

# **THE CHARACTERIZATION OF STORMWATER RUNOFF FROM ROAD SURFACES**

**Clinton Paul Chrystal**

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**Supervisor: Professor DD Stretch**

## ABSTRACT

The water quality of stormwater runoff from various road surfaces in Durban, KwaZulu-Natal was characterised by monitoring programmes established at four study areas. The investigation focussed on obtaining representative stormwater samples in order to quantitatively identify pollutant constituents transported within stormwater runoff from road surfaces during rainfall events. Stormwater runoff is a leading cause of degradation in the water quality of receiving water bodies.

A review of sampling methods and equipment, informed by the objectives and resources of this investigation, resulted in the development of a stormwater runoff sampler. An economical flow weighted composite sampler was designed, developed and tested. The sampler produces one representative composite event mean concentration sample. Controlled laboratory experiments, computer simulations and field tests were conducted in order to test and calibrate the sampler. The product of the event mean concentration and total runoff volume estimated provide an estimation of the total pollutant loading from a particular drainage area.

Twenty stormwater runoff event mean concentration (EMC) and atmospheric deposition samples were collected over an eighteen month period. The characterisation of stormwater runoff for this investigation included heavy metals, oxygen demanding substances, sediments and physico-chemical analysis for pH, conductivity and water hardness. Chemical analysis indicates that the pollutant levels of constituents sometimes exceeded EMCs reported internationally. The majority of contaminant EMCs exceeded the South African wastewater discharge general and special limits. The results also indicate a 60% reduction in lead (Pb) levels since the introduction of lead-free fuel in South Africa in January 2006.

The findings from this investigation will provide decision-makers with an improved local data base for estimating the impacts of road transportation systems on water quality. A comparison between the four study areas also provides guidance concerning the variability of stormwater quality from different road surfaces and usage patterns.

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## PREFACE

I, Clinton Paul Chrystal, hereby declare that the whole of this dissertation is my own work and has not been submitted in part, or in whole to any other University. Where use has been made of the work of others, it has been duly acknowledged in the text. This research work was carried out in the Centre for Research in Environmental, Coastal and Hydraulic Engineering, School of Civil Engineering, Surveying and Construction, University of KwaZulu-Natal, Durban, under the supervision of Professor D. D. Stretch.



.....  
C.P. Chrystal

24/04/07

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Date

As the candidates supervisor I have approved this dissertation for submission



.....  
Professor D. D. Stretch

24/04/2007.

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Date

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**TABLE OF CONTENTS**

ABSTRACT	ii
PREFACE	iii
ACKNOWLEDGEMENTS	iv
TABLE OF CONTENTS	v
LIST OF FIGURES	ix
LIST OF TABLES	xi
LIST OF PLATES	xiii
LIST OF ABBREVIATIONS	xiv
<b>CHAPTER 1: INTRODUCTION</b>	<b>1</b>
1.1 Introduction	1
1.2 Objectives	2
1.3 Motivation for the Investigation	2
1.4 Outline of the Dissertation	3
<b>CHAPTER 2: LITERATURE REVIEW</b>	<b>5</b>
2.1 Introduction to Stormwater Runoff	5
2.1.1 Stormwater runoff from road surfaces	6
2.2 Sources of Contaminants	7
2.2.1 Vehicular motion	7
2.2.2 Atmospheric deposition	8
2.2.3 Erodeable materials	9
2.2.4 Principle pollutant types	9
2.3 Water Quality	9
2.3.1 Water quality guidelines	10
2.3.2 Target water quality range	11
2.3.4 Water quality indicators	12
2.3.5 Analysis method for heavy metals	16
2.4 Monitoring Stormwater Runoff	17
2.4.1 Stormwater runoff events	17
2.4.2 Sampling stormwater runoff	18

---

---

2.4.2.1	Discrete sampling	19
2.4.2.2	Composite sampling	19
2.4.2.3	Summary	20
2.4.3	Event mean concentration	20
2.4.4	Temporal variation of SWR	21
2.5	Managing Stormwater Runoff	22
2.5.1	Pollutant loading of stormwater runoff	23
2.6	Relevant Research done in South Africa	24
2.6.1	Urbanisation rate in SA	25
2.6.2	Pollution assessments of surface waters	25
2.6.3	Urban catchment runoff pollution	25
2.7	Literature Review Conclusion	25
<b>CHAPTER 3: DEVELOPMENT OF A SAMPLER</b>		<b>27</b>
3.1	A Review of Sampling Methods	27
3.1.2	Automatic sampling	29
3.1.3	Flow splitter composite sampler	30
3.1.4	Culvert composite sampler	32
3.1.4	Summary of sampling methods	34
3.2	Initial Attempts at Sampling Stormwater Runoff for this Investigation	35
3.2.1	Manual hand grab sampling	35
3.2.2	ISCO Automatic samplers	36
3.2.3	Culvert composite sampler	36
3.2.4	Modifications to the Culvert composite sampler	37
3.3	New Development: Design of a Stormwater Sampler	39
3.3.1	Outline of design criteria	39
3.3.2	Modification of prototypes	40
3.3.3	Selection of suitable material and fabrication method	42
3.3.4	Selection of the orifice diameter	43
3.4	Collection Properties of the Sampler	44
3.4.1	Sampling rate ( $q_s$ )	45
3.4.2	Sampling rate related to water level and velocity	47
3.5	Stormwater Conduit Flow Estimation	47
3.5.1	Estimation of the total volume discharged	50

---

---

3.5.2	Sensitivity analysis and calibration of the total discharge estimation	53
3.6	Field Concentration Tests for Sampler	57
3.7	Conclusions	60
<b>CHAPTER 4: METHODOLOGY</b>		<b>62</b>
4.1	Study Area Selection	62
4.1.1	Study area characteristics	63
4.1.1.1	National Three Highway (N3)	64
4.1.1.2	Bayhead road	65
4.1.1.3	Booth road	66
4.1.1.4	Pavilion shopping centre	67
4.2	Monitoring Equipment	68
4.2.1	Runoff sampling equipment	69
4.2.2	Atmospheric sampling stations	73
4.2.3	Flow measurement	74
4.2.4	Discharge duration measurement	74
4.3	Procedure for Runoff and Atmospheric Collection	75
4.4	Rainfall and Runoff Quantity Monitoring	76
4.5	Laboratory Techniques and Analysis	77
4.5.1	Preparation for field sampling	77
4.5.2	Collected sample material	77
4.5.3	Analytical procedures	78
4.5.4	Quality control	79
4.6	Data Management	79
4.7	Summary	80
<b>CHAPTER 5: DISCUSSION OF STORM EVENTS AND FIELD WORK</b>		<b>81</b>
5.1	Storm Events	81
5.1.1	Precipitation	81
5.1.2	Representativeness of storm events	82
5.2	Field Work	83
5.2.1	Pavillion shopping centre	84
5.2.2	Classification of runoff samples	85
5.2.3	Composite sampler performance	86

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5.2.4	Discharge duration timing device	86
5.2.5	Quality control	86
5.3	Weekly and Long Atmospheric Samples	87
5.4	Total Culvert Flow Estimation	88
<b>CHAPTER 6: RESULTS AND DISCUSSION</b>		<b>90</b>
6.1	Presentation of Results	90
6.2	Event Mean Concentrations	90
6.2.1	SWR EMCs Exceedance levels	96
6.2.2	EMC comparisons between study areas	96
6.2.3	Comparison of site median EMCs with global reported values	104
6.3	Pollutant Loadings	107
6.3.1	Lognormal distribution test of SWR concentrations	107
6.3.2	Annual pollutant loadings	110
6.4	Atmospheric Deposition Contribution	113
6.5	Factors Affecting Stormwater Quality	116
6.5.1	Antecedent dry weather period	116
6.5.2	Precipitation affects on stormwater quality	118
6.5.3	Legislation affecting lead concentrations	120
6.6	Constituent Relationships for Stormwater Runoff	120
6.7	Environmental Impact Assessment	124
<b>CHAPTER 7: SUMMARY AND CONCLUSIONS</b>		<b>127</b>
7.1	Pro.4 Sampler Developed	127
7.2	Local Concentrations Characterized and Compared To Global Values	127
7.3	Harmful Affects	129
7.4	Atmospheric Contribution	129
7.5	Mitigation Options	130
7.6	Summation	130
7.7	Suggestions for Further Research	131
<b>REFERENCES</b>		<b>132</b>
<b>APPENDICES</b>		<b>139</b>

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**LIST OF FIGURES**

Figure 3-1: The layout of the Flow splitter as installed on the Interstate-5 (Clark and Mar, 1980)	31
Figure 3-2: Culvert composite sampler (Dowling and Mar, 1996)	33
Figure 3-3: Perspex moulded housing with hypodermic needle illustrating blocking off atmospheric air to the collection chamber	39
Figure 3-4: Modified sampling concept with a larger collection chamber and delivery tube	41
Figure 3-5: Medium flume used for testing the sampler	45
Figure 3-6: Estimation of the orifice discharge coefficient value	46
Figure 3-7: Dynamic and hydrostatic pressure driving flow into the collection chamber which is at atmospheric pressure	47
Figure 3-8: Mean orifice collection rates measured for all samplers at several water levels and velocities	48
Figure 3-9: Geometric variables used to calculate the area of flow in a pipe of known dimensions and water level	49
Figure 3-10: Various k values generated for the 720mm diameter culvert at Booth East where initial prototypes were tested	50
Figure 3-11: Relationship established for conduit flow and sampler collection rate	51
Figure 3-12: Regression curve relating $V_Q$ and $V_q$ for a 120min runoff duration	51
Figure 3-13: Procedure followed in order to estimate the total conduit discharge volume from the sampler's collected volume	52
Figure 3-14: Hydrographs 1-3 generated for simulations to investigate the sensitivity of the sampling rate $q_s$ to various runoff responses	55
Figure 3-15: Hydrographs A-B generated for simulations to examine the sensitivity of $V_q$ to different runoff responses with an equal $V_Q$	56
Figure 3-16: Storm test sample collection comparison for total solids	58
Figure 4-1: Monthly mean precipitation for Durban based on data supplied by the South African Weather Service	76
Figure 4-2: Flow chart illustrating analysis and data management of storm events	80

---

Figure 5-1: Comparison of monthly rainfall over the investigation period with the expected average monthly rainfall	82
Figure 5-2: Scatter plots comparing the estimates of total culvert discharge flow (units are m <sup>3</sup> )	89
Figure 6-1: Comparison of Mean Atmospheric and EMCs for TSS	97
Figure 6-3: Comparison of Mean Atmospheric and EMCs for BOD	98
Figure 6-4: Comparison of Mean Atmospheric and EMCs for pH	98
Figure 6-5: Comparison of Mean Atmospheric and EMCs for Aluminium	99
Figure 6-6: Comparison of Mean Atmospheric and EMCs for Chromium	99
Figure 6-7: Comparison of Mean Atmospheric and EMCs for Copper	100
Figure 6-8: Comparison of Mean Atmospheric and EMCs for Iron	100
Figure 6-9: Comparison of Mean Atmospheric and EMCs for Lead	101
Figure 6-10: Comparison of Mean Atmospheric and EMCs for Manganese	101
Figure 6-11: Comparison of Mean Atmospheric and EMCs for Nickel	102
Figure 6-12: Comparison of Mean Atmospheric and EMCs for Zinc	102
Figure 6-13: The accepted Al and failed Cr lognormal distributions	109
Figure 6-14: Site comparisons of SWR annual pollutant loadings for heavy metals ( units in kg/hectare-year )	111
Figure 6-15: Site comparisons of SWR annual pollutant loadings for solids and oxygen demanding indicators (kg/hectare-year)	112
Figure 6-16: Comparison of mean SWR and atmospheric contributions for heavy metals (units in mg/l)	114
Figure 6-17: Comparison of mean SWR and atmospheric contributions for TS, TSS and COD/BOD (units in mg/l)	115
Figure 6-18: Mean atmospheric and EMCs build-up periods (units mg/l)	117
Figure 6-19: Scatter plots for several contaminants and accumulated precipitation totals	119
Figure 6-20: Scatter plots for oxygen demanding substances and solids	121
Figure 6-21: Scatter plots for Cu and Mn vs. solid concentration levels	122
Figure 6-22: Scatter plots for several contaminants and accumulated precipitation totals	124

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## LIST OF TABLES

Table 2-1: Water quality comparisons done between the natural state of water, sewage and urban runoff adapted from Welch (1992)	6
Table 2-2: Highway runoff and their primary sources (U.S. DOT 1987)	7
Table 2-3: Source of Anthropogenic Constituents in Urban Pavement Runoff (Sansalone 1997)	8
Table 2-4: Wastewater limit values applicable to the discharge of wastewater into a water resource (National Water Act, 1998)	11
Table 2-5: SA Standards for acid-soluble aluminium in aquatic ecosystems (DWAF, 1996)	13
Table 2-6: Summary of Composite Methods by Shelly and Kirkpatrick (1975)	20
Table 3-1: Advantages and disadvantages of manual hand grab sampling	28
Table 3-2: Advantages and disadvantages of automatic sampling	30
Table 3-3: Advantages and disadvantages of the flow splitter	32
Table 3-4: Advantages and disadvantages of the culvert composite sampler	<b>Error!</b>
<b>Bookmark not defined.</b>	
Table 3-5: Comparison compiled from the findings noted by Dowling (1995)	34
Table 3-6: Comparison compiled from the findings noted by Dowling (1995)	40
Table 3-7: Values used to establish a relationship for $Q$ , $q_s$ and $V_Q$ and $V_q$	52
Table 3-8: Values used to establish a relationship for $Q$ , $q_s$ and $V_Q$ and $V_q$ .	53
Table 3-9: Sensitivity simulation results for estimation of $V_Q$ from $V_q$ for three hydrographs and varying total discharges	54
Table 3-10: Sensitivity simulation results for estimation of $V_Q$ from $V_q$ for three hydrographs and a selected fixed total discharge	57
Table 3-11: Storm test chemical analysis summary for the culvert discharge and Pro.4 sampler	59
Table 3-14: Evaluation of the Pro.4 sampler satisfying design objectives	60
Table 4-1: Summary of characteristics for the five study areas selected	68
Table 5-1: Storm events sampled with total precipitation, duration and ADP	83
Table 5-2: Classification of runoff samples collected for chemical analysis	85
Table 5-3: Quality control blanks for laboratory distilled water and sampling equipment	87

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Table 5-4: Weekly and extended atmospheric build up	87
Table 5-5: Comparison of total culvert discharge estimations	88
Table 6-1: Estimation of a dissolved fraction coefficient (units are dissolved % of total metals)	91
Table 6-2: Event mean concentrations for individual SWR events at the Booth East monitoring site	92
Table 6-3: Event mean concentrations for individual SWR events at the Booth West monitoring site	93
Table 6-4: Event mean concentrations for individual SWR events at the National 3 highway monitoring site	94
Table 6-5: Event mean concentrations for individual SWR events at the Bayhead road monitoring site	95
Table 6-6: Comparison of site median EMCs with several studies (results in mg/l unless otherwise stated)	106
Table 6-7: Kurtosis and skewness values for SWR constituent concentrations	107
Table 6-8: Lognormal distribution results for SWR based on Chi-squared test at a 95% confidence level	109
Table 6-9: Estimated SWR annual pollutant loadings (kg/year)	110
Table 6-10: Comparison of annual pollutant loadings for storm water runoff <sup>a</sup>	113
Table 6-11: Correlation for total rainfall vs. contaminant concentrations	119
Table 6-12: Change in lead concentrations since the introduction of lead free fuel	120
Table 6-13: Cross-correlation of site solids, oxygen demanding indicators and conductivity	121
Table 6-14: Correlation for TS, TSS with heavy metals	122
Table 6-15: Cross-correlations of site heavy metals	123
Table 6-16: Catchment details assumed for three water bodies	125
Table 6-17: Water quality index for three typical catchments and several heavy metals	126
Table 7-1: Annual pollutant loadings for storm water runoff <sup>a</sup>	128

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## LIST OF PLATES

Plate 3-1: An example of a manual grab sample	29
obtained with an extension pole	29
Plate 3-2: ISCO samplers are one of the most common automatic	
samplers used to collect water samples	30
Plate 3-3: Culvert composite sampler installed in a 750mm diameter	
concrete stormwater pipe	37
Plate 3-4: Modified culvert composite sampler with a Perspex	
housing and hypodermic needle	38
Plate 3-5: Prototype (Pro.1) made from a polyethylene bottle	42
Plate 3-6: Prototype (Pro.4) made from casting resin in silicon moulds	44
Plate 4-1: Aerial image of Durban with selected study areas (Google Earth)	64
Plate 4-2: Aerial photograph of the N3 Highway sampling site	
obtained from the GIS	65
Plate 4-3: Bayhead road with industrial region set back on the western side	
and undeveloped natural vegetation to the east	66
Plate 4-4: Photograph of Booth West looking west	67
Plate 4-5: Photograph of Booth East looking east	67
Plate 4-6: Aerial photograph of the Pavilion shopping centre	68
Plate 4-7: a) Saddles used to attach the sampler in the stormwater pipe	69
b) Modified lid to ensure atmospheric pressure was maintained	69
Plate 4-8: Installation set up for the N3 Highway and manhole entrance	70
Plate 4-9: a) Typical installation for Booth West and Booth East	71
b) Booth West discharge point with shrubbery used to hide equipment	71
c) Sampling equipment locked	71
d) Discharge point into the open culvert for Booth East	71
Plate 4-10: Bayhead road installation setup and steep open culvert	72
Plate 4-11: Pavilion shopping centre installation setup	72
Plate 4-12: Atmospheric sampling station	73
Plate 4-13: Pavilion shopping centre Vegason 61 installation setup	74

## LIST OF ABBREVIATIONS

<b>ADP</b>	Antecedent dry weather period
<b>Al</b>	Aluminium
<b>BE</b>	Booth East
<b>Bh</b>	Bayhead road
<b>BMP</b>	Best management practice
<b>BOD</b>	Biochemical oxygen demand
<b>BW</b>	Booth West
<b>Cd</b>	Cadmium
<b>COD</b>	Chemical oxygen demand
<b>C<sub>r</sub></b>	Runoff coefficient
<b>Cr</b>	Chromium
<b>Cu</b>	Copper
<b>DWAF</b>	Department of Water Affairs and Forestry
<b>EMC</b>	Event mean concentration
<b>Fe</b>	Iron
<b>Mn</b>	Manganese
<b>N3</b>	National 3 highway
<b>Ni</b>	Nickel
<b>NWA</b>	National Water Act
<b>Pb</b>	Lead
<b>PEMC</b>	Partial event mean concentration
<b>pH</b>	Acidity and alkalinity
<b>q<sub>s</sub></b>	Sampling rate of the sampler
<b>TS</b>	Total solids
<b>TSS</b>	Total suspended solids
<b>V<sub>q</sub></b>	Total volume collected by sampler
<b>V<sub>d</sub></b>	Total volume of conduit discharged
<b>Zn</b>	Zinc

# CHAPTER 1

## INTRODUCTION

---

*This chapter introduces the research carried out for this dissertation as well as the motivation behind the research. The main objectives and key issues are introduced. An outline of the dissertation concludes the chapter.*

---

### 1.1 Introduction

The focus of this investigation is to characterize the quality of stormwater runoff from various road surfaces in and around the city of Durban. The characterization aims to qualitatively and quantitatively identify trace metals transported within stormwater runoff from road surfaces during rainfall events.

A change in land use from its natural state, whether for forestry, agriculture, transportation systems or urbanisation will inevitably affect the quality of surface runoff during rainfall events. Non-point sources of pollution have been identified as one of the leading causes of degradation in the quality of receiving water bodies (Barret *et al.*, 1998). Many contaminants contained in stormwater runoff from impervious surfaces result from vehicular motion. Trace metals (also referred to as heavy metals) result from the operation of vehicles through frictional wear and combustion by-products. Trace metals were selected due to their identification as potential toxicants (Maltby *et al.*, 1995). This study investigated the stormwater runoff from several roads that were chosen based on criteria of road usage, number of vehicles using the road, types of vehicles and surrounding land use.

Although road surfaces are not a substantial proportion of most catchments, their effects require management when considering the water quality of the stormwater runoff. This is because small rainfall events only produce runoff from impervious surfaces which are generally linked directly to water bodies via artificial drainage systems. The pollutant build-up on such surfaces can therefore be an important pollution contributor.

## **1.2 Objectives**

The objective was to collect representative stormwater runoff samples and analyse them to estimate the concentrations of heavy metals. The data were to be used to address the following questions:

- How does South Africa's stormwater runoff loadings compare to international values and if there are differences, what are the reasons for them?
- What are the effects on the receiving water bodies and what consequences could this have for those who use the water or for aquatic life?
- What is the contribution of atmospheric deposition compared to that from actual usage of the road by vehicles?
- What could possibly be done to reduce the pollution loadings entering receiving water bodies?

## **1.3 Motivation for the Investigation**

The Department of Water Affairs and Forestry (DWAF) has identified that water quality management is a priority in South Africa. The provisions in the National Water Act, 1998 (Act No. 36 of 1998) include:

- the protection of water resources;
- the establishment of Water Management Strategies;
- the establishment of a national monitoring system and a national information system.

One of the key principles which form the basis of water quality management and practices in South Africa, as stated by DWAF (1996) is:

*'The precautionary approach to water quality management applies, in which active measures are taken to avert or minimise potential risk of undesirable impacts on the environment.'*

An improved understanding of the effects of stormwater runoff pollution loadings from roads systems is required in order to specify mitigation and/or preventative measures. This study should therefore assist in implementing best management practice decisions with regard to minimizing impacts on water resources. These outcomes are consistent with the provisions and policy outlined by DWAF and the need for sanitation in urban and rural areas.

The Department of Environmental Affairs and Tourism and Department of Minerals and Energy have published provisions in the Government Gazette pertaining to heavy metals in fuels. Due to their pollutant properties the use of heavy metals in fuel is to be phased out. The regulations are specifically aimed at reducing lead-based additives, but also aim to restrict and limit the use of other heavy metal additives until phased out. As this study focuses on heavy metals, it will allow for a closer examination and indication as to the effect of 'heavy metal free' fuels.

Reduced contamination of rivers and other water bodies would also be of benefit to the tourism industry – for example there are implications for the water quality of beaches at the coastal cities, marine areas and outdoor activities.

#### **1.4 Outline of the Dissertation**

Chapter two of this dissertation contains a review of literature covering topics of stormwater runoff contaminants, sources, possible effects to aquatic ecosystems and human health, and mitigation options.

Chapter three presents a review of several sampling methods. The development and testing of a sampling tool for collection of stormwater runoff is described.

The installation and collection of atmospheric and runoff sampling equipment is presented in Chapter four. Laboratory procedures and chemical analysis relating to stormwater samples and pollutants are discussed.

Chapter five discusses the field work and monitoring of rainfall events. Problems associated with sampling stormwater are discussed with an evaluation of the sampling device developed.

Chapter six presents the results and discussion of a sixteen month monitoring program for atmospheric deposition and stormwater runoff.

Conclusions of the research and recommendations are summarised in chapter seven. The key questions outlined in the objectives of this investigation are discussed.

## CHAPTER 2

### LITERATURE REVIEW

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*Chapter two introduces stormwater runoff characteristics. A review of current literature identifies sources of contaminants associated with stormwater runoff. The possible effects on receiving water bodies are introduced with a summary of water quality indicators. Methods of estimating pollutant loading and management strategies are reviewed.*

---

#### **2.1 Introduction to Stormwater Runoff**

Stormwater runoff (SWR) is a term used to describe the portion of rainfall that runs off a surface during a rainfall event once the surface cannot retain or absorb any more water. Stormwater runoff is generally discharged into the closest receiving water body. The impact on the environment has become a major concern. The 1972 U.S. Federal Water Pollution Act (known as the Clean Water Act) originally targeted industrial and "municipal point" source pollution in order to decrease the contamination of water bodies. Although this form of point source pollution was greatly reduced (Plater *et al*, 1992) it revealed that urban stormwater contains similar contaminants as industrial and municipal waste discharges. This is evident from Table 2-1 (adapted from Welch, 1992) that compares the concentration levels of several contaminants found in stormwater and sewage to approximate naturally occurring levels. Novotny and Olem (1994) identified urban runoff as a major source of toxic metals, other toxins and petroleum hydrocarbons. This form of contamination is defined as nonpoint source (NPS) pollution as the sources are difficult to identify and are generally associated with land use (Novotny *et al*, 1994). Thomson *et al*. (1997) also characterised highway runoff as a typical NPS pollution defined by loadings that are discontinuous in time; frequently not concentrated at a single location; responsive to climate conditions; difficult to generalise due to being site specific; with extensive variability in constituent concentrations, and which is not repeatable between events.

### 2.1.1 Stormwater runoff from road surfaces

One form of NPS pollution that has been identified as a primary source of contaminants, responsible for the degradation of receiving water bodies, is runoff from road surfaces. Stormwater runoff from road surfaces in urban areas has been shown to contain significant loads of various pollutants (Hoffman et al. 1984 and Barrett et al. 1998). Due to the impervious nature and the method of drainage from road surfaces, rainfall typically accumulates, flows off and is discharged into the nearest receiving water body.

**Table 2-1: Water quality comparisons done between the natural state of water, sewage and urban runoff adapted from Welch (1992)**

Constituent	Concentration (mg/l)		
	Natural	Sewage	Runoff
Total suspended solids (TSS)	0.8	200	630
Biological oxygen demand (BOD)	1.0	200	30
Total nitrogen (TN)	0.5	40	3.1
Total phosphorus (TP)	0.02	10	0.4
Zinc (Zn)	0.002	0.16	0.3
Copper (Cu)	0.002	0.11	0.2
Lead (Pb)	0.002	0.04	0.7

Road surfaces, in general, do not constitute a large proportion of most catchments. However, Ball (2000) noted that although a typical road in a residential area only comprises approximately 10-15% of the area, the management of urban stormwater quantity and quality are important. This is due to the fact that many small rainfall events only generate surface runoff from highly impervious surfaces, such as roads, and that the contaminants transported from these surfaces are as a result of vehicular motion or some form of anthropogenic activity. For this reason the NPS pollution resulting from highways in environmentally sensitive regions requires monitoring and management. Roads provide a surface for pollutants to accumulate during dry periods and also a direct pathway for transportation of these accumulated pollutants into the environment via runoff.

Sensitive water bodies, which receive SWR from road surfaces, are also impacted by increased peak volume discharges as a result of the increased flow from impervious surfaces. The higher runoff velocities increase the possibility of erosion, dislodgement and entrainment of particulate pollutants (Simpson 1986).

## 2.2 Sources of Contaminants

The sources of contaminants deposited on road surfaces fall into three main categories, namely (1) vehicular motion and related activities (2) atmospheric fallout and precipitation and (3) erodeable materials. These are either directly or indirectly associated with the road usage, surface or location. The majority of metals in stormwater runoff originate from streets and parking areas (FWHA, 1987). The primary sources of several constituents found in SWR are listed in Table 2-2. The loading of these pollutants on the road surface are thought to be influenced by many factors such as the number of vehicles using the road, the type of vehicles, the length of dry periods, surrounding land use, road gradients, material of road (concrete or asphalt), rainfall intensity, duration, pH and many more.

**Table 2-2: Highway runoff and their primary sources (U.S. DOT, 1987)**

Constituents	Primary Source
Particulates	Pavement wear, vehicles, atmosphere, maintenance
Nitrogen, phosphorus	Atmosphere, roadside fertilizer application
Lead	Leaded gasoline (auto exhaust), tire wear (lead oxide filler material, lubricating oil and grease, bearing water)
Zinc	Tire wear (filler materials), motor oil (stabilising additive), grease
Iron	Autobody rust, steel highway structures (guards rails, etc.), moving engine parts
Copper	Metal plating, bearing and bushing wear, moving engine parts, brake lining wear, fungicides and insecticides
Cadmium	Tire wear (filler material), insecticide application
Chromium	Metal plating, moving engine parts, brake lining wear
Nickel	Diesel fuel and gasoline (exhaust), lubricating oil, metal plating, bushing wear, brake lining wear, asphalt paving
Manganese	Moving engine parts
Petroleum	Spills, leaks, or blow-by of motor lubricants, antifreeze and hydraulic fluids, asphalt surface leachate
PCB	Spraying of highway rights-of-way, background atmospheric deposition, PCB catalyst in synthetic tires

### 2.2.1 Vehicular motion



Ball (2000) describes how vehicles provide a direct and indirect source of contaminants. Direct sources of contaminants are associated with the operation of the vehicles through frictional wear, normal combustion by-products and construction and maintenance of road surfaces. Contaminants that are deposited onto the road via vehicle activity are regarded

as indirectly sourced. The transport of particulates from their source, such as a construction site, onto the road surface is an example of an indirectly sourced contaminant. A study by Shaheen (1975) indicated that over 95% of the sediment on a highway surface does not originate from the vehicles themselves.

Sansalone (1997) summarised studies by Armstrong (1994), Ball *et al.* (1991), Lygren *et al.* (1984) and Muschack (1990), who investigated urban pavement runoff, into a table which links certain anthropogenic constituents to their corresponding sources (Table 2-3). The heavy metals listed in Table 2-2 and 2-3 are potentially toxic and carcinogenic.

**Table 2-3: Source of Anthropogenic Constituents in Urban Pavement Runoff  
(Sansalone, 1997)**

	Brakes	Tyres	Frame & Body	Fuels & oils	Concrete pavements	Asphalt Pavement	De-icing salts	Litter
Cadmium	Secondary source	Primary source						
Chromium		Primary source						
Copper	Primary source	Primary source						
Iron		Primary source	Primary source					Primary source
Lead	Secondary source	Secondary source		Secondary source			Secondary source	
Nickel		Primary source						
Zinc	Primary source	Primary source	Primary source					
Chlorides							Primary source	
Organic Solids						Primary source		Primary source
Inorganic Solids			Secondary source		Secondary source	Primary source		Primary source
PAHs				Secondary source		Primary source		
Phenols						Primary source		

Primary source       Secondary source 

### 2.2.2 Atmospheric deposition

Atmospheric sources may contribute significantly to the mass of contaminants on a road surface (Ball, 2000). A study by Heaney and Sullivan (1971) estimated that approximately 70% of material found on a road surface originates from dust fallout. Atmospheric deposition is categorised into two types by the method in which they are transported onto the road surface. Dry deposition occurs during the period between storm events while wet deposition occurs when precipitation entrains contaminants in the air removing them from the atmosphere during rainfall events. The location of and terrain surrounding a road

surface combined with the local wind conditions may have a large impact on the quality and quantity of pollutants in SWR discharge. Typical sources of atmospheric pollutants consist of dust, industrial emissions and combustion by-products. These airborne pollutants are transported by the wind and either settle onto the road surface or remain suspended until flushed out by rainfall.

### **2.2.3 Erodeable materials**

High volumes of sediments accumulate on road surfaces due to erosion of exposed soils along road sides, transportation of materials and maintenance/construction work. These sediments often carry adsorbed contaminants such as heavy metals, nutrients and organic matter. Amy and Pitt (1974) established that particulates less than 43  $\mu\text{m}$ , which represented less than 6% of the total solids, contained more than 50% of the metal fractions. A study by Sansalone and Buchberger (1997) found that particulate bound heavy metals (Zn, Pb and Cu) for particles finer than 100 $\mu\text{m}$  exceed 50% of the total metal pollutant load while their weight contribution is just over 10%. Debris from vegetation is also a source often associated with road surfaces.

### **2.2.4 Principle pollutant types**

The principle pollutant types found in stormwater runoff are toxic substances, sediments and oxygen demanding substances, nutrients, oil, grease and pathogens (Boyd and Gardner, 1990). The characterisation of stormwater runoff for this investigation included heavy metals, oxygen demanding substances, sediments and physico-chemical analysis for pH, conductivity and water hardness.

## **2.3 Water Quality**

The term *water quality* is often used to define the state of water with regards to its chemical, physical and biological characteristics. The constituents that are generally used to characterise the water quality are either dissolved or suspended in water.

With scientific analysis of selected water quality indicators, the water quality is classified as either being of 'good' or 'bad' quality with reference to its location and intended use. Therefore, separate guidelines for assessing recreational, domestic, industrial, marine and

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agricultural water have been established. The underlying reason is that water which is suitable for industrial use may not be acceptable for sensitive water systems. The focus of this investigation is on the characteristics of water quality related to stormwater runoff resulting from rainfall on road surfaces.

### 2.3.1 Water quality guidelines

The Department of Water Affairs and Forestry (DWAF, 1996) has compiled guidelines entitled the *South African Water Quality Guidelines*. These guidelines provide water quality criteria for all possible uses from industrial to recreational, with the intention of maintaining and managing sustainable water resources in South Africa at acceptable water quality levels for their intended use.

There are no guidelines specifically for stormwater runoff. The general practice in South Africa has been to use the *General and Special Standards for Discharge, in terms of the South African Water Act* (Section 21 of the Amendment Act, 1980). These were established in 1956 for treatment works and industrial discharges. The introduction of the National Water Act (NWA) (1998) introduced updated general and special limits. Although stormwater is not specifically categorised, the definition of "wastewater" and the "wastewater limit value" are broad enough to include runoff. *Wastewater* is defined as water that contains waste, or has been in contact with waste material (NWA, 1998). The *wastewater limit value* provides the concentration limit for a specific contaminant that may not be exceeded at any time. The limit applies to the last point of collection where the discharge enters the receiving water body (NWA, 1998). Table 2-4 presents the wastewater limit values as presented in the National Water Act (1998).

The special limit values (as seen in Table 2-4) refer to specified rivers, lakes, dams, estuaries and water bodies, such as the St Lucia and Kosi Bay wetlands, listed in the National Water Act (1998). The list covers a significant number of South Africa's water resources, and is therefore included for comparison with water quality indicators. General standards are applicable to wastewater or effluent arising from areas not specified under the special standards. For contaminants not covered in Table 2-4, such as aluminium, the *South African Water Quality Guidelines for Aquatic Ecosystems* (DWAF, 1996) may be consulted. These guidelines are considered the appropriate reference for this investigation. The majority of pollutant constituents found in SWR are covered most

comprehensively in these guidelines. This document is referred to as the SA WQ guidelines.

**Table 2-4: Wastewater limit values applicable to the discharge of wastewater into a water resource (National Water Act, 1998)**

SUBSTANCE/PARAMETER	GENERAL LIMIT	SPECIAL LIMIT
Faecal Coliforms (per 100 ml)	1 000	0
Chemical Oxygen Demand (mg/l)	75	30
pH	5,5-9,5	5,5-7,5
Ammonia (ionised and un-ionised)	6	2
Nitrogen (mg/l)		
Nitrate/Nitrite as Nitrogen (mg/l)	15	1,5
Chlorine as Free Chlorine (mg/l)	0,25	0
Suspended Solids (mg/l)	25	10
Electrical Conductivity (mS/m)	70 mS/m above intake to a maximum of 150 mS/m	50 mS/m above background receiving water, to a maximum of 100 mS/m
Ortho-Phosphate as phosphorous (mg/l)	10	1 (median) and 2,5 (maximum)
Fluoride (mg/l)	1	1
Soap, oil or grease (mg/l)	2,5	0
Dissolved Arsenic (mg/l)	0,02	0,01
Dissolved Cadmium (mg/l)	0,005	0,001
Dissolved Chromium (VI) (mg/l)	0,05	0,02
Dissolved Copper (mg/l)	0,01	0,002
Dissolved Cyanide (mg/l)	0,02	0,01
Dissolved Iron (mg/l)	0,3	0,3
Dissolved Lead (mg/l)	0,01	0,006
Dissolved Manganese (mg/l)	0,1	0,1
Mercury and its compounds (mg/l)	0,005	0,001
Dissolved Selenium (mg/l)	0,02	0,02
Dissolved Zinc (mg/l)	0,1	0,04
Boron (mg/l)	1	0,5

### 2.3.2 Target water quality range

The Target Water Quality Range (TWQR) has been established as a management objective rather than a set water quality criterion (DWAF, 1996). This desirable concentration range of pollutant levels is derived from qualitative and quantitative criteria and assumes that life-long exposure will result in no measurable adverse effects on the health of aquatic ecosystems. Subsequently, the objective of DWAF is to maintain the

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water quality within the TWQR thus ensuring the protection and sustainability of South African water resources.

### 2.3.4 Water quality indicators

There are several methods that may be used to determine water quality. The most widely accepted are scientific analyses of water and sedimentation samples and the biological analysis of organisms present in the water. Assessment of a specific location can also include broader social indicators such as public surveys and monitoring of activities within the system such as the number and health of plant or fish species.

In order to specifically characterise the pollutant concentrations of SWR discharge, samples of runoff are analysed. This provides direct results for the pollutant concentrations entering the aquatic ecosystems via runoff. The water quality indicators selected to characterise the water quality of SWR in this investigation were:

- Concentration of heavy metals (also known as trace metals) - Al, Cd, Cr, Cu, Fe, Mn, Ni, Pb, Zn
- Concentration of sediments – TS, TSS
- Concentration of oxygen demanding substances – BOD, COD
- Chemical properties – pH, conductivity, water hardness

The above water quality indicators were selected (1) in order to provide a broad characterisation (2) based on current literature (3) to provide a comparison with international studies (4) in order to satisfy the objectives of the investigation (5) due to what chemical analysis was available at laboratories in Durban. A brief description of the selected water quality indicators and their associated standards (presented in Table 2-4 unless otherwise noted) follows.

#### Aluminium (Al)

The occurrence of aluminium as a pollutant is largely dependent on pH. Aluminium is only soluble at low pH values and therefore more bioavailable. Although classified as a non-critical element there is increasing concern about the elevated levels found in the environment which interact with acidic water such as acid precipitation. A study by

Schecher and Driscoll (1988) found the concentration of aluminium to have risen in many freshwater sources as a result of acid rain. Mobilised elevated levels of bio-available aluminium are toxic to many species of organisms (DWAF, 1996). There is no wastewater limit value for aluminium. Therefore the SA TWQR criteria for aluminium are used which are based on acid-soluble aluminium concentrations (Table 2-5).

**Table 2-5: SA Standards for acid-soluble aluminium in aquatic ecosystems (DWAF, 1996)**

TWQR and Criteria	Aluminium concentration (µg/l)	
	pH < 6.5	pH > 6.5
Target Water Quality Range (TWQR)	< 5	<<10
Chronic Effect Value (CEV)	10	20
Acute Effect Value (AEV)	100	150

The Chronic Effect Value (CEV) is defined by DWAF (1996) as the concentration at which there is expected to be a significant probability of measurable chronic effects on up to 5% of the species in the aquatic community. Long term or frequent exposure at this level will have considerable negative consequences for aquatic ecosystems due to the eventual disappearance of sensitive species and the interdependence of various species.

The Acute Effect Value (AEV) is the concentration at which a significant probability of measurable toxic effects on up to 5% of the species in the aquatic community is expected (DWAF, 1996). Short term or frequent exposure at this level will have considerable negative consequences on the aquatic ecosystems due to the rapid death or disappearance of sensitive species and the symbiotic relationships between various species.

#### Cadmium (Cd)

Cadmium is classified as highly toxic to marine and freshwater aquatic life and with possible toxicity effects to man (DWAF, 1996; Herber *et al.* 1981). The United States Environmental Protection Agency (USEPA) considers Cd toxic and potentially hazardous to most forms of life. Cadmium is considered to be relatively mobile as a result of being

water soluble and therefore more bioavailable. Consequently Cd tends to bioaccumulate (EU Commission 2002).

#### Chromium (Cr)

Chromium is generally found bound to particulates and differs in its effects on the environment and living organisms with regard to the oxidation state. There is a great difference in the toxicity of Cr (III) and Cr (VI). Cr (III) is an essential nutrient for humans in small dosages whereas Cr (VI) may have a number of adverse effects resulting in irritation and possibly cancer (EU Commission 2002).

#### Copper (Cu)

Copper is an abundant metal that occurs naturally in most waters. The toxicity of Cu may increase or decrease due to water hardness, dissolved oxygen, presence of other metals and changes to the pH level (Avenant-Oldewage and Marx, 2000).

#### Iron (Fe)

Iron is classified as a non critical element due to its limited toxicity and bio-availability (DWAf, 1996). The availability is dependent on environmental conditions and at high concentrations may result in toxic properties.

#### Lead (Pb)

Organic lead, of which lead petrol is the primary source, is more bioavailable and toxic than inorganic lead. Depending on concentration exposure and duration, lead can result in several biological effects, especially with regards to children (EU Commission 2002). DWAf (1996) defines Pb as a toxic trace metal that readily accumulates in living tissue. USEPA considers Pb toxic and potentially hazardous to most forms of life.

#### Manganese (Mn)

Manganese is an abundant metal that is influenced by DO, pH and organic matter. Although Mn is a necessary micronutrient for certain organisms and plants, high concentrations are considered toxic, resulting in central nervous system disturbances (DWAf, 1996).

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### Zinc (Zn)

Zinc is a necessary micronutrient in all organisms although the optimum concentration range is generally narrow (DWAF, 1996). Zn has relatively low toxicity to humans but relatively high toxicity to fish and aquatic organisms (Alabaster and Lloyd, 1980). The toxicity of Zn is influenced by the water hardness, oxygen concentrations and presence of other metals (DWAF, 1996).

### Acidity and Alkalinity (pH)

Acidity and alkalinity (pH) is a measure of the hydrogen ion activity in a solution such as water. The pH is an important indicator as it influences many of the chemical and biological reactions in natural waters. The availability and toxicity of constituents, such as trace metals in the aquatic environment are largely dependant on the pH level (DWAF, 1996). The majority of South African freshwater systems are more or less neutral in pH, ranging between 6 and 8.

### Electrical Conductivity (EC)

The electrical conductivity (EC) is a measurement of the water's ability to conduct an electrical charge. The EC is a useful indicator of the mineral content and generally correlates with the total dissolved solids. High levels of EC, above 370 mS/m, may result in disturbances of salt and water balance in aquatic systems and possible health effects for humans with high blood pressure and renal diseases (DWAF, 1998).

### Total Suspended Solids (TSS)

The measurement of the amount of material suspended in water is defined as the total suspended solids (TSS) concentration. The level of TSS generally increases with the quantity of sediment that is discharged into receiving water bodies. The majority of the TSS concentration results from erosion of materials and anthropogenic activities. The effect of TSS on water systems is a function of concentration levels and frequency of exposure. Suspended sediments may degrade receiving water systems by reducing light penetration and temperature, interfering with aquatic organisms, such as burrowing benthic organisms and interfering with egg deposition and hatching, and photosynthesis. (Boyd and Gardner, 1990). Sediments also serve as carriers of pollutants adsorbed to their surfaces (DWAF, 1996).

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### Total Dissolved Solids (TDS)

Total dissolved solids is a measurement of the dissolved fraction of compounds in water which pass through a 0.45µm pore size filter. The TDS concentration is a function of physical processes such as evaporation, precipitation and the erosion of minerals in rocks, soils and other materials. The effect of TDS is dependent on the rate and duration of change of the concentration against background levels (DWAf, 1996).

### Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD)

The oxygen demand of biodegradable organics is significant since anaerobic conditions, which can severely impact the ecology of an aquatic system, may result if available oxygen levels decrease. BOD concentrations indicate the amount of oxygen required to completely oxidise the organic pollutant load whereas COD is a measurement of the nonbiodegradable organics. The BOD and COD measured levels in SWR discharge give an indication of the potential for organic wastes to lower the aquatic system oxygen levels. Waste water limit values are established for dissolved oxygen (DO) and COD. The EU guidelines for the protection of fisheries and aquatic life are 3.0 to 6.0 mg/l for BOD (Chapman, 1996).

### **2.3.5 Analysis method for heavy metals**

There is a worldwide trend towards using the dissolved fraction of heavy metals for water quality criteria guidelines. The dissolved fraction of metals is considered to more accurately approximate the bioavailable and toxic properties than total metals (dissolved + particulate). The USEPA and NWA (1998) both stipulate the measurement of the dissolved fraction for most metals for water quality criteria. However, as a precautionary method, the measurement of total metals for Al, Cd and Cu is recommended in the SA WQ guidelines.

The partitioning of heavy metals between dissolved and particulate bound is a function of many variables such as pH, pavement residence time, sample retention time, storage container and solids concentration (Sansalone *et al.* 1997). Studies have also shown that the availability and toxicity are affected by pH, redox potential, temperature, hardness, alkalinity, solids, combination of metal ions and pollutants and dissolved oxygen (Avenant-Oldewage and Marx, 2000; Allen Burton *et al.*, 2001; Riba *et al.* 2003).

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Due to the uncertainties, primarily associated with the partitioning between the dissolved and particulate fractions, and secondly the bioavailability and toxic properties associated therewith, the chemical analysis for total metals was selected for this investigation. Total metals also allow for a more comprehensive comparison internationally with data available from previous studies. Where dissolved metals are required, a coefficient derived from previous case studies can be applied to the total metal concentration to provide estimates.

## **2.4 Monitoring Stormwater Runoff**

The monitoring of stormwater runoff requires careful planning due to the unpredictable nature of rainfall and the instrumentation required. A proper monitoring programme is significant as management decisions made with the data can be no more accurate than the data they are based on. Therefore, when to sample, how to sample, where to sample, who will sample and many more questions need to be addressed prior to commencement of stormwater monitoring.

### **2.4.1 Stormwater runoff events**

In order for pollutant assessment and comparison to be done, accurate representative stormwater runoff data from representative storm events were required. The definition of a representative storm event reduces distortions and variability of the data, which may in turn result in inaccurate assessments.

Review of literature indicates three key requirements for defining a representative storm event: the number of dry days preceding the rainfall; the intensity of the rainfall and the depth of total precipitation. There exists a significant variation in the literature as to how many days, how intense and what volume respectively. Barret *et al.* (1998) defined a storm event as a period of rainfall preceded and followed by at least a 10-hour dry period. Characterisation of stormwater runoff studies by Sansalone and Buchberger (1997), Wu *et al.* (1998) and Shinya *et al.* (1999) all had various minimum dry periods ranging from 0.6 to 4 days, rainfall intensities from 1.8 to 6 mm/hr and total precipitation depths of 0.4 to 25mm.

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The USA Environmental Protection Agency (EPA) requires that sampling for the National Pollutant Discharge Elimination System (NPDES), be conducted for storm events that meet a minimum depth and antecedent dry period and fall within a reasonable range of the local average depth and duration. A storm event within these guidelines should thus satisfy the following criteria (USEPA, 1992):

- the total depth of precipitation must be greater than 2.54mm
- the antecedent dry period must be greater than 72 hours
- the precipitation depth and duration should fall within 50% of the average depth and duration.

For the purpose of this investigation the USAEPA criteria were adopted. The minimum antecedent dry period of 72 hours was considered more reasonable for the build up of contaminants, when compared to previous studies that used shorter periods.

#### **2.4.2 Sampling stormwater runoff**

The method of sampling stormwater is often dictated by the intended use of the results with regards to the objectives of the investigation. To truly evaluate and make informative management decisions, the sample must provide the required information. Several methods of collecting stormwater runoff are available. These range from manual hand grab samples to fully automated sampling machines. The advantages and disadvantages are specific to the sampling technique requirements for individual pollutant constituents and to the sampling site (Shelly, 1975). Factors which may determine which method of sampling is appropriate are: (1) the location chosen for collecting samples (2) accessibility for sampling (3) flow conditions expected at the sampling point (4) accuracy of data required (5) security of equipment (6) available man power and finance. These factors need to be systematically evaluated as certain *in situ* conditions may favour different sampling methods. If a compromise cannot be found which will result in a representative sample being obtained, the site may have to be ruled out if no alterations can be made.

Two types of sampling techniques are generally used when requiring the collection of water quality samples for subsequent water quality analysis: discrete and composite sampling (Thomson 1997).

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#### **2.4.2.1 Discrete sampling**

Discrete samples are individual samples taken from the runoff at discrete time intervals (Thomson, 1997). Discrete samples are either obtained manually or by a programmed automatic sampler. Manual grab sampling methods are frequently used and follow basic field procedures to ensure representative samples (Tobaison, 1993). Automatic samplers can be programmed to obtain discrete samples at set times, flow or total volume intervals which can be preset before a storm event. Analysis of a discrete sample provides a characterisation of the quality of the stormwater runoff discharge at the particular time it was obtained (NPDES 1992 EPA). However, it may not reflect the average of a runoff event as extreme concentrations and/or other flow variations can be missed.

#### **2.4.2.2 Composite sampling**

A composite sample is a single sample comprised of discrete sample aliquots which represents the average constituent characteristics of the entire stormwater runoff event. Discrete samples are generally combined based on time averages, flow weighted approaches or total volume discharged. An in-depth study, Shelly and Kirkpatrick (1975) reviewed the various composite methods available (summarised in Table 2-6). Methods 1 to 3 are not true representative samples as they do not account for the unpredictable variations in discharge. Methods 4 to 5 are regarded as flow weighted samples which more closely approximate the mean characteristics of the SWR. Shelly and Kirkpatrick (1975) further examined methods 3 to 6 by computing the ratio of composite sample concentration resulting from four hypothetical flow and concentration relationships to the actual average concentration. The review by Shelly and Kirkpatrick (1975) indicated that a composite sample with the volume proportional to the instantaneous flow rate ( $T_c V_v$ ) attains the highest accuracy.

