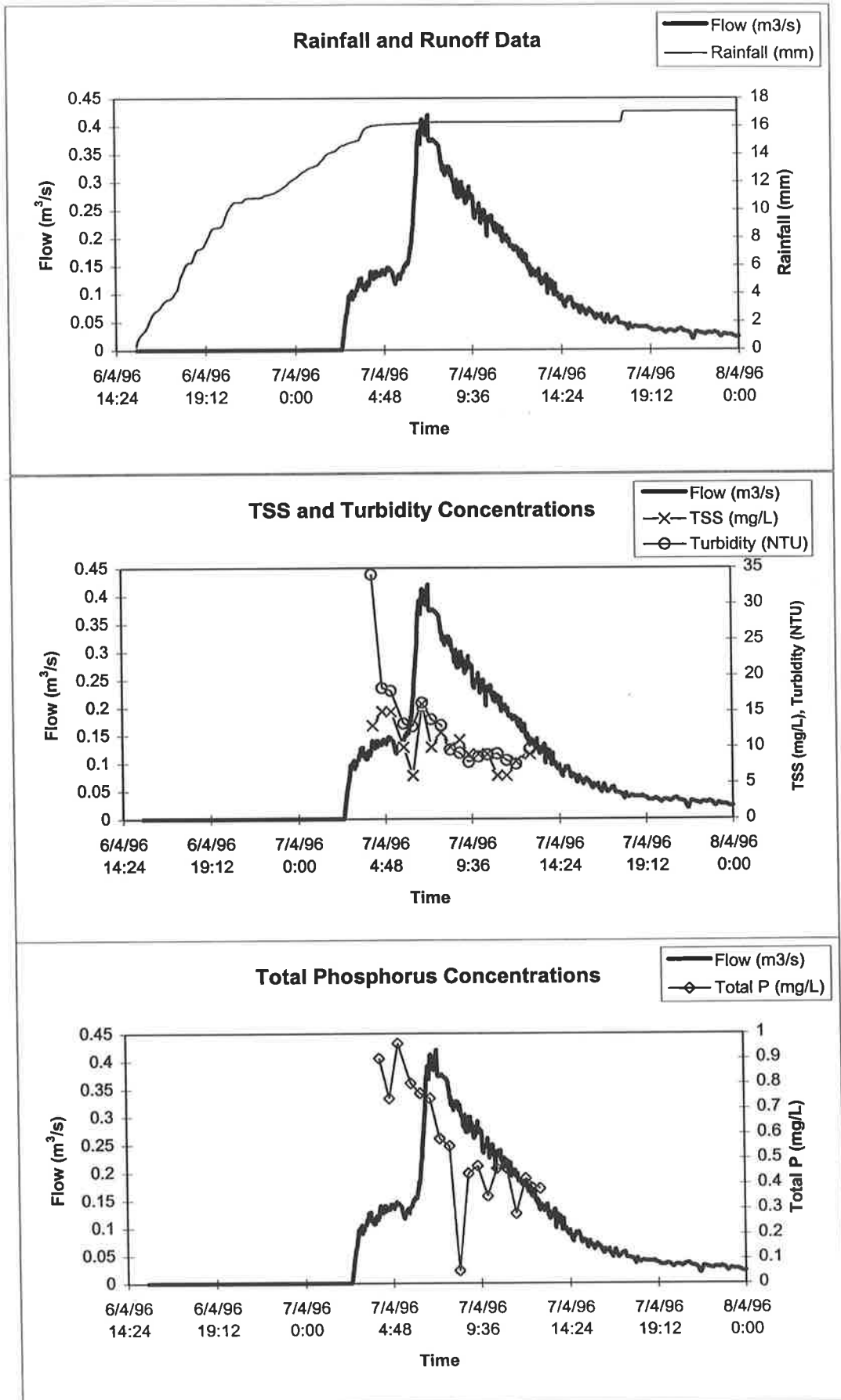
North Arm East Drain (AU504101)

Storm Date : 2-5/97

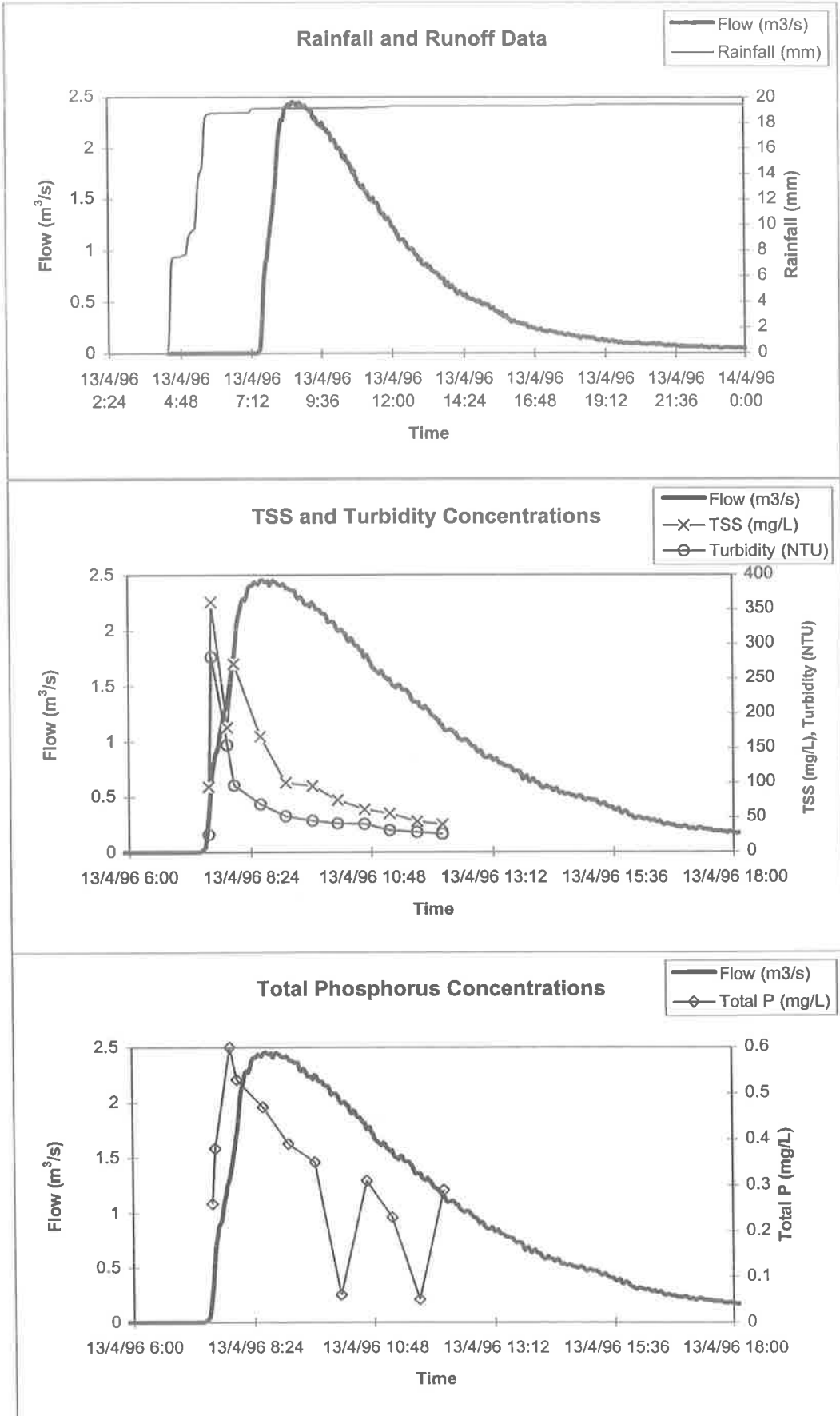


Hindmarsh Enfield Prospect Drain (AU504102)

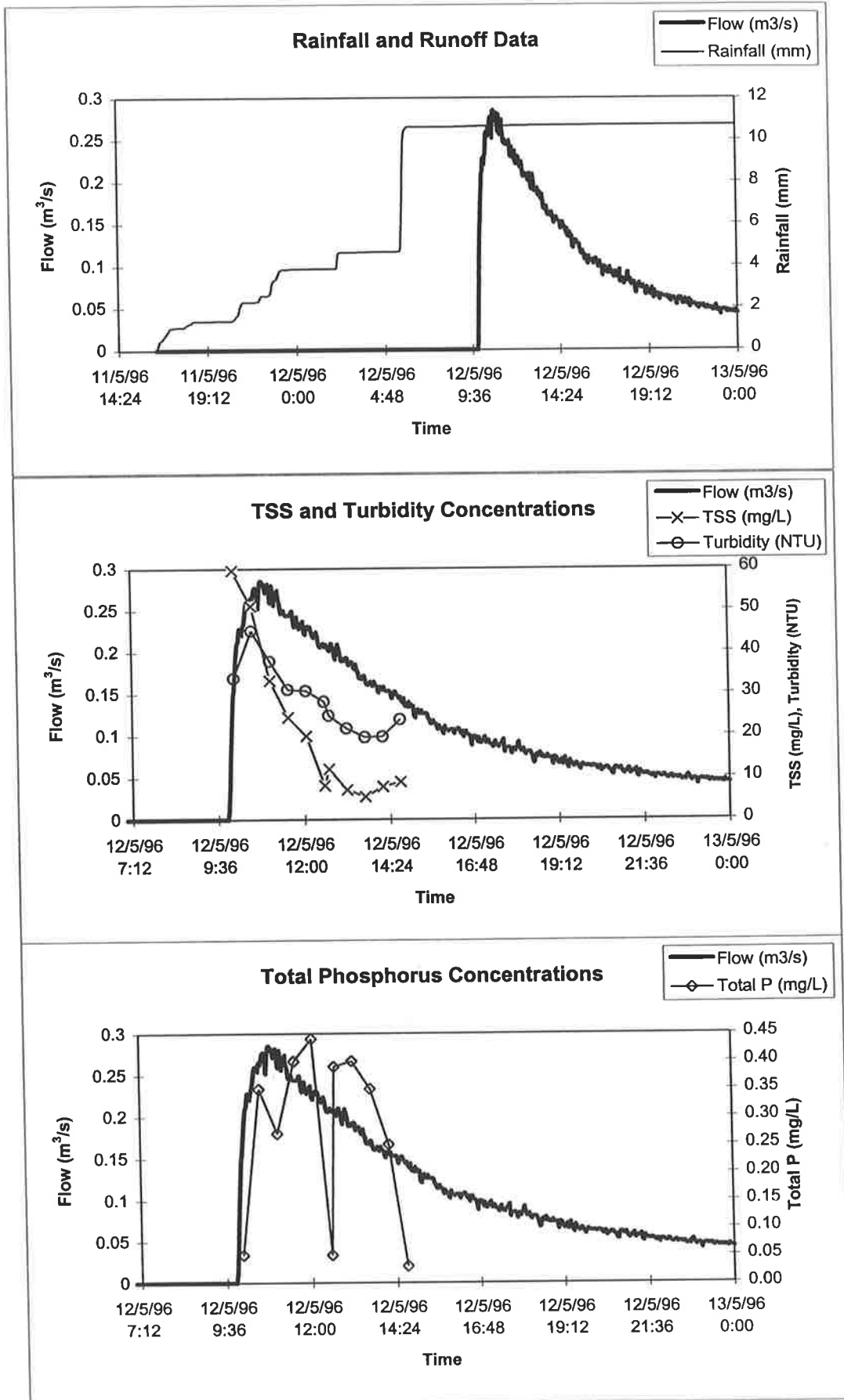
Storm Date : 7/04/96



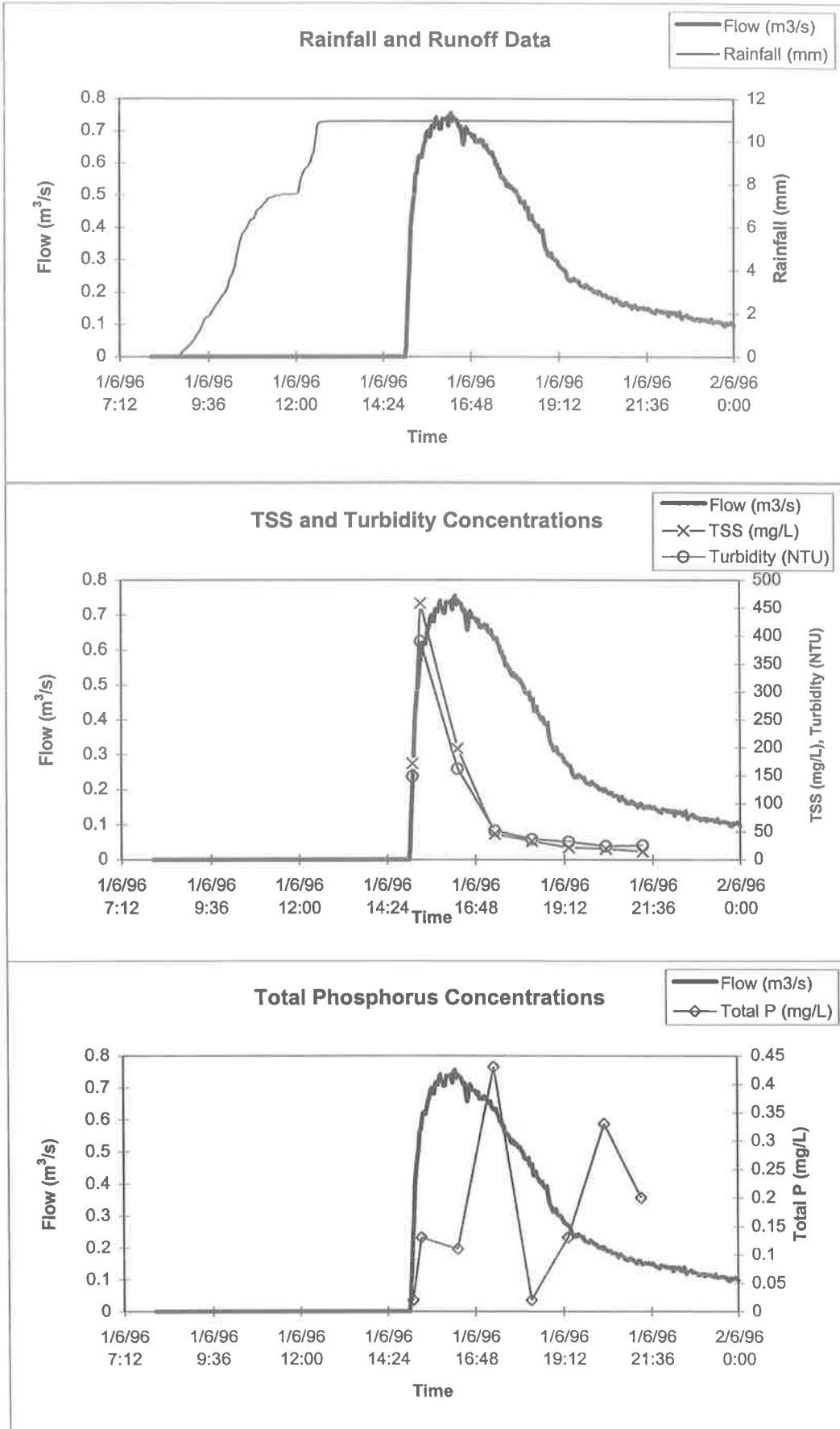
Hindmarsh Enfield Prospect Drain (AU504102)
Storm Date : 13/04/96



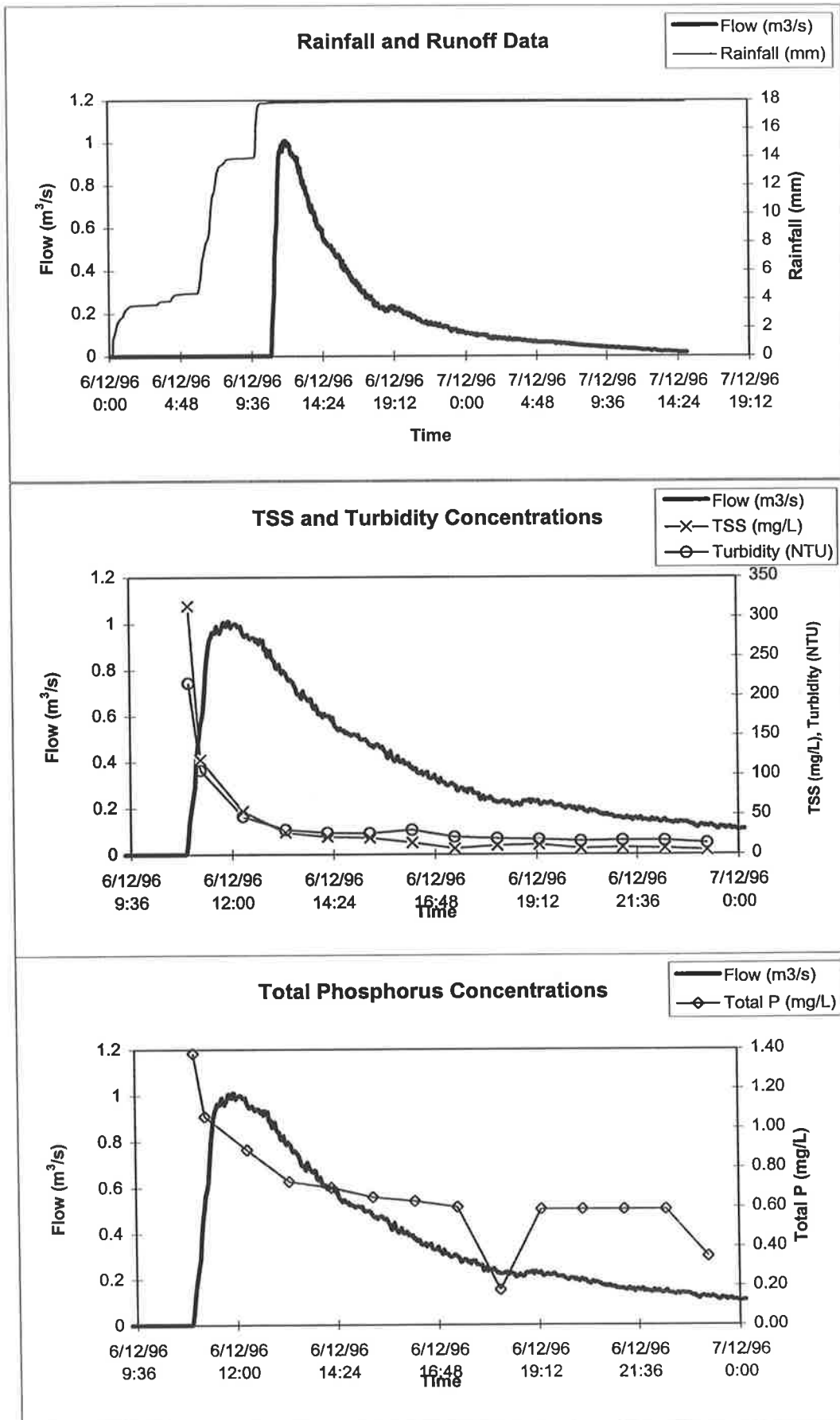
Hindmarsh Enfield Prospect Drain (AU504102)
Storm Date : 12/05/96



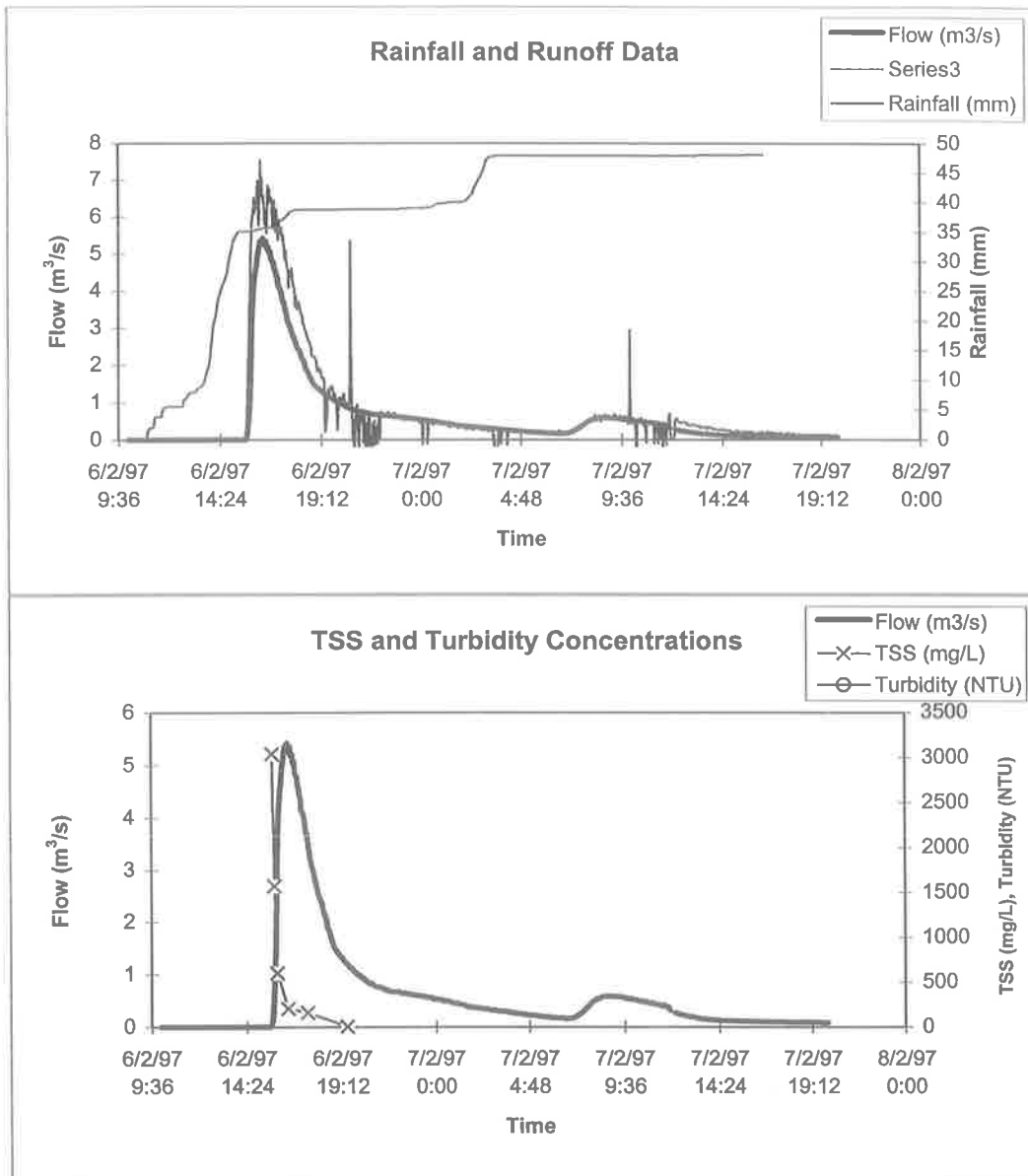
Hindmarsh Enfield Prospect Drain (AU504102)
Storm Date : 1/06/96



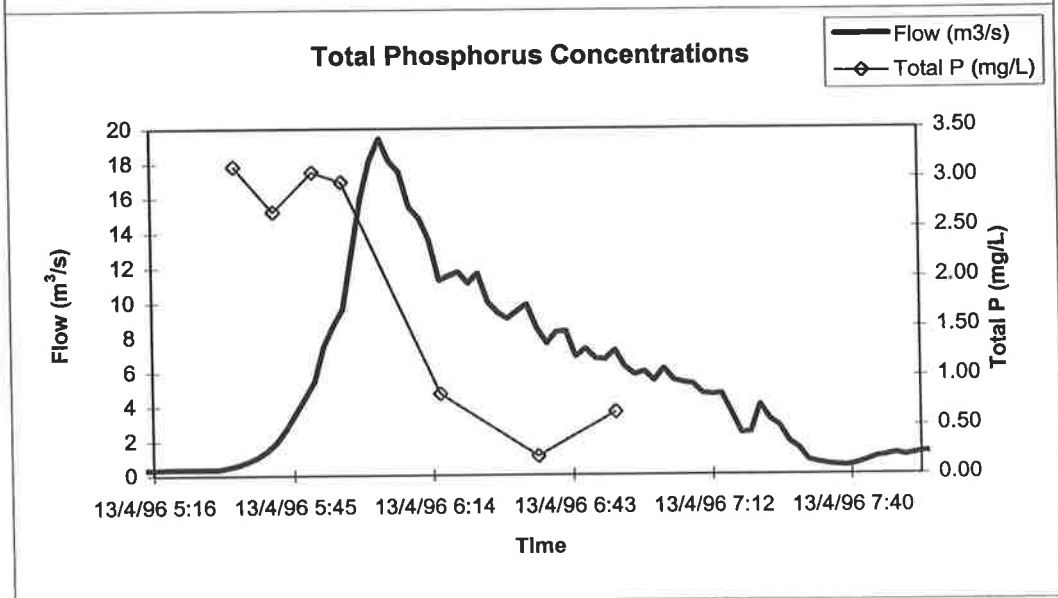
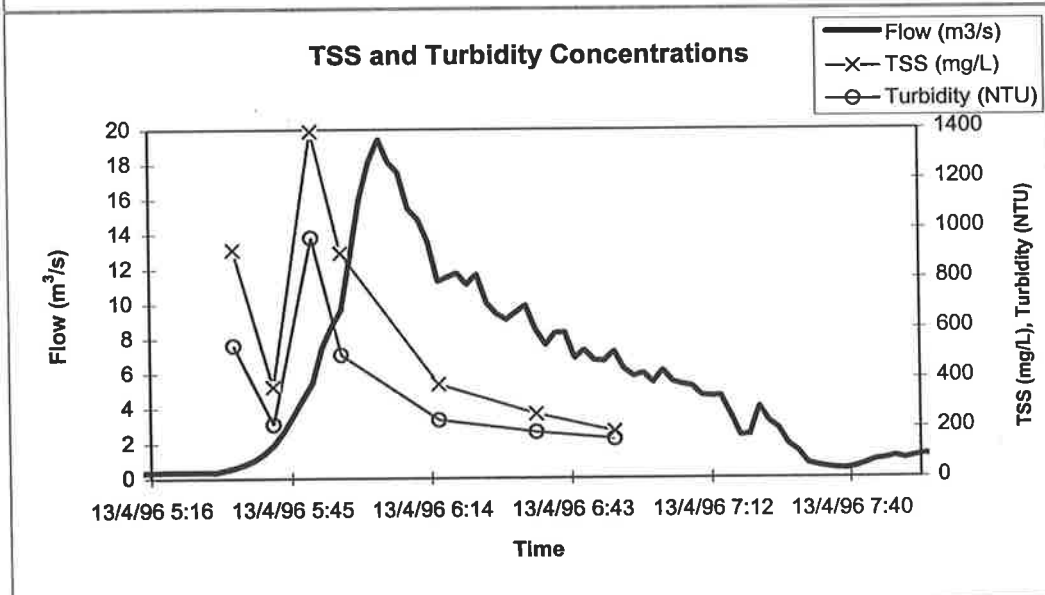
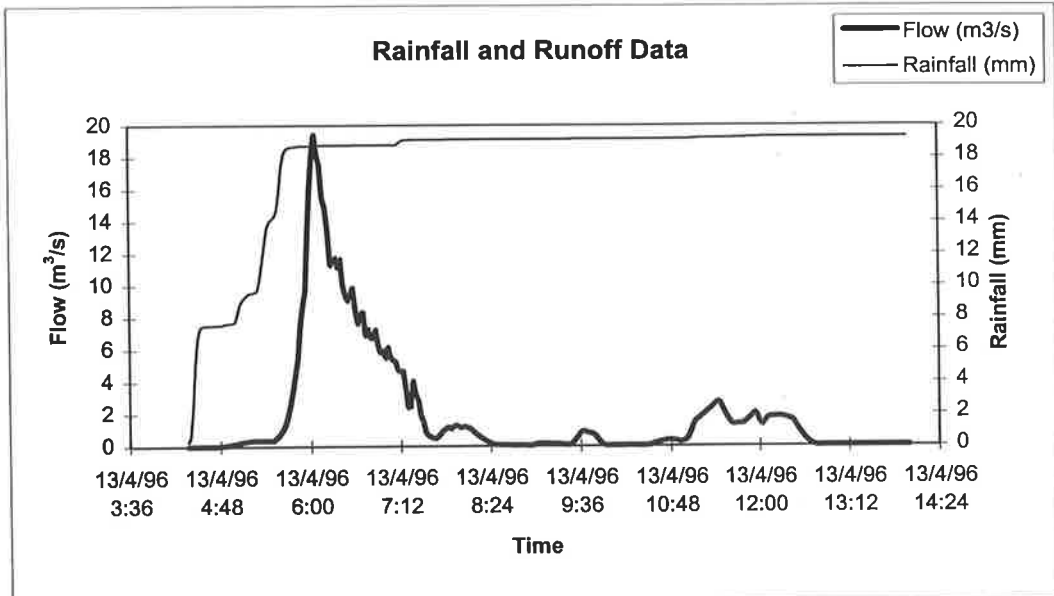
Hindmarsh Enfield Prospect Drain (AU504102)
Storm Date : 6-7/12/1996



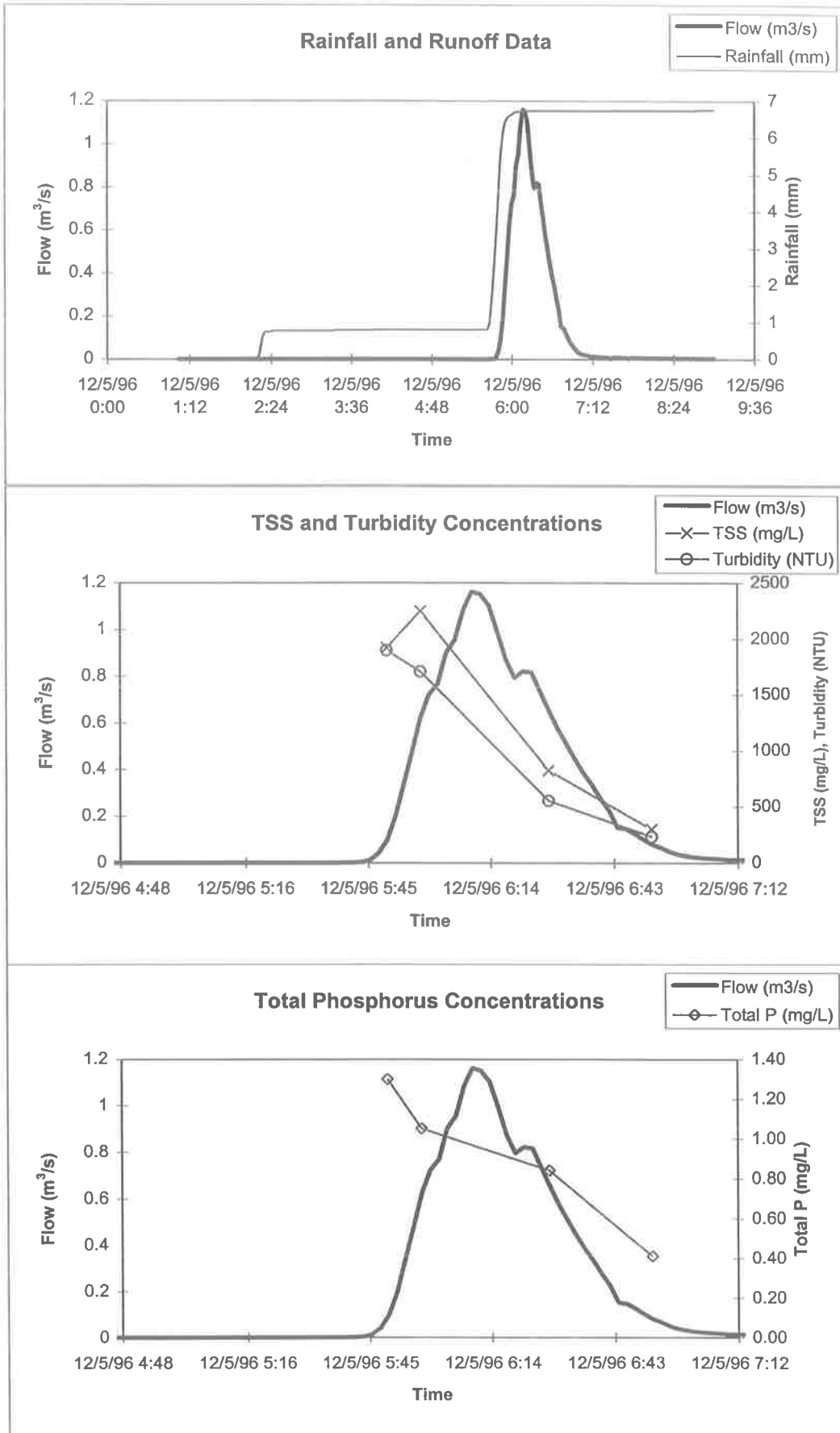
Hindmarsh Enfield Prospect Drain (AU504102)
Storm Date : 6-7/02/1997



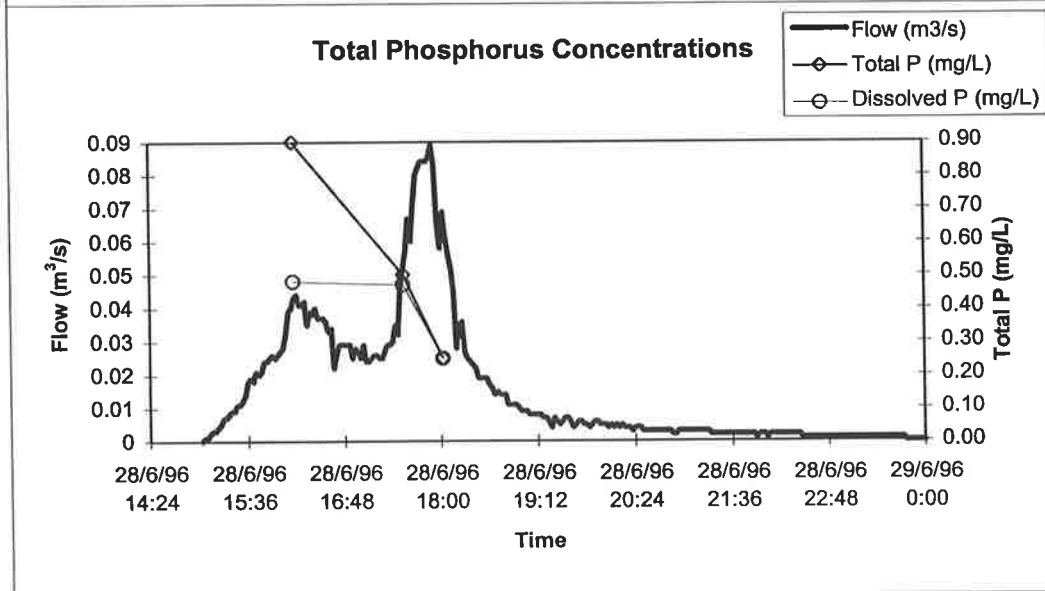
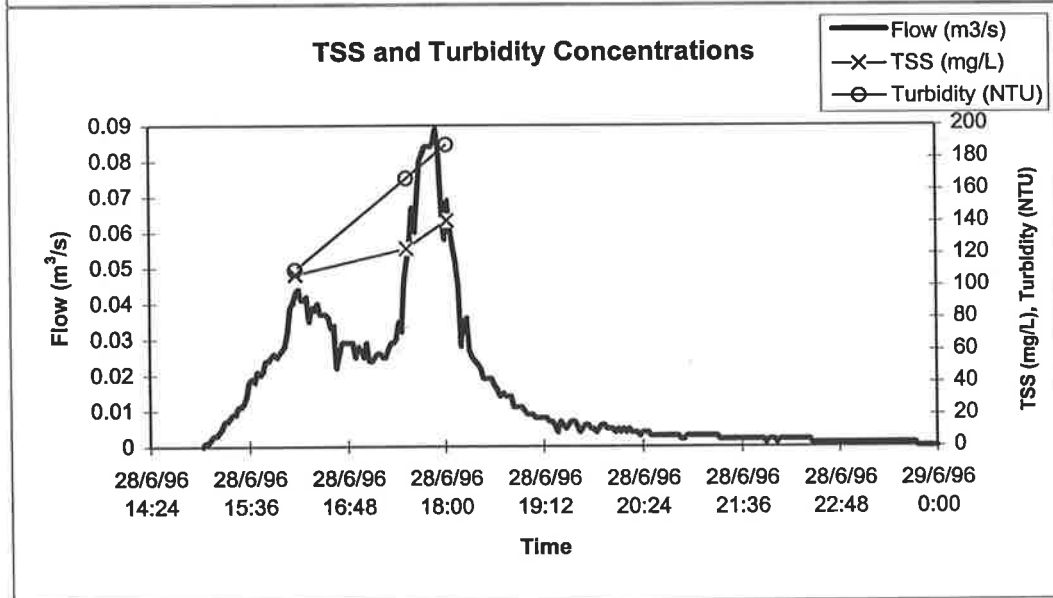
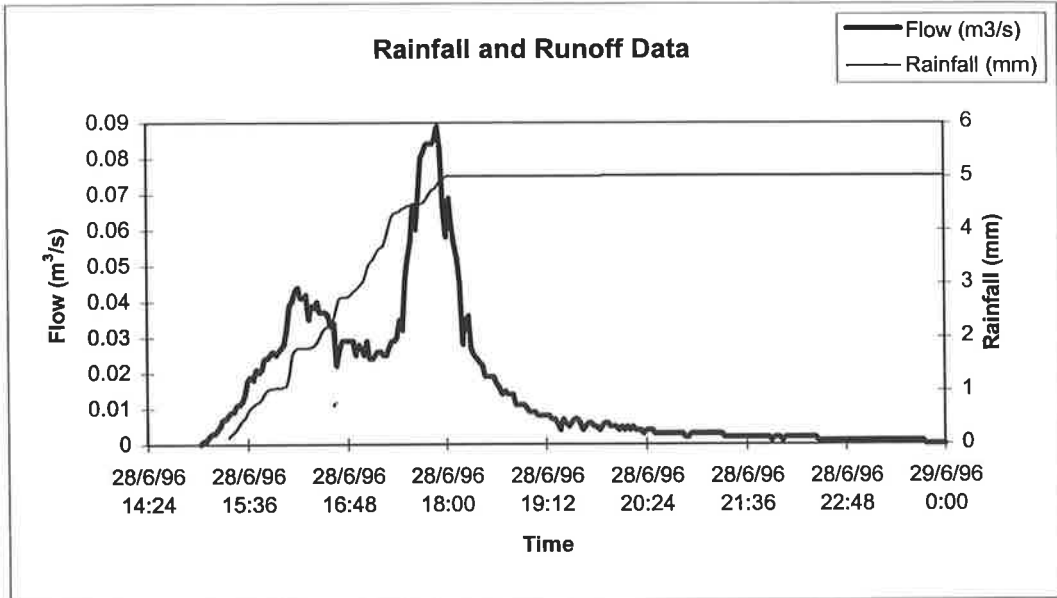
Dunstan Road Drain (AU504103)
Storm Date : 13/04/96



Dunstan Road Drain (AU504103)
Storm Date : 12/05/96

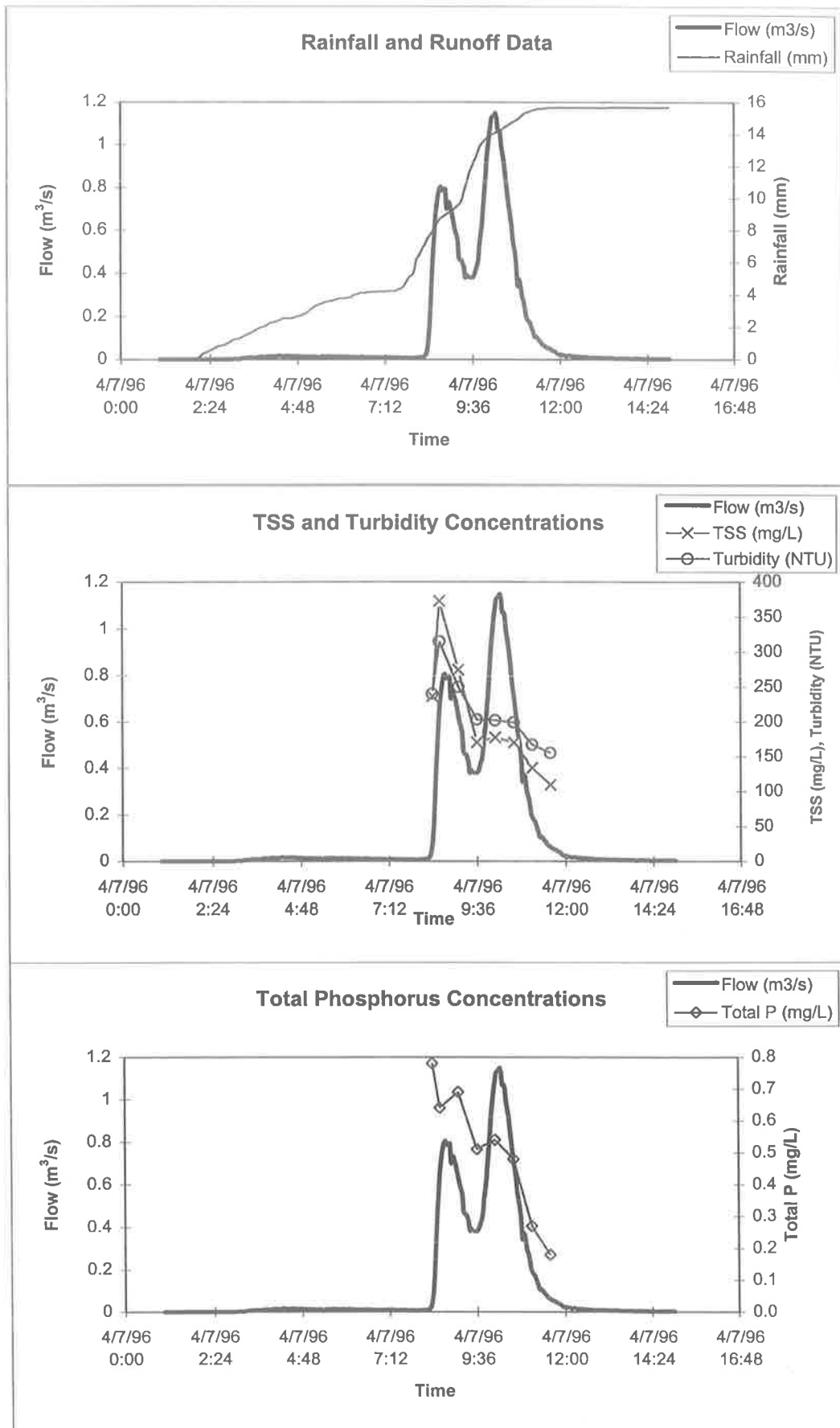


Dunstan Road Drain (AU504103)
Storm Date : 28/06/96

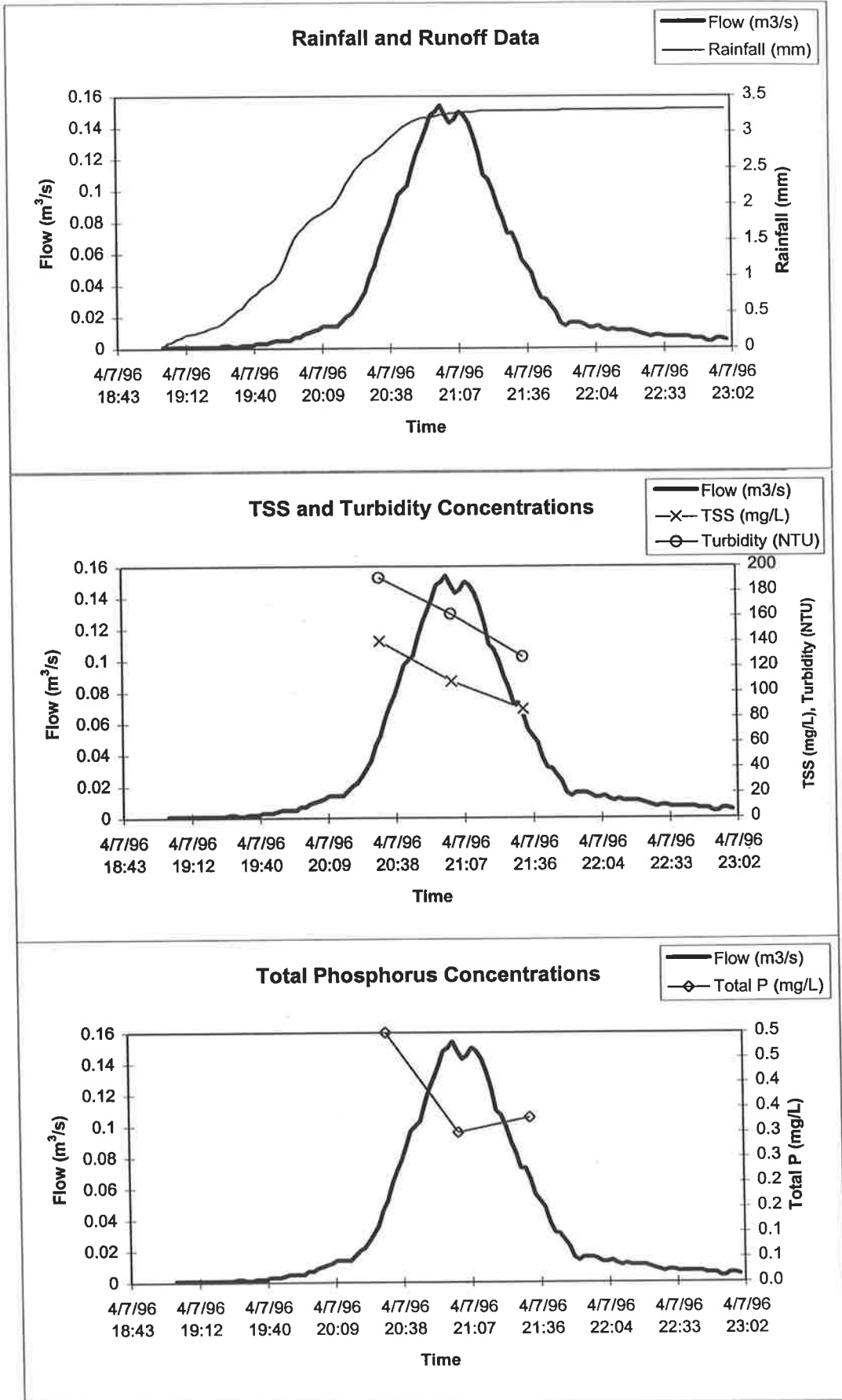


Dunstan Road Drain (AU504103)

Storm Date : 4/07/96

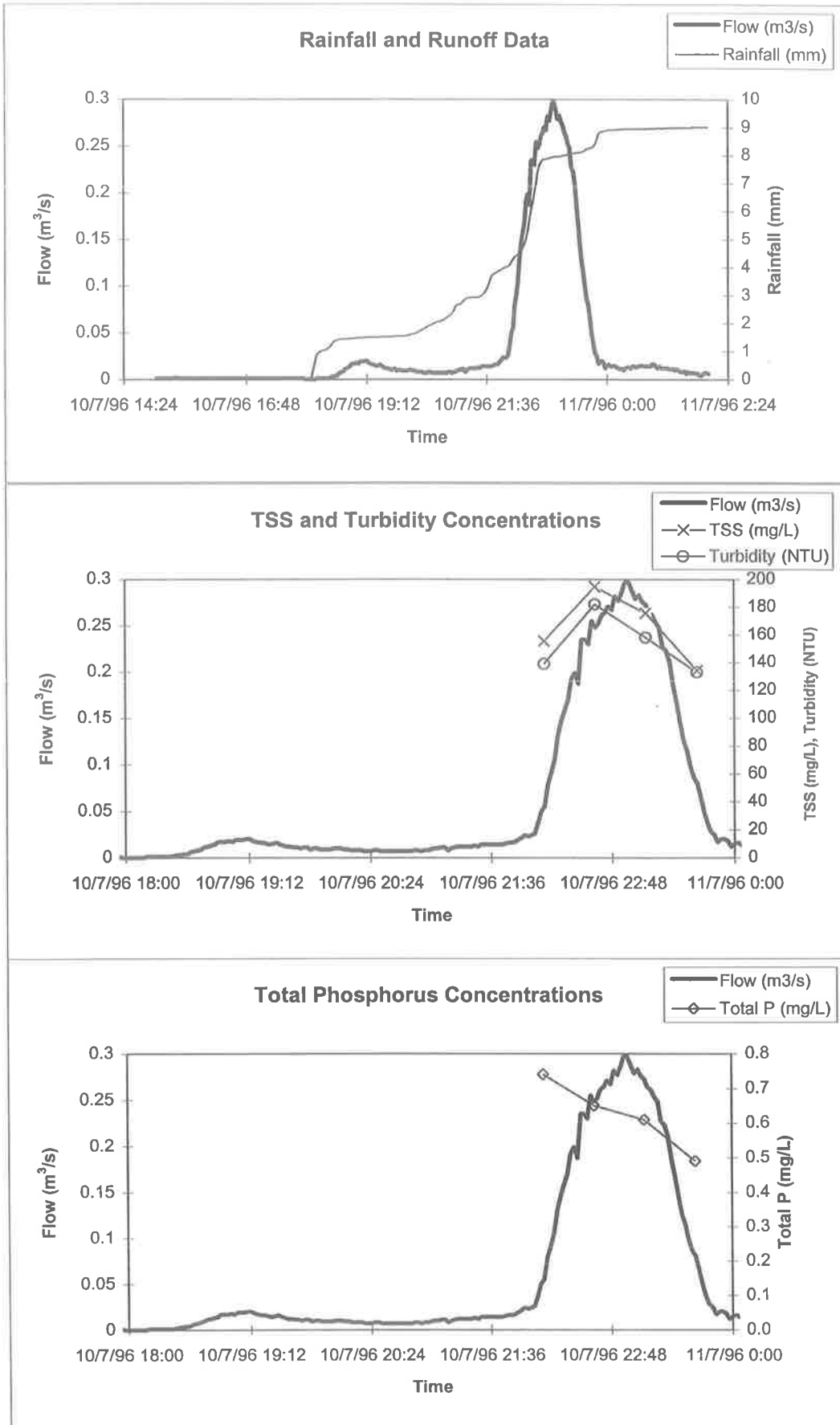


Dunstan Road Drain (AU504103)
Storm Date : 4(b)/7/1996

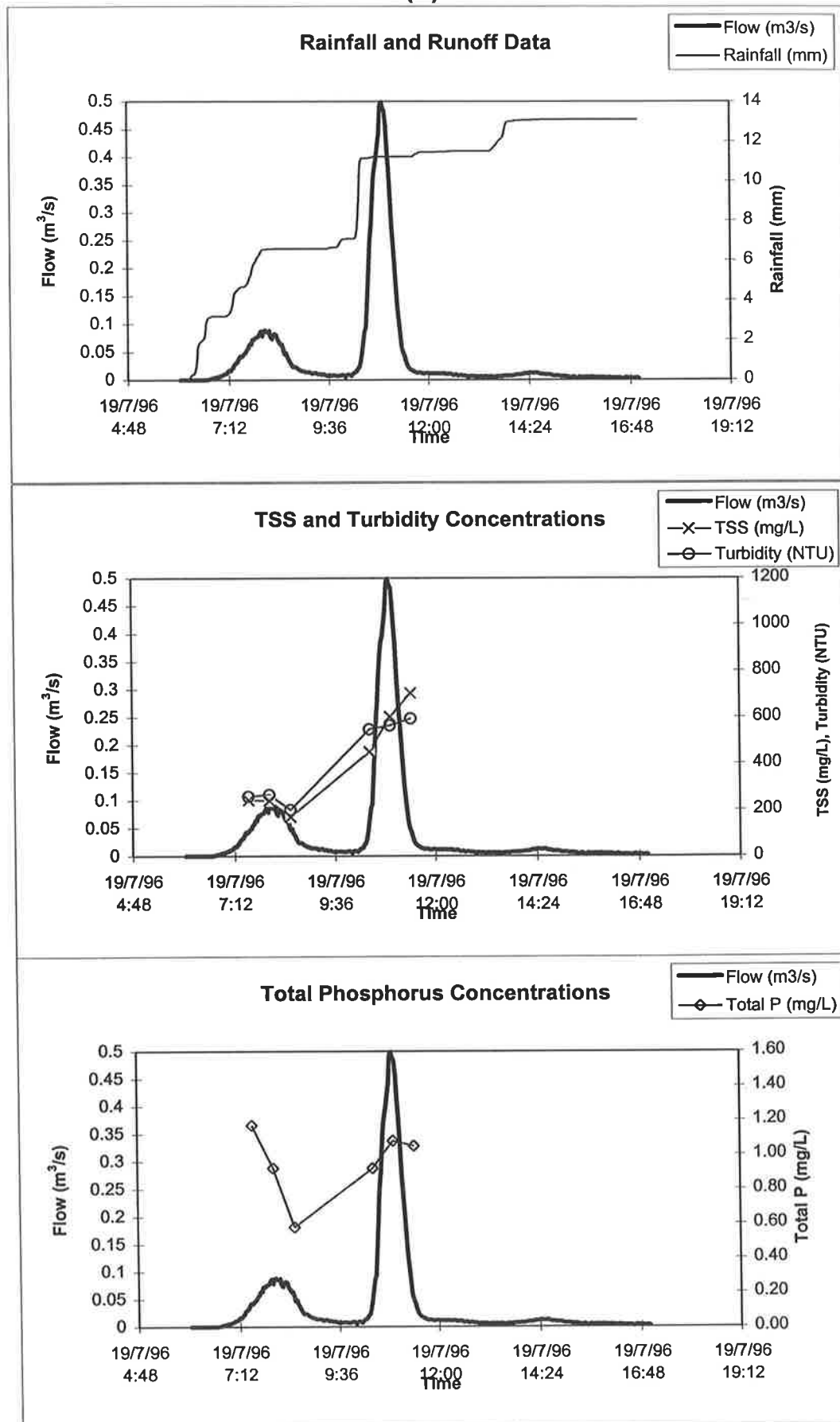


Dunstan Road Drain (AU504103)

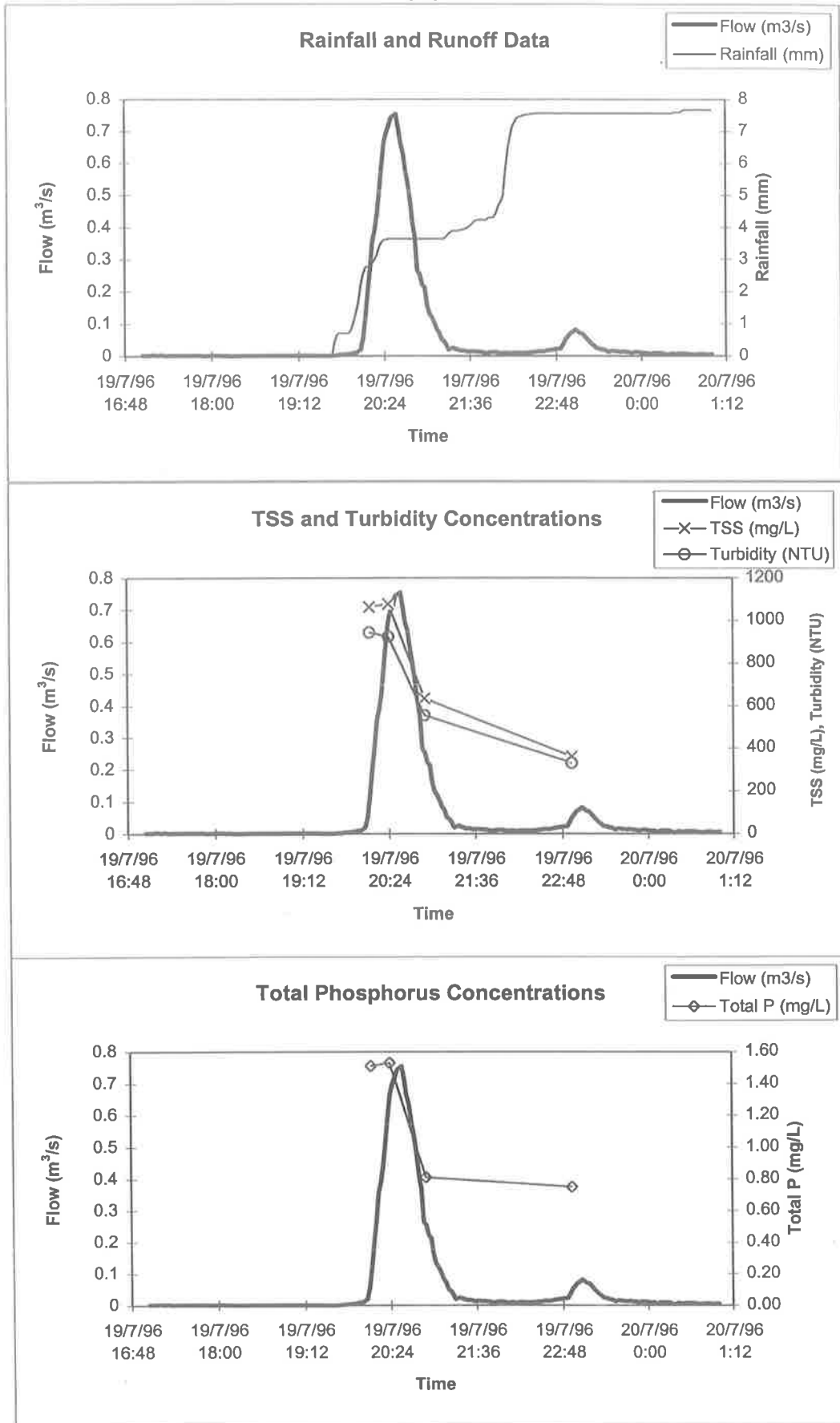
Storm Date : 10/07/96



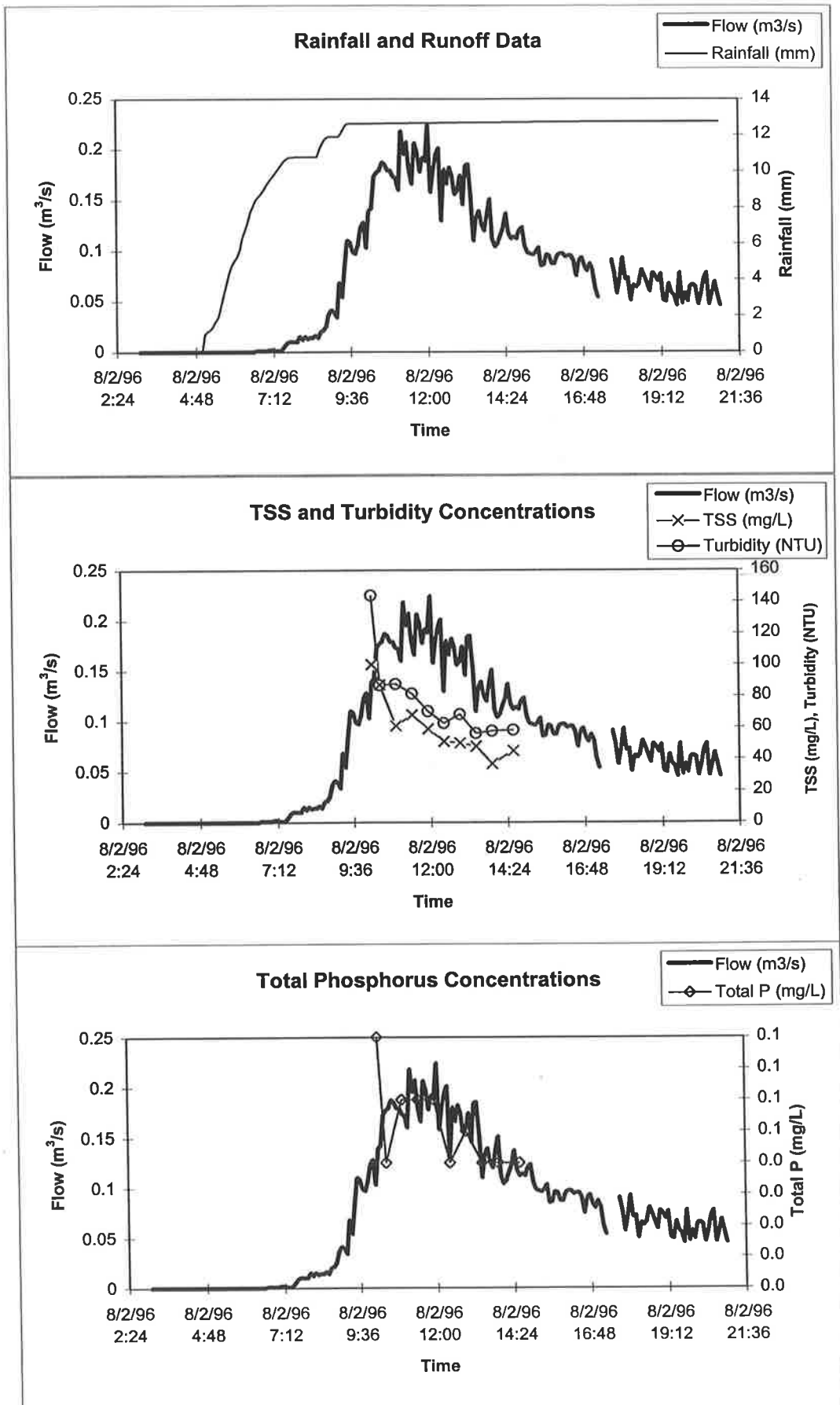
Dunstan Road Drain (AU504103)
Storm Date : 19(a)/07/1996