**Table 2-6: Summary of Composite Methods by Shelly and Kirkpatrick (1975)**

Method	Symbol	Principle	Comments	Disadvantages
1	Vc	Constant sample pumping rate	Practical but not widely used	Yields large sample volume, not true flow-weighted composite
2	Vv	Continuous sample pumping rate proportional to flow	Not widely used	Unpredictable, usually large sample volume, requires accurate flow measurement
3	Tc Vc	Constant time interval, constant sample volume	Common manual method for low variability flows	Not recognized by EPA, not representative of variable storm flows
4	Tc Vq	Constant time, volume proportional to flow rate	Easily adapted to manual sampling and compositing	Ease of manual compositing from flow chart
5	Tc Vv	Constant time, sample volume proportional to flow increment	Adapt to manual and automatic sampling and compositing	Requires accurate flow measurement and integration. Difficult automatic compositing
6	Tv Vc	Time proportional to flow volume increment, constant sample volume	Widely used in automatic sampling and compositing	Difficult manual compositing, requires accurate flow measurement

#### 2.4.2.3 Summary

Instantaneous discrete samples are not capable of representing the average over an entire storm event due to the variation in flow and concentration levels associated with SWR events. Composite samples formed from a combination of discrete samples attain a closer representation of the average characteristics but may miss vital peaks or drops in flow and concentration levels. A reduction in the time step between the collection of samples improves the accuracy although the laboratory costs and labour required to composite such samples increases. A continuous sampling method proportional to the flow rate is optimal although storage requirements limit this method. The resultant single sample would only require a single chemical analysis, and can yield the average characteristics for the entire storm event.

#### 2.4.3 Event mean concentration

The event mean concentration (EMC) is a single index which represents the flow weighted average concentration of an entire runoff event as there are often variations in pollutant

concentrations of several magnitudes during a runoff event (Huber, 1993). The EMC is defined as the total pollutant loading divided by the total volume of flow given by:

$$EMC = \bar{C} = \frac{M}{V} = \frac{\int_0^{t_r} c(t)q(t)dt}{\int_0^{t_r} q(t)dt} \quad (2-1)$$

where

- M** = total mass of constituent over the entire event
- V** = total volume of flow over entire event duration
- $\bar{C}$  = flow weighted average concentration for entire event
- c(t)** = time variable constituent concentration
- q(t)** = time variable flow
- t** = time and  $t_r$  is the total event time

The majority of investigations into SWR have their data represented in the form of EMCs. Therefore the use of EMCs allows the results to be compared to other international studies on SWR (Barret *et al.* 1998).

#### 2.4.4 Temporal variation of SWR

Many studies have investigated the occurrence of the first flush phenomenon in SWR and identified the disproportionately high concentration levels of pollutants in the initial phase of the runoff hydrograph (Shinya, 2000). A review by Deletic (1998) of several investigations done on the first flush phenomenon aimed to define, provide evidence for, and establish factors that influence the first flush. The review found difficulty defining the first flush as different approaches have been used (1) interpretations of the cumulative fraction of total pollutant mass vs. the fraction of total cumulative runoff volume (2) initial slope greater than 45% of pollutant curves (3) percentage of total event pollution load transported by the first 25-30% of stormwater runoff (4) if the percentage of load transferred in first 25-30% of runoff accounted for 80% of the total load.

For the purpose of this investigation, a first flush will be regarded as a partial event mean concentration (PEMC) greater than the EMC, as cited by Sansalone (1997):

$$PEMC = \frac{m(t)}{v(t)} = \frac{\int_0^t c(t)q(t)dt}{\int_0^t q(t)dt} \quad (2-2)$$

where

$m(t)$  = mass of constituent up to a time  $t$

$v(t)$  = volume of flow up to a time  $t$ , with  $t < t_r$

Temporal variations of constituent concentrations in stormwater runoff are generally attributed to the rainfall characteristics, quality and quantity of runoff and climatic characteristics leading up to the storm event (Deletic, 1998). Chang (1990) established that only 40% of pollutant loadings are washed off with the first half inch of precipitation as opposed to the common assumption of 90% and Deletic (1998) concluded that first flushes are more likely to occur with large and intense storms, and that they are complex and site specific.

## 2.5 Managing Stormwater Runoff

The importance of understanding the first flush phenomenon and the temporal variation of constituent concentrations in stormwater runoff is linked to management decisions. Treatment plans which aim to reduce the impact of the NPS pollution as a result of stormwater runoff may utilise the information to assist in management decisions before implementation. Best management practices (BMPs) include on and off-site detention/retention basins, drainage system improvements and improved street sweeping operations. These options are costly and may be optimised with improved understanding of the pollutant loading characteristics (Finnemore, 1982).

Best management practice strategies are generally separated into two categories: source control and treatment control. Source control BMPs aim to prevent contaminants from entering stormwater whereas treatment control BMPs aim to reduce the level of contaminants transported by SWR. Due to the nonpoint source nature of stormwater runoff pollution, the effect of drainage system types and operations are crucial to BMPs that aim to reduce the contaminant loading of receiving water bodies.

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Aldheimer and Bennerstedt (2003) reviewed several BMP strategies for the city of Stockholm with special focus on sedimentation tanks and filters. The sedimentation tanks retained the first 15mm of precipitation with a detention time of 36hrs. The average reduction rates of most contaminants varied between 55-84%. However, the study noted that further treatment was still required dependant on TWQR objectives. The method also requires a large area and capital expenditure unless open basins and wetlands, which are more economically viable, are feasible.

Filtration methods incorporate geotextile filters. The method reduced the suspended solids content by 75% and heavy metal contaminants by approximately 10%. However, Aldheimer and Bennerstedt (2003) noted that clogging and maintenance of the filtration method required further investigation.

The effectiveness of vegetated filter ditches, referred to as grassy swales, in the reduction of many pollutants present in SWR has been reported in several studies (Barrett *et al.*, 1998; Wu *et al.*, 1998). Pollutant reduction is primarily attributed to the sorption properties and infiltration of runoff which promote the settling of particulates (Wu *et al.*, 1998). Schueler *et al.* (1992) reports removal rates of 70% of TSS and 50-90% of various metals in well designed swales.

The BMP strategies are generally site specific and thus highlight the need for local monitoring programmes as discussed in Chapter 2.4. Finnemore (1982) noted that an effective strategy will combine various BMPs which take into consideration local pollutants and conditions with an objective to also provide benefits in flood control, reduced peak runoff flow, soil erosion and education.

### **2.5.1 Pollutant loading of stormwater runoff**

The total annual loading is an important indicator when considering the potential long term or chronic effects on water quality for receiving water body. Pollutant loadings are generally reported in terms of mass/unit area/runoff duration and provide an alternative to EMCs when comparisons are made between storm events and catchments.

Marsalek (1990) proposed a probabilistic method to estimate the total annual load (kg/yr) from available data (division by the catchment area normalises the results for comparisons). The method assumes that pollutant concentrations (EMCs) are log-normally distributed. Event mean concentrations have also been reported to be log-normally distributed by Driscoll *et al.* (1990). The log-normal distribution method of Marsalek (1990) assists in the evaluation of pollutant loading estimates from EMC data which are characterized by large variances and uncertainties.

The annual pollutant load is assumed to be given by the logarithmically transformed mean EMC multiplied by the annual runoff volume:

$$L = R \times C_r \times A \times K \times C \quad (2-3)$$

where

- L = annual pollutant load
- R = annual rainfall
- $C_r$  = runoff coefficient of catchment
- A = area of catchment
- K = conversion factor (unit less)
- C = de-transformed logarithmic mean EMC =  $\exp(u + s^2/2)$   
with  $u$  = mean of the EMCs natural logs,  
 $s^2$  = variance of the EMCs natural logs

## 2.6 Relevant Research done in South Africa

Previous research in South Africa focussed on estimates of runoff volumes from urban catchments. The progression from runoff volumes to the pollutant characterisation and concentrations followed from the identification of stormwater runoff as a significant transport mechanism for pollutants. In South Africa the research into stormwater runoff still pertains mainly to urban catchments (Simpson, 1986; Green, 1984; Coleman and Stephenson, 1993). No research has specifically investigated the concentration of trace metals in stormwater runoff from road surfaces.

### **2.6.1 Urbanisation rate in SA**

A study by Braune and Wood (1999) into the application of Best Management Practices relating to urban runoff in South Africa (SA) outlined several problems. Urbanisation in SA cities is one of the highest in the world. This results in a significant reduction of natural storage and infiltration of stormwater runoff. The presence of large informal developments further compounds the problem with possible severe health hazards. These informal developments are generally not serviced and residents may depend on water from the closest water system such as a river. As many of these developments are located next to highways, the discharge of stormwater runoff from these road surfaces into the nearest water system is therefore of particular concern.

### **2.6.2 Pollution assessments of surface waters**

Several studies have assessed the pollution of surface waters in South Africa (Avenant-Oldewage and Marx, 2000; Fatoki et al., 2003; Fatoki and Awofolu, 2003). These studies have highlighted the elevated levels of water quality indicators in the water systems or in aquatic organisms. The probable sources of pollutants are generally attributed to urban and agriculture runoff and point sources. Little or no mention of stormwater runoff is made in these reports, which indicates that insufficient data and research are available in South Africa.

### **2.6.3 Urban catchment runoff pollution**

Simpson (1986) investigated the stormwater runoff from a mixed residential, commercial and industrial catchment in KwaZulu-Natal, South Africa. The study concluded that the quality of stormwater runoff was far poorer than normal river water by factors of up to 20 for certain constituents. Mean runoff concentrations exceeded recommended levels for the protection of aquatic life while maximum levels greatly exceeded limits.

## **2.7 Literature Review Conclusion**

Review of current literature highlights the contaminants transported by stormwater runoff during rainfall events into receiving water systems. These pollutants can degrade aquatic ecosystems, affect living water organisms and ultimately people dependent on the water

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systems. Atmospheric deposition and vehicular usage have been shown to contribute significant quantities of contaminants onto the road surface. Collection of atmospheric samples is therefore required to fully understand and characterise the contaminants found in stormwater runoff.

Monitoring programs that collect representative runoff samples to assess the contribution of nonpoint source pollution have been reviewed. Stormwater runoff monitoring programs are generally study and site specific and require careful planning in order to satisfy the objectives of an investigation. Review of sampling methods indicates that a flow-weighted composite sample is preferred as it represents the event mean concentration (EMC) for an entire runoff event. Contaminant EMCs can be used to estimate annual pollutant loadings, which provide an indication of the potential long term or chronic effects on the water quality of receiving water bodies.

The need to manage stormwater runoff, reducing the negative impact on the environment, is highlighted by South Africa's high rate of urbanisation. Urbanisation results in an increase in impervious surfaces, and more specifically road surfaces, which result in a increase in stormwater runoff. In order to apply appropriate mitigation strategies used internationally, local data are required.

## CHAPTER 3

### DEVELOPMENT OF A SAMPLER

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*Chapter three presents the development of a sampling tool for monitoring stormwater runoff for this investigation. Initial sampling methods attempted are discussed. The sampler design and associated laboratory, field and computer simulation tests are presented.*

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#### **3.1 A Review of Sampling Methods**

Achieving an acceptable monitoring programme of stormwater runoff poses several problems which must be taken into consideration. Typical stormwater runoff monitoring programmes are labour intensive and require a large capital input. Neither manual hand grab sampling nor the use of automatic sampling devices provide complete solutions as both have their limitations which generally affect the scope of the investigation. Due to each monitoring programme being site specific, there is no single optimum solution and often a compromise between several available options must be made. Brown (1990) noted the unreliability and difficulty of maintaining sampling instruments in the field due to remote locations, inactivity between storm events and adverse conditions associated with stormwater runoff. Such instrument failure results in repair costs and, more importantly, the risk of losing valuable data. This investigation required data based on the analysis of a stormwater sample representing an entire event. Therefore several methods of collecting stormwater were investigated to find the 'optimum' solution.

##### **3.1.1 Manual hand grab sampling**

This labour intensive method requires a large amount of preparation before a storm event. A composite representative sample for an entire storm event was required for the investigation. Therefore numerous grab samples are required throughout the runoff event which can then be combined to produce one calculated composite sample. The sample bottles have to be acid washed prior to the storm event and safely stored to prevent contamination. The unpredictable nature of rainfall compounds the problems associated

with grab sampling. Trained personnel responsible for collecting the grab samples must be ready to respond to rainfall events twenty four hours a day and are often required to sample for long durations. Obtaining the equipment necessary for the sampling operation and proceeding to the monitoring location to collect a sample from the initial runoff is often not possible. The spatial/temporal variation in rainfall of low intensity, and long rainfall durations result in many false alarms for collection personnel (Dowling and Mar, 1996). Impervious catchments result in runoff within minutes from the onset of a storm event which makes it difficult for manual sampling programmes to respond quickly enough to collect data that adequately represents a storm event (Browne, 1990). Even if the sampling personnel commence collection from the onset of runoff, a single composite sample produced from several discrete grab samples may not truly represent the concentration characteristics of a storm. Maestre and Pitt (2006) highlight this potential for error due to the large variation in pollutant concentration characteristics in runoff over time. The underlying reason being that discrete grab sampling may not collect peaks in concentrations as they may go unsampled between sampling intervals.

The formation of a composite sample from discrete grab samples requires trained personnel. The interval between grab sample collections requires the in situ flow or volumes to be estimated. The estimation of flow or volumes requires the operation of some measuring device that may result in errors and therefore limit the accuracy of the composite sample produced. Plate 3-1 illustrates a person obtaining a grab sample. The advantages and disadvantages of manual sampling are summarised in Table 3-1.

**Table 3-1: Advantages and disadvantages of manual hand grab sampling**

<b>Manual hand grab sampling</b>	
<b>Advantages</b>	<b>Disadvantages</b>
Low cost	Site location distance criteria important
No power supply	Labour intensive
Minimal site maintenance	Site location safety an issue for personnel sampling
Minimal equipment maintenance	Require several trained personnel
Minimal site access selection criteria	Number of sites limited by number of trained personnel
	Accuracy of representative samples limited



**Plate 3-1: An example of a manual grab sample obtained with an extension pole**

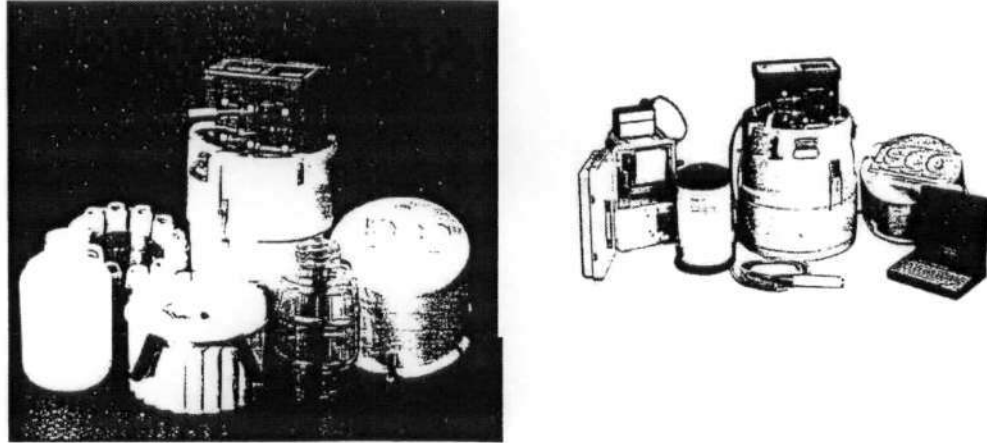
### **3.1.2 Automatic sampling**

Automatic samplers are advantageous as they are less labour intensive and respond immediately to the initial stormwater runoff. There are no 'false alarms' associated with sampling personnel and the samples collected are safely stored within the sampler for collection. However, the use of automatic sampling equipment requires a large capital investment.

Generally, the sampler also requires the purchasing of a flow sensor for operation. The need for a trained technician for installation, operation and maintenance can also be costly.

Automatic samplers can be programmed to sample at various intervals depending on what stormwater data are required. An ISCO Automatic sampler (see Plate 3-2) can collect twenty four individual samples or one composite sample depending on the configuration of the instrument. A flow sensor activates the automatic sampler which obtains discrete grab samples of specified aliquots from the stormwater runoff. Thus the potential for error due to variations in pollutant concentrations over the runoff period, as already mentioned for manual sampling, is also evident in this case. Keith (1991) found that operator skill may be the most significant factor for introducing errors when trying to collect a representative sample using an automatic sampler.

Additional capital resources for the installation of the sampler are often necessary as security measures require that modifications be made to selected site locations to prevent theft. The site location may also require adaptations to be made to the sampler or location for installation purposes in order for the sampler to operate successfully. The advantages and disadvantages of automatic sampling are summarised in Table 3-2.



**Plate 3-2: ISCO samplers are one of the most common automatic samplers used to collect water samples (Dowling, 1995)**

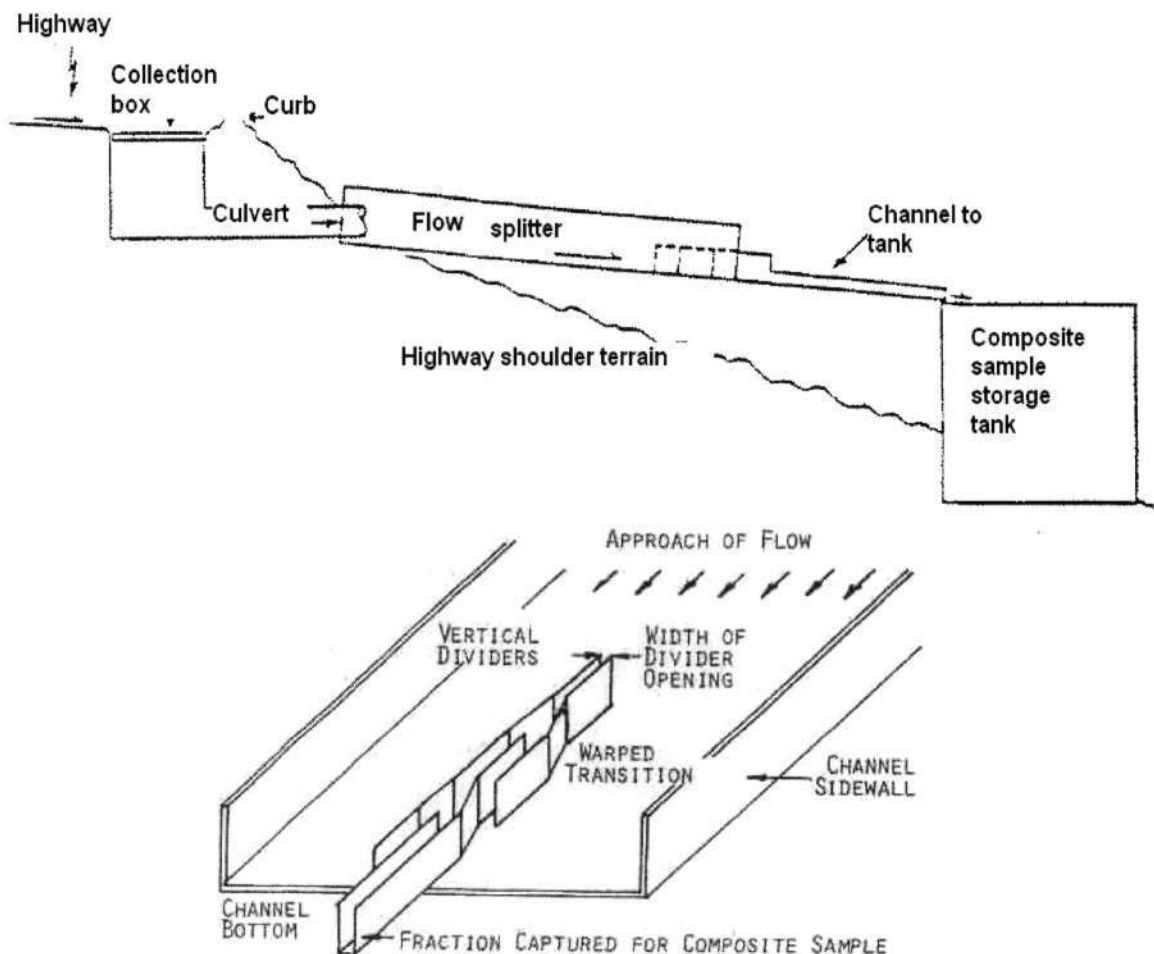
**Table 3-2: Advantages and disadvantages of automatic sampling (Dowling, 1995)**

Automatic sampling	
Advantages	Disadvantages
Not labour intensive once installed Initial runoff collected Several pre-programmed routines available for sampling Flow data recorded by instrument on site Samples stored safely Site location distance criteria not important	Initial capital cost high Installation is labour intensive Requires regular power source replacement Requires regular maintenance and calibration Requires a trained technician to operate Requires additional purchasing of a flow meter/sensor

### 3.1.3 Flow splitter composite sampler

A flow splitter composite sampler was investigated by the University of Washington to collect flow-weighted composite stormwater runoff samples (Clark *et al.* 1981). The device was constructed and tested on the Interstate Highway (I-5) in Seattle. The sampler

consisted of a rectangular open channel with vertical dividers placed parallel to the flow (see Figure 3-1). As the stormwater runoff drained off the highway via the channel a small proportion was continuously diverted into a container to accumulate a composite sample. The fraction diverted was proportional to the runoff flow by removing a larger proportion as the flow increased and a smaller proportion as the flow decreased. The device once built required minimal maintenance as there are no electrical parts. Test results indicated a high accuracy. However, the opening criteria for the flow divider which was required for the device to operate efficiently, introduced concerns. The opening must be large enough to allow debris to pass but small enough to produce a storable volume. Upon collection of a sample to be analysed, the storage volume would be stirred and sampled which would provide a composite sample for the entire storm event (Aye, 1979). The advantages and disadvantages of the flow splitter are summarised in Table 3-3.



**Figure 3-1: The layout of the Flow splitter as installed on the Interstate-5 US  
(Clark and Mar, 1980)**

**Table 3-3: Advantages and disadvantages of the flow splitter (Dowling, 1995)**

Flow splitter	
Advantages	Disadvantages
Not labour intensive once installed No power supply Minimal site maintenance Minimal equipment maintenance Produces a composite flow weighted sample	Installation is labour intensive Requires substantial space for operation Debris transported with discharge can block system

### 3.1.4 Culvert composite sampler

Dowling and Mar (1996) developed a 'cost effective' storm-water monitoring device that provided a composite flow weighted sample. The device was developed on stringent criteria based on economy, flexibility, sample representativeness and quality control requirements. The sampler was made of PVC piping, tubing and a hypodermic needle as an orifice, and could easily be installed in most pipe culverts (see Figure 3-2). The configuration relied on gravity to feed a proportion of runoff discharge when the orifice was submerged. Thus, as the depth and velocity of the discharge increased, the hydrostatic and dynamic pressure would result in the sampling of a larger proportion of discharge. The initiation of sampling was also instantaneous once the orifice was submerged therefore collecting the first flush. Sampling terminates once the water level drops below the orifice entrance. The device therefore continuously collects a flow weighted sample for the entire duration of the discharge.

Results from field and laboratory testing indicated that the sampler collection rate was not linearly proportional to the flow rate. The sampler collected a greater percentage of flow during low-flow conditions. However, concentration tests indicated that the composite sampler produced similar results when compared to a flow splitter (a true flow weighted sampler). Calibration curves from laboratory, field and computer simulations indicated the total runoff discharged could be estimated within approximately ten percent.

The advantages and disadvantages of the culvert sampler outlined by Dowling and Mar (1996) are presented in Table 3-4.

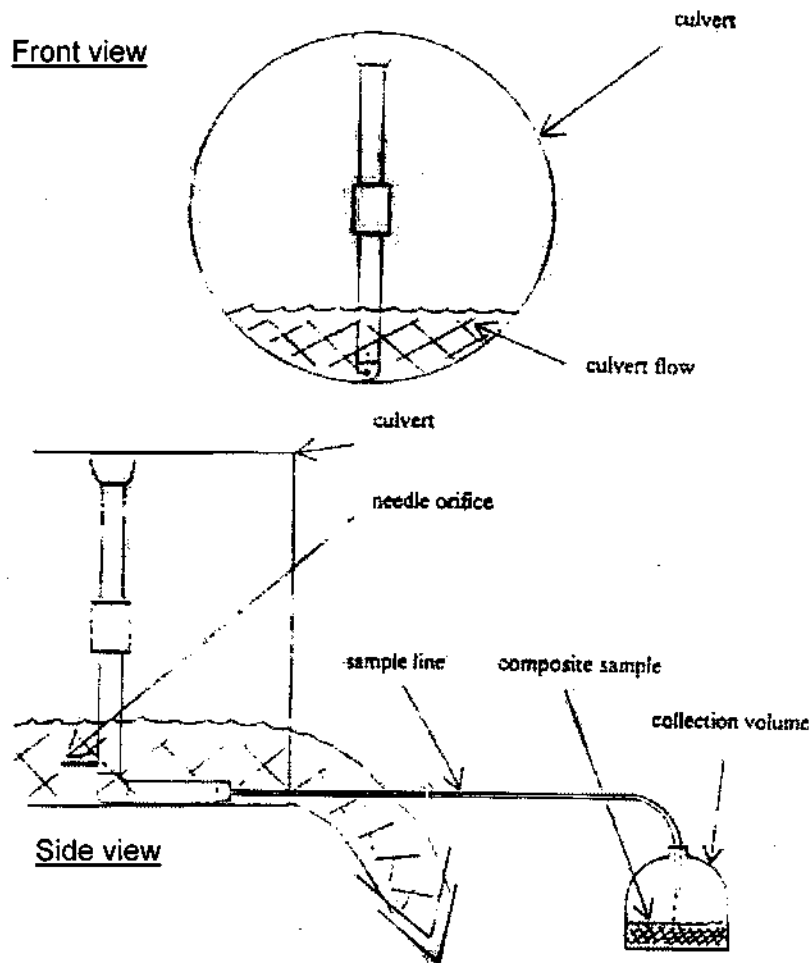


Figure 3-2: Culvert composite sampler (Dowling and Mar, 1996)

Table 3-4: Advantages and disadvantages of the culvert composite sampler (Dowling, 1995)

Culvert composite sampling	
Advantages	Disadvantages
Low installation cost and is not labour intensive Automatic initiation and termination Can approximate total culvert flow from sampled volume Collects an approximate flow-proportional sample Continuous sampling throughout storm event Low cost and low maintenance No power supply	Collects a greater percentage of flow during low-flow conditions Sediment size is limited to orifice size The vessel for sample collection must be below the culvert discharge Total culvert flow determination is time dependent The sampler is very susceptible to blockage by solid waste such as plastic bags

### 3.1.4 Summary of sampling methods

The various methods for collection of stormwater runoff all have positive characteristics for certain conditions and situations. There are large varieties in the costs, need for trained technicians, maintenance, power supply, installation area, sample volumes collected, sampling techniques, etc between the methods. The selection of the most suitable method for a monitoring programme must weigh up the strengths and weaknesses of the existing methods to find an 'optimum option' given the available resources.

Dowling's (1995) review of stormwater samplers investigated several aspects of various sampling methods. A table of comparisons was compiled in which sampling methods were rated from 1 (poor) to 5 (good). Sampling methods from Dowling's original table have been compiled in Table 3-5 to compare the sampling methods investigated.

**Table 3-5: Comparison compiled from the findings noted by Dowling (1995)**

<b>Considerations</b>	<b>ISCO automatic sampler</b>	<b>Flow splitter composite sampler</b>	<b>Manual grab samples</b>	<b>Culvert composite sampler</b>
Capital costs	1	4	3	5
Installation costs	2	1	5	5
Operating costs	2	4	1	4
Installation difficulty	2	1	5	5
Site adaptability	3	1	5	5
Flow-weighted sample	4	5	4	4
First flush sampling	5	5	1	5
Continuous sampling	2	5	1	5
Total flow determination	4	4	4	4
Sample duration	5	5	1	4
<b>Overall rating</b>	<b>3</b>	<b>3.5</b>	<b>3</b>	<b>4.8</b>

It is apparent from Table 3-5 that a continuous flow weighted sampling method such as the culvert composite sampler provides the highest overall benefit to a stormwater monitoring programme.

One aspect of setting up a stormwater monitoring programme which was not investigated or reviewed was that of security. The safety of sampling personnel and security of equipment installed must be addressed when considering the choice of sampling locations and method. It became apparent from initial site inspections that the security of equipment and safety of sampling personnel, needed to be addressed when considering which method to proceed with.

### **3.2 Initial Attempts at Sampling Stormwater Runoff for this Investigation**

Although the culvert composite sampler resulted in the highest overall score, the initial method chosen for sampling was manual hand grab sampling. It required no purchasing of expensive machinery, highly specialised skills of operation and would provided an early indication of contaminant levels. A monitoring site was located close to the University of KwaZulu-Natal where sampling methods were attempted.

#### **3.2.1 Manual hand grab sampling**

Guidelines outlined in the Washington State Department of Ecology's *How to do Storm Water Sampling* (2002) were followed to ensure correct sampling was carried out. Two sampling personnel were used to collect samples once a storm event commenced. Twelve sampling bottles were acid washed and stored in a cooler box to avoid contamination. The sampling team needed to assess whether rainfall events would yield a viable runoff event. Once it was apparent that conditions would produce runoff, the personnel would travel to the University to collect the sampling equipment and instruments to measure flow rates and depths.

It became apparent that manual hand grab sampling would not suffice as a sampling method for the stormwater monitoring programme required for this investigation for the following reasons (1) sampling at night was not an option due to safety concerns (2) the adverse conditions associated with stormwater runoff discharge made accurate measurements of depth and flow rates very difficult (3) the number of sites to be sampled would be limited by the number of trained personnel (4) the unpredictable nature of rainfall resulted in several false alarms and missed opportunities (5) the catchment's highly

impervious nature resulted in rapid stormwater discharges. Consequently, the time to respond to rainfall events did not allow for the initial runoff to be sampled.

### **3.2.2 ISCO Automatic samplers**

The second sampling method investigated was that of ISCO automatic samplers. The Durban Metro Water Service's Pollution Division were approached as they operate several ISCO samplers in the greater Durban region. Originally they agreed to help and could provide up to four ISCO samplers. These however were manually started or pre-programmed to commence at a certain time. Various flow sensors were therefore investigated to initiate the samplers once runoff occurred and to terminate sampling once discharge stopped. The samplers were however then no longer made available for the investigation as the Pollution division required them elsewhere. The resources were not available to purchase four ISCO samplers and flow sensors. The underlying reasons for not pursuing the use of ISCO samplers were (1) the high cost per unit (2) number of site locations would be reduced to one (3) the additional purchasing of flow meters would be necessary (4) the security measures required in South Africa would make identification of suitable sites more difficult and increase installation security costs.

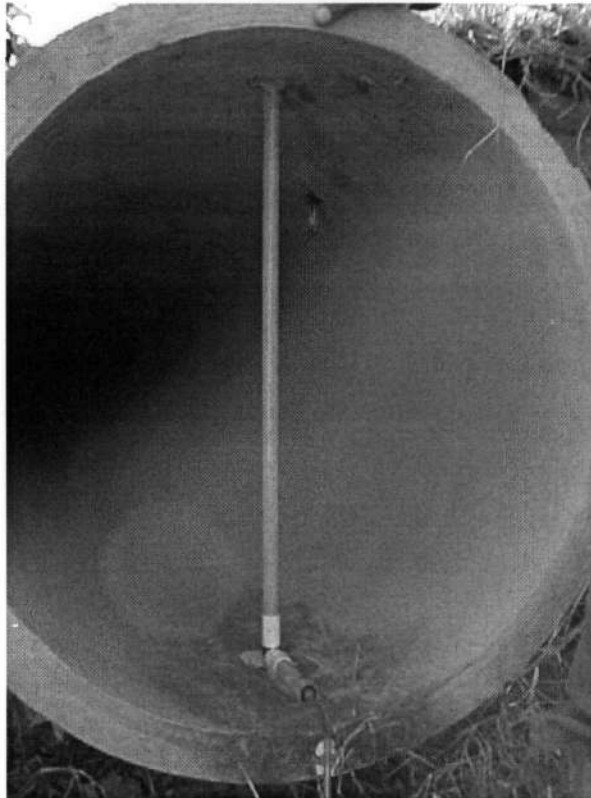
### **3.2.3 Culvert composite sampler**

The third option investigated was that of the culvert composite sampler developed by Dowling and Mar (1996). The original location close to the University (where manual hand grab sampling was tested) provided an ideal location to test the sampling method. The catchment area drains into a stormwater pipe system which discharges from a concrete circular conduit from a height of two meters into a stream. A replica of the culvert composite sampler was constructed and installed in the concrete stormwater pipe (see Plate 3-2). Slight alterations were made for installation purposes with the underlying operational functions the same as the original.

The instrument's performance was tested over several rainfall events. Although laboratory tests indicated that the sampler functioned correctly, it became apparent that the culvert composite sampler method would not function under the prevailing conditions in South Africa. The instrument failed due to the quantity of solid waste transported via the stormwater runoff. The instrument would consistently be clogged up by plastic bags or

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various forms of paper and waste from fast food franchises. These items would wrap around the PVC pipe resulting in the orifice being blocked and causing damage to the hypodermic needle. Methods to prevent the debris from blocking the orifice, such as a mesh, were investigated but not implemented. A blockage in the stormwater pipe could have led to severe consequences. The culvert composite sampler developed by Dowling and Mar (1996) would only operate in an environment relatively free from debris in the runoff.



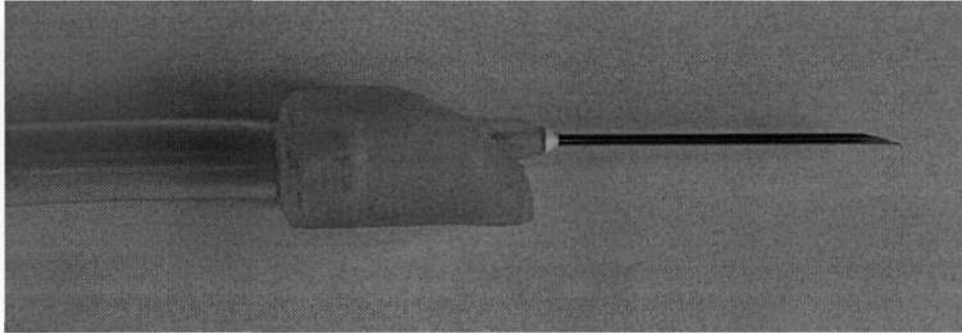
**Plate 3-3: Culvert composite sampler installed in a 750mm diameter concrete stormwater pipe**

#### **3.2.4 Modifications to the Culvert composite sampler**

Modifications were developed for the original culvert composite sampler to overcome the problems encountered. The hypodermic needle orifice concept, which relied on the water depth and velocity for sampling, was incorporated into a smaller design. A small Perspex streamline mould was made to house the hypodermic needle (see Plate 3-3). The Perspex housing was attached to a delivery tube which would transport the sampled runoff

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to a storage container. The design objective was to allow solid waste material to pass over the sampler without obstructing the sampling process.

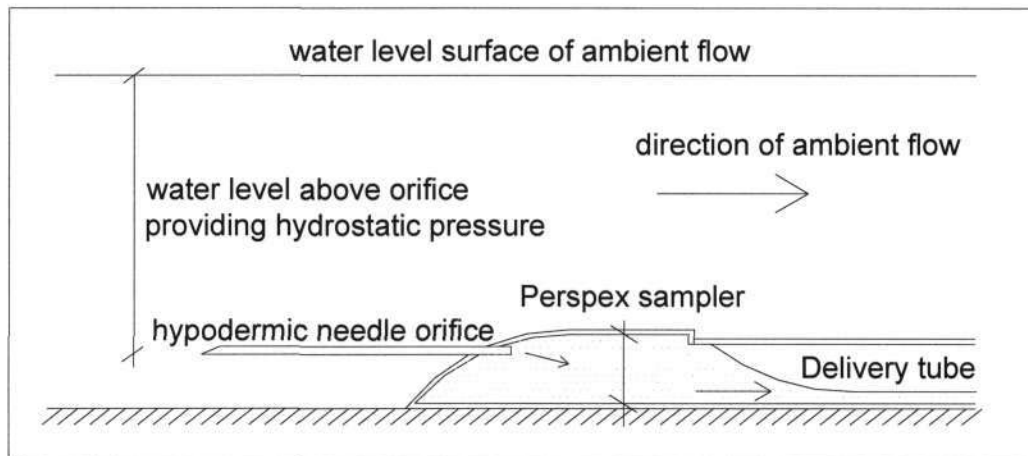


**Plate 3-4: Modified culvert composite sampler with a Perspex housing and hypodermic needle**

Laboratory flume tests confirmed that solid waste material would generally pass over the sampler for most flow conditions. However, waste material transported by the initial runoff at a low depth and low flow rate had a high possibility of becoming entangled with the hypodermic needle. Secondly, tests indicated that the sampling rate of the sampler was much lower than expected under various flume flow rates. Further investigation exposed a flaw in the design's modifications. The small size of the sampler made it impossible for atmospheric air to be present within the collection chamber behind the orifice. The sampled fluid would fill the entire volume available within the Perspex housing before exiting via the delivery tube to the storage container. Therefore the pressure difference between the ambient flow and within the collection chamber was reduced. Subsequently the sampling rate was reduced as the driving force providing the sampling was reduced. The flow within the delivery tube, which no longer maintained an air gap, was now flowing under closed conduit flow conditions. Figure 3-3 illustrates the Perspex housing sampler's collection chamber behind the orifice filling up and preventing atmospheric pressure entering the chamber.

A reduced rate of sampling to the ambient flow conditions results in inefficient collection of sediment. Several field studies have shown that hazardous pollutants from road runoff are transported via fine sediment (Furumai *et al*, 2002). The modifications required to supply a constant atmospheric pressure in the collection chamber would have raised the sampler's height. Tests indicated that this would revert back the original sampler's problems of

blockages. This modified sampler would not be adequate for the stormwater monitoring programme.



**Figure 3-3: Perspex moulded housing with hypodermic needle illustrating blocking off atmospheric air to the collection chamber**

### 3.3 New Development: Design of a Stormwater Sampler

The design of a stormwater pipe sampler was initiated after several failed attempts of sampling methods. The objective was to produce a sampling method which would encompass the positive characteristics of those methods investigated to meet the stormwater monitoring programme required for this investigation.

#### 3.3.1 Outline of design criteria

Design criteria considered important are presented in Table 3-6 and were used as a guideline for the requirements of the sampler development. The design criteria are based on literature surveys and the laboratory and field experiments already completed. Subsequently, the criteria have been established specifically for this investigation. An example of such criteria is that of the sampler being capable of being left out in remote locations for several days unattended. It would be a security risk for the personnel involved if the sampler had to be frequently checked.

**Table 3-6: Comparison complied from the findings noted by Dowling (1995)**

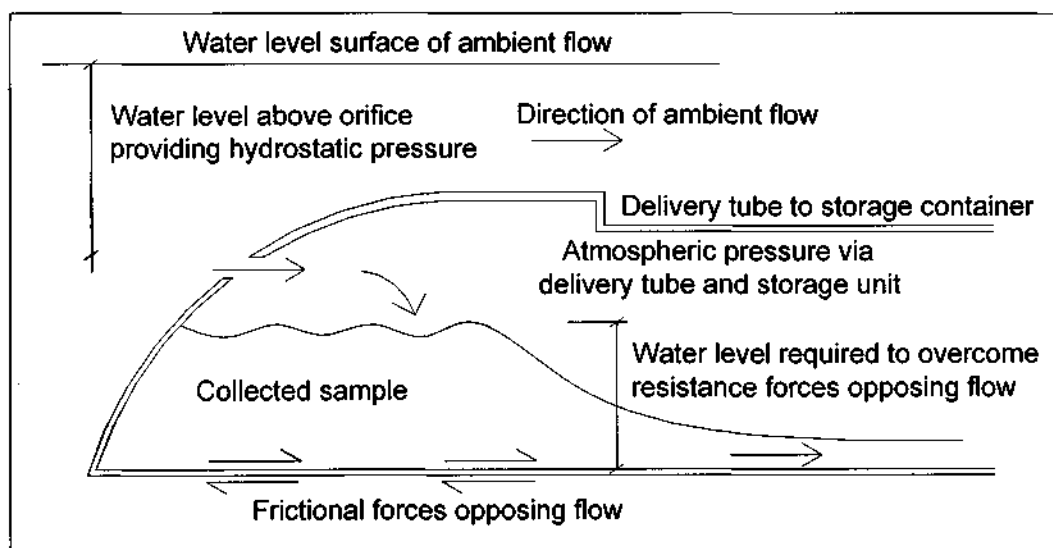
<b>Operational requirements</b>	Automatically commence sampling when discharge occurs and discontinue once the discharge no longer occurs.
	Continuously sample a volume proportional to the flow rate thus producing a flow-weighted sample.
	Provide an intake velocity at the sampling intake orifice of reasonable velocity to ensure adequate sampling of sediment.
	Comprise of an intake sampling point large enough to ensure larger particulates to pass through without blocking the orifice.
	The final volume collected should be of manageable volume to require no further field adjustments before transporting to the laboratory.
	Capable of sampling for a minimum of one hour when heavy downpours occur and up to six hours if moderate rainfall occurs.
	Require minimal installation labour time and maintenance in the field.
	Require no external power source.
	Capable of being left out in remote locations for several days.
	Due to the harsh environment associated with stormwater flow, the sampler must be robust enough to withstand the hydrostatic forces and items such as debris often transported by runoff.
<b>Cost requirements</b>	The cost of the sampler, including the manufacturing, must be low enough to enable several units to be produced.
	The installation and maintenance costs of the sampler should be kept to a minimum.
	The sampler unit as a whole should be small enough to enable one field trip sufficient to transport all units to several sampling locations.
	Sampler must be flexible by design so as to adapt to various stormwater pipes sizes and configurations.
<b>Sample quality requirements</b>	The sampler should produce a composite sample representative of the event mean concentration (EMC) for the runoff from an entire storm event.
	The sample volume collected should allow for an estimation of the total volume of runoff for the whole stormwater runoff discharge.
	Sampled and stored in such a way that does not allow for outside contamination.

### 3.3.2 Modification of prototypes

The *culvert composite sampler* developed by Dowling and Mar (1996) complies with most of the design requirements. Therefore, the option of using a gravity fed orifice intake to sample was further investigated.

The underlying problem associated with the modified Perspex housing sampler was that of the hypodermic needle. A sampler which would not be incapacitated by large debris was

required. Dowling and Mar (1996) only included the hypodermic needle into their design to prevent debris clogging up an orifice located on the vertical section of a PVC pipe incorporated in an initial design. A sampler similar to that of the Perspex housing without the hypodermic needle was therefore investigated. A larger collection chamber and delivery tube was still required to allow a sufficient water level to build up in the collection chamber (see Figure 3-4). The increased water level provided the potential energy of the collected sample to overcome the frictional forces, within the chamber, thus allowing flow towards the storage unit. Secondly, the increase in delivery tube size maintained atmospheric pressure within the collection chamber. This increases the pressure difference between the ambient runoff flow and the collection chamber resulting in an increased sampling rate.

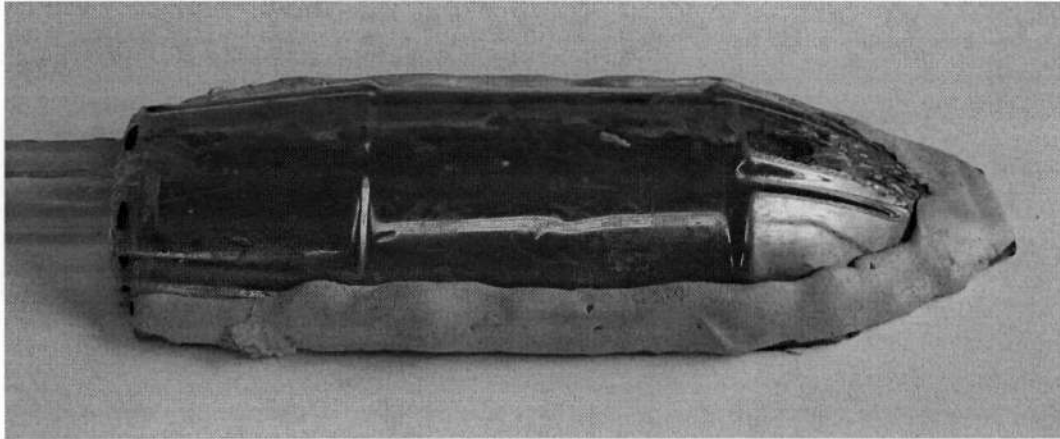


**Figure 3-4: Modified sampling concept with a larger collection chamber and delivery tube**

A small streamlined sampler was required to allow large debris to pass over. Laboratory and field experiments were carried out on a rough prototype (Pro.1) which yielded favourable results. Pro.1 was manufactured using a section of a polyethylene bottle (see Plate 3-4 and was tested under varying flow conditions and levels. Debris and litter were placed upstream of the sampler and observations made as to their interaction with Pro.1. For most flow conditions the debris would pass over the sampler thus achieving the required objective. The Pro.1 failed however, when tested under slow flow conditions of low depth. The size combined with such flow conditions resulted in blockages. Therefore a second prototype (Pro.2) machined out of Perspex was made with smaller dimensions.

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The use of Perspex provided improvement in the accuracy of the orifice alignment and overall control of the sampler shape. The orifice was now placed to meet the requirements of Rankin's 1/3 Rule with the sampler's shape dimensioned on the Rankine half-body. An improvement in collection rates was the underlying reason. The entrance leading to the orifice was machined to streamline the flow towards the orifice.



**Plate 3-5: Prototype (Pro.1) made from a polyethylene bottle**

### **3.3.3 Selection of suitable material and fabrication method**

Laboratory observations indicated that the smaller dimensioned Pro.2 achieved improved results with regards to debris and slow flow conditions of low depth. Machining the Perspex however reduced the collection chamber volume due the brittle nature of the material. The process of machining Perspex also introduces small variances between any two produced. Therefore an alternative material was investigated that would (1) provide the required dimensions externally and internally (2) be robust enough for the machining required for the orifice and streamlined entrance (3) allow simple and cost effective reproducibility with a high degree of similarity.

Several samplers were required that would function identically. Hence, the method of producing the samplers using one mould and casting was selected. The method required the production of one acceptable prototype which could be used to make the mould. As the machined Pro.2 only required a larger collection chamber, it was selected as a starting point to base the acceptable prototype on. A template of the Pro.2 was made on which a two millimetre PVC plastic sheet was heat moulded onto. This resulted in a PVC shell of

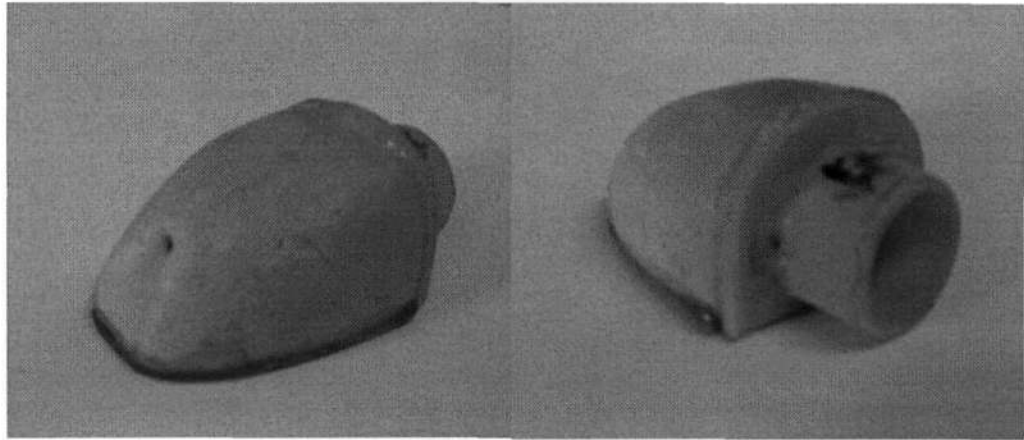
the required dimensions both externally and internally due to the thin walls. The orifice entrance and hole were then machined onto the PVC shell. The sampler now consisted of three pieces (1) an outer streamline shell (2) a back piece which allows a delivery tube to be attached (3) a flat transparent piece for the base. Transparent Perspex was chosen for the base as one could then inspect the inside of the collection chamber. The new prototype (Pro.3) was assembled and tested in the laboratory flumes. Tests indicated that the additional collection chamber volume satisfied the objectives for sampling. The sampler was then disassembled and submerged into Silicon moulding gel. The Silicon moulding gel produces a high quality female mould which can be used to produce exact resin replicas of the original item. This ensures accurate reproducibility with minimum labour.

Two Silicon moulds were produced. One for the top shell of the sampler and one for the rear of the sampler that connects to the delivery tube. The resin selected for the production of samplers satisfied all the material requirements outlined. Several castings were completed and inspected for the degree of similarity, focusing primarily on the orifice hole and entrance as these influence the function of sampling the most. Once tests indicated that the Silicon moulds yielded acceptable 'identical' castings, several samplers were produced for laboratory and field experiments.

The final selected concept incorporated the positive characteristics of previous prototypes. The sampler was produced from assembling two resin moulded components and a Perspex base. The resin component at the rear is designed to provide an air tight fit when coupled up with the delivery tube. Six samplers, named Pro.4 (shown in Plate 3-6), were made in order to test their compliance with the operational requirements specified under laboratory conditions.

#### **3.3.4 Selection of the orifice diameter**

Laboratory tests were conducted on several orifice diameters, ranging from 0.5-2.5mm, simulating stormwater runoff events in a flume to estimate the optimum diameter. Observations indicated that smaller orifices could sample longer periods of runoff requiring a smaller storage unit. The larger orifice diameters collected a larger proportion of the flow but required a much larger storage unit. The smaller diameter however has a higher risk of becoming clogged with larger sediment and thus not collecting a representative sample.