Dunstan Road Drain (AU504103)
Storm Date : 19(b)/07/1996

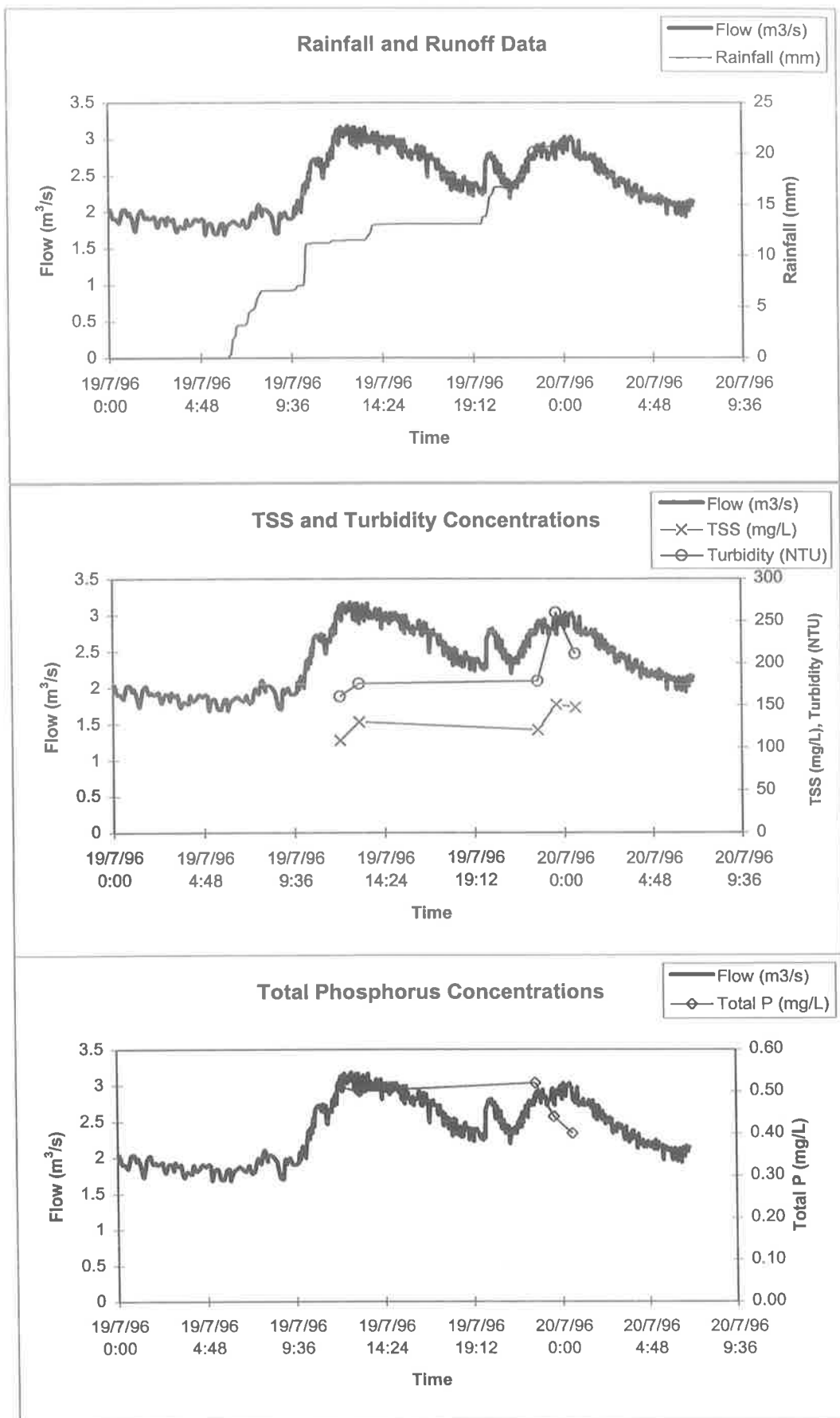


North Arm West Drain (AU504104)
Storm Date : 8/02/96



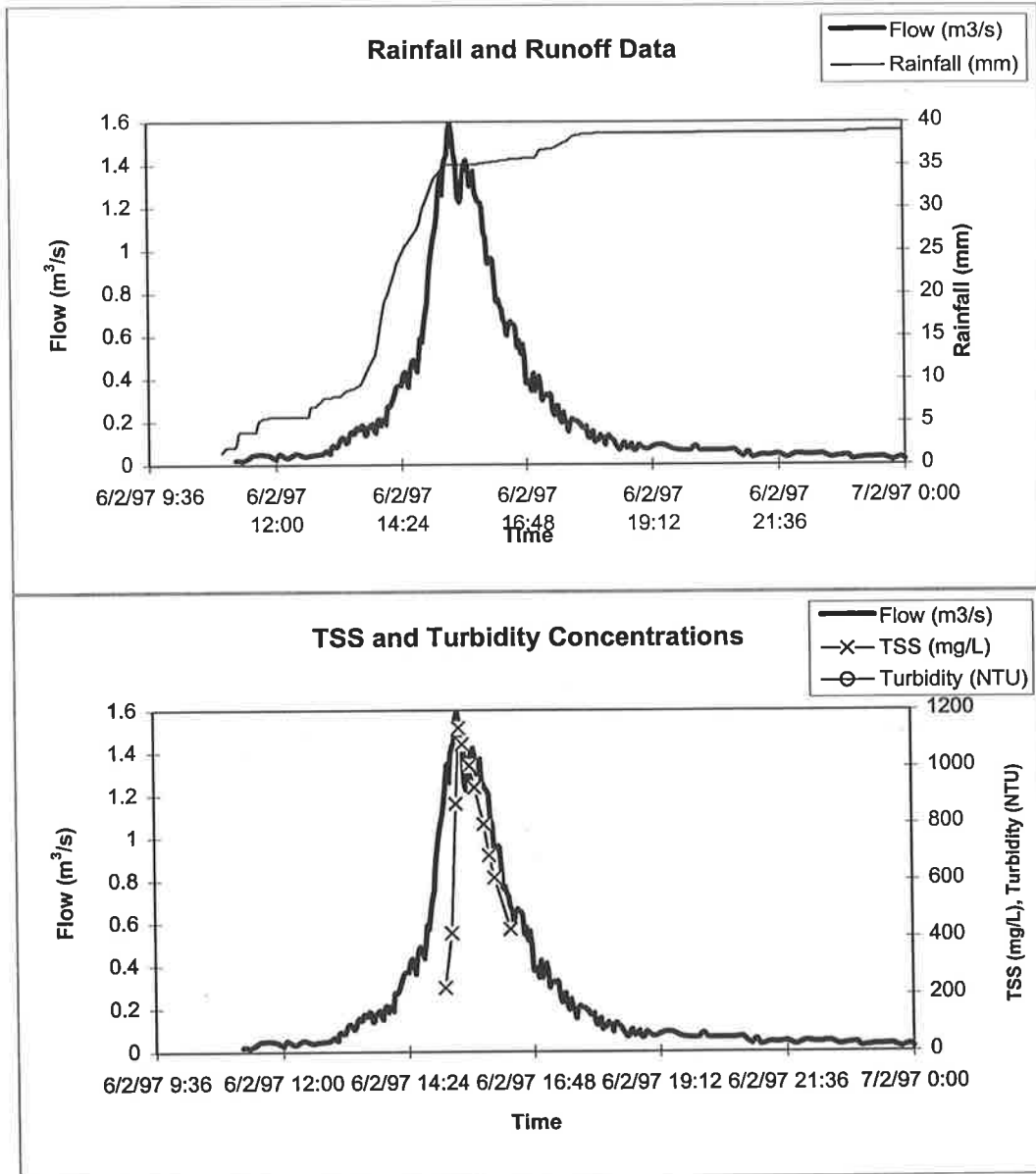
North Arm West Drain (AU504104)

Storm Date : 19/07/96

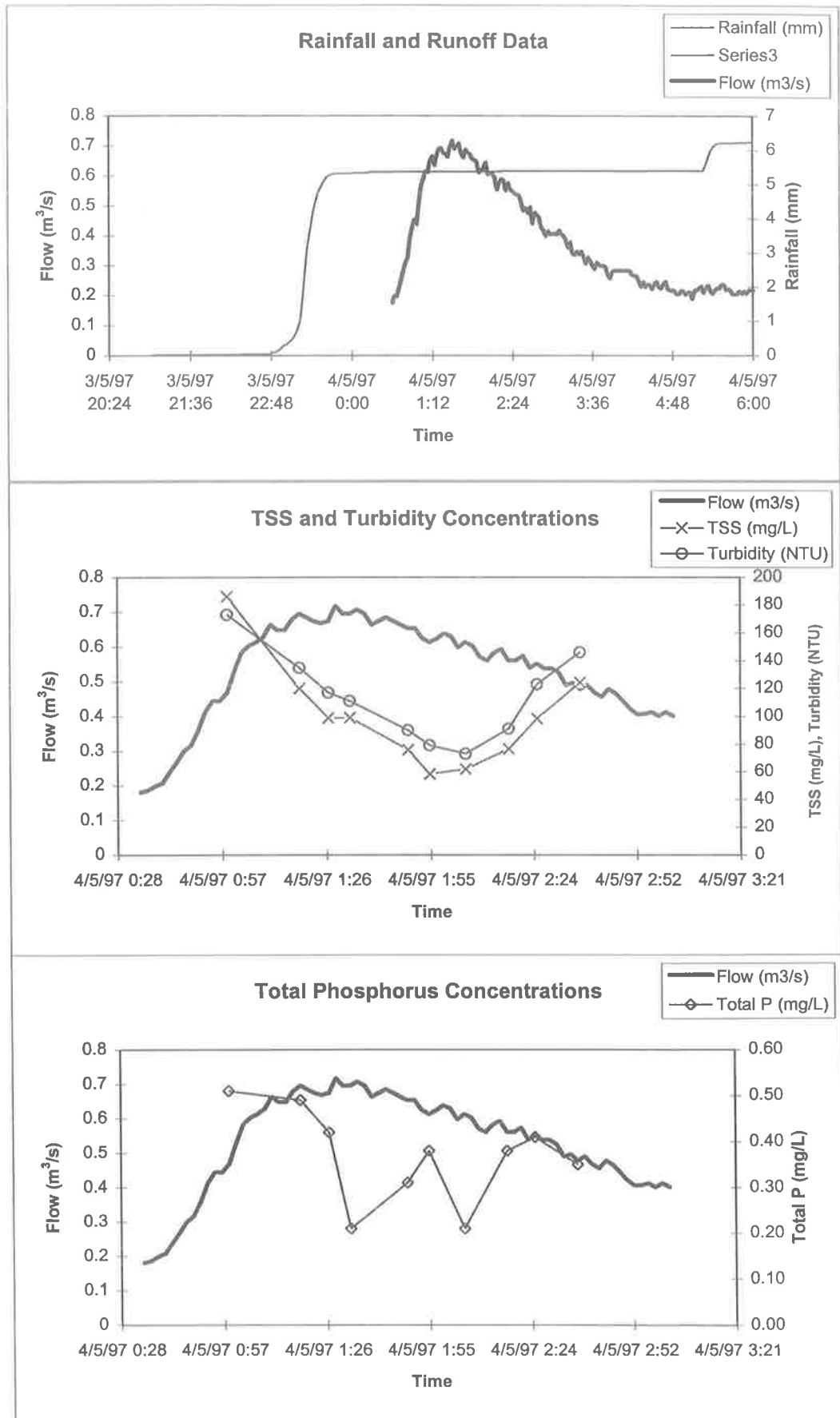


North Arm West Drain (AU504104)

Storm Date : 6/02/97



North Arm West Drain (AU504104)
Storm Date : 4/05/97



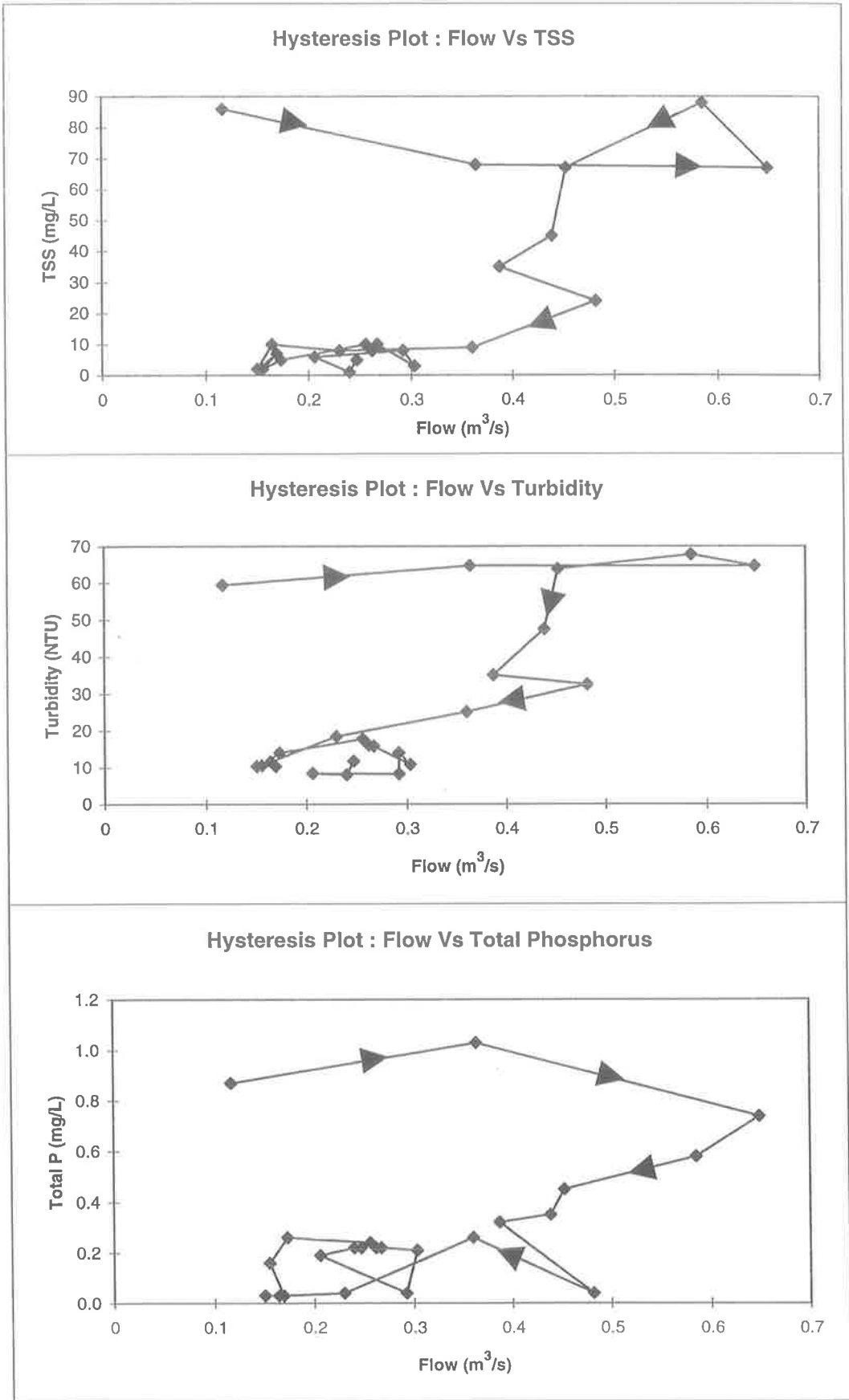
Appendix I

Sequential Sample Hysteresis Plots

Summary

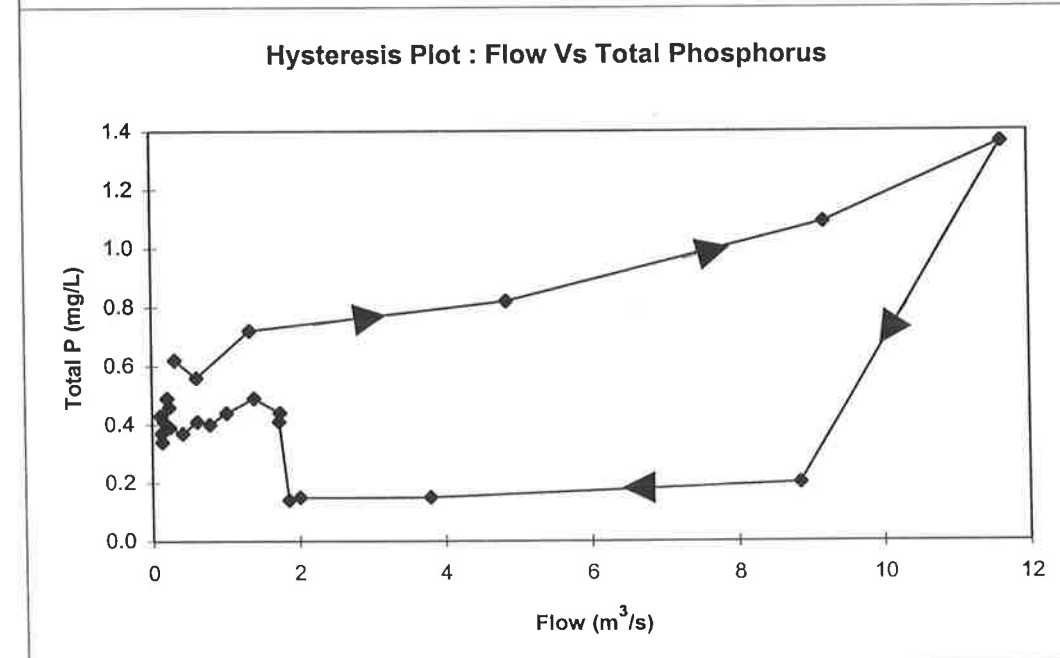
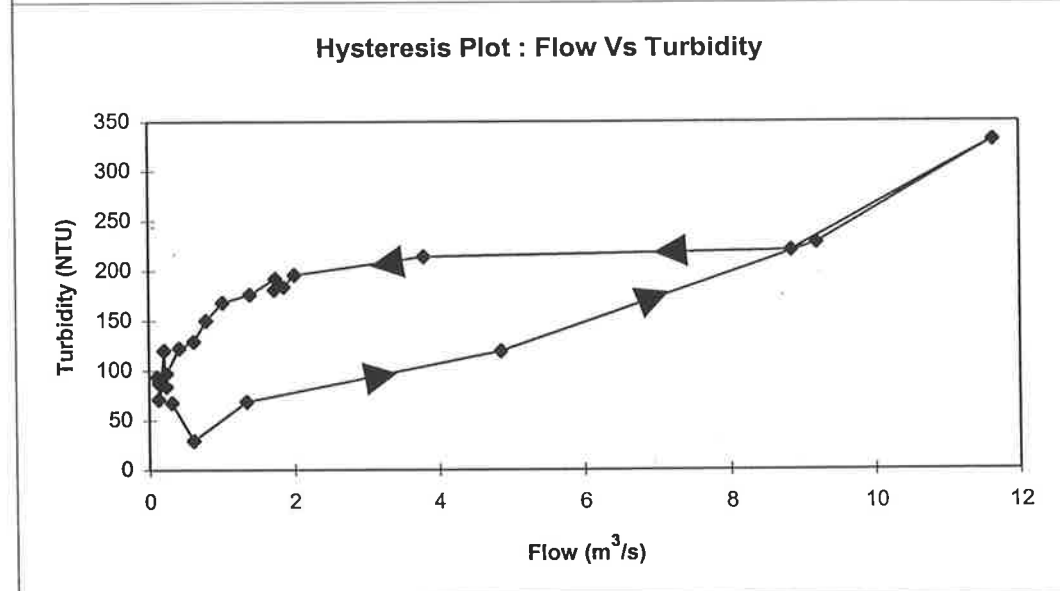
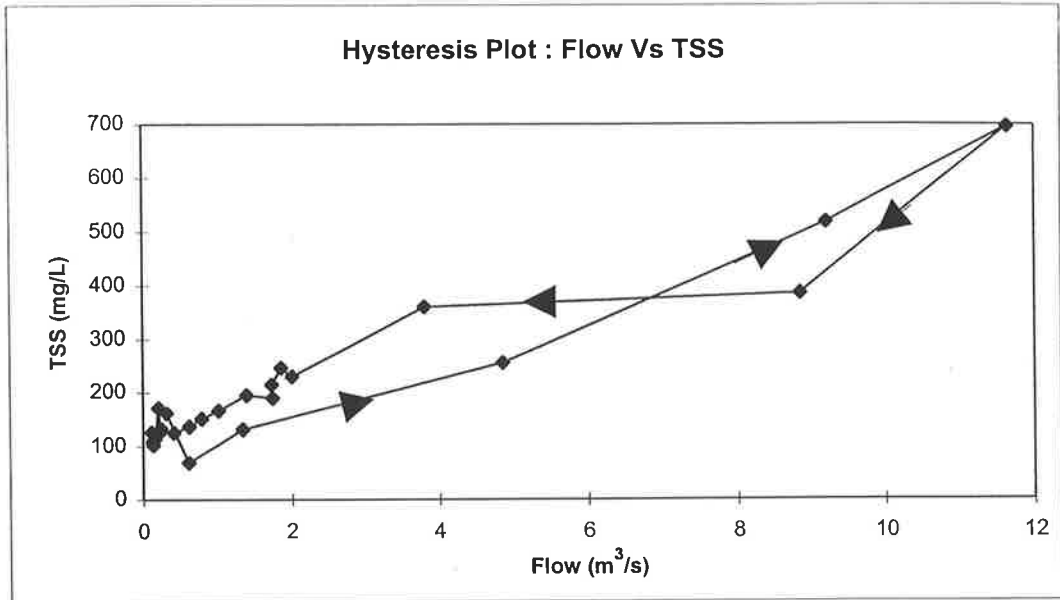
Appendix I outlines the hysteresis plots determined from the analysis of sequential samples.

North Arm East Drain (AU504101)
Storm Date : 6-7/4/96



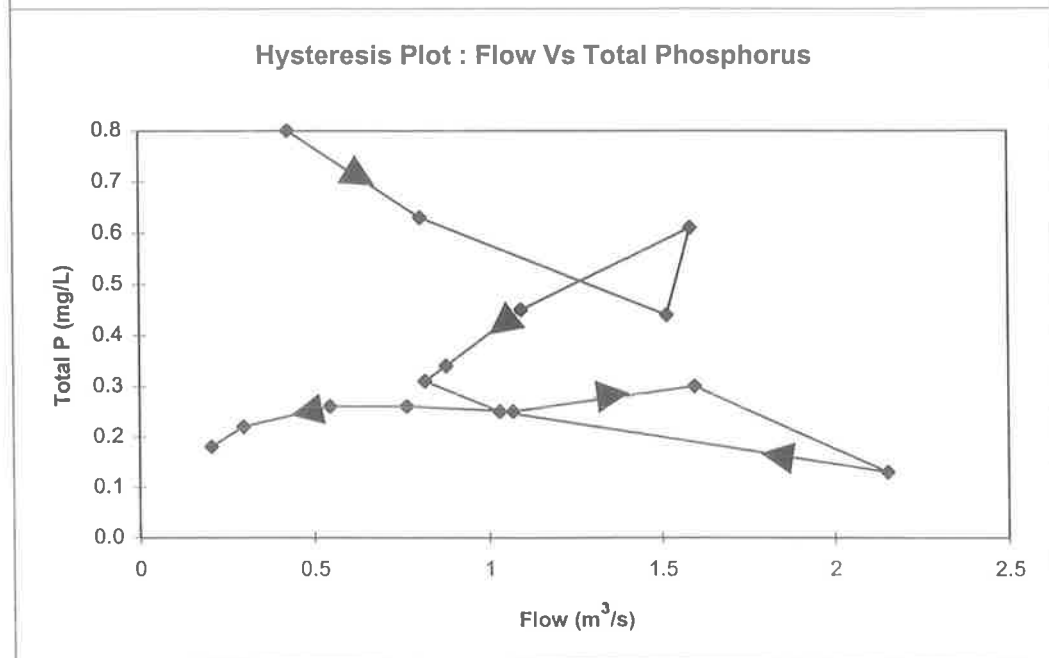
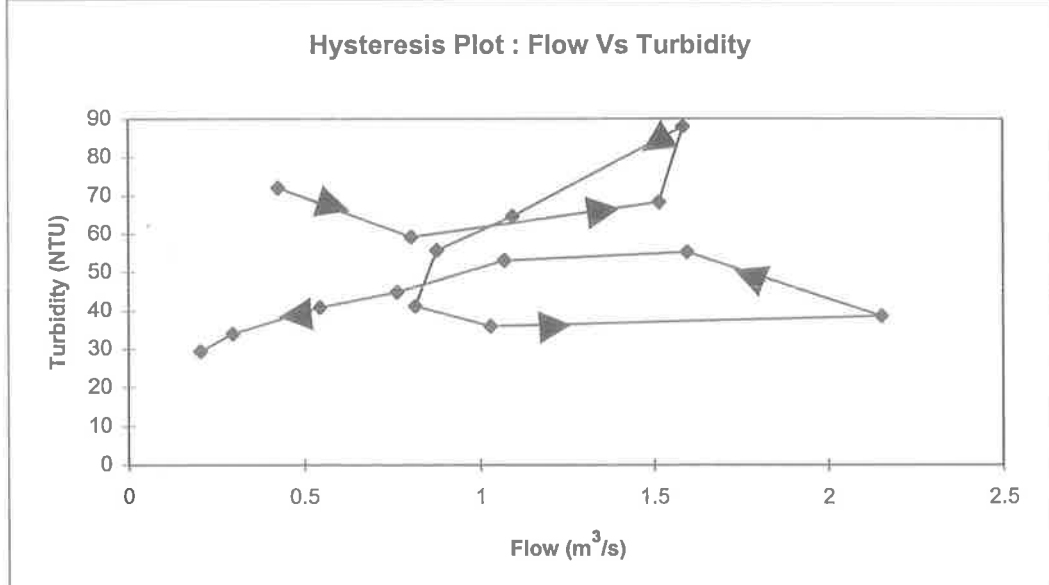
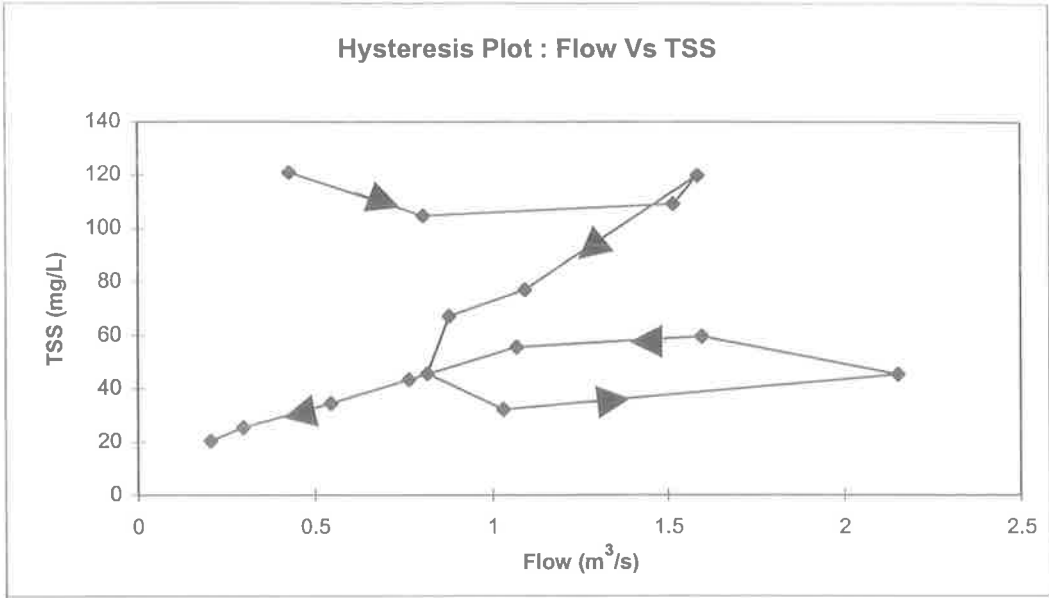
North Arm East Drain (AU504101)

Storm Date : 13/4/96



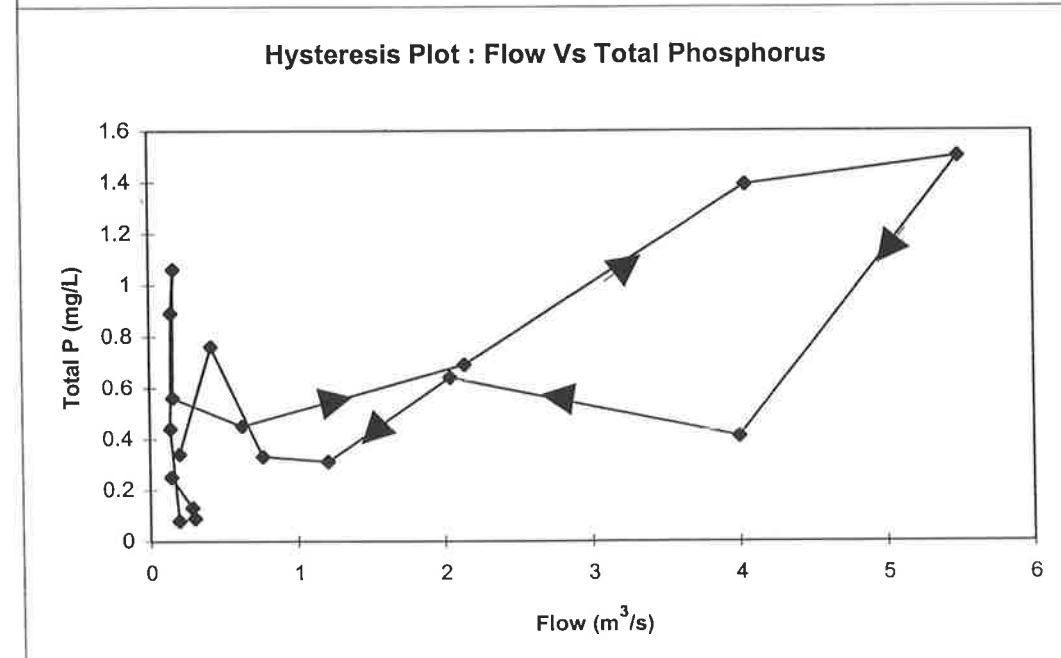
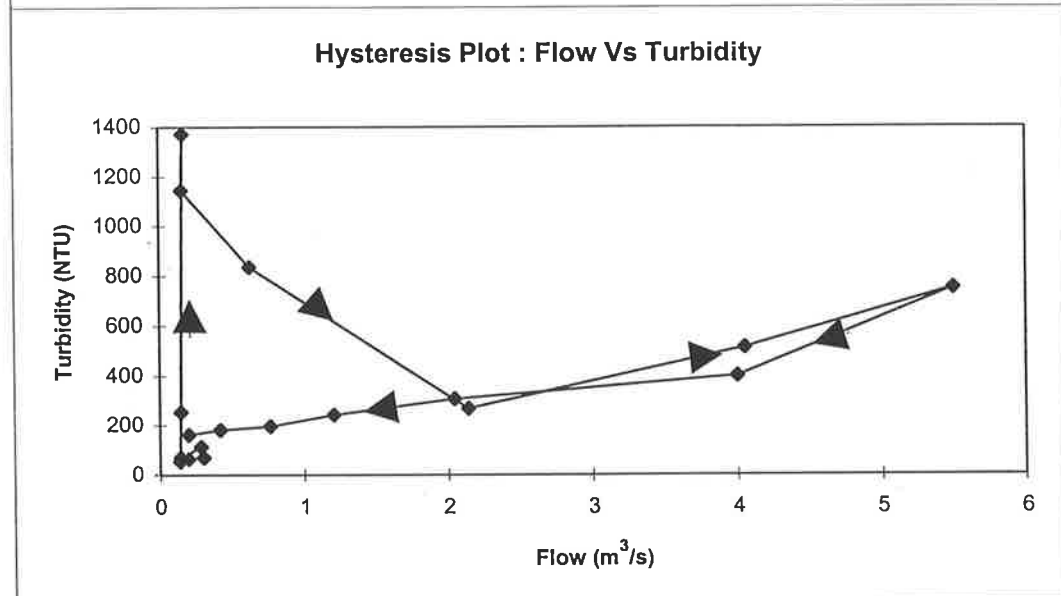
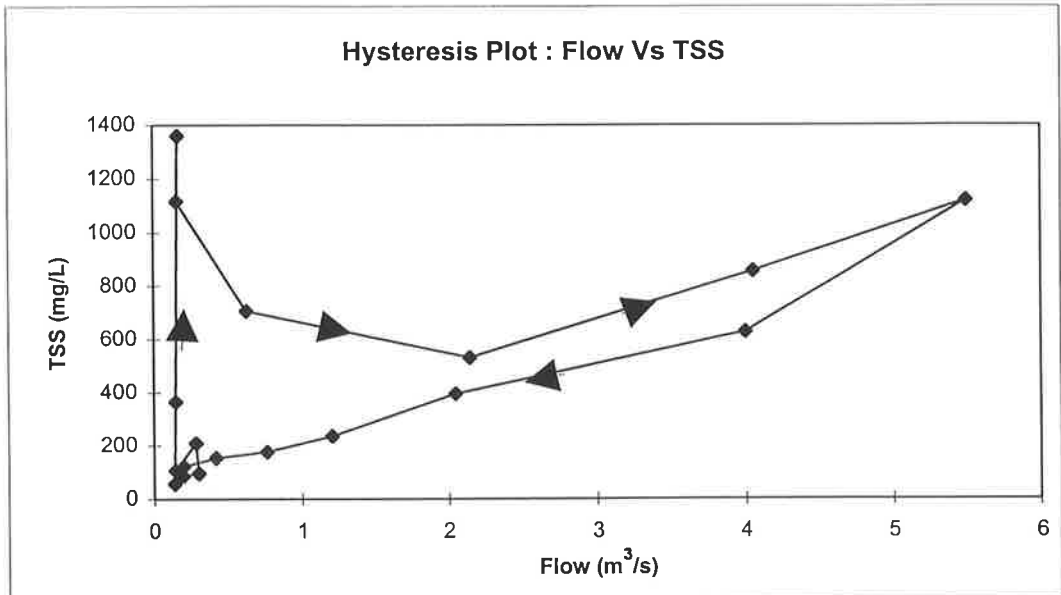
North Arm East Drain (AU504101)

Storm Date : 25/4/96



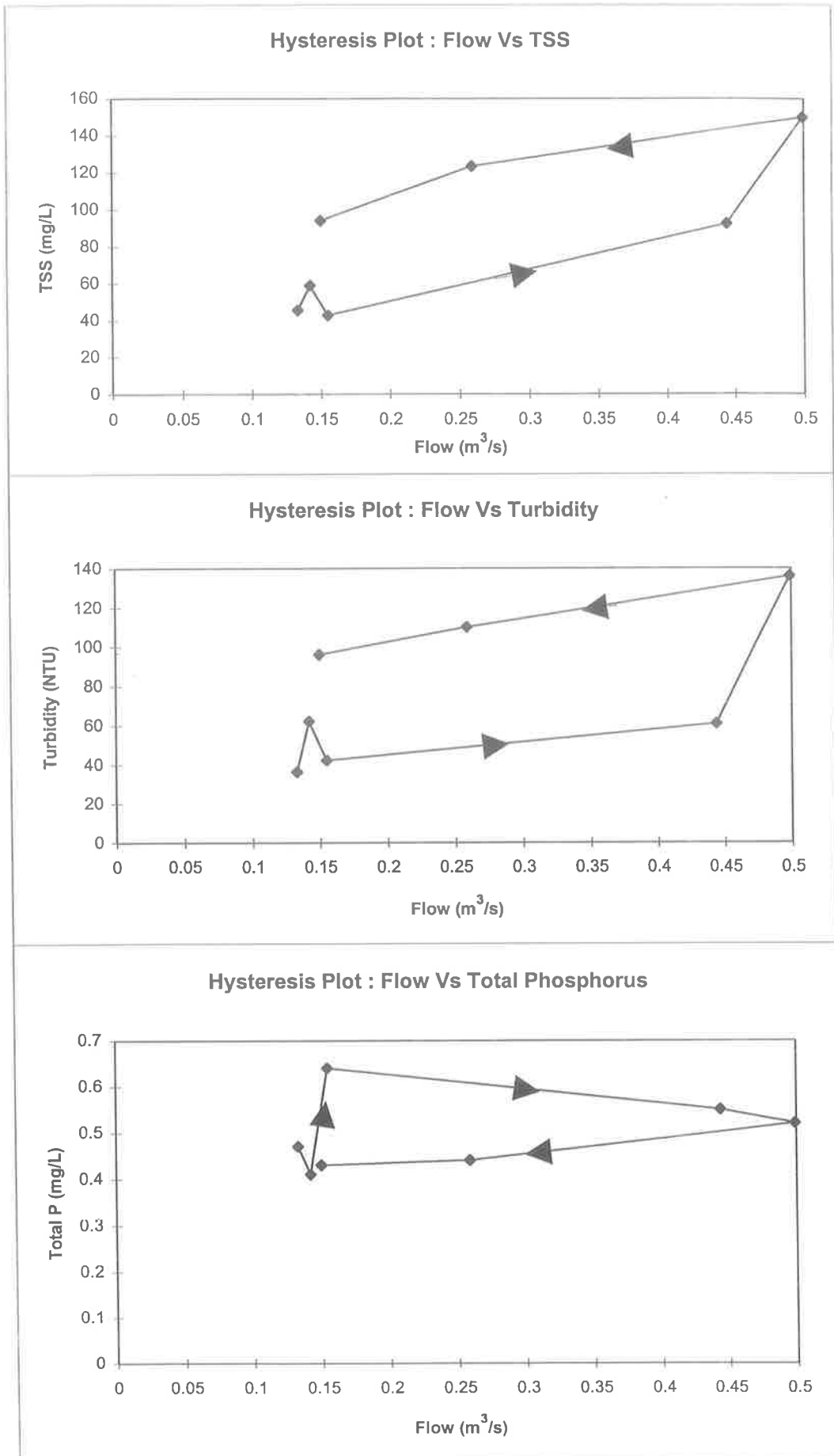
North Arm East Drain (AU504101)

Storm Date : 12/5/96



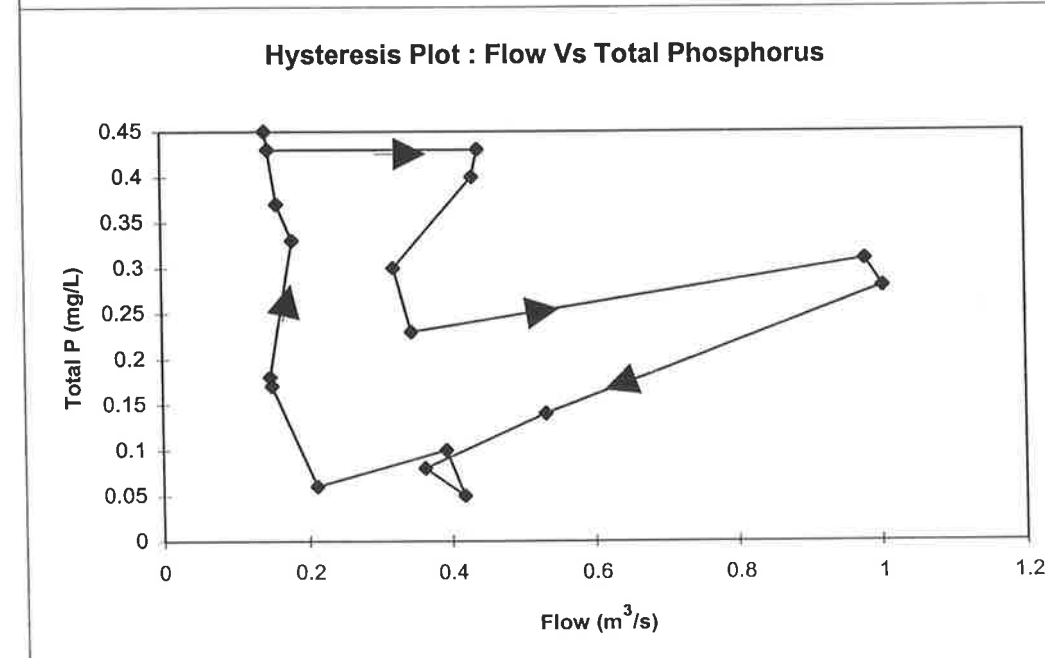
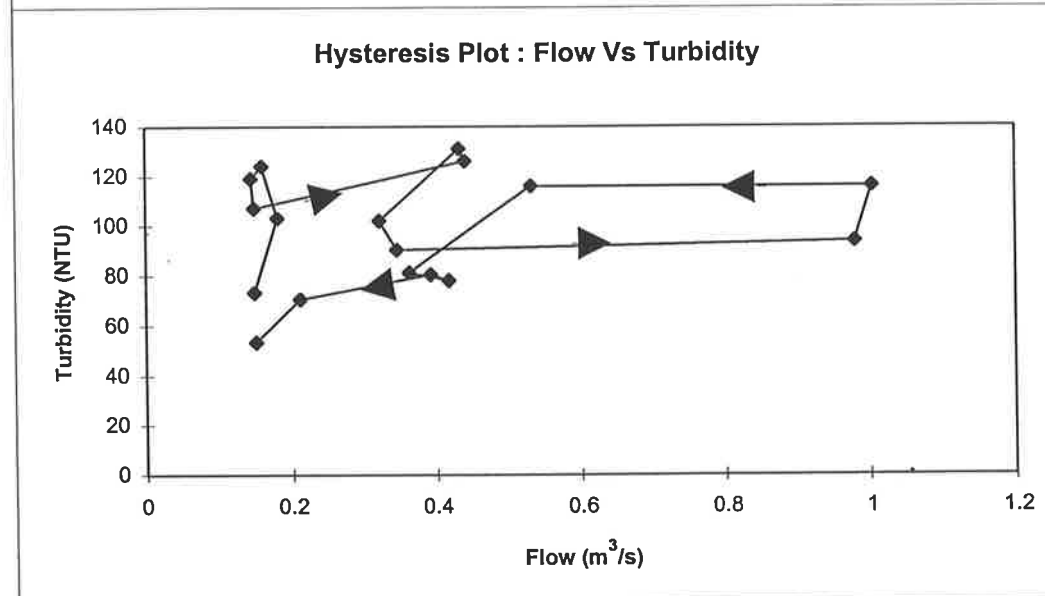
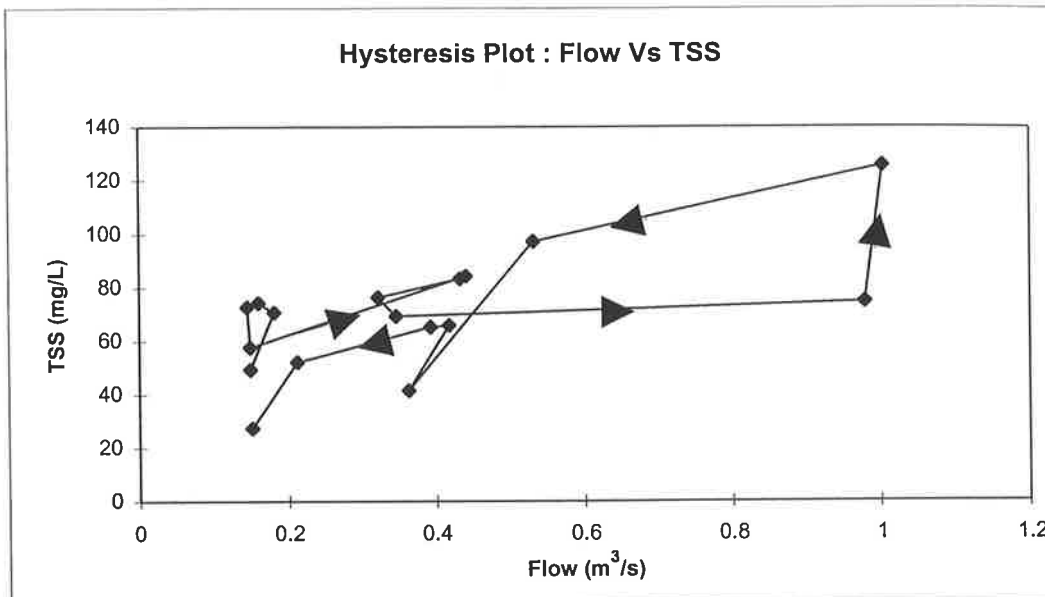
North Arm East Drain (AU504101)

Storm Date : 17/6/96

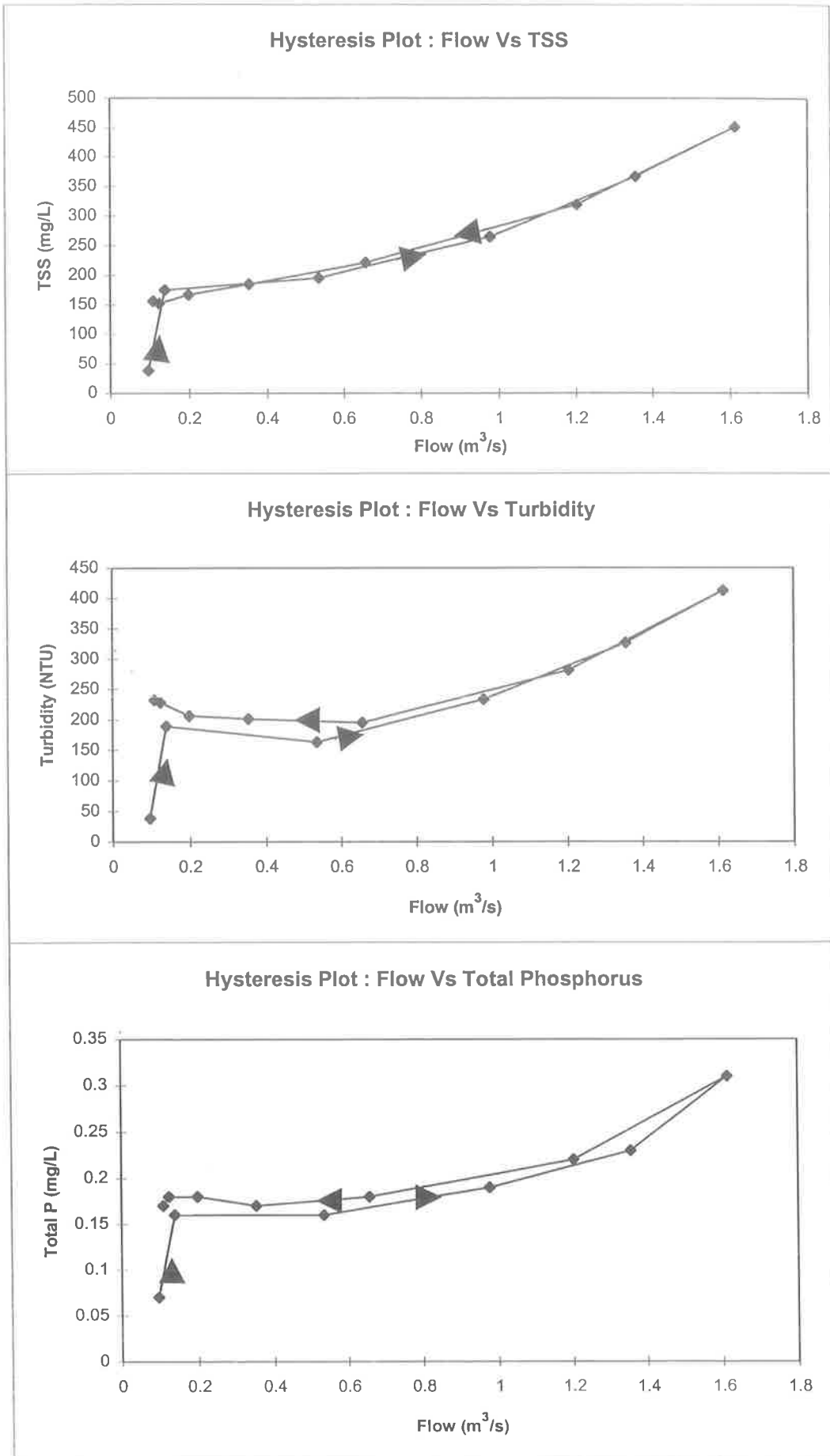


North Arm East Drain (AU504101)

Storm Date : 18/6/96

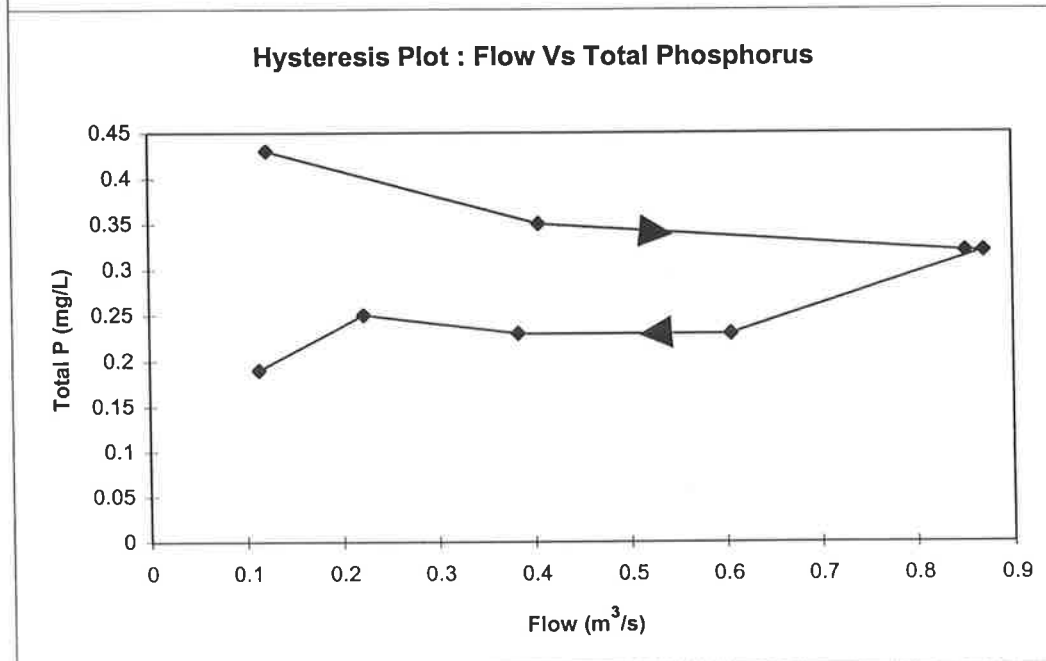
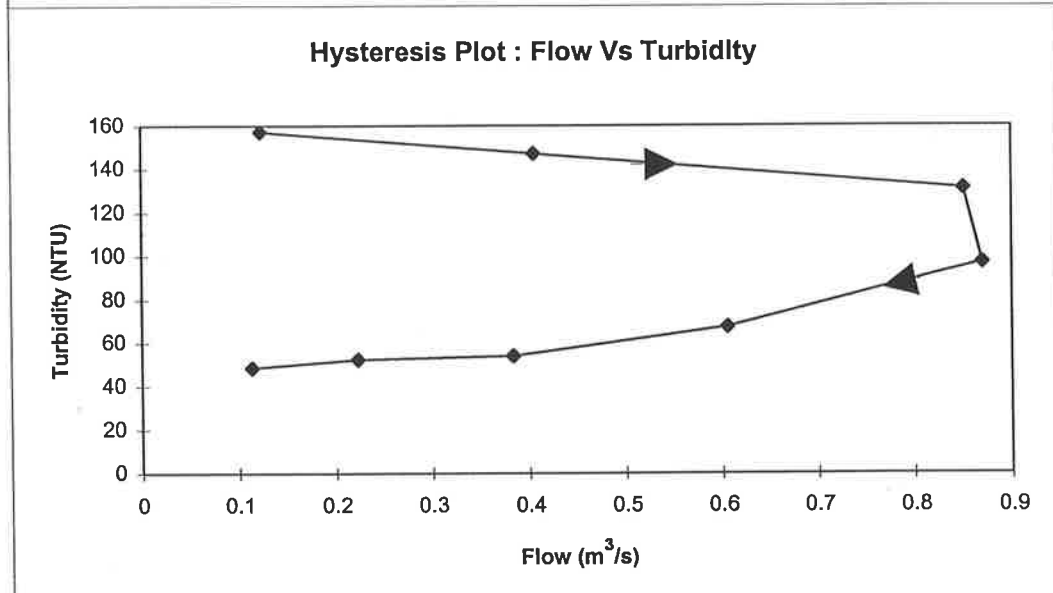
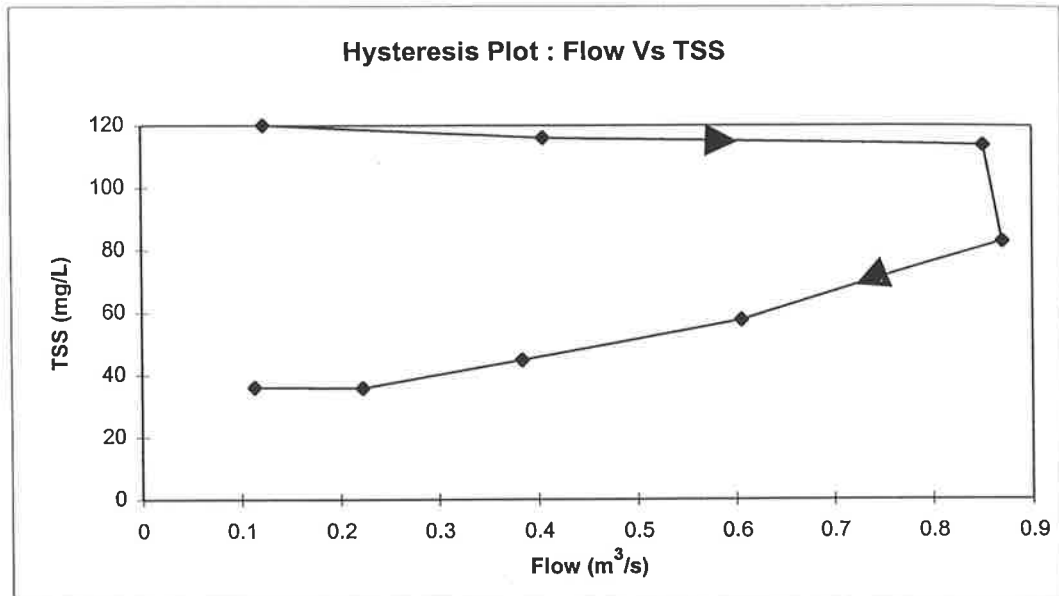


North Arm East Drain (AU504101)
Storm Date : 22/6/96

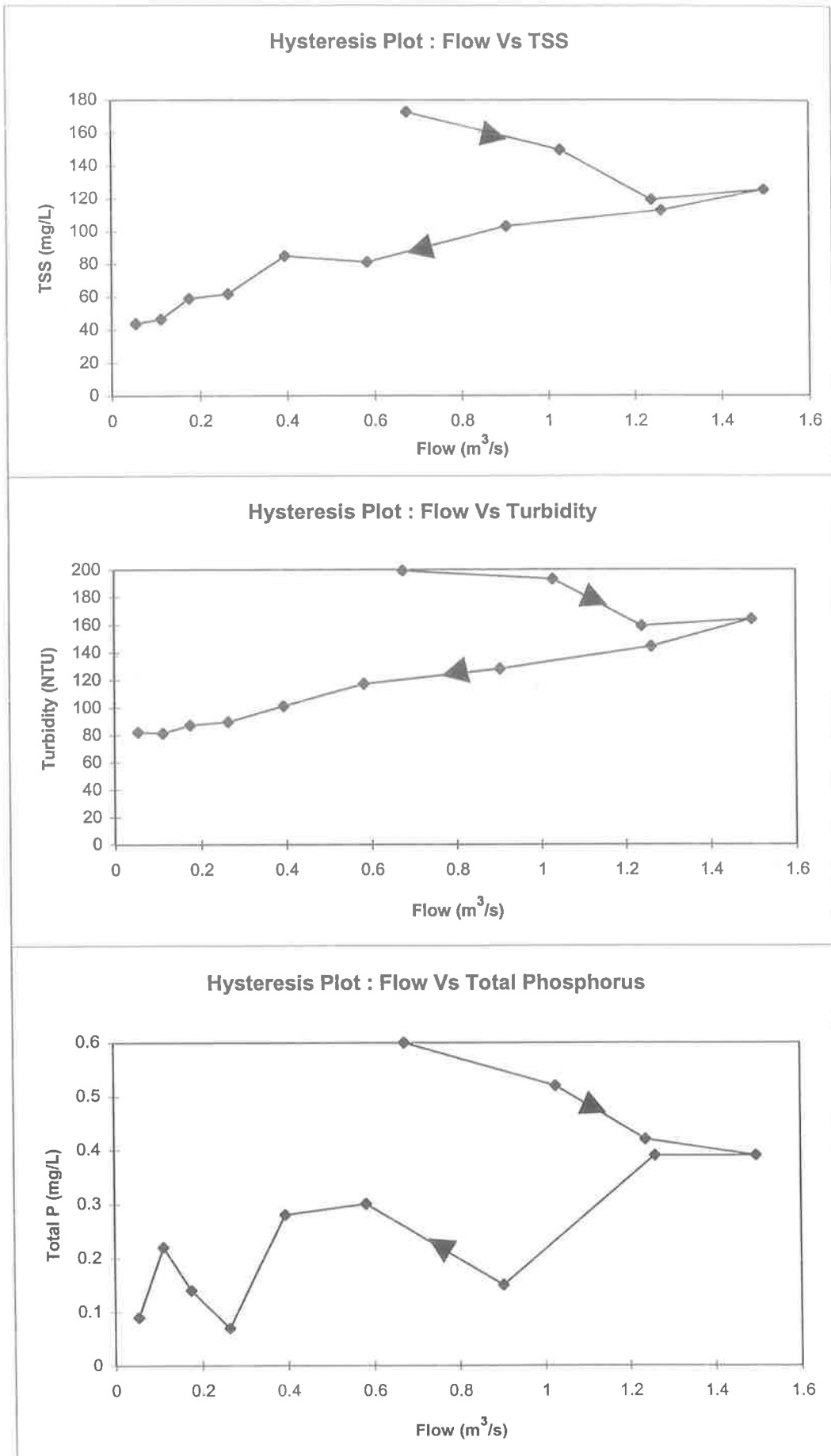


North Arm East Drain (AU504101)

Storm Date : 23/6/96

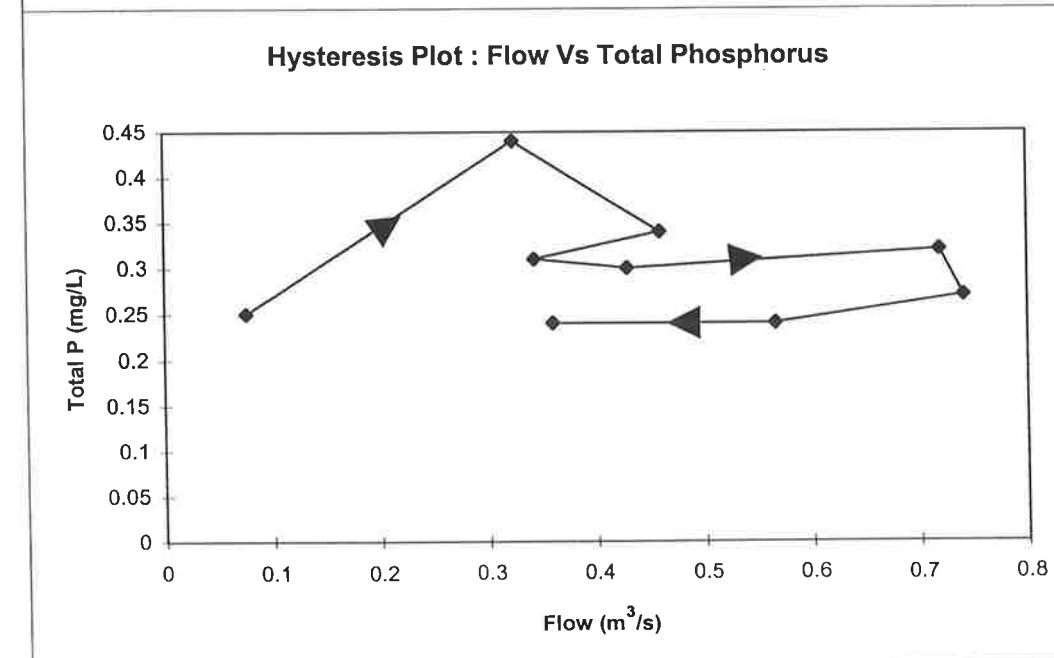
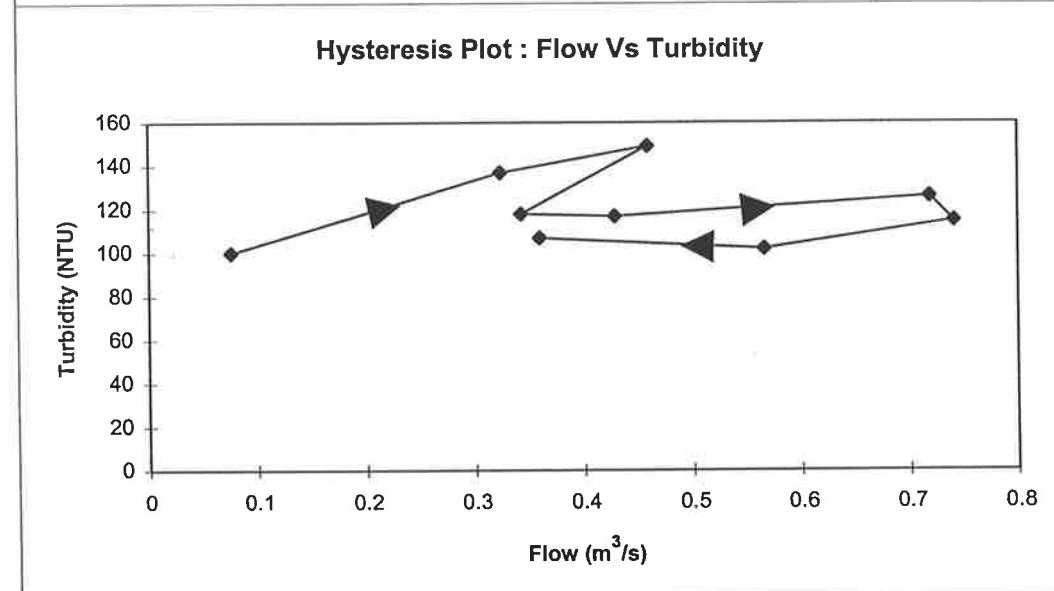
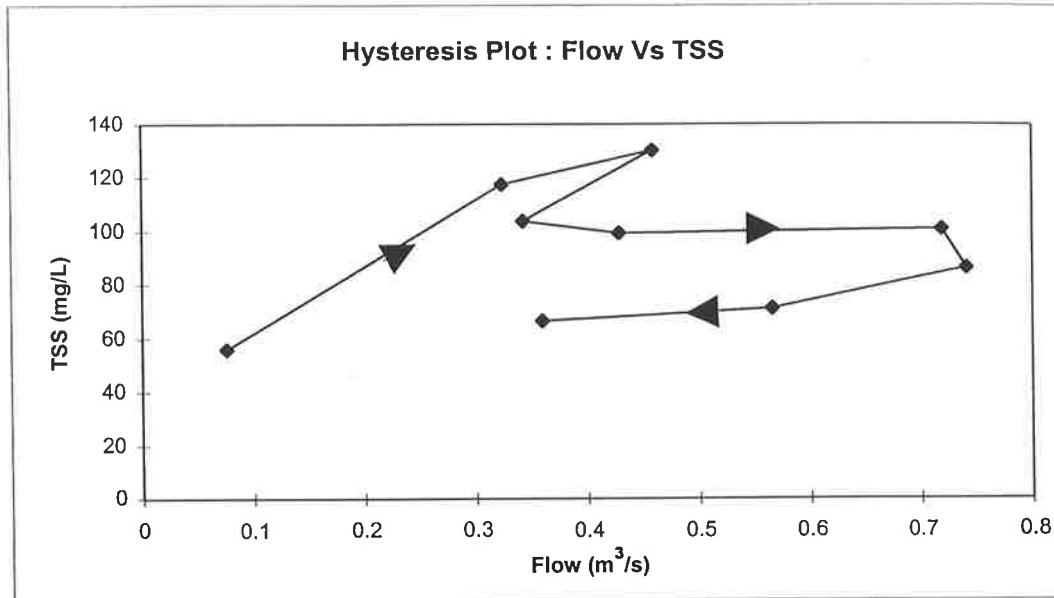


North Arm East Drain (AU504101)
Storm Date : 28/6/96



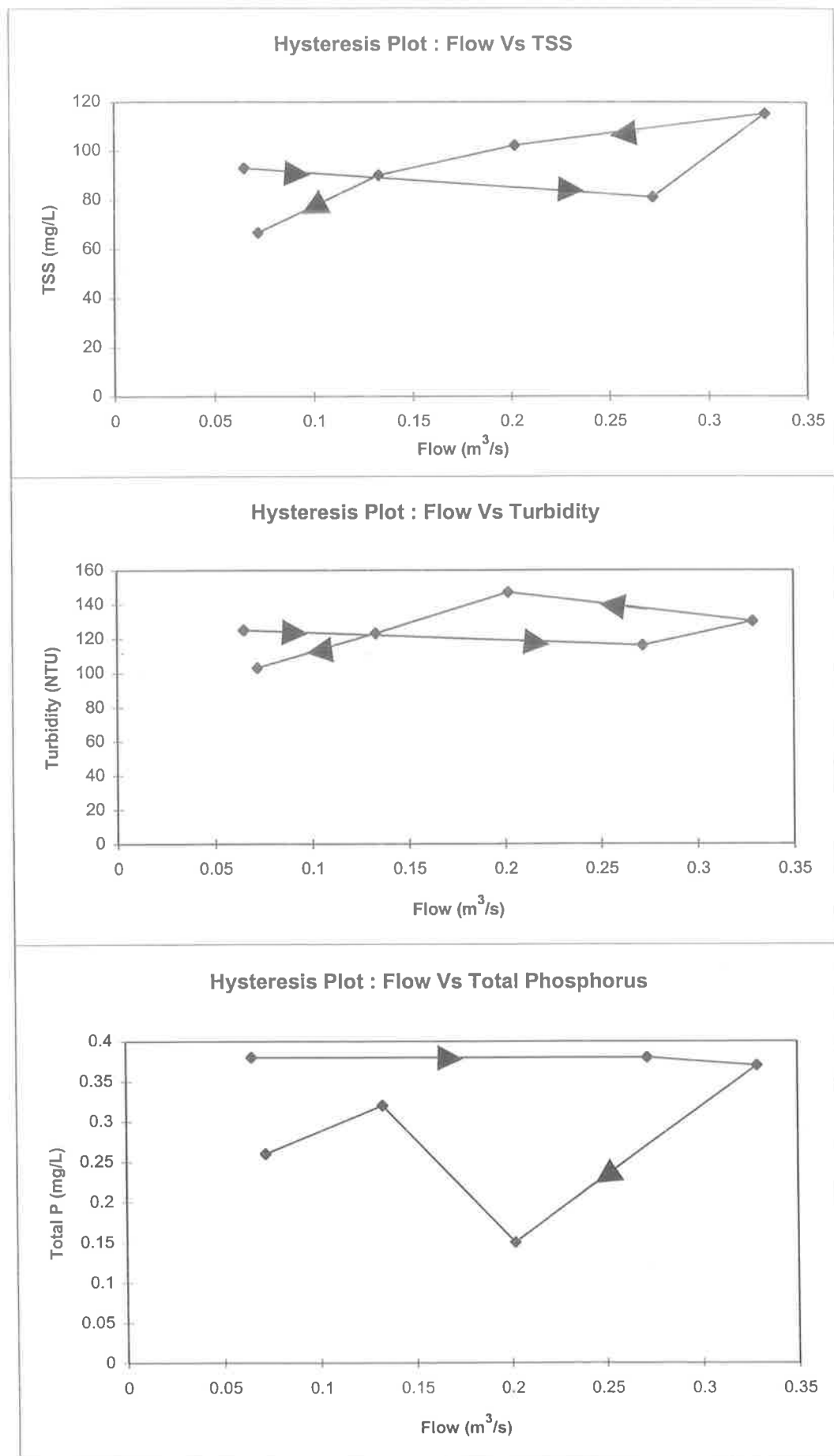
North Arm East Drain (AU504101)

Storm Date : 29/6/96



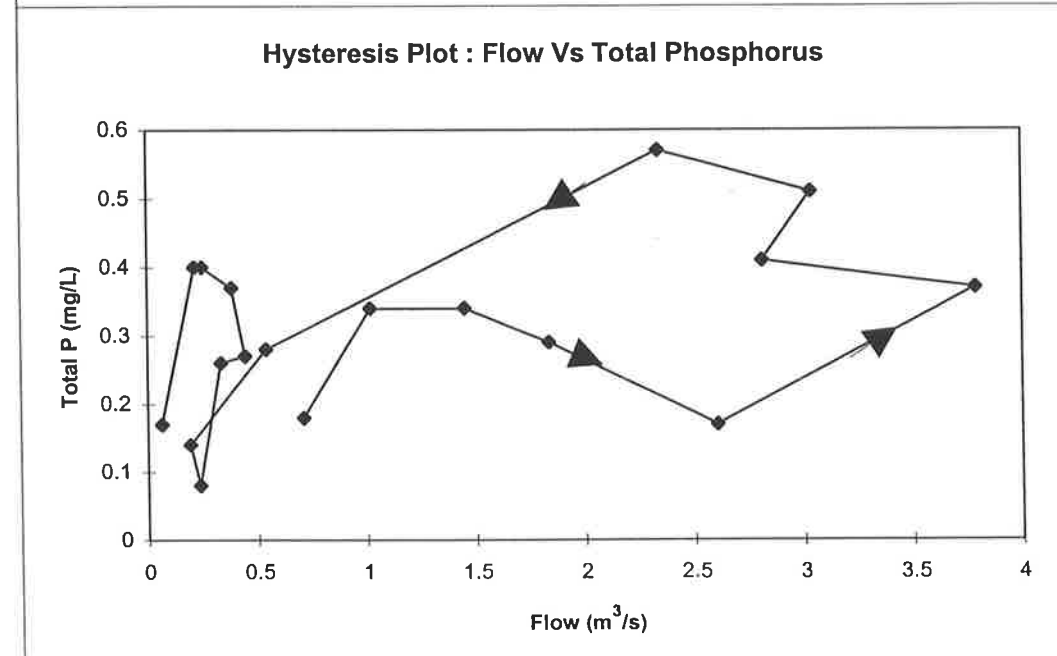
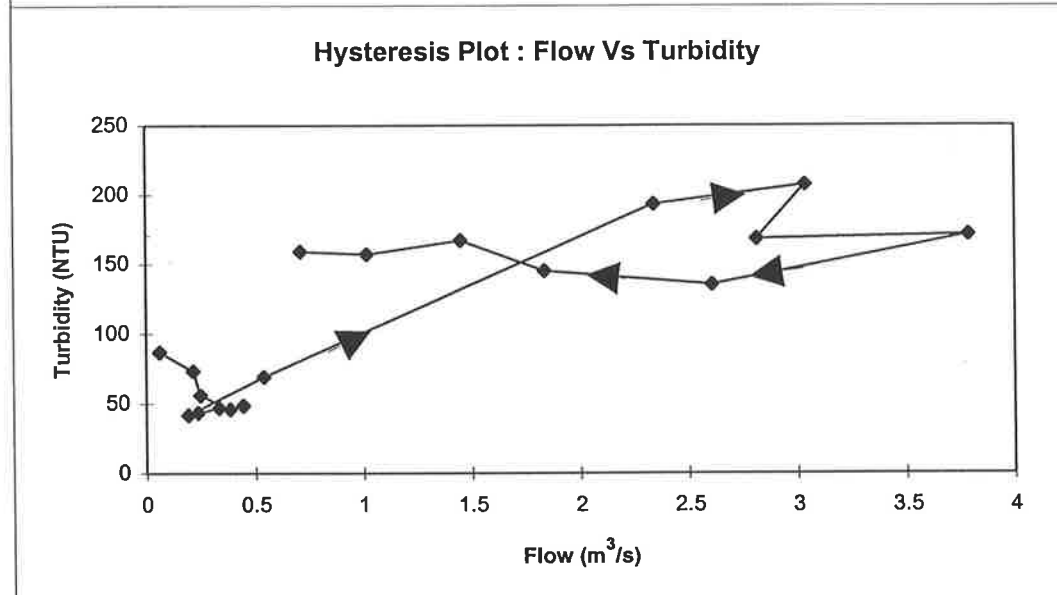
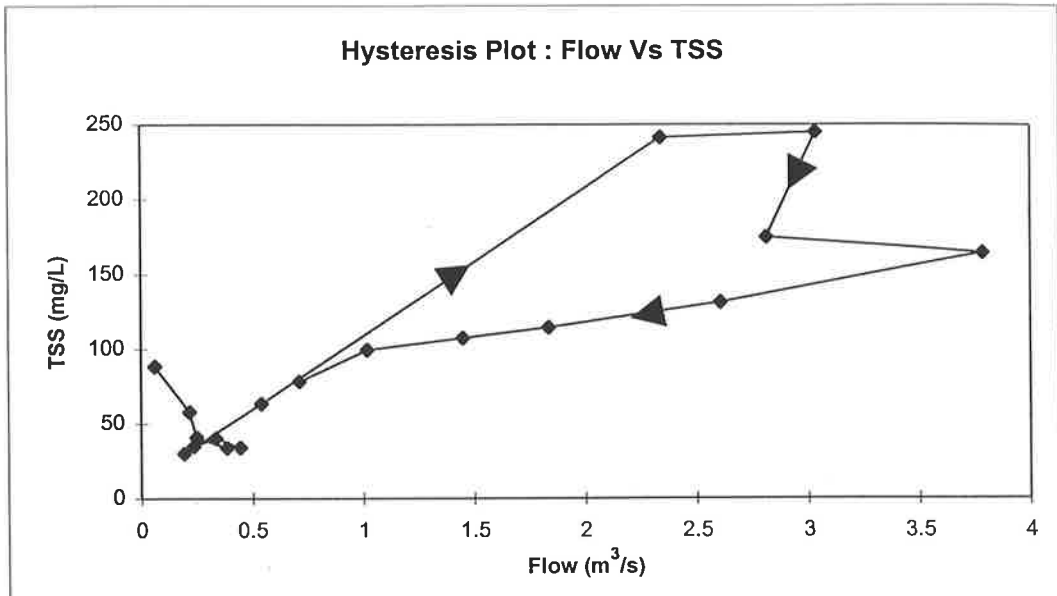
North Arm East Drain (AU504101)

Storm Date : 1/7/96



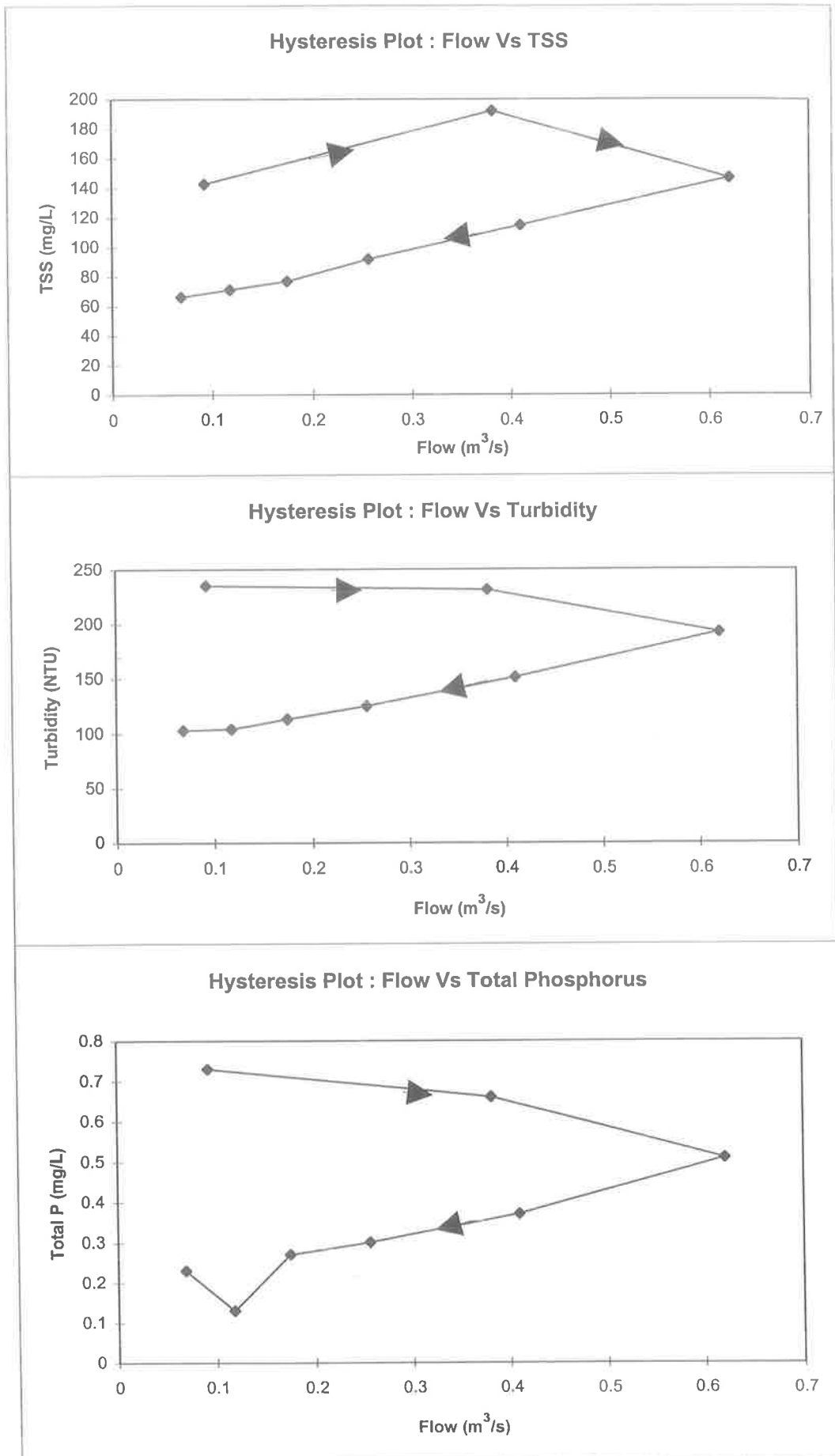
North Arm East Drain (AU504101)

Storm Date : 4/7/96



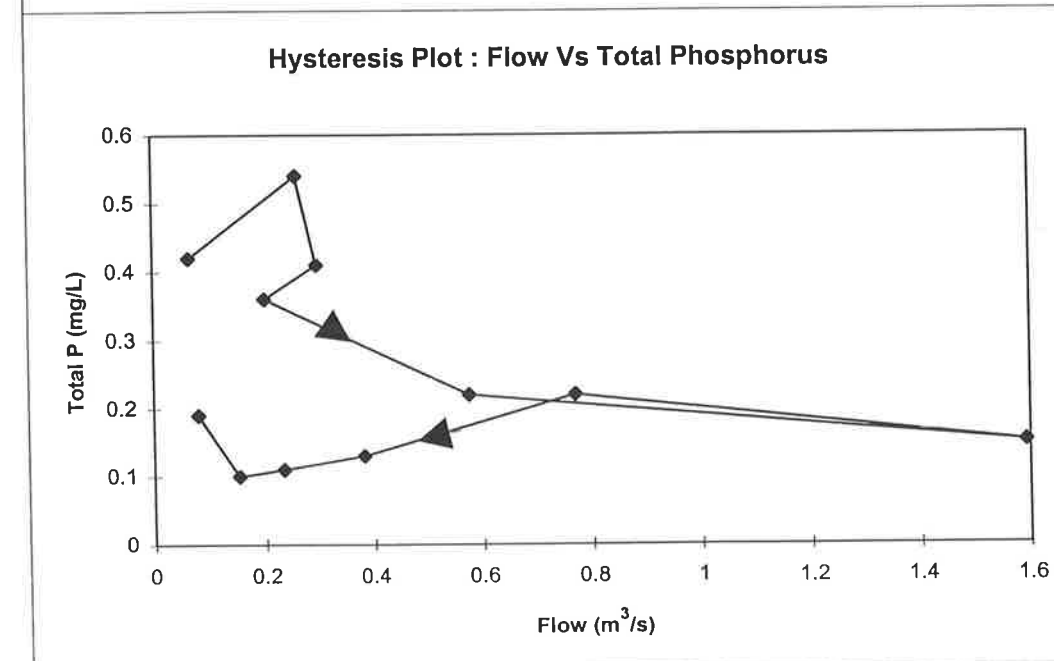
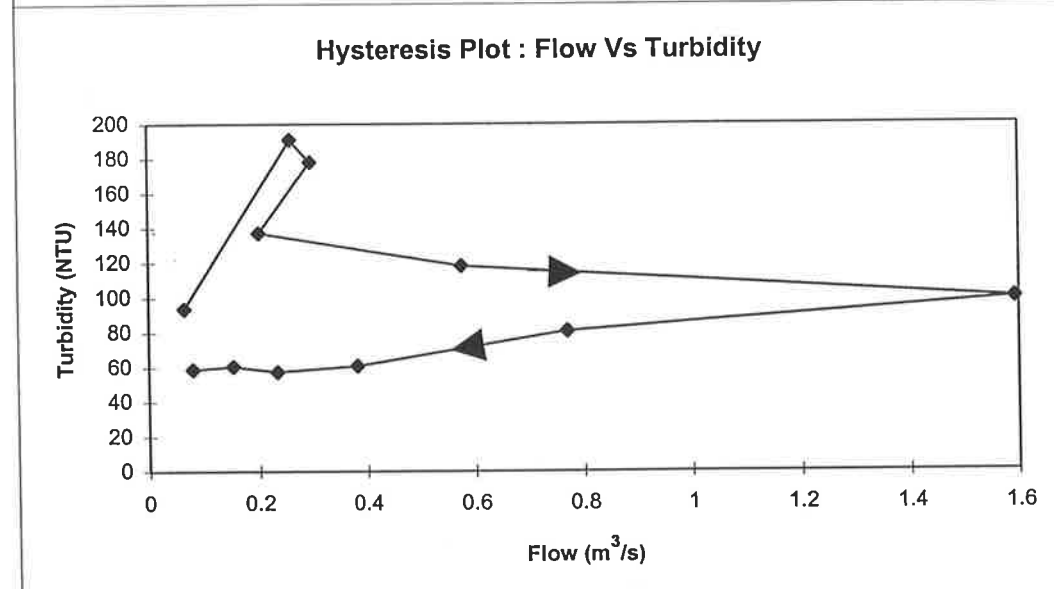
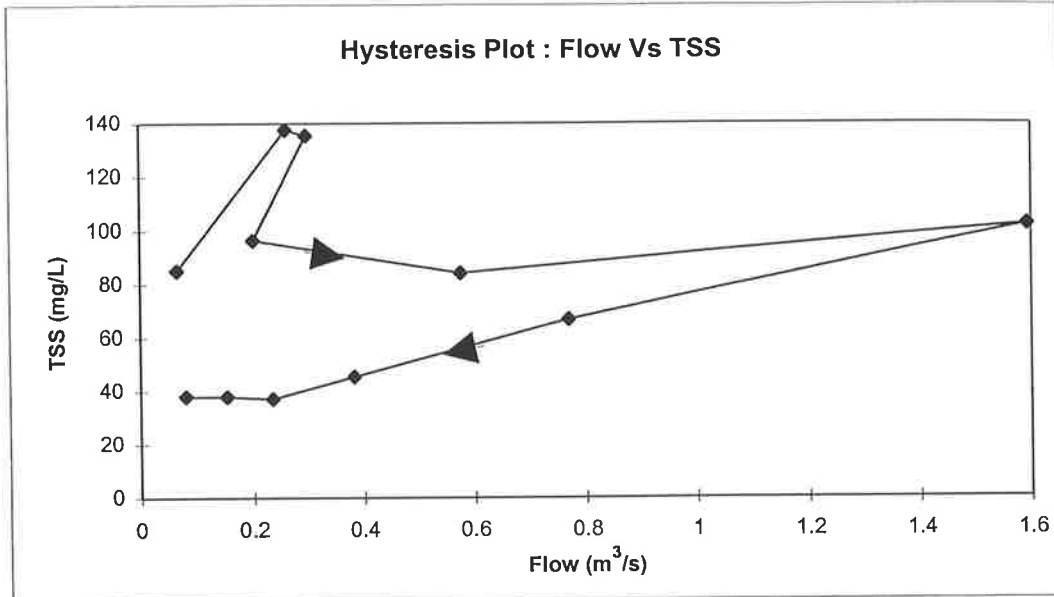
North Arm East Drain (AU504101)

Storm Date : 5-6/7/96



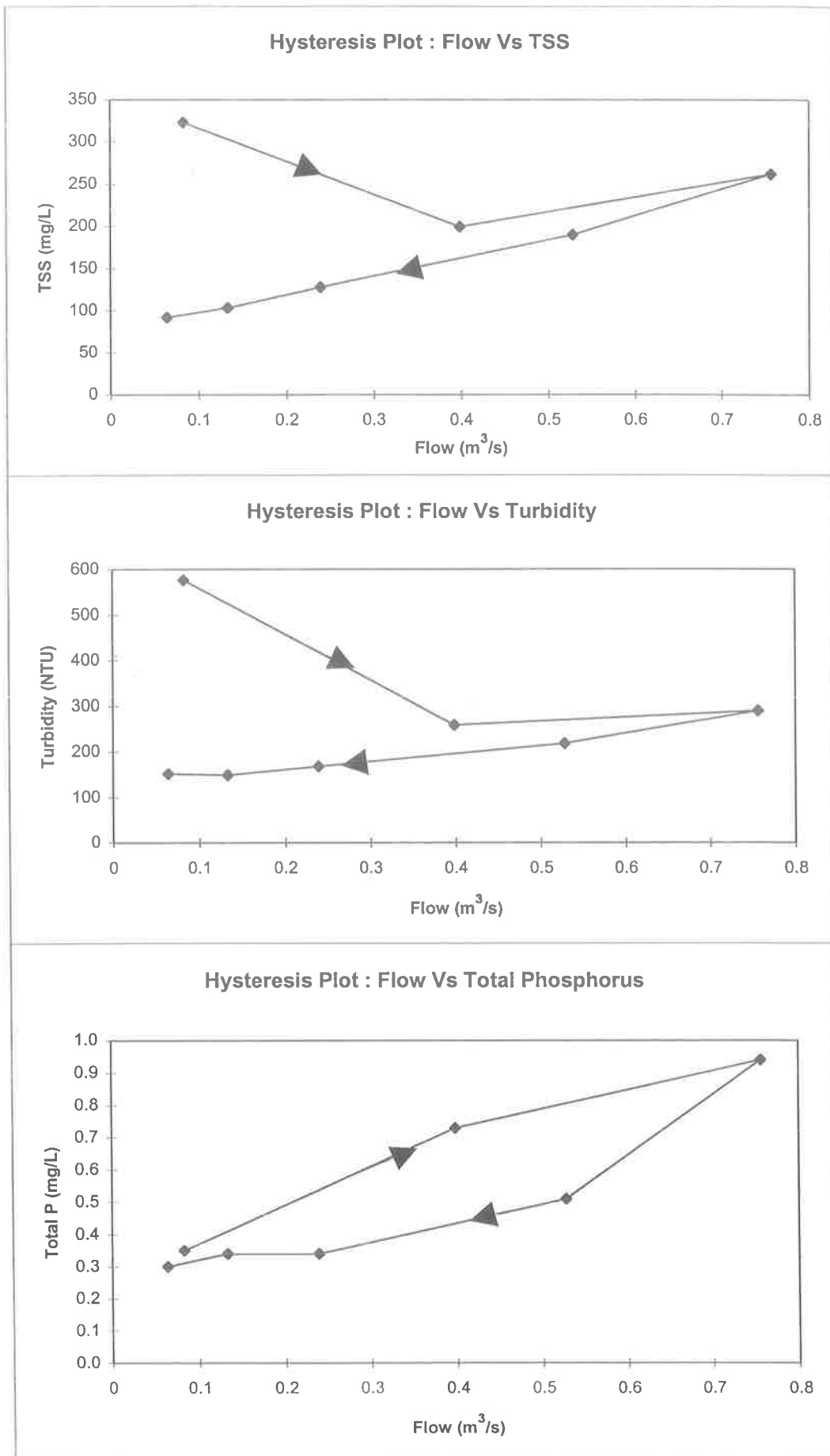
North Arm East Drain (AU504101)

Storm Date : 16/7/96



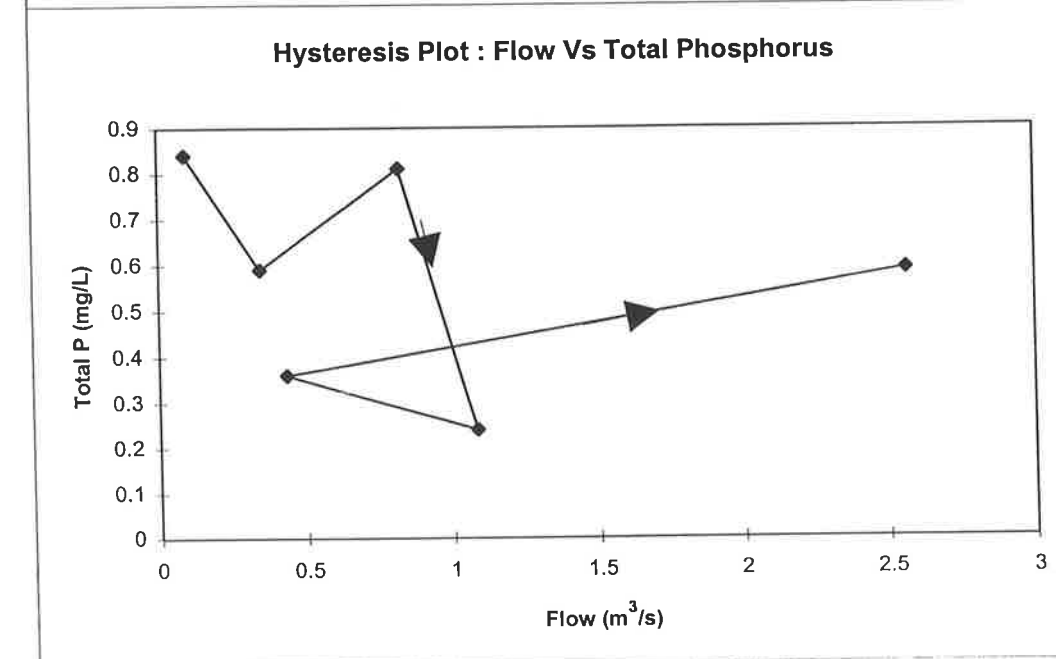
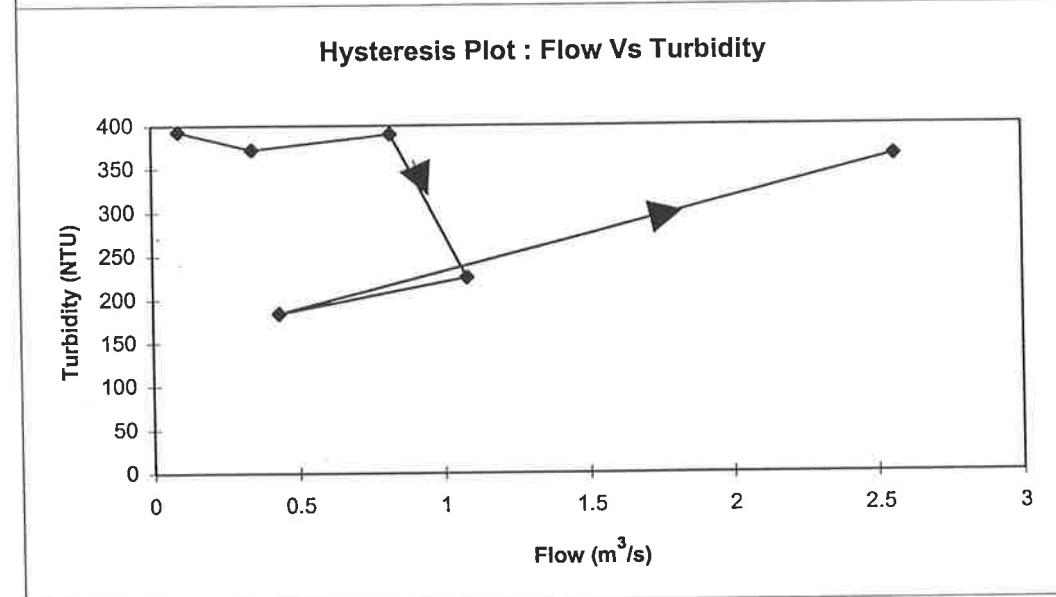
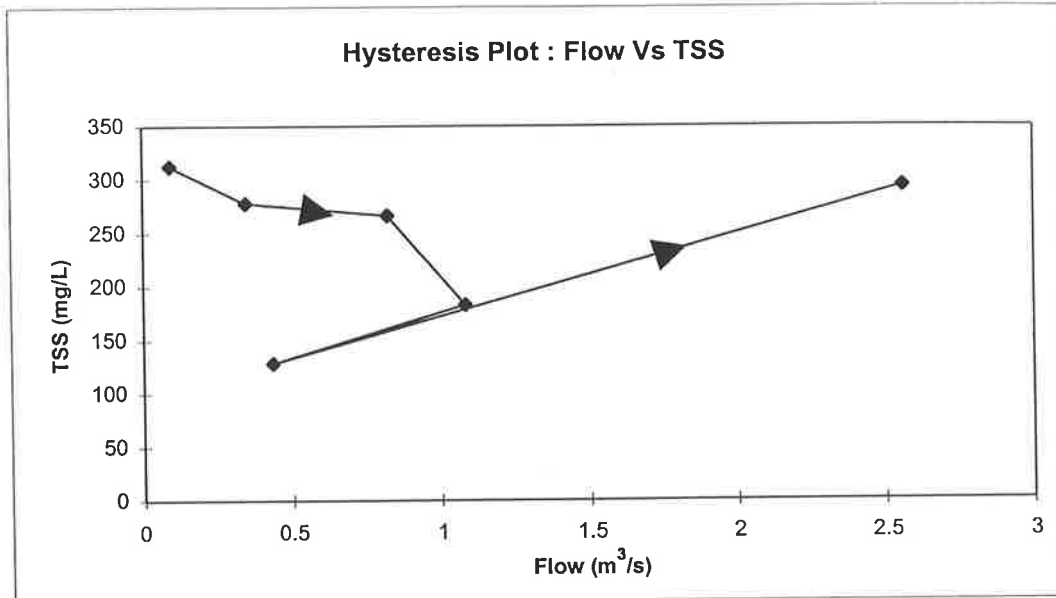
North Arm East Drain (AU504101)

Storm Date : 18/7/96



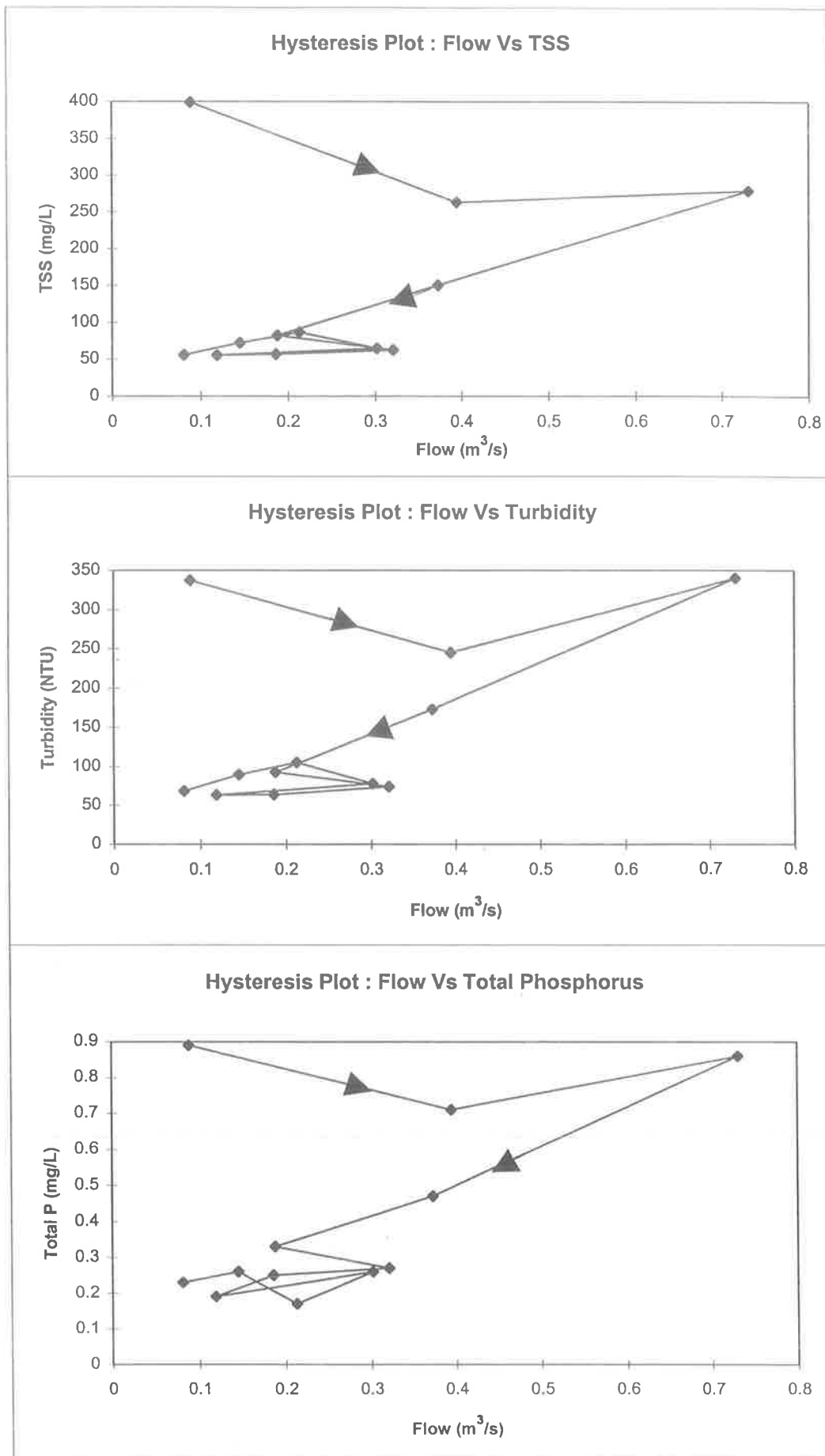
North Arm East Drain (AU504101)

Storm Date : 19/7/96



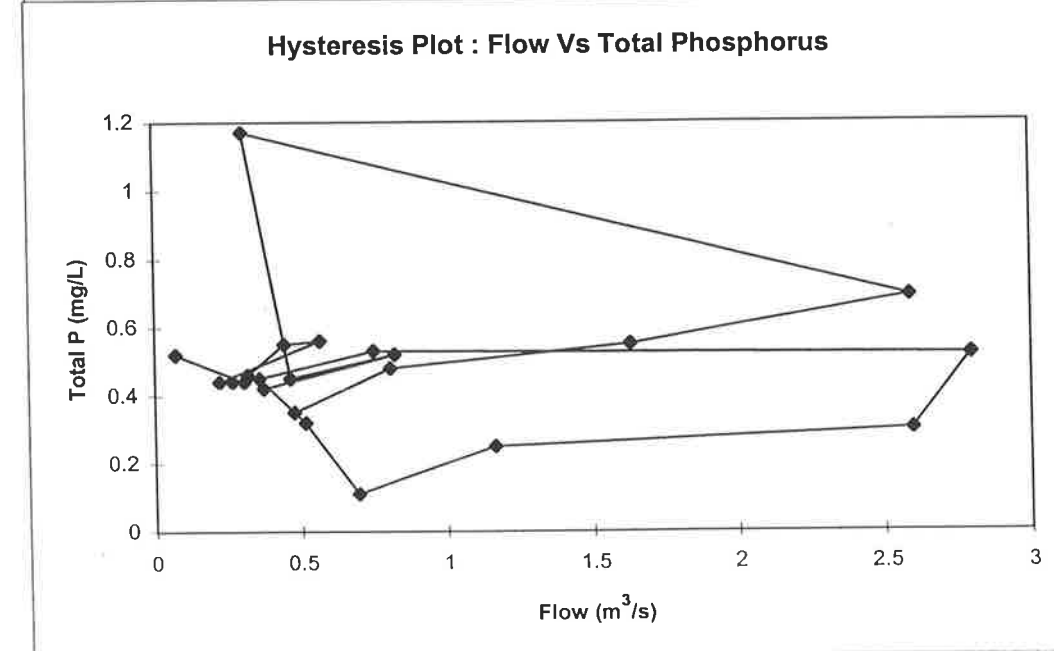
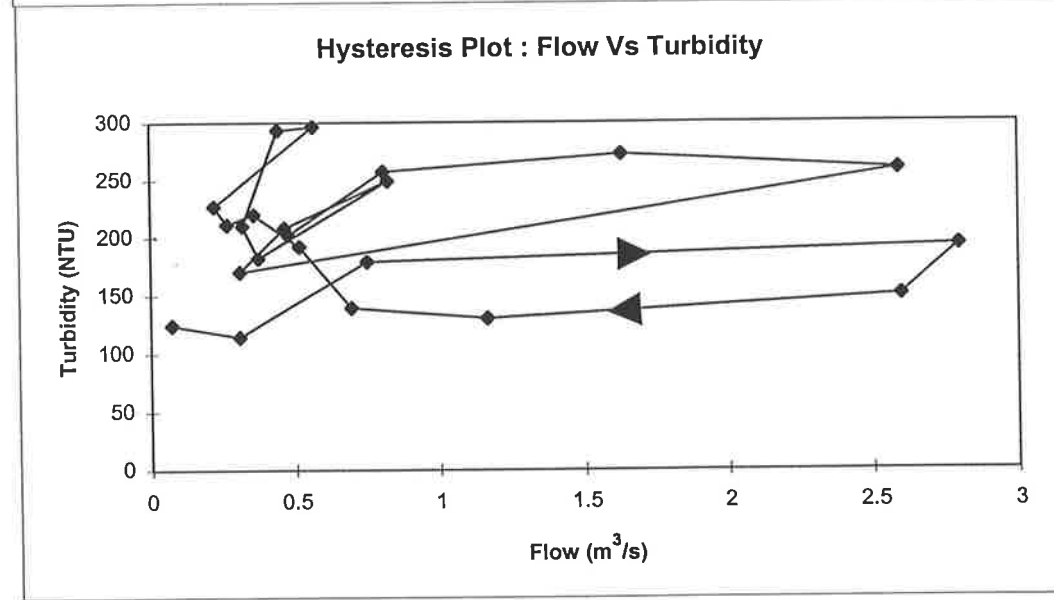
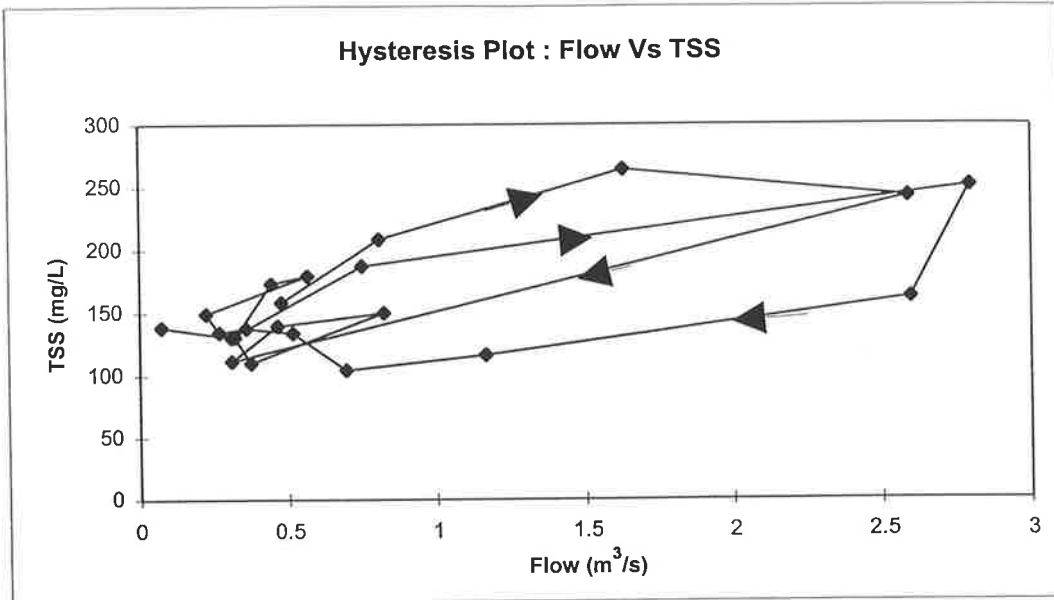
North Arm East Drain (AU504101)

Storm Date : 28-29/7/96

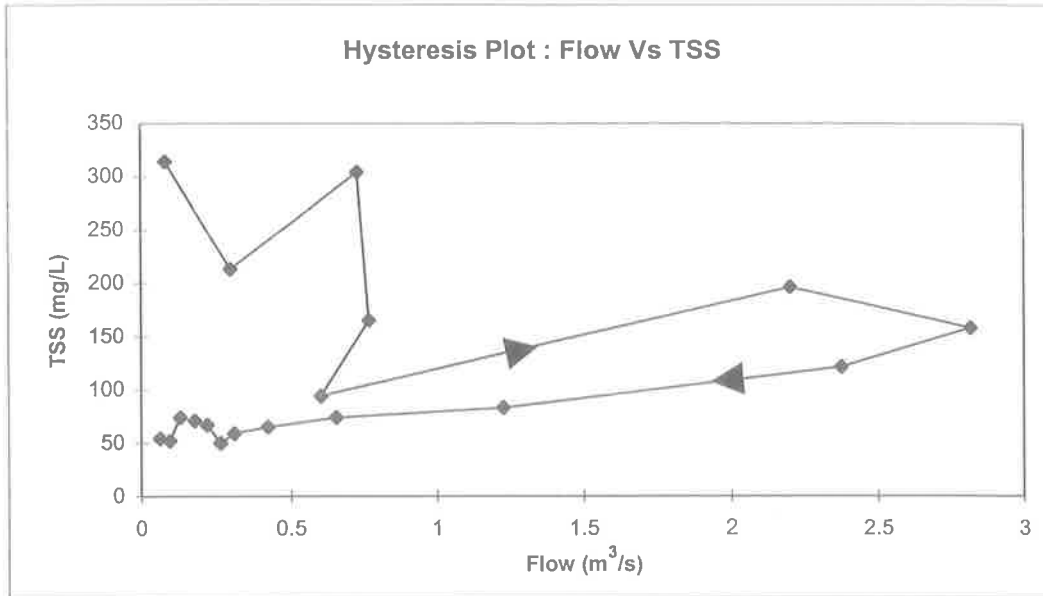


North Arm East Drain (AU504101)

Storm Date : 31/7/96

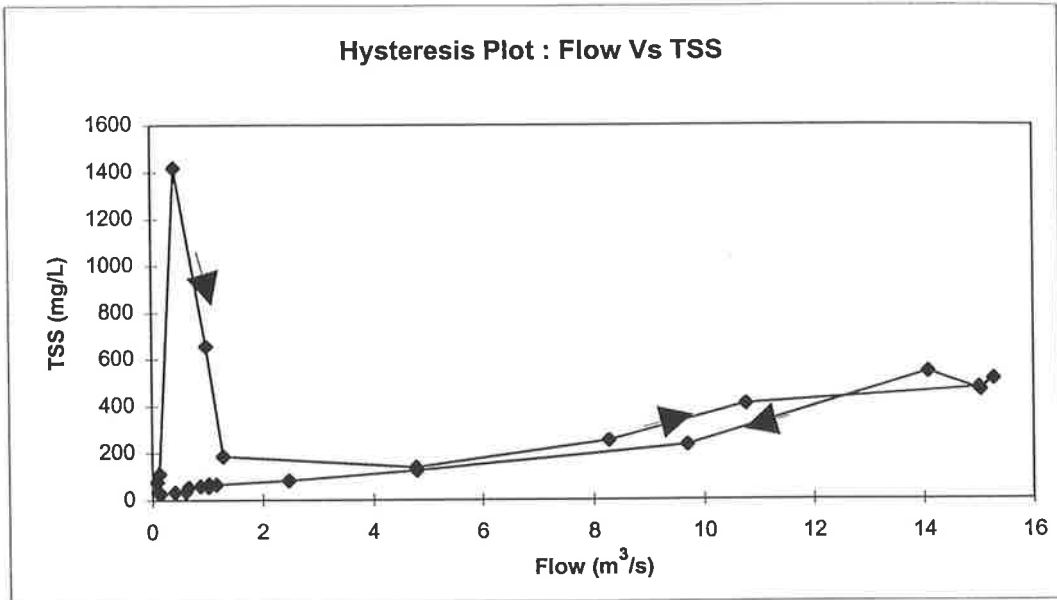


North Arm East Drain (AU504101)
Storm Date : 26-27/8/96

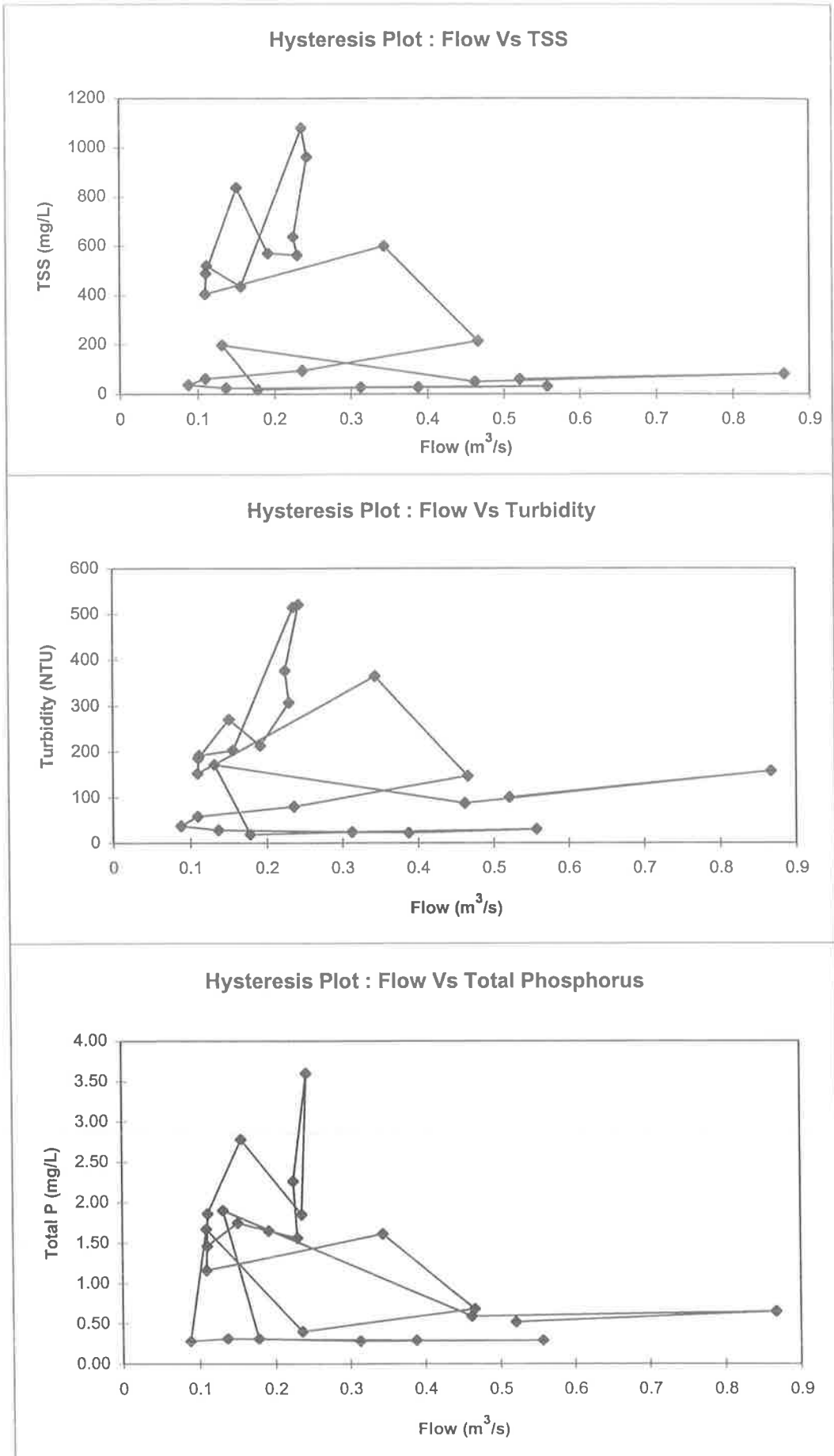


North Arm East Drain (AU504101)

Storm Date : 6/2/97

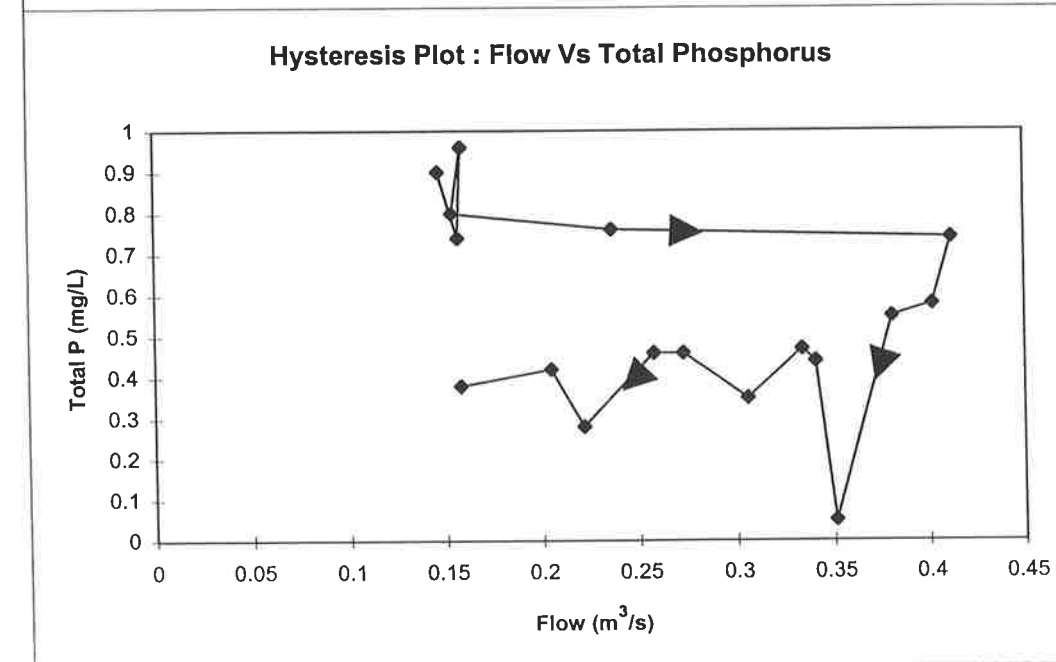
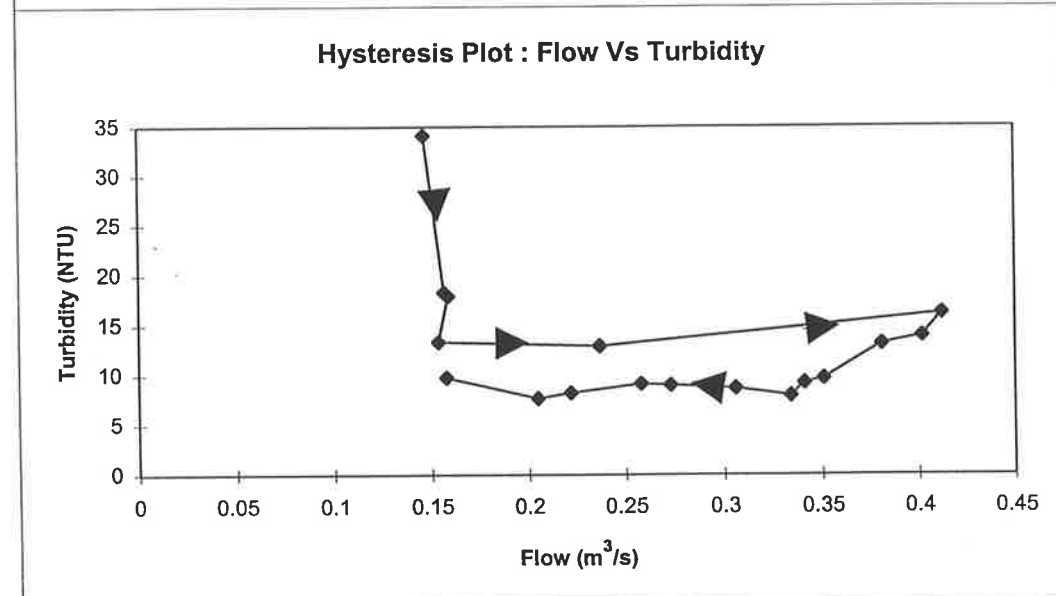
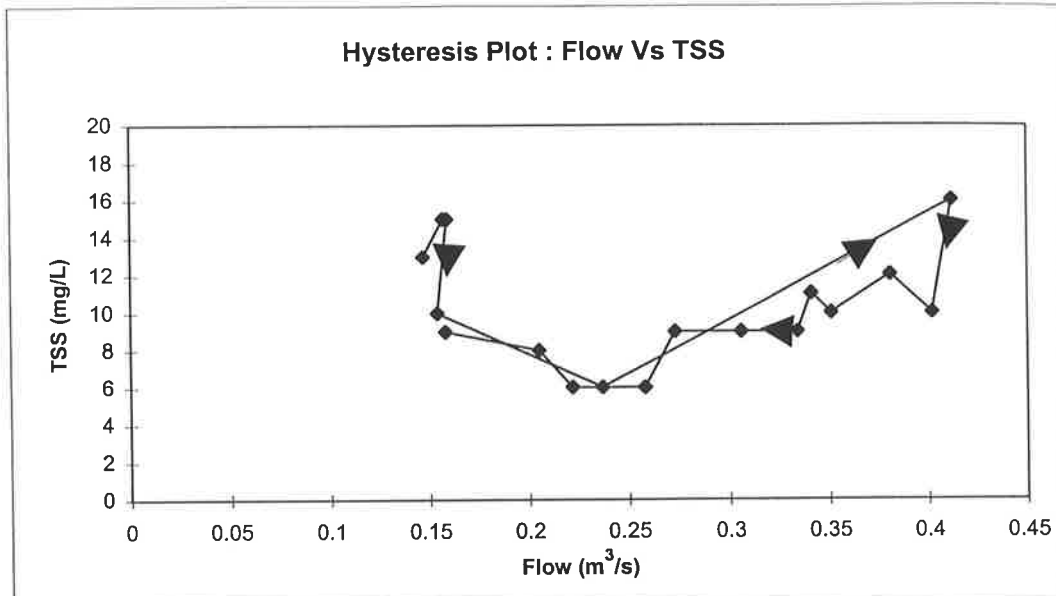