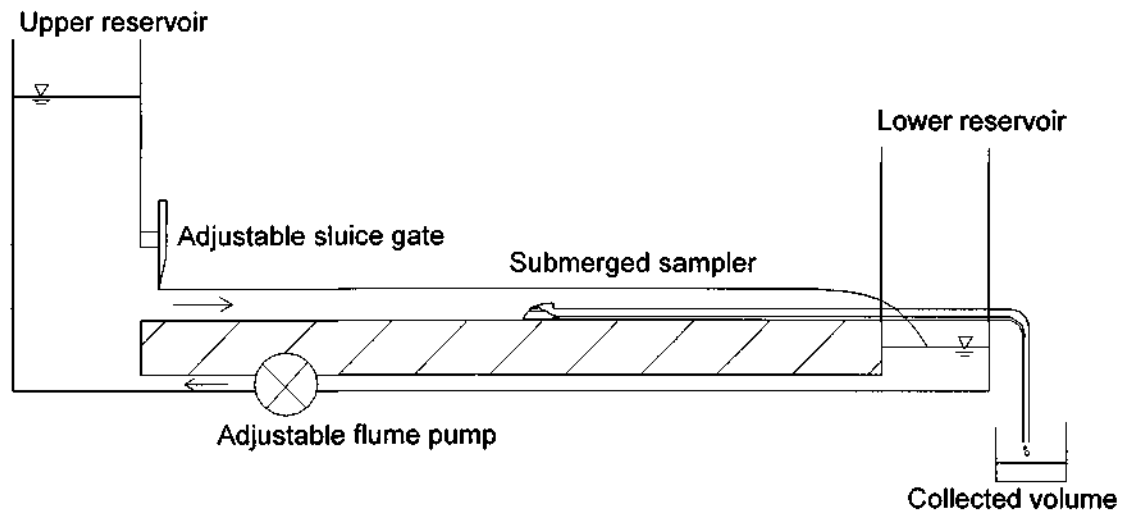
**Plate 3-6: Prototype (Pro.4) made from casting resin in silicon moulds**

The orifice must be large enough to allow particulates to easily pass through. An orifice diameter of 1.5mm was selected. Previous investigations by Sansalone *et al.* (1997) and Furumai *et al.* (2002) have shown that heavy metals such as Pb, Fe, Al and Cr are primarily particulate bound with up to 89% to 96% of the total pollutant load for Zn, Cu and Pb accounted for in smaller particulate fractions. Furumai *et al.* (2002) found that particulates with a diameter over 1mm were seldom found in runoff samples. Thus, the selection of a 1.5mm orifice provided (1) a large enough diameter to allow large sized particulates to be sampled (2) decreased possibility of clogging up the orifice (3) an increased sampling rate over smaller orifices (4) a suitable collected volume for storage. The orifice had the option of being machined to a larger selected diameter if required.

### **3.4 Collection Properties of the Sampler**

Tests were run to estimate the sampler's performance under various flow conditions associated with stormwater discharge. Two water flumes operated at the University of KwaZulu-Natal, School of Civil Engineering Department, hydraulics laboratory were utilised. A medium sized flume (see Figure 3-5) allowed for quick tests to be carried out investigating minor objectives. The flume made of Perspex allowed outside observations of the sampler functioning possible. The flume flow rate was controlled by a variable pump and adjustable sluice gate at the outlet of the upper reservoir. Required open channel conditions were simulated to inspect the sampler's response. The velocity of the water in the flume was measured by a miniature rotating propeller probe (velocimeter). Water

levels were read off an inverted measuring device attached to the flume. The flow was estimated by numerical integration of velocity and area.



**Figure 3-5: Medium flume used for testing the sampler**

The flume produced sub-critical and super-critical flow rates but only at limited water levels. The flume could produce depths of 10-50mm and velocities of 0.25-1.5 m/s. Thus a second larger water flume was utilised to provide a broader range of sub-critical and super-critical flow conditions. The larger flume was approximately 6m long by 1.2m wide with hydraulic jacks on the upstream side which could be used to provide a gradient. The same instruments were used to measure the velocity and water levels. The flow was varied by a valve which controlled the water supply to the upper reservoir and a sluice gate which was constructed specifically for this investigation. This flume could produce depths of 10-150 mm and velocities of 0.2-1.7 m/s.

#### **3.4.1 Sampling rate ( $q_s$ )**

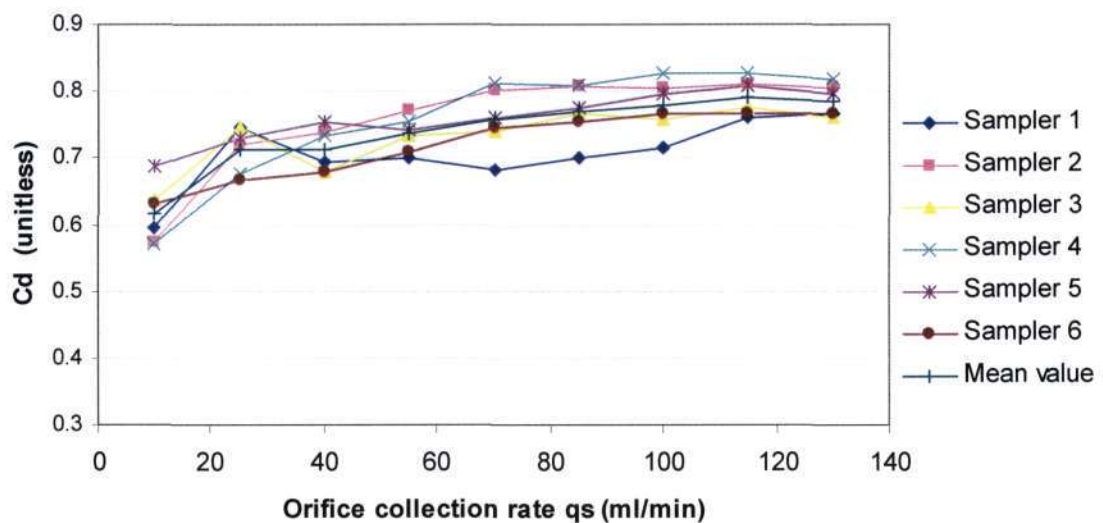
The Pro.4 samplers were subjected to several static and dynamic flow conditions to estimate their sampling response and rate. The static conditions provide an estimate of the orifice coefficient while the dynamic flow conditions provide an approximation of the sampling performance in an actual stormwater pipe. The tests also provided a comparison between the six samplers.

### **Static flow**

The sampling rate ( $q_s$ ) of the sampler's orifice for static flow conditions is a function of the water level above the orifice, orifice diameter, gravity and a unitless discharge coefficient. The orifice discharge coefficient,  $C_d$  value, was determined empirically by measuring the orifice collection rate at several static water levels (see Equation 3-1). The water levels above the orifice ranged from 10-130mm with orifice collection rates approximately 25-140ml/min.

$$C_d = \frac{Q \times A}{\sqrt{2 \times g \times h}} \quad (3-1)$$

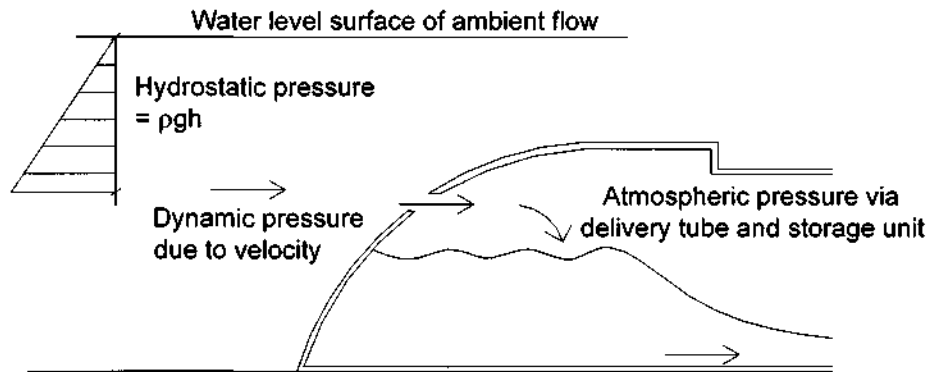
Where  $C_d$  is a discharge coefficient accounting for contraction effects,  $Q$  is the flow,  $h$  is the static head,  $A$  is the orifice cross sectional area and  $g = 9.81\text{m}^2/\text{s}$ . The  $C_d$  value ranged from 0.6-0.8 using an estimated orifice cross sectional area of  $1.77\text{mm}^2$  (see Figure 3-6).



**Figure 3-6: Estimation of the orifice discharge coefficient value**

### **Dynamic flow**

The orifice collection rates of the samplers for dynamic flow conditions were measured for several water level heights and flow velocities. The collection rate is primarily dependant on these two variables under dynamic flow conditions. The velocity of the ambient flow provides a dynamic pressure whereas the water level above the orifice provides a hydrostatic pressure (See Figure 3-7).



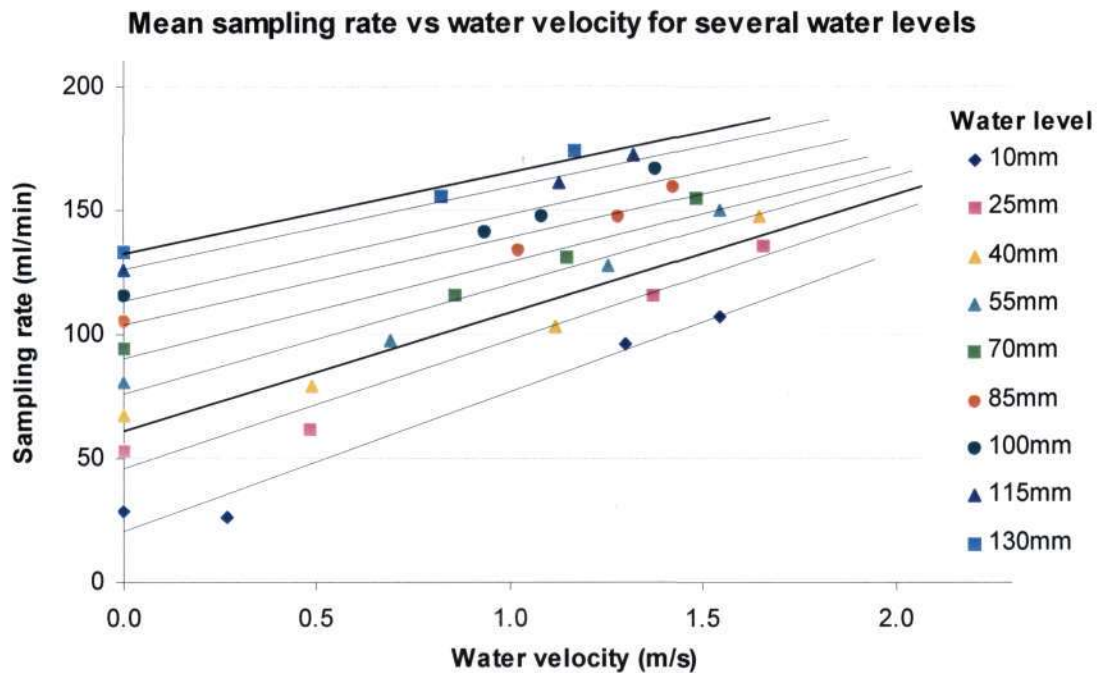
**Figure 3-7: Dynamic and hydrostatic pressure driving flow into the collection chamber which is at atmospheric pressure**

### 3.4.2 Sampling rate related to water level and velocity

The collection rates for static and dynamic flow conditions were combined to establish a relationship with the water levels and velocities. Figure 3-8 illustrates the approximate linear relationship for the six samplers combined data. The individual graphs and data from laboratory testing for each sampler can be found in Appendix A. A relationship established for the collection rates, water levels and velocities provides an estimation of the sampler's response to stormwater discharges. The discharge of stormwater runoff is governed by open channel flows, which are similar to the experiments run in the laboratory. Thus, as the intensity of a rainfall event increases or decreases, so the sampler's collection response will be affected due to changes in the water level and velocity of the discharge.

### 3.5 Stormwater Conduit Flow Estimation

The flow of stormwater runoff from road surfaces is generally due to rainfall that has entered kerb inlets, which direct the flow along a pipe network usually culminating in one large pipe, that discharges into a culvert or receiving water system. Stormwater systems are designed to accommodate the estimated runoff volume of a selected one in  $n^{\text{th}}$  year flood. The design will also incorporate a safety factor to accommodate industrial and residential *dry weather* flow and possible ground water *base flow*. The resultant sized stormwater pipe will in all probability never reach maximum capable capacity of flow. Consequently, stormwater runoff for most rainfall events will be characterised by open channel flow conditions



**Figure 3-8: Mean orifice collection rates measured for all samplers at several water levels and velocities**

Open channel flow is defined as a flow where the upper surface of the liquid is in contact with the atmosphere and is driven by gravity (Roberson *et al.* 1997). Open channel flow for a circular conduit such as a stormwater pipe can be estimated using the Manning discharge equation:

$$Q = \frac{1}{n} AR^{2/3} S_0^{1/2} \quad (3-2)$$

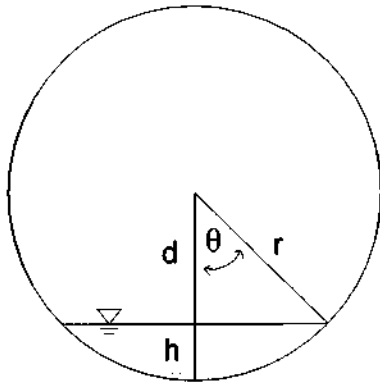
where

- n = roughness coefficient (unitless)
- A = cross sectional area of the flow (mm<sup>2</sup>)
- R = hydraulic radius (mm)
- S<sub>0</sub> = slope (unitless)

The hydraulic radius is determined by dividing the flow area by the wetted perimeter of flow. The roughness coefficient is a friction factor selected based on the conduit material. Typical values for n can be found in most hydraulic engineering material with values ranging from 0.011-0.05. Most stormwater pipes are made from cement with a smooth

finish which would typically result in a roughness coefficient  $n = 0.012$ . The slope is determined from the gradient of the stormwater pipe expressed as a fraction.

Once the roughness coefficient and slope for a pipe have been determined, only the height of the water level is required to estimate the flow (for a pipe of known dimensions). Relationships exist between the parameters of a circle which allow the area of a segment to be calculated if the radius  $r$ , apothem  $d$  and height  $h$  are known (see Figure 3-9 and Equations 3-3 to 3-5).



**Figure 3-9: Geometric variables used to calculate the area of flow in a pipe of known dimensions and water level.**

The angle  $\theta$  is calculated using  $d$  and  $r$ :

$$\theta = 2 \times \arccos \left( \frac{d}{r} \right) \quad (3-3)$$

Wetted perimeter equals the arc length:

$$\text{arc length} = r \times \theta \quad (3-4)$$

$$\text{The area} = r^2 \times \frac{(\theta_{\text{rad}} - \sin \theta_{\text{rad}})}{2} \quad (3-5)$$

Estimations of the roughness coefficient and slope can introduce errors which may require field calibration (Corbitt, 1990). Errors pertaining to the slope estimation are however reduced as the variable is raised to the power of a half in Equation 3-2 (Tobaison, 1993).

Dowling (1995) introduced a  $k$  value to decrease errors in estimating  $n$  and  $S_0$ . The  $k$  value (see Equation is substituted into the Manning equation which is divided by the area of the flow to be an expression related to the velocity of the flow.

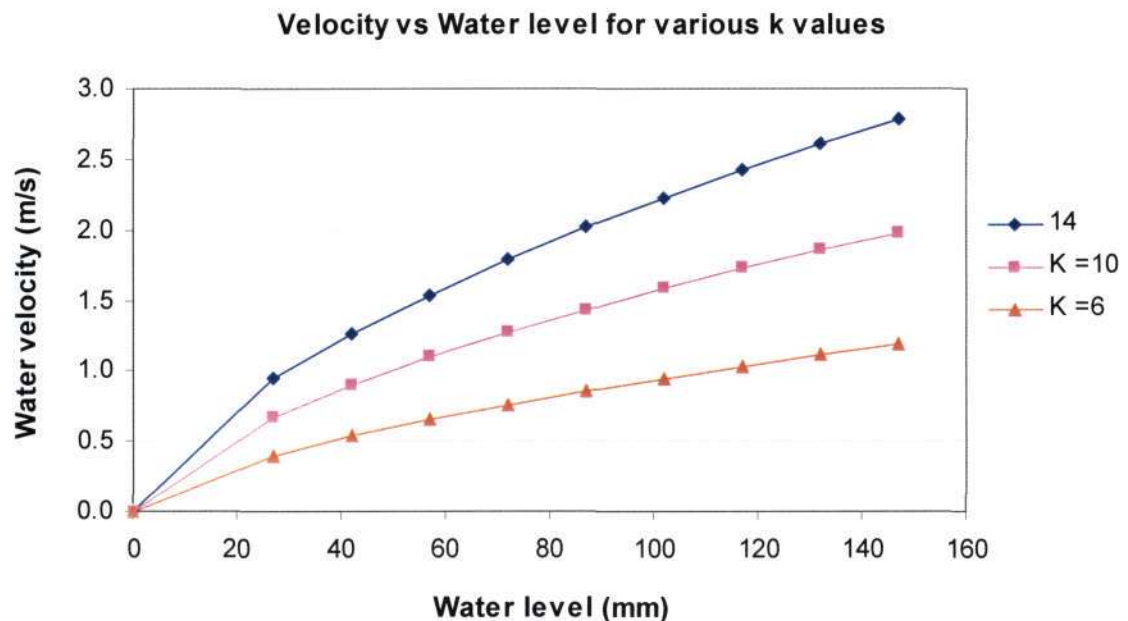
Substituting: 
$$v = \frac{Q}{A} \quad (3-6)$$

and 
$$k = \frac{1}{n} \times S_0^{1/2} \quad (3-7)$$

into equation (3-2) gives

$$v = k \times R^{2/3} \quad (3-8)$$

A series of curves relating velocity and water level were produced by adjustment of the  $k$  value (see Figure 3-10). A high  $k$  value indicates a high flow rate. Dowling (1995) noted that this may be due to a larger slope, smaller roughness coefficient or a combination of the two. Estimation of the  $k$  value requires plotting several velocity and water level field data points onto the same axis used for the  $k$  value curves to find the best fit. The relationship established for a specific stormwater pipe, with regards to velocity and water level, predicts the conditions the sampler will be exposed to during a storm event. This relationship provides an indication of the response of the sampler to the rainfall event as the discharge water level changes. Given that the orifice collection rate is primarily a function of the water velocity and water level, a relationship was established to estimate the total volume discharged from the volume collected by the sampler.



**Figure 3-10: Various  $k$  values generated for the 720mm diameter culvert at Booth East where initial prototypes were tested**

### 3.5.1 Estimation of the total volume discharged

The total volume discharged is estimated by formulating a relationship between the conduit discharge ( $Q$ ) and the orifice collection rate ( $q_s$ ). The relationship is possible as  $Q$  (estimated by the Manning equation) and  $q_s$  are dependent on the discharge water level. The discharge velocity is estimated from the water level (for a conduit of known properties). Therefore, for a selected conduit, the flow  $Q$  is initially estimated for several

water levels which are then used to estimate  $q_s$ . Subsequently  $q_s$  can be estimated from  $Q$  by generating a regression curve through the flow and sampling rates (see Figure 3-11).

Multiplying the regression curve equation, derived from Figure 3-11, by a time variable estimates the total volume of conduit discharge ( $V_Q$ ) and volume collected by the sampler ( $V_q$ ). The time variable represents the duration of discharge from the stormwater pipe and not the rainfall event. A second graph relating  $V_Q$  and  $V_q$  were plotted and a regression curve is fitted to establish a relationship between the two (see Figure 3-12). Table 3-7 presents the values used in generating Figures 3-11 and 3-12 with a runoff duration of 120min selected.

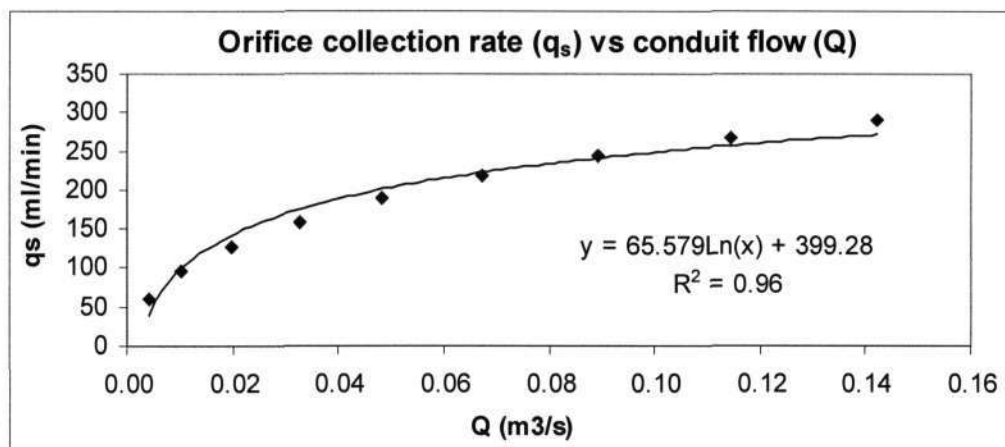


Figure 3-11: Relationship established for conduit flow and sampler collection rate

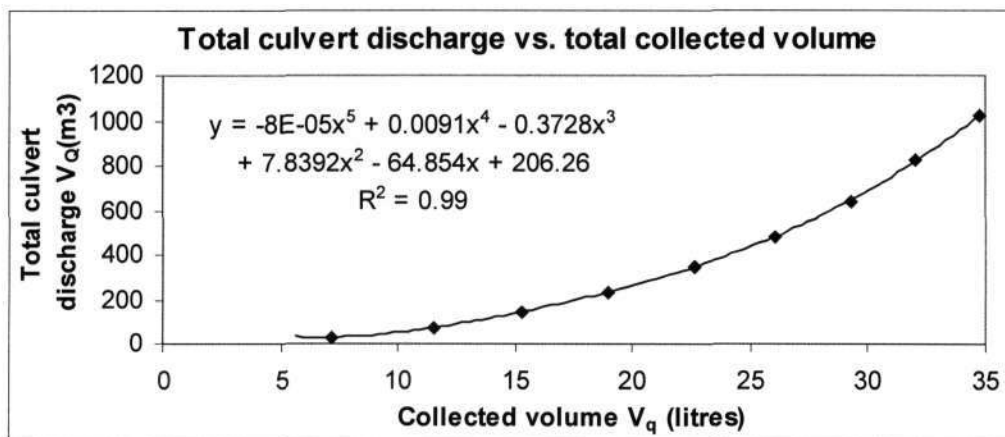
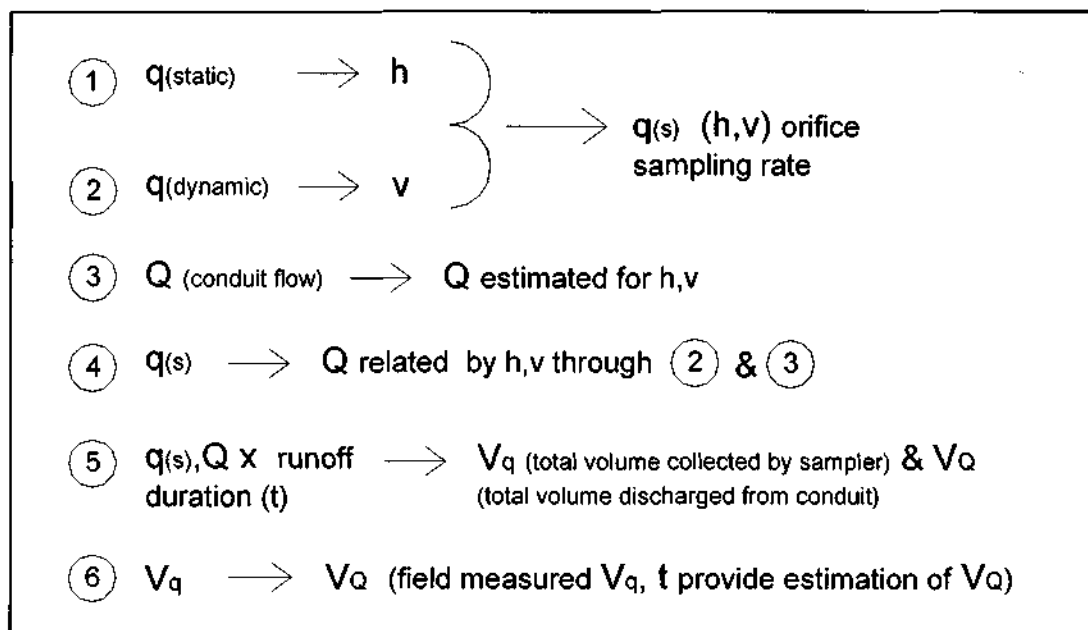


Figure 3-12: Regression curve relating  $V_Q$  and  $V_q$  for a 120min runoff duration

**Table 3-7: Values used to establish a relationship for  $Q$ ,  $q_s$  and  $V_Q$  and  $V_q$** 

Sampling rate ( $q_s$ ) ml/min	Conduit Flow ( $Q$ ) m <sup>3</sup> /s	Time variable (min)	Sampled volume $V_q$ (l)	Culvert discharge $V_Q$ (m <sup>3</sup> )
59.7	0.004	120	7.17	29.1
95.9	0.010		11.51	74.8
127.4	0.020		15.28	143.1
157.8	0.033		18.93	234.1
188.5	0.048		22.62	348.0
217.1	0.067		26.05	484.4
243.9	0.089		29.27	642.9
266.6	0.114		31.99	822.9
289.9	0.142		34.79	1023.9

The regression curve fitted to the  $V_Q$  and  $V_q$  data points produces a 5<sup>th</sup> order polynomial. The relationship was regenerated for each rainfall event due to varying discharge times. If the runoff discharge duration and sampler collected volume are known, an estimation of the total conduit discharge volume is possible. Figure 3-13 presents the steps followed in establishing the sampler's performance, conduit flow rates and estimation of the total conduit discharge volume from the sampler's collected volume.

**Figure 3-13: Procedure followed in order to estimate the total conduit discharge volume from the sampler's collected volume**

### 3.5.2 Sensitivity analysis and calibration of the total discharge estimation

Dowling (1995) investigated the sensitivity of the orifice collection rate ( $q_s$ ) and total discharge estimation ( $V_q$  to  $V_Q$ ) with regards to varying runoff hydrographs. Storm event hydrographs were simulated, for storms with varying and fixed total flows, and the difference between the calculated and estimated  $V_Q$  examined. Dowling (1995) concluded that (1) a calibration constant resulted in estimated total discharges being within 10% of the actual discharge (2) for a given total discharge, the sample volume collected is practically independent of the storm hydrograph shape.

To establish whether the Pro.4 sampler complied with these findings, simulations similar to Dowling's (1995) were carried out. Three hydrographs representing different runoff responses for rainfall events were generated. Runoff responses were generated for a one, two and three hour period. Table 3-8 and Figure 3-14 present the hydrographs generated for simulations.

**Table 3-8: Values used to establish a relationship for  $Q$ ,  $q_s$  and  $V_Q$  and  $V_q$ .**

	<b>Hydrograph characteristics</b>
<b>Hydrograph 1</b>	Gradually builds up to mid way through the response and then gradually decreases
<b>Hydrograph 2</b>	Rapid increase to a level discharge which is maintained for most of the runoff event and then rapidly decreases
<b>Hydrograph 3</b>	Initial peak early on which slowly decreases through the runoff event

Appendix A contains the calculations used to generate the hydrographs and graphs for each specified response and time period. All simulations were done for a 720mm diameter stormwater pipe having an assumed  $k$  value of 12.

Once a specific hydrograph shape had been generated for a selected time period, steps 3-6 (see Figure 3-13) were followed. Step 3, the water levels in conjunction with the Manning equation, pipe geometrics, and  $k$  value were use to calculate the flow rate. Step 4, a regression curve was also generated to determine the orifice collection rate of the sampler

for the specified stormwater pipe and flow rates from step 3. The change in the flow rate of the discharge was then used to estimate the change in the orifice collection rate throughout the runoff event. Step 5, the total discharge and the volume collected by the sampler, for an entire runoff event, were calculated by summation of the incremented flow and collection rates multiplied by the corresponding time increment. Multiplying the regression curve for the orifice collection rate and flow rates by the runoff discharge time, generates a second regression curve (step 5-6) which estimates the total volume discharged from the collected sample volume. This relationship was used to estimate the total volume discharged for each hydrograph generated.

Simulation results for varying total discharges, shown in Table 3-9, indicate the estimation of  $V_Q$  from  $V_q$  errors range between six and twenty one percent. This is dependant on the hydrograph shape and time period. A correction factor of 1.15 due to the varying hydrograph shapes reduces the errors to below nine percent (see Appendix A).

**Table 3-9: Sensitivity simulation results for estimation of  $V_Q$  from  $V_q$  for three hydrographs and varying total discharges**

Hydrograph period (min)	Hydrograph 1			Hydrograph 2			Hydrograph 3		
	60	120	180	60	120	180	60	120	180
Total collected $V_q$ (litre)	9.2	18.3	29.0	11.6	23.3	35.3	9.5	18.9	27.5
Calculated $V_Q$ ( $m^3$ )	117	231	424	208	417	685	142	265	414
Estimated $V_Q$ ( $m^3$ )	108	216	368	176	368	569	115	232	327
Error (%)	8.1	6.3	13.2	15.1	11.7	17.1	19.3	12.3	21.0
Corrected Estimate ( $m^3$ )	124	249	424	203	424	655	133	267	377
Error (%)	5.9	8.0	0.0	2.2	1.8	4.4	7.0	1.0	9.0

Simulations to examine whether  $V_q$  is 'practically' independent of the storm hydrograph shape. Three hydrographs were generated for each selected fixed  $V_Q$  and a constant time period (120min). Hydrographs were adjusted to generate the required  $V_Q$  whilst maintaining a selected response shape. Figure 3-15 illustrates Hydrographs A-C generated for the simulations. The hydrographs generated and tables can be found in Appendix A.

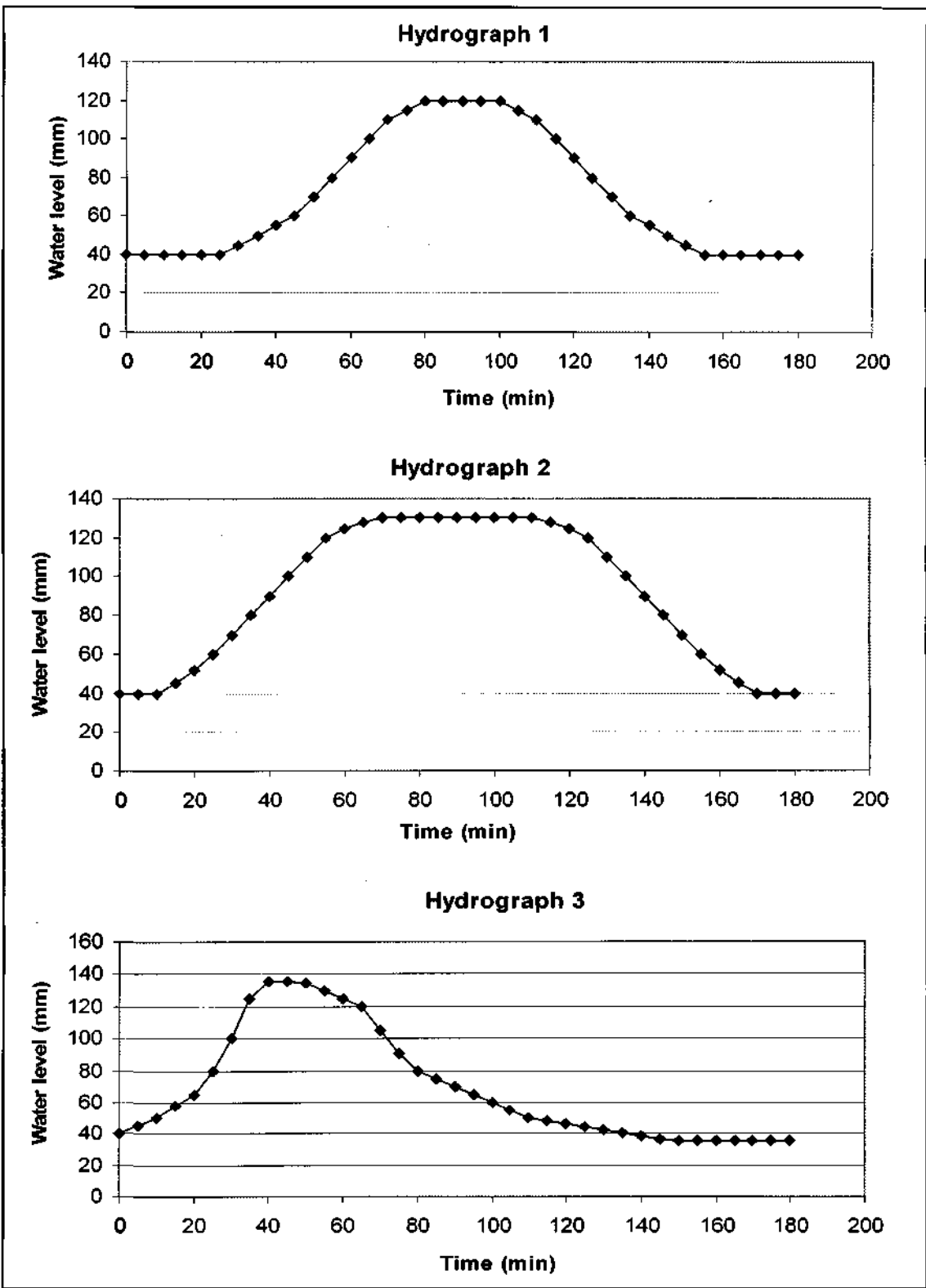
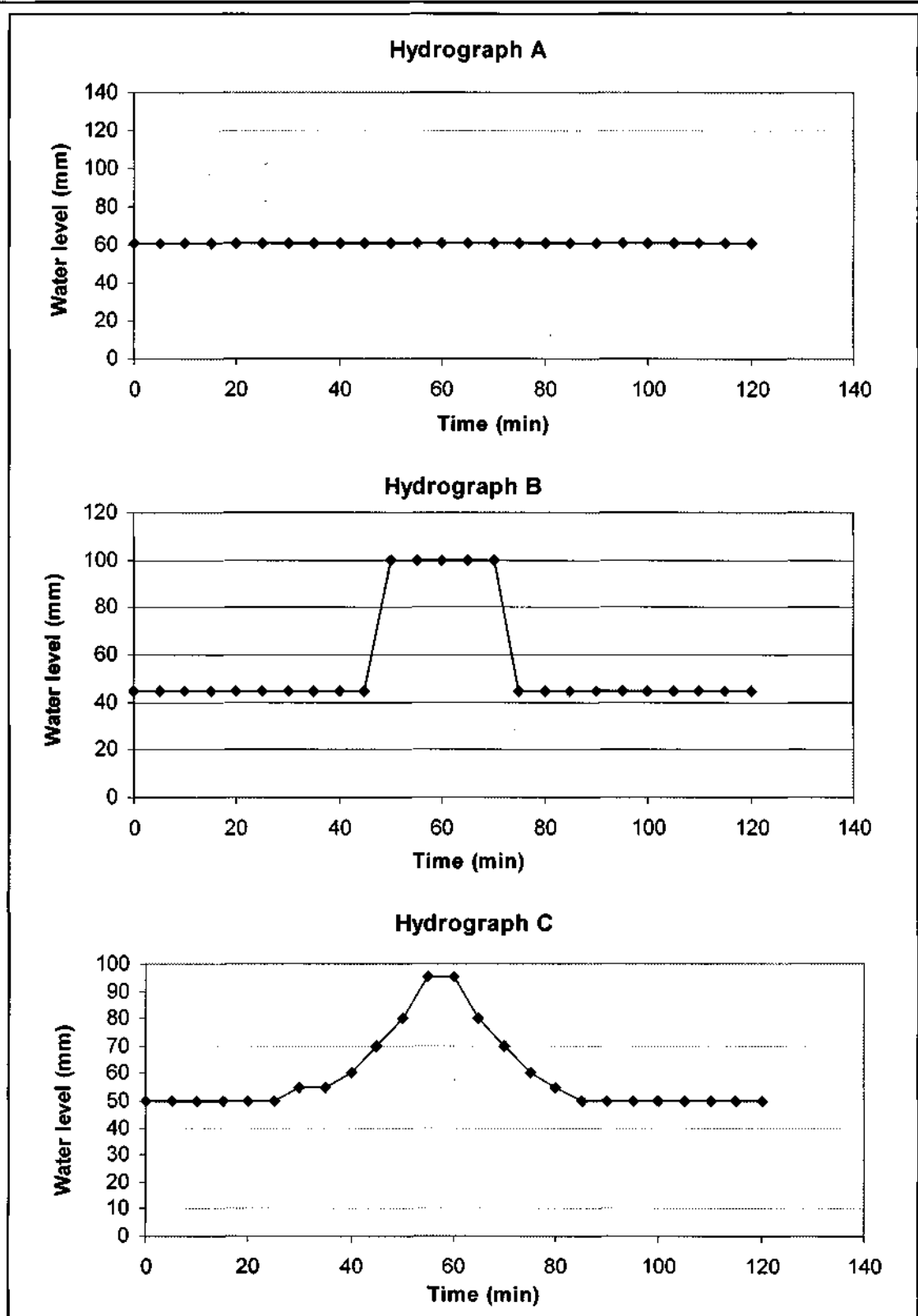


Figure 3-14: Hydrographs 1-3 generated for simulations to investigate the sensitivity of the sampling rate  $q_s$  to various runoff responses



**Figure 3-15: Hydrographs A-B generated for simulations to examine the sensitivity of  $V_q$  to different runoff responses with an equal  $VQ$**

Simulations indicated that for a selected fixed  $V_Q$ , produced from any of the three hydrographs, the sample is minimally affected. A standard deviation of 0.6, 1.2 and 1.9 litres were found for sampled volumes of 8.4, 17.1 and 20.8 litres respectively, pertaining to three different fixed  $V_Q$  simulations. Estimation errors of  $V_Q$  from  $V_q$  were reduced to an average error of 9.9 percent for all simulations by applying a correction factor. The correction factor of 0.87-1.3 was dependent on the fixed  $V_Q$  selected. Table 3-10 presents the  $V_q$  for each hydrograph,  $V_Q$  selected and errors in the estimations.

**Table 3-10: Sensitivity simulation results for estimation of  $V_Q$  from  $V_q$  for three hydrographs and a selected fixed total discharge**

Hydrograph (No)	Fixed $V_Q$ 1			Fixed $V_Q$ 2			Fixed $V_Q$ 3		
	A	B	C	A	B	C	A	B	C
Hydrograph period (min)	120	120	120	120	120	120	120	120	120
Total collected $V_q$ (litre)	8.9	7.7	8.5	18.2	15.9	17.3	22.7	18.8	20.9
Calculated ( $m^3$ )	50.7	50.5	50.6	165	165	166	292	281	287
Estimated $V_Q$ ( $m^3$ )	39.8	31.3	36.4	214	159	191	347	230	289
Error (%)	21.5	38.0	28.1	29.5	4.1	15.2	18.8	18.2	0.8
Corrected Estimate ( $m^3$ )	55.3	43.5	50.6	186	138	166	344	228	287
Error (%)	9.1	13.8	0.0	12.4	16.7	0.0	17.8	18.9	0.0

The results from the simulations indicate that the collection rate response of the sampler to variations in runoff hydrographs under variable and fixed volume discharges is acceptable. Estimation errors of  $V_Q$  from  $V_q$  were reduced by applying correction factors dependent on hydrograph shape or  $V_Q$ .

### 3.6 Field Concentration Tests for Sampler

A field concentration test during a storm event was carried out in order to evaluate the representativeness of samples collected by the Pro.4 sampler. The Pro.4 sampler was installed at the Booth east stormwater conduit prior to a storm event. Once rainfall commenced, two sampling personnel proceeded with manual grab sampling equipment to the sampling point. Eleven discrete grab samples were obtained at the same time from the culvert discharge and Pro.4 delivery tube over a ninety minute sampling period. The performance of the sampler was evaluated by a comparison of the discrete sampled and

actual in situ concentration levels. Discrete grab samples were collected and stored in one litre acid washed bottles.

Chemical analysis for pH, EC, TS, TDS and TSS were completed for both the culvert and the Pro.4 sampler samples. The chemical results in Table 3-11 show that the Pro.4 sampler concentrations are very similar to those of the culvert discharge. The difference in concentration values was generally below ten percent.

The storm test discrete sampling was initiated approximately ten to fifteen minutes after the runoff discharge commenced. A first flush is evident from the 'true' in situ culvert samples results as there was a steady decrease in concentration levels from the onset of sampling. This was also reflected by the Pro.4 sample concentration. Figure 3-16 illustrates the first flush although the peak was most likely missed. Figures comparing the chemical results presented in Table 3-11 are located in Appendix A. The chemical results also provide an indication of the Pro.4 sampler's ability to collect an uncontaminated sample. The low error between the culvert and sampler results indicates that the materials used to manufacture the sampler do not contaminate the sample collected.

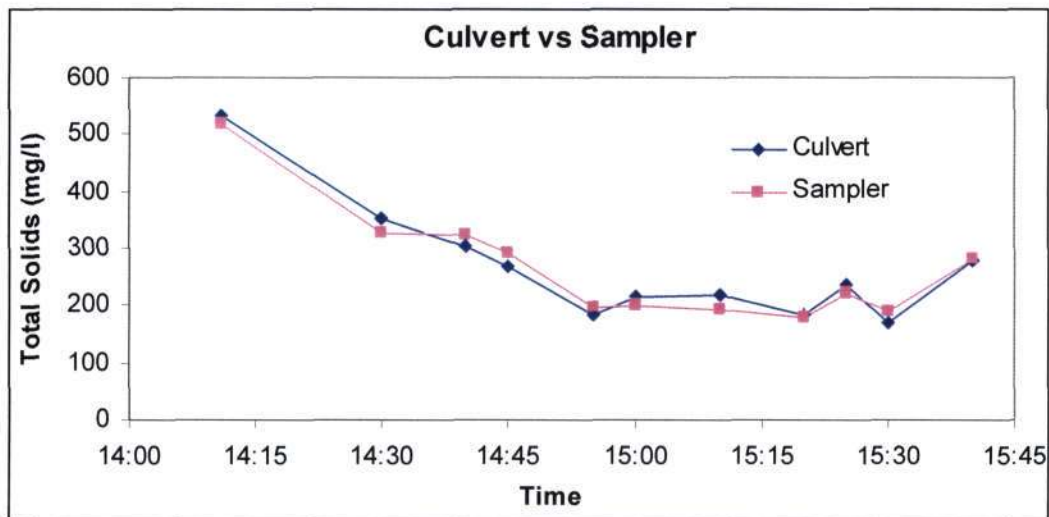


Figure 3-16: Storm test sample collection comparison for total solids

Table 3-11: Storm test chemical analysis summary for the culvert discharge and Pro.4 sampler

Sample		pH			EC ( $\mu\text{s}/\text{cm}$ )			TDS (mg/l)			TSS (mg/l)			TS (mg/l)		
No.	Time	Culvert	Sampler	Error (%)	Culvert	Sampler	Error (%)	Culvert	Sampler	Error (%)	Culvert	Sampler	Error (%)	Culvert	Sampler	Error (%)
A	14:11	6.72	6.78	0.9	137.4	127.3	7.4	72.7	67.4	7.3	352	375	6.5	532	518	2.6
B	14:30	7.01	6.98	0.4	35.9	37.4	4.2	19.2	20.0	4.2				354	328	7.3
C	14:40	6.86	6.89	0.4	34.3	35.9	4.7	19.0	19.1	0.4	262	268	2.3	303	324	6.9
D	14:45	6.96	6.97	0.1	33.9	33.1	2.4	18.0	17.7	2.2				269	292	8.6
E	14:55	6.99	6.96	0.4	30.0	31.0	3.3	16.0	16.5	3.4	226	240	6.2	184	196	6.5
F	15:00	6.98	6.97	0.1	32.7	34.4	5.2	17.4	18.3	5.2				216	200	7.4
G	15:10	6.97	6.93	0.6	35.8	37.3	4.2	19.1	19.8	4.0	188	188	0.0	220	194	11.8
H	15:20	6.94	6.92	0.3	34.2	35.1	2.6	18.3	18.5	1.1				184	180	2.2
I	15:25	6.98	6.93	0.7	30.8	33.1	7.5	16.3	17.5	7.6	222	232	4.5	236	224	5.1
J	15:30	7.02	6.99	0.4	29.9	30.3	1.3	15.9	16.1	1.3				170	192	12.9
K	15:40	6.97	6.96	0.1	23.9	24.2	1.3	12.8	12.9	1.4	236	258	9.3	280	284	1.4
$r^2$ value		0.930			0.999			0.999			0.988			0.967		

### 3.7 Conclusions

To meet the needs of a stormwater monitoring program with limited resources, a stormwater runoff sampling tool was developed. Different sampling methods were investigated and 'optimum' design guidelines formulated. Several concepts and prototypes were configured and tested in a controlled environment or at a storm water monitoring site. The tests conducted were used to examine how well the samplers satisfied the design requirements. Table 3-12 presents an evaluation of the Pro.4 sampler similar to Table 3-5 in which sampling methods were rated from 1 (poor) to 5 (good).

**Table 3-12: Evaluation of the Pro.4 sampler satisfying design objectives**

<b>Considerations</b>	<b>Pro.4 composite sampler</b>
Capital costs	5
Installation costs	4
Operating costs	5
Installation difficulty	4
Site adaptability	4
Flow-weighted sample	4
First flush sampling	5
Continuous sampling	5
Total flow determination	4
Sample duration	4
<b>Overall rating</b>	<b>4.4</b>

The cost per sampling unit (Pr.4 sampler, delivery tube and storage unit) including the installation and operation was less than R100. The sampler required no external power source, was maintenance free once installed and robust enough to be left out in the field for long periods of time. The installation was easy and adaptable to any stormwater pipe that would enable the gravity sampler to operate.

The Pro.4 sampler developed collected a representative flow-weighted composite stormwater sample that satisfied the stormwater monitoring program sampling objectives. However, because the relationship established between the culvert discharge and sampling rate is non-linear, the sample collected is not a true flow-weighted sample. Storm test chemical results do however indicate that the sampler collected comparatively good

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flow-weighted samples that were similar to the actual culvert runoff discharge concentrations. The sampler automatically starts sampling when runoff discharge commences therefore sampling the first flush. Since the sampler continuously collects a flow-weighted discharge throughout the storm event, no compositing was required.

Computer simulations indicated that the total culvert discharge can be estimated from the volume sampled. However, tests in the field are required to further test the method. In summary, the Pro.4 sampler satisfies the majority of the operational, cost and sample quality requirements established.

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## CHAPTER 4

### METHODOLOGY

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*Chapter four presents the selection of study areas, characteristics of selected sites and identification of monitoring stations for the installation of runoff and atmospheric sampling equipment. Laboratory procedures and techniques associated with collection of samples and water quality analysis are discussed. The monitoring of storm events is also discussed.*

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#### **4.1 Study Area Selection**

The study areas selected for this investigation are all within the City of Durban, eThekweni Municipality. Durban is the largest city in the province of KwaZulu-Natal, which is located on the east coast of South Africa.

Potential study areas were initially identified based upon location and predominant usage in order to meet the objectives of the investigation. Four road surfaces were highlighted that would provide sufficient variance: a national highway, an urban arterial road, a large parking lot and a heavy vehicle route. A primary objective in selection of the study areas was to identify regions unaffected by industry which produce large quantities of airborne pollutants. This decreases the potential for outside contamination and reduces the variables contributing to pollutants. This would also ensure that the results obtained would not be limited to this investigation and may be used to estimate pollutant loadings elsewhere.

Guidelines were therefore established to enable a form of assessment when considering the selection of possible study areas. Guidelines included: the surrounding land use and associations; classification of road; the usage based on number and variety of vehicles; total drainage area; location of discharge points; accessibility; acceptable conditions for placement of sampling instrumentation; security of equipment and personnel safety.

The eThekweni Municipality of Durban has developed a Geographic Information System (GIS) which was used to search for possible study areas. The GIS is an electronic

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database that contains information such as contours, stormwater pipe and sewer networks, manholes and discharge points and land use overlaid on aerial photographs. Several sites were identified within each category of road surfaces required based upon the guidelines established. Several field inspections were carried out to assess potential sites, which resulted in the elimination of the majority of possibilities. Three general problems arose: accessibility, safety and the manner of discharge. The method of sampling developed in Chapter 3 and selected for this investigation, is dependent on gravitational flow from the sampler to the storage drum. Thus, a requirement for the study areas was a discharge point conducive to this method. Stormwater pipes which discharged directly into open culverts or were sufficiently elevated when joining a secondary stormwater pipe were required.

Five study areas were selected that satisfied the guidelines sufficiently to ensure the collection of representative data. The four study areas selected were a national highway, a major arterial road, a large shopping centre parking lot and a major harbour route.