North Arm East Drain (AU504101)
Storm Date : 2-5/5/97



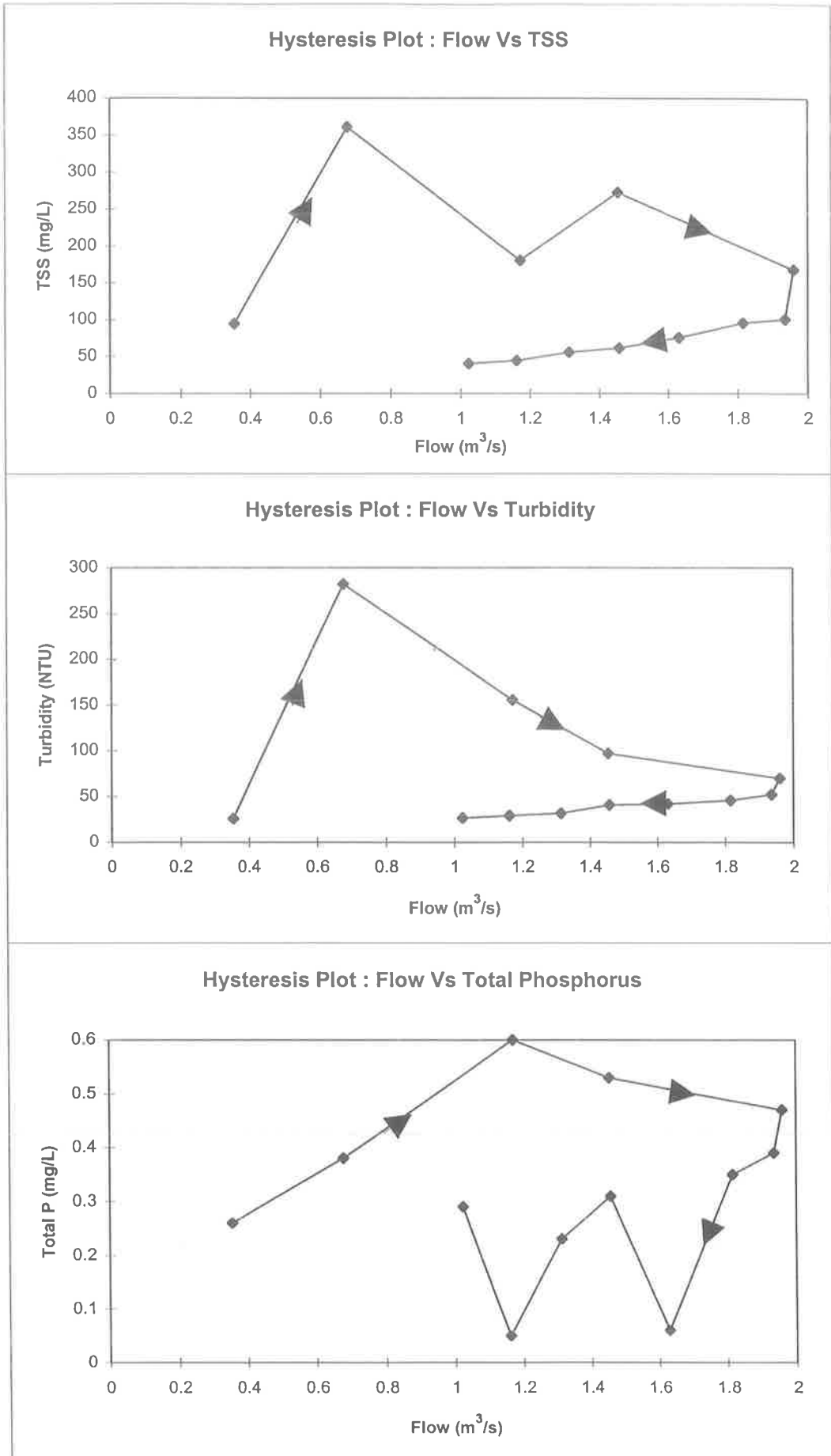
Hindmarsh Enfield Prospect Drain (AU504102)

Storm Date : 7/4/96



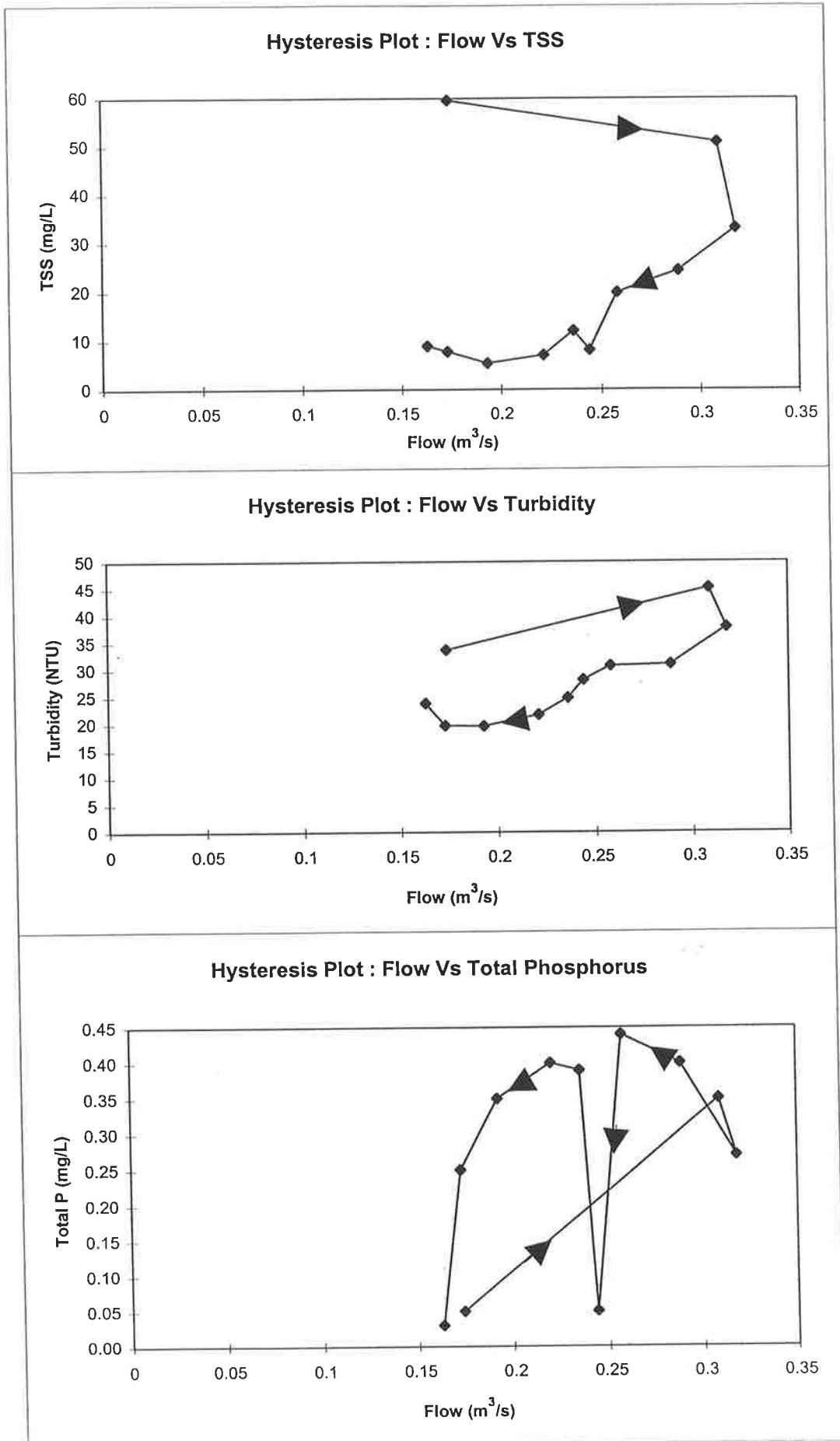
Hindmarsh Enfield Prospect Drain (AU504102)

Storm Date : 13/4/96



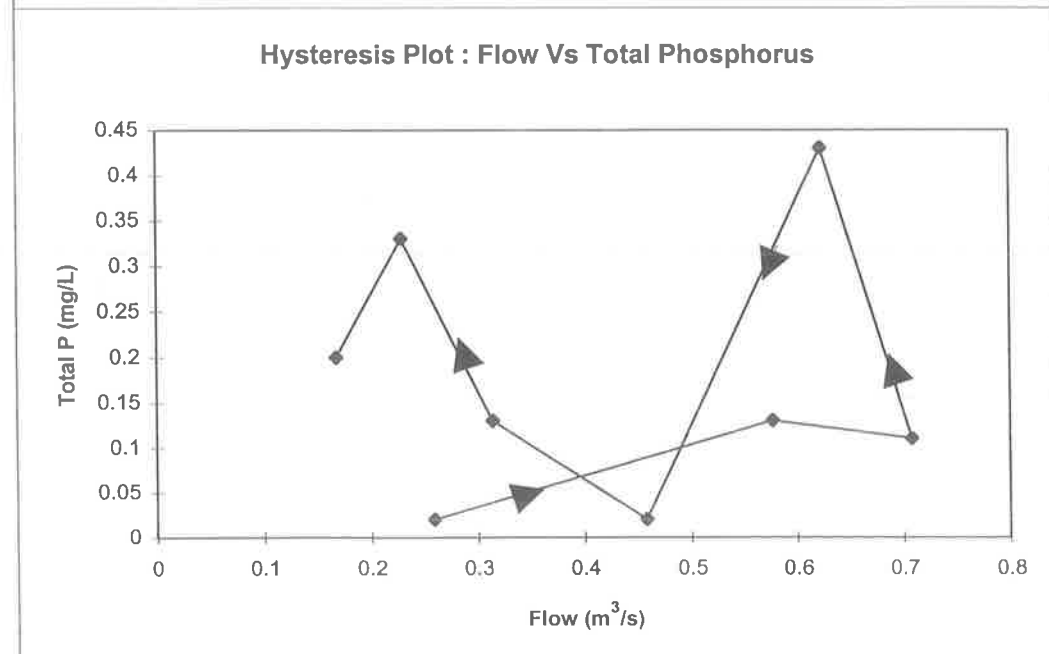
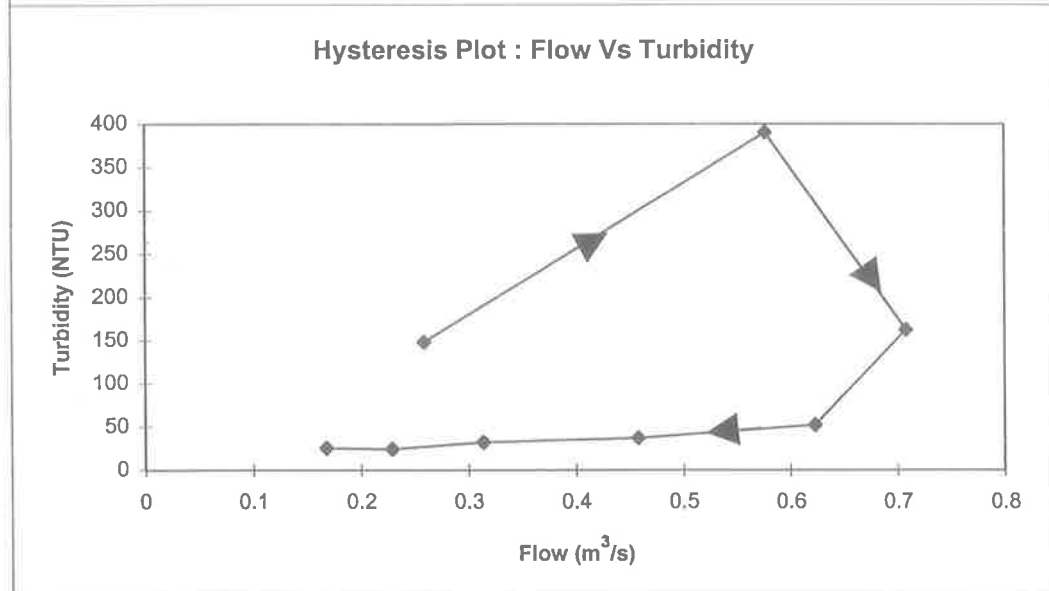
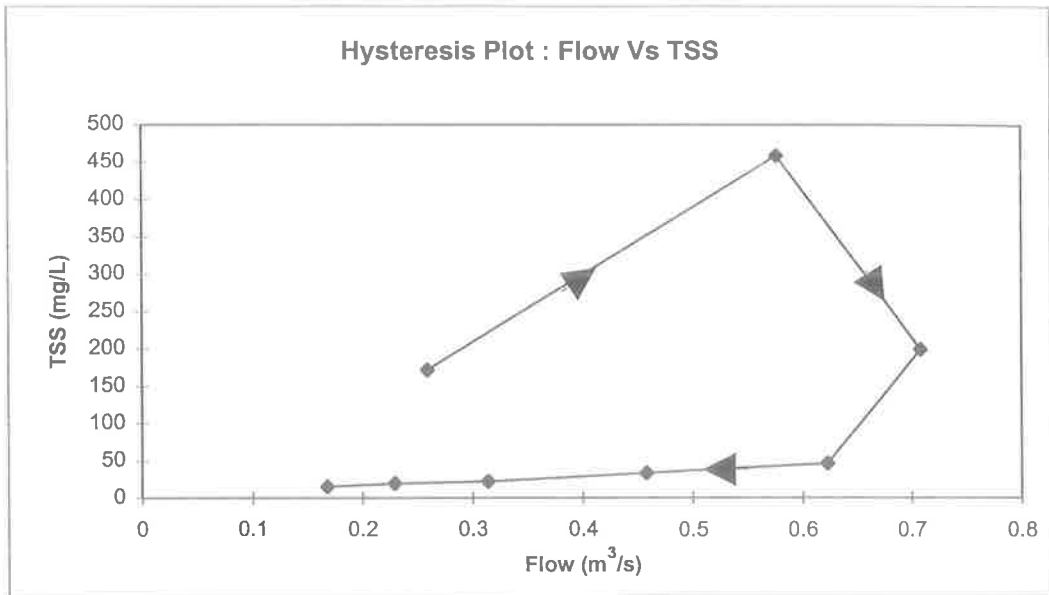
Hindmarsh Enfield Prospect Drain (AU504102)

Storm Date : 12/5/96



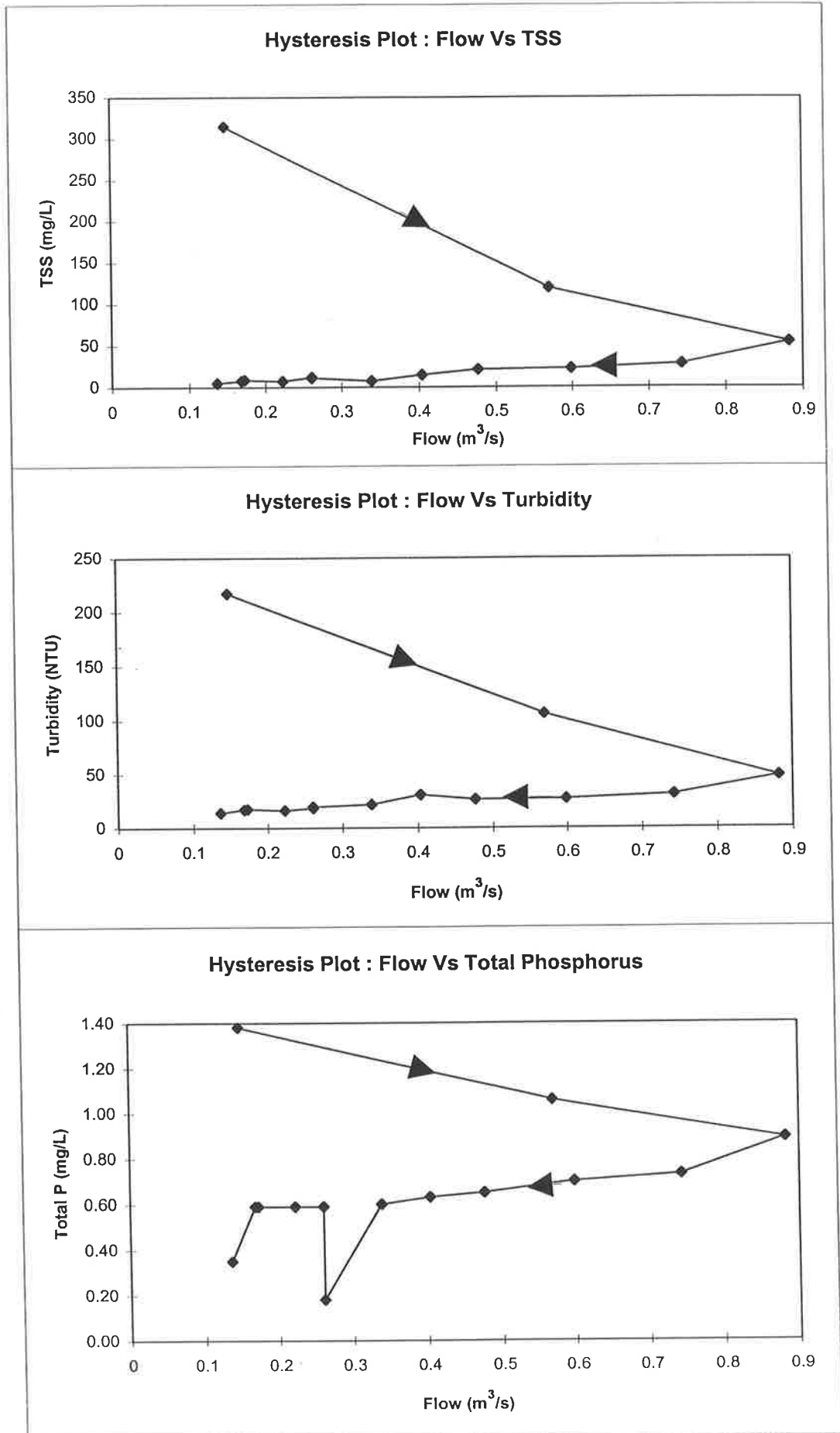
Hindmarsh Enfield Prospect Drain (AU504102)

Storm Date : 1/6/96

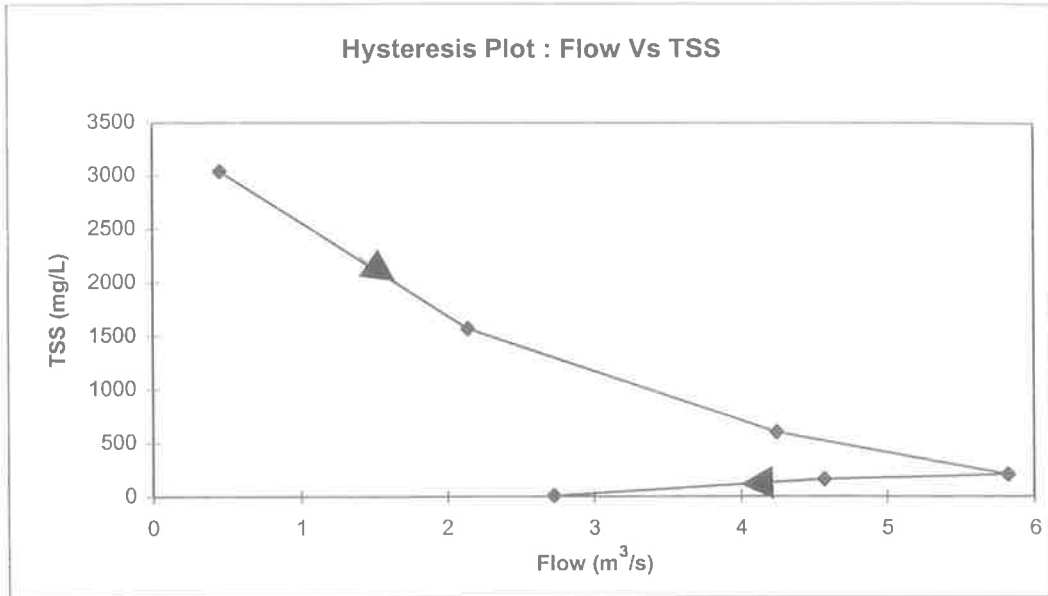


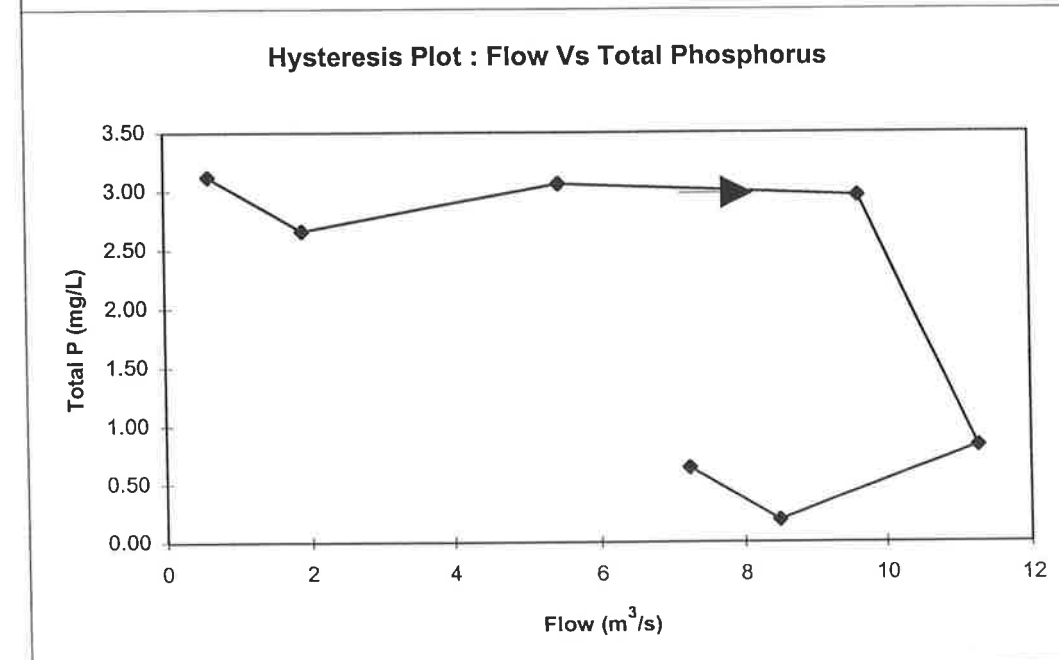
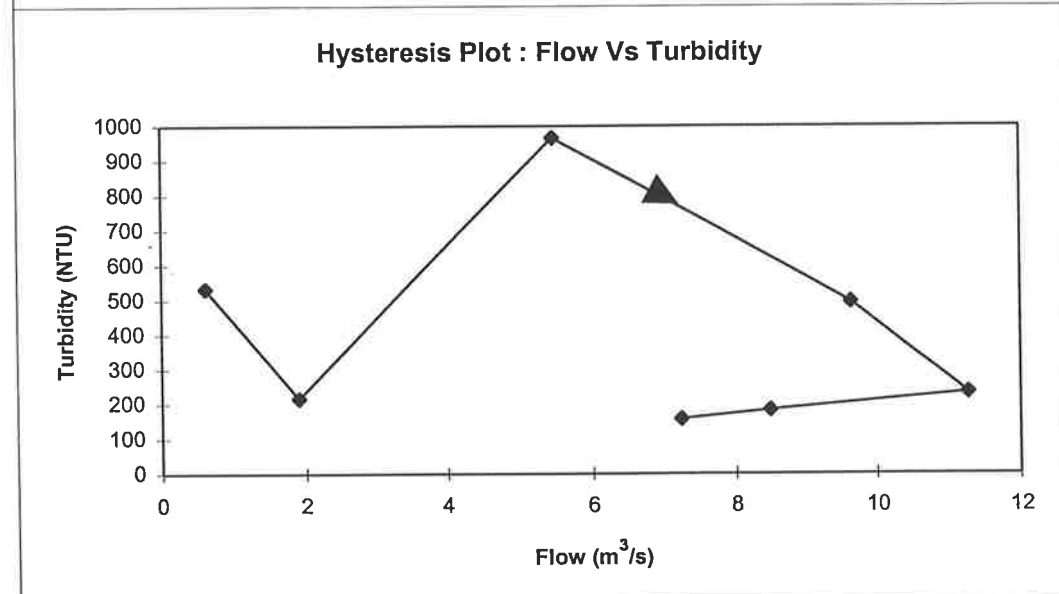
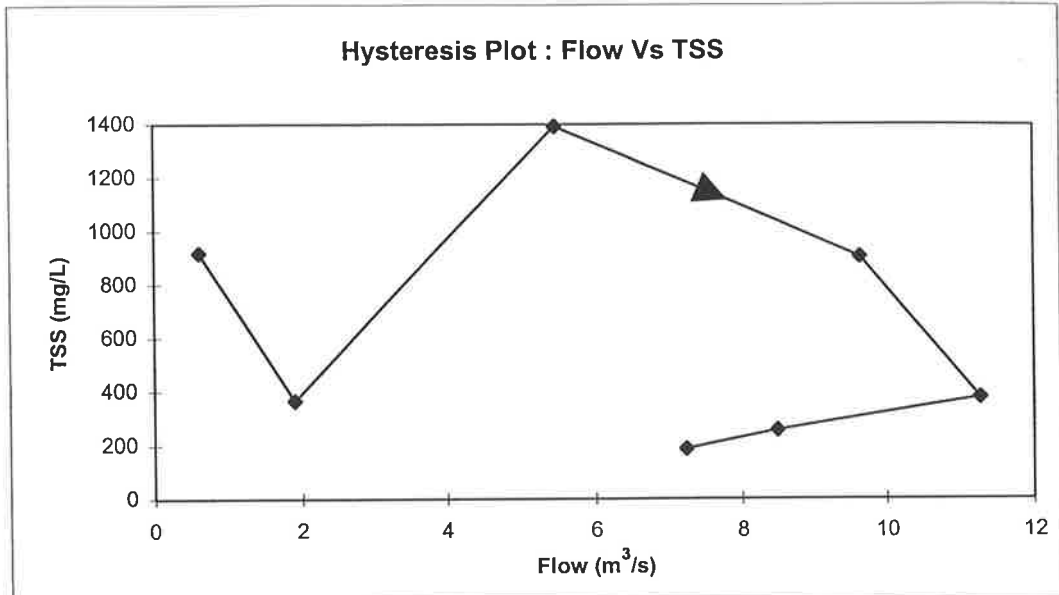
Hindmarsh Enfield Prospect Drain (AU504102)

Storm Date : 6-7/12/1996



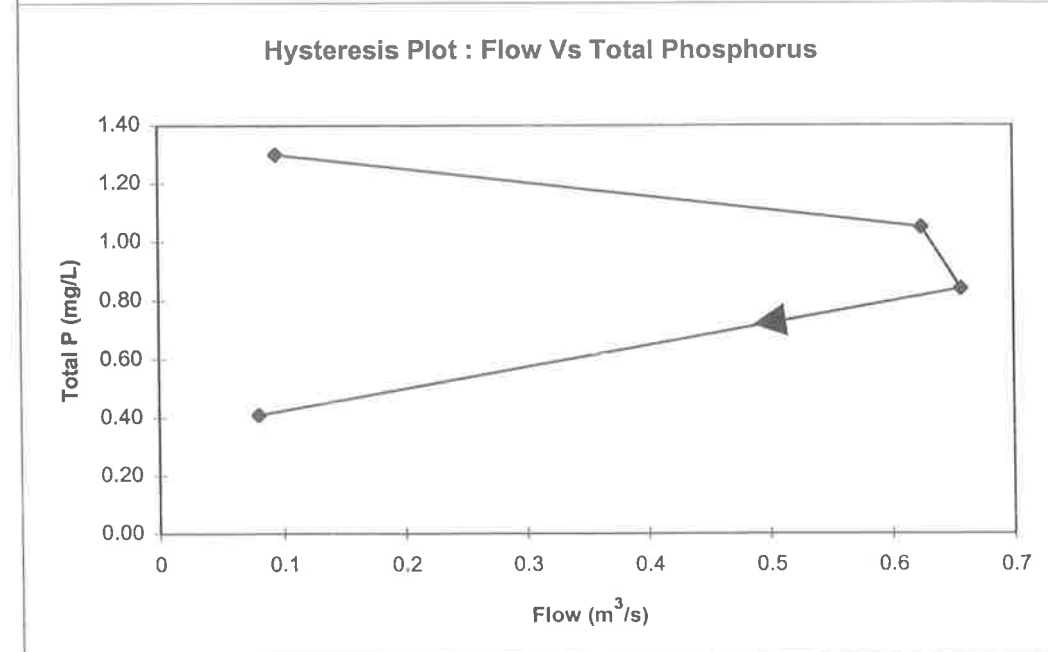
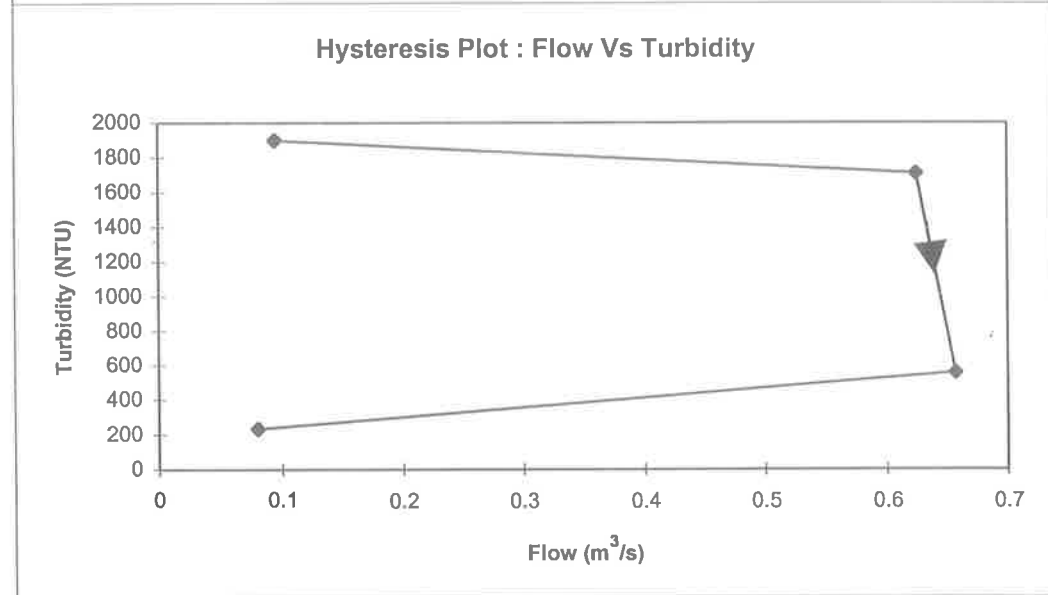
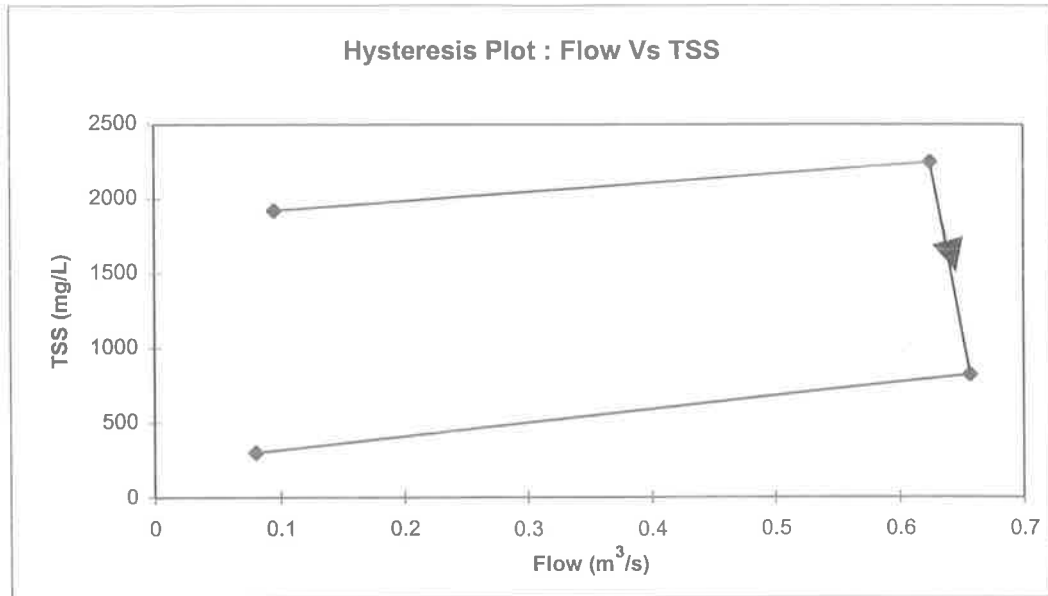
Hindmarsh Enfield Prospect Drain (AU504102)
Storm Date : 6-7/02/1997



Dunstan Road Drain (AU504103)**Storm Date : 13/4/96**

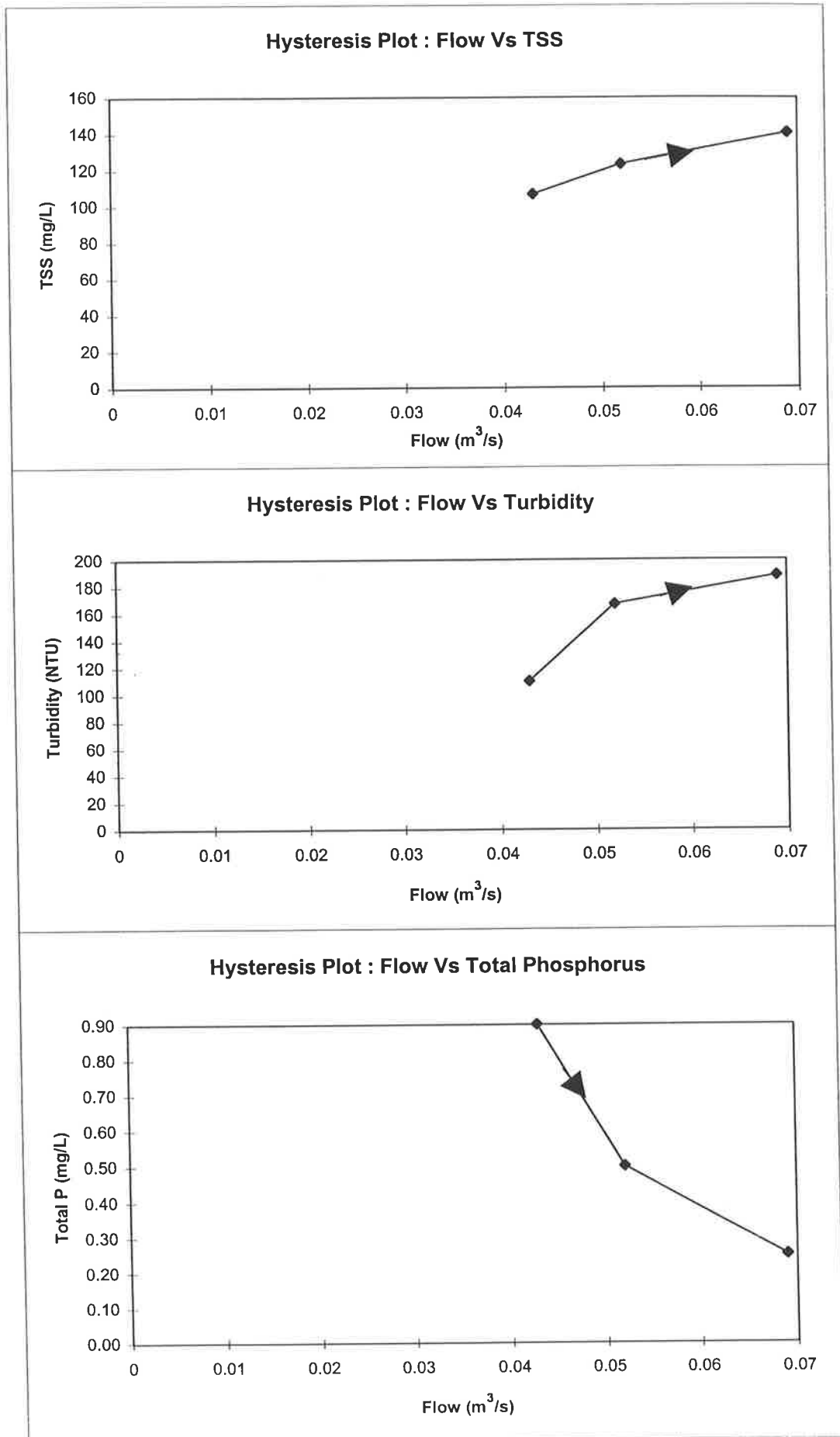
Dunstan Road Drain (AU504103)

Storm Date : 12/5/96



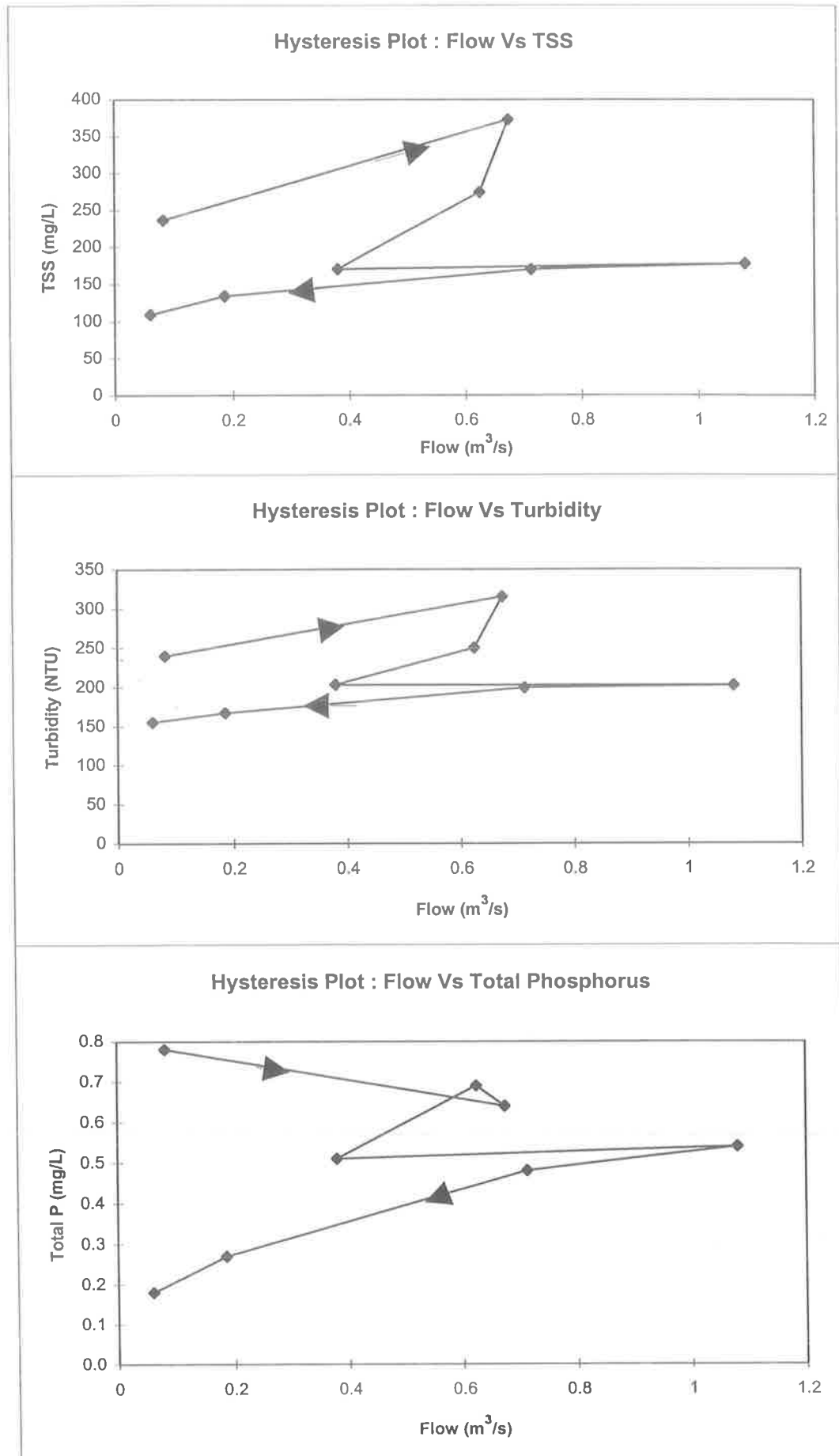
Dunstan Road Drain (AU504103)

Storm Date : 28/6/96



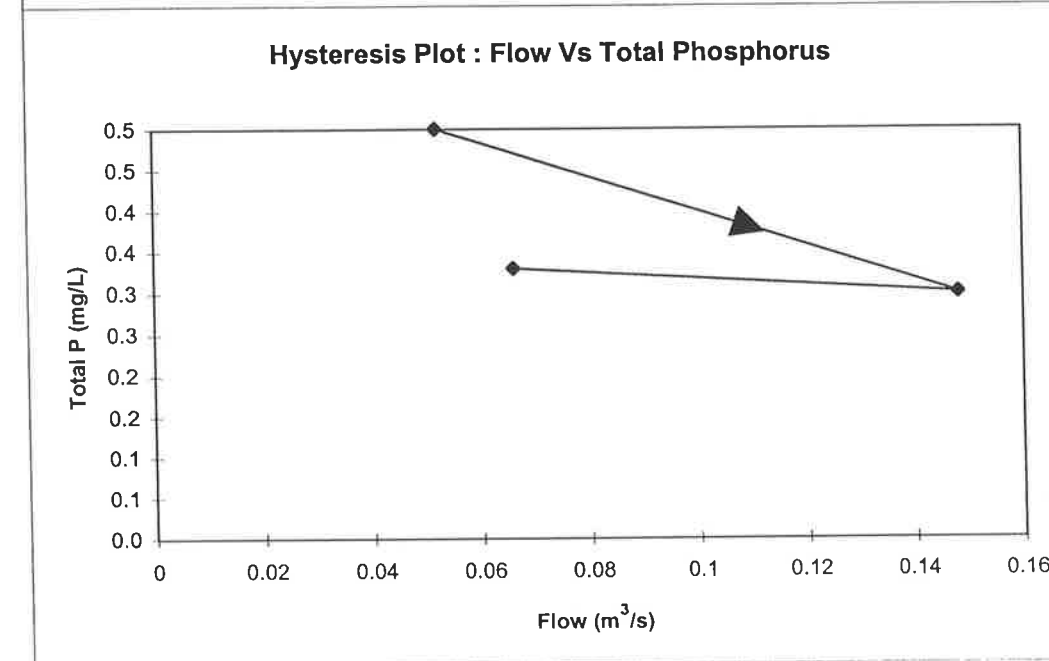
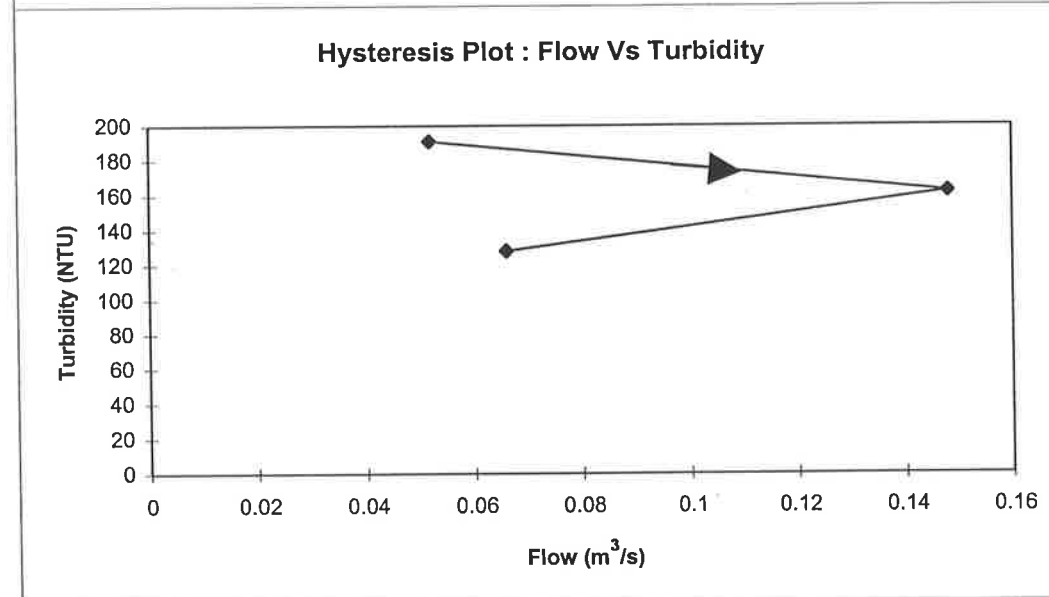
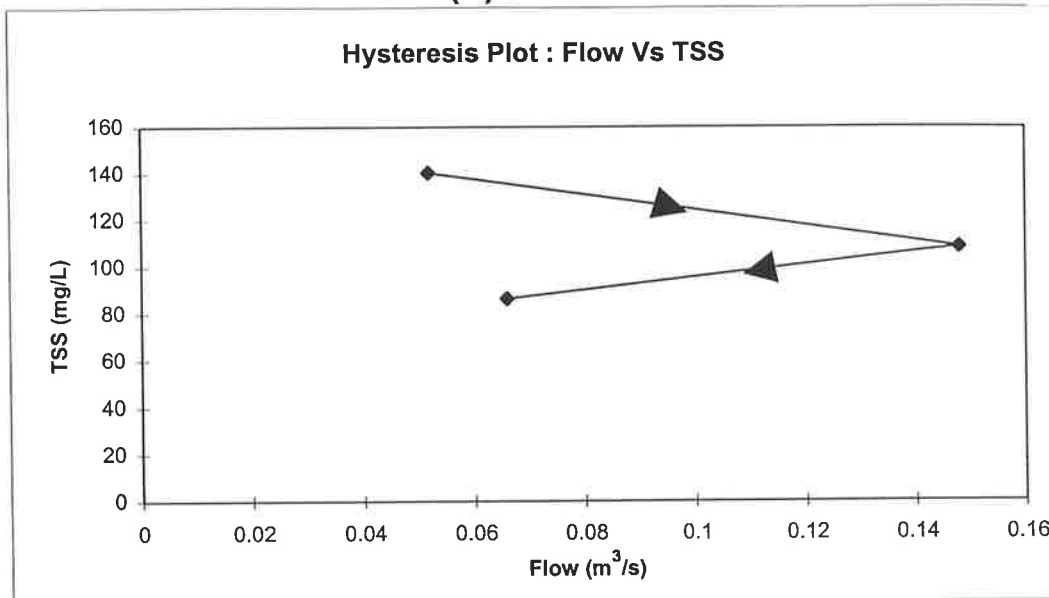
Dunstan Road Drain (AU504103)

Storm Date : 4/7/96



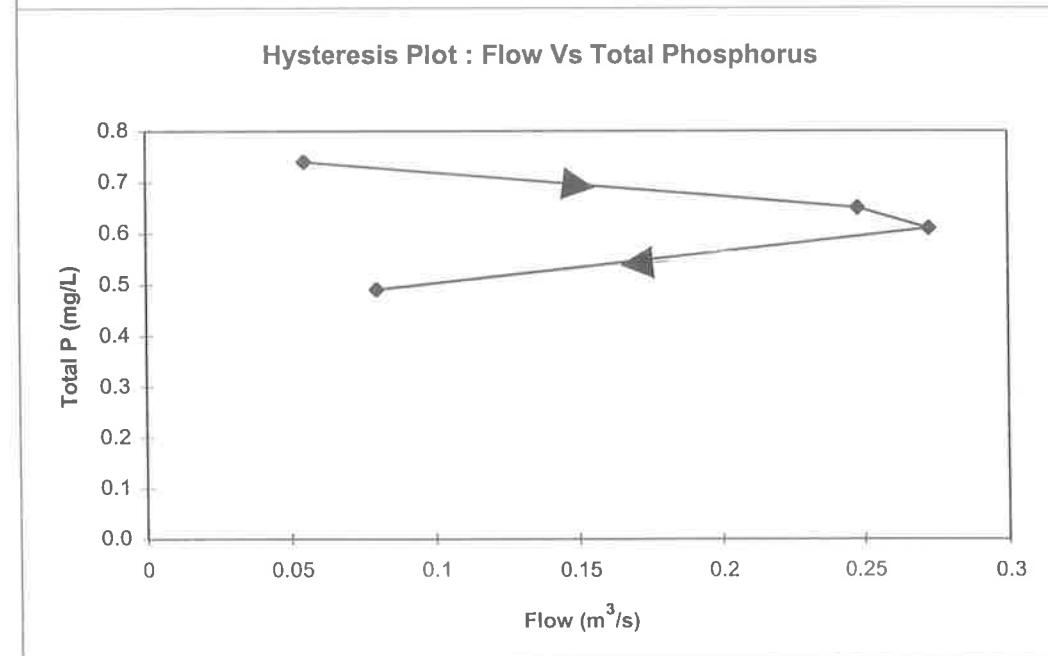
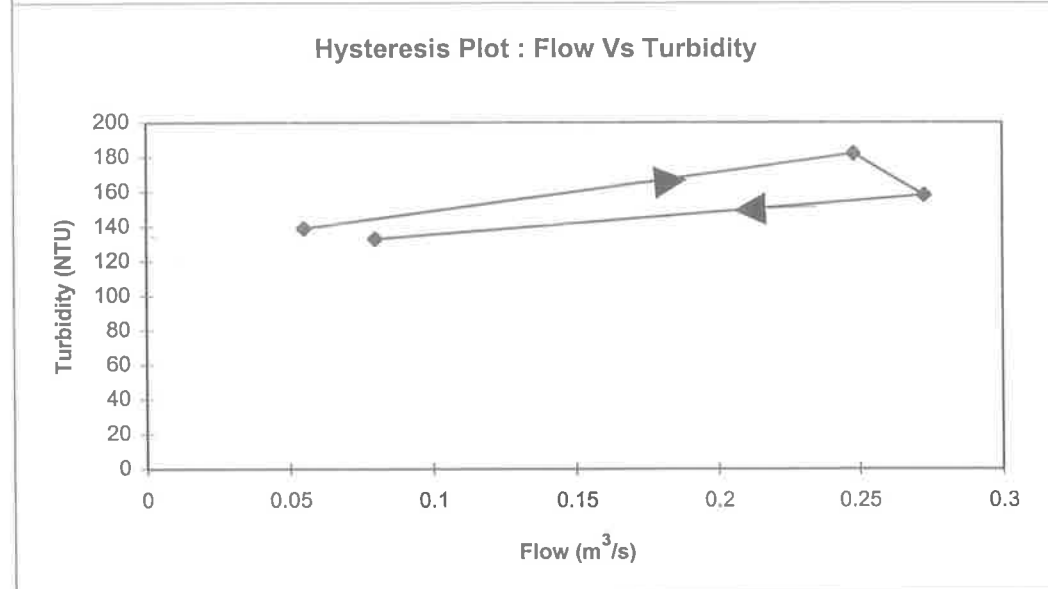
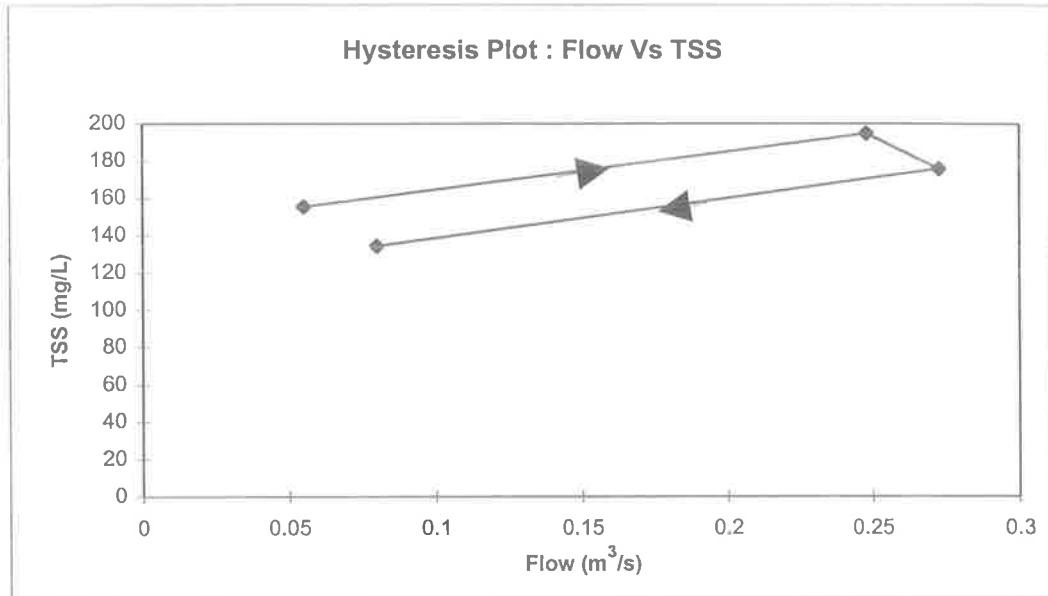
Dunstan Road Drain (AU504103)

Storm Date : 4(b)/7/1996



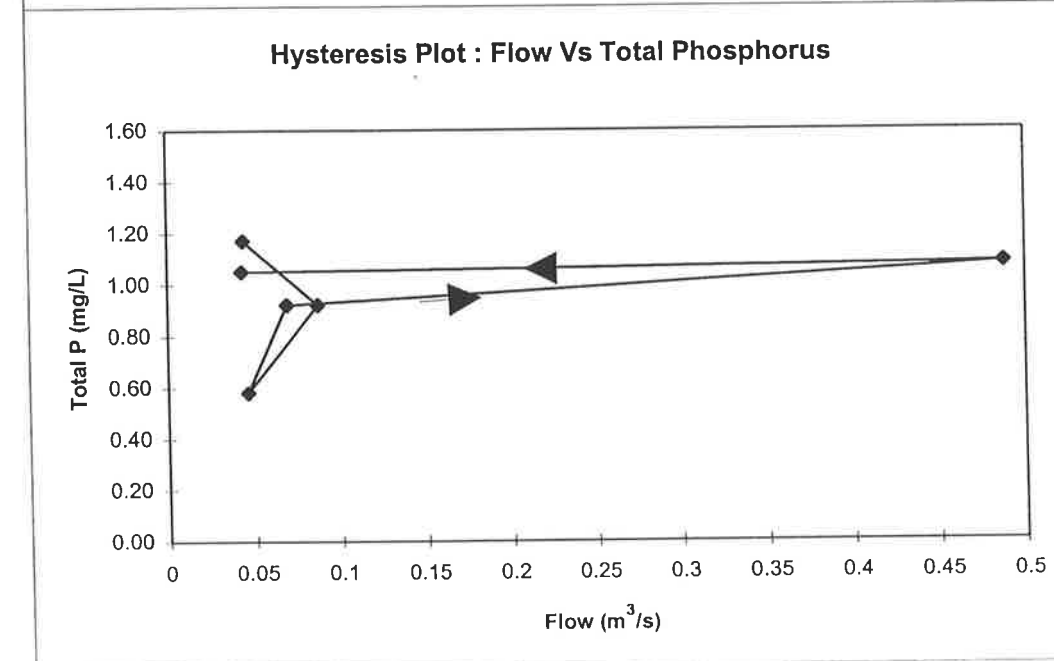
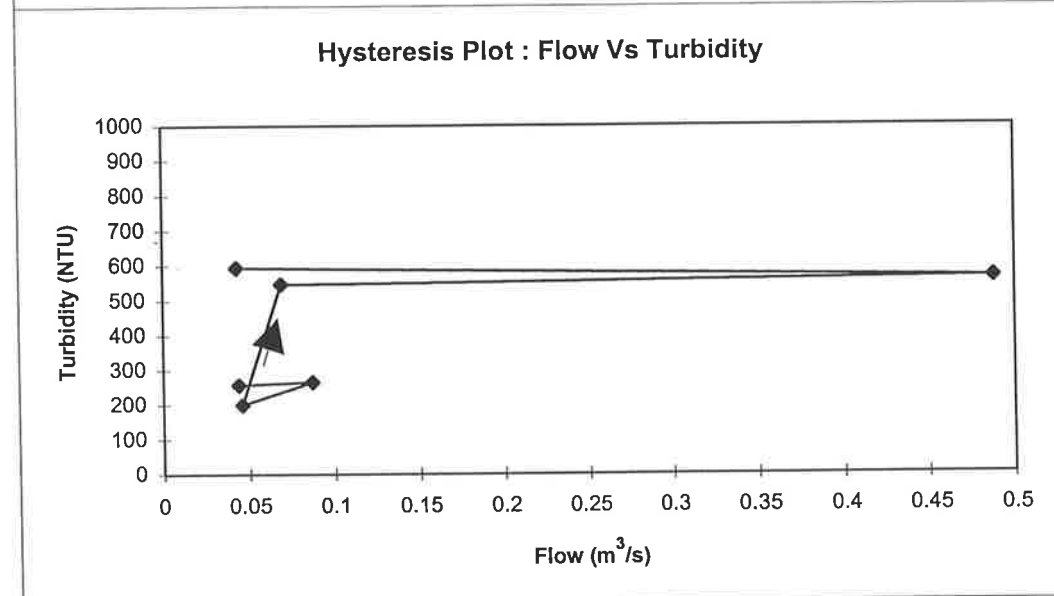
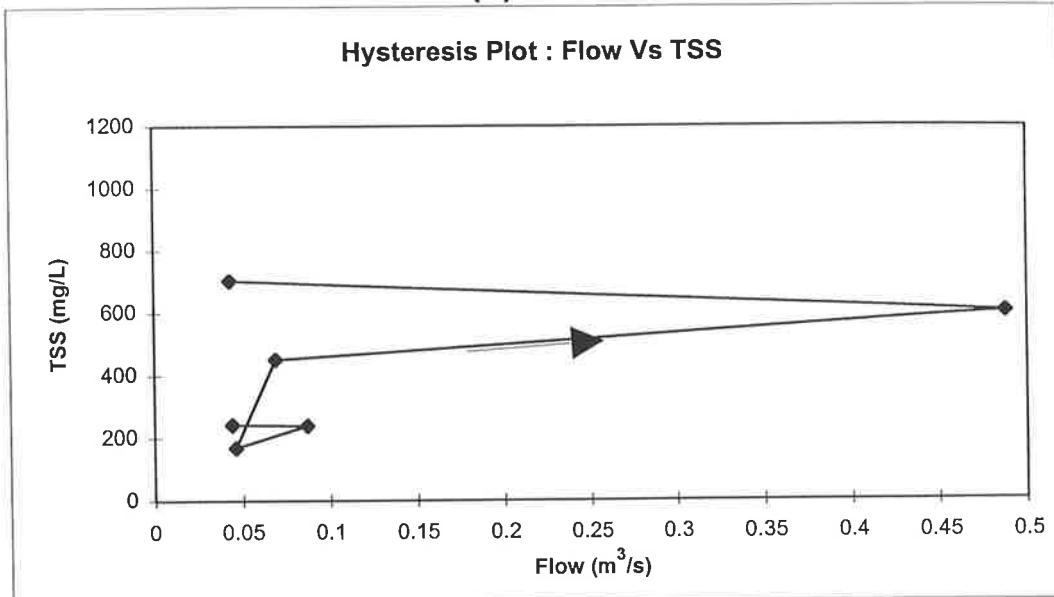
Dunstan Road Drain (AU504103)

Storm Date : 10/7/96



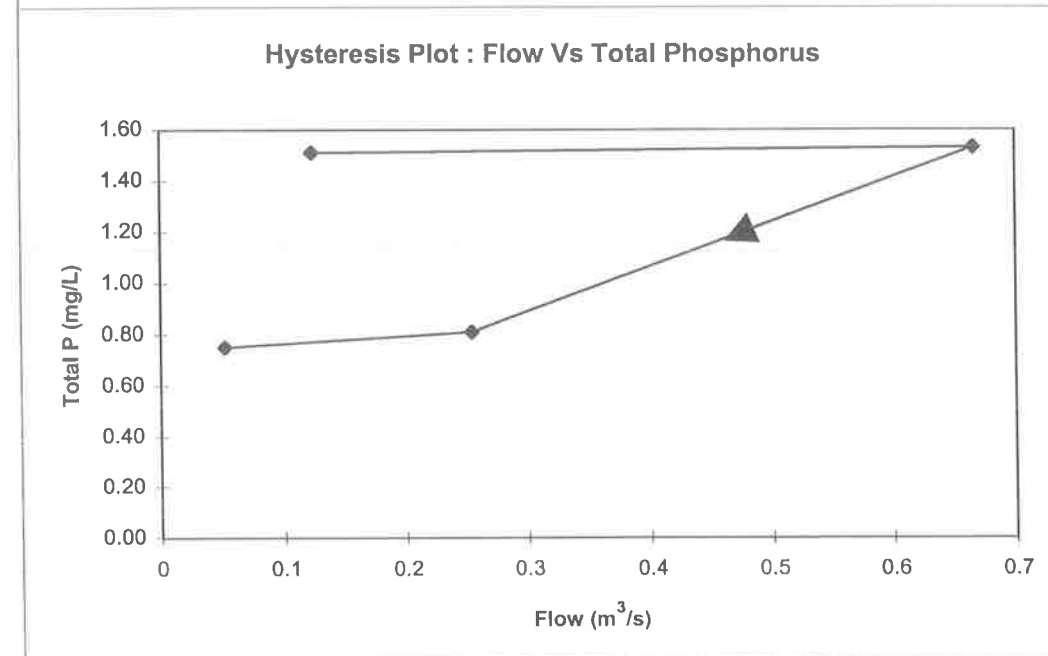
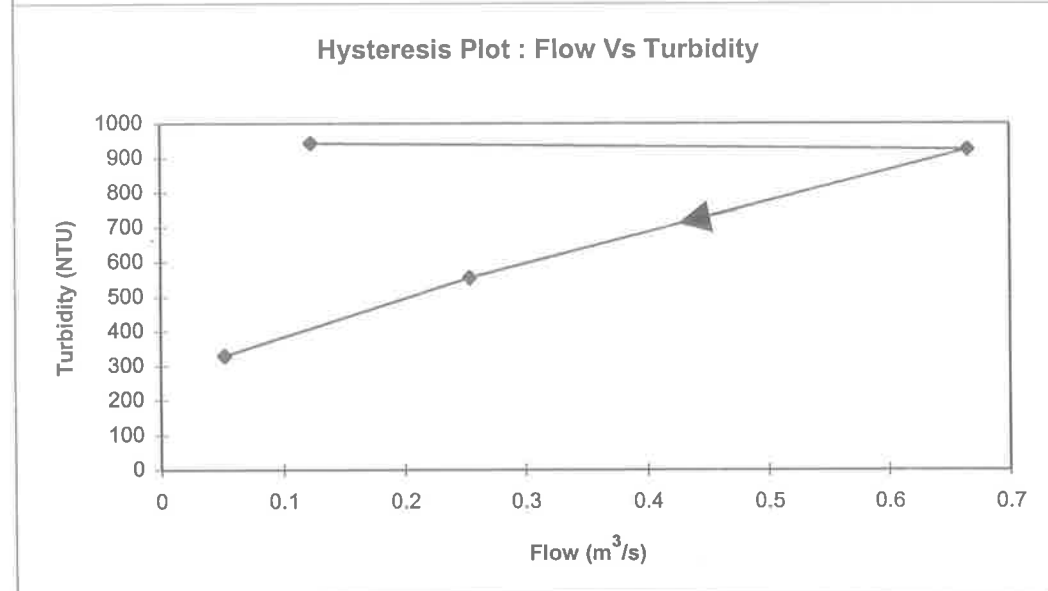
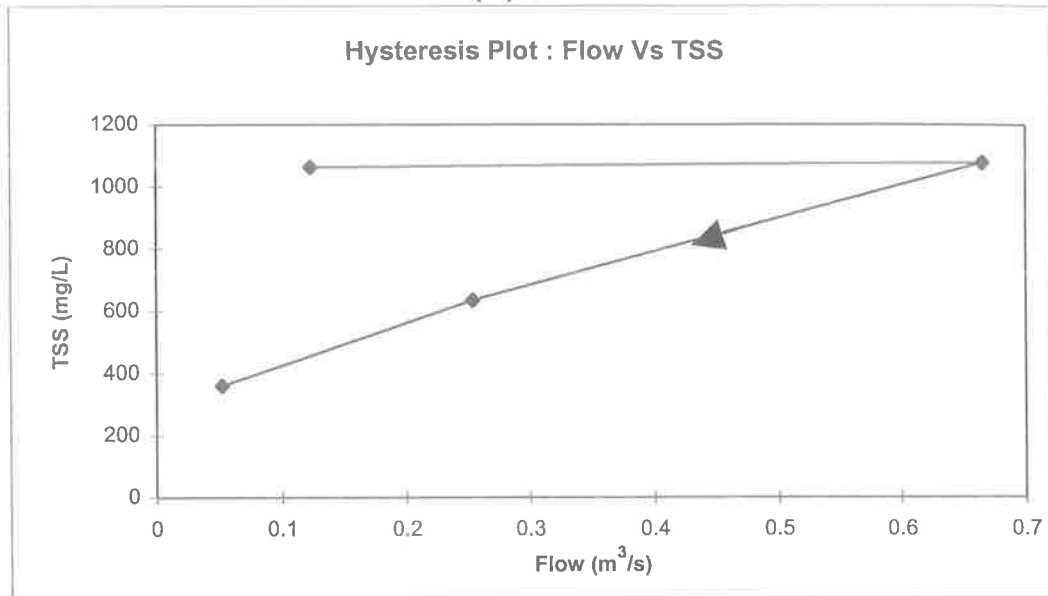
Dunstan Road Drain (AU504103)

Storm Date : 19(a)/07/1996



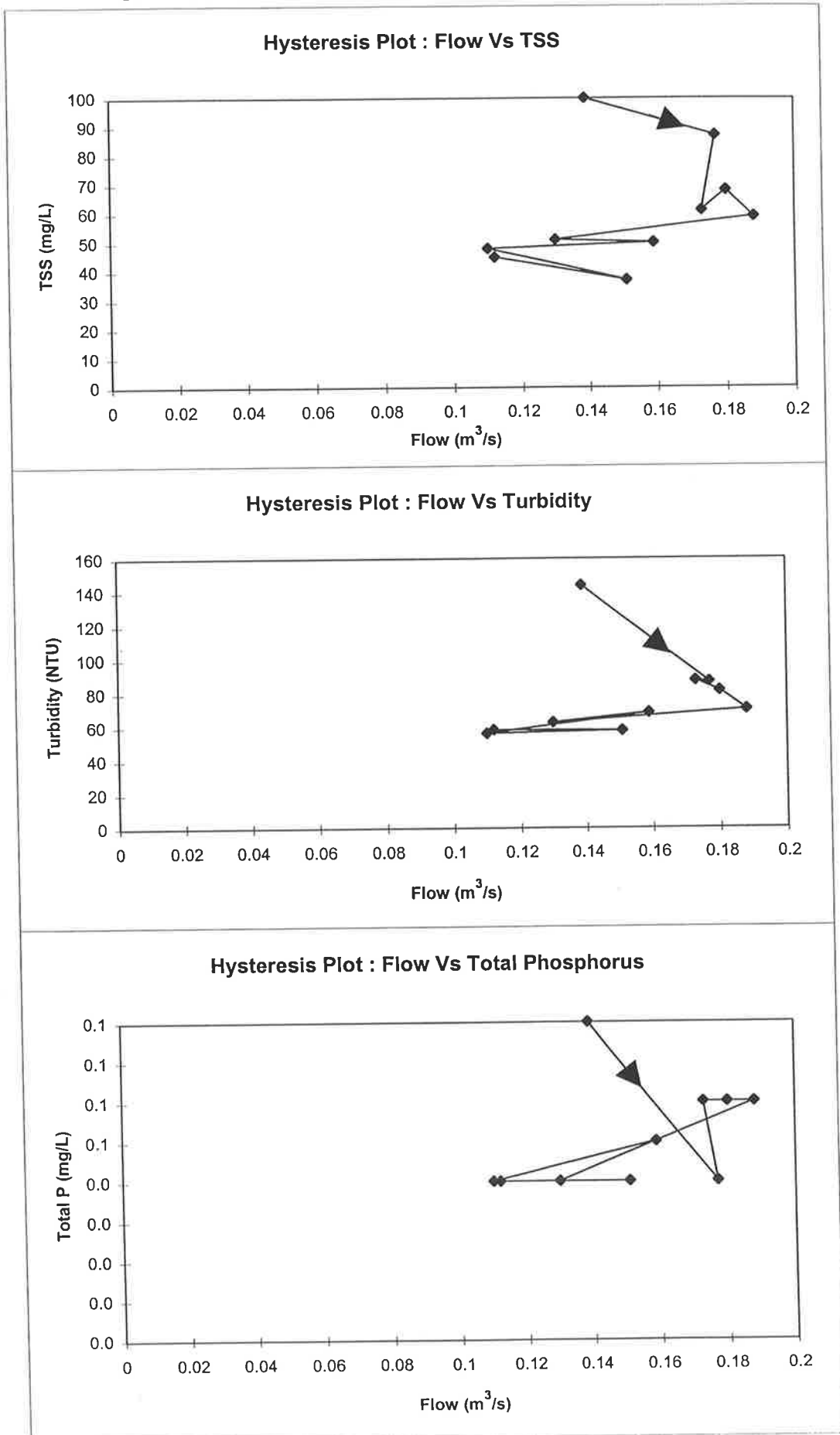
Dunstan Road Drain (AU504103)

Storm Date : 19(b)/07/1996



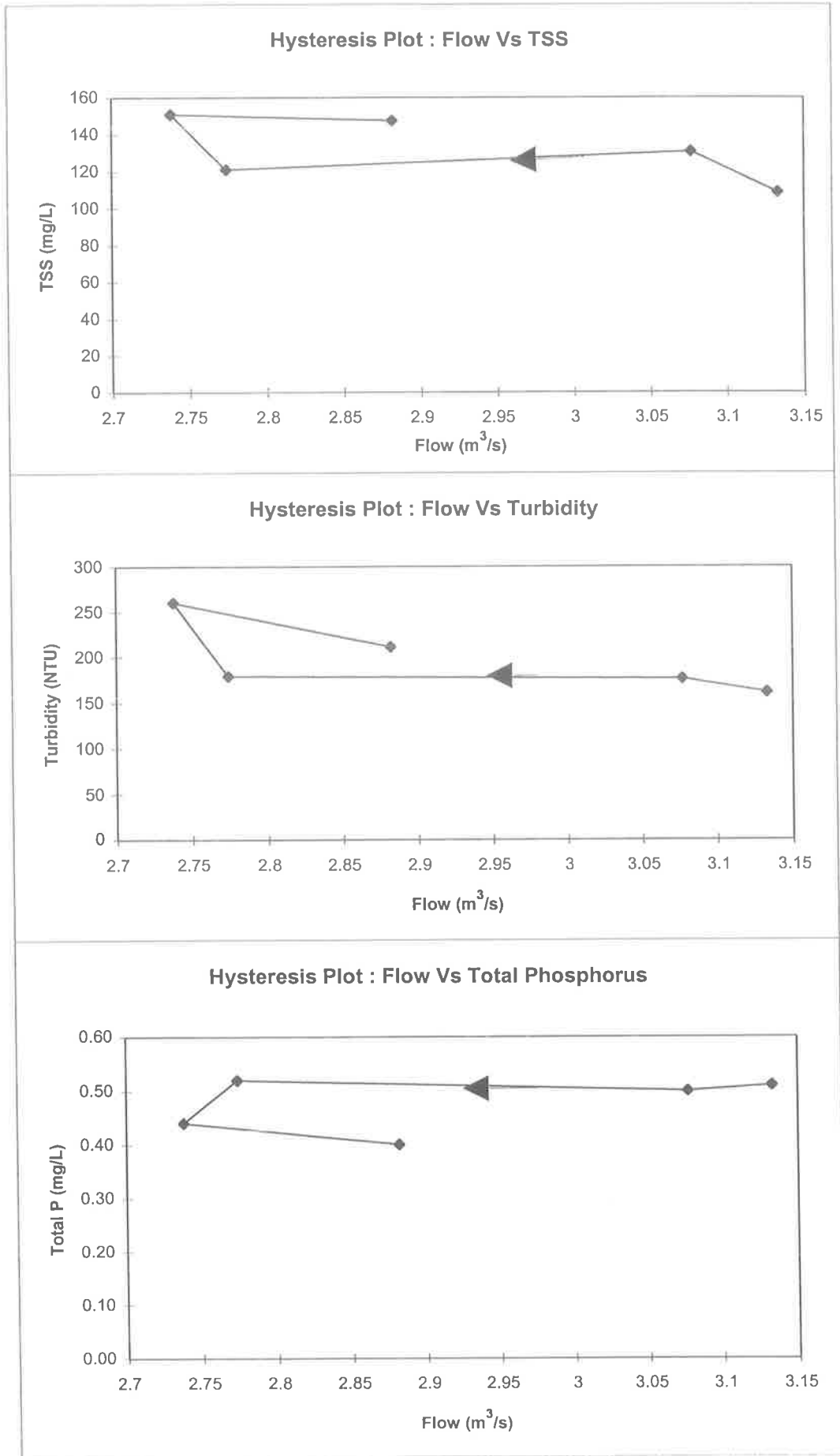
North Arm West Drain (AU504104)

Storm Date : 8/2/96



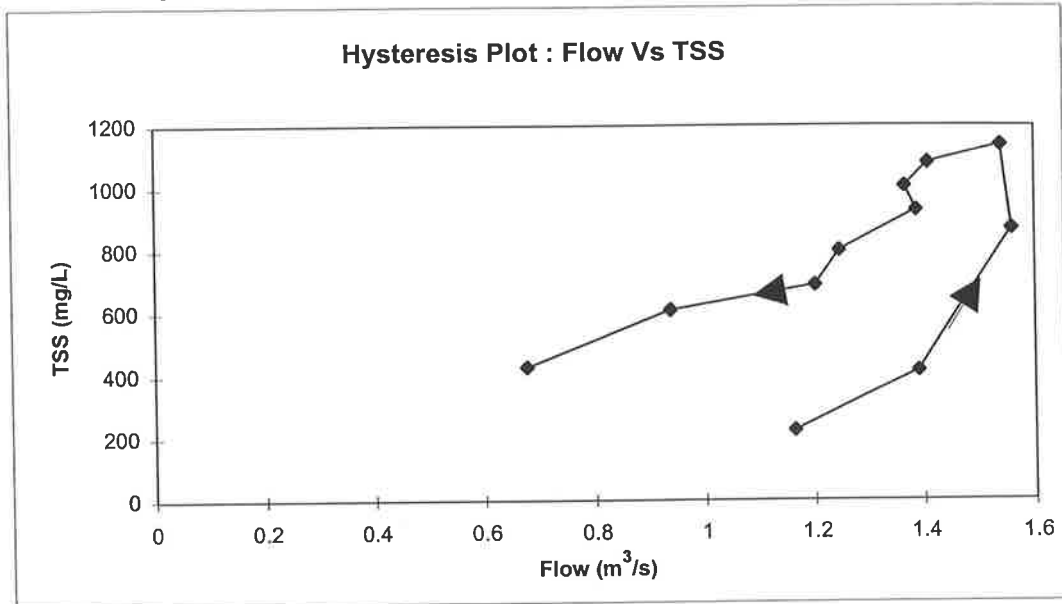
North Arm West Drain (AU504104)

Storm Date : 19/7/96



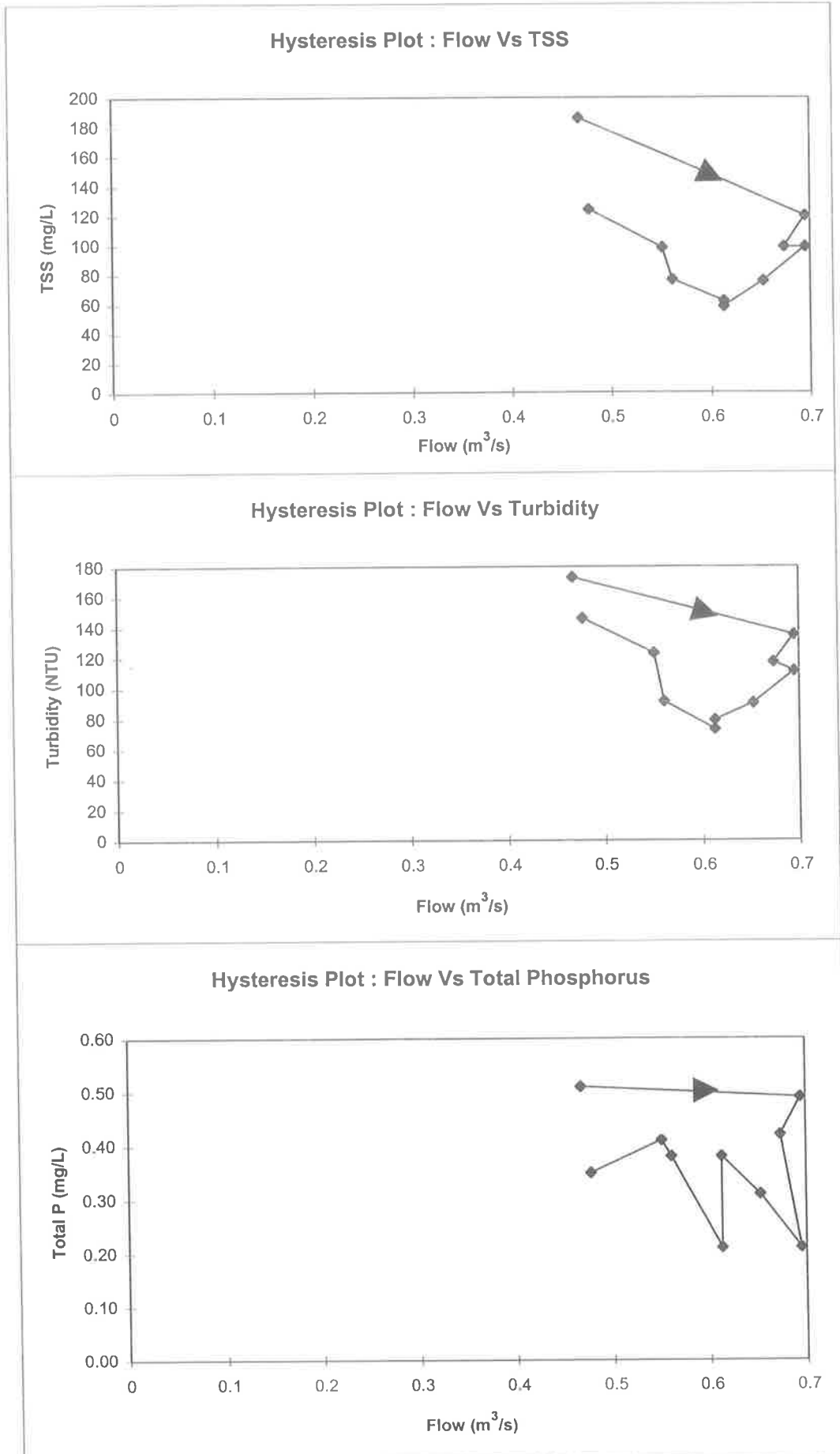
North Arm West Drain (AU504104)

Storm Date : 6/2/97



North Arm West Drain (AU504104)

Storm Date : 4/5/97



Appendix J

Event Mean Concentration and Event Load Results

Summary

Appendix J presents the event mean concentration and event load results for the North Arm East (AU504101), Hindmarsh Enfield Prospect (AU504102), Dunstan Road (AU504103), North Arm West (AU504104) and Eastern Parade (AU504201) Catchments.

AU504101 : North Arm East Drain

Event mean concentrations (mg/L)

Storm date	24/9/95	30/9/95	2/10/95	24/1/96	8/2/96	9/2/96	16/3/96	6-7/04/96	13/4/96	25/4/96	12(a)/05/96	12(b)/05/96
Runoff Volume (ML)	66.43	24.91	18.50	13.81	27.00	11.97	28.84	25.49	79.25	66.52	11.89	45.88
NUTRIENTS (mg/L)												
Ammonia as N	0.038	0.48	0.19	0.14	0.036	0.11	1.1	0.27	0.16	0.27	0.3	0.06
Organic Nitrogen	1.67	1.30	0.63	4.82	4.15	1.25	3.32	1.15	1.64	1.13	2.29	2.64
TKN as Nitrogen	1.71	1.78	0.82	4.96	4.19	1.36	4.42	1.42	1.8	1.4	2.59	2.7
Nitrate + Nitrite as N	0.27	0.26	0.34	0.54	0.29	0.26	0.02	0.33	0.25	0.42	0.54	0.26
Total Nitrogen	1.98	2.04	1.16	5.50	4.48	1.62	4.44	1.75	2.05	1.82	3.13	2.96
Filt. Reactive Phosphorus as P	0.045	0.107	0.035	0.024	0.021	0.047	0.278	0.114	0.044	0.095	0.137	0.055
Particulate Phosphorus	0.189	0.298	0.146	0.726	0.511	0.19	0.222	0.196	0.346	0.225	0.359	0.745
Phosphorus (Total as P)	0.234	0.405	0.181	0.75	0.532	0.237	0.5	0.31	0.39	0.32	0.496	0.8
METALS (mg/L)												
Aluminium (Al)-Total	3.46	1.02	0.417	4.58	3.69	0.993	1.68	1.16	4.59	1.48	1.41	5.53
Arsenic (Ar)- Inorganic	0.003	0.002	0.002	0.004	0.005	0.002	0.002	0.003	0.004	0.002	0.002	0.005
Cadmium (Cd)-Total	0.001	0.0014	0.0003	0.0011	0.0009	0.0005	0.0005	0.0018	0.0014	0.001	0.0009	0.0019
Chromium (Cr)-Total	0.026	0.007	0.008	0.028	0.03	0.011	0.017	0.007	0.014	0.005	0.008	0.021
Copper (Cu)- Total	0.081	0.028	0.034	0.077	0.082	0.032	0.052	0.035	0.059	0.025	N/A	N/A
Iron (Fe)- Total	4.08	1.37	0.469	4.42	4.26	0.994	1.71	0.754	4.36	1.22	1.64	6.36
Lead (Pb) - Total	0.24	0.12	0.042	0.334	0.36	0.106	0.056	0.067	0.325	0.072	0.09	0.345
Manganese (Mn)- Total	0.137	0.065	0.029	0.2	0.134	0.049	0.057	0.046	0.104	0.059	0.086	0.201
Mercury (Hg)- Total	0.0002	0.0004	0.0004	0.0005	0.0003	0.0001	0.0005	0.0001	0.0002	0.0001	0.0003	0.003
Nickel (Ni)- Total	0.033	0.014	0.02	0.012	0.008	0.004	0.007	0.009	0.009	0.004	0.009	0.017
Zinc (Zn)- Total	0.732	0.401	0.258	0.938	0.823	0.438	0.29	0.501	0.571	0.364	0.935	1.01
TSS (mg/L)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	27.1	319.9	62.7	99.6	529.4

Total Event Loads (kg)

Storm date	24/9/95	30/9/95	2/10/95	24/1/96	8/2/96	9/2/96	16/3/96	6-7/04/96	13/4/96	25/4/96	12(a)/05/96	12(b)/05/96
NUTRIENTS (kg)												
Ammonia as N	2.52	11.96	3.52	1.93	0.97	1.32	31.72	6.88	12.68	17.96	3.57	2.75
Organic Nitrogen	111.07	32.38	11.66	66.57	112.16	14.96	95.75	29.31	129.97	75.17	27.23	121.12
TKN as Nitrogen	113.60	44.34	15.17	68.50	113.13	16.28	127.47	36.20	142.65	93.13	30.80	123.88
Nitrate + Nitrite as N	17.94	6.48	6.29	7.46	7.83	3.11	0.59	8.41	19.81	27.94	6.42	11.93
Total Nitrogen	131.53	50.82	21.46	75.96	120.96	19.39	128.05	44.61	162.46	121.07	37.22	135.80
Filt. Reactive Phosphorus as P	2.99	2.67	0.65	0.33	0.57	0.56	8.02	2.91	3.49	6.32	1.63	2.52
Particulate Phosphorus	12.56	7.42	2.70	10.03	13.80	2.27	6.40	5.00	27.42	14.97	4.27	34.18
Phosphorus (Total as P)	15.54	10.09	3.35	10.36	14.36	2.84	14.42	7.90	30.91	21.29	5.90	36.70
METALS (kg)												
Aluminium (Al)-Total	229.85	25.41	7.71	63.25	99.63	11.89	48.45	29.57	363.76	98.45	16.76	253.72
Arsenic (Ar)- inorganic	0.20	0.05	0.04	0.06	0.14	0.02	0.06	0.08	0.32	0.13	0.02	0.23
Cadmium (Cd)-Total	0.07	0.03	0.01	0.02	0.02	0.01	0.01	0.05	0.11	0.07	0.01	0.09
Chromium (Cr)-Total	1.73	0.17	0.15	0.39	0.81	0.13	0.49	0.18	1.11	0.33	0.10	0.96
Copper (Cu)- Total	5.38	0.70	0.63	1.06	2.21	0.38	1.50	0.89	4.68	1.66	N/A	N/A
Iron (Fe)- Total	271.03	34.13	8.68	61.04	115.02	11.90	49.32	19.22	345.53	81.15	19.50	291.80
Lead (Pb) - Total	15.94	2.99	0.78	4.61	9.72	1.27	1.62	1.71	25.76	4.79	1.07	15.83
Manganese (Mn)- Total	9.10	1.62	0.54	2.76	3.62	0.59	1.64	1.17	8.24	3.92	1.02	9.22
Mercury (Hg)- Total	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.00	0.02	0.01	0.00	0.14
Nickel (Ni)- Total	2.19	0.35	0.37	0.17	0.22	0.05	0.20	0.23	0.71	0.27	0.11	0.78
Zinc (Zn)- Total	48.63	9.99	4.77	12.95	22.22	5.24	8.36	12.77	45.25	24.21	11.12	46.34
TSS (kg)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	691	25352	4171	1184	24289

AU504101 : North Arm East Drain

Event mean concentrations (mg/L)

Storm date	17-18/6/96	18/6/96	22/6/96	23/6/96	28/6/96	29/6/96	1/07/96	4/07/96	5-6/07/96	6(b)/07/96	16/07/96	18/7/96
Runoff Volume (ML)	15.09	50.62	27.40	17.31	32.93	40.89	4.35	90.90	8.45	2.23	39.23	11.09
NUTRIENTS (mg/L)												
Ammonia as N	0.28	0.16	0.25	0.15	0.11	0.066	0.15	0.1	0.1	0.074	0.16	0.1
Organic Nitrogen	1.15	0.94	1.71	0.77	1.48	0.81	0.93	0.34	1.06	0.68	0.83	1.61
TKN as Nitrogen	1.43	1.1	1.96	0.92	1.59	0.88	1.08	0.44	1.16	0.75	0.99	1.71
Nitrate + Nitrite as N	0.5	0.44	0.4	0.42	0.43	0.3	0.44	0.25	0.01	0.31	0.33	0.18
Total Nitrogen	1.93	1.54	2.36	1.34	2.02	1.18	1.52	0.69	1.17	1.06	1.32	1.89
Filt. Reactive Phosphorus as P	0.115	0.084	0.102	0.072	0.059	0.042	0.065	0.051	0.089	0.079	0.072	0.026
Particulate Phosphorus	0.165	0.149	0.37	0.127	0.215	0.133	0.175	0.065	0.191	0.109	0.146	0.346
Phosphorus (Total as P)	0.28	0.233	0.472	0.199	0.274	0.175	0.24	0.116	0.28	0.188	0.218	0.372
METALS (mg/L)												
Aluminium (Al)-Total	1.51	1.86	3.57	1.64	2.56	2.11	2.72	3	2.36	1.58	1.9	3.39
Arsenic (Ar)- Inorganic	0.001	0.001	0.005	0.004	0.004	0.004	0.003	0.003	0.002	0.001	0.003	0.004
Cadmium (Cd)-Total	0.0006	0.0004	0.0008	0.0003	0.0015	0.001	0.0005	0.0003	0.0004	0.0002	0.0004	0.0005
Chromium (Cr)-Total	0.009	0.01	0.011	0.005	0.009	0.007	0.016	0.008	0.005	0.005	0.01	0.013
Copper (Cu)- Total	0.024	0.017	0.056	0.03	0.027	0.022	0.029	0.031	0.027	0.016	0.03	0.041
Iron (Fe)- Total	1.51	1.62	3.76	1.39	2.34	1.78	2.44	2.68	2.21	1.34	1.86	3.35
Lead (Pb) - Total	0.102	0.095	0.33	0.078	0.121	0.073	0.126	0.109	0.156	0.069	0.086	0.15
Manganese (Mn)- Total	0.064	0.044	0.134	0.048	0.06	0.046	0.061	0.074	0.064	0.034	0.055	0.111
Mercury (Hg)- Total	0.0001	0.0001	0.0002	0.0001	0.0001	0.0001	0.0002	0.0002	0.0001	0.0001	0.0001	0.0002
Nickel (Ni)- Total	0.005	0.004	0.01	0.003	0.007	0.004	0.007	0.008	0.007	0.006	0.003	0.007
Zinc (Zn)- Total	0.431	0.398	0.577	0.333	0.448	0.349	0.495	0.425	0.454	0.28	0.378	0.461
TSS (mg/L)	92.4	68	256.9	76.7	112.9	83.4	96.9	132.2	122.9	58.3	83.4	187.8

Total Event Loads (kg)

Storm date	17-18/6/96	18/6/96	22/6/96	23/6/96	28/6/96	29/6/96	1/07/96	4/07/96	5-6/07/96	6(b)/07/96	16/07/96	18/7/96
NUTRIENTS (kg)												
Ammonia as N	4.23	8.10	6.85	2.60	3.62	2.70	0.65	9.09	0.85	0.17	6.28	1.11
Organic Nitrogen	17.35	47.58	46.85	13.33	48.74	33.28	4.05	30.91	8.96	1.51	32.56	17.85
TKN as Nitrogen	21.58	55.68	53.70	15.93	52.36	35.98	4.70	40.00	9.80	1.67	38.84	18.96
Nitrate + Nitrite as N	7.55	22.27	10.96	7.27	14.16	12.27	1.91	22.73	0.08	0.69	12.95	2.00
Total Nitrogen	29.12	77.95	64.66	23.20	66.52	48.25	6.61	62.72	9.89	2.36	51.78	20.96
Filt. Reactive Phosphorus as P	1.74	4.25	2.79	1.25	1.94	1.72	0.28	4.84	0.75	0.18	2.82	0.29
Particulate Phosphorus	2.49	7.54	10.14	2.20	7.08	5.44	0.76	5.91	1.61	0.24	5.73	3.84
Phosphorus (Total as P)	4.23	11.79	12.93	3.44	9.02	7.16	1.04	10.54	2.37	0.42	8.55	4.13
METALS (kg)												
Aluminium (Al)-Total	22.79	94.15	97.82	28.39	84.30	86.28	11.83	272.70	19.94	3.52	74.54	37.60
Arsenic (Ar)- Inorganic	0.02	0.05	0.14	0.07	0.13	0.16	0.01	0.27	0.02	0.00	0.12	0.04
Cadmium (Cd)-Total	0.01	0.02	0.02	0.01	0.05	0.04	0.00	0.03	0.00	0.00	0.02	0.01
Chromium (Cr)-Total	0.14	0.51	0.30	0.09	0.30	0.29	0.07	0.73	0.04	0.01	0.39	0.14
Copper (Cu)- Total	0.36	0.86	1.53	0.52	0.89	0.90	0.13	2.82	0.23	0.04	1.1769	0.45469
Iron (Fe)- Total	22.79	82.00	103.02	24.06	77.06	72.78	10.61	243.61	18.67	2.99	72.97	37.15
Lead (Pb) - Total	1.54	4.81	9.04	1.35	3.98	2.98	0.55	9.91	1.32	0.15	3.37	1.66
Manganese (Mn)- Total	0.97	2.23	3.67	0.83	1.98	1.88	0.27	6.73	0.54	0.08	2.16	1.23
Mercury (Hg)- Total	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
Nickel (Ni)- Total	0.08	0.20	0.27	0.05	0.23	0.16	0.03	0.73	0.06	0.01	0.12	0.08
Zinc (Zn)- Total	6.50	20.15	15.81	5.76	14.75	14.27	2.15	38.63	3.84	0.62	14.83	5.11
TSS (kg)	1394	3442	7039	1328	3718	3410	422	12017	1039	130	3272	2083

AU504101 : North Arm East Drain

Event mean concentrations (mg/L)

Storm date	19/7/96	28-29/7/96	31/7/96	26-27/08/96	6/12/96	14/1/97	21/01/97	6/02/97	2/05/97	2-3/5/97	3(b)/5/97	6/05/97
Runoff Volume (ML)	67.28	14.17	105.64	103.10	49.43	6.27	144.97	170.06	3.93	21.88	11.84	10.74
NUTRIENTS (mg/L)												
Ammonia as N	0.033	0.19	0.082	0.071	0.7	0.66895	N/A	0.05	0.86	0.12	0.17	0.016
Organic Nitrogen	1.38	1.36	1.16	1.16	3.51	5.40	N/A	2.15	7.19	2.54	1.89	1.24
TKN as Nitrogen	1.41	1.55	1.24	1.23	4.21	6.0694	N/A	2.2	8.05	2.66	2.06	1.26
Nitrate + Nitrite as N	0.28	0.418	0.313	0.441	0.592	0.014231	N/A	0.116	0.101	0.384	0.342	0.277
Total Nitrogen	1.69	1.97	1.55	1.67	4.80	6.08	N/A	2.32	8.15	3.04	2.40	1.54
Filt. Reactive Phosphorus as P	0.051	0.088	0.073	0.128	0.083	0.297391	N/A	0.051	0.342	0.15	0.125	0.082
Particulate Phosphorus	0.302	0.273	0.241	0.216	0.557	0.556109	N/A	0.369	1.598	0.325	0.307	0.173
Phosphorus (Total as P)	0.353	0.361	0.314	0.344	0.64	0.85349	N/A	0.42	1.94	0.475	0.432	0.255
METALS (mg/L)												
Aluminium (Al)-Total	4.74	2.7	3.51	2.39	2.35	0.908568	1.3	3.83	3.37	1.62	1.88	2.25
Arsenic (Ar)- Inorganic	0.005	0.004	0.003	0.003	0.004	0.001789	0.003	0.005	0.003	0.003	0.004	0.003
Cadmium (Cd)-Total	0.0008	0.0005	0.0004	0.0005	0.0012	0.0013936	0.0003	0.0015	0.0015	0.0009	0.0011	0.0006
Chromium (Cr)-Total	0.014	0.008	0.008	0.007	0.022	0.005523	0.012	0.01	0.038	0.03	0.036	0.006
Copper (Cu)- Total	0.041	0.047	0.026	0.035	0.058	0.061503	0.076	0.051	0.087	0.055	0.047	0.021
Iron (Fe)- Total	4.5	2.71	3.01	2.17	2.49	1.40508	1.06	3.84	4.24	1.74	2.23	2.03
Lead (Pb) - Total	0.177	0.112	0.124	0.111	0.164	0.144809	0.046	0.224	0.234	0.117	0.143	0.1
Manganese (Mn)- Total	0.132	0.084	0.078	0.072	0.159	0.273523	0.045	0.117	0.19	0.056	0.062	0.054
Mercury (Hg)- Total	0.0002	0.0001	0.0001	0.0003	0.0003	0.0001001	0.0005	0.0001	0.0002	0.0001	0.0001	0.0001
Nickel (Ni)- Total	0.006	0.006	0.008	0.004	0.008	0.010318	0.004	0.007	0.01	0.005	0.007	0.005
Zinc (Zn)- Total	0.561	0.414	0.371	0.346	0.713	0.824459	0.22	0.616	0.852	0.527	0.366	0.358
TSS (mg/L)	254.3	120.3	172.8	128.2	161.5	N/A	N/A	270.9	631.9	159.5	71.2	123.3

Total Event Loads (kg)

Storm date	19/7/96	28-29/7/96	31/7/96	26-27/08/96	6/12/96	14/1/97	21/01/97	6/02/97	2/05/97	2-3/5/97	3(b)/5/97	3(b)/5/97
NUTRIENTS (kg)												
Ammonia as N	2.22	2.69	8.66	7.32	34.80	4.19	N/A	8.50	3.38	2.63	2.01	0.17
Organic Nitrogen	92.64	19.27	122.33	119.49	173.50	33.86	N/A	365.63	28.26	55.58	22.38	13.36
TKN as Nitrogen	94.86	21.96	130.99	126.81	208.10	38.06	N/A	374.13	31.64	58.20	24.39	13.53
Nitrate + Nitrite as N	18.84	5.92	33.07	45.47	29.26	0.09	N/A	19.73	0.40	8.40	4.05	2.97
Total Nitrogen	113.70	27.89	164.06	172.28	237.36	38.14	N/A	393.86	32.03	66.60	28.44	16.51
Filt. Reactive Phosphorus as P	3.43	1.25	7.71	13.20	4.10	1.86	N/A	8.67	1.34	3.28	1.48	0.88
Particulate Phosphorus	20.32	3.87	25.46	22.27	27.53	3.49	N/A	62.75	6.28	7.11	3.63	1.86
Phosphorus (Total as P)	23.75	5.12	33.17	35.47	31.64	5.35	N/A	71.43	7.62	10.39	5.11	2.74
METALS (kg)												
Aluminium (Al)-Total	318.91	38.26	370.80	246.41	116.16	5.68	188.46	651.33	13.24	35.45	22.26	24.17
Arsenic (Ar)- Inorganic	0.34	0.06	0.32	0.31	0.20	0.01	0.43	0.85	0.01	0.07	0.05	0.03
Cadmium (Cd)-Total	0.05	0.01	0.04	0.05	0.06	0.01	0.04	0.26	0.01	0.02	0.01	0.01
Chromium (Cr)-Total	0.94	0.11	0.85	0.72	1.09	0.03	1.74	1.70	0.15	0.66	0.43	0.06
Copper (Cu)- Total	2.76	0.67	2.75	3.61	2.87	0.39	11.02	8.67	0.34	1.20	0.55648	0.22554
Iron (Fe)- Total	302.76	38.40	317.98	223.73	123.08	8.81	153.67	653.03	16.66	38.07	28.40	21.80
Lead (Pb) - Total	11.91	1.59	13.10	11.44	8.11	0.91	6.67	38.09	0.92	2.56	1.69	1.07
Manganese (Mn)- Total	8.88	1.19	8.24	7.42	7.86	1.71	6.52	19.90	0.75	1.23	0.73	0.58
Mercury (Hg)- Total	0.01	0.00	0.01	0.03	0.01	0.00	0.07	0.02	0.00	0.00	0.00	0.00
Nickel (Ni)- Total	0.40	0.09	0.85	0.41	0.40	0.06	0.58	1.19	0.04	0.11	0.08	0.05
Zinc (Zn)- Total	37.74	5.87	39.19	35.67	35.24	5.17	31.89	104.76	3.35	11.53	4.33	3.84
TSS (kg)	17109	1705	18255	13217	7983	N/A	N/A	46069	2483	3490	843	1324

AU504102 : Hindmarsh Enfield Prospect Drain**Concentrations (mg/L)**

Storm date	6/04/95	8/02/96	10/02/96	16/3/96	7/04/96	13/4/96	25/4/96	12/05/96	1/06/96	6/12/96	16/01/97	22/01/97	7/02/97
Storm Volume (ML)	9.26	5.13	5.25	5.00	10.11	43.54	7.90	6.12	11.22	21.3	4.91	69.74	72.96
NUTRIENTS (mg/L)													
Ammonia as N	0.021	0.024	0.12	4.2	0.29	0.14	0.15	0.15	0.13	0.80	1.20	N/A	0.04
Organic Nitrogen	0.53	1.53	0.71	5.70	1.07	0.73	1.25	0.88	1.78	2.07	3.10	N/A	1.27
TKN as Nitrogen	0.55	1.55	0.83	9.9	1.36	0.87	1.4	1.03	1.91	2.87	4.30	N/A	1.30
Nitrate + Nitrite as N	0.06	0.2	0.01	0.01	0.01	0.24	0.17	0.12	0.41	0.01	0.01	N/A	0.01
Total Nitrogen	0.61	1.75	0.84	9.91	1.37	1.11	1.57	1.15	2.32	2.88	4.31	N/A	1.31
Filt. Reactive Phosphorus as P	0.145	0.176	0.132	0.013	0.338	0.156	0.305	0.198	0.26	0.34	0.11	N/A	0.10
Particulate Phosphorus	0.07	0.174	0.085	0.747	0.214	0.139	0.125	0.141	0.304	0.28	1.027	N/A	0.153
Phosphorus (Total as P)	0.215	0.35	0.217	0.76	0.552	0.295	0.43	0.339	0.564	0.62	1.14	N/A	0.25
METALS (mg/L)													
Aluminium (Al)-Total	0.652	0.645	0.323	2.49	0.82	1.31	0.517	1.04	3.01	0.606	0.180	0.123	1.540
Arsenic (Ar)- Inorganic	0.001	0.004	0.003	0.005	0.003	0.002	0.003	0.002	0.005	0.005	0.019	0.005	0.005
Cadmium (Cd)-Total	0.0002	0.0005	0.0005	0.0006	0.0017	0.0006	0.0007	0.0004	0.0004	0.0006	0.0004	0.0002	0.0005
Chromium (Cr)-Total	0.021	0.01	0.01	0.018	0.008	0.005	0.005	0.005	0.009	0.005	0.005	0.010	0.005
Copper (Cu)- Total	0.046	0.044	0.031	0.114	0.31	0.021	0.019	N/A	0.027	0.040	0.068	0.024	0.027
Iron (Fe)- Total	0.548	0.49	0.182	2.1	0.444	0.913	0.328	2.66	2.94	0.620	0.582	0.282	1.540
Lead (Pb) - Total	0.018	0.036	0.014	0.052	0.03	0.029	0.015	0.045	0.065	0.046	0.055	0.008	0.042
Manganese (Mn)- Total	0.013	0.041	0.011	0.14	0.079	0.021	0.023	0.047	0.071	0.065	0.632	0.011	0.058
Mercury (Hg)- Total	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0005	0.0001	0.0001	0.0001	0.0003	0.0004
Nickel (Ni)- Total	0.03	0.003	0.002	0.007	0.005	0.002	0.002	0.01	0.01	0.004	0.010	0.002	0.006
Zinc (Zn)- Total	0.104	0.143	0.118	0.381	0.196	0.244	0.143	0.33	0.207	0.214	0.258	0.081	0.214
TSS (mg/L)	N/A	20.6	5.8	N/A	8.8	108.2	8	20.2	109	32.7	N/A	N/A	264.5

Total Loads (kg)

Storm date	6/04/95	8/02/96	10/02/96	16/3/96	7/04/96	13/4/96	25/4/96	12/05/96	1/06/96	6/12/96	16/01/97	22/01/97	7/02/97
NUTRIENTS (kg)													
Ammonia as N	0.19	0.12	0.63	21.00	2.93	6.10	1.19	0.92	1.46	17.04	5.89	N/A	2.55
Organic Nitrogen	4.90	7.83	3.73	28.50	10.82	31.78	9.88	5.39	19.97	44.09	15.22	N/A	92.29
TKN as Nitrogen	5.09	7.95	4.36	49.50	13.75	37.88	11.06	6.30	21.43	61.13	21.11	N/A	94.85
Nitrate + Nitrite as N	0.56	1.03	0.05	0.05	0.10	10.45	1.34	0.73	4.60	0.28	0.03	N/A	0.51
Total Nitrogen	5.65	8.98	4.41	49.55	13.85	48.33	12.40	7.04	26.03	61.41	21.15	N/A	95.36
Filt. Reactive Phosphorus as P	1.34	0.90	0.69	0.07	3.42	6.79	2.41	1.21	2.92	7.24	0.55	N/A	7.08
Particulate Phosphorus	0.65	0.89	0.45	3.74	2.16	6.05	0.99	0.86	3.41	5.96	5.04	N/A	11.16
Phosphorus (Total as P)	1.99	1.80	1.14	3.80	5.58	12.84	3.40	2.07	6.33	13.21	5.60	N/A	18.24
METALS (kg)													
Aluminium (Al)-Total	6.04	3.309	1.696	12.450	8.290	57.037	4.084	6.365	33.772	12.908	0.884	8.578	112.358
Arsenic (Ar)- Inorganic	0.01	0.021	0.016	0.025	0.030	0.087	0.024	0.012	0.056	0.107	0.093	0.349	0.365
Cadmium (Cd)-Total	0.00	0.003	0.003	0.003	0.017	0.026	0.0055	0.0024	0.0045	0.013	0.002	0.014	0.036
Chromium (Cr)-Total	0.19	0.051	0.053	0.090	0.081	0.218	0.040	0.031	0.101	0.107	0.025	0.697	0.365
Copper (Cu)- Total	0.43	0.226	0.163	0.570	3.134	0.914	0.150	N/A	0.303	0.852	0.334	1.674	1.970
Iron (Fe)- Total	5.07	2.514	0.956	10.500	4.489	39.752	2.591	16.279	32.987	13.206	2.858	19.667	112.358
Lead (Pb) - Total	0.17	0.185	0.074	0.260	0.303	1.263	0.119	0.275	0.729	0.980	0.270	0.558	3.064
Manganese (Mn)- Total	0.12	0.210	0.058	0.700	0.799	0.914	0.182	0.288	0.797	1.385	3.103	0.767	4.232
Mercury (Hg)- Total	0.00	0.001	0.001	0.001	0.001	0.004	0.0008	0.0031	0.0011	0.002	0.000	0.021	0.029
Nickel (Ni)- Total	0.28	0.015	0.011	0.035	0.051	0.087	0.016	0.061	0.112	0.085	0.049	0.139	0.438
Zinc (Zn)- Total	0.96	0.734	0.620	1.905	1.982	10.624	1.130	2.020	2.323	4.558	1.267	5.649	15.613
TSS (mg/L)	N/A	105.7	30.5	N/A	89.0	4711.0	63.2	123.6	1223.0	696.5	N/A	N/A	19297.9

AU504103 : Dunstan Road Drain

Concentrations (mg/L)

Storm date	30/01/95	6/04/95	13/04/96	12/05/96	22/06/96	23/06/96	28/06/96	4/07/96	5/07/96	11/07/96	19/07/96	20/07/96	Storm date
Storm Volume (ML)	2.5	1.2	10.61	2.32	6.87	3.12	0.49	6.73	0.57	1.57	1.56	1.86	Storm Volume (ML)
NUTRIENTS (mg/L)													
Ammonia as N	2.7	0.340	0.770	0.390	0.310	5.900	N/A	0.070	0.006	0.005	0.11	0.07	Ammonia as N
Organic Nitrogen	16.00	1.09	3.43	2.61	10.69	58.20	N/A	1.13	0.45	1.25	0.46	3.43	Organic Nitrogen
TKN as Nitrogen	18.700	1.430	4.200	3.000	11.000	64.100	5.600	1.200	0.460	1.250	0.57	3.5	TKN as Nitrogen
Nitrate + Nitrite as N	0.010	0.220	0.140	0.480	0.350	0.010	0.410	0.330	0.280	0.310	0.45	0.268	Nitrate + Nitrite as N
Total Nitrogen	18.71	1.65	4.34	3.48	11.35	64.11	6.01	1.53	0.74	1.56	1.02	3.77	Total Nitrogen
Filt. Reactive Phosphorus as P	0.074	0.400	0.265	0.150	0.333	3.930	0.296	0.109	0.111	0.100	0.18	0.133	Filt. Reactive Phosphorus as P
Particulate Phosphorus	2.246	0.410	1.255	0.560	4.447	6.770	0.284	0.329	0.047	0.307	0.01	1.027	Particulate Phosphorus
Phosphorus (Total as P)	2.320	0.810	1.520	0.710	4.780	10.7	0.560	0.438	0.158	0.407	0.19	1.16	Phosphorus (Total as P)
METALS (mg/L)													
Aluminium (Al)-Total	0.005	11.800	9.720	1.610	10.400	6.790	2.740	4.620	3.190	2.550	9.510	12.400	Aluminium (Al)-Total
Arsenic (Ar)- Inorganic	0.011	0.008	0.004	0.002	0.007	0.006	0.005	0.002	0.002	0.003	0.005	0.008	Arsenic (Ar)- Inorganic
Cadmium (Cd)-Total	0.0032	0.0003	0.0028	0.0011	0.0045	0.0078	0.0010	0.0006	0.0005	0.0005	0.0014	0.0016	Cadmium (Cd)-Total
Chromium (Cr)-Total	0.005	0.034	0.035	0.007	0.048	0.039	0.010	0.012	0.017	0.010	0.030	0.033	Chromium (Cr)-Total
Copper (Cu)- Total	0.005	0.044	0.146	N/A	0.224	0.292	0.044	0.047	0.025	0.032	0.089	0.094	Copper (Cu)- Total
Iron (Fe)- Total	0.005	10.800	10.500	1.980	12.000	8.800	2.750	4.430	2.880	2.400	9.880	11.900	Iron (Fe)- Total
Lead (Pb) - Total	0.244	0.082	0.188	0.114	0.510	0.580	0.071	0.099	0.071	0.079	0.238	0.293	Lead (Pb) - Total
Manganese (Mn)- Total	0.005	0.175	0.223	0.110	0.361	0.638	0.077	0.100	0.064	0.069	0.225	0.342	Manganese (Mn)- Total
Mercury (Hg)- Total	0.0017	0.0001	0.0001	0.0001	0.0005	0.0009	0.0001	0.0001	0.0001	0.0001	0.0001	0.0003	Mercury (Hg)- Total
Nickel (Ni)- Total	0.010	0.067	0.016	0.012	0.020	0.018	0.004	0.010	0.007	0.150	0.019	0.023	Nickel (Ni)- Total
Zinc (Zn)- Total	0.005	0.367	0.918	1.060	1.830	2.050	0.436	0.406	0.296	0.381	0.747	0.971	Zinc (Zn)- Total
TSS (mg/L)	N/A	N/A	521.9	1232.0	861.0	1148.0	125.5	206.9	104.5	161.2	293.0	741.0	TSS (mg/L)

Total Loads (kg)

Total Loads (kg)

Storm date	30/01/95	6/04/96	13/04/96	12/05/96	22/06/96	23/06/96	28/06/96	4/07/96	5/07/96	11/07/96	19/07/96	20/07/96	Storm date
NUTRIENTS (kg)													
Ammonia as N	6.75	0.41	8.17	0.90	2.13	18.41	N/A	0.47	0.00	0.01	0.17	0.13	Ammonia as N
Organic Nitrogen	40.00	1.31	36.39	6.06	73.44	181.58	N/A	7.60	0.26	1.95	0.72	6.38	Organic Nitrogen
TKN as Nitrogen	46.75	1.72	44.56	6.96	75.57	199.99	2.74	8.08	0.26	1.96	0.89	6.51	TKN as Nitrogen
Nitrate + Nitrite as N	0.03	0.26	1.49	1.11	2.40	0.03	0.20	2.22	0.16	0.49	0.71	0.50	Nitrate + Nitrite as N
Total Nitrogen	46.78	1.98	46.05	8.07	77.97	200.02	2.94	10.30	0.42	2.45	1.59	7.01	Total Nitrogen
Filt. Reactive Phosphorus as P	0.19	0.48	2.81	0.35	2.29	12.26	0.15	0.73	0.06	0.16	0.27	0.25	Filt. Reactive Phosphorus as P
Particulate Phosphorus	5.62	0.49	13.32	1.30	30.55	21.12	0.13	2.21	0.03	0.48	0.02	1.91	Particulate Phosphorus
Phosphorus (Total as P)	5.80	0.97	16.13	1.65	32.84	33.38	0.27	2.95	0.09	0.64	0.30	2.16	Phosphorus (Total as P)
METALS (kg)													
Aluminium (Al)-Total	0.01	14.160	103.129	3.735	71.45	21.18	1.343	31.093	1.818	4.004	14.836	23.064	Aluminium (Al)-Total
Arsenic (Ar)- Inorganic	0.03	0.010	0.042	0.005	0.05	0.02	0.002	0.013	0.001	0.005	0.008	0.015	Arsenic (Ar)- Inorganic
Cadmium (Cd)-Total	0.01	0.000	0.030	0.003	0.03	0.02	0.0005	0.0040	0.0003	0.0008	0.0022	0.0030	Cadmium (Cd)-Total
Chromium (Cr)-Total	0.01	0.041	0.371	0.016	0.33	0.12	0.005	0.081	0.010	0.016	0.047	0.081	Chromium (Cr)-Total
Copper (Cu)- Total	0.01	0.053	1.549	N/A	1.54	0.91	0.022	0.316	0.014	0.050	0.139	0.175	Copper (Cu)- Total
Iron (Fe)- Total	0.01	12.960	111.405	4.594	82.44	27.46	1.348	29.814	1.642	3.768	15.413	22.134	Iron (Fe)- Total
Lead (Pb) - Total	0.61	0.098	1.995	0.264	3.50	1.81	0.035	0.666	0.040	0.124	0.371	0.545	Lead (Pb) - Total
Manganese (Mn)- Total	0.01	0.210	2.366	0.255	2.48	1.99	0.038	0.673	0.036	0.108	0.351	0.536	Manganese (Mn)- Total
Mercury (Hg)- Total	0.00	0.0001	0.0011	0.0002	0.00	0.00	0.0000	0.0007	0.0001	0.0002	0.0002	0.0006	Mercury (Hg)- Total
Nickel (Ni)- Total	0.03	0.080	0.170	0.028	0.14	0.06	0.002	0.067	0.004	0.236	0.030	0.043	Nickel (Ni)- Total
Zinc (Zn)- Total	0.01	0.440	9.740	2.459	12.57	6.40	0.214	2.732	0.169	0.567	1.165	1.808	Zinc (Zn)- Total
TSS (kg)	N/A	N/A	5537.4	2858.2	5915.1	3581.8	61.5	1392.4	59.6	253.1	457.1	1378.3	TSS (kg)

AU504104 : North Arm West Drain

Concentrations (mg/L)

Storm date	30/01/95	6/04/96	30/09/95	8/02/96	23/06/96	26/07/96	6/02/97	4/05/97	Storm date
Storm Volume (ML)	8.76	3.42	3.1	6.12	10.95	28.46	11.66	4.79	Storm Volume (ML)
NUTRIENTS (mg/L)									
Ammonia as N	0.49	0.036	0.140	0.018	0.170	0.018	0.24	0.160	Ammonia as N
Organic Nitrogen	2.15	0.99	0.76	2.22	1.10	1.04	2.56	1.53	Organic Nitrogen
TKN as Nitrogen	2.640	1.030	0.900	2.240	1.270	1.080	2.800	1.690	TKN as Nitrogen
Nitrate + Nitrite as N	0.040	0.100	0.230	0.350	0.410	0.700	0.121	0.341	Nitrate + Nitrite as N
Total Nitrogen	2.680	1.130	1.130	2.590	1.680	1.760	2.921	2.031	Total Nitrogen
Filt. Reactive Phosphorus as P	0.035	0.121	0.026	0.006	0.104	0.106	0.054	0.100	Filt. Reactive Phosphorus as P
Particulate Phosphorus	0.405	0.199	0.158	0.338	0.277	0.252	0.566	0.231	Particulate Phosphorus
Phosphorus (Total as P)	0.440	0.320	0.184	0.344	0.381	0.358	0.620	0.331	Phosphorus (Total as P)
METALS (mg/L)									
Aluminium (Al)-Total	0.005	2.870	0.801	1.520	4.310	3.000	9.950	2.210	Aluminium (Al)-Total
Arsenic (Ar)- Inorganic	0.010	0.004	0.003	0.004	0.003	0.003	0.007	0.001	Arsenic (Ar)- Inorganic
Cadmium (Cd)-Total	0.0022	0.0005	0.0007	0.0006	0.0007	0.0009	0.0006	0.0006	Cadmium (Cd)-Total
Chromium (Cr)-Total	0.005	0.060	0.011	0.038	0.017	0.014	0.039	0.040	Chromium (Cr)-Total
Copper (Cu)- Total	0.005	0.068	0.021	0.044	0.036	0.033	0.070	0.051	Copper (Cu)- Total
Iron (Fe)- Total	0.005	2.960	1.610	1.880	4.150	3.020	13.000	2.370	Iron (Fe)- Total
Lead (Pb) - Total	0.027	0.042	0.032	0.055	0.086	0.080	0.024	0.064	Lead (Pb) - Total
Manganese (Mn)- Total	0.005	0.085	0.084	0.151	0.088	0.070	0.268	0.128	Manganese (Mn)- Total
Mercury (Hg)- Total	0.0018	0.0001	0.0004	0.0001	0.0001	0.0001	0.0001	0.0001	Mercury (Hg)- Total
Nickel (Ni)- Total	0.010	0.048	0.020	0.024	0.007	0.022	0.020	0.014	Nickel (Ni)- Total
Zinc (Zn)- Total	0.005	0.397	0.189	0.322	0.304	0.381	0.604	0.324	Zinc (Zn)- Total
TSS (mg/L)	N/A	N/A	N/A	54.5	152.4	131.7	680.9	72.9	TSS (mg/L)

Total Loads (kg)

Storm date	30/01/95	6/04/96	30/09/95	8/02/96	23/06/96	26/07/96	6/02/97	4/05/97	Storm date
NUTRIENTS (kg)									
Ammonia as N	4.292	0.123	0.434	0.110	1.862	0.512	2.798	0.766	Ammonia as N
Organic Nitrogen	18.834	3.399	2.356	13.599	12.045	29.655	29.850	7.329	Organic Nitrogen
TKN as Nitrogen	23.126	3.523	2.790	13.709	13.907	30.168	32.848	8.095	TKN as Nitrogen
Nitrate + Nitrite as N	0.350	0.342	0.713	2.142	4.490	19.922	1.411	1.633	Nitrate + Nitrite as N
Total Nitrogen	23.477	3.865	3.503	15.851	18.396	50.090	34.059	9.728	Total Nitrogen
Filt. Reactive Phosphorus as P	0.307	0.414	0.081	0.037	1.139	3.017	0.630	0.479	Filt. Reactive Phosphorus as P
Particulate Phosphorus	3.548	0.681	0.490	2.069	3.033	7.172	6.600	1.106	Particulate Phosphorus
Phosphorus (Total as P)	3.854	1.094	0.570	2.105	4.172	10.189	7.229	1.585	Phosphorus (Total as P)
METALS (kg)									
Aluminium (Al)-Total	0.044	9.815	2.483	9.302	47.195	85.380	116.017	10.586	Aluminium (Al)-Total
Arsenic (Ar)- Inorganic	0.088	0.014	0.009	0.024	0.033	0.085	0.082	0.005	Arsenic (Ar)- Inorganic
Cadmium (Cd)-Total	0.019	0.0017	0.0022	0.0037	0.008	0.026	0.0070	0.003	Cadmium (Cd)-Total
Chromium (Cr)-Total	0.044	0.205	0.034	0.233	0.186	0.398	0.455	0.192	Chromium (Cr)-Total
Copper (Cu)- Total	0.044	0.233	0.065	0.269	0.394	0.939	0.816	0.244	Copper (Cu)- Total
Iron (Fe)- Total	0.044	10.123	4.991	11.506	45.443	85.949	151.580	11.352	Iron (Fe)- Total
Lead (Pb) - Total	0.237	0.144	0.099	0.337	0.942	2.277	0.260	0.307	Lead (Pb) - Total
Manganese (Mn)- Total	0.044	0.291	0.260	0.924	0.964	1.992	3.125	0.613	Manganese (Mn)- Total
Mercury (Hg)- Total	0.016	0.0003	0.0012	0.0006	0.001	0.003	0.0012	0.000	Mercury (Hg)- Total
Nickel (Ni)- Total	0.088	0.164	0.062	0.147	0.077	0.626	0.233	0.067	Nickel (Ni)- Total
Zinc (Zn)- Total	0.044	1.358	0.586	1.971	3.329	10.843	7.043	1.552	Zinc (Zn)- Total
TSS (kg)	N/A	N/A	N/A	333.5	1668.8	3748.2	7939.3	349.2	TSS (kg)

AU504105 : Eastern Parade Drain (Gillman)**Concentrations (mg/L)**

Storm date	6/12/96	16/01/97	22/01/97	7/02/97	3/05/97	4/05/97	Storm date
Storm Volume (ML)							Storm Volume (ML)
NUTRIENTS (mg/L)							NUTRIENTS (mg/L)
Ammonia as N	1.48	0.330	N/A	0.078	1.200	0.110	Ammonia as N
Organic Nitrogen	17.24	2.27	N/A	1.72	48.60	55.99	
TKN as Nitrogen	18.72	2.6	N/A	1.8	49.80	56.10	TKN as Nitrogen
Nitrate + Nitrite as N	0.012	0.122	N/A	0.075	0.023	0.025	Nitrate + Nitrite as N
Total Nitrogen	18.73	2.72	N/A	1.88	49.82	56.13	
Filt. Reactive Phosphorus as P	0.923	1.05	N/A	0.126	0.528	0.908	Filt. Reactive Phosphorus as P
Particulate Phosphorus	8.93	0.03	N/A	0.37	13.07	13.29	
Phosphorus (Total as P)	9.85	1.08	N/A	0.50	13.600	14.2	Phosphorus (Total as P)
METALS (mg/L)							METALS (mg/L)
Aluminium (Al)-Total	11.670	0.458	2.330	2.200	41.300	29.600	Aluminium (Al)-Total
Arsenic (Ar)- Inorganic	0.001	0.004	0.007	0.005	0.001	0.001	Arsenic (Ar)- Inorganic
Cadmium (Cd)-Total	0.0260	0.0114	0.0010	0.0010	0.0034	0.0165	Cadmium (Cd)-Total
Chromium (Cr)-Total	0.135	0.005	0.020	0.012	0.226	0.179	Chromium (Cr)-Total
Copper (Cu)- Total	0.383	0.043	0.075	0.077	1.230	1.040	Copper (Cu)- Total
Iron (Fe)- Total	19.540	1.300	2.910	2.460	102.000	52.500	Iron (Fe)- Total
Lead (Pb) - Total	1.152	0.095	0.168	0.167	4.200	3.530	Lead (Pb) - Total
Manganese (Mn)- Total	0.573	0.126	0.086	0.089	1.730	1.270	Manganese (Mn)- Total
Mercury (Hg)- Total	0.0003	0.0001	0.0003	0.0002	0.0012	0.0010	Mercury (Hg)- Total
Nickel (Ni)- Total	0.027	0.006	0.006	0.006	0.149	0.109	Nickel (Ni)- Total
Zinc (Zn)- Total	5.010	0.653	0.757	0.590	54.400	24.400	Zinc (Zn)- Total

Appendix K

Event Mean Concentration Probability Curves

Summary

Appendix K outlines the concentration probability curves derived from the event mean concentration results.