#### **4.1.1 Study area characteristics**

A description of each study area is given as the characteristics of a drainage basin may influence the results of the water quality data and thus the conclusions made. The characteristics of the drainage area include: impervious percentage, traffic volumes, types of vehicles, adjacent land use and activities that affect the hydrology and resultant stormwater runoff. Drainage areas and impervious percentage are based on estimates from the GIS and road maps obtained from the eThekweni Municipality. Runoff coefficients were estimated by the method of Schueler (1987):

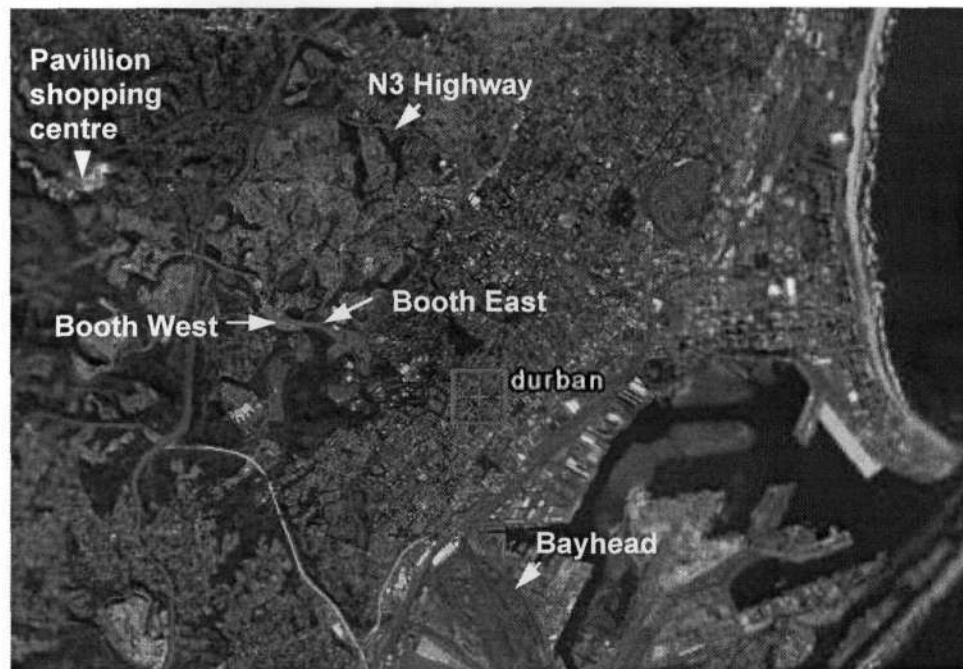
$$C_r = 0.009 (I) + 0.05 \quad (4-1)$$

where

$C_r$  = runoff coefficient (unitless)

$I$  = percentage impervious area (%)

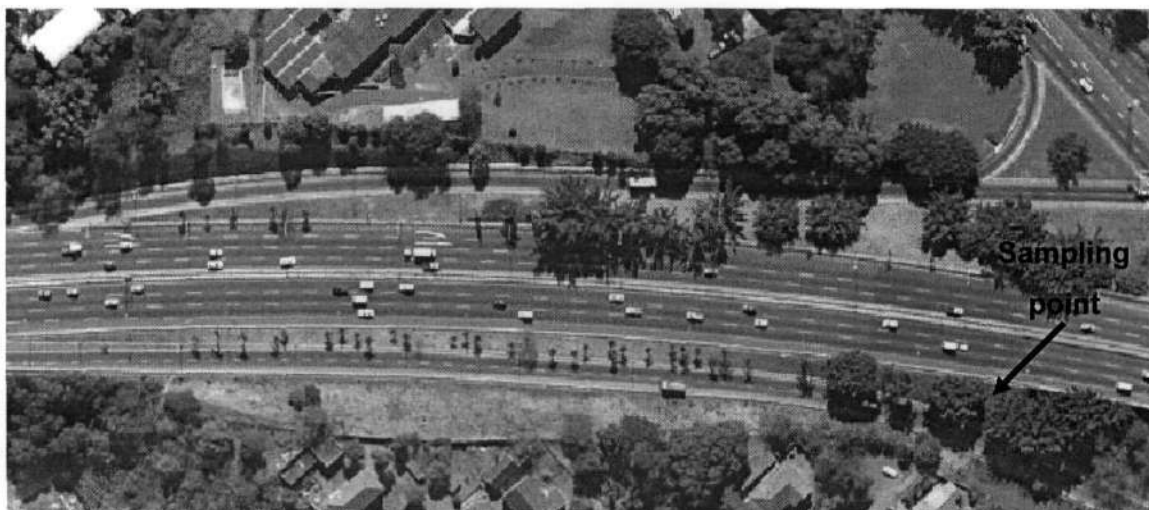
Each of the selected sites is described below. An aerial image of Durban is presented with the location of selected study areas (see Plate4-1).



**Plate 4-1: Aerial image of Durban with selected study areas (Google Earth)**

#### **4.1.1.1 National Three Highway (N3)**

The N3 Highway is a high volume traffic road entering and exiting the centre of Durban. The N3 continues to Johannesburg approximately 500km inland. The specific section of road selected as a study area comprises three lanes and wide shoulders in either direction separated by a concrete barrier. The average volume of traffic at this site is approximately 90 000 vehicles per day. The land use of the area adjacent to the highway is predominantly residential with a small percentage of commercial use. The design of the highway does not allow for any drainage of the adjacent lots onto its surface and there is no dry flow between storm events. A runoff coefficient of 0.95 was estimated. The road surface is paved with asphalt and the road has a slope of approximately 0.015. Runoff enters kerb inlets that feed into a 400mm diameter stormwater pipe that discharges from an elevated level into a secondary pipe inside a manhole chamber. The drainage area is approximately 8900m<sup>2</sup>. Plate 4-2 provides an aerial view of the N3 segment sampled.



**Plate 4-2: Aerial photograph of the N3 Highway sampling site obtained from the GIS**

#### **4.1.1.2 Bayhead road**

Bayhead road was selected as it is a major route for heavy duty vehicles into the Durban harbour region. The segment of road sampled has a total drainage area of 2550m<sup>2</sup> of which 550m<sup>2</sup> is a six meter wide elevated kerb grass island barrier which separates the two lanes in either direction. The layout of the elevated grass island indicates that only large precipitations with high intensity would result in runoff. The runoff coefficient was calculated as 0.73 using an estimated impervious percentage of 80%. Traffic counts indicate that both directions received approximately 8500 vehicles per day with heavy vehicles making up 34% of the total usage. This value is slightly conservative as the traffic counts were done from 6am to 6pm with heavy vehicle activity generally not decreasing to the same extent as light vehicles over night. Runoff enters kerb inlets that discharge the water into an open culvert via a 450 diameter stormwater pipe. Although this road is found in an industrial harbour region there is no production of materials in the vicinity resulting in the release of airborne material, with only deliveries and collections taking place. There is also a distance of approximately forty meters from the western road edge (the road is aligned south to north) to the commercial region with no development on the eastern side of the road (see Plate 4-3 below). Therefore, although the land use is classified as industrial, there is no direct contamination off industrial land onto the road. The heavy vehicle road usage provides an indirect source of contamination, because of spillage onto the road surface during transporting of goods, related to the industry.



**Plate 4-3: Bayhead road with industrial region set back on the western side and undeveloped natural vegetation to the east**

#### **4.1.1.3 Booth road**

Booth road is a major urban arterial road that links several residential and commercial areas with each other and the N3 highway. Two discharge points were selected for sampling from different segments along the road: Booth East and Booth West. Both locations are considered 100% impervious with asphalt surfaces. Booth West has a drainage area of approximately 8900m<sup>2</sup>. The overall road surface slope is considered flat and the average traffic count is approximately 17 500 vehicles per day. Booth East has a drainage area of approximately 7350m<sup>2</sup>. The major difference is that Booth East has an average road surface slope of 0.065. The average traffic count is approximately 16 000 vehicles per day on Booth East. Both road segments collect runoff via kerb inlets and discharges into an open culvert via 750mm diameter stormwater pipes at different locations. The land use adjacent to the road surfaces is predominately undeveloped with only the University sports grounds and one commercial company besides natural vegetation. A petrol station was built, several months into this investigation, which will have to be accounted for when considering Booth West results. Plate 4-4 and 4-5 present Booth West and Booth East respectively.



**Plate 4-4: Photograph of Booth West looking west**



**Plate 4-5: Photograph of Booth East looking east**

#### **4.1.1.4 Pavilion shopping centre**

A large shopping centre was selected as a fourth study area. The drainage area of approximately 18000m<sup>2</sup> from an outside parking area limited to light vehicles accumulates runoff via a stormwater system that discharged into a neighbouring naturally vegetated valley. The surface is approximately 90% impervious due to small vegetated sections within the parking area. The runoff was sampled from inside a 2.5m deep manhole chamber where a 720mm diameter stormwater pipe discharged into a 1000mm diameter pipe leading off the premises. The discharge point has a dry flow of varying depths due to cleaning and irrigation operations. Plate 4-6 presents an aerial view of the Pavillion shopping centre that illustrates the outside parking area and sampling point.



**Plate 4-6: Aerial photograph of the Pavilion shopping centre**

A summary of the physical characteristics of the selected study areas is presented in Table 4-1. The roads selected are all oriented north-south, approximately 90 degrees to the prevailing wind directions for Durban.

**Table 4-1: Summary of characteristics for the five study areas selected**

Characteristics	Sampling Sites				
	N3 Highway	Bayhead Road	Booth West	Booth East	Pavilion Centre
Drainage area	8900	2550	8900	7350	18000
Pavement	asphalt	asphalt/ concrete	asphalt	asphalt	concrete
Slope	0.015	Approx. flat	Approx. flat	0.06	Approx. flat
Runoff coefficient	0.95	0.73	0.95	0.95	0.86
Lanes of traffic	6	4	2 to 4	2 to 4	parking bays
Shoulders	3.5m on LHS	one 3.7m	none	none	-
Curb/guard rail	1m retainer & kerbs	kerbs	kerbs	kerbs	-
Average daily traffic	90 000	17000	17500	16000	N.A <sup>a</sup>
Land use	residential/ commercial	industrial	sports grounds	undeveloped/ commercial	commercial

<sup>a</sup> N.A - Not available

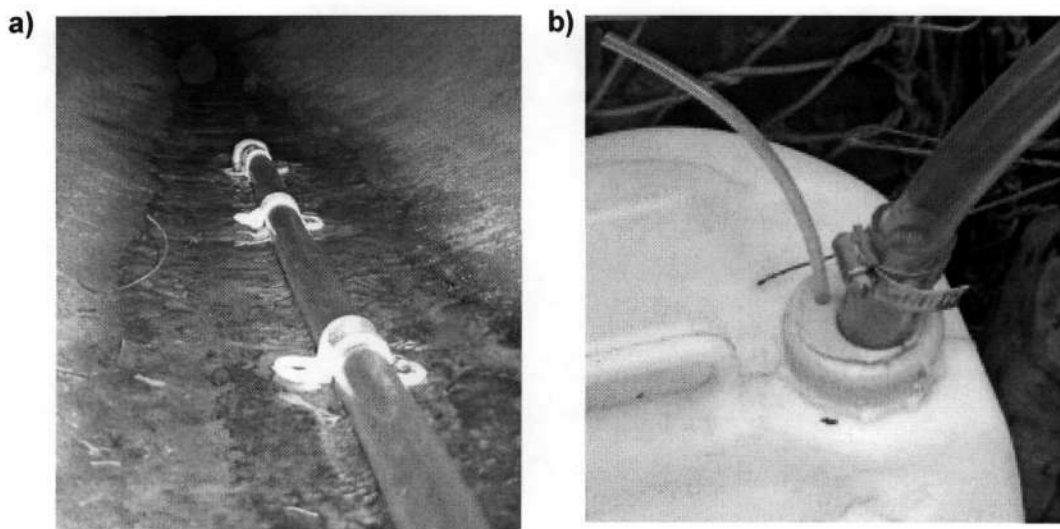
## 4.2 Monitoring Equipment

Each study area selected required unique on site preparations to enable the correct installation of stormwater runoff and atmospheric collection equipment. The installation of equipment aimed to limit the visibility and accessibility (to the general public) in order to

reduce the risk of vandalism and theft. A structure could have been constructed on site to house and protect the equipment however this may have attracted unwanted attention.

#### 4.2.1 Runoff sampling equipment

The installation of the sampler required a method of attaching the sampler and delivery tube to the central bottom position of a stormwater pipe leading outwards. A simplistic method was incorporated using electrical conduit saddles and screws that would provided quick and easy attachment with minimal obstruction to the flow. Holes were drilled into the bottom of the pipe and plastic plugs inserted that matched the saddle dimensions. The saddle held the delivery pipe in the correct position and thus orientated the sampler and orifice entrance directly upstream (see Plate 4-7a). The delivery tube leading out of the stormwater pipe was carefully directed at a constant downwards gradient to a storage drum. Additional saddle brackets were utilised when there was a small height difference from the pipe exit to drum entrance. To maintain atmospheric pressure in the sampling equipment and eliminate outside contamination a special lid was made. The original drum lid was modified to allow a breather tube and the delivery tube to pass through. This modified lid was then used to replicate several more resin lids using moulding silicon and casting resin (see Plate 4-7b).



**Plate 4-7: a) Saddles used to attach the sampler in the stormwater pipe  
b) Modified lid to ensure atmospheric pressure was maintained**

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### **National Three Highway (N3)**

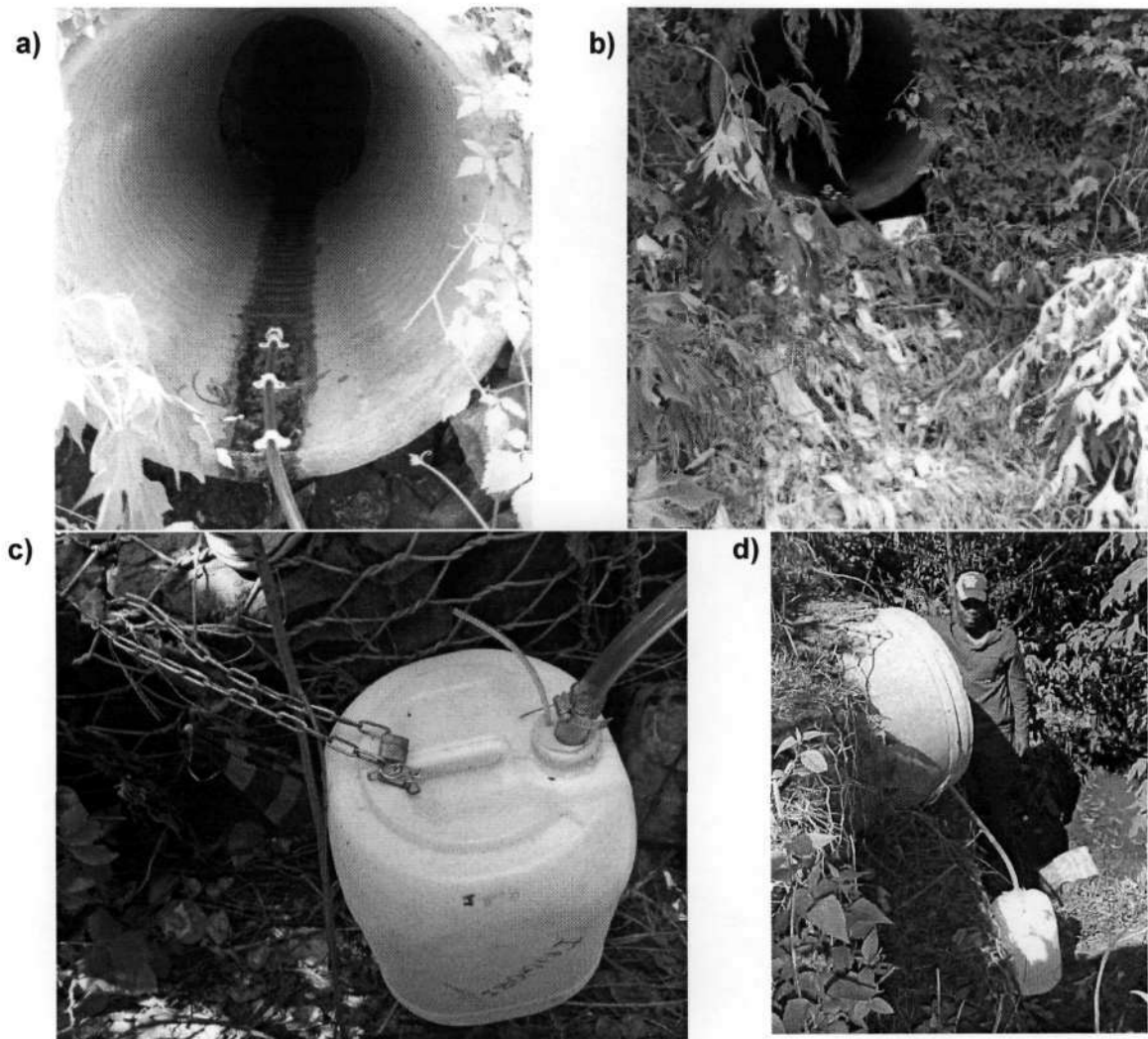
The N3 sampling point required additional caution to ensure that a constant decreasing gradient was maintained due to the confined and limited space available. The discharge point was located inside a 1.5m deep manhole. Plate 4-8 shows the equipment installation setup used for collection of samples.



**Plate 4-8: Installation set up for the N3 Highway and manhole entrance**

### **Booth West and Booth East**

The sampling points for these study areas were located at stormwater pipes that discharged into large open culverts. These installations were the easiest as work space was not limited. The installation of equipment was complicated by the close proximity of an informal settlement. Additional security measures were used after the theft of equipment and hostile confrontations. Plates 4-9a-d illustrate the equipment set up for Booth West and the security measures and open culvert at Booth East.



**Plate 4-9:** a) Typical installation for Booth West and Booth East  
b) Booth West discharge point with shrubbery used to hide equipment  
c) Sampling equipment locked  
d) Discharge point into the open culvert for Booth East

### **Bayhead Road**

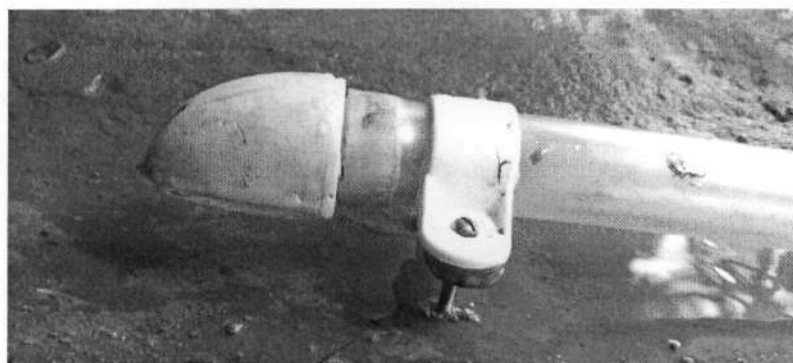
Bay head road posed installation challenges as the stormwater pipe discharged midway down a steep sloped open culvert. A ladder attached by rope to the varsity van was used to descend and install the equipment. Additional complications arose due to the tidal influence in the culvert, which is linked to the harbour, thus limiting the distance available between the pipe exit and drum entrance. A bracket was mounted to the culvert wall to prevent the drum from moving due to buoyancy forces at spring tides and theft. Plate 4-10 illustrates the installation setup and steep open culvert.



**Plate 4-10: Bayhead road installation setup and steep open culvert**

#### **Pavilion shopping centre**

The Pavilion shopping centre required working inside a 2.5m deep manhole. This made the discharge point inaccessible without a ladder and thus the safest with regards to equipment utilised. A Vegason 61 ultrasonic water level sensor was installed and used to estimate the average height of a variable continuous dry flow. Water level measurements were conducted over a two week period which included three rainfall events. The average height of the dry flow was estimated to be 16.1mm. The sampler was installed at an elevated height such that the orifice was 7mm above the average dry flow. This height accounted for the standard deviation of the dry flow and would result in sampling if sufficient rainfall occurred. Plate 4-11 illustrates the installation of the equipment at the Pavilion shopping centre.



**Plate 4-11: Pavilion shopping centre installation setup**

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#### 4.2.2 Atmospheric sampling stations

Atmospheric sampling stations comprised of an atmospheric fallout collector and rain gauge. The location of each station was selected in order to avoid contamination from undesirable particles raised from local disturbances such as vehicular motion. One station per study area was considered sufficient and any spatial rainfall variation was assumed to be negligible. The Pavilion shopping centre and Booth road stations were elevated by placement on roof-tops. The N3 highway and Bayhead road stations were placed on the premises of plots adjacent to the roads. The N3 station was approximately 7.5m above the road surface and located far enough from the road to eliminate contamination from vehicular activity. The Bayhead road station could not be elevated and was therefore placed far enough from the road surface in a secure green field location to minimise road activity interference. Plate 4-12 illustrates the positioning of the atmospheric sampling station used for Booth road.

Cylindrical metal tube frames were built to support the 310mm diameter plastic funnel collectors. The funnel was connected to a 5L plastic bottle for storage of collected material. Fine non-metallic mesh placed inside the funnel neck and nylon string supported around the perimeter of the funnel top prevented possible contamination from birds and entrapment of insects. The rain gauge was attached to the side of the metal frame. The support arm was distanced from the funnel entrance to avoid any possible influence on each other. Padding was also placed on the support arm to prevent rain drops splashing into either one.

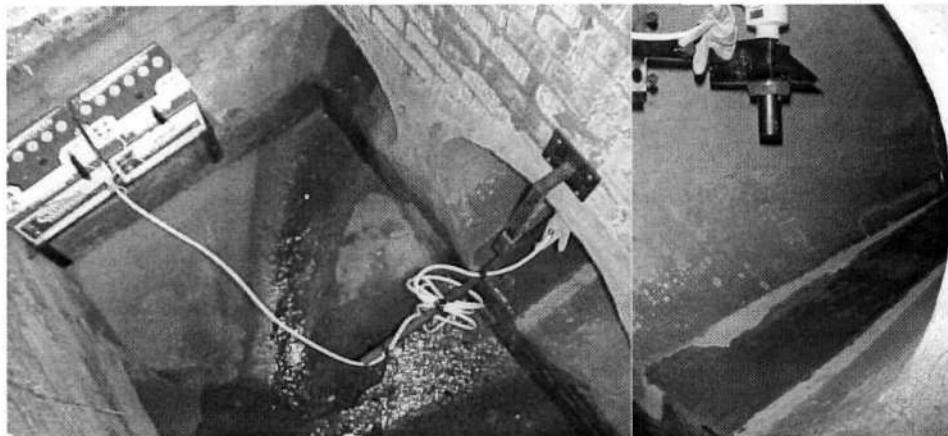


**Plate 4-12: Atmospheric sampling station**

### 4.2.3 Flow measurement

Direct methods of measuring the discharge rate from stormwater pipes were performed on several occasions. Initially flow measurements were attempted using a volumetric-time based method. A bucket and stop watch were used which proved to be very inaccurate due to the high flow rates that would fill the bucket uncontrollably. A propeller type velocimeter instrument was then used in conjunction with measuring the water level. The flow was estimated as the product of the area and velocity.

A Vegason 61 ultrasonic water level sensor was installed at the Pavilion shopping centre. Brackets were made in order to position the Vegason 61 one meter into the stormwater pipe and to support two onsite batteries (see Plate 4-13). The Vegason 61 has a variable milliamp output range proportional to the distance to the water surface. The current loop milliamp signal was converted into volts by placing two 1000 ohm resistors in the circuit. A Tinytalk TK 0702 miniature data logger was used to store the voltage readings at specified time intervals. Changes in the water level were determined by relating the voltage change to preset distance ranges selected on the Vegason 61. The flow rate was estimated using the water level readings, pipe properties and the Manning equation. Calibrations for the propeller velocimeter and Vegason 61 are located in Appendix B.



**Plate 4-13: Pavilion shopping centre Vegason 61 installation setup**

### 4.2.4 Discharge duration measurement

The estimation of the total runoff volume discharged from the total runoff volume sampled required an estimation of the discharge duration. A small, compact, inexpensive and water

resistant device was required. Based on these considerations it was decided to use the conductivity of the stormwater runoff to measure the duration of discharge. A device was developed that would automatically start/stop timing when the current loop was closed/opened due to the conductivity of the stormwater. Tests indicated that the conductivity of stormwater would provide the required electron conductivity.

The device would commence timing once the conductivity of the stormwater closed the circuit between two wires attached to the delivery tube behind the sampler. The device would stop timing when the water level dropped below the orifice entrance level (as the circuit would be broken). This provides an approximation of the discharge duration and the sample collection period.

The device was installed outside the stormwater pipe to prevent moisture damage. The wires were attached to the delivery tube to prevent debris catching and damaging the device. A portable reader would take field readings (number of seconds accumulated) and reset the device. Calibration of the device is prevented in Appendix B.

#### **4.3 Procedure for Runoff and Atmospheric Collection**

Sampling equipment for runoff was stored on campus and installed prior to storm events as predicted by weather forecasts. This prevented theft, tampering with or contamination of equipment. The atmospheric sampling equipment was reinstalled or rotated subsequent to rainfall events in order to commence collection in anticipation of the next storm event. If a sufficient build up period was not reached before the next event, the equipment was cleaned in the field after the following rainfall event when a new build up period started. The rain gauge was cleaned after every reading recorded.

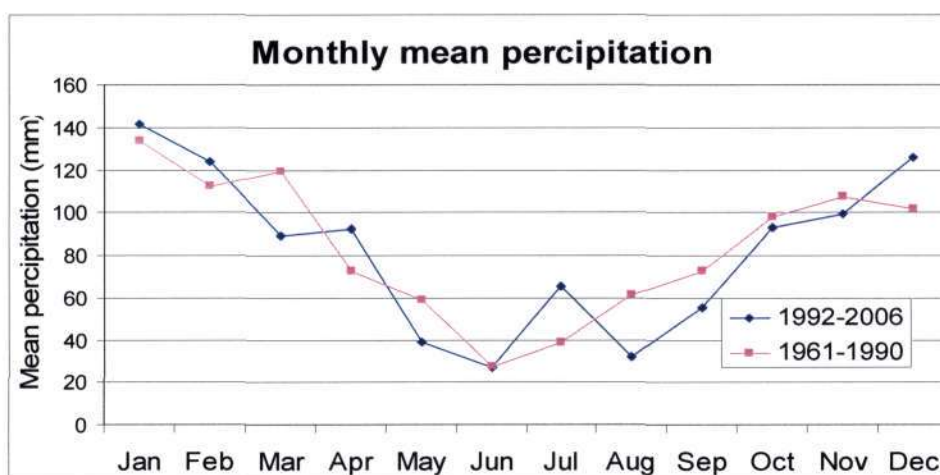
Runoff samples were collected as soon as possible to prevent contamination of samples and maintain the reliability of results. Samples resulting from daytime rainfall events were collected immediately whereas those resulting from rainfall over night were collected the following morning. Sampling equipment were inspected upon collection to ensure that a representative sample had been collected. Items checked would include: the orifice entrance for blockages; damage to the sampler; the delivery pipe to the sample bottle; the sample storage drum for breakages, whether the venting tube still operated correctly and the general appearance of the site for any objects upstream that may have influenced the

sampling. Any abnormalities, which may influence the representativeness of a sample, were recorded.

If a representative sample was deemed to have been collected, the sampling lid would be replaced with a sealed lid to ensure no spillage during transport. All runoff instrumentation were returned to the laboratory in plastic bags for cleaning.

#### 4.4 Rainfall and Runoff Quantity Monitoring

The mean annual precipitation for the City of Durban is between 950-1100mm although inter annual variations may be high (coefficient of variation = 0.69). Sixty percent of the annual precipitation falls in the warmer months of October to February. Summer is characterized by short intense down-pours while winter generally receives light drizzle often not resulting in significant runoff. The average storm event precipitation is approximately 5.7mm with a standard deviation of 1.6mm. The monthly distributions of precipitation for Durban are represented in Figure 4-1.



**Figure 4-1: Monthly mean precipitation for Durban based on data supplied by the South African Weather Service**

Rainfall was monitored using the South African Weather Service (SAWS) forecasts and associated radar images. The information was used to identify representative storm events. The SAWS operates several tipping-bucket type rain gauges, which take readings every five minutes, in and around Durban. Three of these were in close proximity to the study areas and therefore used to estimate rainfall intensities, build up periods and total

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rainfall which was checked against the atmospheric sampling station static rain gauge. Monitoring of rainfall played an important part of this investigation as it reduced the number of field trips and false alarms often associated with the unpredictable nature of rainfall.

The total precipitation estimated from the static rain gauges and SAWS, in conjunction with the runoff coefficients estimated by the method of Schueler (1987), were used to estimate the total runoff for each study area discharge point and rainfall. The estimated runoff volume was used to estimate total pollutant loadings.

#### **4.5 Laboratory Techniques and Analysis**

The Standard Methods for the Examination of Water and Wastewater 20th Edition (Clesceri *et al.*, 1998) were used as a guide for all laboratory procedures and analysis. The Civil Engineering Department's Environmental laboratory was utilised for the majority of preparation, analysis and storage of equipment and samples.

##### **4.5.1 Preparation for field sampling**

All the equipment used in the collection of samples in the field underwent acid washing to prevent contamination. The equipment was initially soaked in warm detergent solution overnight and then rinsed out with several aliquots of distilled water. The equipment was then soaked in 2-5% (v/v) nitric acid overnight and rinsed out with aliquots of distilled water before being hung upside-down to dry. A dry rack was constructed to avoid contamination from dust settlement. Sampling equipment was then sealed in plastic bags, to isolate from dust, for installation in the field.

##### **4.5.2 Collected sample material**

The total sampled volume for runoff and atmospheric samples for each event were measured and recorded. Samples were then well shaken and two representative portions taken for analysis. One portion was digested using nitric acid, filtered through a 0.45 micron filter paper and preserved at four degrees Celsius. Filtering was selected after several failed attempts at chemical analysis due to high turbidity levels as a result of suspended particulates. Centrifuging samples reduced the turbidity level but not sufficiently to eliminate interference in the chemical analysis. The second portion of

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sample was used in analysis for water quality parameters that required raw samples such as TS, TSS, BOD, COD, pH and water hardness.

#### **4.5.3 Analytical procedures**

The analytical procedures are outlined below for the standard types of analyses undertaken in this investigation. All samples were well mixed before any portion of sample was analysed. Samples were generally collected, preserved (if required) and stored within twenty four hours.

##### pH and EC

Calibrated CORNING CHECKMATE II probes were used to measure the pH and electrical conductivity (EC) in the laboratory. As these values may change significantly over a twenty four hour period, samples were measured as soon as possible.

##### Dissolved, Particulate and Volatile Matter

Analysis for total suspended solids, total suspended volatile solids, total solids and total volatile solids were completed according to the Standard Methods (Clesceri *et al.*, 1998). A 0.45 micron filter paper was used for TSS and total suspended volatile solids, and were dried in an oven and furnace respectively.

##### Water Hardness

The calcium carbonate ( $\text{CaCO}_3$ ) concentration was measured using the EDTA titrimetric method. The majority of samples required high dilutions to reduce the interference of heavy metals.

##### Oxygen Demand Indicators

Biochemical oxygen demand (BOD) levels were measured by incubation of a selected sample volume in an air tight bottle, Oxy top pressure heads for the Sensomat-System were supplied by WTW. A calibrated pressure reading head was used to estimate the  $\text{BOD}_5$  level. The maximum volume of 428ml of sample was used due to the low BOD levels measured from initial stormwater runoff sampled. The analysis for chemical oxygen demand (COD) was done using the closed reflux method. A spectrophotometer was calibrated and used to estimate the final refluxed COD level by a colorimetric method. This

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method was selected as it reduces the resultant hazardous waste and yielded the same accuracy as the open reflux method.

### **Metals**

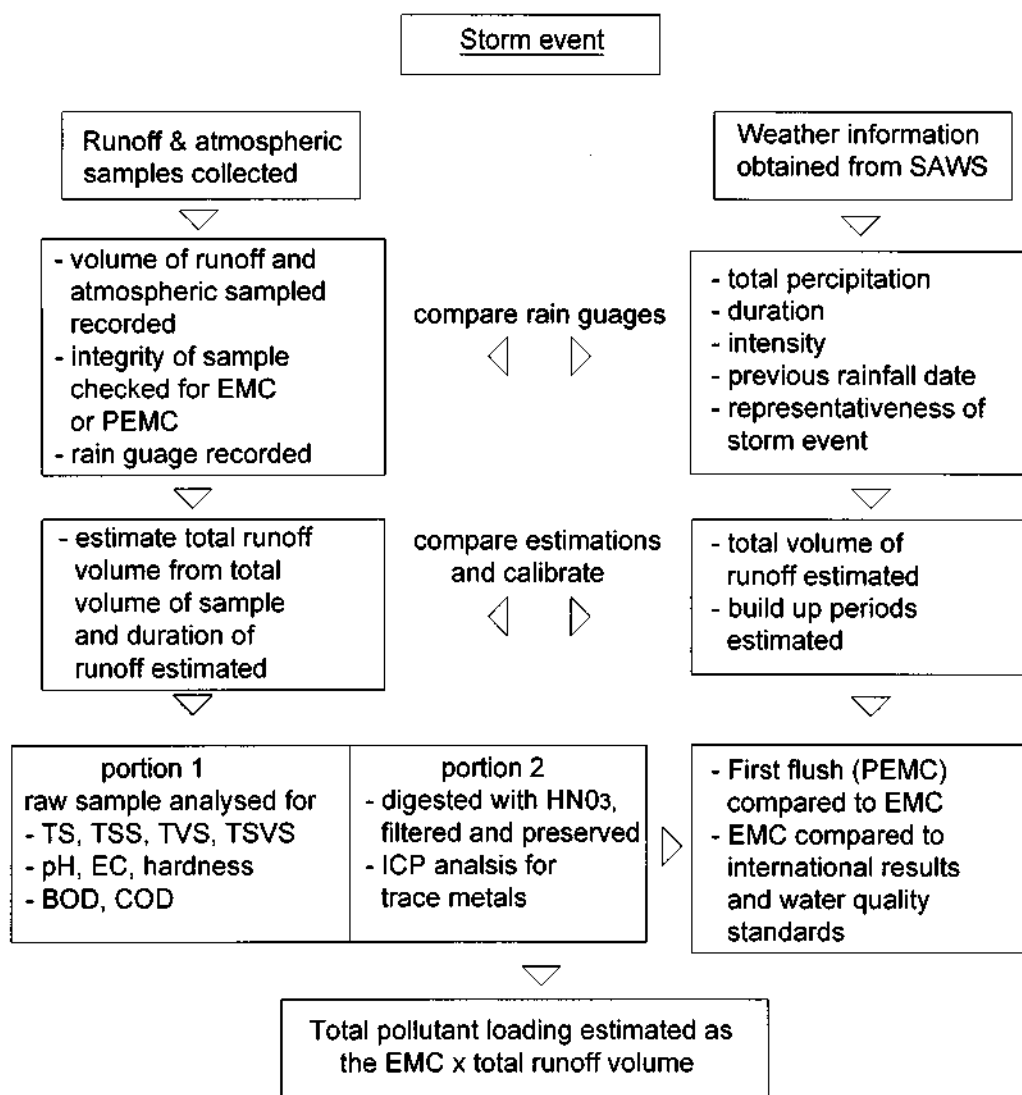
The mass of trace metals transported by stormwater runoff were estimated from the portion of sample digested, filtered and preserved. Samples were analysed using a PerkinElmer Optima 5000 Inductively Coupled Plasma Spectrophotometer (ICP-AES). Calibration standards required for analysis were obtained from an independent certified laboratory. Randomly selected samples were also sent to an independent certified laboratory to verify results obtained from the ICP-AES.

#### **4.5.4 Quality control**

Quality control consisted of procedures that indicate if there is contamination during any of the laboratory or field methods practised. Method blanks, equipment blanks and distilled water blanks were collected and analysed. Equipment blanks were obtained by flushing a known quantity of distilled water through the sampling equipment to simulate the same conditions as during a storm event. All glassware used in analytical procedures and storage bottles were acid washed in 2-10% (v/v) nitric acid. Powderless gloves were worn for installation, collection and laboratory analysis to prevent contamination. Analytical procedures followed standard methods (Clesceri *et al.*, 1998) and were done in duplicate.

#### **4.6 Data Management**

The quantity of information and data collected and produced in this investigation required extensive data management. The manipulation and analysis of data was done in spreadsheets. Storm events required processing of information relating to field and equipment operations, volumes sampled, total rainfall volume and intensities, and build up periods as illustrated by the flow chart in Fig 4-2.



**Figure 4-2: Flow chart illustrating analysis and data management of storm events**

#### 4.7 Summary

Five study areas were selected after a detailed investigation identified four road surfaces which satisfied the guidelines established from the objectives. The sampler developed in Chapter 3 and atmospheric sampling stations were installed at specific locations chosen to best produce representative data. Samples that showed no form of outside contamination were used to obtain event mean concentrations. Samples which exhibited interference (such as blocking of the orifice sampling entrance) were evaluated and either discarded or analysed for partial event mean concentrations.

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## CHAPTER 5

### DISCUSSION OF STORM EVENTS AND FIELD WORK

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*This chapter presents a discussion of the field work and storm events relating to the stormwater monitoring program. The method of sampling developed for this investigation is evaluated and the related performance discussed. Observations and challenges encountered with investigating stormwater runoff are discussed.*

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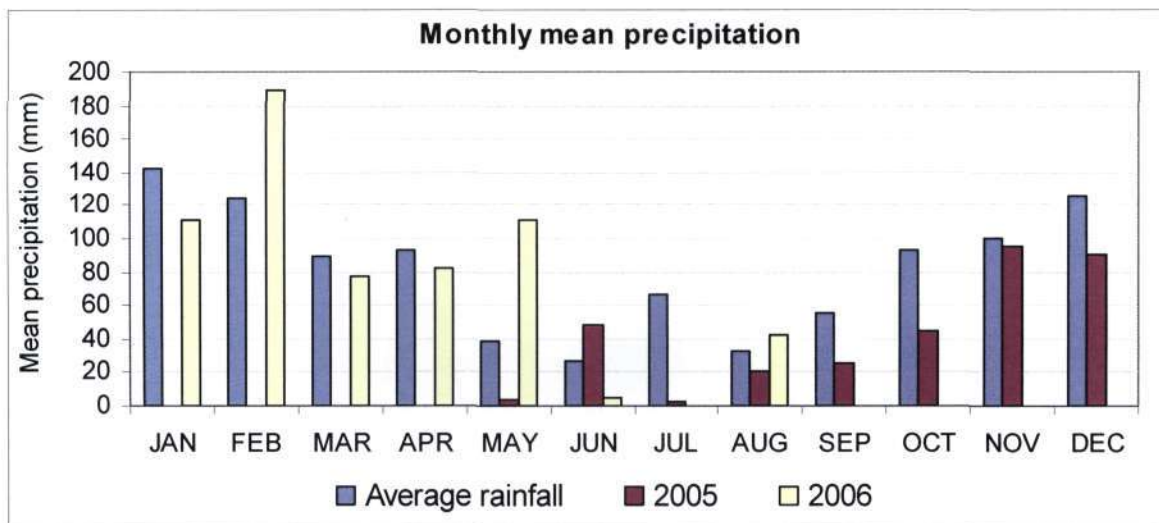
#### 5.1 Storm Events

Approximately thirty storm events were monitored which resulted in the collection of samples from twenty events. Logistics, equipment failures and the irregular nature of rainfall prevented the collection of runoff samples from each collection point for the twenty storm events, as some samples were discarded if they were considered contaminated. No prior experience of stormwater runoff sampling was readily available to assist in this investigation. Consequently the one-man learning curve resulted in several unsuccessful attempts in obtaining representative EMC samples acceptable for water quality analysis.

##### 5.1.1 Precipitation

The total precipitation for the entire investigation period of sixteen months (May 2005 to August 2006) was approximately 950mm. This accounts for approximately 82% of the expected rainfall for this period. The precipitation was therefore slightly below 'normal'. Linear regression comparisons between the static rain gauges and SAWS tipping bucket gauges yielded linear correlations of greater than 0.9. Faulty rainfall data from the SAWS tipping bucket gauges near Booth road and the N3 (due to maintenance problems) were substituted with data obtained from a gauge 15km away that showed a strong correlation to the static gauges.

Figure 5-1 illustrates the observed monthly precipitation for the study period with the expected monthly average precipitation. This data was obtained from the SAWS.



**Figure 5-1: Comparison of monthly rainfall over the investigation period with the expected average monthly rainfall**

### 5.1.2 Representativeness of storm events

Representative data is required to provide decision makers with accurate information and supportive tools. A description of the decisions made to scrutinize storm events is given below and the definition of a *storm event* that was used to evaluate the representativeness of the samples is discussed.

Of the twenty events sampled, ninety percent exceeded the criterion of a 72 hour antecedent dry period (ADP) and the remainder were equal to it. The mean rainfall duration for the study period was 3.1 hours with a standard deviation of 1.5 hours. The total precipitation for all but three storm events exceeded the required criterion of 2.54mm. The samples for the three exceptions were not however discarded since sufficient runoff was collected for chemical analysis. One large summer storm event was sampled at the N3 monitoring site on the 21<sup>st</sup> of February 06. A total precipitation of 70mm was measured. The storm has a 5 year return period according to local storm data (Smithers and Schulze, 2003).

Table 5-1 presents the storm event information for the twenty events sampled that were considered suitable for water quality analysis. Precipitation readings are not included if there was insufficient rainfall for runoff or if samples were discarded due to operational problems.

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**Table 5-1: Storm events sampled with total precipitation, duration and ADP**

Storm Event		Total precipitation			Duration	ADP <sup>a</sup>
No.	Date	Booth	N3	Bh	Hours	(days)
1	20-May-05	2.5	2	-	0.8	15.0
2	07-Sep-05	6.5	6.3	-	4.3	5.0
3	27-Sep-05	4.5	2.7	2.5	2.3	11.0
4	06-Oct-05	12	13.8	9.2	1.3	8.0
5	13-Nov-05	7.4	7	2.8	2.5	6.0
6	09-Dec-05	9.5	9.3	15	1.6	7.5
7	16-Dec-05	4.7	3.7	5	4.7	3.7
8	06-Feb-06	30	26	31.5	5.5	3.7
9	16-Feb-06	2.5	1.6	4.5	0.7	3.0
10	21-Feb-06	2.8	70	1.3	4.5	3.7
11	25-Feb-06	19	18.8	29	4.5	3.5
12	02-Mar-06	18	20	22	2.5	3.2
13	12-Mar-06	17.8	17.8	18.4	3.6	7.3
14	16-Mar-06	7	7	-	2.9	3.0
15	23-Apr-06	23	21	24	5.8	5.0
16	18-May-06	11	12	14	2.2	7.3
17	24-May-06	3.5	-	-	4.7	3.3
18	28-May-06	3.5	3.5	-	1.8	4.0
19	23-Jun-06	5	3.5	3.5	2.5	24.0
20	09-Aug-06	14	12	14.5	3.1	6.5

<sup>a</sup> Antecedent dry period

- indicates insufficient rainfall, discarded runoff sample or operational problems

Differences in the ADP observed for some events are not reflected in Table 5-1. For example, storm event No. 10 includes readings from each station although one day separates the readings taken from the N3 and other locations. Rainfall only occurred at Booth and Bayhead road on the evening of the 21<sup>st</sup> February resulting in no sampled runoff at the N3. The rainfall materialised on the following day with the largest precipitation recorded of all the events. This storm event is combined into one to simplify the analysis and discussion.

## 5.2 Field Work

The main objective of the fieldwork was to obtain reliable, representative event mean concentrations. The preparation, installation and collection of equipment were continuously

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modified and improved in the initial phases of the investigation. Considerable effort was made to prevent contamination of equipment and samples. The installation method for collecting runoff samples involved several adaptations in order to minimise maintenance and installation/collection times. Unfortunately the nature of stormwater runoff and the presence of floating debris resulted in equipment failures and the loss of several samples.

### **5.2.1 Pavillion shopping centre**

The Pavillion shopping centre provided a unique study area although it required working inside a 2.5m deep manhole. Safety precautions were followed and a large quantity of time and human resources invested in the location. The Vegason 61 and accompanying batteries were installed with brackets made to prevent moisture contact from surface water infiltrating from above, and from the continuous dry flow.

The sources of dry flow were assumed to be flora irrigation and fountain overflow. Water used for cleaning purposes is supposed to be disposed of into sanitation systems for treatment. However, the dry flow constantly left a form of residue on the bottom of the storm water pipe and on the sampling equipment that would build up over time. Routine maintenance was required to prevent blocking of the sampler orifice, which would affect runoff collection.

Several storm events resulted in failure to collect samples. The sampling equipment was repeatedly washed out of position. This is attributed to debris that managed to enter the pipe system in some way. The dry flow residue could also be attributed to unlawful discharges into the storm water systems or to leaks. Contaminants from such sources may have grossly distorted any data obtained, even if background levels were established from random sample collection.

Therefore, due to the questionable nature of the data obtained from this location, the Pavillion shopping centre was discarded as a study area.

## 5.2.2 Classification of runoff samples

The classification of samples was derived from a checklist used upon collection of the samples. Factors that may have compromised the EMC of a sample were accessed in conjunction with the storm event characteristics and sampled volume. Samples were classified as 'EMC' if (1) the orifice entrance exhibited no form of blockage and an adequate volume had been collected (2) the volume of sample collected indicated that although the orifice entrance may have exhibited some form of blockage, the sampler functioned adequately for a significant proportion of the event. A sample was classified as a 'PEMC' if the volume collected indicated that a blockage might have occurred during the initial stages of discharge. PEMCs were considered as indicators of a first flush and were thus retained for analysis.

**Table 5-2: Classification of runoff samples collected for chemical analysis**

Rainfall Event Date	Booth		N 3	Bayhead
	B <sub>E</sub>	B <sub>W</sub>		Bh
20-May-05	EMC	-	EMC	-
07-Sep-05	EMC	EMC	-	-
27-Sep-05	EMC	PEMC	EMC	EMC
06-Oct-05	EMC	PEMC	EMC	EMC
13-Nov-05	PEMC	PEMC	PEMC	EMC
09-Dec-05	EMC	EMC	EMC	EMC
16-Dec-05	EMC	EMC	PEMC	EMC
06-Feb-06	EMC	EMC	EMC	EMC
16-Feb-06	EMC	EMC	EMC	EMC
21-Feb-06	EMC	EMC	EMC	EMC
25-Feb-06	EMC	EMC	EMC	EMC
02-Mar-06	EMC	EMC	EMC	EMC
12-Mar-06	PEMC	EMC	PEMC	EMC
16-Mar-06	EMC	EMC	EMC	-
23-Apr-06	EMC	-	EMC	EMC
18-May-06	EMC	EMC	PEMC	PEMC
29-May-06	EMC	EMC	-	-
23-Jun-06	PEMC	EMC	PEMC	-
09-Aug-06	PEMC	EMC	PEMC	PEMC

B<sub>E</sub> = Booth east B<sub>W</sub> = Booth west

EMC = Event mean concentration

PEMC = Partial event mean concentration

- = Indicates a discarded sample or no sampled runoff

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### **5.2.3 Composite sampler performance**

The sampler performed well for the duration of the investigation, requiring minimal maintenance. The installation process, once optimised, reduced trip generation and was adaptable to a variety of conduit sizes. The robustness and simplicity of the equipment also reduced chances of damage and theft.

Table 5-2 illustrates that the sampler collected a total of 52 'EMC' and 15 'PEMC' samples with 7 discarded from a total of 77 runoff discharges (3 were excluded as the sites were not operational). As the 15 PEMCs may provide information on possible first flushes, the sampler's performance is thus satisfactory with an 87% return rate of data. The seven discards included installation errors, complete blockages due to debris in the runoff, and high tide interference at Bayhead road.

### **5.2.4 Discharge duration timing device**

The timing device developed to estimate the discharge duration was incorporated into the investigation at a late phase (storm event No. 15). Although laboratory flume calibrations resulted in accurate discharge estimations, the device failed on several field installations. The housing, installation and logistics require improvements to deal with moisture damage and data capture losses. These improvements are minor and if the study period was extended, could have been solved. The SAWS tipping bucket readings that would have been used for comparison provided a reliable back-up. The Vegason 61 water level sensor, which was subsequently removed from the Pavillion shopping centre, could have been utilised to obtain discharge durations and water levels, but was not deployed at other sampling sites due to security concerns.

### **5.2.5 Quality control**

Quality control samples for laboratory distilled water and sampling equipment were analysed as discussed in Section 4.5.4. The results shown in Table 5-3 indicate that contamination was minimal to zero. Runoff and atmospheric sampling equipment values indicate no addition of pollutant to collected samples, except for lead. The heavy metal raw data was adjusted by the lead and distilled water heavy metal concentrations to account for possible contamination.

**Table 5-3: Quality control blanks for laboratory distilled water and sampling equipment**

Heavy metal	Laboratory distilled water	Sampling equipment	
		Runoff	Atmospheric
Al	0.120	< DL	< DL
Cd	0.005	0.000	< DL
Cr	0.000	< DL	0.000
Cu	0.001	0.000	0.000
Fe	0.002	< DL	< DL
Pb	0.012	0.018	0.017
Mn	0.009	0.000	0.001
Ni	0.001	0.005	< DL
Zn	0.000	0.000	0.001

<DL = concentration below the method detection limit

### 5.3 Weekly and Long Atmospheric Samples

Atmospheric samplers were installed at the end of rainfall events to capture the next build up period. The containers would thus typically remain dry for the entire build up period until the following storm event. If the required ADP was not attained, and runoff occurred, the container was changed with a new one. The intention was to collect only the atmospheric fallout related to each specific runoff event. The procedure was changed in order to obtain several weekly and long-term samples. In these cases, atmospheric samplers were rotated on weekly or longer periods, whether rainfall had occurred or not. The periods ranged from seven to twenty one days, sampling two or more rainfall events (illustrated in Table 5-4 below).