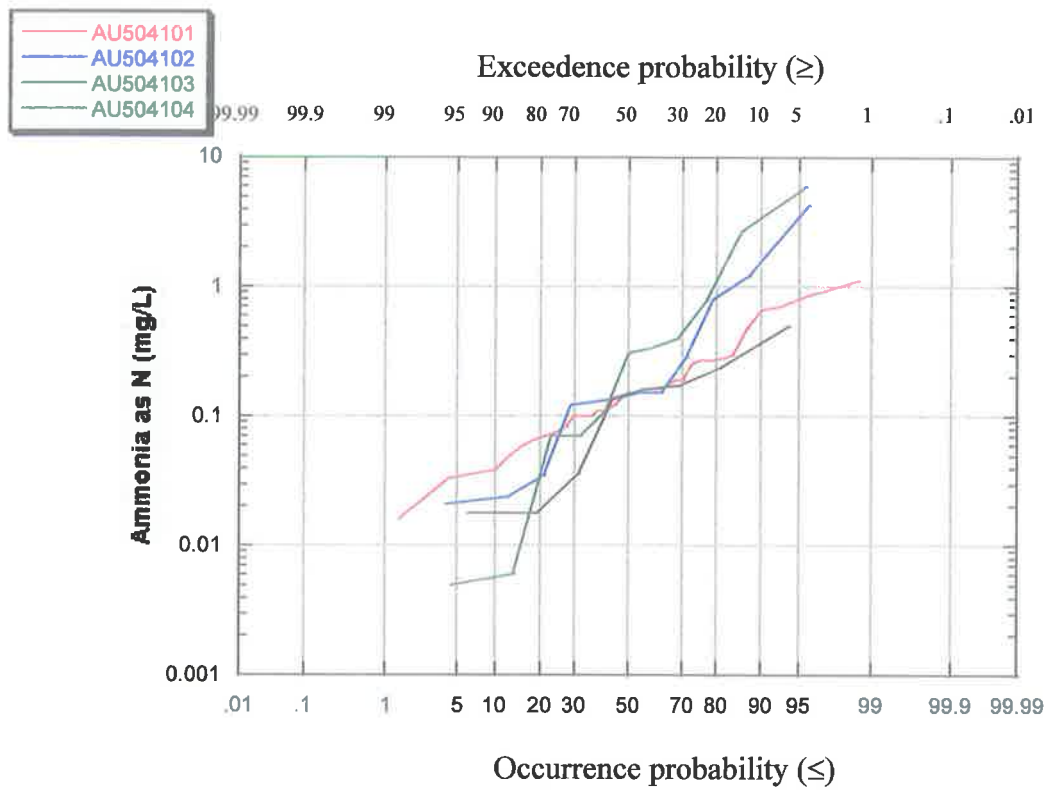


Figure K-1 : Ammonia (NH₄) EMC Probability Curve (mg/L)

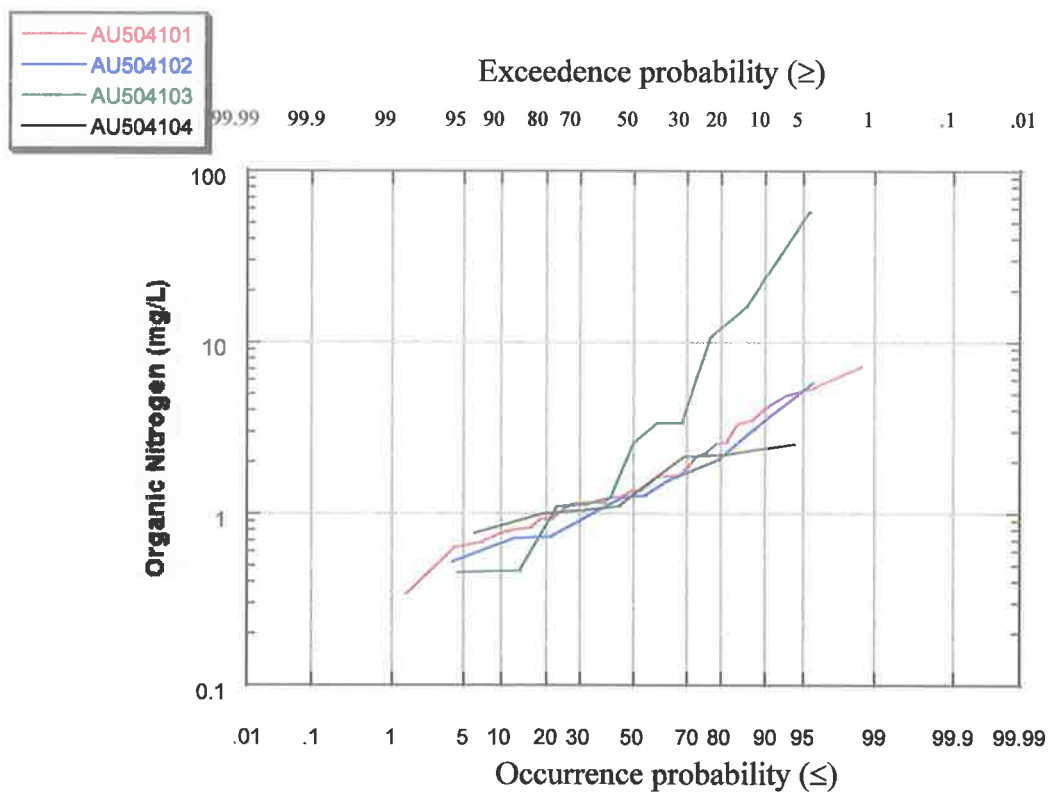


Figure K-2 : Organic Nitrogen EMC Probability Curve (mg/L)

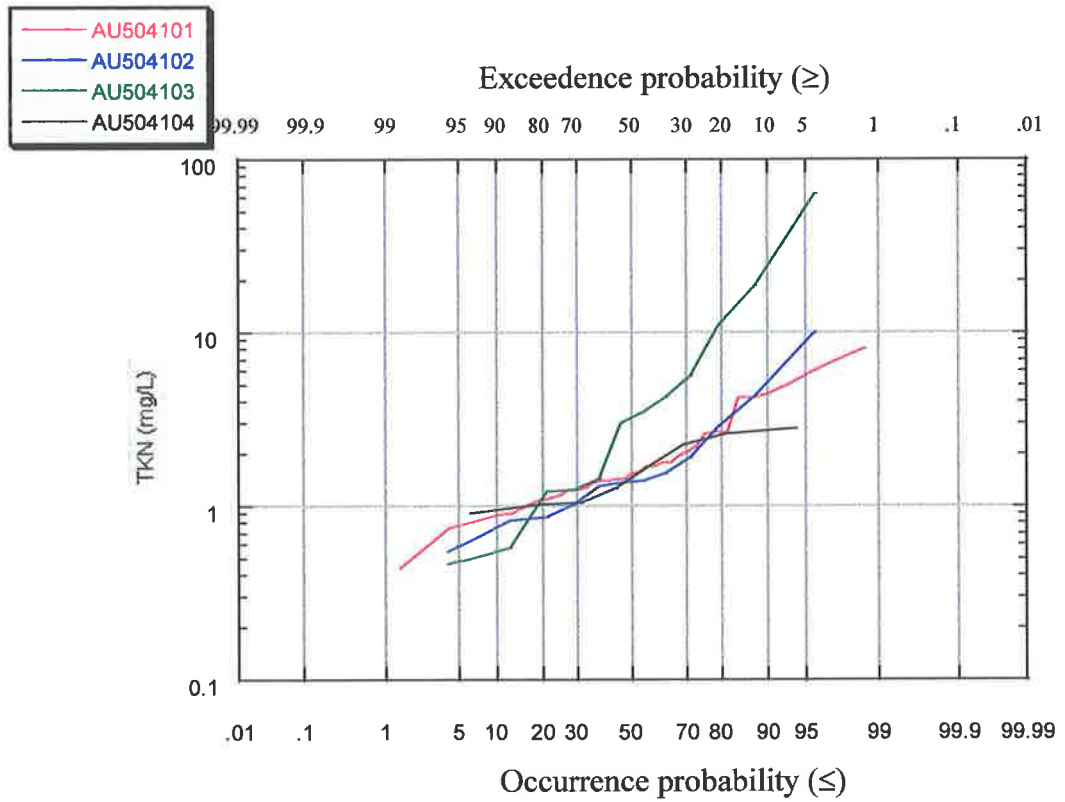


Figure K-3 : Total Kjeldahl Nitrogen (TKN) EMC Probability Curve (mg/L)

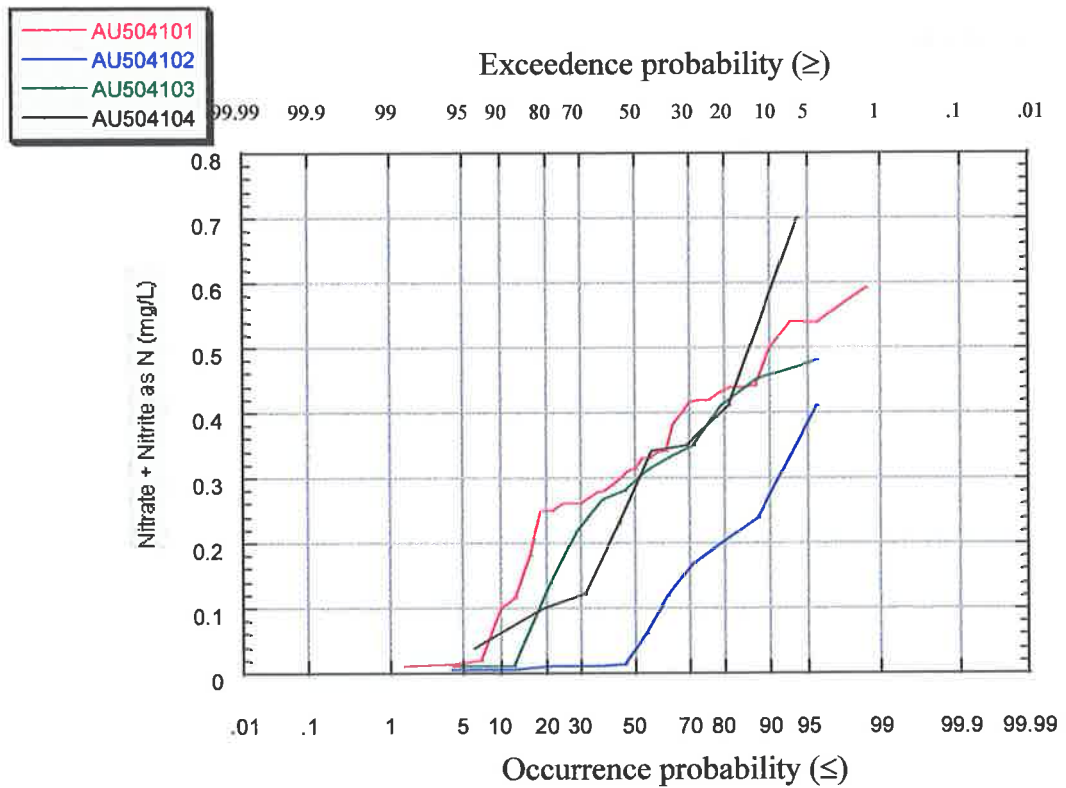


Figure K-4 : Nitrate + Nitrite EMC Probability Curve (mg/L)

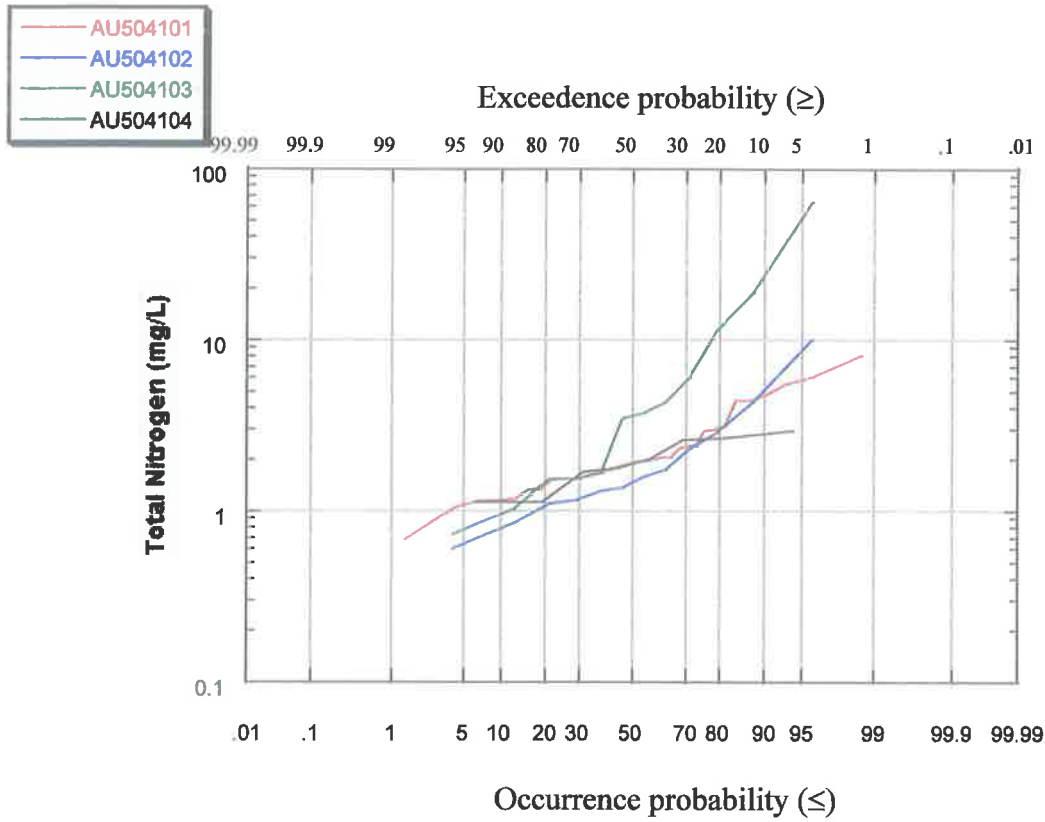


Figure K-5 : Total Nitrogen EMC Probability Curve (mg/L)

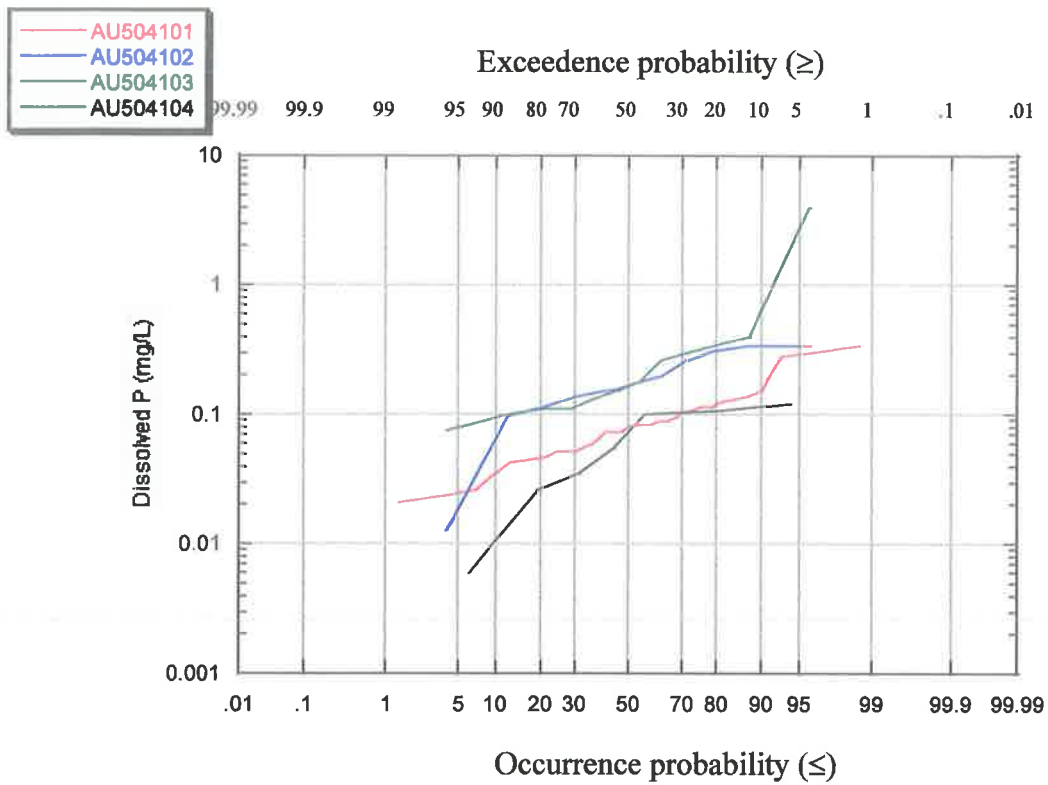


Figure K-6 : Dissolved Phosphorus EMC Probability Curve (mg/L)

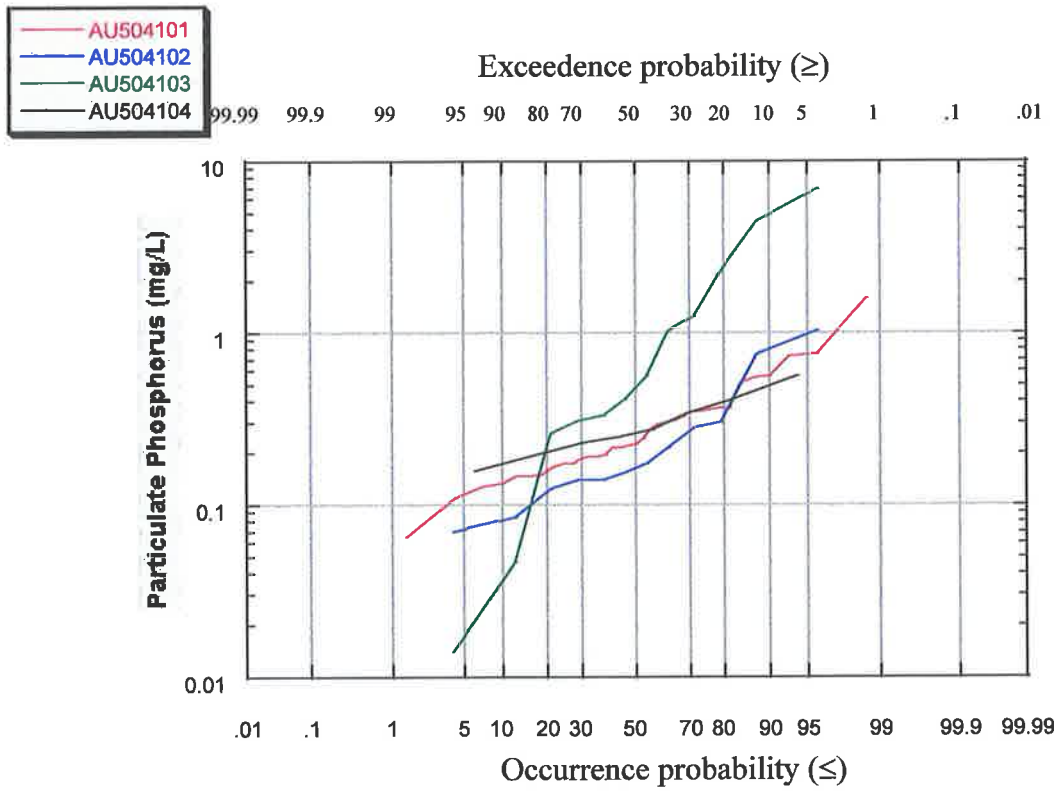


Figure K-7 : Particulate Phosphorus EMC Probability Curve (mg/L)

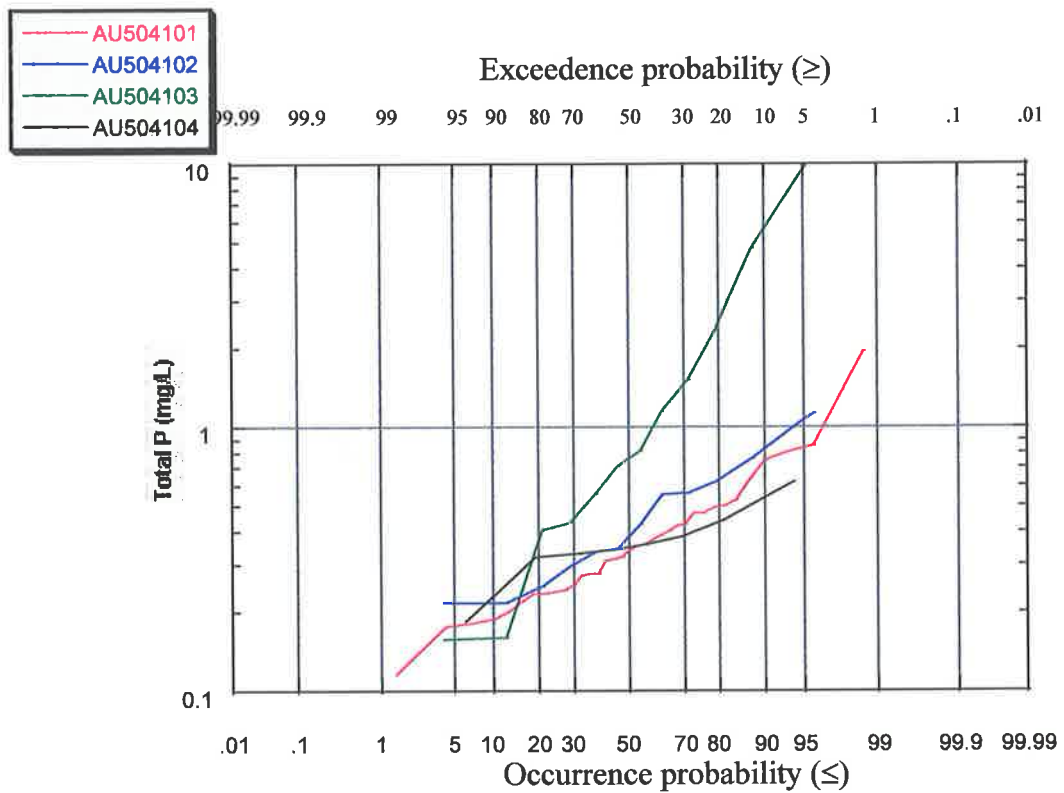


Figure K-8 : Total Phosphorus EMC Probability Curve (mg/L)

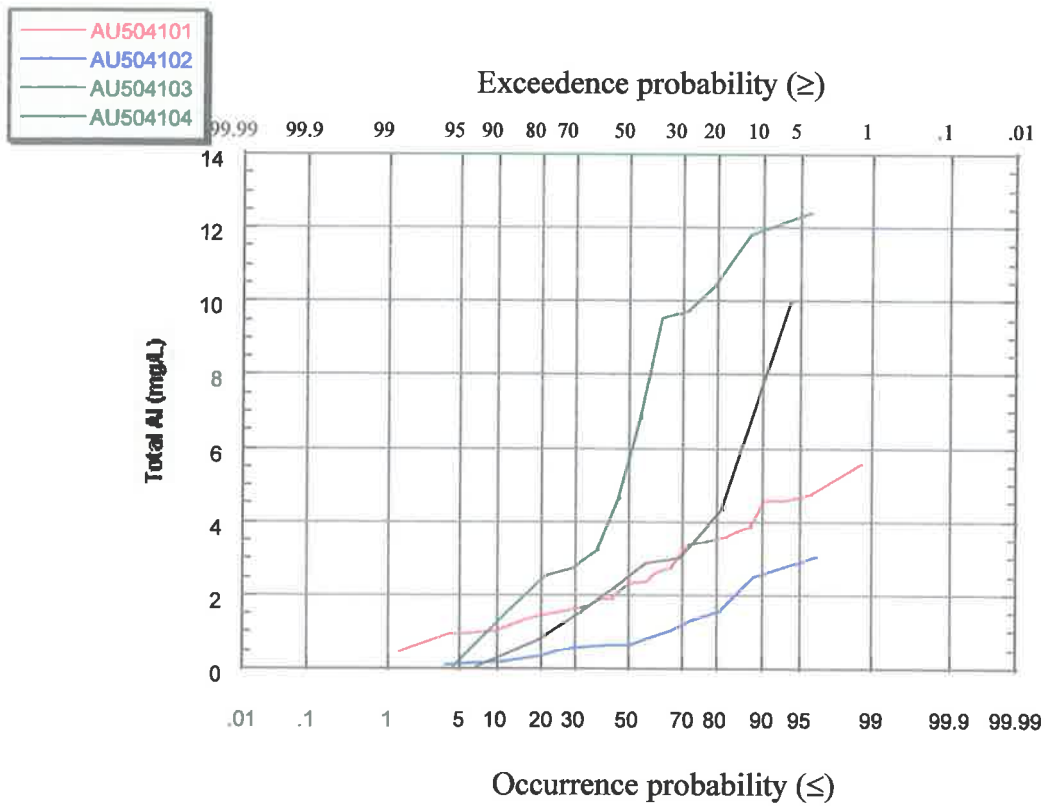


Figure K-9 : Aluminium (Al) EMC Probability Curve (mg/L)

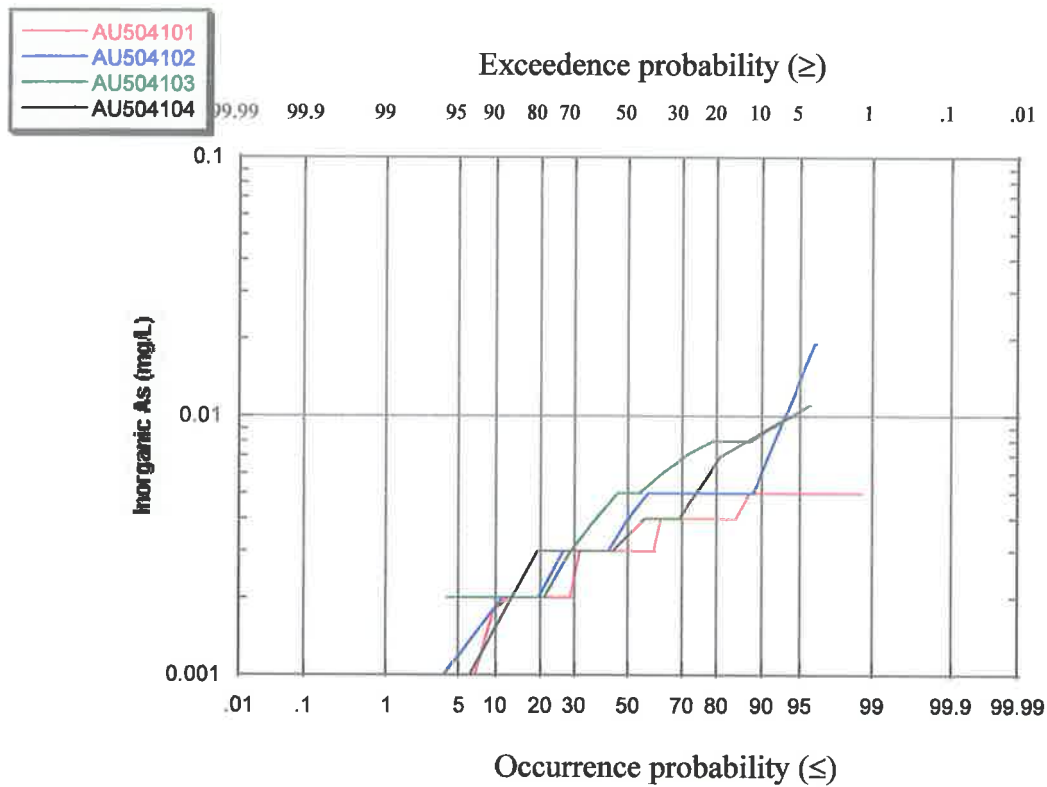


Figure K-10 : Arsenic (As) EMC Probability Curve (mg/L)

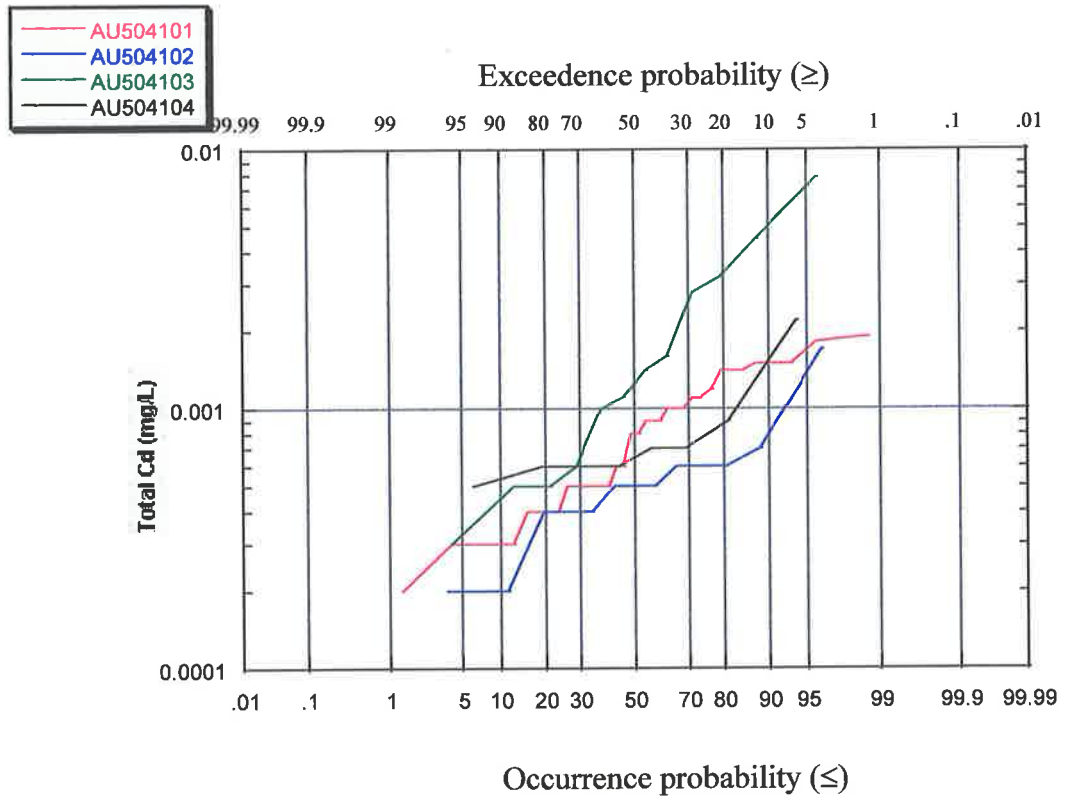


Figure K-11 : Cadmium (Cd) EMC Probability Curve (mg/L)

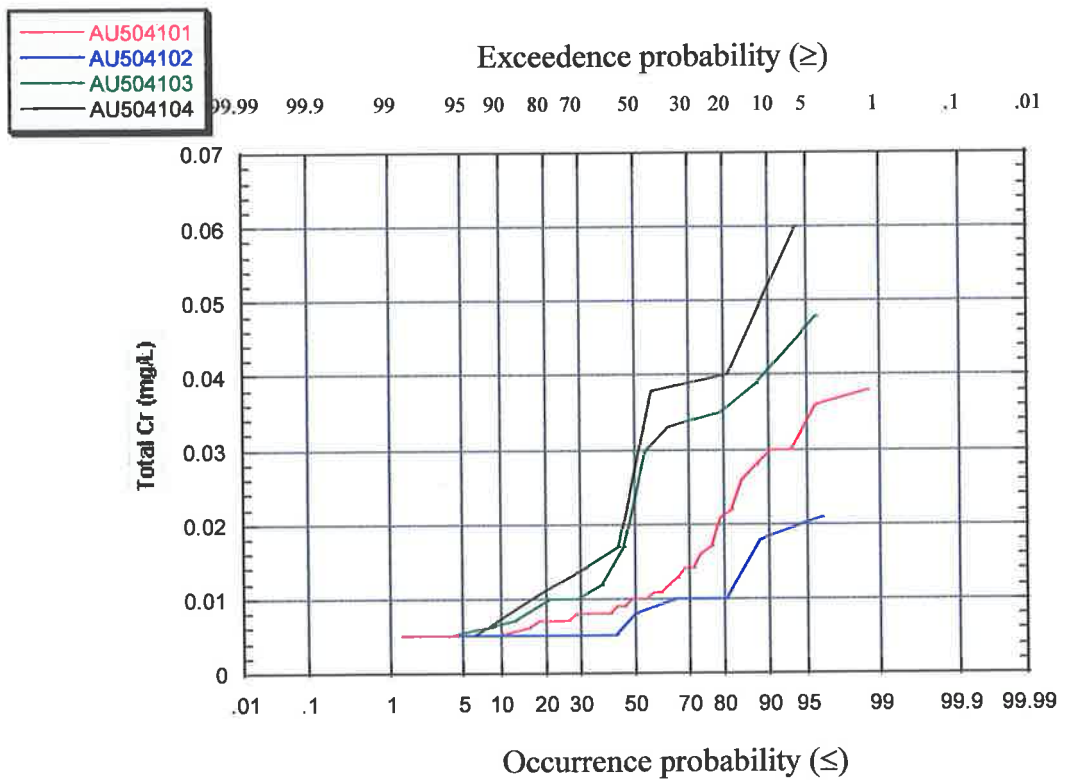


Figure K-12 : Chromium (Cr) EMC Probability Curve (mg/L)

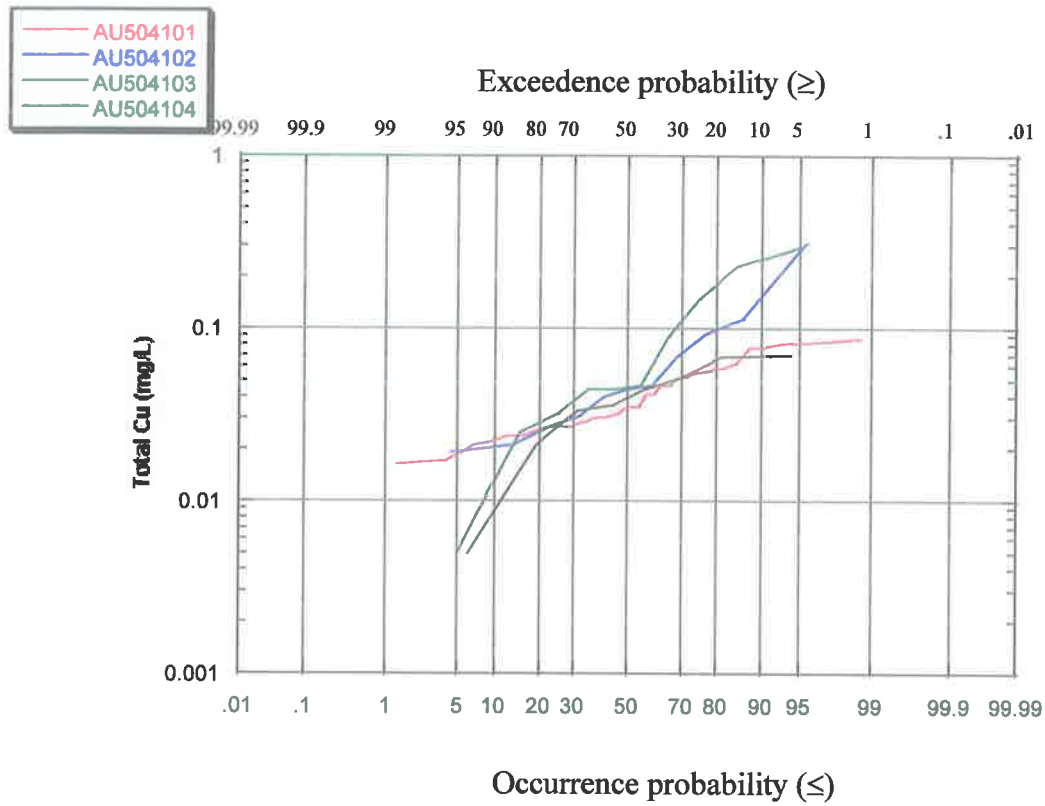


Figure K-13 : Copper (Cu) EMC Probability Curve (mg/L)

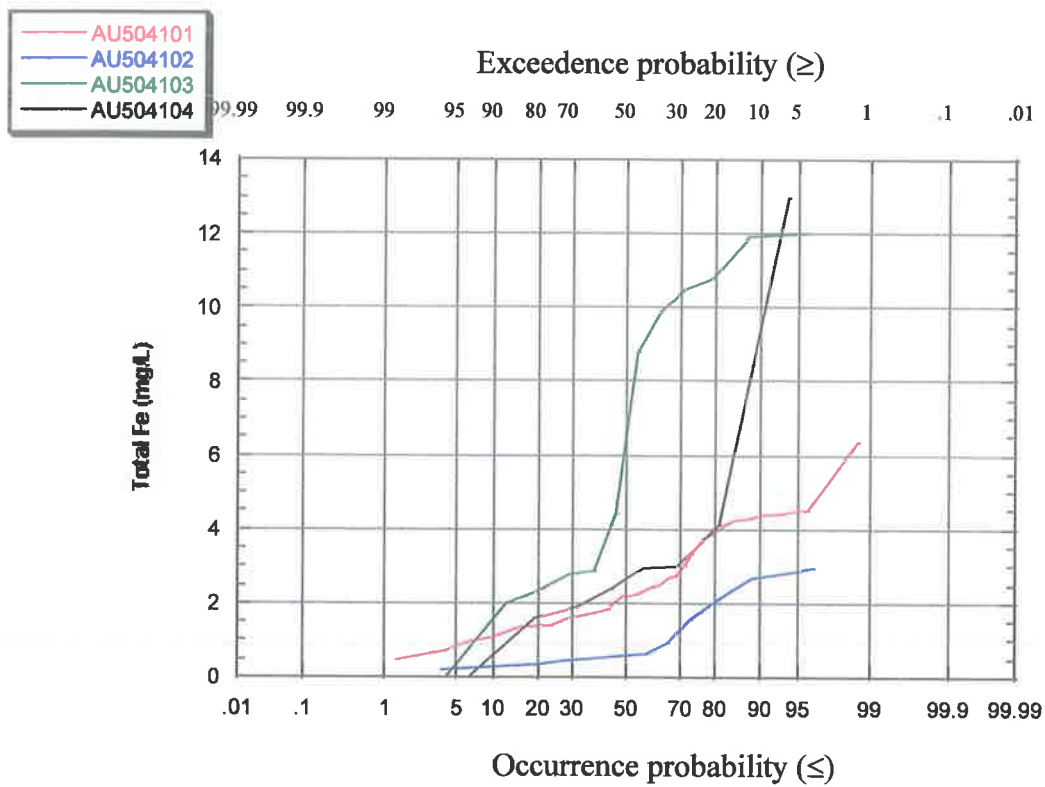


Figure K-14 : Iron (Fe) EMC Probability Curve (mg/L)

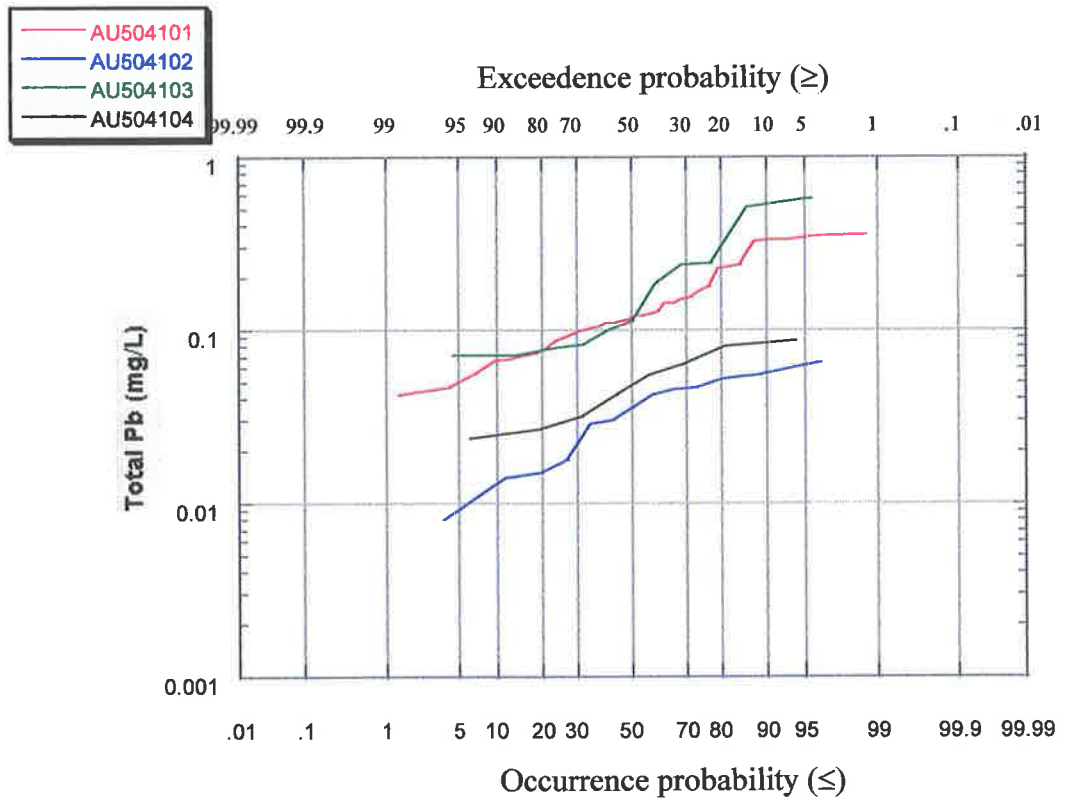


Figure K-15 : Lead (Pb) EMC Probability Curve (mg/L)

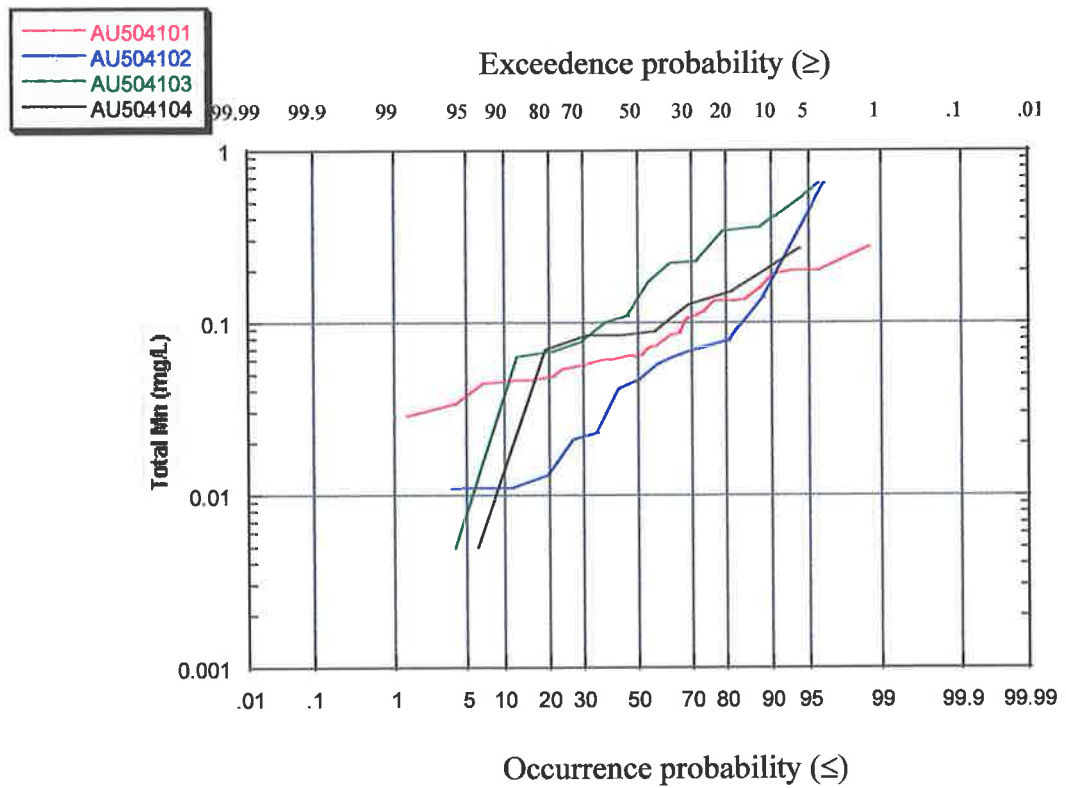


Figure K-16 : Manganese (Mn) EMC Probability Curve (mg/L)

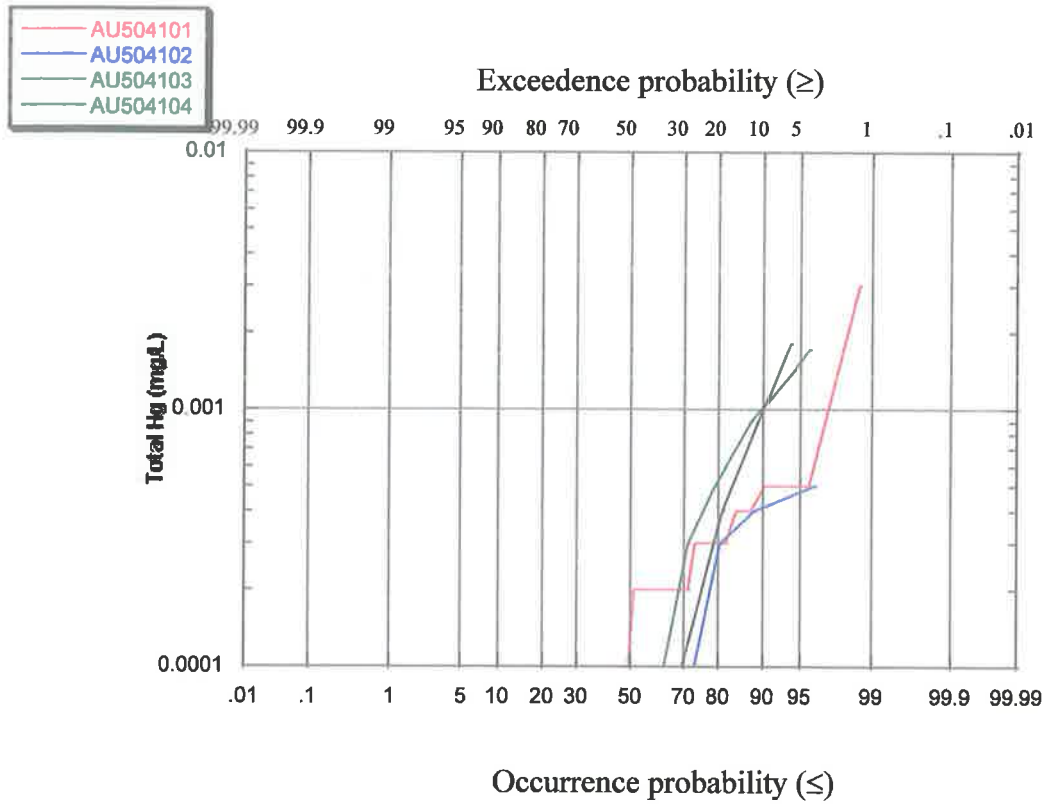


Figure K-17 : Mercury (Hg) EMC Probability Curve (mg/L)

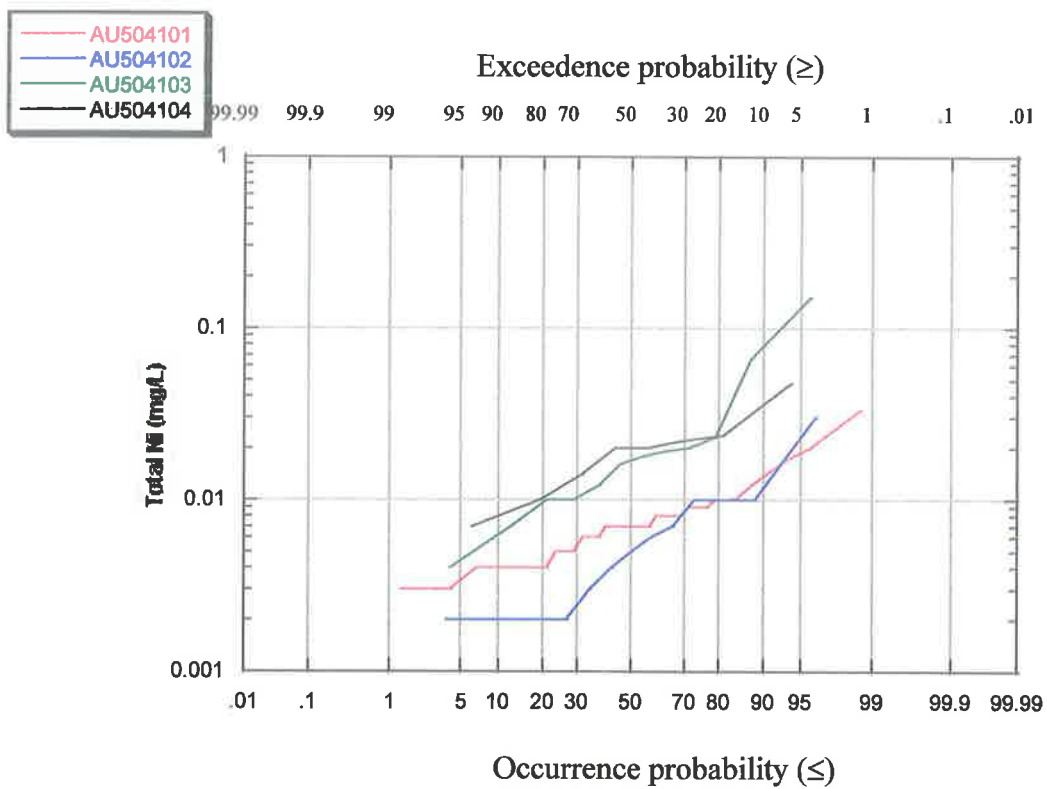


Figure K-18 : Nickel (Ni) EMC Probability Curve (mg/L)

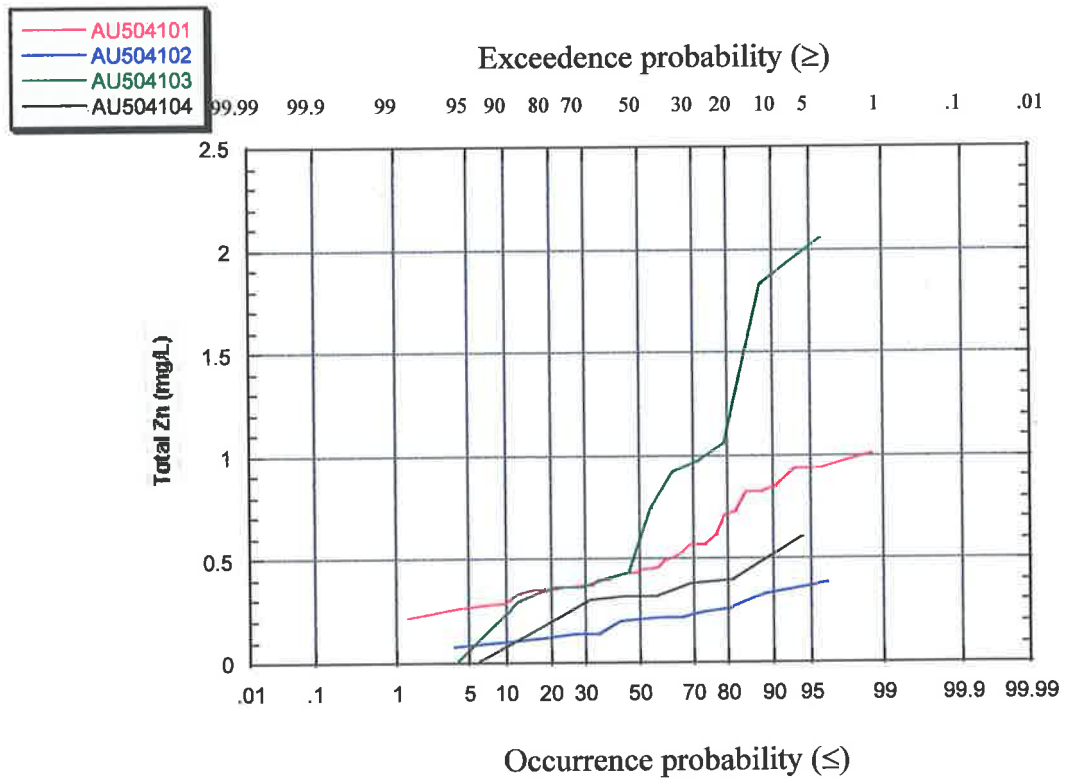


Figure K-19 : Zinc (Zn) EMC Probability Curve (mg/L)

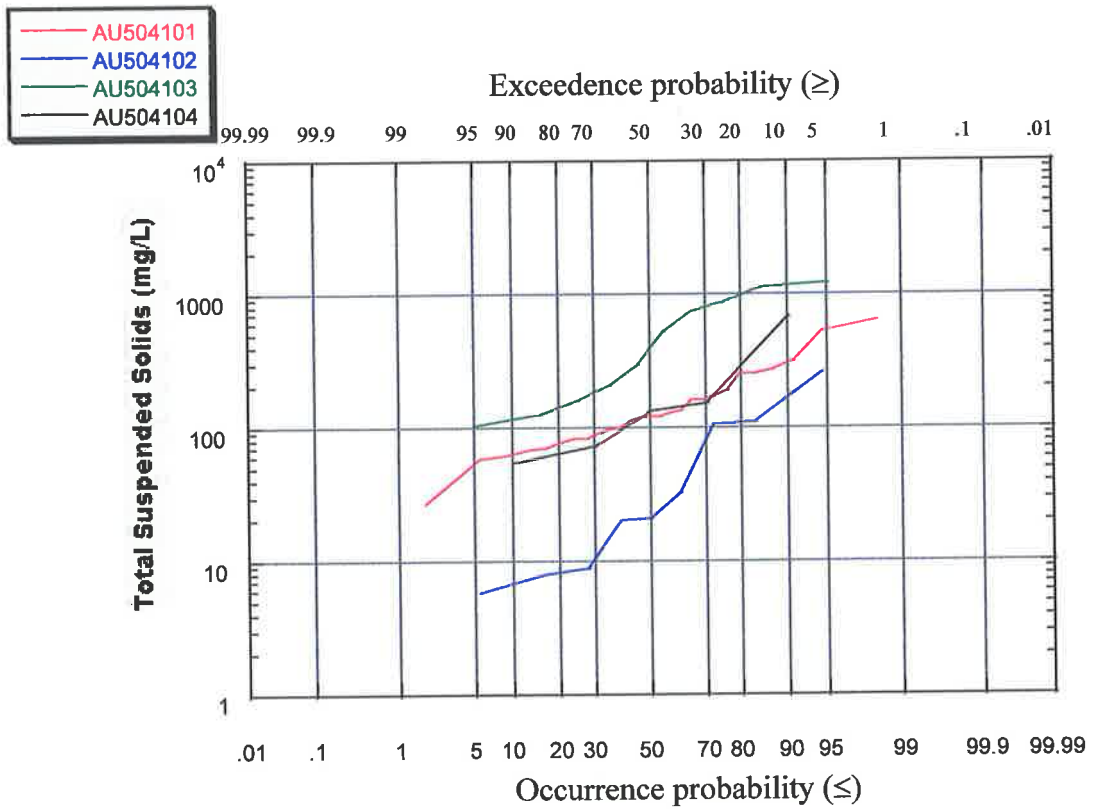


Figure K-20 : Total Suspended Solids EMC Probability Curve (mg/L)

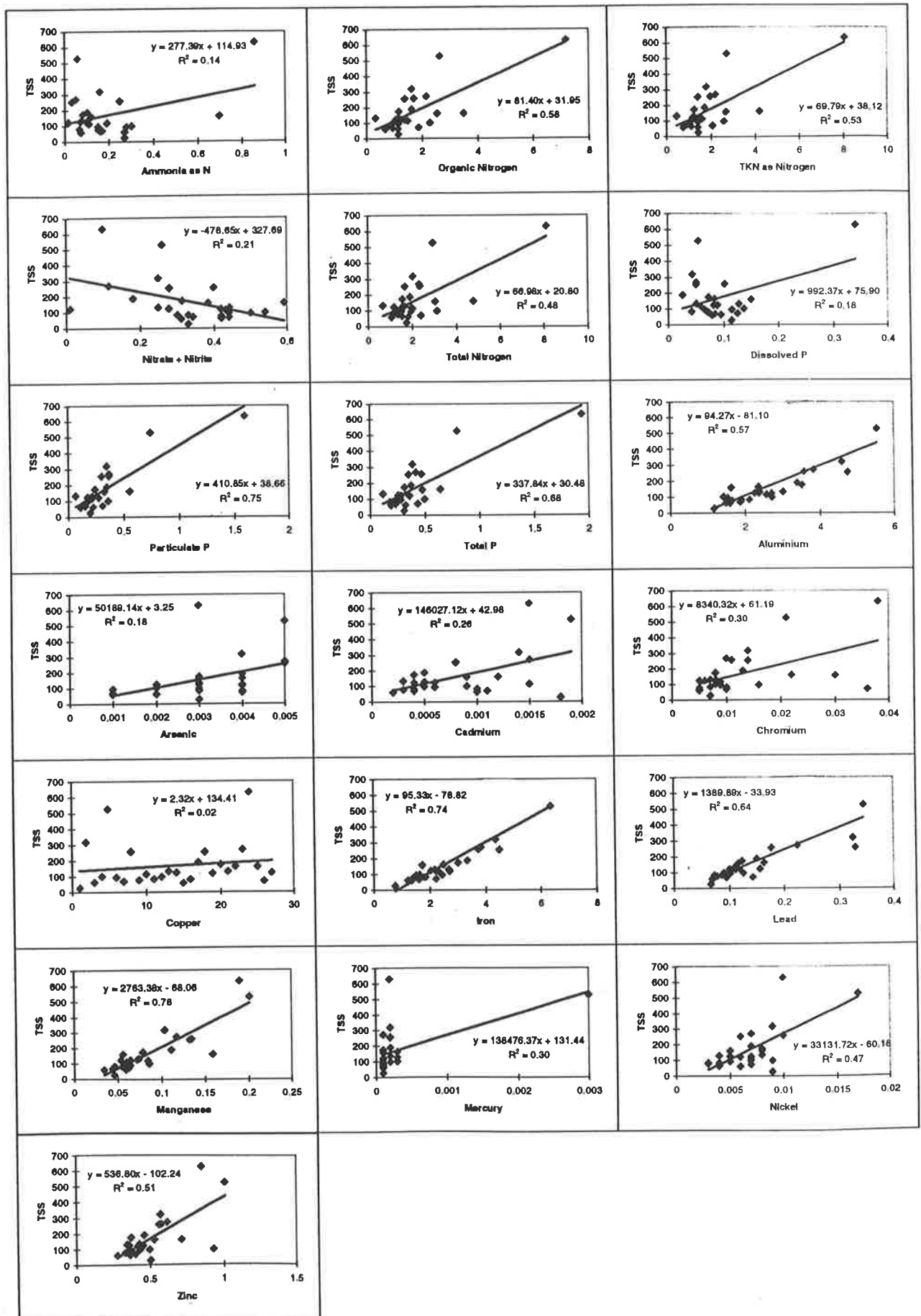
Appendix L

Event Mean Concentration Correlations

Summary

Appendix L outlines the results of an investigation into the correlations between event mean concentration parameters in the North Arm East (AU504101) Drain.