**Table 5-4: Weekly and extended atmospheric build up**

Rainfall Event Date	Atmospheric build up (days)	No of rainfall events
16-Feb-06	8.5	4
24-Feb-06	7.0	4
03-Mar-06	7.0	2
13-Mar-06	10.0	5
03-Apr-06	17.0	4
19-Apr-06	16.3	5
Long <sup>a</sup>	21.0	6

<sup>a</sup> Collected on the 5-Dec-05

## 5.4 Total Culvert Flow Estimation

The procedure for estimating the total culvert discharge flow from the sample volume is described in Chapter 3. A comparison with estimates made using the method of Schueler (1987) was done. Curves relating the total culvert flow to the sample volume were generated for each monitoring site. The duration for each storm was adjusted in order to estimate the culvert discharge duration. These are required in order to generate estimates for specific storm events. Table 5-5 presents the total culvert discharge volumes estimated from both methods for comparison. Comparisons considered reasonable are highlighted.

The comparison indicates that the Pro.4 sample volume estimation method requires further calibration. Although Booth East was the only monitoring site to result in frequent 'good' comparisons, the Spearman's rank correlation for all sites resulted in significance levels greater than 95% (as determined by the t-test). Figure 5-2 presents scatter plots for the flow estimates from the Pro.4 and Schueler (1987) methods.

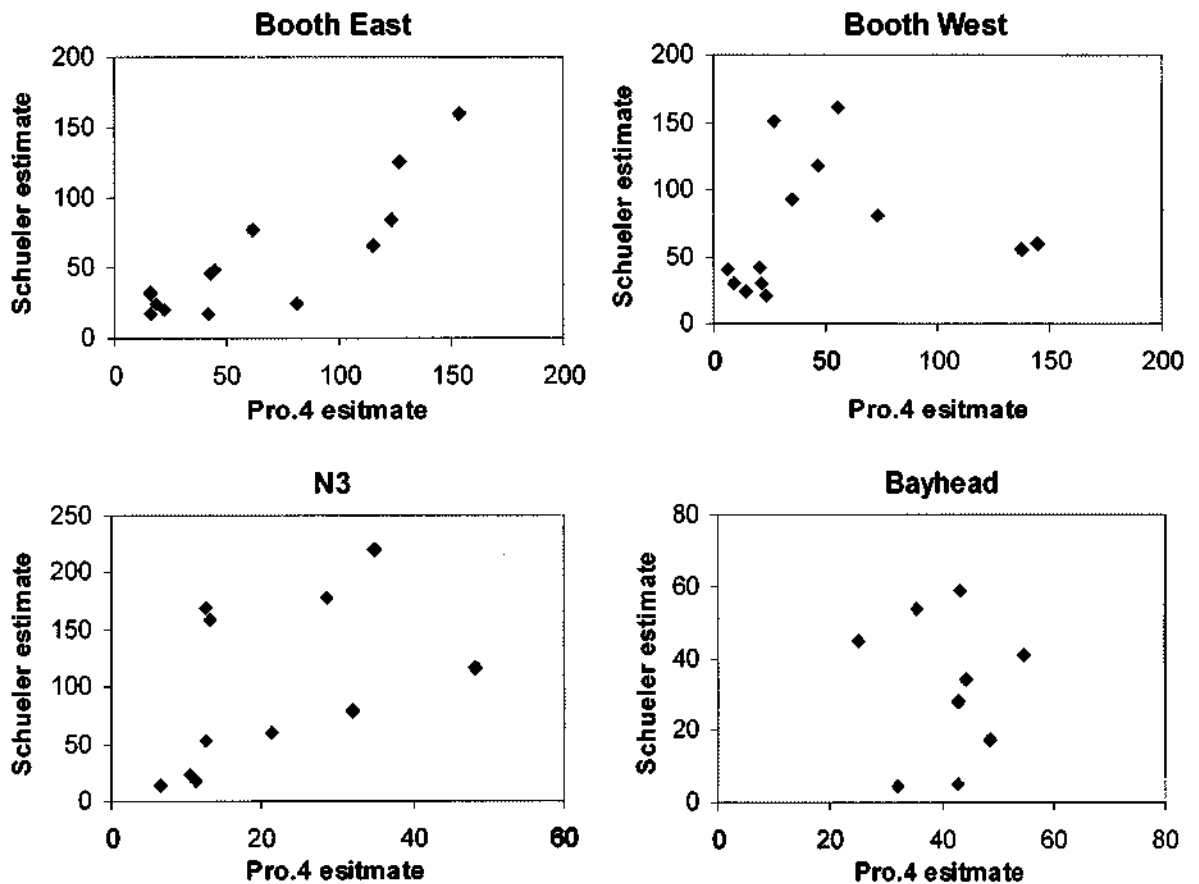
**Table 5-5: Comparison of total culvert discharge estimations**

Rainfall Date	Booth East		Booth West		N3		Bayhead	
	Schueler <sup>a</sup>	Pro.4 <sup>b</sup>	Schueler <sup>a</sup>	Pro.4 <sup>b</sup>	Schueler <sup>a</sup>	Pro.4 <sup>b</sup>	Schueler <sup>a</sup>	Pro.4 <sup>b</sup>
20-May-05	17.5	42.1	-	-	16.9	11.3	-	-
07-Sep-05	45.4	43.0	55.0	137.7	53.3	12.6	-	-
27-Sep-05	31.4	15.7	-	-	22.8	10.6	4.7	32.0
06-Oct-05	83.8	123.4	-	-	116.7	48.2	17.1	48.6
13-Nov-05	-	-	-	-	-	-	5.2	42.9
09-Dec-05	66.3	115.6	80.3	72.9	78.6	31.9	27.9	42.8
16-Dec-05	32.8	15.7	39.7	6.5	-	-	9.3	339.7
06-Feb-06	-	-	253.7	72.1	219.8	34.9	58.6	43.1
16-Feb-06	17.5	16.1	21.1	23.2	13.5	6.7	8.4	96.1
21-Feb-06	19.6	22.0	23.7	14.2	591.9	101.4	2.4	177.0
25-Feb-06	132.7	-	160.6	55.4	159.0	13.2	54.0	35.4
02-Mar-06	125.7	126.5	-	-	169.1	12.5	41.0	54.7
12-Mar-06	-	-	150.5	27.1	-	-	34.3	44.2
16-Mar-06	48.9	44.9	59.2	144.9	59.2	21.1	-	-
23-Apr-06	160.6	153.8	-	-	177.6	28.6	44.7	25.0
18-May-06	76.8	61.5	93.0	34.5	-	-	-	-
24-May-06	24.4	19.1	29.6	9.3	-	-	-	-
29-May-06	24.4	81.3	29.6	21.5	-	-	-	-
23-Jun-06	-	-	42.3	20.1	-	-	-	-
09-Aug-06	-	-	118.4	46.2	-	-	-	-

<sup>a</sup> Culvert discharge estimated by the method of Schueler (1987)

<sup>b</sup> Total culvert discharge estimated from the Pro.4 sampled volume

There are several possible reasons for inaccuracies in the Pro.4 sample volume method (1) the curves generated for each monitoring site relating the total culvert flow to the sample volume require additional calibration (since they are based on limited data) (2) the lower range of sample volumes are within the lower end of the curves which are less accurate (3) the discharge duration estimates are uncertain. The fact that Booth East is the only monitoring site characterized with a large gradient may also be a factor as the velocities are higher.



**Figure 5-2: Scatter plots comparing the estimates of total culvert discharge flow (units are m<sup>3</sup>)**

The method of Schueler (1987) was selected for estimating the total culvert discharge flow. The method provides a consistent and reliable estimation method compared to the Pro.4 method.

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## CHAPTER 6

### RESULTS AND DISCUSSION

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*Chapter Six presents the results for atmospheric and runoff samples collected for the investigation period of sixteen months (May 2005 to August 2006). Flow weighted event mean concentrations and mean atmospheric deposition concentrations are presented. Individual stormwater runoff EMCs were compared to the South African wastewater discharge limit values for exceedance of concentration level. The relationship between constituent concentrations and factors such as build-up periods, rainfall and study area characteristics are presented using correlation analysis. Estimated total pollutant loadings obtained from a lognormal probabilistic method are presented.*

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#### **6.1 Presentation of Results**

The results tables and figures are summaries of the large quantity of collected data. Several maximum concentration levels in the figures have been truncated, in order to focus on the majority of results since there were extreme variations in some water quality indicators between storm events and study areas. The truncated data may be found in the relevant tables presented in section 6.2 or in Appendix C.

#### **6.2 Event Mean Concentrations**

Event mean concentrations for each study area are presented in Tables 6-2 to 6-7. Chemical analysis for the total heavy metal fraction was done. Estimates of the dissolved fraction were based on proportions reported in several international studies as shown in Table 6-1. The "applied" fraction (dissolved fraction of the total fraction selected) was used, and a conservative value was selected where there are variations.

**Table 6-1: Estimation of a dissolved fraction coefficient  
(units are dissolved fraction of total metals)**

Heavy metal	Sansole <sup>a</sup>	Pitt <sup>b</sup>			Simpson <sup>e</sup>	Driscoll <sup>f</sup>	Dissolved %	
	Highway	General <sup>c</sup>	Overall <sup>d</sup>	Freeway	Urban	Highway	Mean	Applied
<b>Al</b>	0.10							<b>0.1</b>
<b>Cd</b>	0.66	0.43	0.5	0.68	0.77		0.57	<b>0.6</b>
<b>Cr</b>	0.57	0.31	0.30	0.28	0.51		0.36	<b>0.3</b>
<b>Cu</b>	0.52	0.43	0.50	0.31	0.38	0.4-0.75	0.44	<b>0.4</b>
<b>Fe</b>	0.07				0.07			<b>0.07</b>
<b>Mn</b>	0.70				0.37			<b>0.7</b>
<b>Ni</b>	0.59	0.49	0.50	0.44			0.51	<b>0.5</b>
<b>Pb</b>	0.27	0.21	0.18	0.07	0.28	0.1-0.24	0.18	<b>0.1</b>
<b>Zn</b>	0.77	0.46	0.44	0.26	0.26	0.49-0.59	0.48	<b>0.26</b>

<sup>a</sup> Sansole *et al.* (1997)

<sup>b</sup> Pitt *et al.* (2004) National Stormwater quality Database (NSQD)

<sup>c</sup> Average estimated for several road surfaces

<sup>d</sup> Overall average provided by the data base - all data inclusive

<sup>e</sup> Simpson (1986)

<sup>f</sup> Driscoll *et al.* (1990)

Concentration levels that exceed the SA wastewater limit values are indicated with a different colour. Red indicates the exceedance of the general standard (or TWQR in the case of aluminium), and orange the special standards. Different colours were utilised as the values presented in the tables are the original total metal EMCs and not the adjusted dissolved fraction. Nickel and hardness were not compared to the SA wastewater limit values or SA guidelines as there are no limits. For clarification, results obtained for PEMC samples are underlined.

The calculated values for the median, mean and coefficient of variation exclude PEMCs. The PEMC mean, factor of PEMC over EMC and percentage exceedance of the SA wastewater limit values are also presented.

Table 6-2: Event mean concentrations for individual SWR events at the Booth East monitoring site

Storm Event	TSS (mg/l)	COD (mg/l)	BOD (mg/l)	EC ( $\mu$ s/cm)	pH	Hardness (mg/l)	Al (mg/l)	Cd ( $\mu$ g/l)	Cr ( $\mu$ g/l)	Cu ( $\mu$ g/l)	Fe (mg/l)	Mn ( $\mu$ g/l)	Ni ( $\mu$ g/l)	Pb ( $\mu$ g/l)	Zn ( $\mu$ g/l)
20-May-05	68	-	-	-	-	45	1.67	ND <sup>b</sup>	4	29	2.05	49	3	76	9
07-Sep-05	-	-	-	-	-	41	3.40	1	16	56	3.97	182	9	192	153
27-Sep-05	41	-	15	373	7.0	-	1.40	ND	22	173	1.80	83	5	47	75
06-Oct-05	217	112	12	167	7.0	65	7.79	1	27	72	9.82	234	20	254	220
13-Nov-05	504	219	-	224	8.2	152	23.5	11	287	282	37.0	818	113	987	829
09-Dec-05	86	92	3	407	7.2	84	4.73	2	21	44	5.39	127	15	110	113
16-Dec-05	192	188	-	149	6.5	-	22.5	6	92	119	32.4	780	59	457	539
06-Feb-06	109	98	11	237	7.0	76	5.09	2	21	43	5.29	130	18	106	125
16-Feb-06	52	125	17	317	7.4	88	2.81	1	13	41	2.92	55	16	48	57
21-Feb-06	54	108	19	351	7.2	115	2.88	1	15	52	3.21	94	15	70	86
25-Feb-06	64	40	11	577	7.6	129	11.3	1	26	29	7.80	69	18	50	65
02-Mar-06	20	51	8	135	7.6	36	4.34	0.3	17	26	4.03	66	10	62	67
12-Mar-06	300	121	-	335	7.2	108	8.17	2	34	68	10.6	278	23	228	217
16-Mar-06	102	100	8	118	6.6	30	4.31	1	20	47	4.98	118	15	95	121
23-Apr-06	80	59	2	228	7.7	120	11.8	3	41	38	10.4	82	32	47	80
18-May-06	144	110	6	324	7.3	-	24.7	5	82	66	21.6	224	52	117	179
25-May-06	54	119	17	254	7.0	-	3.56	2	36	63	4.66	106	30	83	122
29-May-06	-	46	-	138	5.3	48	1.78	3	24	39	2.27	46	21	48	89
23-Jun-06	98	211	-	294	6.3	154	17.7	7	78	243	24.5	644	67	313	592
09-Aug-06	68	123	17	127	6.3	46	2.56	2	16	64	3.22	86	16	77	134
Median <sup>c</sup>	74	100	11	246	7	70	4	1	21	45	5	100	17	80	101
Mean <sup>c</sup>	92	96	11	270	7	73	7	2	30	58	8	153	21	116	131
COV <sup>a,c</sup>	0.6	0.4	0.5	0.5	0.1	0.5	1.0	0.8	0.8	0.6	1.1	1.2	0.7	0.9	0.9
PEMC Mean	243	169	17	245	7	115	13	5	104	164	19	456	55	401	443
PEMC/EMC	3.3	1.7	1.6	1.0	1.0	1.6	3.0	3.7	4.8	3.6	3.9	4.6	3.3	5.0	4.4
TWQR Exc.%	94	82	85	0	0	-	100	6	6	100	55	35	-	45	15

<sup>a</sup> Coefficient of variation = standard deviation/mean

<sup>b</sup> ND = not detected

<sup>c</sup> Exclude PEMC concentrations

<sup>d</sup> Exceedance percentages of the SA wastewater limit values for general standards (EU limit used for BOD)

Legend: Exceed General Limit (TWQR for Al) Exceed Special Limit Partial EMC

Table 6-3: Event mean concentrations for individual SWR events at the Booth West monitoring site

Storm Event	TSS (mg/l)	COD (mg/l)	BOD (mg/l)	EC ( $\mu\text{s}/\text{cm}$ )	pH	Hardness (mg/l)	Al (mg/l)	Cd ( $\mu\text{g}/\text{l}$ )	Cr ( $\mu\text{g}/\text{l}$ )	Cu ( $\mu\text{g}/\text{l}$ )	Fe (mg/l)	Mn ( $\mu\text{g}/\text{l}$ )	Ni ( $\mu\text{g}/\text{l}$ )	Pb ( $\mu\text{g}/\text{l}$ )	Zn ( $\mu\text{g}/\text{l}$ )
20-May-05	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
07-Sep-05	-	-	-	-	-	84	2.00	ND <sup>b</sup>	41	15	2.02	310	3	93	257
27-Sep-05	-	-	-	-	-	43	4.58	-	-	-	-	-	-	-	-
06-Oct-05	123	121	27	299	7.3	87	9.47	2	26	44	11.3	218	19	98	157
13-Nov-05	508	221	-	343	6.4	313	18.2	10	65	255	14.4	463	53	278	553
09-Dec-05	406	137	3	307	7.2	84	16.0	4	44	54	20.6	381	36	149	290
16-Dec-05	684	226	-	232	7.1	119	36.4	7	85	88	50.0	801	60	254	502
06-Feb-06	530	145	14	167	7.0	90	26.1	4	58	60	29.3	482	40	123	238
16-Feb-06	112	119	17	518	7.2	127	7.62	1	17	29	7.59	199	13	40	119
21-Feb-06	410	125	19	498	7.0	228	18.6	3	40	55	20.3	591	31	93	365
25-Feb-06	120	70	12	610	7.7	173	11.5	1	23	31	11.1	143	17	37	88
02-Mar-06	304	110	8	163	7.9	105	18.0	2	36	38	19.1	323	24	78	173
12-Mar-06	314	113	-	393	7.2	121	13.3	2	29	40	17.1	288	21	64	171
16-Mar-06	290	126	10	187	6.9	84	13.7	0.3	32	40	14.6	305	24	70	159
23-Apr-06	834	301	14	100	7.6	96	25.5	6	78	90	33.7	621	54	139	344
18-May-06	588	185	10	335	6.9	180	22.2	6	79	76	27.4	641	63	81	297
25-May-06	-	113	12	405	7.4	135	0.36	1	16	23	0.44	68	16	9	19
29-May-06	100	80	-	316	6.3	81	3.26	7	28	40	4.33	220	27	30	133
23-Jun-06	124	108	-	241	6.4	137	18.0	2	14	28	1.70	548	12	68	91
09-Aug-06	242	170	13	172	6.5	72	7.71	1	28	59	9.66	230	26	43	225
Median <sup>c</sup>	309	125	12	307	7	105	14	2	34	40	16	317	25	74	199
Mean <sup>c</sup>	361	142	12	310	7	115	14	3	40	48	17	384	29	85	217
COV <sup>a,c</sup>	0.6	0.4	0.3	0.5	0.1	0.4	0.7	0.7	0.6	0.5	0.8	0.5	0.6	0.7	0.6
PEMC Mean	316	171	27	321	7	147	11	6	46	149	13	340	36	188	355
PEMC/EMC	1.0	1.4	2.2	1.0	1.0	1.4	0.8	2.6	1.3	3.7	0.8	1.1	1.4	2.6	1.8
NWA Exc.% <sup>d</sup>	100	100	92	0	0	-	100	6	-	100	78	94	-	33	11

<sup>a</sup> Coefficient of variation = standard deviation/mean

<sup>b</sup> ND = not detected

Legend: Exceed General Limit (TWQR for Al) Exceed Special Limit Partial EMC

<sup>c</sup> Exclude PEMC concentrations

<sup>d</sup> Exceedance percentages of the SA wastewater limit values for general standards (EU limit used for BOD)

Table 6-4: Event mean concentrations for individual SWR events at the National 3 highway monitoring site

Storm Event	TSS (mg/l)	COD (mg/l)	BOD (mg/l)	EC ( $\mu\text{s}/\text{cm}$ )	pH	Hardness (mg/l)	Al (mg/l)	Cd ( $\mu\text{g}/\text{l}$ )	Cr ( $\mu\text{g}/\text{l}$ )	Cu ( $\mu\text{g}/\text{l}$ )	Fe (mg/l)	Mn ( $\mu\text{g}/\text{l}$ )	Ni ( $\mu\text{g}/\text{l}$ )	Pb ( $\mu\text{g}/\text{l}$ )	Zn ( $\mu\text{g}/\text{l}$ )
20-May-05	60	-	-	-	-	33	1.02	13	4	64	1.47	138	5	356	254
07-Sep-05	-	-	-	-	-	99	14.1	2	40	18	17.5	320	28	178	239
27-Sep-05	92	-	-	1008	6.8	264	3.60	3	15	178	3.57	1082	47	295	1561
06-Oct-05	57	212	85	551	7.5	96	1.75	2	12	119	2.36	354	18	328	807
13-Nov-05	76	101	31	145	7.6	130	4.25	5	48	164	12.1	363	29	1988	755
09-Dec-05	202	198	7	280	7.3	-	5.25	3	29	99	7.08	226	25	618	449
16-Dec-05	168	350	-	254	7.7	99	12.2	8	118	268	29.9	664	66	3018	1361
06-Feb-06	203	183	-	229	7.0	80	6.31	2	30	98	6.58	228	27	393	496
16-Feb-06	294	327	35	368	7.1	144	8.01	3	62	135	10.9	347	44	519	404
21-Feb-06	138	102	43	136	7.2	-	-	-	-	51	5.75	136	-	286	213
25-Feb-06	196	68	19	107	7.8	69	8.09	1	43	40	6.83	133	16	229	149
02-Mar-06	154	154	16	300	7.9	99	5.13	1	34	85	5.71	216	21	330	330
12-Mar-06	236	270	8	554	6.9	288	8.85	3	55	205	10.2	519	47	549	494
16-Mar-06	118	221	-	265	6.6	75	3.44	1	22	95	3.75	179	19	262	324
23-Apr-06	1088	200	40	134	7.7	216	24.4	5	180	70	25.7	262	41	412	229
18-May-06	1056	385	17	294	7.1	325	30.3	7	173	178	32.7	635	73	892	658
25-May-06	-	-	37	-	-	-	-	-	-	-	-	-	-	-	-
29-May-06	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
23-Jun-06	372	319	-	456	6.5	197	17.7	3	92	187	16.1	487	58	302	492
09-Aug-06	196	370	58	736	7.1	144	3.94	2	42	188	4.42	399	46	281	587
Median <sup>c</sup>	154	198	35	273	7	97	5	2	30	90	6	227	25	329	327
Mean <sup>c</sup>	237	185	35	338	7	118	7	3	43	88	8	302	26	350	455
COV <sup>a,c</sup>	1.2	0.4	0.7	0.8	0.1	0.6	0.9	1.1	1.1	0.5	0.9	0.9	0.5	0.4	0.9
PEMC Mean	351	299	28	406	7	197	13	4	88	198	18	511	53	1172	724
PEMC/EMC	2.3	1.5	0.8	1.5	1.0	2.0	2.5	3.0	3.0	2.2	2.8	2.2	2.2	3.6	2.2
TWQR Exc.%	100	93	100	0	0	-	100	6	12	94	100	100	-	100	64

<sup>a</sup> Coefficient of variation = standard deviation/mean

<sup>b</sup> ND = not detected

<sup>c</sup> Exclude PEMC concentrations

<sup>d</sup> Exceedance percentages of the SA wastewater limit values for general standards (EU limit used for BOD)

Legend: Exceed General Limit (TWQR for Al) Exceed Special Limit Partial EMC

**Table 6-5: Event mean concentrations for individual SWR events at the Bayhead road monitoring site**

Storm Event	TSS (mg/l)	COD (mg/l)	BOD (mg/l)	EC (ms/cm)	pH	Hardness (mg/l)	Al (mg/l)	Cd (µg/l)	Cr (µg/l)	Cu (µg/l)	Fe (mg/l)	Mn (µg/l)	Ni (µg/l)	Pb (µg/l)	Zn (µg/l)
20-May-05	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
07-Sep-05	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
27-Sep-05	35	-	9	46	6.3	96	1.46	ND <sup>b</sup>	6	56	2.27	151	8	96	117
06-Oct-05	725	-	-	49	7.7	-	4.20	2	36	170	4.14	87	9	37	89
13-Nov-05	192	-	2	36	8.0	4255	0.73	1	33	164	1.29	51	12	31	56
09-Dec-05	224	276	3	20	7.0	2060	2.31	1	32	112	4.73	202	20	43	177
16-Dec-05	388	343	-	39	7.3	-	2.59	2	29	125	4.02	133	14	83	95
06-Feb-06	145	202	15	14	6.7	1442	2.34	1	28	95	4.08	238	20	47	155
16-Feb-06	170	339	10	50	7.5	-	0.61	1	17	85	0.80	20	7	11	21
21-Feb-06	142	338	15	33	7.3	3606	0.38	ND	18	84	0.42	24	5	8	18
25-Feb-06	30	109	9	11	7.4	1154	1.38	1	17	73	1.54	66	13	20	35
02-Mar-06	488	560	28	37	7.3	4115	1.18	ND	20	92	1.60	57	5	19	52
12-Mar-06	116	740	-	25	7.0	2673	1.02	1	18	84	1.20	65	9	17	40
16-Mar-06	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
23-Apr-06	166	-	21	0.1	6.9	75	4.42	2	44	110	8.23	474	38	61	328
18-May-06	446	313	32	18	8.0	-	-	ND	ND	75	ND	ND	ND	ND	-
25-May-06	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
29-May-06	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
23-Jun-06	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
09-Aug-06	100	586	8	30	7.3	5327	0.97	1	28	111	0.88	38	12	5	34
Median <sup>c</sup>	168	338	10	35	7	2060	1	1	24	93	2	77	10	34	72
Mean <sup>c</sup>	235	363	12	30	7	2164	2	1	25	104	3	130	13	39	98
COV <sup>a,c</sup>	0.9	0.6	0.7	0.5	0.1	0.7	0.7	0.5	0.4	0.3	0.8	1.0	0.7	0.7	0.9
PEMC Mean	273	450	20	24	8	5327	1	1	28	93	1	38	12	5	34
PEMC/EMC	1.6	1.3	2.0	0.7	1.1	2.6	0.7	0.5	1.1	1.0	0.5	0.5	1.1	0.1	0.5
TWQR Exc.%	100	100	100	-	0	-	100	0	0	100	18	36	-	0	0

<sup>a</sup> Coefficient of variation = standard deviation/mean<sup>b</sup> ND = not detected<sup>c</sup> Exclude PEMC concentrations<sup>d</sup> Exceedance percentages of the SA wastewater limit values for general standards (EU limit used for BOD)

Legend: Exceed General Limit (TWQR for Al) Exceed Special Limit Partial EMC

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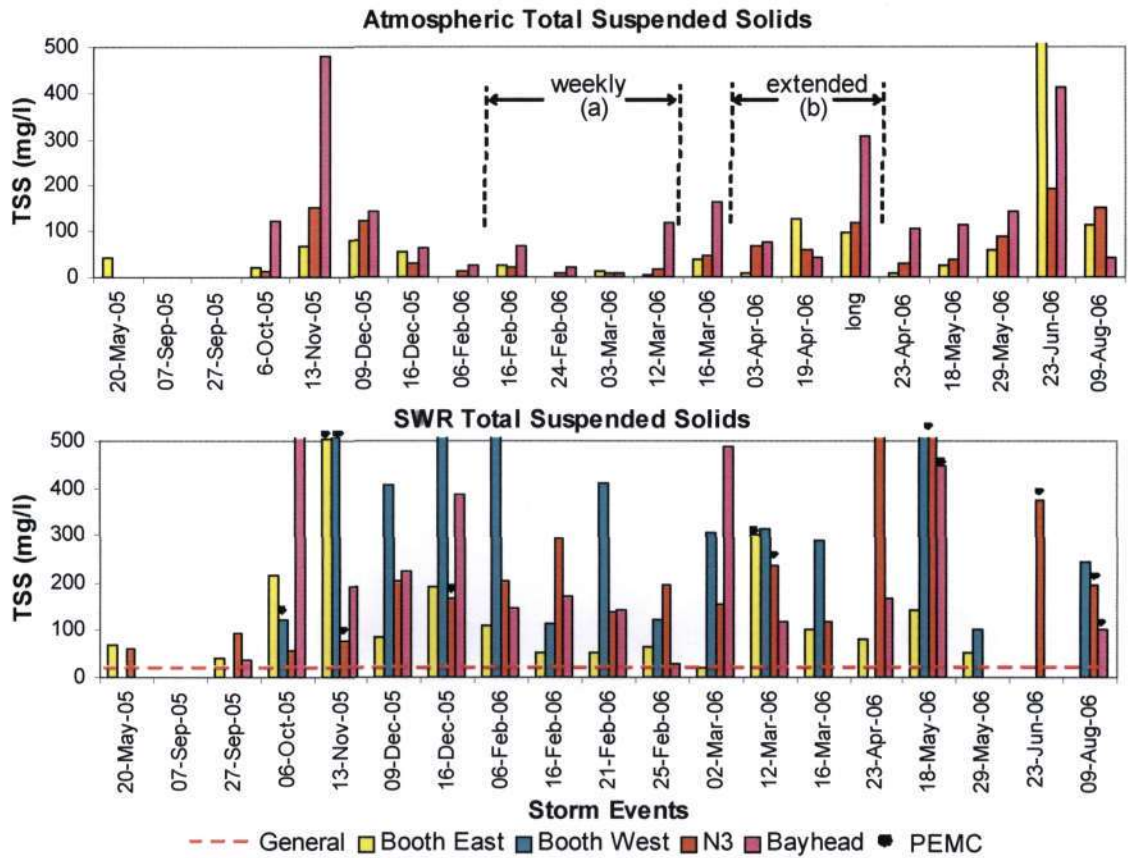
### 6.2.1 SWR EMCs Exceedance levels

The majority of water quality indicators frequently exceeded the SA wastewater limit values. The only exceptions were Cd and Cr with a high percentage of concentrations below the wastewater limit values. Concentrations for TSS, COD, BOD, Al and Cu exceeded the wastewater limit for more than 80% of results. The SA wastewater limit values stipulate that all measured concentrations should be below the specified criteria concentration. The exceedance of the general limits indicates EMCs for stormwater runoff are significantly higher than the special limit for specified locations. Tables for atmospheric bulk deposition are presented in Appendix C.

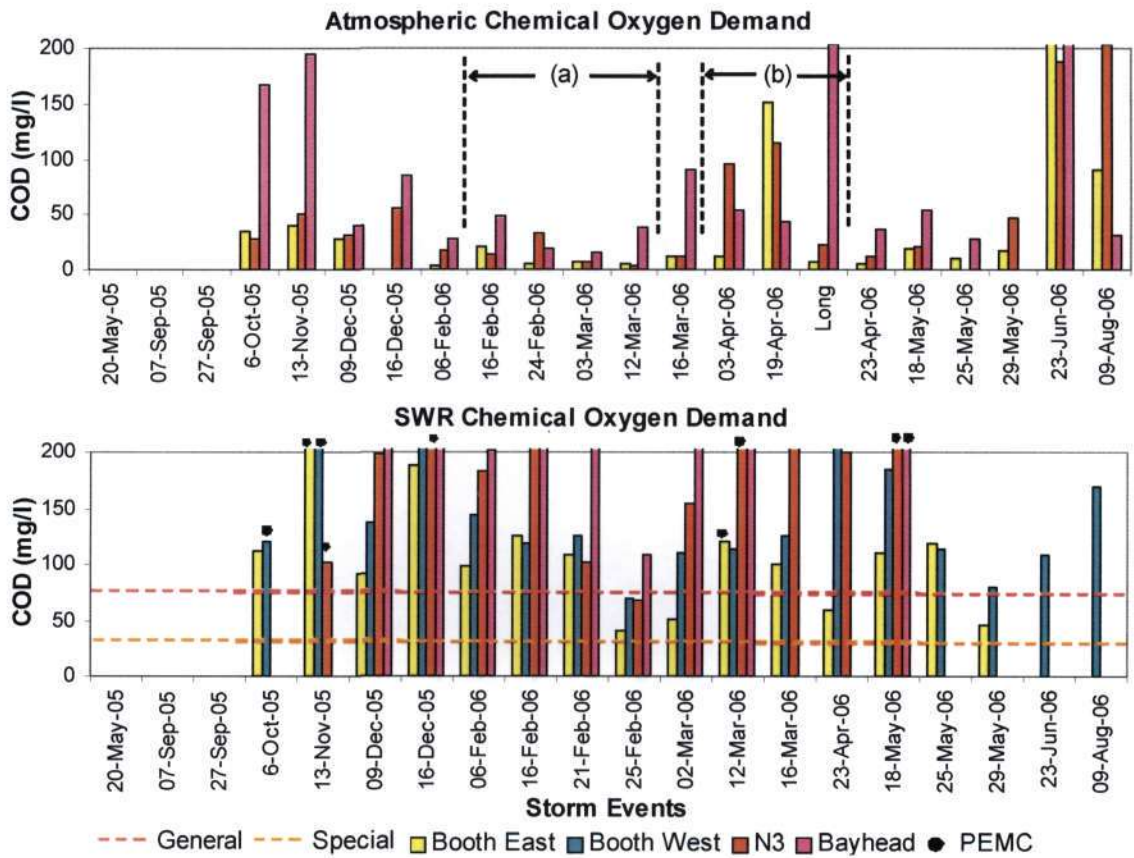
The ratio of the means for PEMCs to EMCs is generally greater than one. This indicates that a first flush phenomenon occurs where elevated concentrations exceeding the EMCs are discharged during the initial phase of runoff. Bayhead road is the only study area that does not clearly exhibit this, and is probably due to insufficient PEMC samples. The PEMC samples collected for Booth East, Booth West and the N3 do however provide a strong indication that a first flush occurs. Consequently, this indicates that the SA wastewater limit values are significantly exceeded during the initial discharge of runoff events.

### 6.2.2 EMC comparisons between study areas

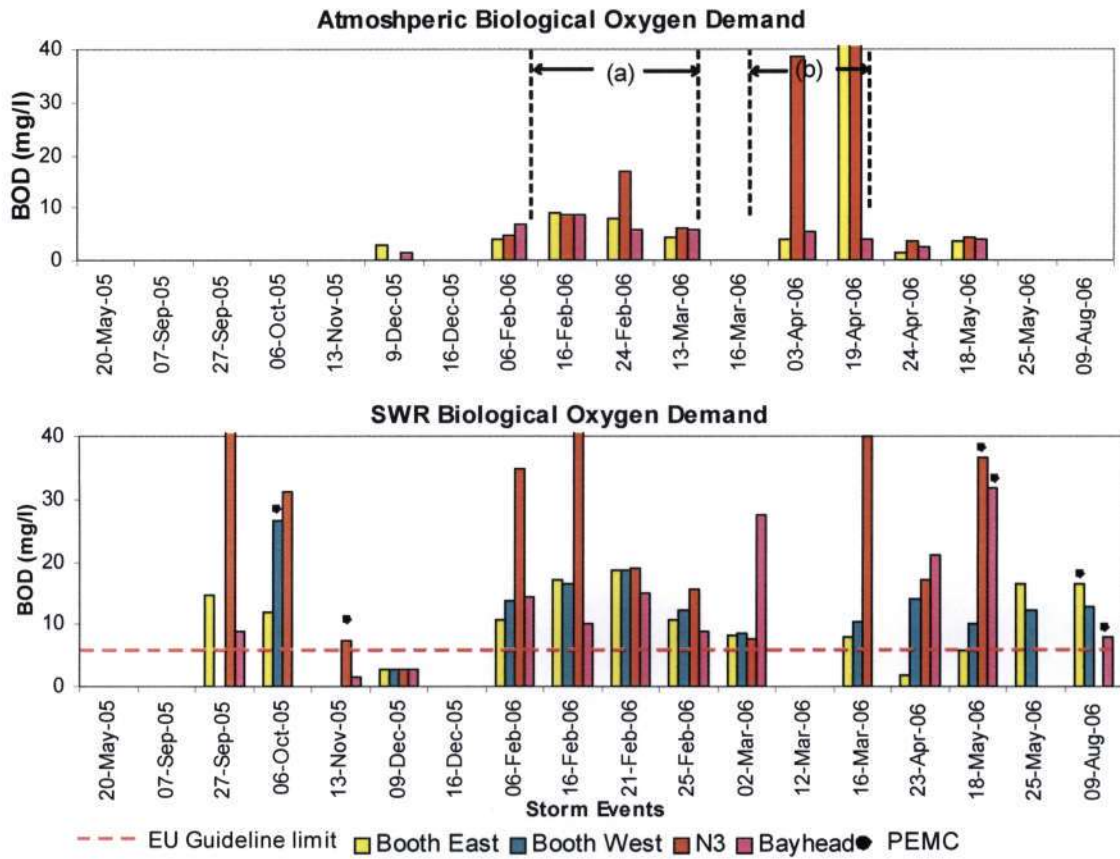
EMC results for all monitoring sites are grouped together for a particular water quality indicator and presented in Figures 6-1 to 6-12. The figures show all EMCs collected for individual storm events and provide a comparison between study areas. Bulk atmospheric deposition samples were assumed to represent the mean fallout concentration of a particular study area and build up period. The weekly and long period samples are labelled, (a) and (b) respectively, in the figures. The SWR results include PEMC values. A long dashed line in the figures indicates the exceedance limit for the relevant water quality guideline.



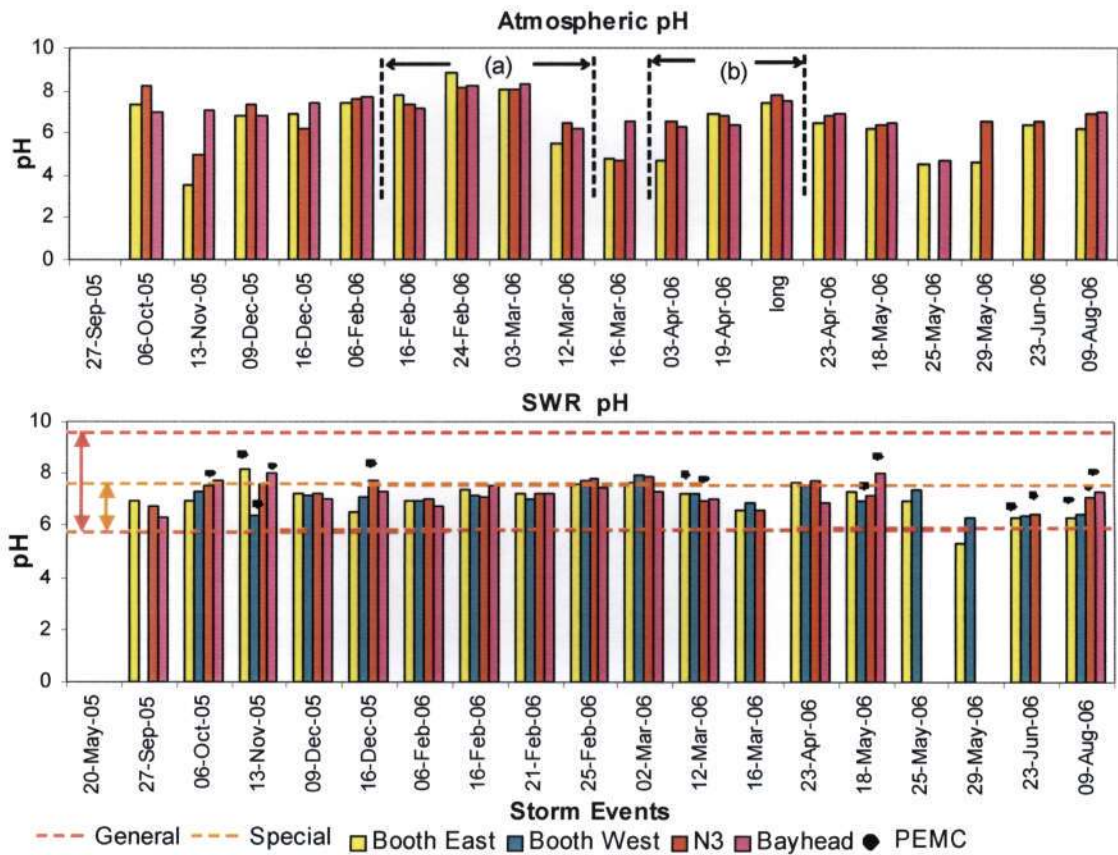
**Figure 6-1: Comparison of Mean Atmospheric and EMCs for TSS**



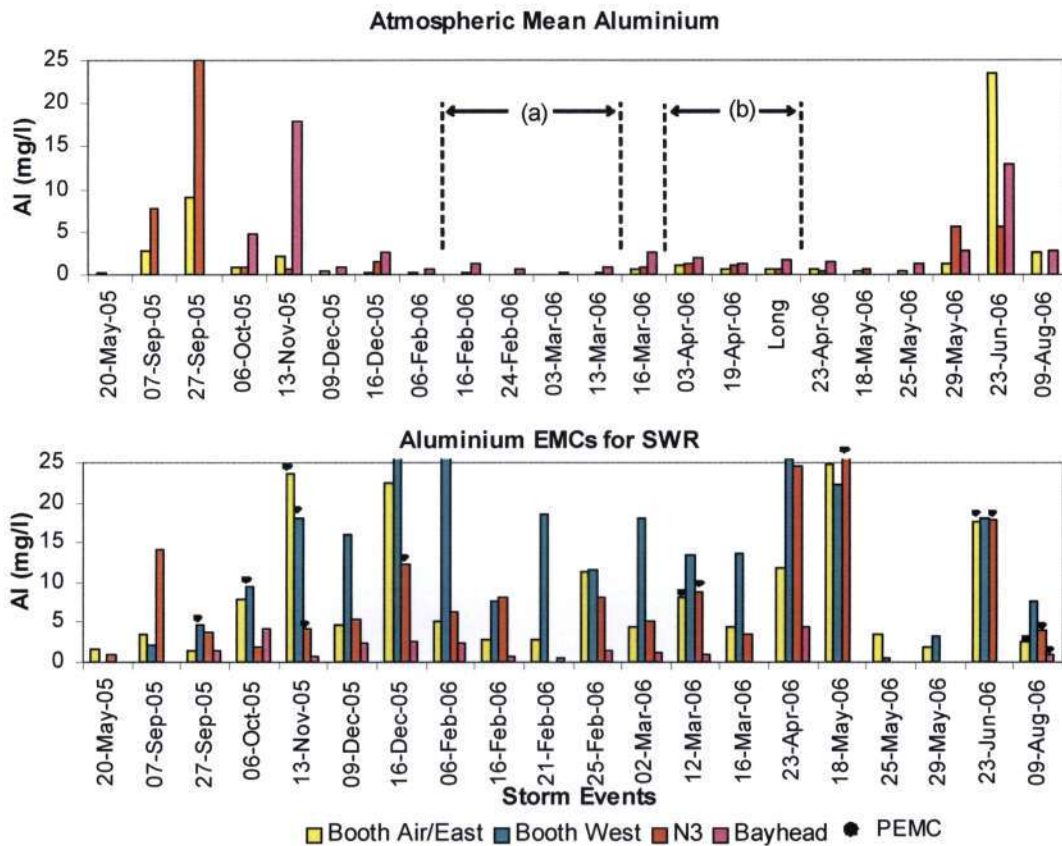
**Figure 6-2: Comparison of Mean Atmospheric and EMCs for COD**



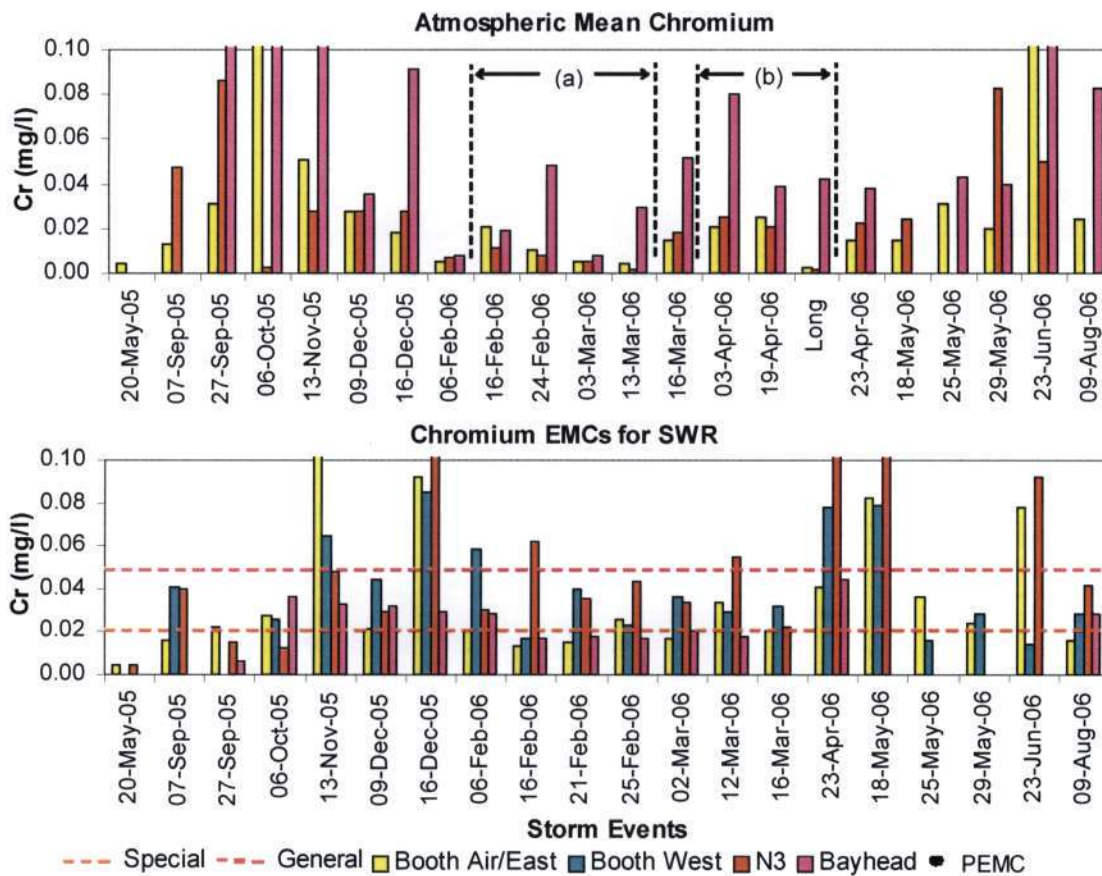
**Figure 6-3: Comparison of Mean Atmospheric and EMCs for BOD**



**Figure 6-4: Comparison of Mean Atmospheric and EMCs for pH**



**Figure 6-5: Comparison of Mean Atmospheric and EMCs for Aluminium**



**Figure 6-6: Comparison of Mean Atmospheric and EMCs for Chromium**

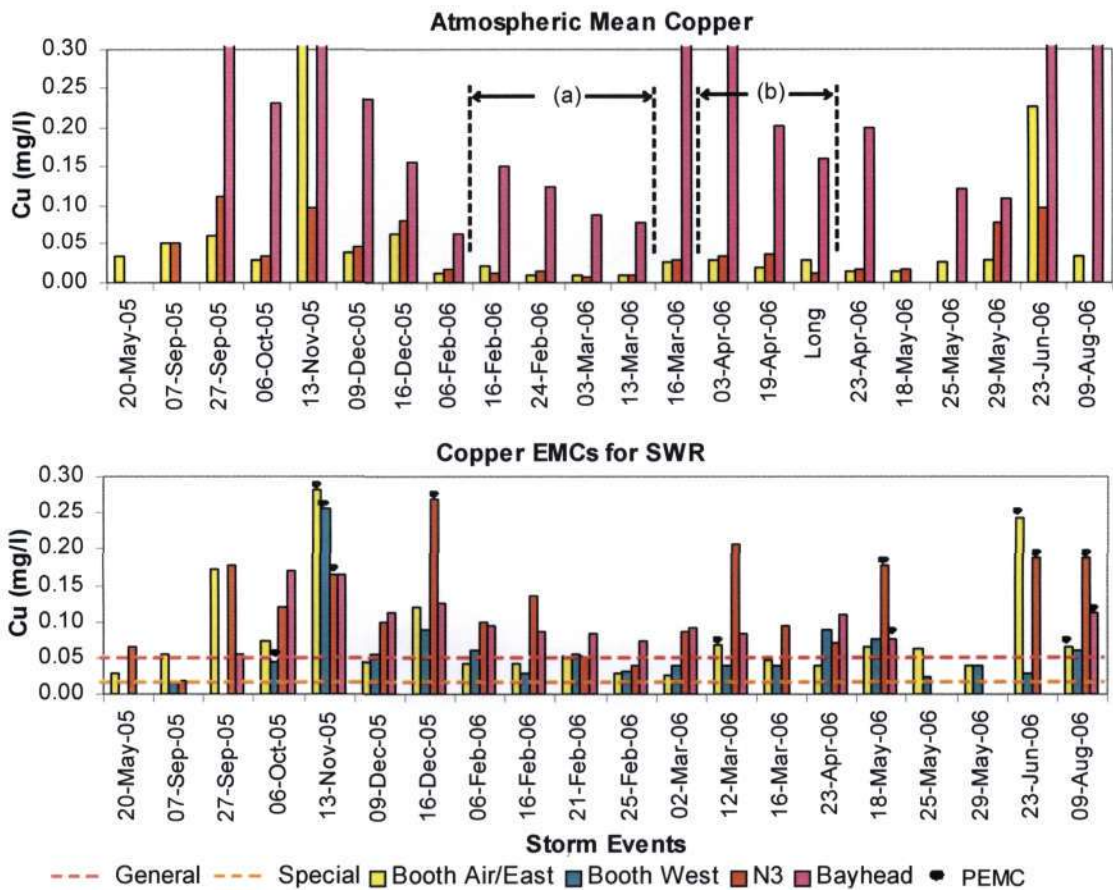


Figure 6-7: Comparison of Mean Atmospheric and EMCs for Copper

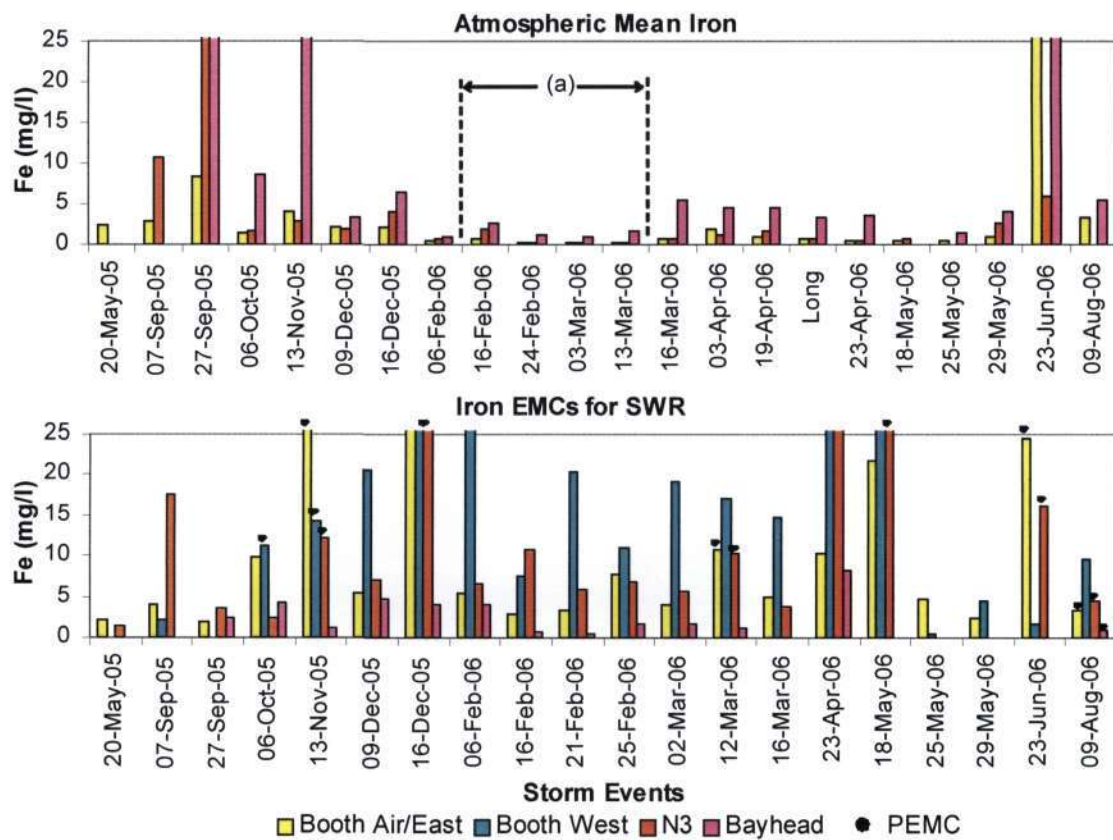


Figure 6-8: Comparison of Mean Atmospheric and EMCs for Iron

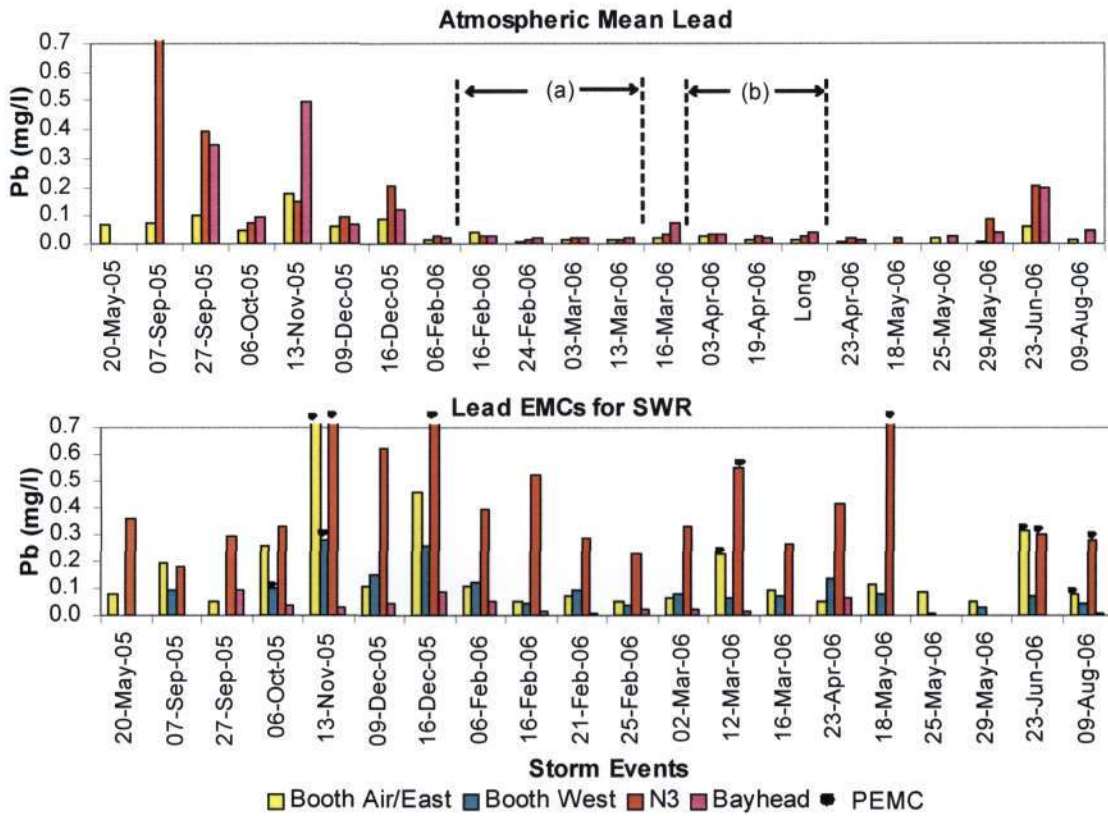


Figure 6-9: Comparison of Mean Atmospheric and EMCs for Lead

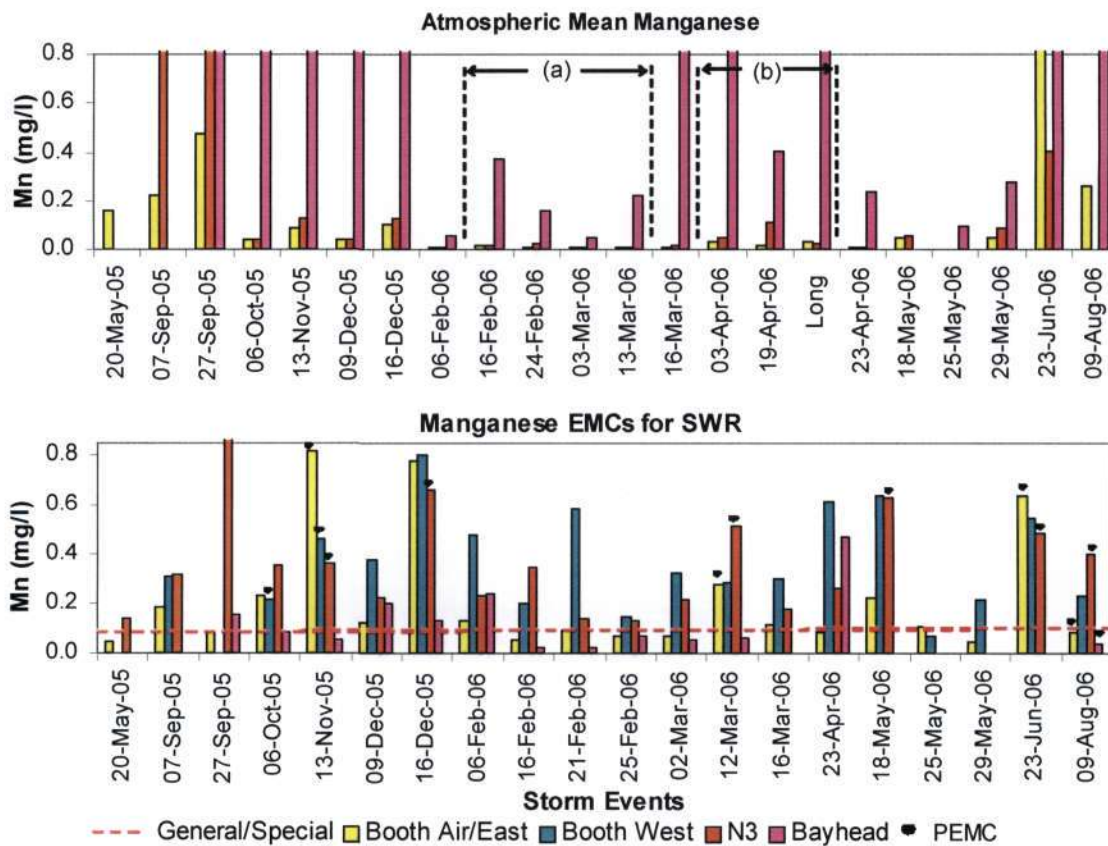


Figure 6-10: Comparison of Mean Atmospheric and EMCs for Manganese

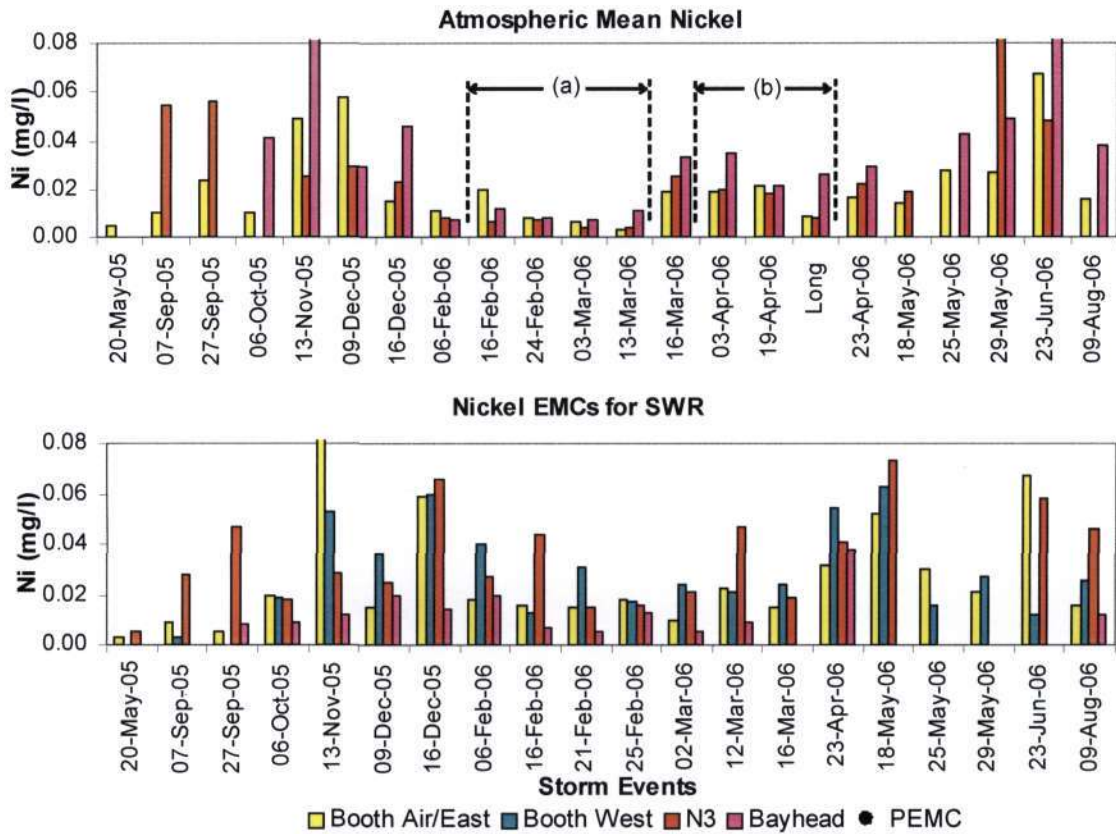


Figure 6-11: Comparison of Mean Atmospheric and EMCs for Nickel

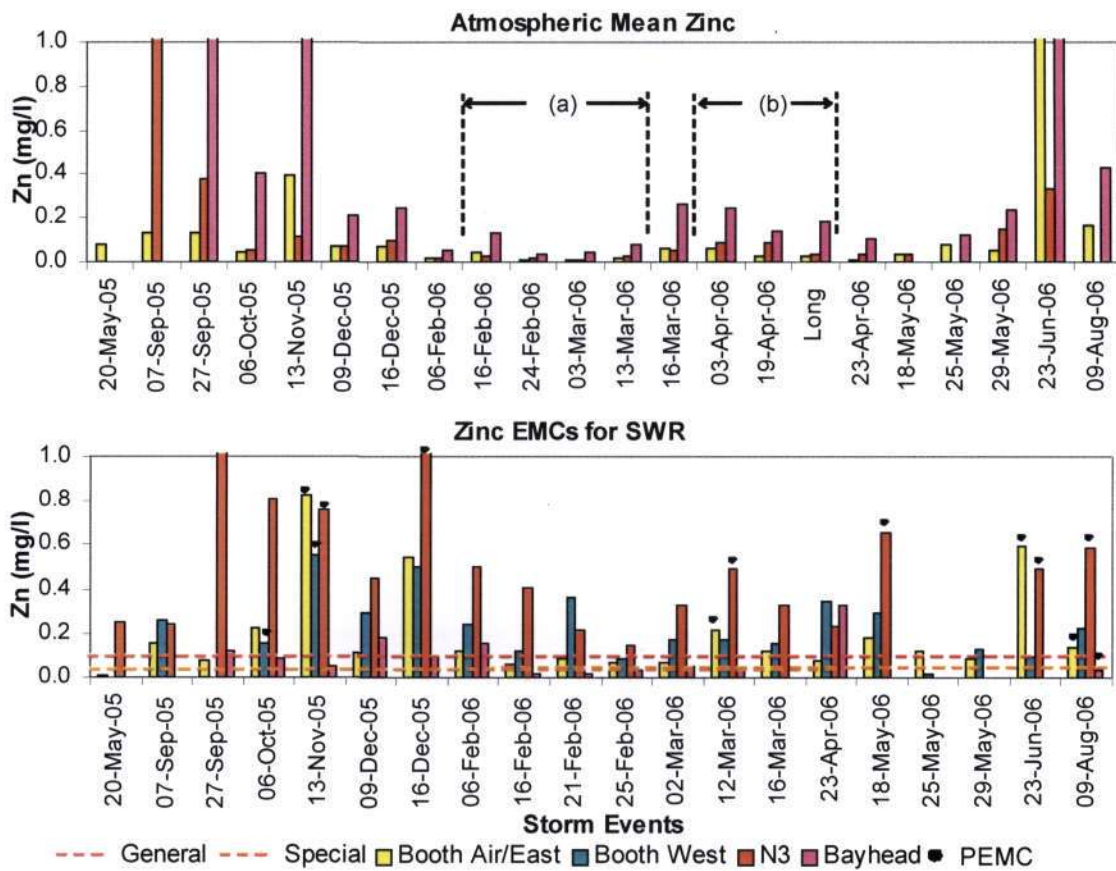


Figure 6-12: Comparison of Mean Atmospheric and EMCs for Zinc

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Comments on the results in Figures 6-2 to 6-12 are as follows:

#### Total Suspended Solids

A large variation exists between individual storm events and study areas. Bayhead road generally produced the highest levels of atmospheric fallout followed by the N3 highway. The weekly and extended periods showed no indication of higher readings than the shorter build-up periods indicating the attainment of saturated/equilibrium levels. Bayhead, Booth West and the N3 generally produced higher levels during storm events. The high Booth West values may be due to developments in the area that result in an increase in sediment deposition onto the road surface.

#### Oxygen Demand Substances

COD concentrations for atmospheric and SWR samples indicate that Bayhead road and the N3 produced the highest concentrations. SWR levels were generally between 50 to 150mg/l with Bayhead frequently exceeding 250mg/l. Salt deposition (from sea water carried by the wind) may have interfered with the Bayhead SWR COD analysis. The concentrations for BOD are comparatively similar between the study areas for both atmospheric and SWR samples except for the N3, which produced slightly higher levels. Samples for SWR frequently exceeded the EU guidelines of 6mg/l recommended for the protection of aquatic life. BOD analysis was limited due to availability of equipment. The extended period of atmospheric samples produced higher concentrations in this case.

#### pH

The majority of pH levels range from approximately neutral to slightly acidic for all atmospheric and SWR samples collected. There is no significant variation for the weekly and extended samples from the overall data. The variation between events is reflected at all collection points, except Booth atmospheric, as results generally changed in unison. Concentration levels from SWR samples indicate that the road surface has a buffering effect on the rainfall pH, resulting in neutral SWR discharges levels.

#### Heavy Metals

Atmospheric heavy metal concentrations for Bayhead generally exceeded those for N3 and Booth. For SWR however, Bayhead road frequently resulted in concentrations lower

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than the other study areas. The N3 and Booth West SWR samples were generally higher than at Booth East, which was in turn higher than Bayhead.

Copper levels, for the entire investigation, were the only concentrations that remained fairly consistent between sites and storm events. The remaining elements generally resulted in large variations between study areas and individual storm events.

Lead comparisons between sites indicate that the N3 consistently produced the highest levels, followed by Booth West.

There are several storm events characterised by elevated concentration peaks for water quality indicators: 27<sup>th</sup> September 05; 13<sup>th</sup> November 05; 16<sup>th</sup> December 05; 23<sup>rd</sup> April 06; 18<sup>th</sup> May 06 and the 23<sup>rd</sup> June 06. These high levels can mostly be attributed to PEMCs as shown in the figures. In other cases the elevated concentrations may be associated with high intensity rainfall, such as occurred on the 16<sup>th</sup> December 05. Above average rainfall intensities were also associated with the 23<sup>rd</sup> of April 06 and 18<sup>th</sup> of May 06 events.

Several of the SWR concentration peaks coincide with elevated concentrations in atmospheric deposition i.e. many of the pollutants in SWR were present in large quantities in the atmospheric deposition. The N3 peak on the 27<sup>th</sup> of September 05 for certain elements may be attributed to high atmospheric deposition levels.

### **6.2.3 Comparison of site median EMCs with global reported values**

Site median EMCs for the investigation were compared with median EMCs reported by the National Stormwater Quality Database (Pitt *et al.*, 2004) and Nationwide program (Driscoll *et al.*, 1990) in the U.S. and two case studies. The data is shown in Table 6-6.

Sites medians for EC, Cd, Pb and Zn were generally the same as reported values. Values for TSS and COD indicate that only Booth East falls within the expected range while Booth West, N3 and Bayhead results were higher. Bayhead results for Al, Fe and Ni are typical, while Booth East, Booth West and N3 exceed reported values.

BOD results are slightly higher than reported values with the exception of the N3, which was significantly higher. Medians for Cu indicate that Booth East and West are within

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range while the N3 and Bayhead exceed reported values. Values for Mn show the N3 and Booth West exceeded expected values.

There is a large variation between the monitoring sites and water quality parameters when compared with previously reported values. The majority of site medians for the N3, Booth West and Bayhead were similar to values reported by Driscoll *et al.* (1990) for urban highways (ADT > 30 000 vehicles/day) with the exception that (1) Al and Fe medians for the N3 and Booth West were significantly higher; (2) Zn site medians for Bayhead were much lower; and (3) COD medians for the N3 and Bayhead were higher.

Site medians for Booth East were not significantly lower than freeways or urban highway values with the exception that (1) medians for Pb and Fe are higher and (2) medians for Zn are lower.

**Table 6-6: Comparison of site median EMCs with several studies  
(results in mg/l unless otherwise stated)**

Parameter	U.S. Data Base <sup>a</sup>				Barrett <sup>b</sup>		Driscoll <sup>c</sup>		Shinya <sup>d</sup>		Booth				N 3		Bayhead	
	Freeways		Mixed Freeways		Urban Road		>30000 ADT <sup>e</sup>	<30000 ADT	Urban Highway		East		West		Highway		Industrial Route	
	Median	COV	Median	COV	Median	COV	Median	Median	Median	COV	Median	COV	Median	COV	Median	COV	Median	COV
<b>TSS</b>	99	2.6	81	1.2	91	0.9	142	41	58	0.4	74	0.6	309	0.6	154	1.2	168	0.9
<b>VSS</b>	-	-	-	-	18	0.7	39	12	-	-	17	1.2	52	0.9	54	1.1	32	1.2
<b>BOD<sub>5</sub></b>	8	1.3	7.4	0.7	5	0.7			-	-	11	0.5	12	0.3	31	0.7	10	0.7
<b>COD</b>	100	1.1	48	0.5	39	0.7	114	49	-	-	100	0.4	125	0.4	191	0.4	338	0.6
<b>pH</b>	7.1	0.1	7.8	0.1	-	-	-	-	-	-	7	0.1	7	0.1	7	0.1	7	0.1
<b>EC (µs/cm)</b>	99	1	418	0.6	-	-	-	-	-	-	246	0.5	307	0.5	273	0.8	34550	0.5
<b>Hardness</b>	34	1.9	83	0.3	-	-	-	-	-	-	76	0.5	112	0.4	99	0.5	2060	0.7
<b>Al</b>	-	-	-	-	-	-	-	-	1.35	0.6	4.32	1.0	14.8	0.6	5.25	0.9	1.42	0.7
<b>Cd</b>	0.001	0.9	0.001	0.7	-	-	.01-.03	.01-.03	-	-	0.001	0.9	0.002	0.8	0.002	1.2	0.001	0.8
<b>Cr</b>	0.008	0.7	0.006	1.1	-	-	-	-	-	-	0.02	0.8	0.03	0.6	0.03	1.1	0.02	0.4
<b>Cu</b>	0.035	1	0.009	1.1	0.007	1.0	0.054	0.022	0.068	0.4	0.05	0.7	0.04	0.5	0.09	0.5	0.09	0.3
<b>Fe</b>	-	-	-	-	1.401	1.1	-	-	2.49	0.5	4.82	1.1	15.9	0.8	6.17	0.9	1.93	0.8
<b>Mn</b>	-	-	-	-	-	-	-	-	0.099	0.5	0.10	0.9	0.32	0.7	0.23	0.4	0.08	0.7
<b>Ni</b>	0.009	0.9	-	-	-	-	-	-	-	-	0.02	1.2	0.02	0.5	0.02	0.9	0.01	1.0
<b>Pb</b>	0.025	1.5	0.010	0.9	0.015	1.4	0.4	0.08	0.031	0.5	0.08	0.7	0.07	0.6	0.33	0.5	0.03	0.7
<b>Zn</b>	0.200	1	0.090	0.9	0.044	1.0	0.329	0.08	0.718	0.6	0.101	0.9	0.199	0.6	0.327	0.9	0.072	0.9

<sup>a</sup> Pitt *et al.* (2004)

<sup>b</sup> Barrett *et al.* (1998)

<sup>c</sup> Driscoll *et al.* (1998)

<sup>d</sup> Shinya *et al.* (2003)

<sup>e</sup> ADT = Average daily traffic

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### 6.3 Pollutant Loadings

The probabilistic method of Marsalek (1990), for estimating annual pollutant loadings, assumes that the EMC pollutant concentrations are log-normally distributed. An indication of the probability distribution of the water quality parameters is given by the kurtosis and skewness values. Table 6-7 presents a summary of the kurtosis and skewness values for SWR constituents. The positive kurtosis values indicate that the distributions are relatively peaked. A Gaussian distributed random variable has a kurtosis value of three. All the skewness values are positive with the majority significantly larger than zero. The positive nature of the skewness indicates a distribution with an asymmetrical tail extending towards larger values. These results indicate that the concentrations are not Gaussian distributed.

**Table 6-7: Kurtosis and skewness values for SWR constituent concentrations**

<b>Parameter</b>	<b>Kurtosis</b>	<b>Skewness</b>
Al	1.22	1.37
Cd	0.86	1.34
Cr	12.31	2.96
Cu	0.40	0.93
Fe	1.29	1.48
Mn	3.37	1.76
Ni	0.55	1.08
Pb	1.85	1.55
Zn	17.69	3.60
TS	2.25	1.44
TVS	2.04	1.39
TSS	5.32	2.11
TSVS	6.32	2.21
COD	7.34	2.42
BOD	7.72	2.42
EC	5.05	1.82

#### 6.3.1 Lognormal distribution test of SWR concentrations

The hypothesis that stormwater concentrations follow a lognormal distribution was tested by fitting a Gaussian curve to the normalised logarithms of concentration values and applying the chi-square goodness-of-fit test. This tests the hypothesis that a sample of data comes from a specified distribution.

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The chi-squared test is based on the computed chi-squared statistic defined as:

$$X^2 = \sum_{I=i}^K (O_i - E_i)^2 / E_i \quad (6-1)$$

with,  $O_i$  = observed frequency for bin  $i$   
 $E_i$  = expected frequency for bin  $i$  =  $N [ F(Y_U) - F(Y_L) ]$   
 $F$  = cumulative distribution function for the distribution being tested  
 $Y_U$  = upper limit for class  $i$   
 $Y_L$  = lower limit for class  $i$   
 $N$  = sample size

The hypothesis that the concentration values are from a specified distribution is rejected if:

$$X^2 > X^2_{(\alpha, k-c)} \quad (6-2)$$

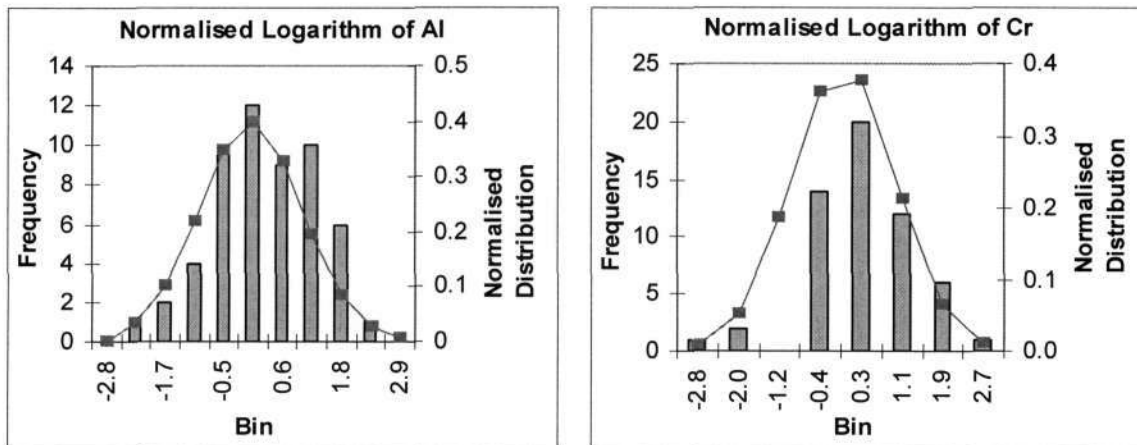
with,  $\alpha$  = significance level  
 $k$  = no of non-empty cells for the binned data  
 $c$  = number of estimated parameters for the distribution + 1

The results of the chi-square tests are shown in Table 6-8. The table indicates whether the stormwater runoff concentrations were lognormally distributed based on a 95% confidence level. Appendix C presents more detailed results of the fitted lognormal distributions and chi-square tests.

**Table 6-8: Lognormal distribution results for SWR based on Chi-squared test at a 95% confidence level**

Parameter	$\chi^2$	$\chi^2_{(0.95)}$	Result
Al	2.96	12.59	Yes
Cd	16.28	12.59	No
Cr	11.74	11.07	No
Cu	3.42	11.07	Yes
Fe	1.82	12.59	Yes
Mn	3.56	11.07	Yes
Ni	14.65	11.07	No
Pb	5.15	12.59	Yes
Zn	8.39	12.59	Yes
TS	2.46	9.49	Yes
TVS	0.70	9.49	Yes
TSS	1.55	11.07	Yes
COD	2.47	9.49	Yes
EC	3.00	9.49	Yes

In general the hypothesis that SWR concentrations may be described by a lognormal distribution was accepted at the 95% confidence level. An example of an accepted and rejected hypothesis is presented in Figure 6-13. The bins containing no data influenced the chi-square test significantly, and if excluded would result in the acceptance of the hypothesis.



**Figure 6-13: The accepted Al and failed Cr lognormal distributions**

We conclude that the assumption that the EMCs are lognormally distributed is valid.

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### 6.3.2 Annual pollutant loadings

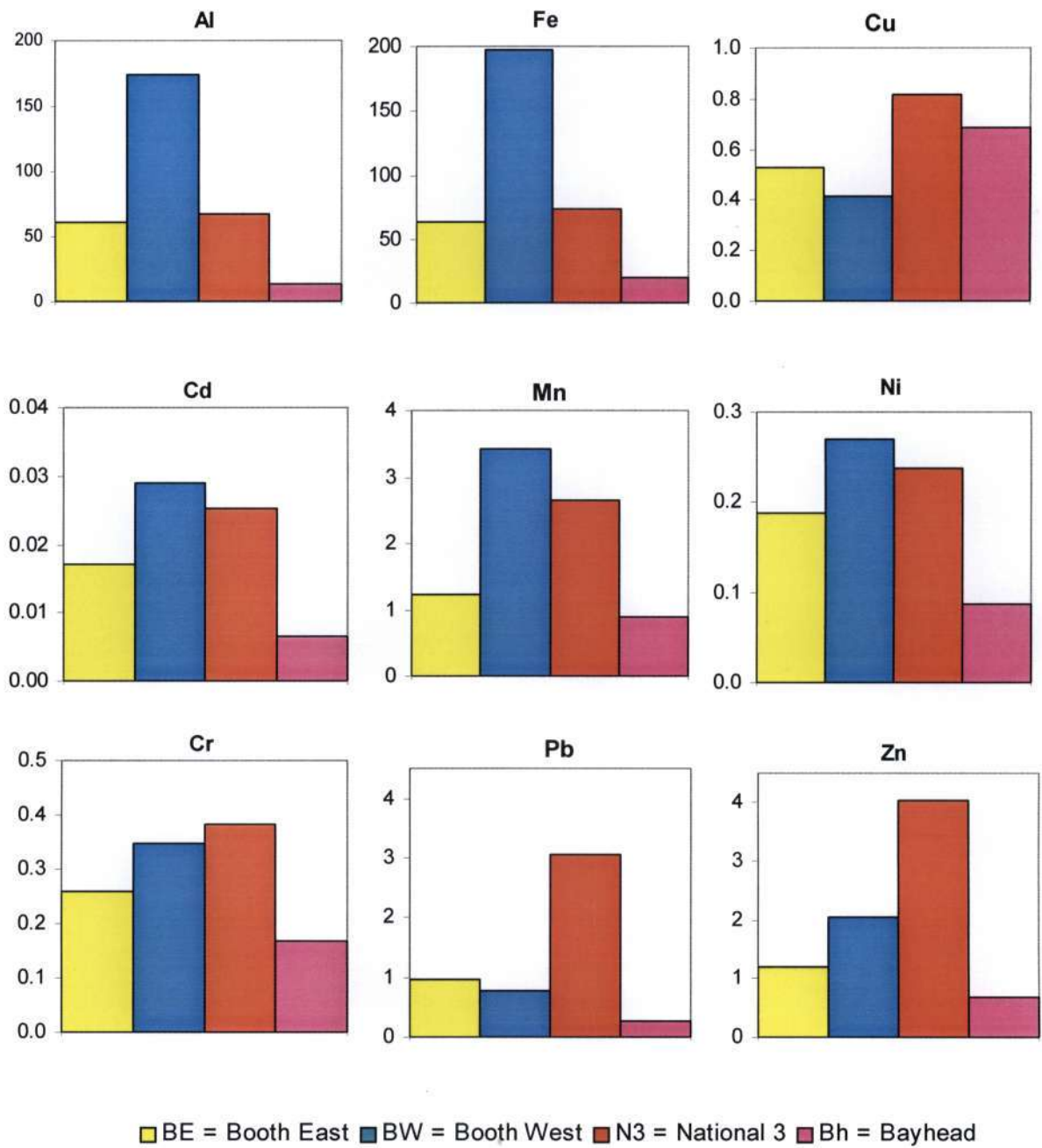
The probabilistic method for estimating annual pollutant loadings is a function of the mean and standard deviation of the log-transformed concentrations, total annual precipitation and catchment characteristics. The mean and standard deviation were estimated from the lognormal cumulative distribution function fitted using the maximum likelihood method that provides 'unbiased' estimates.

A precautionary correction factor (CF) that adjusts for storm events where no runoff occurs, described by Schueler (1987), was incorporated into Marsalek's (1990) probabilistic method. Estimated annual loadings are presented in Table 6-9. A correction factor of 0.9 and total precipitation of 1000mm were used.

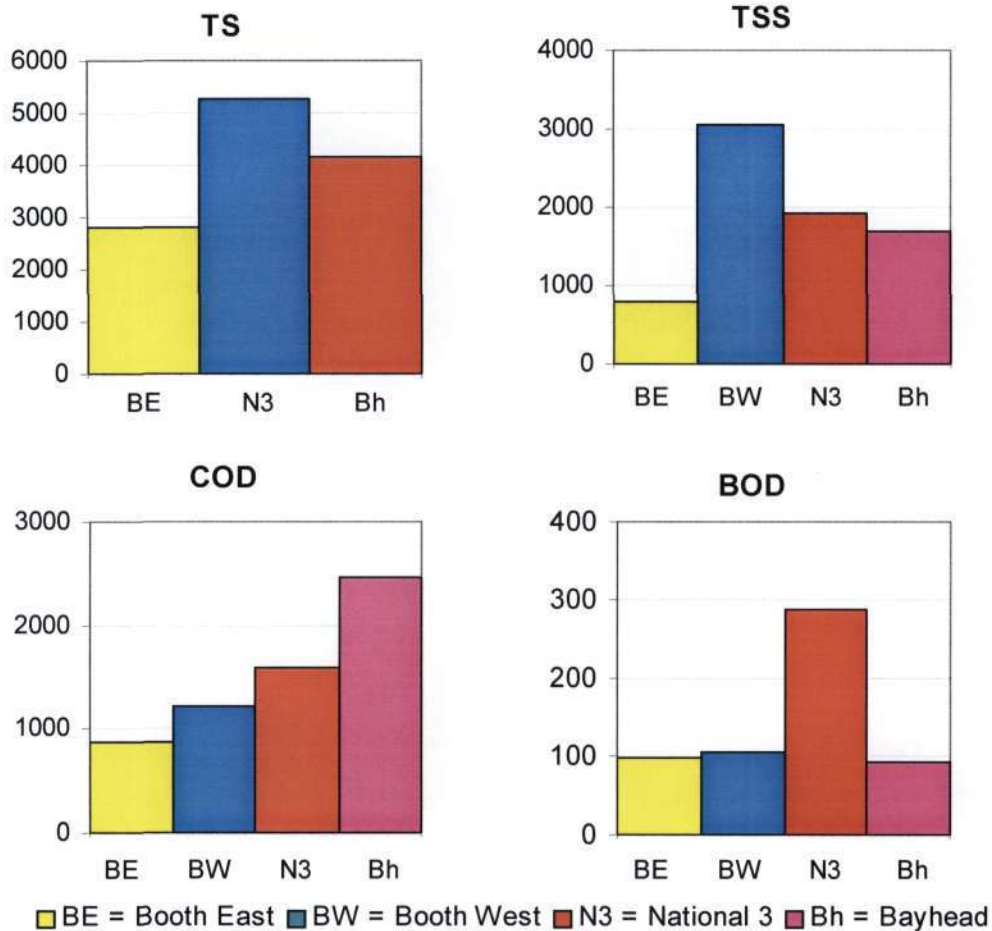
**Table 6-9: Estimated SWR annual pollutant loadings (kg/year)**

Parameter	Booth		N 3	Bayhead
	East	West		
TS	2052	4699	3699	75641
TVS	645	1035	1463	15304
TSS	589	2708	1719	430
TSVS	198	541	662	114
COD	639	1080	1418	629
BOD	72	94	257	24
Al	44.7	155.2	59.4	3.29
Cd	0.013	0.026	0.023	0.002
Cr	0.191	0.310	0.339	0.043
Cu	0.390	0.368	0.729	0.175
Fe	46.7	175.3	65.5	5.10
Pb	0.708	0.696	2.727	0.069
Mn	0.905	3.046	2.357	0.229
Ni	0.139	0.240	0.211	0.022
Zn	0.879	1.811	3.588	0.172

To facilitate a comparison between the four monitoring sites, the annual loadings for each site were normalised by the catchment area (kg/hectare-year). Figures 6-14 and 6-15 present the normalised annual loadings for several water quality indicators. The annual loading rates varied among the four sites although the N3 and Booth West values were the highest for the majority of water quality indicators with Bayhead generally the lowest.



**Figure 6-14: Site comparisons of SWR annual pollutant loadings for heavy metals ( units in kg/hectare-year )**



**Figure 6-15: Site comparisons of SWR annual pollutant loadings for solids and oxygen demanding indicators (kg/hectare-year)**

Annual pollutant loadings are very similar for the Cd, Cr, Cu, Ni, and COD. The most significant differences are generally at Booth West and N3 for Al, Fe, Pb, Zn, TSS and BOD. The COD peak for Bayhead is most likely due to salt deposition interference with the chemical analysis procedures.

Table 6-10 compares the annual normalised pollutant loading rates (kg/ha-year) of this study with those reported in the literature for studies by U.S. and German investigations. Comparisons indicate that only TSS, Cd and Pb (except the N3) are lower or similar to reported values. Oxygen demanding indicators BOD and COD were higher than the U.S. and German data by factors of up to 10 and 5 respectively. Annual loadings for Cr, Cu (except Booth East), Mn (except Bayhead) and Zn are generally 2-5 times higher than the international values while those for Fe (except Bayhead) are 4-12 times higher.

**Table 6-10: Comparison of annual pollutant loadings for storm water runoff <sup>a</sup>**

Parameter	German Highway Study <sup>b</sup>		Barrett <sup>c</sup>	Simpson <sup>d</sup>	Wu <sup>e</sup>	Booth Road		N3	Bayt
	100% paved	86% paved	Urban Road	Urban	Highway	East	West	Highway	Harbor
ADT(veh/day)	41,000	47,000	8,780	-	25,000	16,000	17,500	90,000	17,000
TSS	873	848	977	1224	2678	802	3,043	1,932	1,600
VSS	-	-	126	-	-	269	608	744	440
BOD <sub>5</sub>	-	-	28	-	-	97	106	288	90
COD	672	557	258	475	603	870	1,214	1,593	2,400
Al	-	-	-	-	-	60.8	174	66.8	120
Cd	0.04	0.03	-	0.02	0.03	0.017	0.029	0.025	0.020
Cr	0.06	0.1	-	0.33	0.09	0.260	0.348	0.381	0.100
Cu	0.62	0.54	0.08	0.2	0.28	0.531	0.414	0.819	0.600
Fe	-	-	16	30	-	63.5	197	73.6	200
Mn	-	-	-	0.51	-	1.23	3.42	2.65	0.800
Ni	-	-	-	-	0.09	0.189	0.270	0.237	0.020
Pb	1.33	1.15	0.2	1.3	0.20	0.964	0.782	3.06	0.200
Zn	-	-	0.45	1.9	-	1.2	2.04	4.03	0.600

<sup>a</sup> Units in kg/ha-year

<sup>b</sup> Stotz (1987)

<sup>c</sup> Barrett *et al.* (1998)

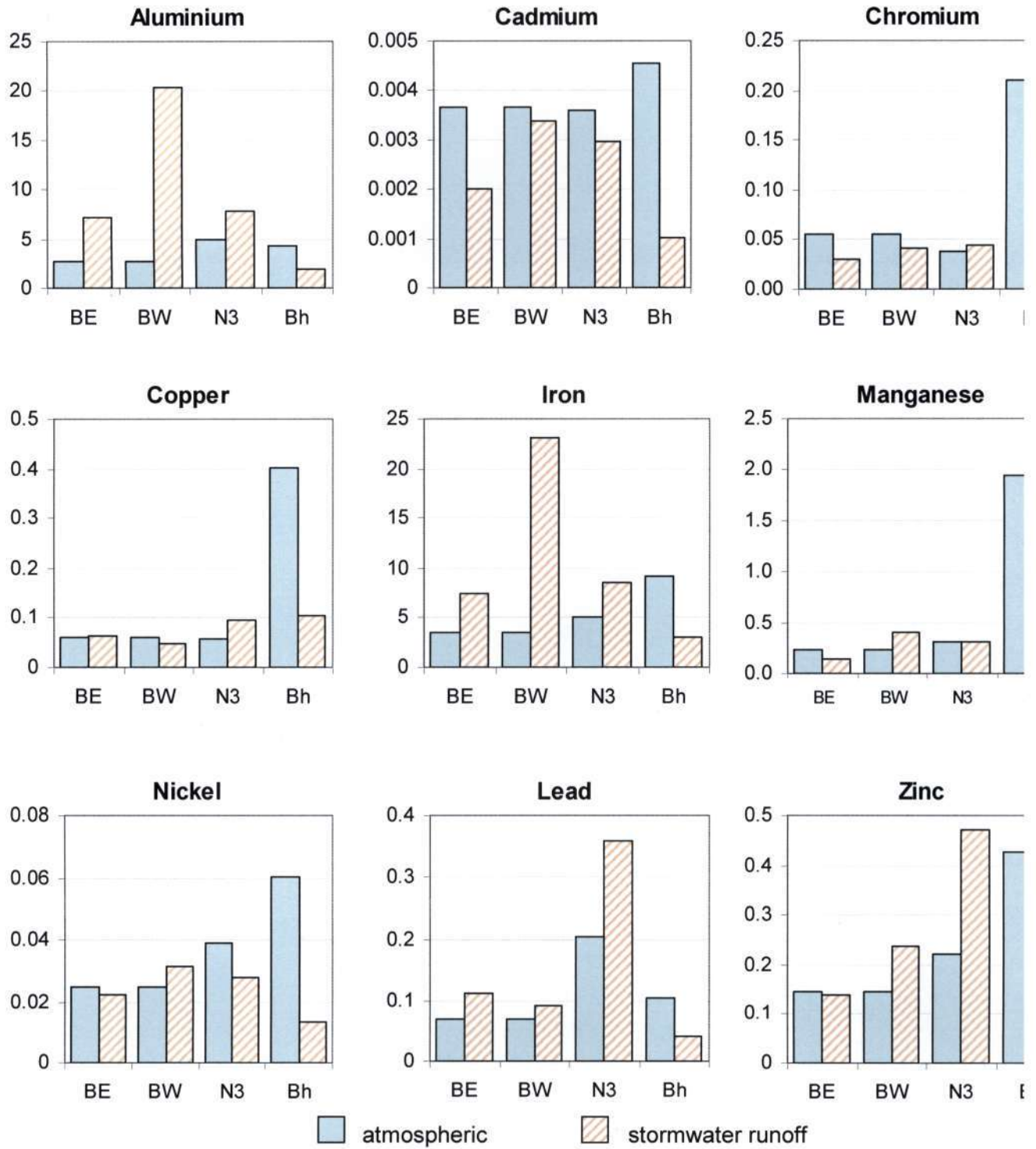
<sup>d</sup> Simpson (1986)

<sup>e</sup> Wu *et al.* (1998)

#### 6.4 Atmospheric Deposition Contribution

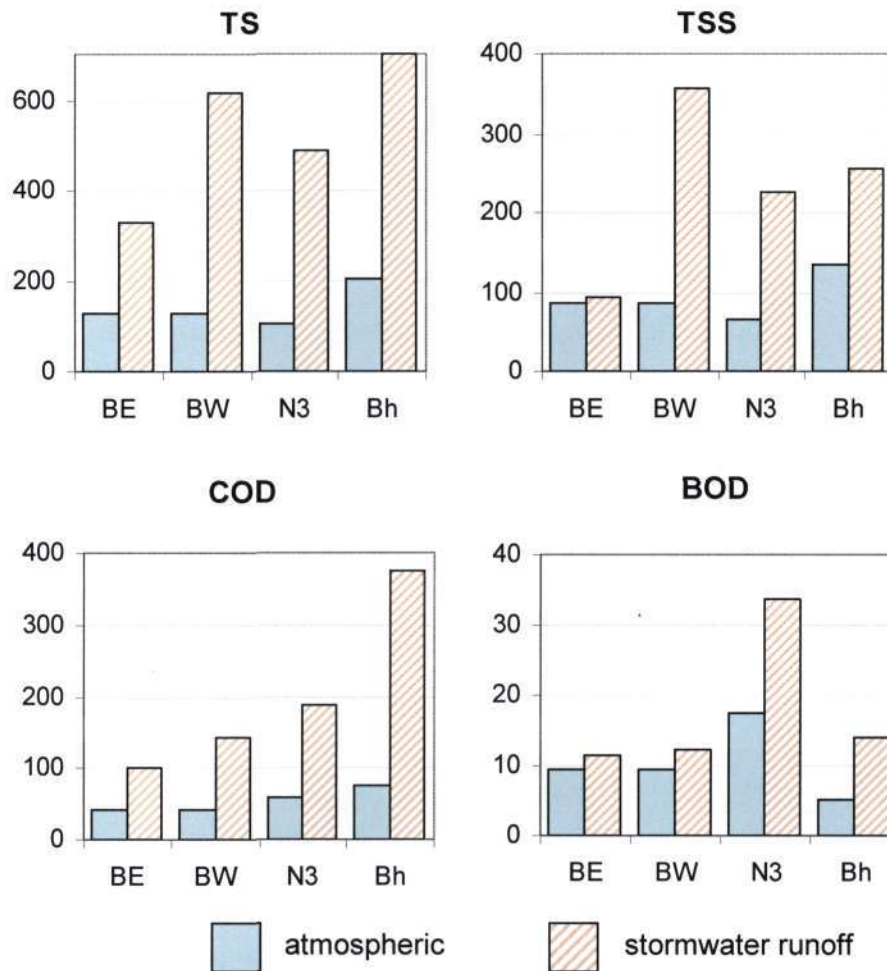
Significant quantities of certain pollutant constituents due to atmospheric deposition are transported in highway runoff. Bulk precipitation samples collecting fallout during both wet and dry periods were obtained for this investigation. The mean concentrations estimated from the logarithms for the atmospheric samples were compared with the measured SWR EMCs. Comparing the mean values is considered more accurate than using respective annual loads as not all rainfall appears as runoff (Simpson, 1986). Figures 6-16 and 6-17 present the site atmospheric and runoff mean values for several water quality indicators.

The atmospheric mean values for Bayhead heavy metals were higher than all runoff mean values. Atmospheric mean values for Cd, Cr and Ni were also frequently higher than runoff concentrations.



BE = Booth West    BE = Booth East    N3 = National Highway    Bh = Bayhead

**Figure 6-16: Comparison of mean SWR and atmospheric contributions for heavy metals (units in mg/l)**



BE = Booth West    BE = Booth East    N3 = National Highway    Bh = Bayhead

**Figure 6-17: Comparison of mean SWR and atmospheric contributions for TS, TSS and COD/BOD (units in mg/l)**

There are several possible reasons for this occurrence: (1) Removal of deposition may occur through street sweeping and local turbulence arising from vehicular motion or regional wind. The atmospheric fallout collector would however trap the deposition. (2) Inadequate road surface cleaning operations can allow sediment to accumulate in the gutters and kerb-inlets. The sediment may act as a simplified filtration system. (3) The atmospheric collection unit placement may have resulted in a form of continual indirect contamination.

The comparison of the mean values indicates that atmospheric deposition is a significant source of pollutants transported in stormwater runoff. An indication of pollutants generated within a study area is given by cases where runoff means exceed atmospheric means.

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## **6.5 Factors Affecting Stormwater Quality**

The variability of stormwater quality between the four monitoring sites is the focus of this section. Precipitation and catchment characteristics are generally regarded as the major influencing factors. Study areas with similar percentages of imperviousness, land use and type of drainage system were selected for this investigation to minimise the influence of these variables. The only catchment characteristics that varied were the surface slopes, and type/number of vehicles using the roads. The influence of build-up periods and total precipitation are now discussed.

### **6.5.1 Antecedent dry weather period**

The antecedent dry weather period (ADP) is generally considered a variable that influences the pollutant levels in stormwater runoff. A study by Ball *et al.* (1996) found that equilibrium was reached after 10 days with the rate of contaminant deposition similar to the removal rate due to air turbulence induced by vehicular and regional atmospheric motion. Figure 6-18 presents the mean atmospheric and runoff EMCs for several contaminants and their associated ADP. The majority of plots indicate that the number of antecedent dry days do not significantly influence the pollutant level. The pollutant concentrations for three to five days are similar to those measured for longer periods. Thus, it would suggest equilibrium is attained within a short time frame.