The concentrations are presented in the unit of mg/L



Appendix M

Event Load Probability Curves

Summary

Appendix M outlines the event load probability curves derived by combining the event mean concentration results with the total event runoff volumes. The curves have been normalised by dividing by the catchment area which gives an event load unit of mg/m^2 .

The catchment areas are outlined in Table M-1.

TABLE M-1 : Summary of Catchment and Station details

Catchment	Station No.	Area (km^2)
North Arm East Drain	AU504101	21.7
Hindmarsh Enfield Prospect Drain	AU504102	13.0
Dunstan Road Drain	AU504103	2.23
South Road North Arm West Drain	AU504104	7.82

Multiplying the normalised event load unit of mg/m^2 by the catchment area in km^2 produces a total event load in kg units.

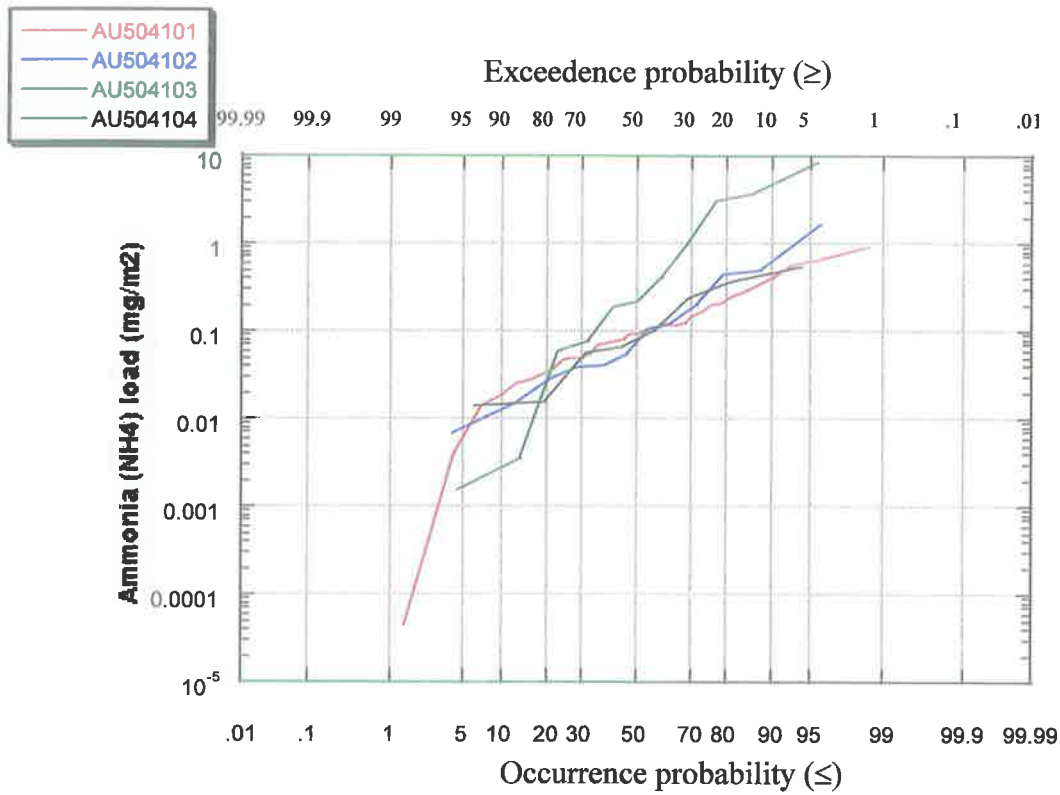


Figure M-1 : Ammonia (NH₄) Event Load Probability Curve (mg/m²)

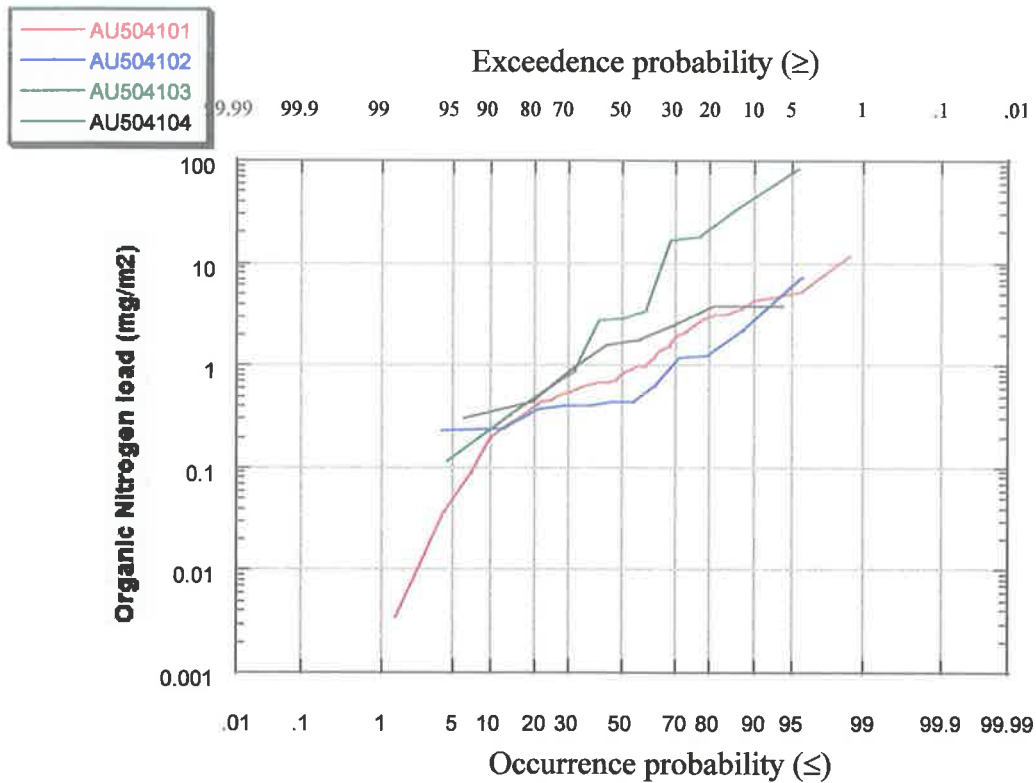


Figure M-2 : Organic Nitrogen Event Load Probability Curve (mg/m²)

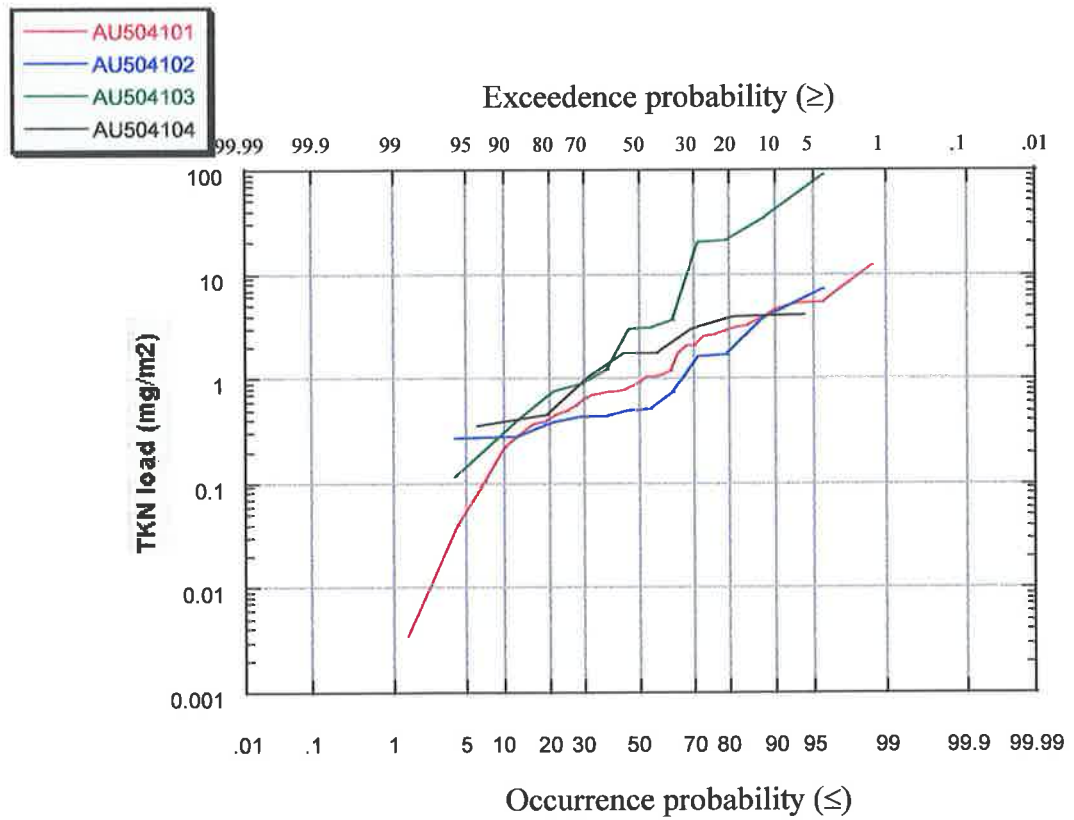


Figure M-3 : Total Kjeldahl Nitrogen (TKN) Event Load Probability Curve (mg/m²)

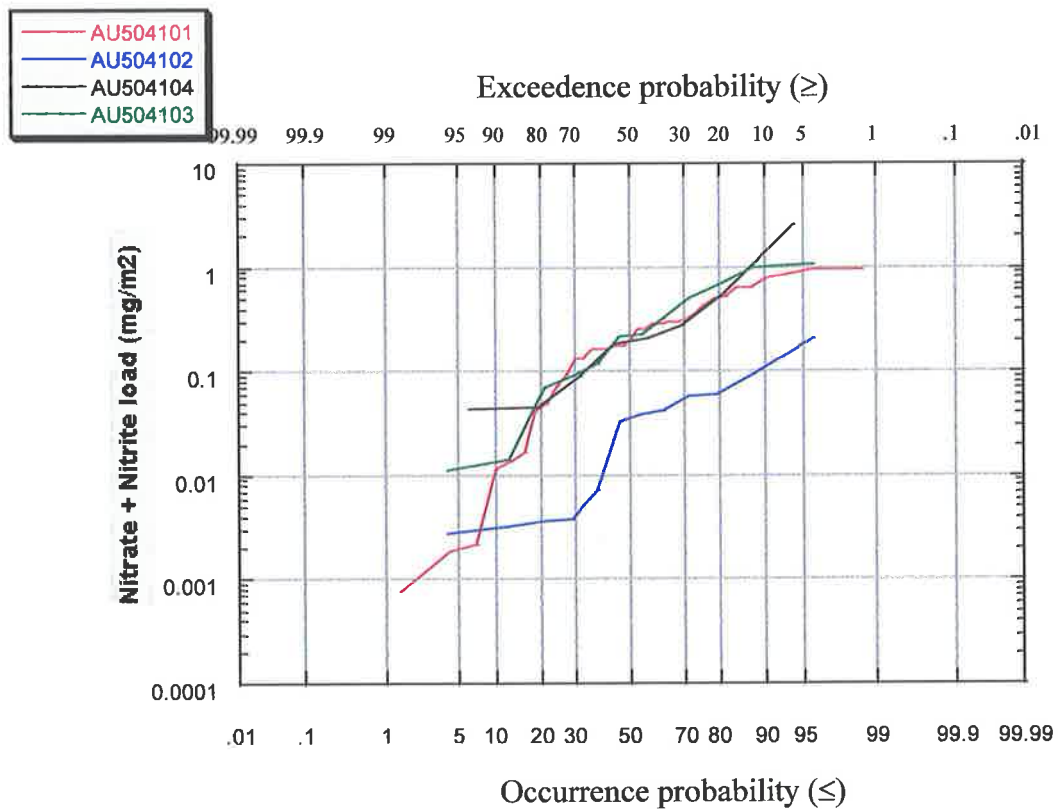


Figure M-4 : Nitrate + Nitrite Event Load Probability Curve (mg/m²)

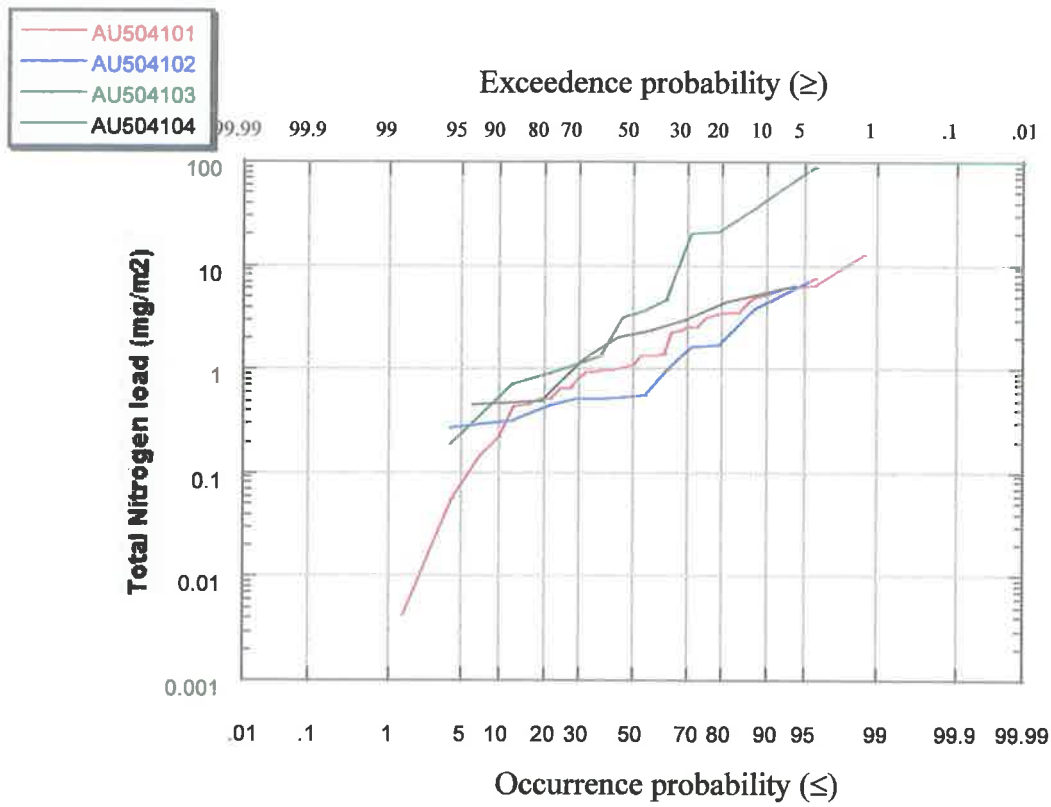


Figure M-5 : Total Nitrogen Event Load Probability Curve (mg/m²)

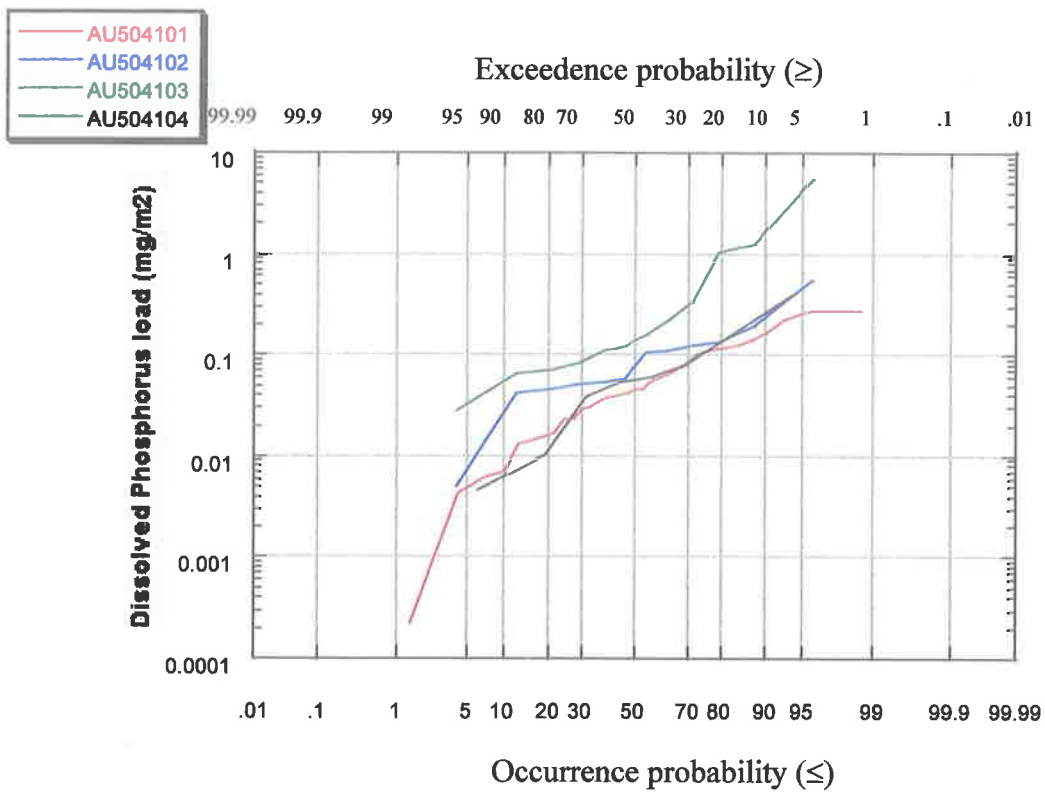


Figure M-6 : Dissolved Phosphorus Event Load Probability Curve (mg/m²)

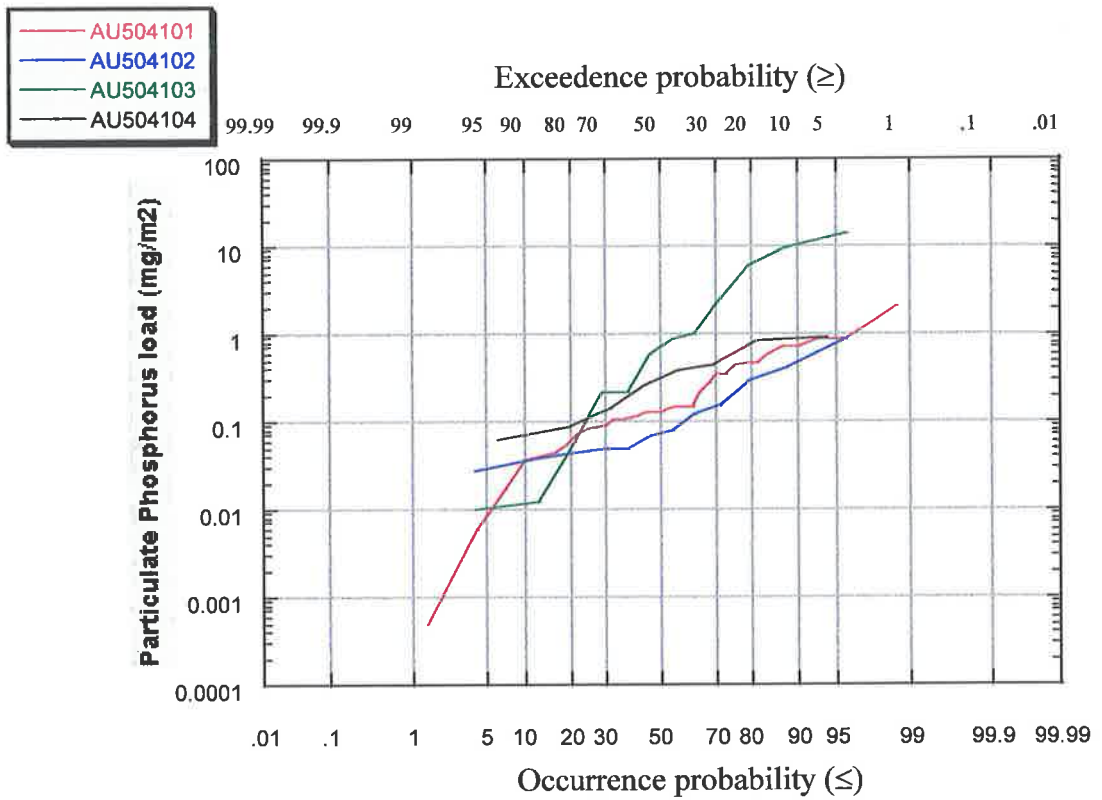


Figure M-7 : Particulate Phosphorus Event Load Probability Curve (mg/m²)

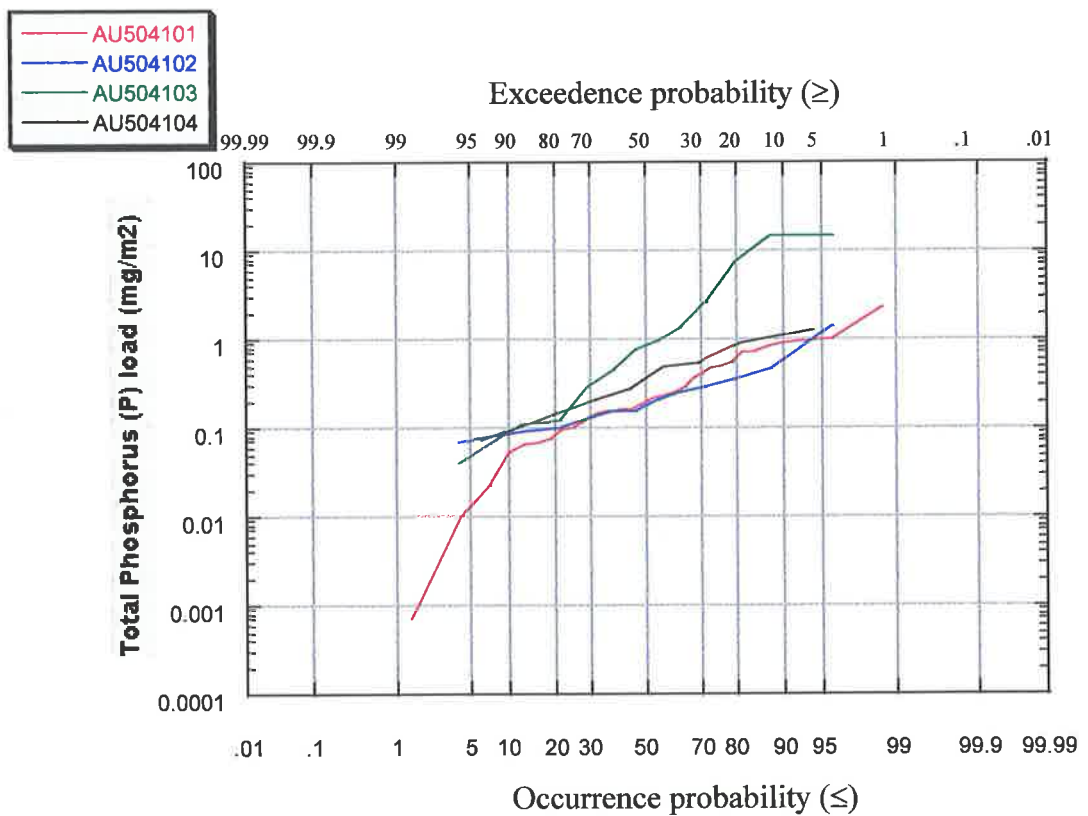


Figure M-8 : Total Phosphorus Event Load Probability Curve (mg/m²)

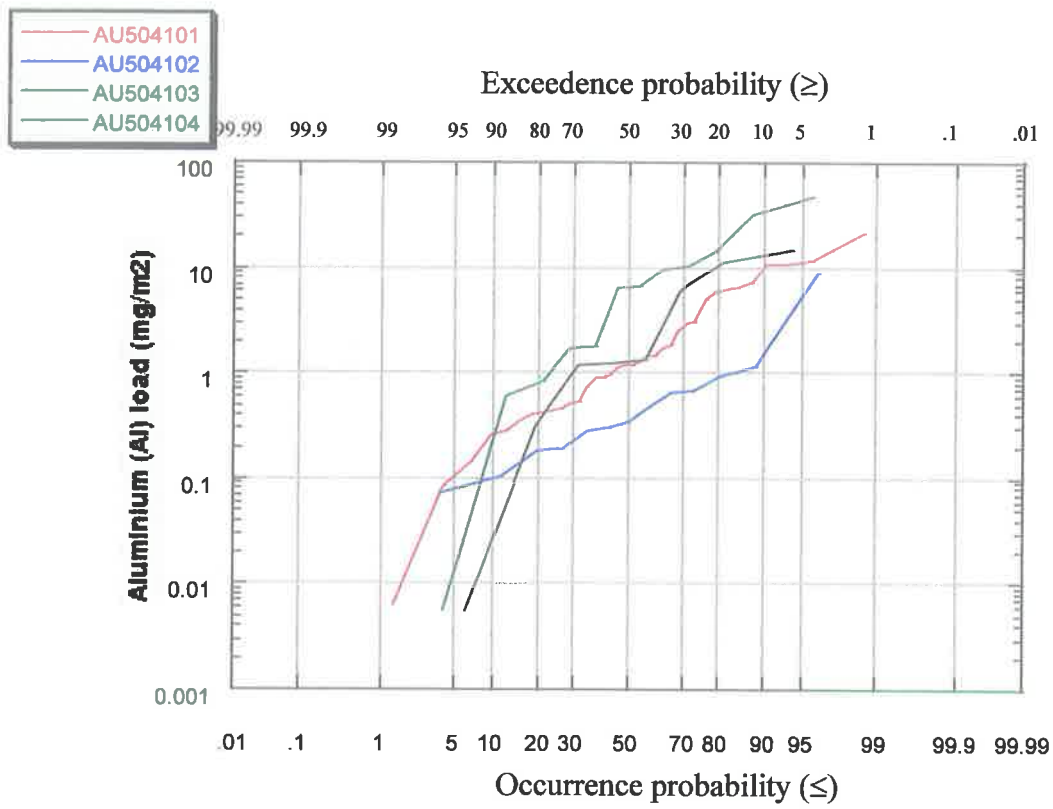


Figure M-9 : Aluminium (Al) Event Load Probability Curve (mg/m²)

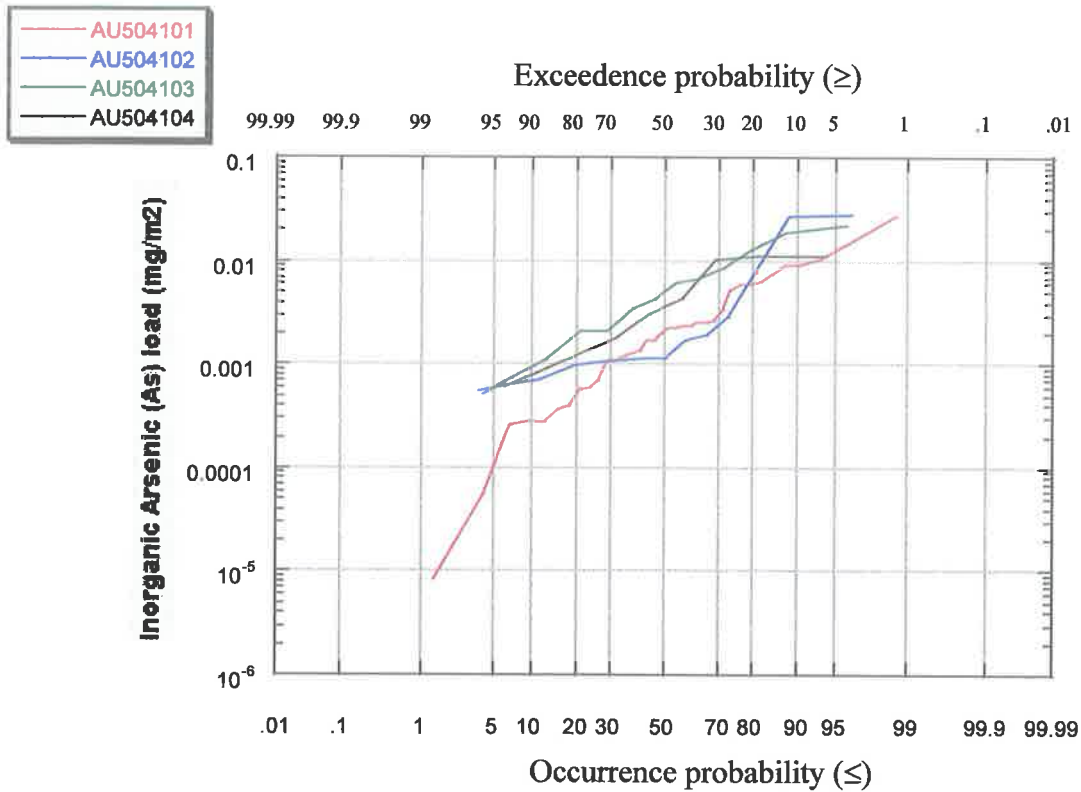


Figure M-10 : Inorganic Arsenic (As) Event Load Probability Curve (mg/m²)

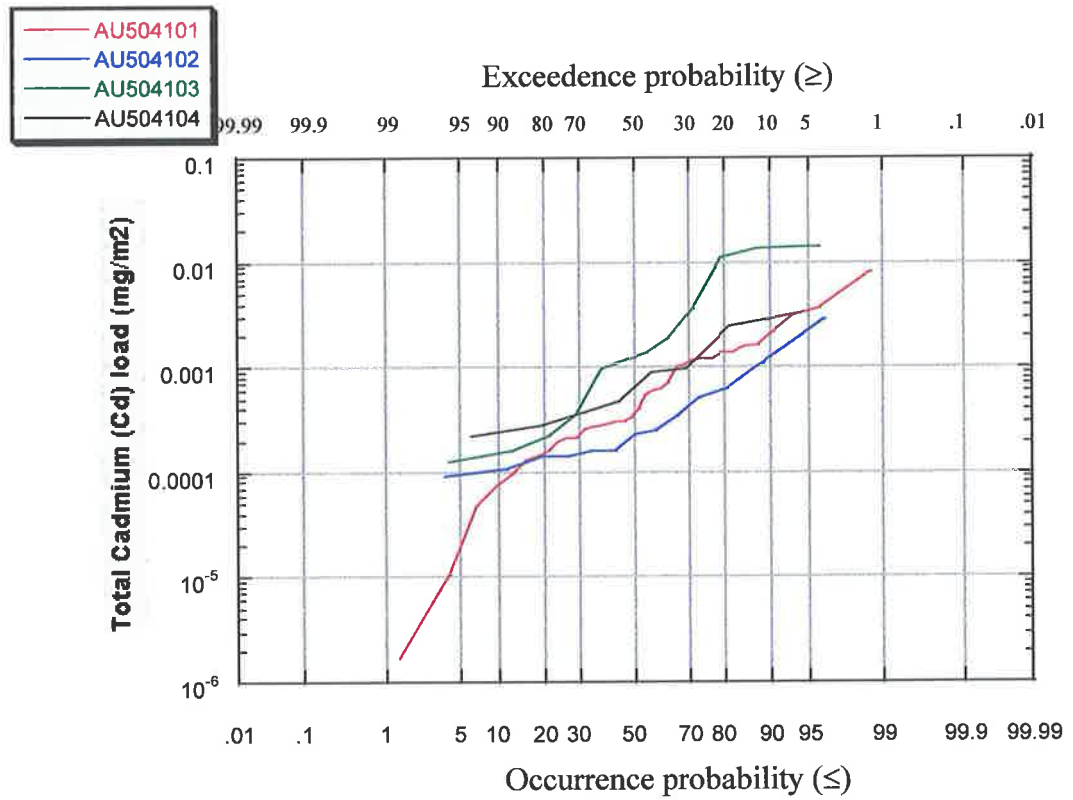


Figure M-11 : Cadmium (Cd) Event Load Probability Curve (mg/m²)

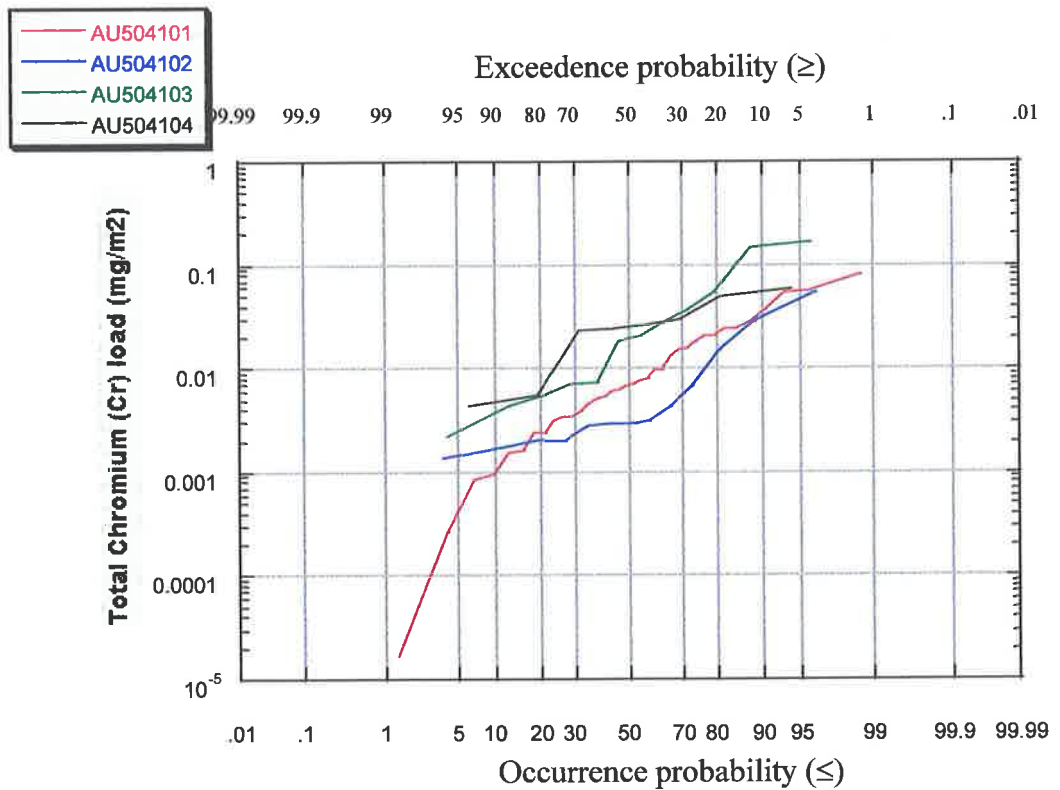


Figure M-12 : Chromium (Cr) Event Load Probability Curve (mg/m²)

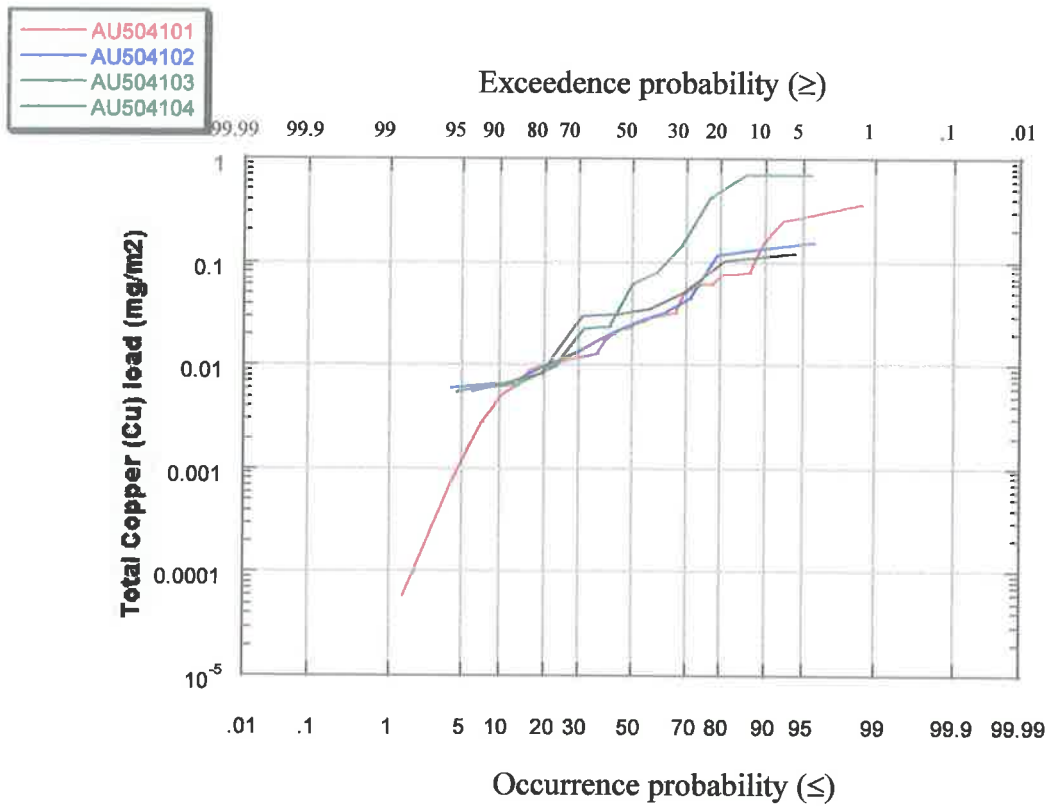


Figure M-13 : Copper (Cu) Event Load Probability Curve (mg/m²)

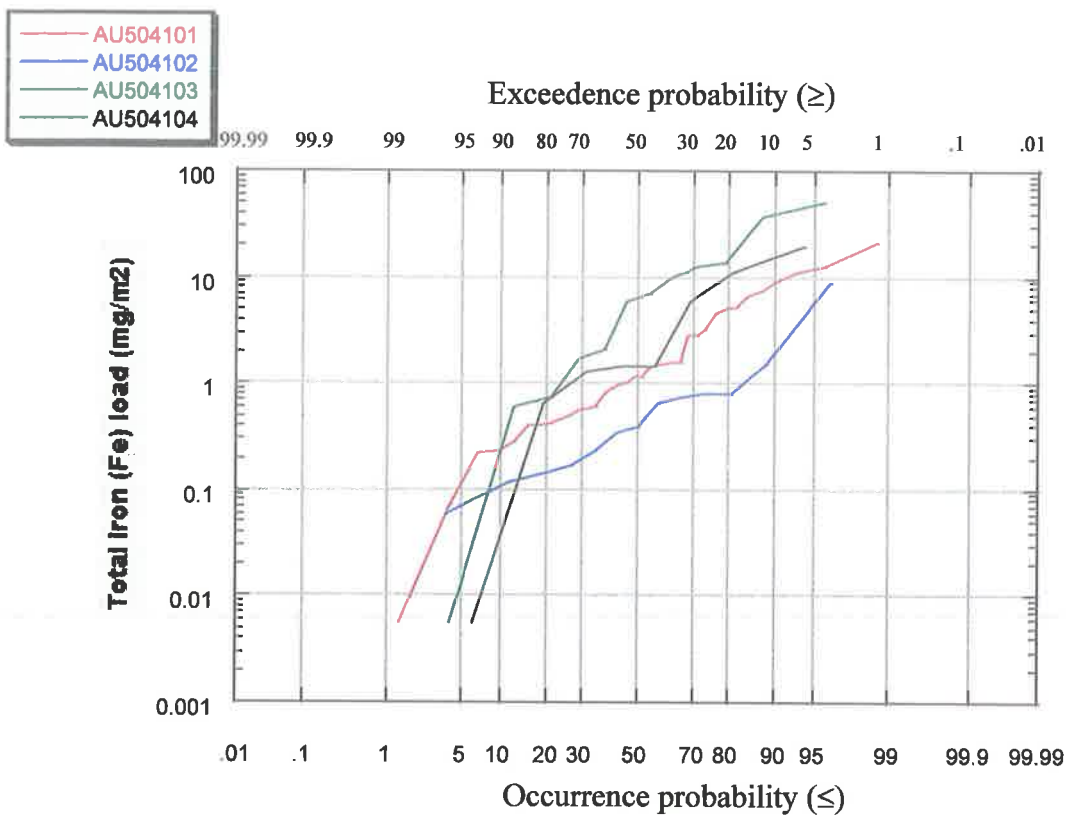


Figure M-14 : Iron (Fe) Event Load Probability Curve (mg/m²)

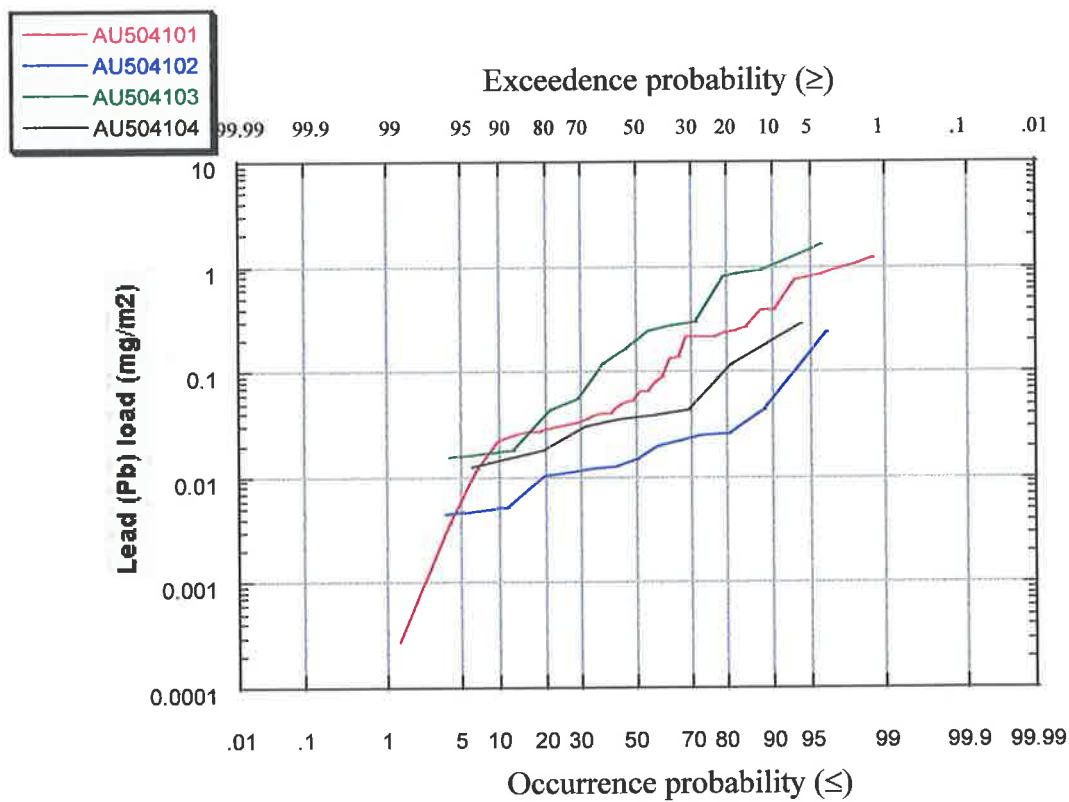


Figure M-15 : Lead (Pb) Event Load Probability Curve (mg/m²)

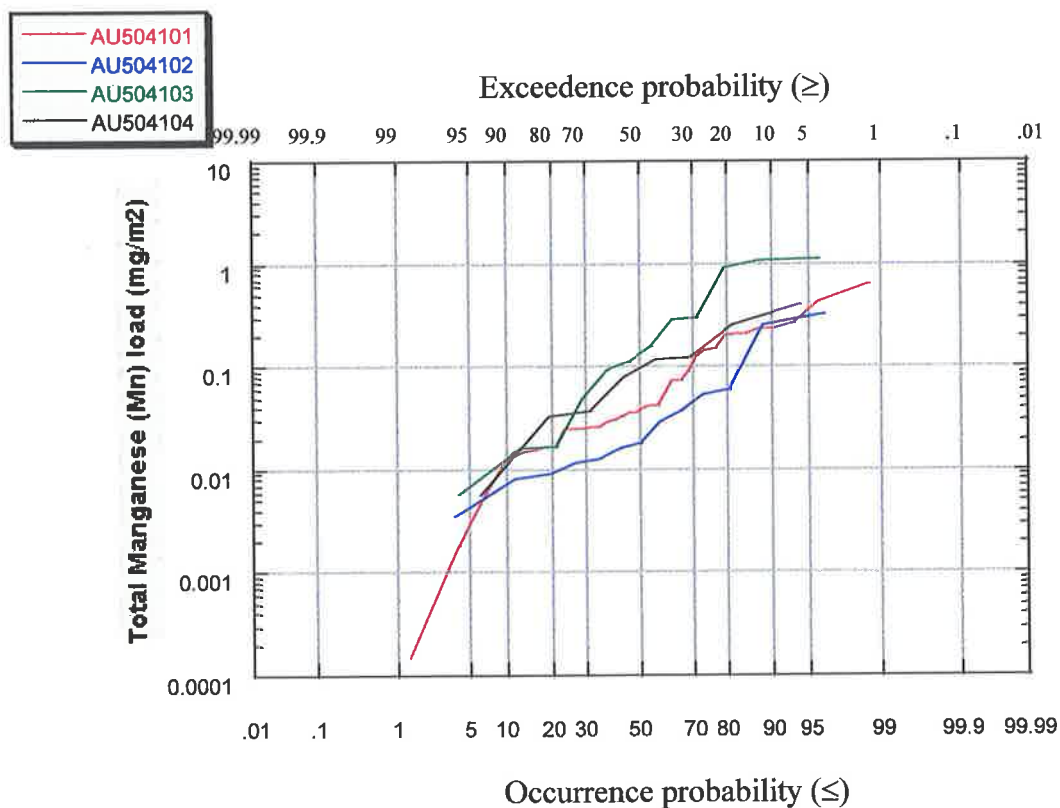


Figure M-16 : Manganese (Mn) Event Load Probability Curve (mg/m²)

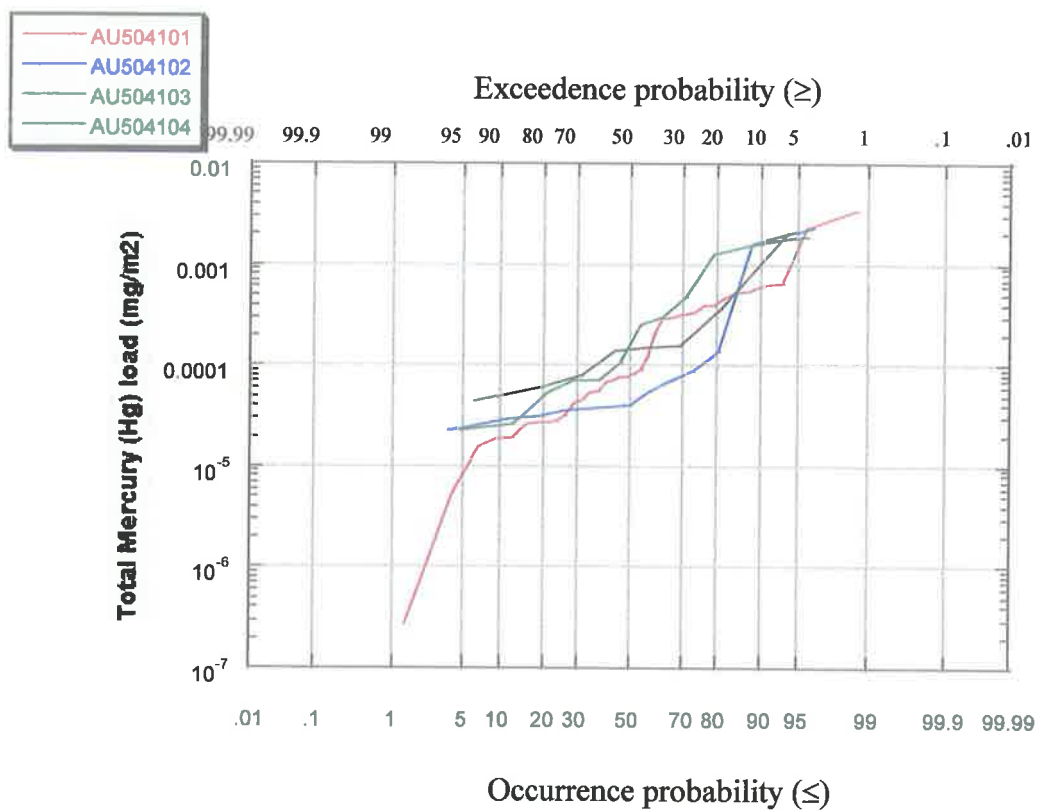


Figure M-17 : Mercury (Hg) Event Load Probability Curve (mg/m²)

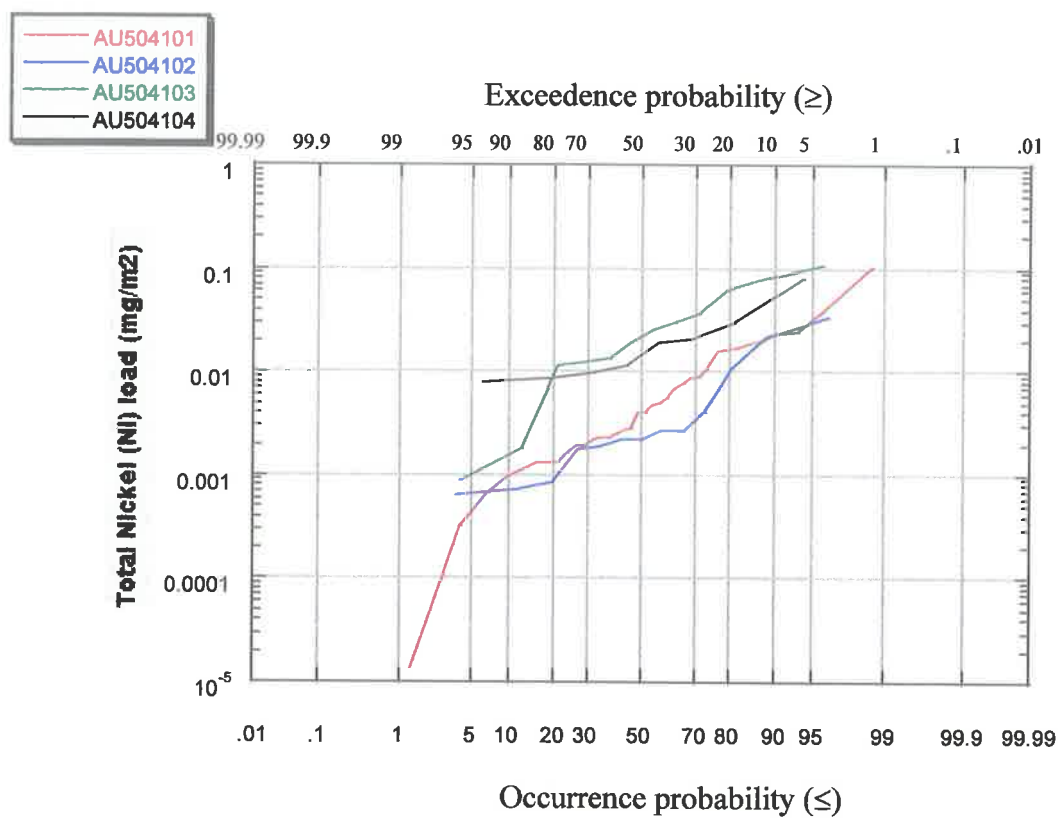


Figure M-18 : Nickel (Ni) Event Load Probability Curve (mg/m²)

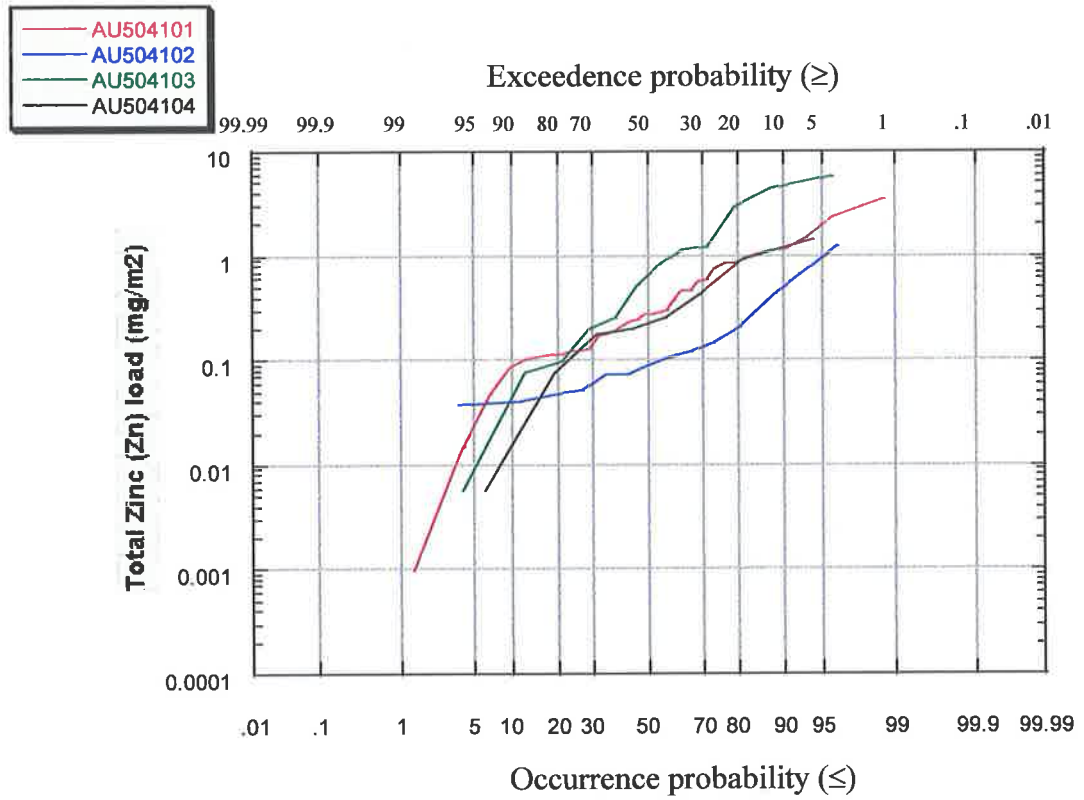


Figure M-19 : Zinc (Zn) Event Load Probability Curve (mg/m²)

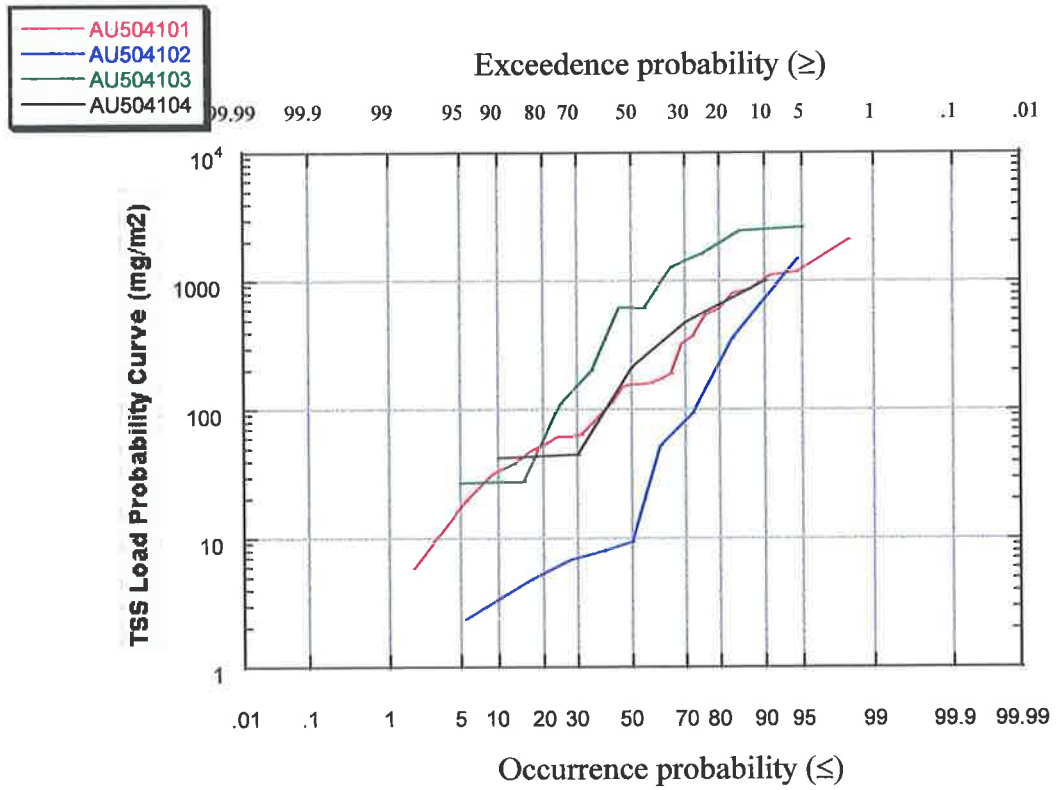


Figure M-20 : Total Suspended Solids (TSS) Event Load Probability Curve (mg/m²)

Appendix N

Continuous Real Time Monitoring Data Set

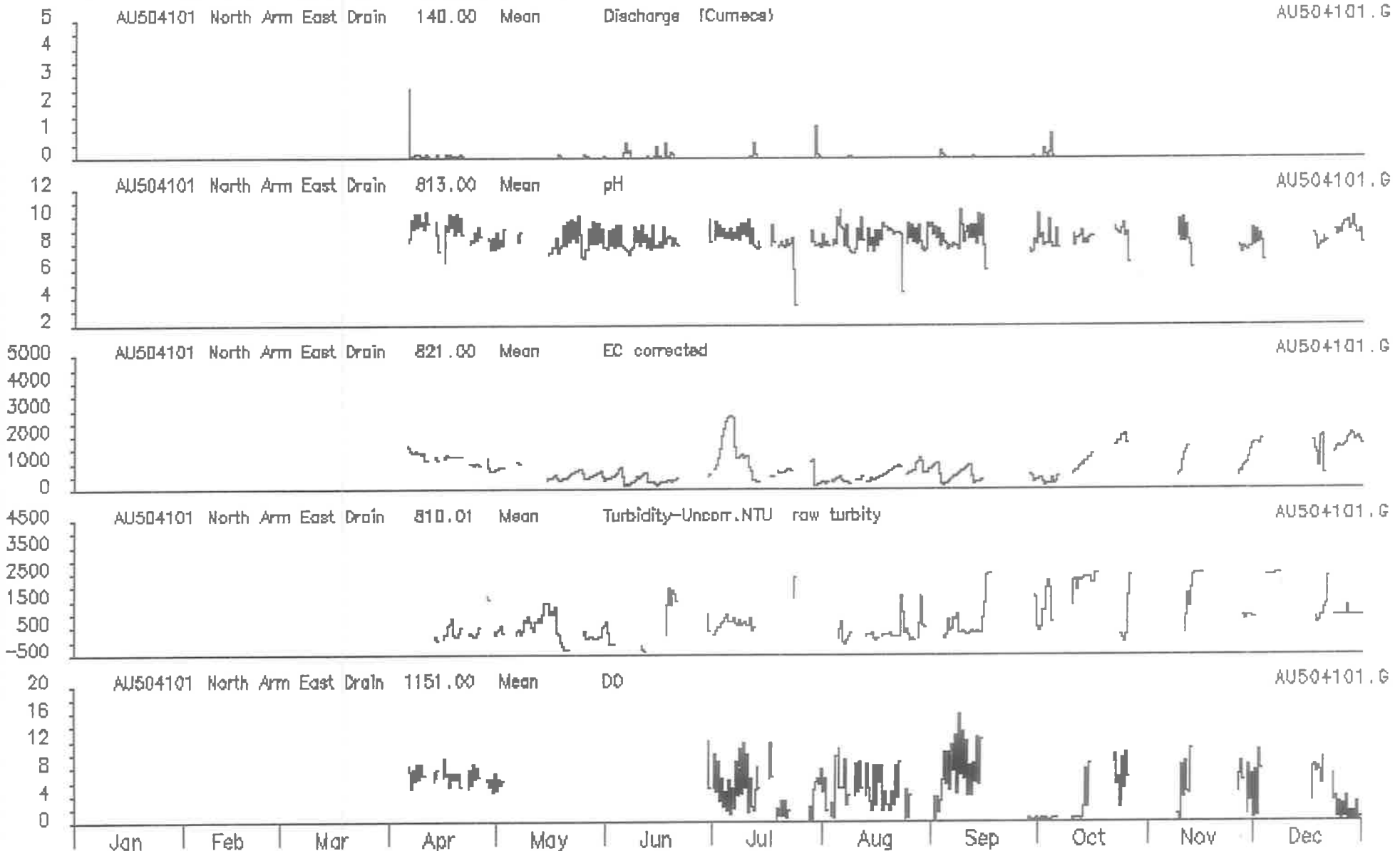
Summary

Appendix N outlines the real time data set from four years of continuous water quality monitoring from 1994 to 1997.