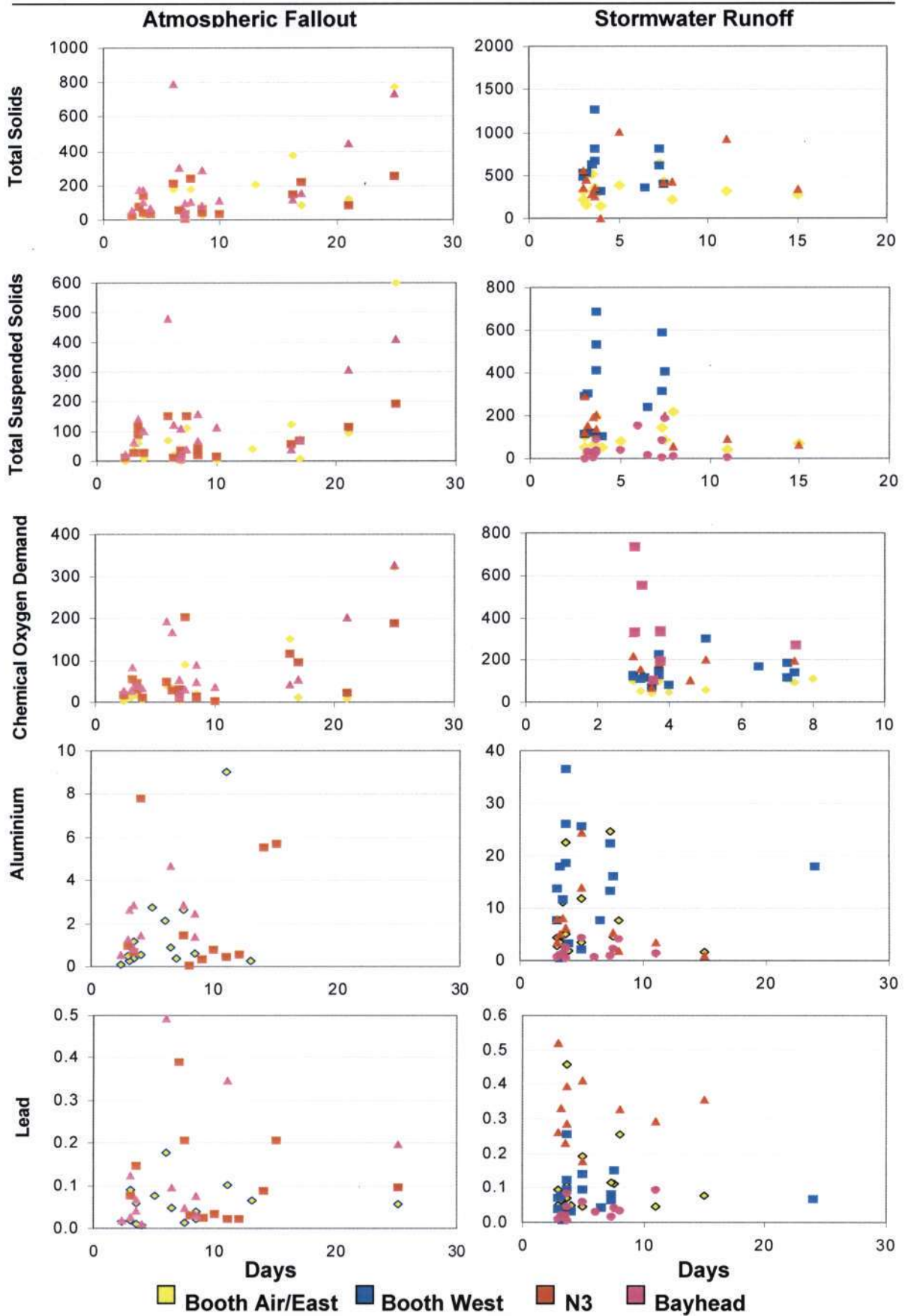


Figure 6-18: Mean atmospheric and EMCs build-up periods (units mg/l)

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### 6.5.2 Precipitation affects on stormwater quality

The relationship between stormwater contaminant levels and total precipitation depth was analyzed using Spearman's rank correlation coefficient method. The correlation of two variables is defined by (Helsel and Hirsh, 2002):

$$\rho = 1 - \frac{6 \sum d_i^2}{n(n^2 - 1)} \quad (6-3)$$

where

$\rho$  = Spearman's correlation coefficient

$d_i$  = difference between the rank of corresponding x and y values

$n$  = number of paired values

The significance of each correlation was determined by calculating a new random variable T defined by (Helsel and Hirsh, 2002):

$$T = \frac{\rho}{\sqrt{(1 - \rho^2)/(n - 2)}} \quad (6-4)$$

where

$n$  = the sample size

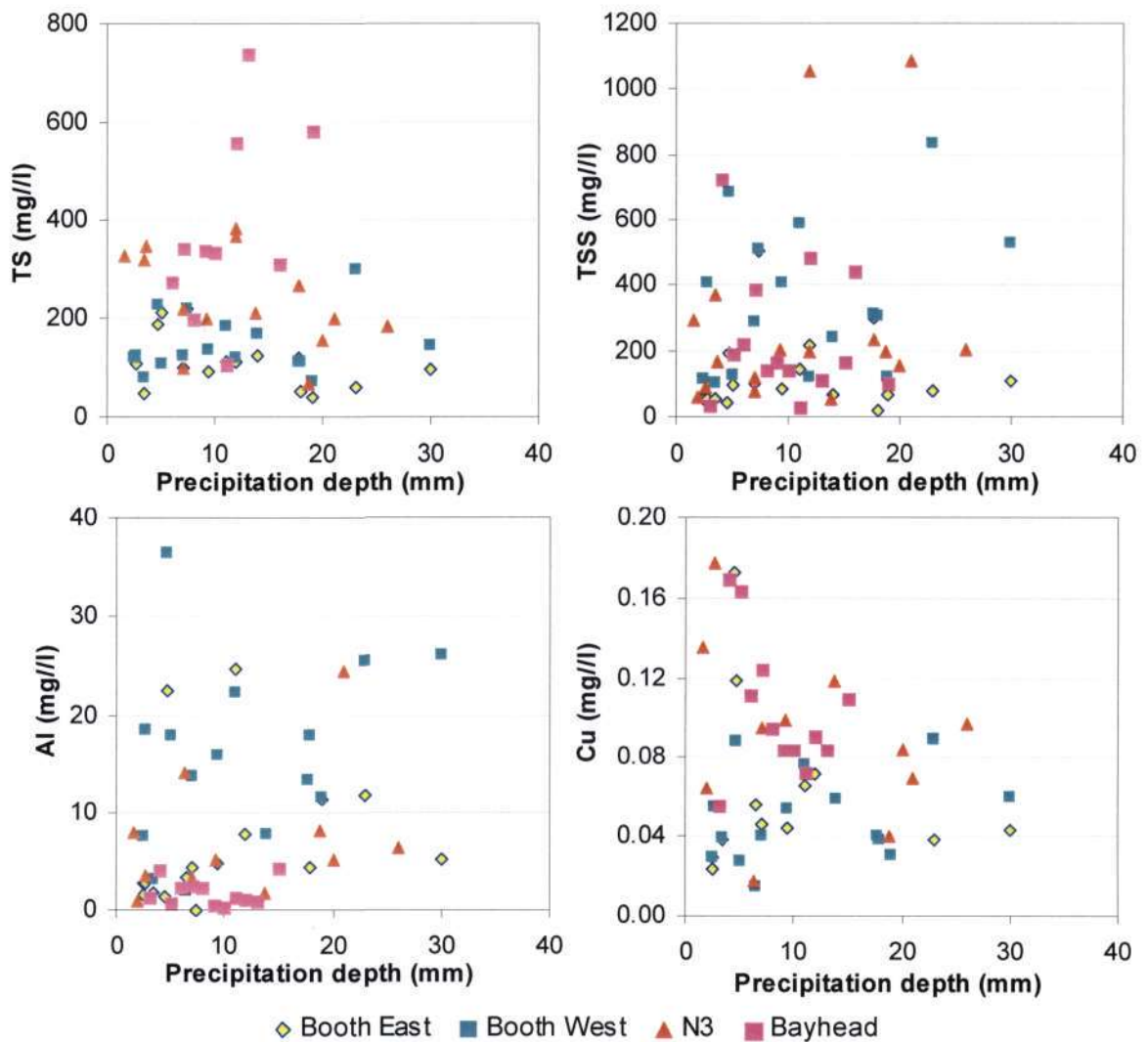
The T value is then compared against percentile values of the student's t-distribution, calculated using the appropriate degrees of freedom (sample size -2) and confidence level (Helsel and Hirsh, 2002).

A strong correlation between rainfall and measured concentration was expected. The results shown in Table 6-11 indicate however that correlations are generally low and not significant. Statistically significant values (at the 95% confidence level) are highlighted.

The high number of negative correlations at Booth East indicates that higher runoff concentrations are associated with smaller events. These may be attributed to the dilution affect of larger rainfall events and the steep gradient at Booth East. The scatter plots shown in Figure 6-19 suggest that there are no obvious trends of mean concentration levels associated with rain depth.

**Table 6-11: Correlation for total rainfall vs. contaminant concentrations**

	BE	BW	N3	Bh
TS	0.16	0.11	-0.22	-0.61
TSS	0.29	0.28	0.19	-0.08
COD	-0.58	0.12	-0.31	-0.27
BOD	-0.49	-0.09	-0.79	0.15
Al	0.54	0.31	0.31	0.48
Cr	0.24	0.24	0.11	0.19
Cu	-0.63	0.31	-0.06	0.06
Fe	0.45	0.39	0.17	0.46
Pb	-0.30	0.14	0.13	0.14
Mn	-0.02	0.03	-0.03	0.50
Ni	0.07	0.20	0.08	0.55
Zn	-0.09	0.01	0.05	0.33



**Figure 6-19: Scatter plots for several contaminants and accumulated precipitation totals**

### 6.5.3 Legislation affecting lead concentrations

A change in legislation by the South African government has recently prohibited the use of lead in fuel. On the 1<sup>st</sup> of January 2006, fuel stations introduced 'lead free replacement' fuel for those vehicles that could not operate on 'unleaded' fuel. The primary source of lead found in stormwater from road surfaces is attributed to the vehicular combustion processes utilising fuel with lead. The date for service stations to comply with the fuel change occurred near the middle of the investigation period. Therefore a comparison between 'before and after' median lead concentrations was done as shown in Table 6-12. The results indicate a significant decrease in atmospheric (about 80%) and runoff (about 60%) concentrations at all stations except the N3. The upgrading and maintenance works, which started at the end of 2005, and increased traffic volumes on the N3 may account for the different result at that site.

**Table 6-12: Change in lead concentrations since the introduction of lead free fuel**

	Booth Road			National 3 Highway		Bayhead Road	
	Atmos <sup>a</sup>	East	West	Atmos <sup>a</sup>	N3	Atmos <sup>a</sup>	Bh
M <sub>B</sub> / M <sub>A</sub> <sup>b</sup>	4.8	2.3	3.1	6.3	1.0	4.2	2.2
% Decrease <sup>c</sup>	79	57	67	84	-0.7	76	55

<sup>a</sup> Atmospheric fallout

<sup>b</sup> Ration of median values before and after the 1<sup>st</sup> of January 06

<sup>c</sup> Percentage decrease in median values since the 1<sup>st</sup> of January 06

### 6.6 Constituent Relationships for Stormwater Runoff

The inter-relationship between stormwater contaminants was analyzed using cross-correlation analysis based on Spearman's rank correlation method. Strong correlations indicate whether relatively high concentrations of one pollutant are likely to occur together with another. Strong relationships may indicate that the source of a certain contaminant might be related to the source of another. Tables 6-12, 6-13 and 6-14 present the correlation coefficients. Statistically significant values (at the 95% confidence level) are highlighted. Correlation calculations exclude PEMCs.

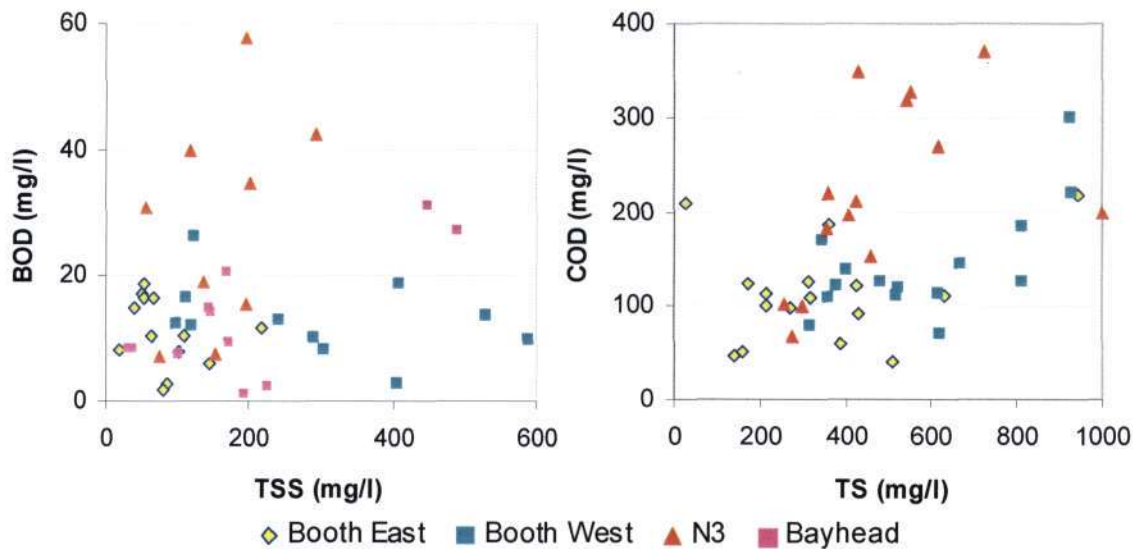
The majority of cross-correlations between solids, oxygen demanding substances and conductivity (excluding heavy metals) were low (-0.6 to 0.6). The correlations between

different water quality parameters at the various sampling sites indicate that inter-relationships tend to be site specific.

**Table 6-13: Cross-correlation of site solids, oxygen demanding indicators and conductivity**

		TS	TSS	COD	BOD	EC
Booth East	TS	1	0.37	0.06	-0.39	0.56
	TSS	0.37	1	0.51	-0.49	-0.12
	COD	0.06	0.51	1	0.55	-0.10
	BOD	-0.39	-0.49	0.55	1	-0.06
	EC	0.56	-0.12	-0.10	-0.06	1
Booth West	TS	1	0.77	0.58	0.18	0.11
	TSS	0.77	1	0.82	-0.12	-0.36
	COD	0.58	0.82	1	0.22	-0.40
	BOD	0.18	-0.12	0.22	1	0.08
	EC	0.11	-0.36	-0.40	0.08	1
N3	TS	1	0.55	0.77	0.48	0.57
	TSS	0.55	1	0.42	0.10	-0.07
	COD	0.77	0.42	1	0.85	0.64
	BOD	0.48	0.10	0.85	1	0.60
	EC	0.57	-0.07	0.64	0.60	1
Bayhead	TS	1	0.24	0.66	-0.20	0.92
	TSS	0.24	1	-0.11	0.35	0.32
	COD	0.66	-0.11	1	-0.14	0.64
	BOD	-0.20	0.35	-0.14	1	0.14
	EC	0.92	0.32	0.64	0.14	1

Figure 6-20 presents scatter plots of oxygen demanding indicators BOD and COD with solids TSS and TS.



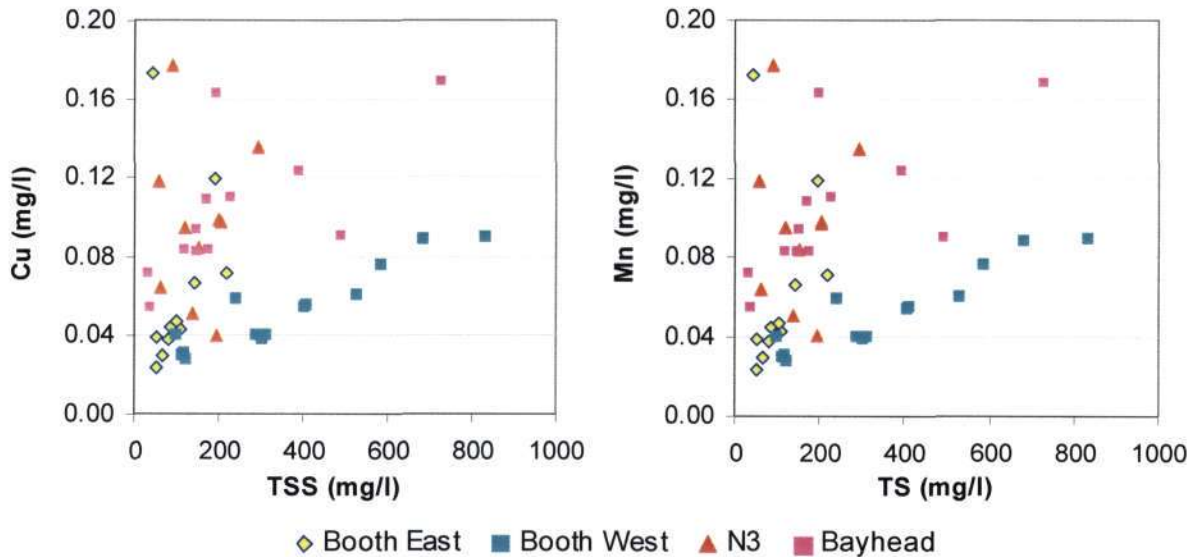
**Figure 6-20: Scatter plots for oxygen demanding substances and solids**

The correlations between the TS, TSS and heavy metal pollution levels are shown in Table 6-14. Statistically significant values at a 95% confidence level are highlighted. Scatter plots for Cu and Mn are presented in Figure 6-21. It is noted that the same two indicators from different sites may be equally strong and significant, however, one relationship is positive and the other is negative. For example, the correlation coefficient values for TSS and Mn at Booth West (0.81) and the N3 (-0.81) (see Table 6-14).

**Table 6-14: Correlation for TS, TSS with heavy metals**

	TS				TSS			
	B <sub>E</sub>	B <sub>W</sub>	N3	Bh	B <sub>E</sub>	B <sub>W</sub>	N3	Bh
Al	0.37	0.71	-0.79	-0.53	0.58	0.87	0.20	0.13
Cr	0.18	0.62	-0.53	-0.50	0.39	0.88	0.48	0.57
Cu	-0.74	0.53	0.23	-0.19	-0.58	0.82	-0.75	0.73
Fe	0.35	0.77	-0.40	-0.51	0.66	0.90	0.64	0.20
Pb	-0.11	0.52	-0.02	-0.30	0.72	0.84	0.15	-0.15
Mn	0.11	0.49	0.44	-0.76	0.75	0.81	-0.80	-0.25
Ni	0.13	0.47	0.55	-1.20	0.41	0.75	0.01	-0.33
Zn	-0.21	0.55	-0.11	-0.51	0.75	0.82	-1.25	0.03

B<sub>E</sub> = Booth East      B<sub>W</sub> = Booth West      Bh = Bayhead



**Figure 6-21: Scatter plots for Cu and Mn vs. solid concentration levels**

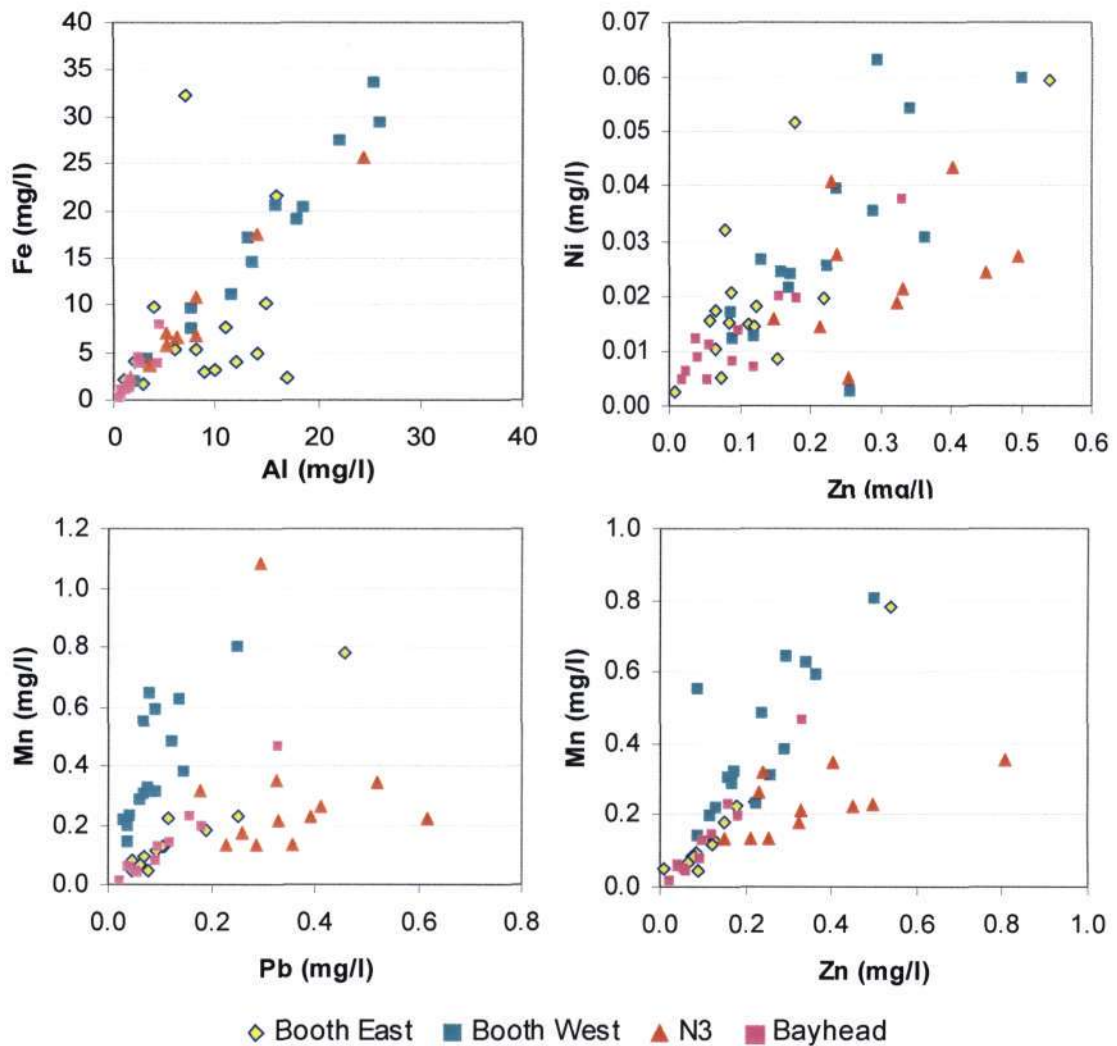
The relationships for TS and TSS indicate that detention storage may be a means for improving the quality of stormwater runoff. The settling of solids may decrease the contamination levels for several heavy metal pollutants.

The Cross-correlation relationships between the stormwater heavy metals concentrations at a particular monitoring site are shown in Table 6-15. Statistically significant values (at a 95% confidence level) are highlighted. There are many strong ( $\geq 0.80$ ) and significant correlations between the metals for individual sites. Aluminium is strongly related to iron ( $\geq 0.95$ ) and manganese to zinc ( $\geq 0.71$ ) for all sites. The consistently high correlation coefficients highlighted at Booth West (Tables 6-13 and 6-14) indicates that they may share a common source within the catchment. The fuel station built during the investigation period may be the underlying reason although Booth East, which is not affected by the station, also indicates high cross-correlations.

**Table 6-15: Cross-correlations of site heavy metals**

		Al	Cr	Cu	Fe	Pb	Mn	Ni	Zn
Booth East	Al	1	0.73	-0.10	0.99	0.44	0.61	0.73	0.54
	Cr	0.73	1	0.25	0.74	0.16	0.46	0.78	0.54
	Cu	-0.10	0.25	1	-0.09	0.06	0.42	-0.43	0.32
	Fe	0.99	0.74	-0.09	1	0.50	0.66	0.73	0.60
	Pb	0.44	0.16	0.06	0.50	1	0.82	0.17	0.77
	Mn	0.61	0.46	0.42	0.66	0.82	1	0.35	0.89
	Ni	0.73	0.78	-0.43	0.73	0.17	0.35	1	0.51
	Zn	0.54	0.54	0.32	0.60	0.77	0.89	0.51	1
Booth West	Al	1	0.68	0.73	0.98	0.73	0.85	0.72	0.60
	Cr	0.68	1	0.72	0.84	0.87	0.76	0.76	0.88
	Cu	0.73	0.72	1	0.86	0.58	0.61	0.94	0.73
	Fe	0.98	0.84	0.86	1	0.75	0.66	0.85	0.74
	Pb	0.73	0.87	0.58	0.75	1	0.83	0.59	0.85
	Mn	0.85	0.76	0.61	0.66	0.83	1	0.65	0.78
	Ni	0.72	0.76	0.94	0.85	0.59	0.65	1	0.72
	Zn	0.60	0.88	0.73	0.74	0.85	0.78	0.72	1
National 3 Highway	Al	1	0.91	-0.54	0.92	-0.14	-0.04	0.45	-0.62
	Cr	0.91	1	-0.35	0.88	0.03	-0.07	0.36	-0.56
	Cu	-0.54	-0.35	1	-0.26	0.53	0.66	0.50	0.89
	Fe	0.92	0.88	-0.26	1	0.19	0.09	0.50	-0.38
	Pb	-0.14	0.03	0.53	0.19	1	0.24	0.29	0.39
	Mn	-0.04	-0.07	0.66	0.09	0.24	1	0.77	0.71
	Ni	0.45	0.36	0.50	0.50	0.29	0.77	1	0.43
	Zn	-0.62	-0.56	0.89	-0.38	0.39	0.71	0.43	1
Bayhead	Al	1	0.58	0.47	0.94	0.80	0.87	0.67	0.82
	Cr	0.58	1	0.91	0.65	0.32	0.39	0.49	0.58
	Cu	0.47	0.91	1	0.51	0.27	0.20	0.37	0.43
	Fe	0.94	0.65	0.51	1	0.78	0.90	0.67	0.92
	Pb	0.80	0.32	0.27	0.78	1	0.84	0.60	0.87
	Mn	0.87	0.39	0.20	0.90	0.84	1	0.77	0.92
	Ni	0.67	0.49	0.37	0.67	0.60	0.77	1	0.72
	Zn	0.82	0.58	0.43	0.92	0.87	0.92	0.72	1

Scatter plots illustrating the relationship between several metals are presented in Figure 6-22.



**Figure 6-22: Scatter plots for several contaminants and accumulated precipitation totals**

The main conclusion from this analysis is that the cross-correlation relationships, although strong for several metals, are site specific.

### 6.7 Environmental Impact Assessment

The majority of heavy metal EMCs exceed the SA WQ guideline criteria for aquatic ecosystems. Since these are average concentrations it follows that levels will be much higher at certain times. Some perspective is however required when considering the

impact on aquatic ecosystems. A basic water quality index (WQI) may be defined in order to assess the impact of stormwater runoff from a road surface in to receiving water bodies. The WQI is defined as:

$$WQI = \frac{Load}{Vol \cdot Std} \tag{6-5}$$

where,

- WQI = Water quality index
- Load = Annual load estimated based on the type of road
- Vol = Storage volume of receiving water body
- Std = Contaminant target water quality requirement

The annual load is a function of the annual export coefficient based on the type of road, annual total rainfall, runoff coefficient and road surface area. Three generic water bodies of varying storage volume are considered for this assessment. The percentage of road surface within the catchment is assumed constant. The relevant catchment characteristics and road surface details assumed are given in Table 6-15.

**Table 6-16: Catchment details assumed for three water bodies**

Catchment details			
Water body	A	B	C
Drainage area (hectare)	8000	8000	8000
Storage volume (m <sup>3</sup> )	5,000	500,000	5,000,000
Road surface area (hectare)	15	15	15
% of catchment	0.19	0.19	0.19
Runoff coefficient	0.95	0.95	0.95

Catchments A, B and C represent storage volumes associated with (1) ponds and small wet lands (2) estuaries (3) dams, lakes and large wetlands respectively. The normalized annual pollutant loading export coefficients (estimated in section 6.3.2) for the N3 were used to estimate the SWR annual loadings for each catchment. The estimated total annual loading was divided by the assumed storage volume. This provides an estimation of the dilution effect on the SWR loadings for one year. The predicted loadings (after dilution) were compared to the SA WQ guidelines for aquatic ecosystems. The comparison indicated that the large storage volume diluted the metal concentration to acceptable levels. The question of how long it would take for metal concentrations to exceed the SA WQ guideline TWQR limits due to the bioaccumulation was then addressed. It was

assumed for simplicity that every year would result in the same pollutant loading, which would accumulate. Table 6-17 presents the number of years for exceedance to occur for several heavy metals.

**Table 6-17: Water quality index for three typical catchments and several heavy metals**

Heavy metal	Years to exceed TWQR (recommended limit)		
	A	B	C
Al	0.05	5	50
Cd	3.3	329	3289
Cr	10.5	1049	10488
Cu	0.3	33	325
Fe	4.5	453	4526
Mn	15.1	1510	15105
Pb	0.1	5	54
Zn	0.2	17	165

This simple method of estimation excludes other sources of pollutants such as atmospheric and urban runoff loadings. It does however serve to show that although the road surface is a small percentage of a catchment (<0.2%), it can generate enough SWR to significantly influence the water quality of a receiving water body. The results shown in Table 6-17 indicates that Al and Pb will accumulate and exceed recommended levels for aquatic ecosystems first, with Zn followed by Cu.

This simplified assessment indicates that certain water bodies that have a high retention rate of pollutant inputs, such as lakes and dams, may already exceed the SA WQ guideline criteria. A study by Cambell (2001) on a typical South African river showed that the water was unfit for certain water user groups, and that the river beds showed elevated levels of pollutants due to entrainment of pollutants. This finding is consistent with the bioaccumulation of contaminants, even in a flowing river, that was assumed for the foregoing analysis.

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## CHAPTER 7

### SUMMARY AND CONCLUSIONS

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*Four questions were proposed at the onset of this dissertation, with the aim of characterizing stormwater runoff from road surfaces. The quality of stormwater runoff from four different road surfaces was characterised by representative flow-weighted event mean concentration samples. The samples were collected by the Pro.4 sampling tool developed in this investigation. The contribution of atmospheric deposition was examined. Contaminant concentrations were compared to aquatic ecosystem limits, discharge criteria and global values. This chapter presents a summary of the results, conclusions and recommendations.*

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#### **7.1 Pro.4 Sampler Developed**

A sampling device was developed, tested and used to collect representative flow weighted composite stormwater samples that satisfied the stormwater monitoring program sampling objectives. Laboratory, computer, field and chemical analysis tests were used to evaluate the sampler performance. The sampler, with some calibration, may provide an economical and reliable sampling option for monitoring stormwater runoff.

#### **7.2 Local Concentrations Characterized and Compared To Global Values**

*How does South Africa's stormwater runoff loadings compare to international values and if there are differences, what are the reasons for them?*

The majority of contaminants analysed are similar to or exceed global values reported for urban highways. Table 7-1 presents the annual normalised pollutant loadings for this study. The highest concentrations of pollutants in runoff occurred at the N3 highway and Booth West monitoring sites. The high values at the N3 were expected as it has the highest traffic volume. Booth West however, with only a fifth of the traffic volume has a fuel station. Normalised for surface area, the N3 and Booth West sites generated the highest

annual pollutant loadings. There is high number of old and inefficient vehicles on South Africa's roads. These may contribute significantly to the elevated heavy metals levels.

**Table 7-1: Annual pollutant loadings for storm water runoff <sup>a</sup>**

Parameter	Booth Road		N 3	Bayhead
	East	West	Highway	Harbor Road
<b>ADT(veh/day)</b>	16,000	17,500	90,000	17,000
<b>TSS</b>	802	3,043	1,932	1,688
<b>VSS</b>	269	608	744	447
<b>BOD<sub>5</sub></b>	97	106	288	93
<b>COD</b>	870	1,214	1,593	2,465
<b>Al</b>	60.8	174	66.8	12.9
<b>Cd</b>	0.017	0.029	0.025	0.007
<b>Cr</b>	0.260	0.348	0.381	0.168
<b>Cu</b>	0.531	0.414	0.819	0.686
<b>Fe</b>	63.5	197	73.6	20.0
<b>Mn</b>	1.23	3.42	2.65	0.897
<b>Ni</b>	0.189	0.270	0.237	0.087
<b>Pb</b>	0.964	0.782	3.06	0.271
<b>Zn</b>	1.2	2.04	4.03	0.676

<sup>a</sup> Units in kg/ha-year

Event mean concentrations indicate that contaminant concentrations are highly variable between storm events and sites. This is noteworthy since sites were selected in order to minimise the influence of catchment land use. Contaminant concentrations were shown to be lognormally distributed. The inter-relationships that exist between water quality indicators and with rainfall were quantified using Spearman's rank correlation analysis. The results show that accumulated rainfall and pollutant levels are only weakly correlated, suggesting dilution effects. The correlation between different contaminants suggests that inter-relationships are generally site specific. The only consistently high and significant correlations (as determined by the student t-test), for all monitoring sites, was that of aluminium to iron ( $\geq 0.95$ ) and manganese to zinc ( $\geq 0.71$ ). In the case of the Booth West site, most of the correlations were high, which indicates a common source, most likely the fuel station. The significance of the antecedent dry weather period was shown to be minimal as concentrations for short and long periods were similar. The high rate of atmospheric deposition contribution measured may account for this.

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### **7.3 Harmful Affects**

*What are the effects on the receiving water bodies and what consequences could this have for those who use the water or for aquatic life?*

The majority of water quality indicators frequently exceeded the SA wastewater general and special standards. These limits should not be exceeded at any time. Long term or frequent exposures at these levels will have considerable negative consequences for aquatic ecosystems. The health risks for people making use of small water bodies that receive stormwater runoff, is of concern.

A 'simplistic' environmental impact assessment concluded that the bioaccumulation of stormwater runoff contaminants can result in significant degradation of receiving water bodies. Long-term effects of stormwater runoff on aquatic ecosystems, with an accumulation of contaminants is probably more important than short term effects associated with specific events.

### **7.4 Atmospheric Contribution**

*What is the contribution of atmospheric deposition compared to that from actual usage of the road by vehicles?*

The contribution of contaminants from atmospheric deposition varied from event to event. Comparisons of mean atmospheric deposition concentrations and EMCs for stormwater runoff indicate that atmospheric deposition is generally a significant source of pollutants. Heavy metal levels for Cd, Cr and Ni from atmospheric deposition, generally exceeded stormwater runoff concentrations. Factors that influence atmospheric deposition, such as wind, rainfall and cleaning operations may account for the elevated atmospheric levels and low stormwater levels.

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## **7.5 Mitigation Options**

*What could possibly be done to reduce the pollution loadings entering receiving water bodies?*

The high correlation between water quality indicators and solids (total solids and suspended solids) indicates that natural filtration or settlement methods may be effective mitigation methods. Vegetated roadside shoulders, medians and swales can effectively remove certain highway contaminants (Wu *et al.*, 1998). Many of South Africa's road surfaces discharge into vegetated areas. The majority of these are not intentional mitigation measures but are a matter of convenience. The stormwater from roads within cities and near sensitive water bodies requires particular attention. City roads are generally located where there is very limited space. Therefore, sedimentation tanks, although expensive, would be recommended. Storage tanks would also retain the first flush as indicated by results of high PEMCs to EMCs. Roads near sensitive water bodies require planned construction of natural vegetated filters to prevent untreated stormwater runoff being discharged directly into the water bodies.

A review of international trends in stormwater runoff quality characterization suggests that the SA water quality guidelines for discharge criteria should be revised. Guidelines should be developed similar to those developed by the US Environmental Protection Agency, defining methods for stormwater runoff sample collection, analysis of contaminants and discharge criteria. A nationwide stormwater runoff monitoring program similar to US *National Pollutant Discharge Elimination System (NPDES)* should be investigated, which would aim to quantify and reduce stormwater contaminant levels.

The results indicate a significant decrease in atmospheric (about 80%) and runoff (about 60%) concentrations since the introduction of 'lead free' fuels. This highlights the effectiveness of preventative mitigation measures.

## **7.6 Summation**

The original objectives of the study were achieved by a sixteen-month stormwater runoff and atmospheric deposition monitoring program utilising a sampling tool developed for this

investigation. Comparisons with values previously reported in the international literature indicate that, although generally within the same order of magnitude, there is no substitution for local research due to the site specific nature of contaminant levels. The Pro.4 sampler developed operated well as a stormwater runoff monitoring tool.

### **7.7 Suggestions for Further Research**

In order to further this research, factors influencing the local stormwater contaminant concentration levels should be further investigated. A long-term nationwide continuous stormwater monitoring program should be investigated in order to build up a South African stormwater runoff database. This could be used to inform decisions made by management with regards to mitigation measures.

The Pro.4 sampler developed for this investigation may provide an inexpensive option for collection of samples from discharge conduits. Further studies could focus on (1) improvement of the sampler collection properties (2) the adaptability of the sampler to other studies requiring the collection of samples (3) the installation requirements related to the gravity driven orifice collection.

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## APPENDICES

**APPENDIX A**  
**SAMPLER COLLECTION PROPERTIES**

**This Appendix contains the experimental data used to evaluate and calibrate the Pro.4 sampler developed for this investigation**

## A1: Sampler collection rate

Table A-1: Determination of the orifice c value

Water Height (mm)	Orifice collection rate (ml/min)						Average qs ml/min	Flow Q m3/s	regression curve equation (ml/min)	Ave. qs - RC qs squared	Orifice c value calculated = $Q/(2 \cdot g \cdot h)^{0.5}$
	Sampler 1	Sampler 2	Sampler 3	Sampler 4	Sampler 5	Sampler 6					
0	0	0	0	0	0	0	0				
10	28.0	27.0	30.0	22.4	32.4	29.7	28.3	4.7E-07	36.0	60.0	1.063
25	55.5	53.6	55.4	50.3	54.3	49.5	53.1	8.8E-07	56.9	14.8	1.263
40	65.3	69.6	63.8	69.0	71.0	63.8	67.1	1.1E-06	72.0	24.4	1.261
55	77.4	85.4	81.0	83.1	81.8	78.3	81.2	1.4E-06	84.4	10.7	1.302
70	84.8	100.1	92.0	101.1	94.5	92.7	94.2	1.6E-06	95.2	1.1	1.339
85	96.2	111.0	105.0	111.0	106.5	103.5	105.5	1.8E-06	104.9	0.3	1.362
100	106.5	120.0	112.5	123.0	118.5	114.0	115.8	1.9E-06	113.8	3.7	1.377
115	121.5	129.5	123.8	132.0	129.0	122.3	126.3	2.1E-06	122.1	18.1	1.402
130	129.8	136.5	129.0	138.8	135.0	129.8	133.1	2.2E-06	129.8	11.1	1.389
Total =										144.3	Average = 1.307

Manning Equation  $Q = C \cdot A \cdot (2 \cdot g \cdot h)^{0.5}$

$c = A \cdot C$  gives  $Q = c \cdot (2 \cdot g \cdot h)^{0.5}$

$c = 1.354$  using a Solver tool which minimises the difference between the average qs and regression curve value

The R<sup>2</sup> value between the average qs and regression curve 0.999

The orifice c value was also calculated for each water level and averaged 1.307

**Table A-2: Collection rates for six Pro.4 samplers under several water depths  
and velocities**

Flume level mm	Water level <sup>a</sup> mm	Sampler # 1		Sampler # 2		Sampler # 3		Sampler # 4		Sampler # 5		Sampler # 6	
		qs <sup>b</sup> ml/min	Vel <sup>c</sup> m/s	qs ml/min	Vel m/s	qs ml/min	Vel m/s	qs ml/min	Vel m/s	qs ml/min	Vel m/s	qs ml/min	Vel m/s
Static 27 27 27	10	28.0	0.00	27.0	0.00	30.0	0.00	22.4	0.00	32.4	0.00	29.7	0.00
	10			36.0	0.27	24.4	0.27	26.2	0.27	17.6	0.21	25.6	0.34
	10	90.0	1.31	90.0	1.31	99.6	1.31	108.0	1.31	100.2	1.31	88.0	1.27
	10	103.2	1.50	106.8	1.51	102.4	1.51	110.4	1.48	112.8	1.62	105.6	1.65
Static 42 42 42	25	55.5	0.00	53.6	0.00	55.4	0.00	50.3	0.00	54.3	0.00	49.5	0.00
	25	60.5	0.48	61.4	0.48	62.4	0.48	66.5	0.48	64.0	0.48	56.0	0.48
	25	110.4	1.44	119.5	1.34	113.3	1.34	119.8	1.34	118.2	1.34	111.0	1.41
	25	129.0	1.72	135.0	1.58	144.0	1.75	143.0	1.58	134.3	1.58	126.8	1.72
Static 57 57 57	40	65.3	0.00	69.6	0.00	63.8	0.00	69.0	0.00	71.0	0.00	63.8	0.00
	40	72.5	0.48	83.3	0.48	78.8	0.48	85.5	0.52	81.0	0.48	76.7	0.48
	40	101.0	1.14	110.3	1.14	102.0	1.14	109.8	1.10	103.8	1.10	93.4	1.10
	40	139.5	1.65	157.5	1.65	144.9	1.65	153.8	1.58	149.0	1.65	140.3	1.69
Static 72 72 72	55	77.4	0.00	85.4	0.00	81.0	0.00	83.1	0.00	81.8	0.00	78.3	0.00
	55	91.0	0.69	99.1	0.69	98.4	0.69	104.0	0.69	99.0	0.69	94.6	0.69
	55	126.0	1.31	129.8	1.24	128.0	1.31	128.4	1.17	128.3	1.26	124.5	1.24
	55	140.8	1.55	159.9	1.55	144.8	1.51	161.3	1.57	149.3	1.53	143.0	1.55
Static 87 87 87	70	84.8	0.00	100.1	0.00	92.0	0.00	101.1	0.00	94.5	0.00	92.7	0.00
	70	107.8	0.84	123.6	0.93	112.5	0.84	120.7	0.84	116.7	0.84	112.1	0.84
	70	124.5	1.14	132.0	1.10	132.0	1.14	134.3	1.14	134.0	1.17	129.8	1.20
	70	141.8	1.44	157.5	1.41	155.4	1.51	163.5	1.51	159.0	1.51	151.0	1.51
Static 102 102 102	85	96.2	0.00	111.0	0.00	105.0	0.00	111.0	0.00	106.5	0.00	103.5	0.00
	85	126.0	1.10	138.0	0.96	132.6	1.03	142.5	1.03	132.8	1.03	129.8	0.96
	85	136.8	1.27	156.8	1.27	143.3	1.27	158.3	1.27	147.0	1.27	142.5	1.31
	85	144.0	1.41	172.0	1.44	157.0	1.41	167.0	1.41	157.0	1.41	159.0	1.44
Static 117 117 117	100	106.5	0.00	120.0	0.00	112.5	0.00	123.0	0.00	118.5	0.00	114.0	0.00
	100	134.3	0.93	147.0	0.96	138.0	0.93	144.8	0.89	144.0	0.93	138.8	0.96
	100	140.0	1.10	150.0	1.03	144.0	1.10	156.8	1.14	146.0	1.03	145.5	1.10
	100	154.0	1.31	180.0	1.44	162.0	1.34	175.0	1.41	168.0	1.38	161.3	1.38
Static 132 132	115	121.5	0.00	129.5	0.00	123.8	0.00	132.0	0.00	129.0	0.00	122.3	0.00
	115	153.0	1.12	162.4	1.14	163.0	1.20	166.0	1.10	160.0	1.08	159.0	1.12
	115	166.0	1.36	174.0	1.31	168.0	1.29	182.4	1.36	173.0	1.31	170.0	1.31
Static 147 147	130	129.8	0.00	136.5	0.00	129.0	0.00	138.8	0.00	135.0	0.00	129.8	0.00
	130	155.0	0.83	155.0	0.80	155.0	0.85	155.0	0.81	155.0	0.84	155.0	0.80
	130	162.0	1.17	180.0	1.17	172.0	1.17	181.0	1.17	174.0	1.17	170.0	1.17

<sup>a</sup> Water level above the orifice entrance

<sup>b</sup> Sampler collection rate

<sup>c</sup> Velocity of flume

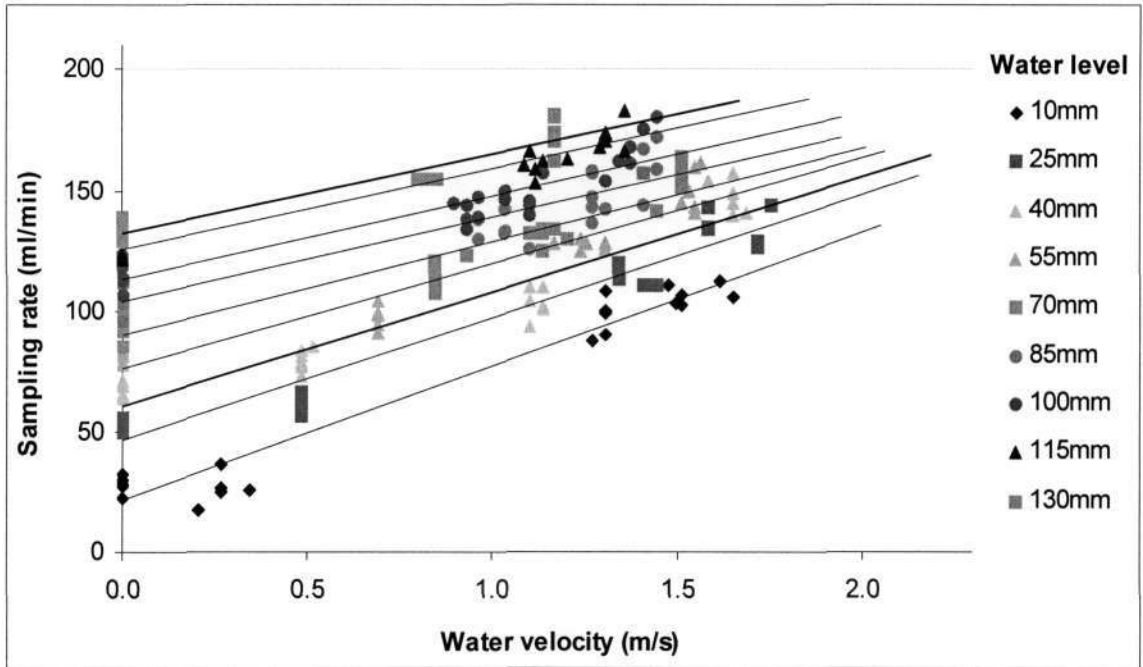


Figure A-1: Sampling rate for six Pro. 4 samplers related to the water level and velocity

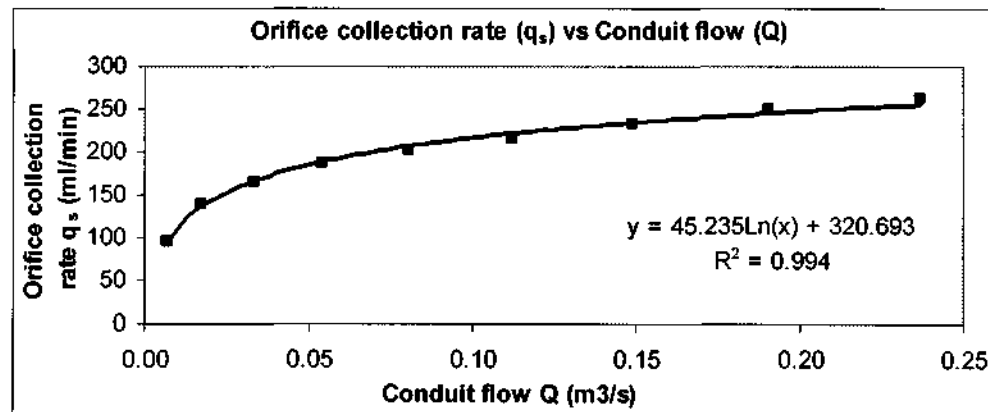
**A2: Sample volume collected related to culvert discharge**

**Table A-3: Booth East culvert discharge estimated using Manning's equation and a selected k-value of 20 for several water levels**

Culvert radius mm	Water level mm	Theta	Area of flow mm <sup>2</sup>	Flow perimeter mm	Hydraulic radius mm	Velocity K = 20 m/s	Culvert flow l/s	Culvert flow m/s
375	0	0.00	0.0	0.0	0.0	0	0	0
375	27	0.76	5067.2	286.3	17.7	1.36	6.9	0.007
375	42	0.96	9770.3	358.4	27.3	1.81	17.7	0.018
375	57	1.12	15350.5	418.9	36.6	2.21	33.9	0.034
375	72	1.26	21654.5	472.5	45.8	2.56	55.5	0.055
375	87	1.39	28577.6	521.3	54.8	2.89	82.5	0.082
375	102	1.51	36041.6	566.5	63.6	3.19	114.9	0.115
375	117	1.62	43984.4	609.1	72.2	3.47	152.6	0.153
375	132	1.73	52354.4	649.4	80.6	3.73	195.4	0.195
375	147	1.83	61107.7	687.9	88.8	3.98	243.3	0.243

**Table A-4: Pro.4 sampler collection rates related to the Booth East culvert discharge**

Discharge water level mm	Water level above sampler mm	Trendline function for orifice collection		Velocity predicted m/s	Orifice collection	
		x	c		ml/min	l/hr
27	10	56.1	20.6	1.36	96.7	5.8
42	25	51.4	46.3	1.81	139.4	8.4
57	40	47.6	60.7	2.20	165.7	9.9
72	55	43.8	75.9	2.56	187.9	11.3
87	70	38.7	90.0	2.88	201.5	12.1
102	85	35.2	103.7	3.18	215.8	12.9
117	100	34.3	113.5	3.46	232.3	13.9
132	115	33.2	125.9	3.72	249.7	15.0
147	130	32.9	132.0	3.97	262.4	15.7