Civil Engineering, Adelaide University

HYPLOT V74 Output 20/11/1997
1994

Period 1 Year Plot Start 00:00_01/01/1994
Interval 12 Hour Plot End 00:00_01/01/1995



Civil Engineering, Adelaide University

HYPL0T V74 Output 20/11/1997

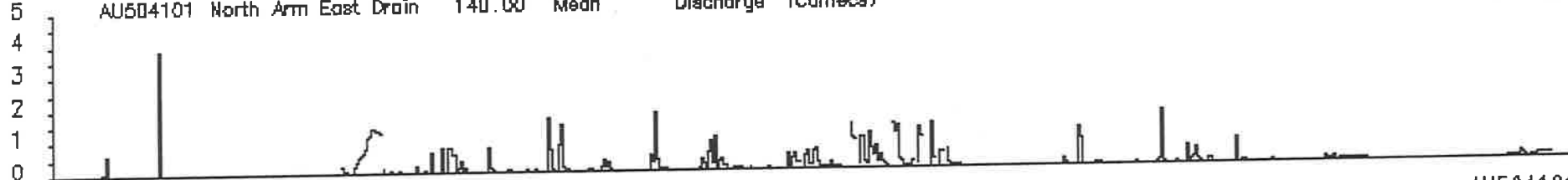
1995

Period 1 Year Plot Start 00:00_01/01/1995

Interval 12 Hour Plot End 00:00_01/01/1996

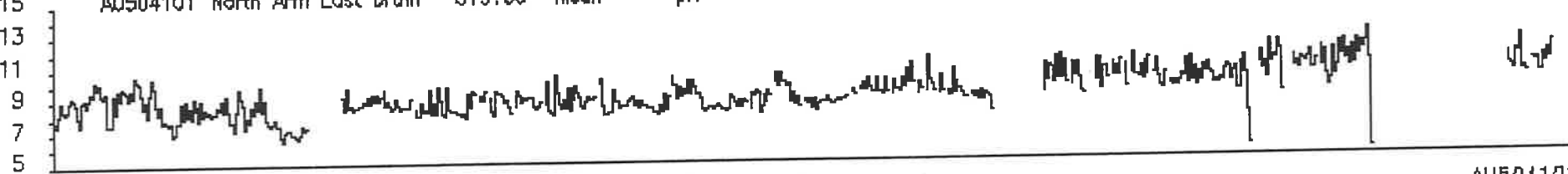
AU504101.G

AU504101 North Arm East Drain 140.00 Mean Discharge (Cumecs)



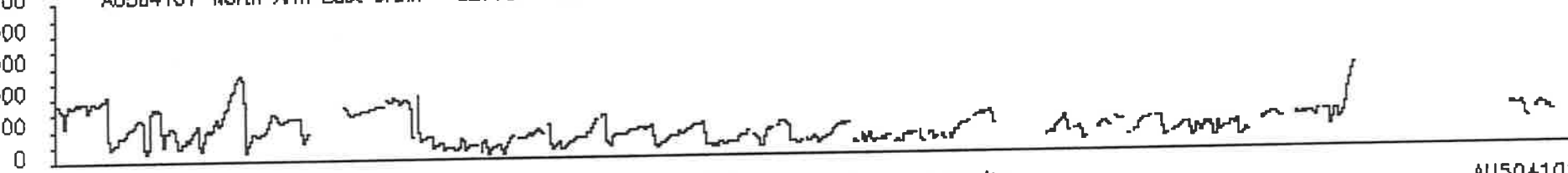
AU504101.G

AU504101 North Arm East Drain 813.00 Mean pH



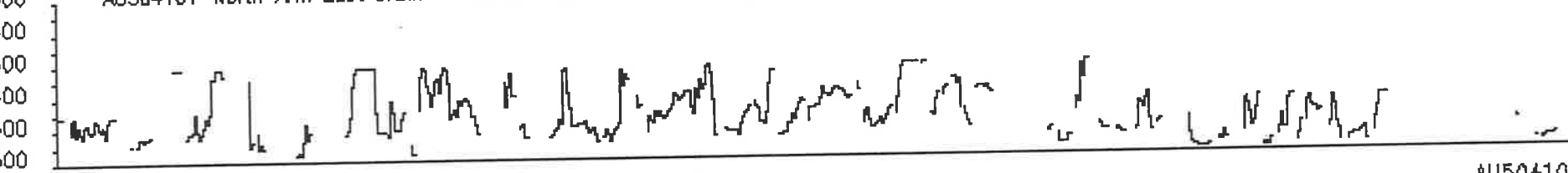
AU504101.G

AU504101 North Arm East Drain 821.00 Mean EC corrected



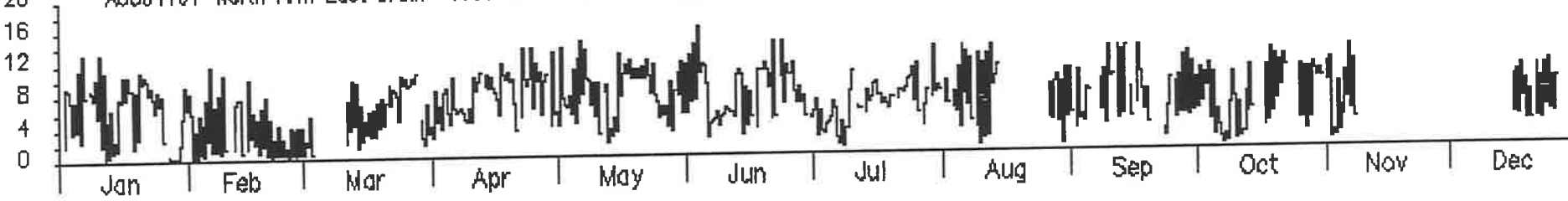
AU504101.G

AU504101 North Arm East Drain 810.01 Mean Turbidity-Uncorr.NTU raw turbity



AU504101.G

AU504101 North Arm East Drain 1151.00 Mean DO



Appendix N : Continuous Real Time Monitoring Data Set

Civil Engineering, Adelaide University

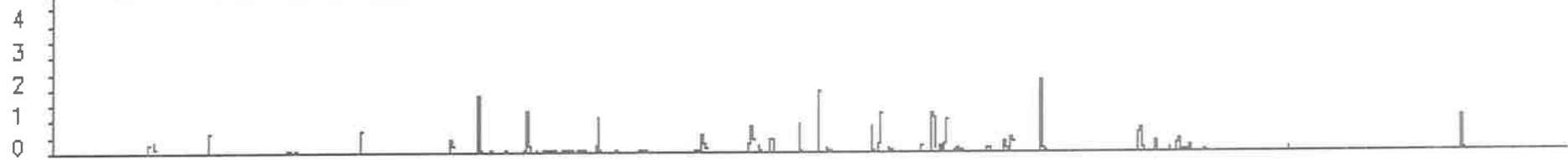
HYPLOT V74 Output 20/11/1987

Period 1 Year Plot Start 00:00_01/01/1996

1996

Interval 12 Hour Plot End 00:00_01/01/1997

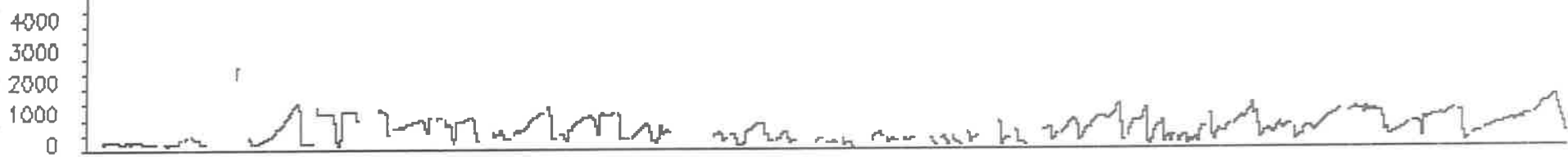
AU504101 North Arm East Drain 140.00 Mean Discharge (Cumecs) AU504101.G



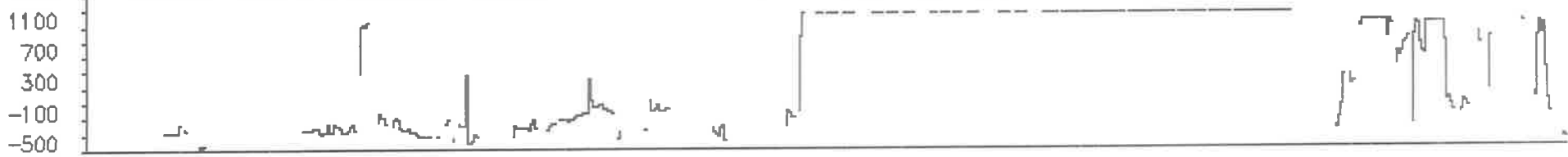
AU504101 North Arm East Drain 813.00 Mean pH AU504101.G



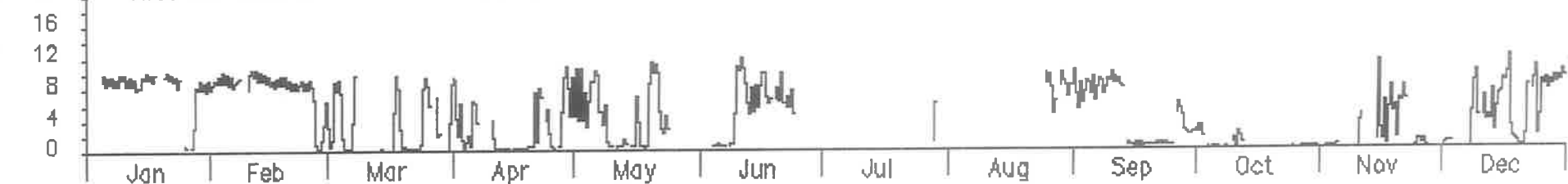
AU504101 North Arm East Drain 821.00 Mean EC corrected AU504101.G



AU504101 North Arm East Drain 810.01 Mean Turbidity-Uncorr.NTU raw turbidity AU504101.G



AU504101 North Arm East Drain 1151.00 Mean DO AU504101.G



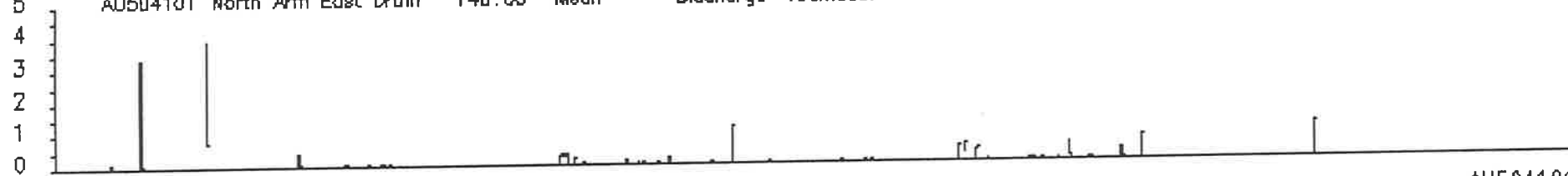
Civil Engineering, Adelaide University

HYPL0T V74 Output 20/11/1997
1997

Period 1 Year Plot Start 00:00_01/01/1997
Interval 12 Hour Plot End 00:00_01/01/1998

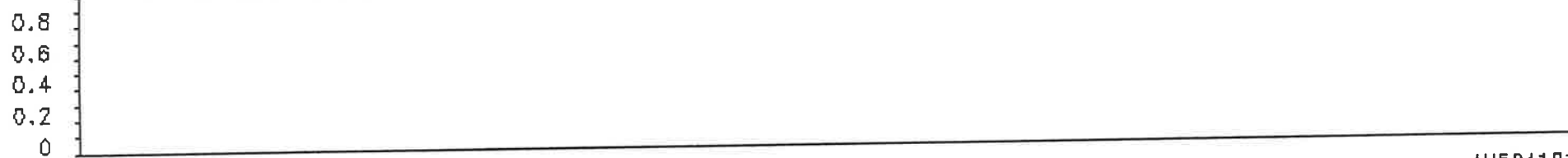
AU504101.G

AU504101 North Arm East Drain 140.00 Mean Discharge (Cumecs)



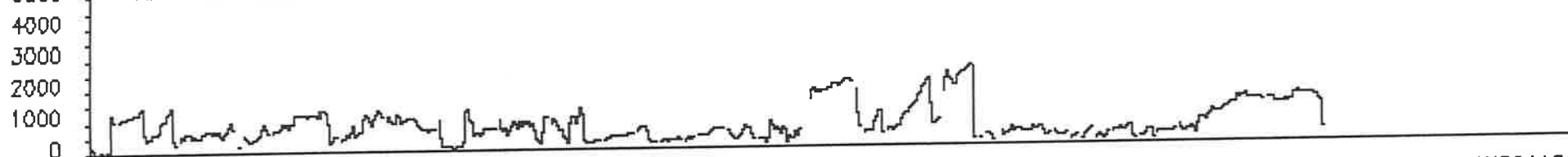
AU504101.G

AU504101 North Arm East Drain 813.00 Mean pH



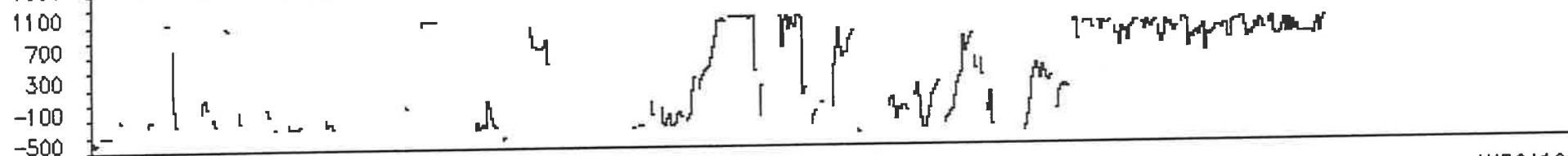
AU504101.G

AU504101 North Arm East Drain 821.00 Mean EC corrected



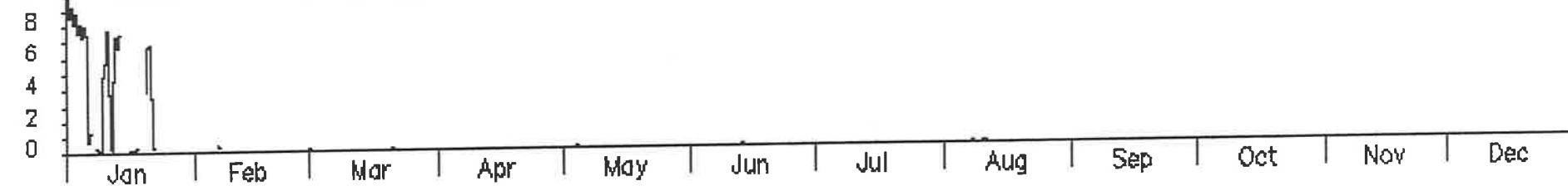
AU504101.G

AU504101 North Arm East Drain 810.01 Mean Turbidity-Uncorr.NTU raw turbidity



AU504101.G

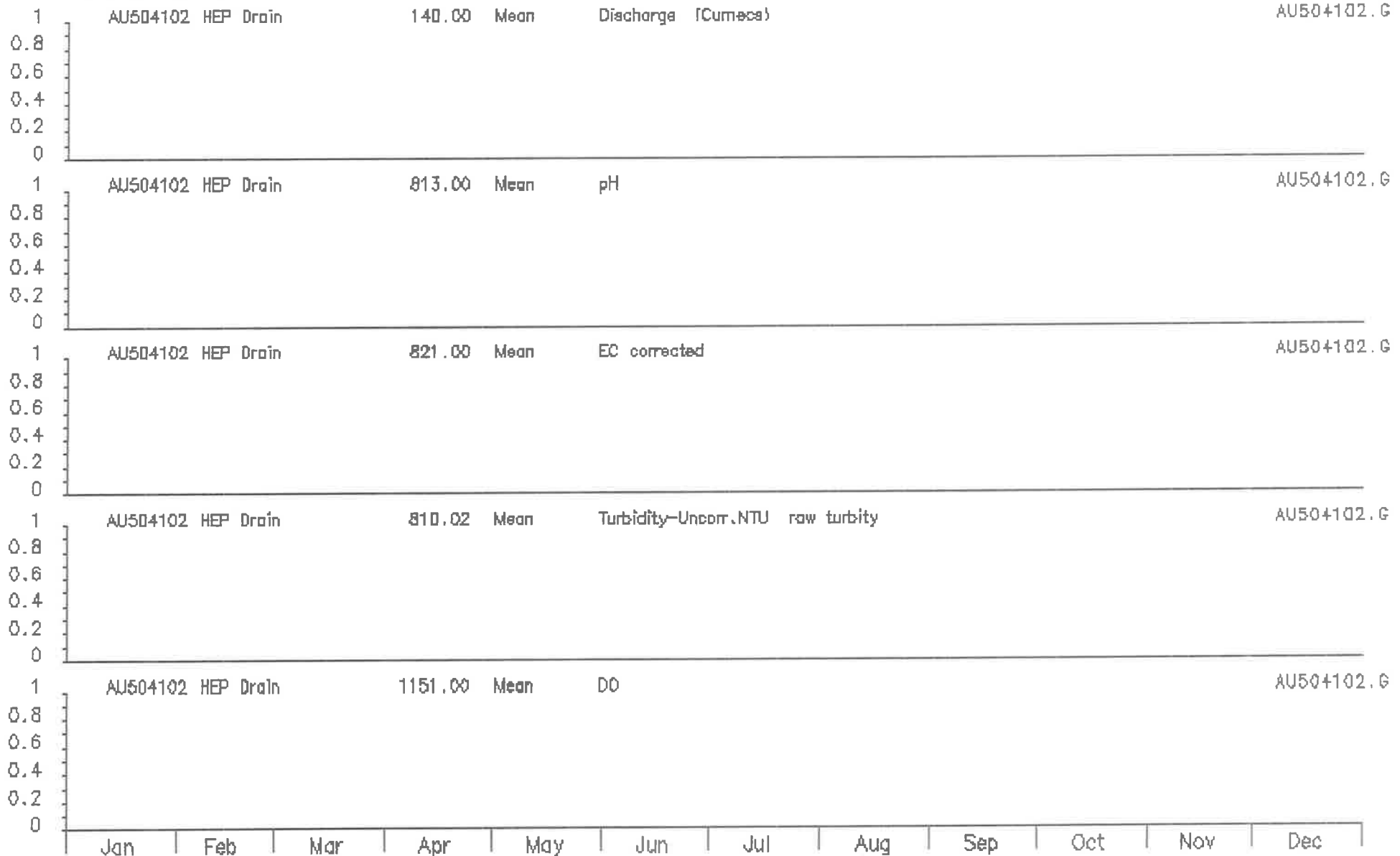
AU504101 North Arm East Drain 1151.00 Mean DO



Civil Engineering, Adelaide University

HYPLOT V74 Output 21/11/1997
1994

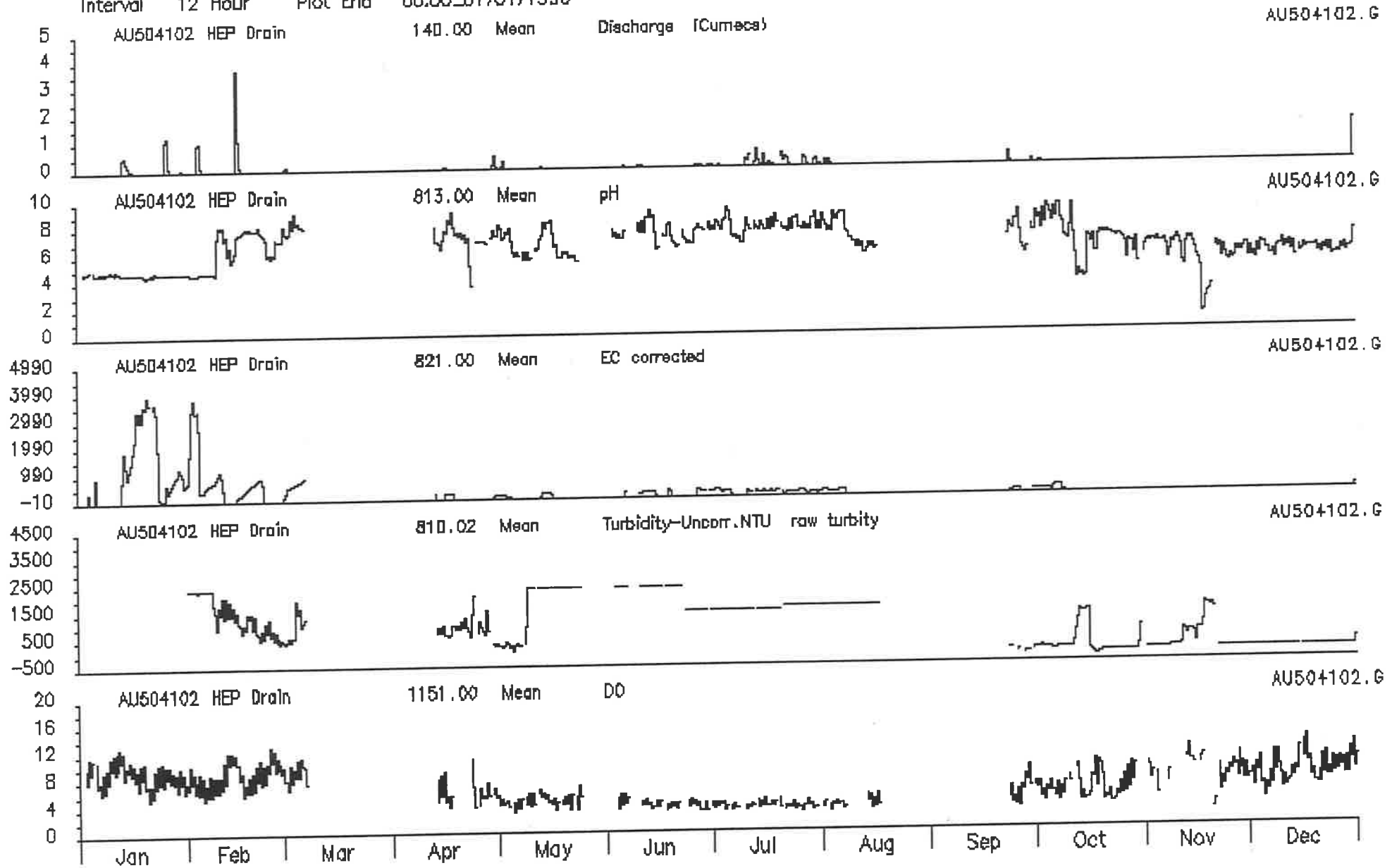
Period 1 Year Plot Start 00:00_01/01/1994
Interval 12 Hour Plot End 00:00_01/01/1995



Civil Engineering, Adelaide University

HYPLOT V74 Output 21/11/1997
1995

Period 1 Year Plot Start 00:00_01/01/1995
Interval 12 Hour Plot End 00:00_01/01/1996



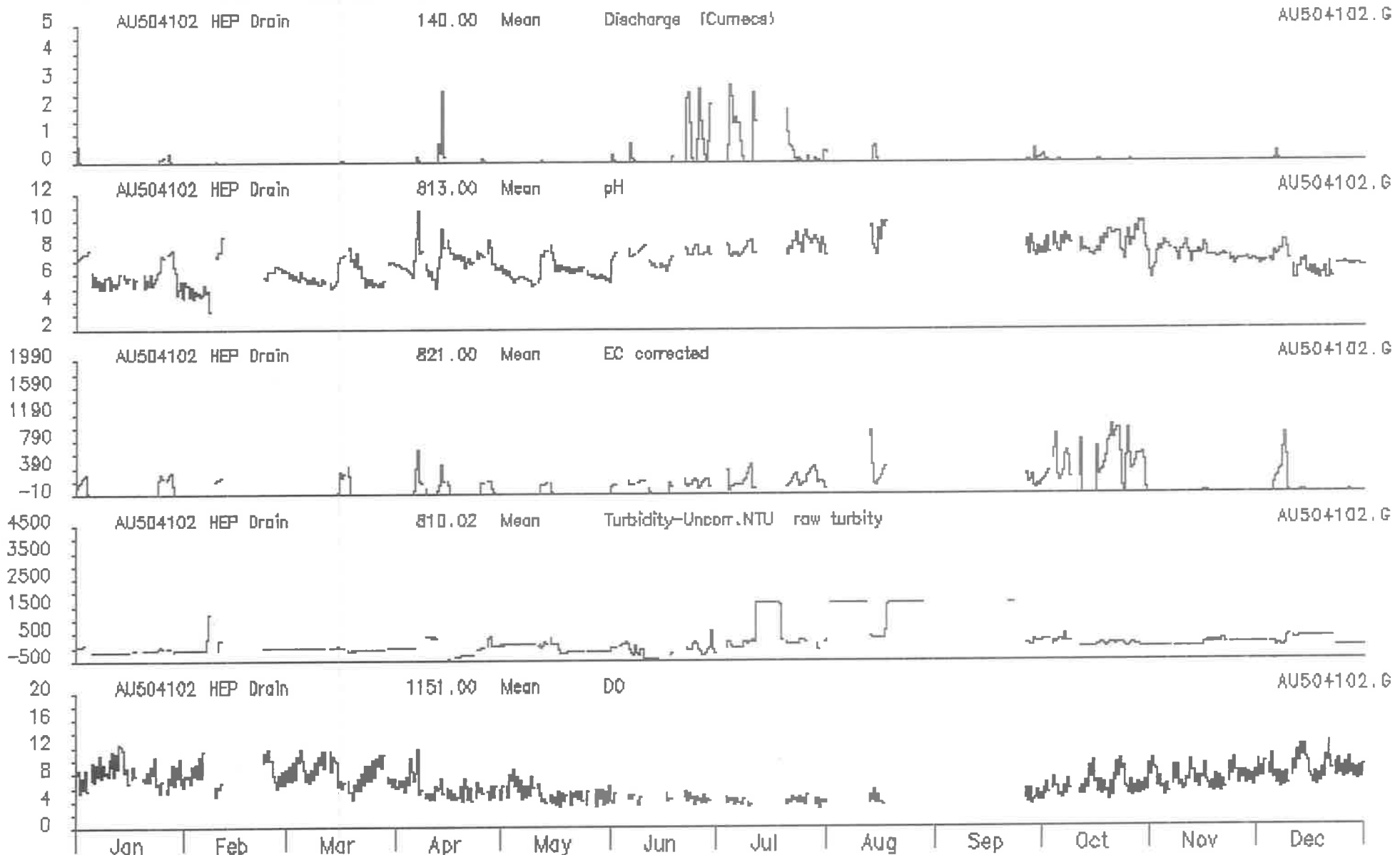
Civil Engineering, Adelaide University

HYPL0T V74 Output 21/11/1997

Period 1 Year Plot Start 00:00_01/01/1996

1996

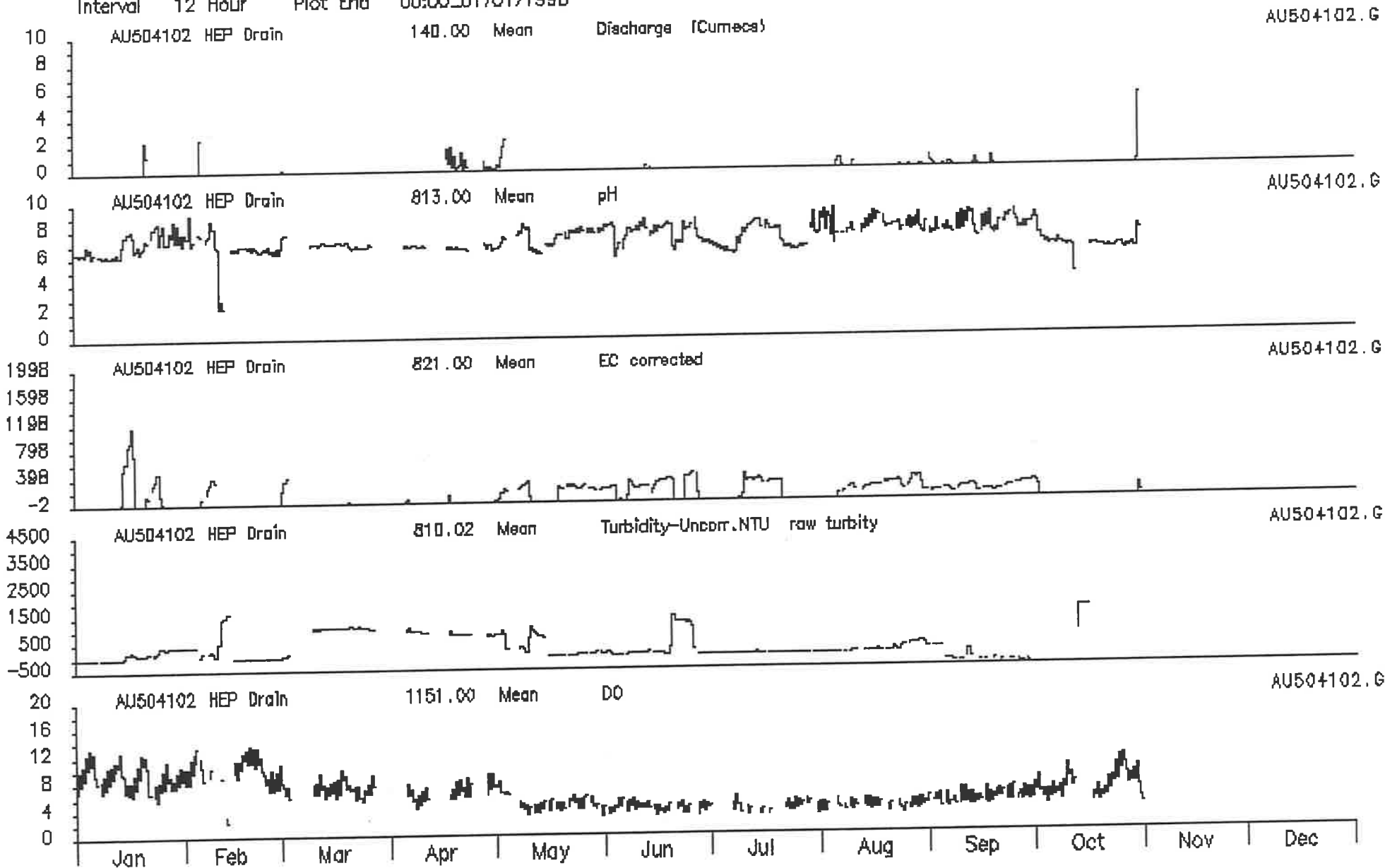
Interval 12 Hour Plot End 00:00_01/01/1997



Civil Engineering, Adelaide University

HYPL0T V74 Output 21/11/1997
1997

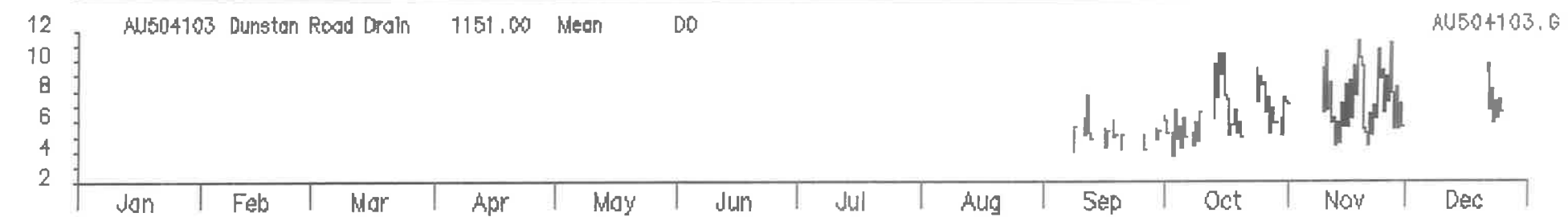
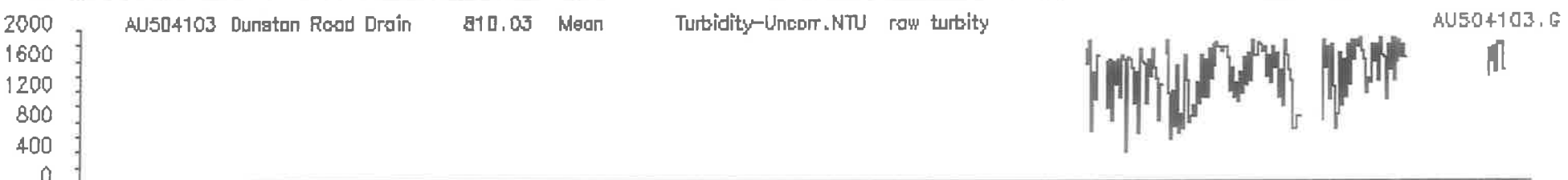
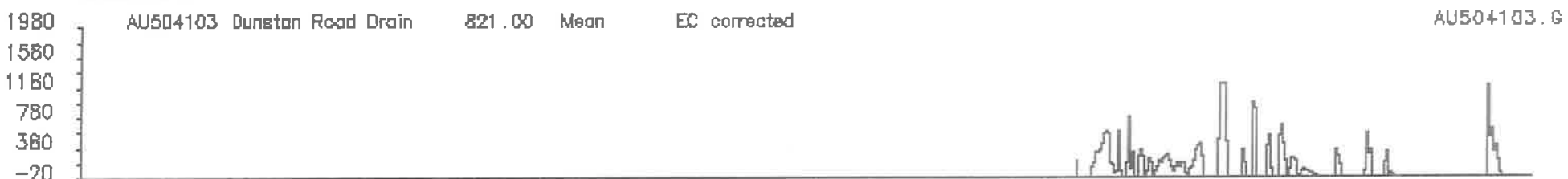
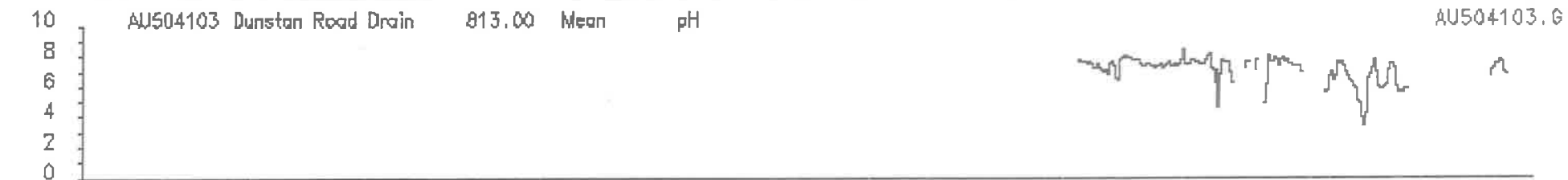
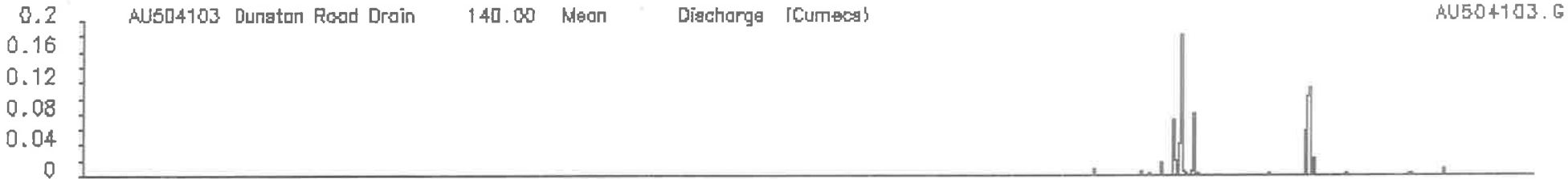
Period 1 Year Plot Start 00:00_01/01/1997
Interval 12 Hour Plot End 00:00_01/01/1998



Civil Engineering, Adelaide University

HYPL0T V74 Output 20/11/1997
1994

Period 1 Year Plot Start 00:00_01/01/1994
Interval 12 Hour Plot End 00:00_01/01/1995



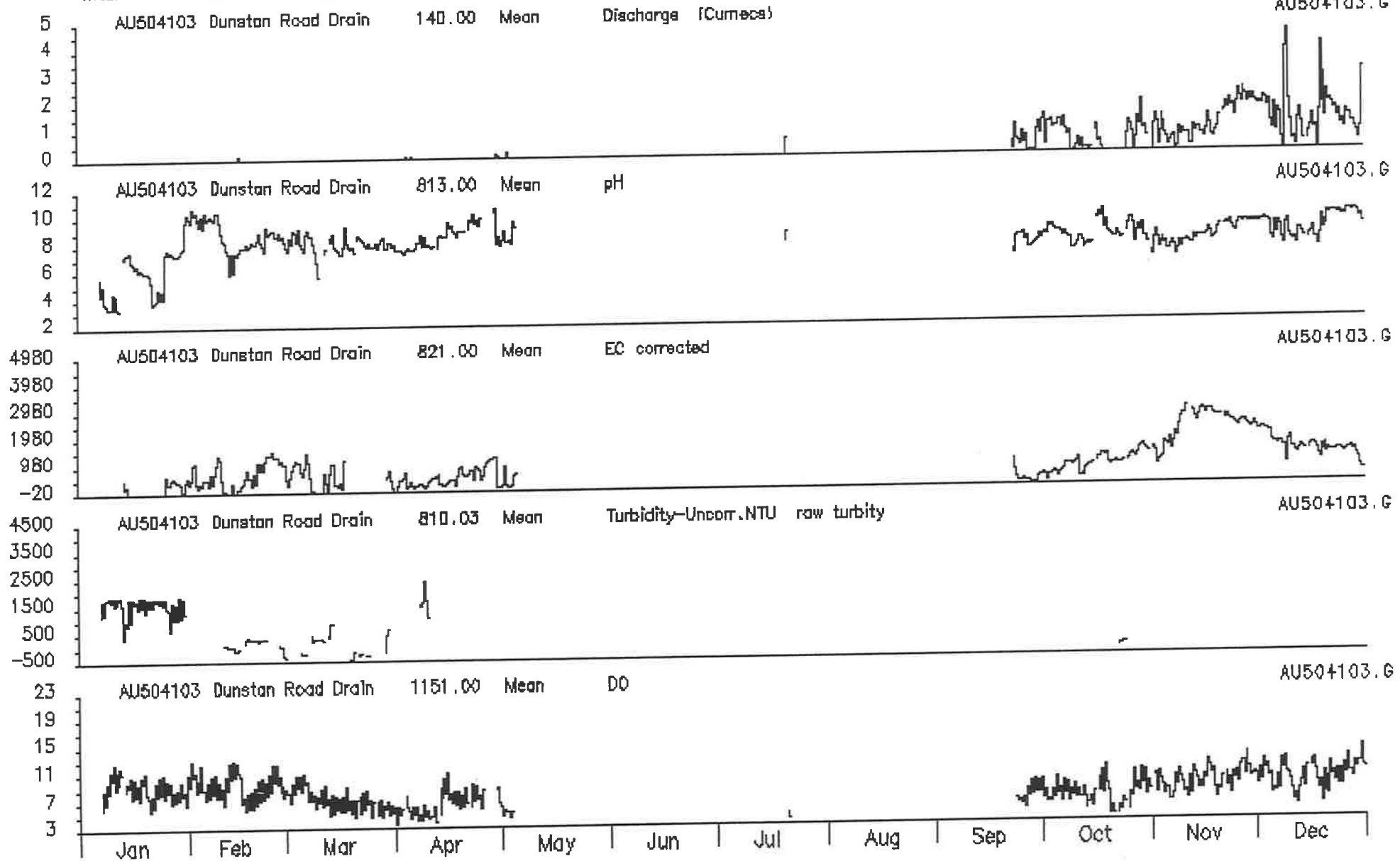
Civil Engineering, Adelaide University

HYPL0T V74 Output 20/11/1997

1995

Period 1 Year Plot Start 00:00_01/01/1995

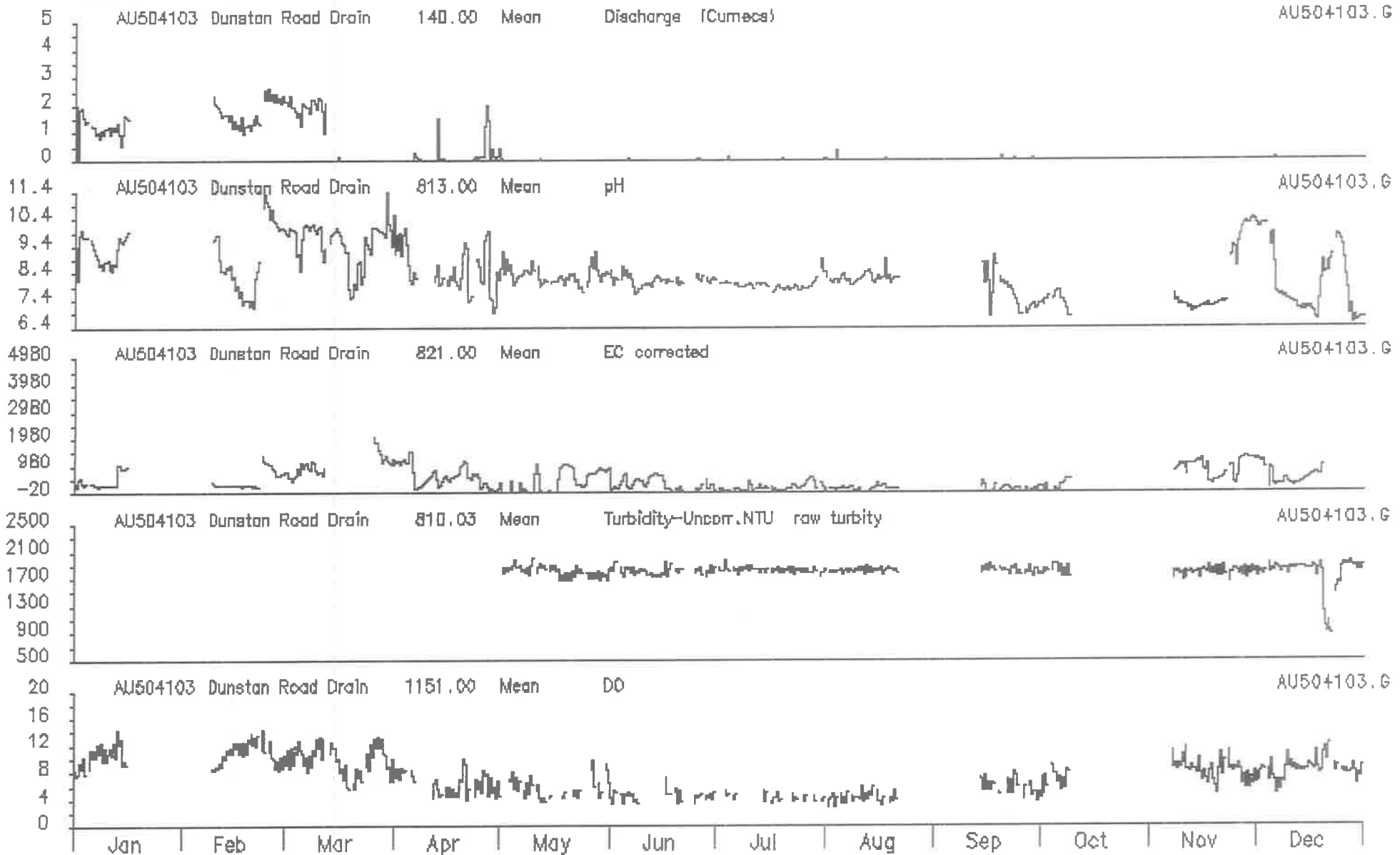
Interval 12 Hour Plot End 00:00_01/01/1996



Civil Engineering, Adelaide University

HYPLQT V74 Output 20/11/1997
1996

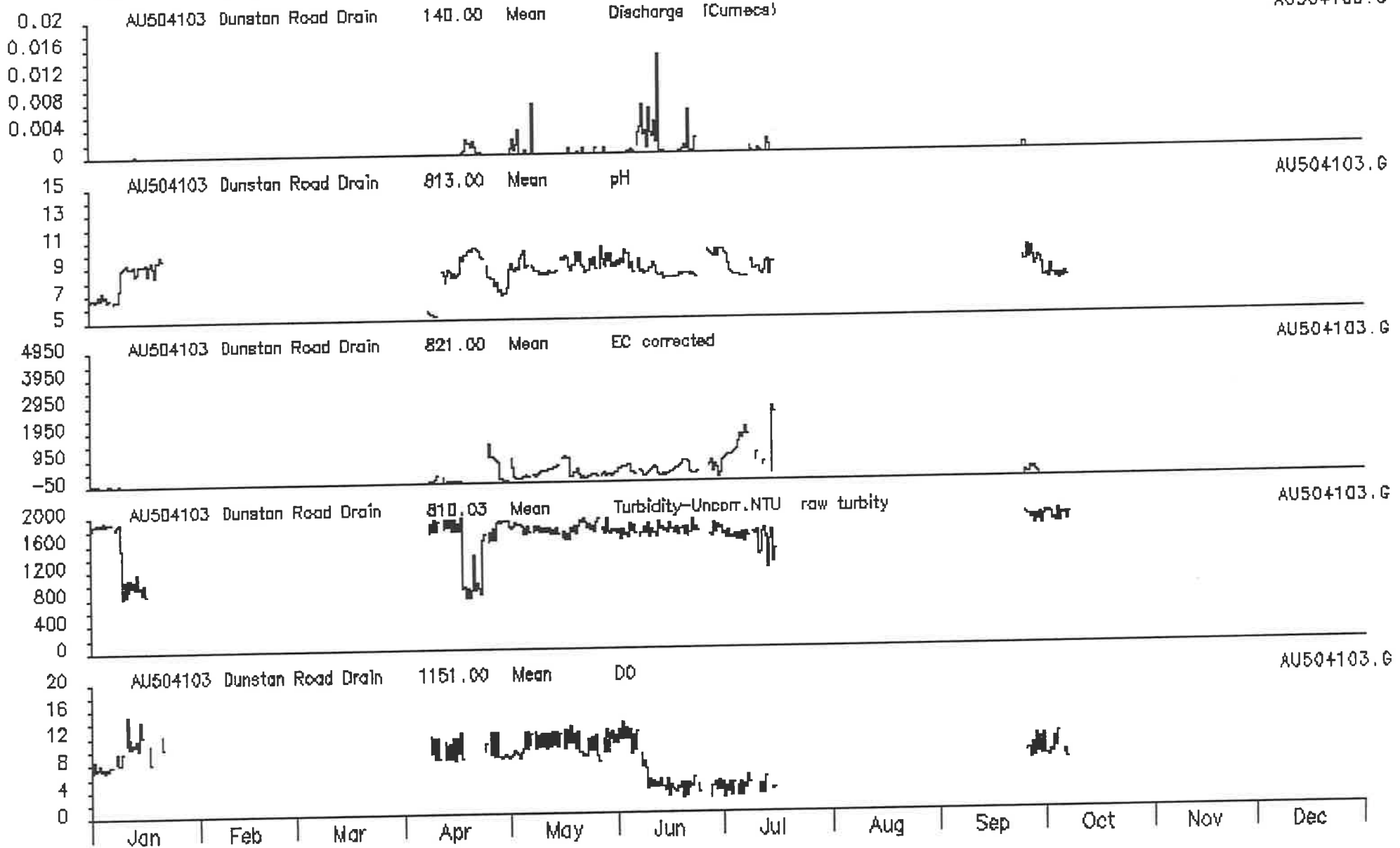
Period 1 Year Plot Start 00:00_01/01/1996
Interval 12 Hour Plot End 00:00_01/01/1997



Civil Engineering, Adelaide University

HYPL0T V74 Output 20/11/1997
1997

Period 1 Year Plot Start 00:00_01/01/1997
Interval 12 Hour Plot End 00:00_01/01/1998



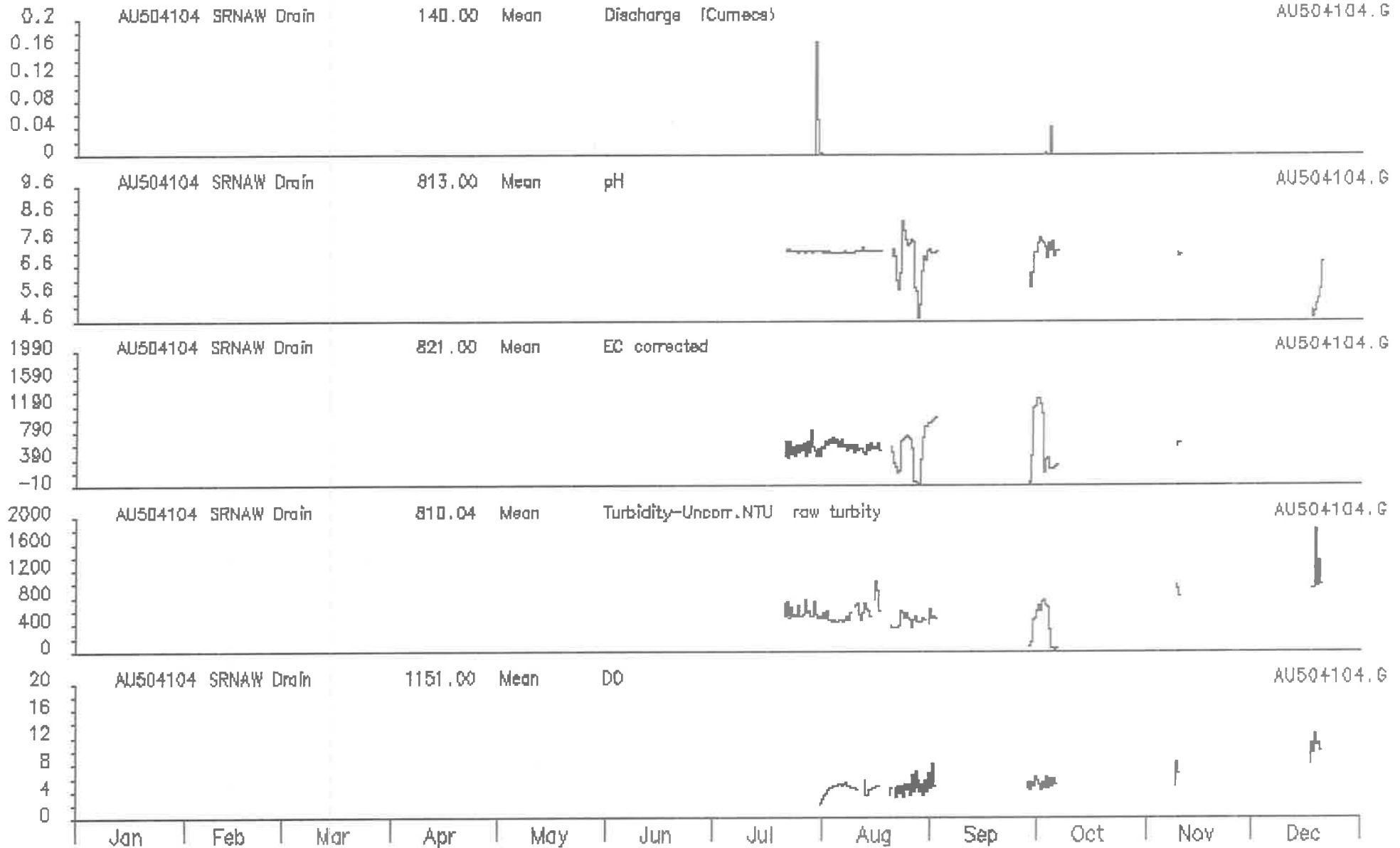
Civil Engineering, Adelaide University

HYPLAT V74 Output 21/11/1987

Period 1 Year Plot Start 00:00_01/01/1994

1994

Interval 12 Hour Plot End 00:00_01/01/1995



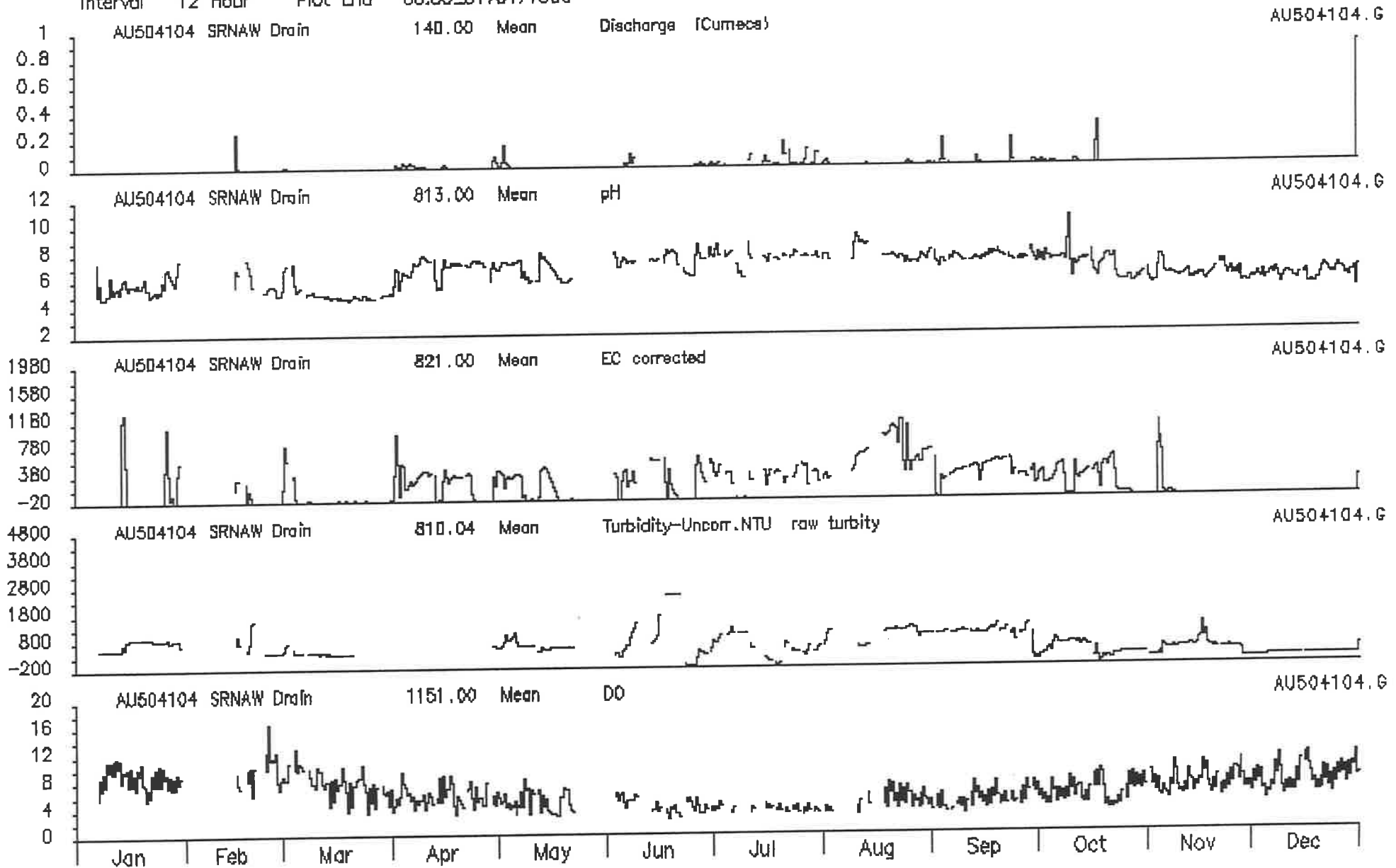
Civil Engineering, Adelaide University

HYPLOT V74 Output 21/11/1997

1995

Period 1 Year Plot Start 00:00_01/01/1995

Interval 12 Hour Plot End 00:00_01/01/1996



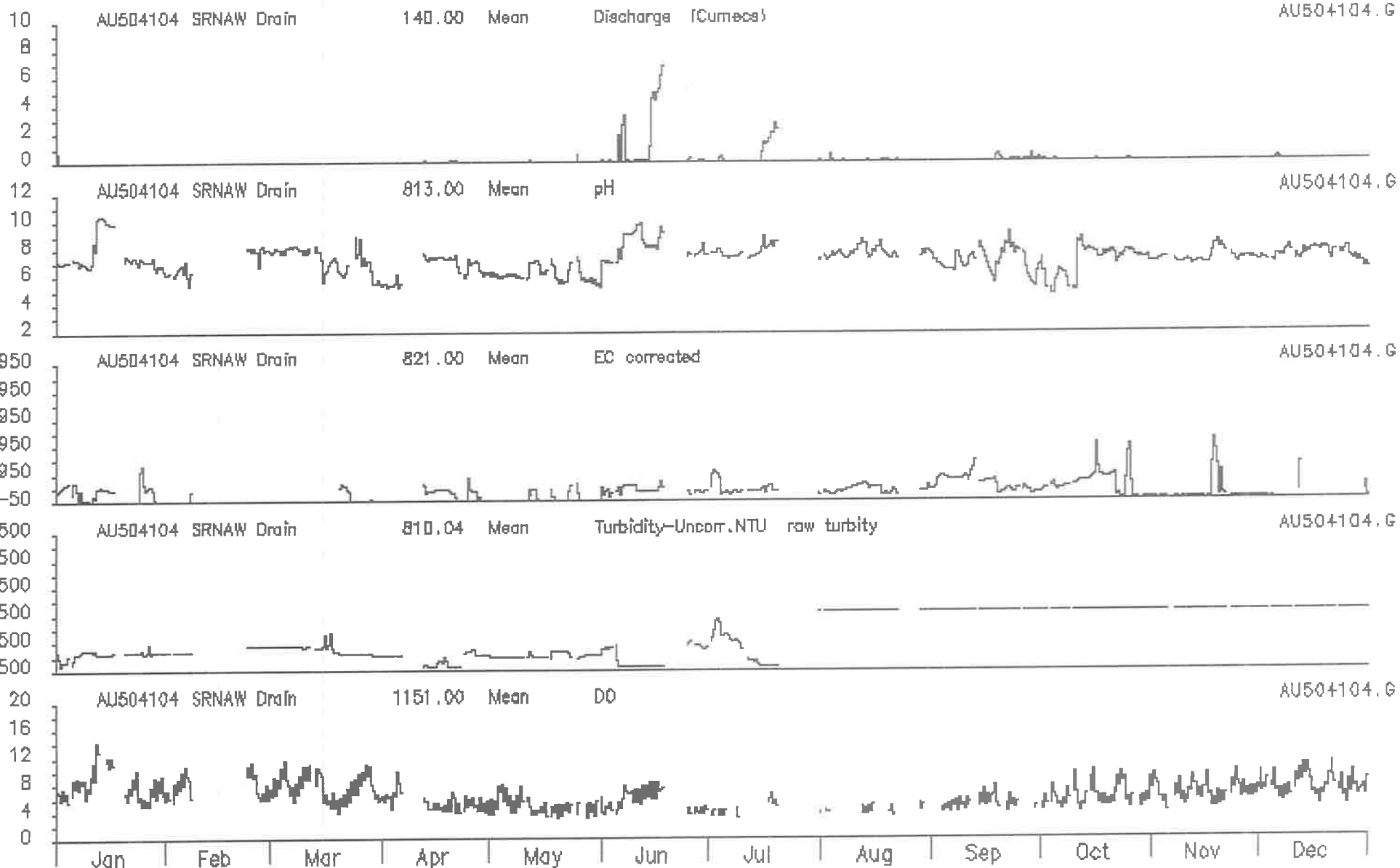
Civil Engineering, Adelaide University

HYPL0T V74 Output 21/11/1997

1996

Period 1 Year Plot Start 00:00_01/01/1996

Interval 12 Hour Plot End 00:00_01/01/1997



Civil Engineering, Adelaide University

HYPLOT V74 Output 21/11/1987
1997

Period 1 Year Plot Start 00:00_01/01/1997
Interval 12 Hour Plot End 00:00_01/01/1998