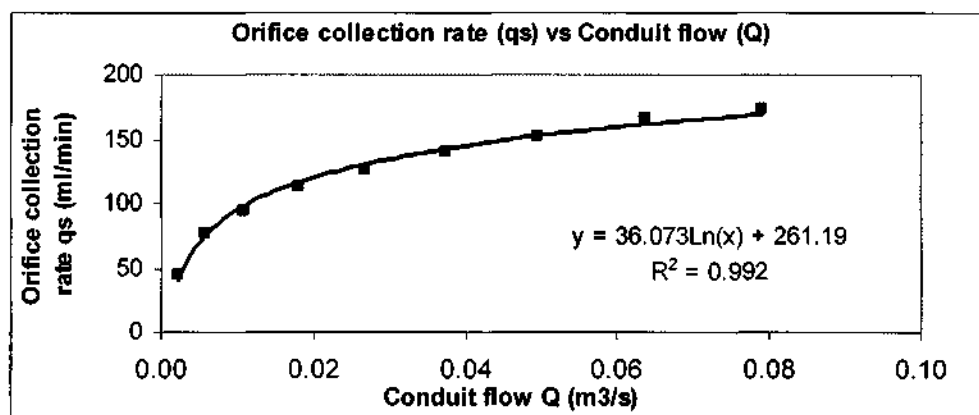
**Figure A-2: Sampling rate  $q_s$  related to the Booth East conduit flow  $Q$**

**Table A-5: Booth West culvert discharge estimated using Manning's equation and a selected k-value of 6.5 for several water levels**

Culvert radius mm	Water level mm	Theta	Area of flow mm <sup>2</sup>	Flow perimeter mm	Hydraulic radius mm	Velocity K = 6.5 m/s	Culvert flow l/s	Culvert flow m/s
375	0	0.00	0.0	0.0	0.0	0.00	0.0	0.000
375	27	0.76	5067.2	286.3	17.7	0.44	2.2	0.002
375	42	0.96	9770.3	358.4	27.3	0.59	5.8	0.006
375	57	1.12	15350.5	418.9	36.6	0.72	11.0	0.011
375	72	1.26	21654.5	472.5	45.8	0.83	18.0	0.018
375	87	1.39	28577.6	521.3	54.8	0.94	26.8	0.027
375	102	1.51	36041.6	566.5	63.6	1.04	37.3	0.037
375	117	1.62	43984.4	609.1	72.2	1.13	49.6	0.050
375	132	1.73	52354.4	649.4	80.6	1.21	63.5	0.064
375	147	1.83	61107.7	687.9	88.8	1.29	79.1	0.079

**Table A-6: Pro.4 sampler collection rates related to the Booth West culvert discharge**

Discharge water level mm	Water level above sampler mm	Trendline function for orifice collection		Velocity predicted m/s	Orifice collection	
		x	c		ml/min	l/hr
27	10	56.068	20.561	0.44	45.3	2.7
42	25	51.428	46.277	0.59	76.6	4.6
57	40	47.634	60.672	0.72	94.8	5.7
72	55	43.778	75.91	0.83	112.3	6.7
87	70	38.695	90	0.94	126.3	7.6
102	85	35.247	103.68	1.04	140.2	8.4
117	100	34.333	113.53	1.13	152.2	9.1
132	115	33.245	125.91	1.21	166.2	10.0
147	130	32.866	131.95	1.29	174.5	10.5



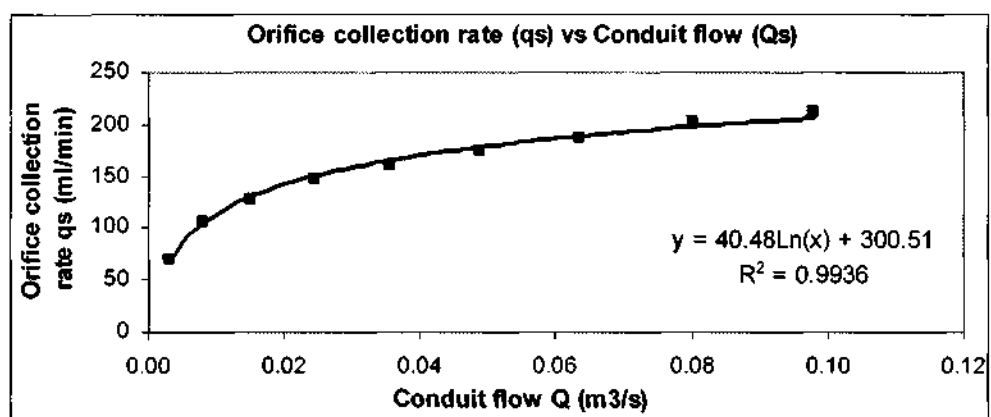
**Figure A-3: Sampling rate  $q_s$  related to the Booth West conduit flow  $Q$**

**Table A-7: N3 culvert discharge estimated using Manning's equation and a selected k-value of 13.2 for several water levels**

Culvert radius mm	Water level mm	Theta	Area of flow mm <sup>2</sup>	Flow perimeter mm	Hydraulic radius mm	Velocity K = 13.2 m/s	Culvert flow l/s	Culvert flow m/s
187.5	0	0.00	0.0	0.0	0.0	0.00	0.0	0.000
187.5	27	1.09	3543.2	203.7	17.4	0.89	3.1	0.003
187.5	42	1.36	6786.9	255.9	26.5	1.17	8.0	0.008
187.5	57	1.60	10590.0	300.4	35.3	1.42	15.0	0.015
187.5	72	1.81	14832.1	340.2	43.6	1.64	24.3	0.024
187.5	87	2.01	19427.5	376.9	51.5	1.83	35.5	0.036
187.5	102	2.19	24309.5	411.5	59.1	2.00	48.7	0.049
187.5	117	2.37	29422.7	444.5	66.2	2.16	63.6	0.064
187.5	132	2.54	34718.9	476.4	72.9	2.30	80.0	0.080
187.5	147	2.71	40154.7	507.4	79.1	2.43	97.7	0.098

**Table A-8: Pro.4 sampler collection rates related to the N3 culvert discharge**

Discharge water level mm	Water level above sampler mm	Trendline function for orifice collection		Velocity predicted m/s	Orifice collection	
		x	c		ml/min	l/hr
27	10	56.068	20.561	0.89	70.2	4.2
42	25	51.428	46.277	1.17	106.6	6.4
57	40	47.634	60.672	1.42	128.3	7.7
72	55	43.778	75.91	1.64	147.5	8.8
87	70	38.695	90	1.83	160.7	9.6
102	85	35.247	103.68	2.00	174.3	10.5
117	100	34.333	113.53	2.16	187.7	11.3
132	115	33.245	125.91	2.30	202.5	12.1
147	130	32.866	131.95	2.43	211.9	12.7



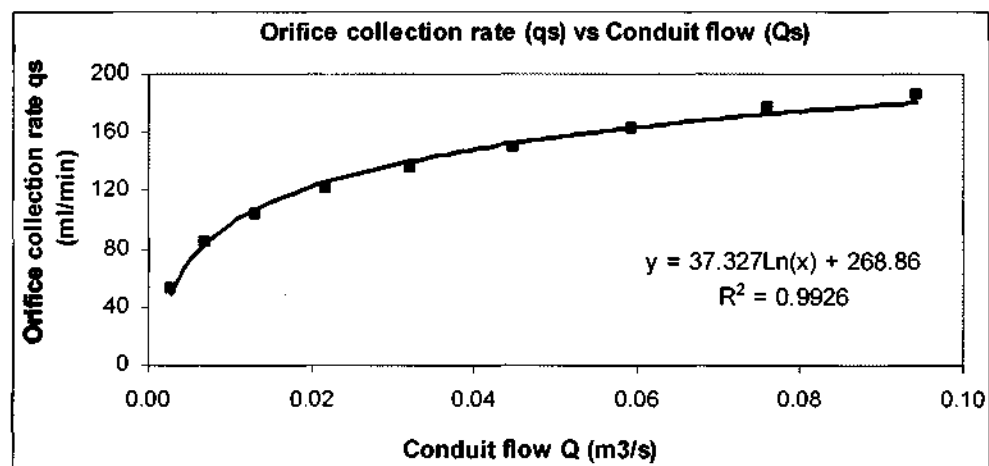
**Figure A-4: Sampling rate  $q_s$  related to the N3 conduit flow  $Q$**

**Table A-9: Bayhead culvert discharge estimated using Manning's equation and a selected k-value of 8.3 for several water levels**

Culvert radius mm	Water level mm	Theta	Area of flow mm <sup>2</sup>	Flow perimeter mm	Hydraulic radius mm	Velocity K = 8.3 m/s	Culvert flow l/s	Culvert flow m/s
337.5	0	0.00	0.0	0.0	0.0	0.00	0.00	0.000
337.5	27	0.81	4801.3	271.8	17.7	0.56	2.70	0.003
337.5	42	1.01	9251.0	340.3	27.2	0.75	6.94	0.007
337.5	57	1.18	14523.9	398.0	36.5	0.91	13.26	0.013
337.5	72	1.33	20472.9	449.1	45.6	1.06	21.68	0.022
337.5	87	1.47	26997.3	495.7	54.5	1.19	32.19	0.032
337.5	102	1.60	34021.2	539.0	63.1	1.32	44.77	0.045
337.5	117	1.72	41484.4	579.7	71.6	1.43	59.35	0.059
337.5	132	1.83	49336.5	618.4	79.8	1.54	75.89	0.076
337.5	147	1.94	57534.5	655.4	87.8	1.64	94.32	0.094

**Table A-10: Pro.4 sampler collection rates related to the Bayhead culvert discharge**

Discharge water level mm	Water level above sampler mm	Trendline function for orifice collection		Velocity predicted m/s	Orifice collection	
		x	c		ml/min	l/hr
27	10	56.068	20.561	0.56	52.1	3.1
42	25	51.428	46.277	0.75	84.9	5.1
57	40	47.634	60.672	0.91	104.2	6.2
72	55	43.778	75.91	1.06	122.3	7.3
87	70	38.695	90	1.19	136.1	8.2
102	85	35.247	103.68	1.32	150.1	9.0
117	100	34.333	113.53	1.43	162.6	9.8
132	115	33.245	125.91	1.54	177.0	10.6
147	130	32.866	131.95	1.64	185.8	11.1



**Figure A-5: Sampling rate  $q_s$  related to the Bayhead conduit flow  $Q$**

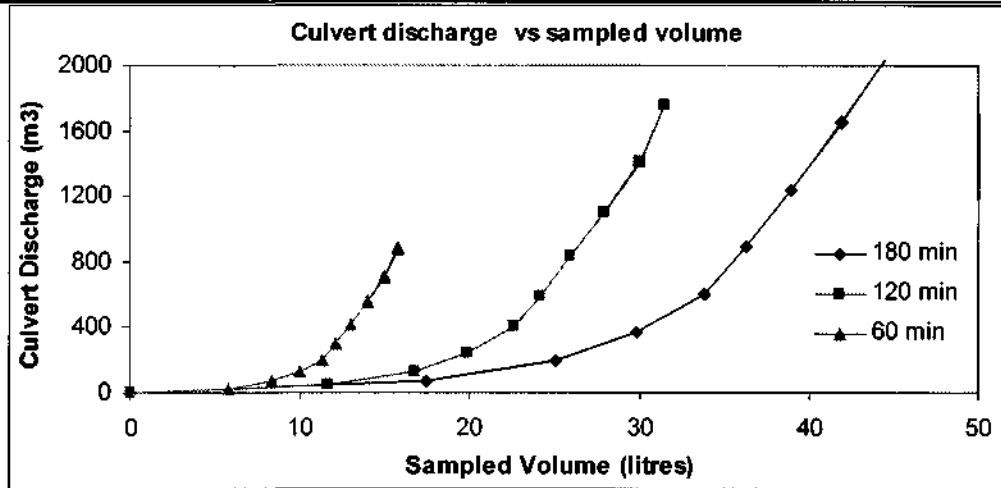


Figure A-6: Total culvert flow curves for the Booth East conduit

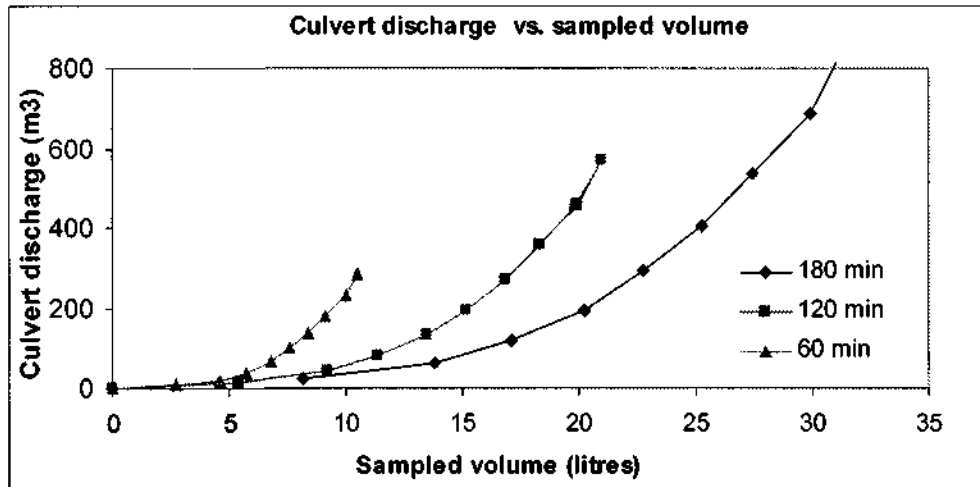


Figure A-7: Total culvert flow curves for the Booth West conduit

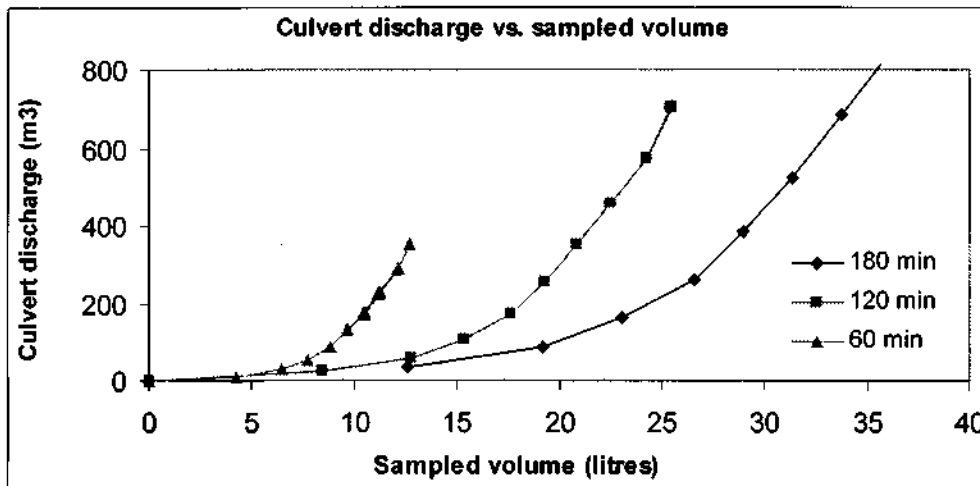
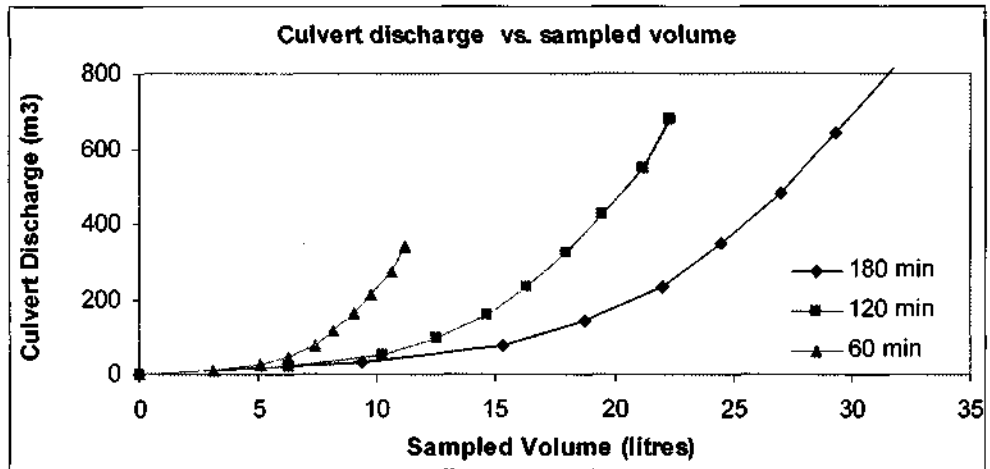


Figure A-8: Total culvert flow curves for the N3 conduit

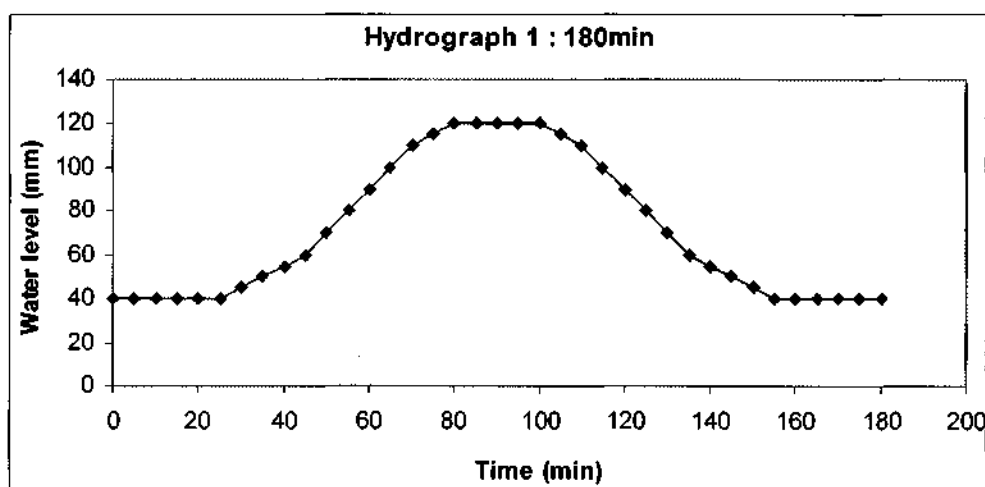


**Figure A-9: Total culvert flow curves for the Bayhead conduit**

**A3: Storm simulation tests**

**Table A-11: Hydrograph 1. 180min storm simulation with varying total culvert flow**

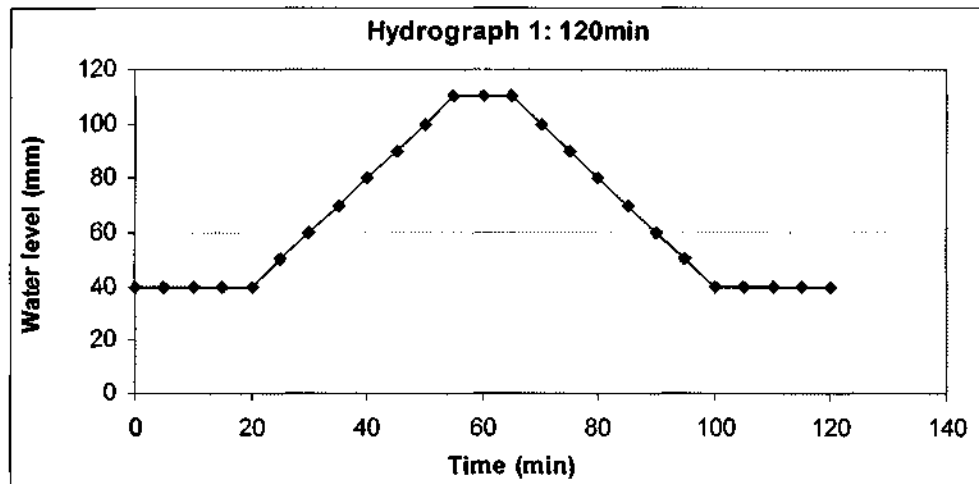
Time (min)	Water level (mm)	Theta	Area of flow (mm <sup>2</sup> )	Perimeter (mm)	Hydraulic radius (mm)	Selected velocity (m/s)	Flow Q (l/s)	Flow Q (m/s)	Orifice collection (ml/min)	Total sampled (litres)	Total calc flow (m <sup>3</sup> )
0	40	0.95	8898.6	342.6	26.0	1.05	9.36	0.009	93.0	0.0	0
5	40	0.95	8898.6	342.6	26.0	1.05	9.36	0.009	93.0	0.5	2.8
10	40	0.95	8898.6	342.6	26.0	1.05	9.36	0.009	93.0	0.5	2.8
15	40	0.95	8898.6	342.6	26.0	1.05	9.36	0.009	93.0	0.5	2.8
20	40	0.95	8898.6	342.6	26.0	1.05	9.36	0.009	93.0	0.5	2.8
25	40	0.95	8898.6	342.6	26.0	1.05	9.36	0.009	93.0	0.5	2.8
30	45	1.01	10595.2	363.9	29.1	1.14	12.03	0.012	109.4	0.5	3.2
35	50	1.07	12382.2	384.0	32.2	1.22	15.05	0.015	124.1	0.6	4.1
40	55	1.12	14254.0	403.2	35.3	1.29	18.42	0.018	137.3	0.7	5.0
45	60	1.17	16205.6	421.7	38.4	1.37	22.15	0.022	149.4	0.7	6.1
50	70	1.27	20331.1	456.6	44.5	1.51	30.65	0.031	170.7	0.8	7.9
55	80	1.36	24729.0	489.4	50.5	1.64	40.56	0.041	189.1	0.9	10.7
60	90	1.45	29374.6	520.4	56.4	1.77	51.87	0.052	205.2	1.0	13.9
65	100	1.53	34247.3	549.9	62.3	1.89	64.57	0.065	219.6	1.1	17.5
70	110	1.61	39328.9	578.3	68.0	2.00	78.63	0.079	232.5	1.1	21.5
75	115	1.64	41943.1	592.0	70.8	2.05	86.18	0.086	238.5	1.2	24.7
80	120	1.68	44603.7	605.6	73.7	2.11	94.05	0.094	244.3	1.2	27.0
85	120	1.68	44603.7	605.6	73.7	2.11	94.05	0.094	244.3	1.2	28.2
90	120	1.68	44603.7	605.6	73.7	2.11	94.05	0.094	244.3	1.2	28.2
95	120	1.68	44603.7	605.6	73.7	2.11	94.05	0.094	244.3	1.2	28.2
100	120	1.68	44603.7	605.6	73.7	2.11	94.05	0.094	244.3	1.2	28.2
105	115	1.64	41943.1	592.0	70.8	2.05	86.18	0.086	238.5	1.2	27.0
110	110	1.61	39328.9	578.3	68.0	2.00	78.63	0.079	232.5	1.2	24.7
115	100	1.53	34247.3	549.9	62.3	1.89	64.57	0.065	219.6	1.1	21.5
120	90	1.45	29374.6	520.4	56.4	1.77	51.87	0.052	205.2	1.1	17.5
125	80	1.36	24729.0	489.4	50.5	1.64	40.56	0.041	189.1	1.0	13.9
130	70	1.27	20331.1	456.6	44.5	1.51	30.65	0.031	170.7	0.9	10.7
135	60	1.17	16205.6	421.7	38.4	1.37	22.15	0.022	149.4	0.8	7.9
140	55	1.12	14254.0	403.2	35.3	1.29	18.42	0.018	137.3	0.7	6.1
145	50	1.07	12382.2	384.0	32.2	1.22	15.05	0.015	124.1	0.7	5.0
150	45	1.01	10595.2	363.9	29.1	1.14	12.03	0.012	109.4	0.6	4.1
155	40	0.95	8898.6	342.6	26.0	1.05	9.36	0.009	93.0	0.5	3.2
160	40	0.95	8898.6	342.6	26.0	1.05	9.36	0.009	93.0	0.5	2.8
165	40	0.95	8898.6	342.6	26.0	1.05	9.36	0.009	93.0	0.5	2.8
170	40	0.95	8898.6	342.6	26.0	1.05	9.36	0.009	93.0	0.5	2.8
175	40	0.95	8898.6	342.6	26.0	1.05	9.36	0.009	93.0	0.5	2.8
180	40	0.95	8898.6	342.6	26.0	1.05	9.36	0.009	93.0	0.5	2.8



**Figure A-10: Hydrograph 1, 180min storm simulation with varying total culvert flow**

**Table A-12: Hydrograph 1, 120min storm simulation with varying total culvert flow**

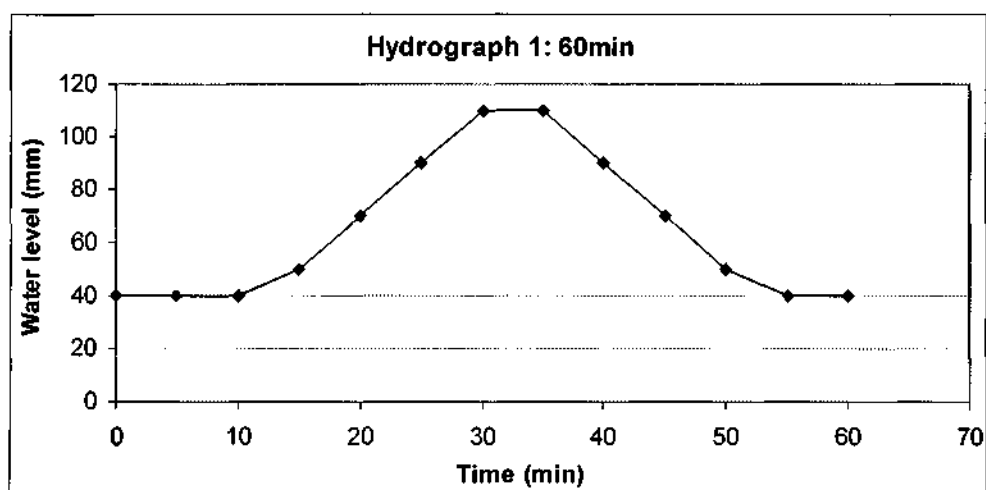
Time (min)	Water level (mm)	Theta	Area of flow (mm <sup>2</sup> )	Perimeter (mm)	Hydraulic radius (mm)	Selected velocity (m/s)	Flow Q (l/s)	Flow Q (m/s)	Orifice collection (ml/min)	Total sampled (litres)	Total calc flow (m <sup>3</sup> )
0	40	0.95	8898.6	342.6	26.0	1.05	9.36	0.009	93.0	0.0	0
5	40	0.95	8898.6	342.6	26.0	1.05	9.36	0.009	93.0	0.5	2.8
10	40	0.95	8898.6	342.6	26.0	1.05	9.36	0.009	93.0	0.5	2.8
15	40	0.95	8898.6	342.6	26.0	1.05	9.36	0.009	93.0	0.5	2.8
20	40	0.95	8898.6	342.6	26.0	1.05	9.36	0.009	93.0	0.5	2.8
25	50	1.07	12382.2	384.0	32.2	1.22	15.05	0.015	124.1	0.5	3.7
30	60	1.17	16205.6	421.7	38.4	1.37	22.15	0.022	149.4	0.7	5.6
35	70	1.27	20331.1	456.6	44.5	1.51	30.65	0.031	170.7	0.8	7.9
40	80	1.36	24729.0	489.4	50.5	1.64	40.56	0.041	189.1	0.9	10.7
45	90	1.45	29374.6	520.4	56.4	1.77	51.87	0.052	205.2	1.0	13.9
50	100	1.53	34247.3	549.9	62.3	1.89	64.57	0.065	219.6	1.1	17.5
55	110	1.61	39328.9	578.3	68.0	2.00	78.63	0.079	232.5	1.1	21.5
60	110	1.61	39328.9	578.3	68.0	2.00	78.63	0.079	232.5	1.2	23.6
65	110	1.61	39328.9	578.3	68.0	2.00	78.63	0.079	232.5	1.2	23.6
70	100	1.53	34247.3	549.9	62.3	1.89	64.57	0.065	219.6	1.1	21.5
75	90	1.45	29374.6	520.4	56.4	1.77	51.87	0.052	205.2	1.1	17.5
80	80	1.36	24729.0	489.4	50.5	1.64	40.56	0.041	189.1	1.0	13.9
85	70	1.27	20331.1	456.6	44.5	1.51	30.65	0.031	170.7	0.9	10.7
90	60	1.17	16205.6	421.7	38.4	1.37	22.15	0.022	149.4	0.8	7.9
95	50	1.07	12382.2	384.0	32.2	1.22	15.05	0.015	124.1	0.7	5.6
100	40	0.95	8898.6	342.6	26.0	1.05	9.36	0.009	93.0	0.5	3.7
105	40	0.95	8898.6	342.6	26.0	1.05	9.36	0.009	93.0	0.5	2.8
110	40	0.95	8898.6	342.6	26.0	1.05	9.36	0.009	93.0	0.5	2.8
115	40	0.95	8898.6	342.6	26.0	1.05	9.36	0.009	93.0	0.5	2.8
120	40	0.95	8898.6	342.6	26.0	1.05	9.36	0.009	93.0	0.5	2.8



**Figure A-11: Hydrograph 1, 120min storm simulation with varying total culvert flow**

**Table A-13: Hydrograph 1, 60min storm simulation with varying total culvert flow**

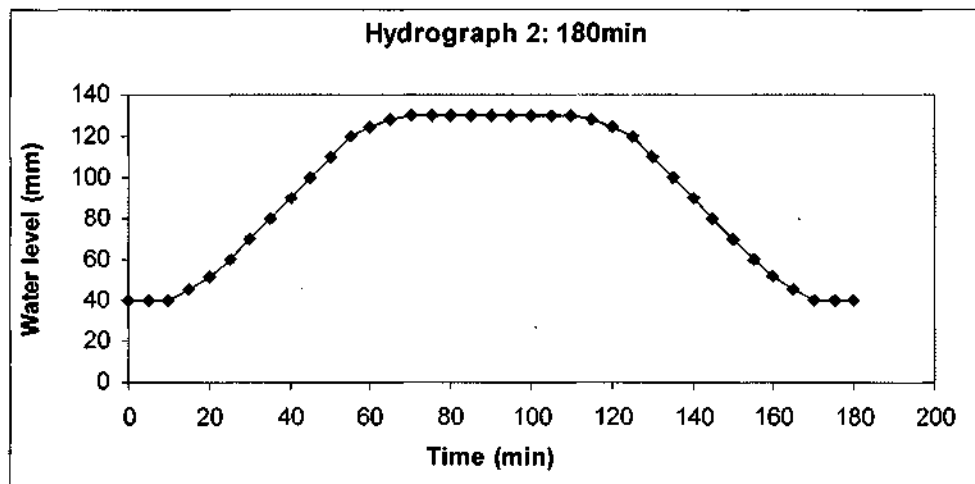
Time (min)	Water level (mm)	Theta	Area of flow (mm <sup>2</sup> )	Perimeter (mm)	Hydraulic radius (mm)	Selected velocity (m/s)	Flow Q (l/s)	Flow Q (m/s)	Orifice collection (ml/min)	Total sampled (litres)	Total calc flow (m <sup>3</sup> )
0	40	0.95	8898.6	342.6	26.0	1.05	9.36	0.009	93.0	0.0	0
5	40	0.95	8898.6	342.6	26.0	1.05	9.36	0.009	93.0	0.5	2.8
10	40	0.95	8898.6	342.6	26.0	1.05	9.36	0.009	93.0	0.5	2.8
15	50	1.07	12382.2	384.0	32.2	1.22	15.05	0.015	124.1	0.5	3.7
20	70	1.27	20331.1	456.6	44.5	1.51	30.65	0.031	170.7	0.7	6.9
25	90	1.45	29374.6	520.4	56.4	1.77	51.87	0.052	205.2	0.9	12.4
30	110	1.61	39328.9	578.3	68.0	2.00	78.63	0.079	232.5	1.1	19.6
35	110	1.61	39328.9	578.3	68.0	2.00	78.63	0.079	232.5	1.2	23.6
40	90	1.45	29374.6	520.4	56.4	1.77	51.87	0.052	205.2	1.1	19.6
45	70	1.27	20331.1	456.6	44.5	1.51	30.65	0.031	170.7	0.9	12.4
50	50	1.07	12382.2	384.0	32.2	1.22	15.05	0.015	124.1	0.7	6.9
55	40	0.95	8898.6	342.6	26.0	1.05	9.36	0.009	93.0	0.5	3.7
60	40	0.95	8898.6	342.6	26.0	1.05	9.36	0.009	93.0	0.5	2.8

**Figure A-12: Hydrograph 1, 60min storm simulation with varying total culvert flow****Table A-14: Summary of hydrograph 1 storm simulations with varying total culvert flow**

Sample time	(min)	60	120	180
Total collected	(litres)	9.2	18.3	29.0
Total discharge	(m <sup>3</sup> )	117.0	231.0	424.0
Estimated tot Q	(m <sup>3</sup> )	107.5	216.4	368
Error	(%)	8.09	6.31	13.22

**Table A-15: Hydrograph 2, 180min storm simulation with varying total culvert flow**

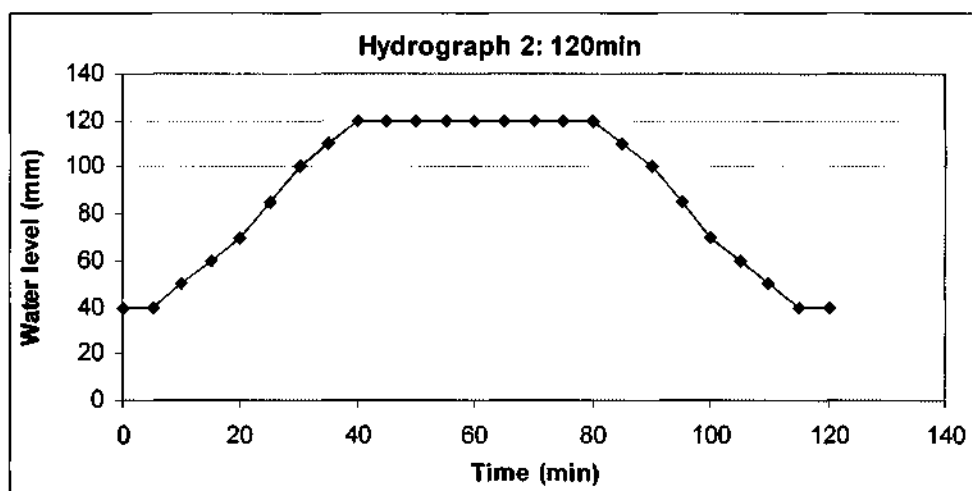
Time (min)	Water level (mm)	Theta	Area of flow (mm <sup>2</sup> )	Perimeter (mm)	Hydraulic radius (mm)	Selected velocity (m/s)	Flow Q (l/s)	Flow Q (m/s)	Orifice collection (ml/min)	Total sampled (litres)	Total calc flow (m <sup>3</sup> )
0	40	0.95	8898.6	342.6	26.0	1.05	9.36	0.009	93.0	0.0	0
5	40	0.95	8898.6	342.6	26.0	1.05	9.36	0.009	93.0	0.5	2.8
10	40	0.95	8898.6	342.6	26.0	1.05	9.36	0.009	93.0	0.5	2.8
15	45	1.01	10595.2	363.9	29.1	1.14	12.03	0.012	109.4	0.5	3.2
20	52	1.09	13121.1	391.8	33.5	1.25	16.36	0.016	129.6	0.6	4.3
25	60	1.17	16205.6	421.7	38.4	1.37	22.15	0.022	149.4	0.7	5.8
30	70	1.27	20331.1	456.6	44.5	1.51	30.65	0.031	170.7	0.8	7.9
35	80	1.36	24729.0	489.4	50.5	1.64	40.56	0.041	189.1	0.9	10.7
40	90	1.45	29374.6	520.4	56.4	1.77	51.87	0.052	205.2	1.0	13.9
45	100	1.53	34247.3	549.9	62.3	1.89	64.57	0.065	219.6	1.1	17.5
50	110	1.61	39328.9	578.3	68.0	2.00	78.63	0.079	232.5	1.1	21.5
55	120	1.68	44603.7	605.6	73.7	2.11	94.05	0.094	244.3	1.2	25.9
60	125	1.72	47309.1	618.9	76.4	2.16	102.26	0.102	249.7	1.2	29.4
65	128	1.74	48953.1	626.8	78.1	2.19	107.34	0.107	252.9	1.3	31.4
70	130	1.76	50057.6	632.0	79.2	2.21	110.79	0.111	255.0	1.3	32.7
75	130	1.76	50057.6	632.0	79.2	2.21	110.79	0.111	255.0	1.3	33.2
80	130	1.76	50057.6	632.0	79.2	2.21	110.79	0.111	255.0	1.3	33.2
85	130	1.76	50057.6	632.0	79.2	2.21	110.79	0.111	255.0	1.3	33.2
90	130	1.76	50057.6	632.0	79.2	2.21	110.79	0.111	255.0	1.3	33.2
95	130	1.76	50057.6	632.0	79.2	2.21	110.79	0.111	255.0	1.3	33.2
100	130	1.76	50057.6	632.0	79.2	2.21	110.79	0.111	255.0	1.3	33.2
105	130	1.76	50057.6	632.0	79.2	2.21	110.79	0.111	255.0	1.3	33.2
110	130	1.76	50057.6	632.0	79.2	2.21	110.79	0.111	255.0	1.3	33.2
115	128	1.74	48953.1	626.8	78.1	2.19	107.34	0.107	252.9	1.3	32.7
120	125	1.72	47309.1	618.9	76.4	2.16	102.26	0.102	249.7	1.3	31.4
125	120	1.68	44603.7	605.6	73.7	2.11	94.05	0.094	244.3	1.2	29.4
130	110	1.61	39328.9	578.3	68.0	2.00	78.63	0.079	232.5	1.2	25.9
135	100	1.53	34247.3	549.9	62.3	1.89	64.57	0.065	219.6	1.1	21.5
140	90	1.45	29374.6	520.4	56.4	1.77	51.87	0.052	205.2	1.1	17.5
145	80	1.36	24729.0	489.4	50.5	1.64	40.56	0.041	189.1	1.0	13.9
150	70	1.27	20331.1	456.6	44.5	1.51	30.65	0.031	170.7	0.9	10.7
155	60	1.17	16205.6	421.7	38.4	1.37	22.15	0.022	149.4	0.8	7.9
160	52	1.09	13121.1	391.8	33.5	1.25	16.36	0.016	129.6	0.7	5.8
165	45	1.01	10595.2	363.9	29.1	1.14	12.03	0.012	109.4	0.6	4.3
170	40	0.95	8898.6	342.6	26.0	1.05	9.36	0.009	93.0	0.5	3.2
175	40	0.95	8898.6	342.6	26.0	1.05	9.36	0.009	93.0	0.5	2.8
180	40	0.95	8898.6	342.6	26.0	1.05	9.36	0.009	93.0	0.5	2.8



**Figure A-13: Hydrograph 2, 180min storm simulation with varying total culvert flow**

**Table A-16: Hydrograph 2, 120min storm simulation with varying total culvert flow**

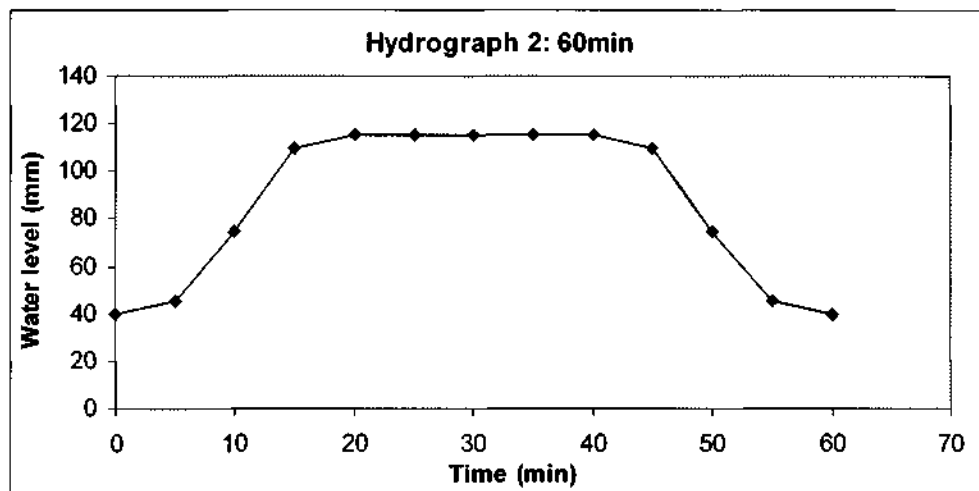
Time (min)	Water level (mm)	Theta	Area of flow (mm <sup>2</sup> )	Perimeter (mm)	Hydraulic radius (mm)	Selected velocity (m/s)	Flow Q (l/s)	Flow Q (m/s)	Orifice collection (ml/min)	Total sampled (litres)	Total calc flow (m <sup>3</sup> )
0	40	0.95	8898.6	342.6	26.0	1.05	9.36	0.009	93.0	0.0	0
5	40	0.95	8898.6	342.6	26.0	1.05	9.36	0.009	93.0	0.5	2.8
10	50	1.07	12382.2	384.0	32.2	1.22	15.05	0.015	124.1	0.5	3.7
15	60	1.17	16205.6	421.7	38.4	1.37	22.15	0.022	149.4	0.7	5.6
20	70	1.27	20331.1	456.6	44.5	1.51	30.65	0.031	170.7	0.8	7.9
25	85	1.40	27022.2	505.1	53.5	1.70	46.04	0.046	197.4	0.9	11.5
30	100	1.53	34247.3	549.9	62.3	1.89	64.57	0.065	219.6	1.0	16.6
35	110	1.61	39328.9	578.3	68.0	2.00	78.63	0.079	232.5	1.1	21.5
40	120	1.68	44603.7	605.6	73.7	2.11	94.05	0.094	244.3	1.2	25.9
45	120	1.68	44603.7	605.6	73.7	2.11	94.05	0.094	244.3	1.2	28.2
50	120	1.68	44603.7	605.6	73.7	2.11	94.05	0.094	244.3	1.2	28.2
55	120	1.68	44603.7	605.6	73.7	2.11	94.05	0.094	244.3	1.2	28.2
60	120	1.68	44603.7	605.6	73.7	2.11	94.05	0.094	244.3	1.2	28.2
65	120	1.68	44603.7	605.6	73.7	2.11	94.05	0.094	244.3	1.2	28.2
70	120	1.68	44603.7	605.6	73.7	2.11	94.05	0.094	244.3	1.2	28.2
75	120	1.68	44603.7	605.6	73.7	2.11	94.05	0.094	244.3	1.2	28.2
80	120	1.68	44603.7	605.6	73.7	2.11	94.05	0.094	244.3	1.2	28.2
85	110	1.61	39328.9	578.3	68.0	2.00	78.63	0.079	232.5	1.2	25.9
90	100	1.53	34247.3	549.9	62.3	1.89	64.57	0.065	219.6	1.1	21.5
95	85	1.40	27022.2	505.1	53.5	1.70	46.04	0.046	197.4	1.0	16.6
100	70	1.27	20331.1	456.6	44.5	1.51	30.65	0.031	170.7	0.9	11.5
105	60	1.17	16205.6	421.7	38.4	1.37	22.15	0.022	149.4	0.8	7.9
110	50	1.07	12382.2	384.0	32.2	1.22	15.05	0.015	124.1	0.7	5.6
115	40	0.95	8898.6	342.6	26.0	1.05	9.36	0.009	93.0	0.5	3.7
120	40	0.95	8898.6	342.6	26.0	1.05	9.36	0.009	93.0	0.5	2.8



**Figure A-14: Hydrograph 2, 120min storm simulation with varying total culvert flow**

**Table A-17: Hydrograph 2, 60min storm simulation with varying total culvert flow**

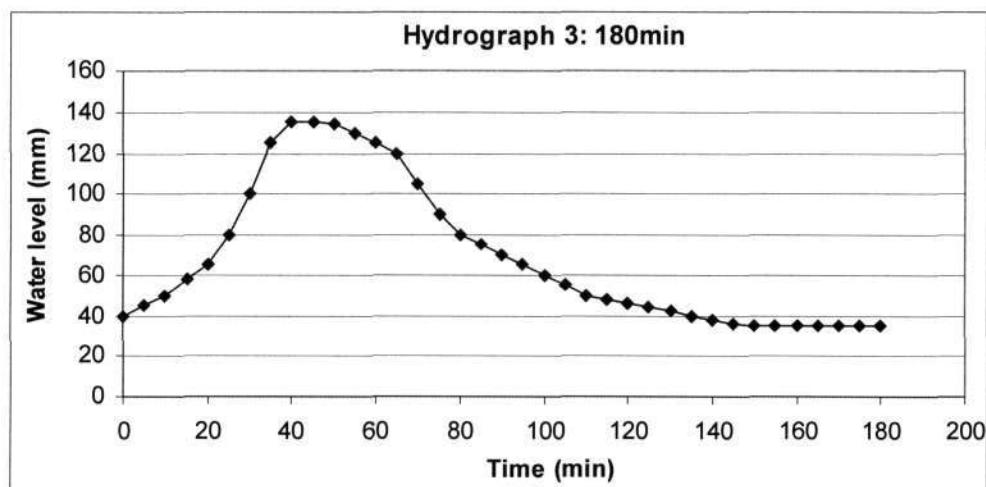
Time (min)	Water level (mm)	Theta	Area of flow (mm <sup>2</sup> )	Perimeter (mm)	Hydraulic radius (mm)	Selected velocity (m/s)	Flow Q (l/s)	Flow Q (m/s)	Orifice collection (ml/min)	Total sampled (litres)	Total calc flow (m <sup>3</sup> )
0	40	0.95	8898.6	342.6	26.0	1.05	9.36	0.009	93.0	0.0	0
5	45	1.01	10595.2	363.9	29.1	1.14	12.03	0.012	109.4	0.5	3.2
10	75	1.31	22497.6	473.2	47.5	1.57	35.43	0.035	180.2	0.7	7.1
15	110	1.61	39328.9	578.3	68.0	2.00	78.63	0.079	232.5	1.0	17.1
20	115	1.64	41943.1	592.0	70.8	2.05	86.18	0.086	238.5	1.2	24.7
25	115	1.64	41943.1	592.0	70.8	2.05	86.18	0.086	238.5	1.2	25.9
30	115	1.64	41943.1	592.0	70.8	2.05	86.18	0.086	238.5	1.2	25.9
35	115	1.64	41943.1	592.0	70.8	2.05	86.18	0.086	238.5	1.2	25.9
40	115	1.64	41943.1	592.0	70.8	2.05	86.18	0.086	238.5	1.2	25.9
45	110	1.61	39328.9	578.3	68.0	2.00	78.63	0.079	232.5	1.2	24.7
50	75	1.31	22497.6	473.2	47.5	1.57	35.43	0.035	180.2	1.0	17.1
55	45	1.01	10595.2	363.9	29.1	1.14	12.03	0.012	109.4	0.7	7.1
60	40	0.95	8898.6	342.6	26.0	1.05	9.36	0.009	93.0	0.5	3.2

**Figure A-15: Hydrograph 2, 60min storm simulation with varying total culvert flow****Table A-18: Summary of hydrograph 2 storm simulations with varying total culvert flow**

Sample time	min	60	120	180
Total collected	litres	11.6	23.3	35.3
Total discharge	m <sup>3</sup>	207.7	416.6	685.5
Estimated tot Q	m <sup>3</sup>	176.3	368	568.5
Error	%	15.13	11.67	17.06

**Table A-19: Hydrograph 3, 180min storm simulation with varying total culvert flow**

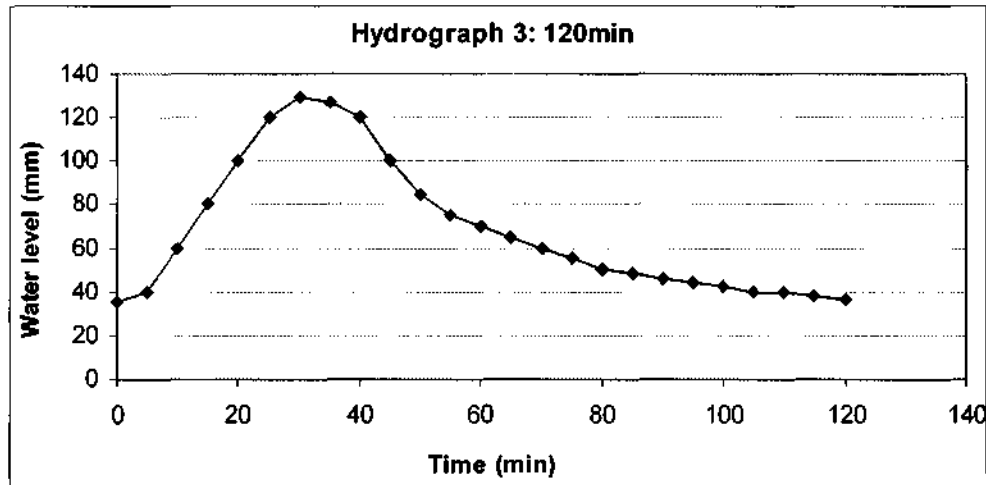
Time (min)	Water level (mm)	Theta	Area of flow (mm <sup>2</sup> )	Perimeter (mm)	Hydraulic radius (mm)	Velocity K = 12 (m/s)	Flow Q (l/s)	Flow Q (m/s)	Orifice collection (ml/min)	Total sampled (litres)	Total calc flow (m <sup>3</sup> )
0	40	0.95	8898.6	342.6	26.0	1.05	9.36	0.009	93.0	0.0	0
5	45	1.01	10595.2	363.9	29.1	1.14	12.03	0.012	109.4	0.5	3.2
10	50	1.07	12382.2	384.0	32.2	1.22	15.05	0.015	124.1	0.6	4.1
15	58	1.15	15415.7	414.4	37.2	1.34	20.61	0.021	144.7	0.7	5.4
20	65	1.22	18232.6	439.5	41.5	1.44	26.22	0.026	160.5	0.8	7.0
25	80	1.36	24729.0	489.4	50.5	1.64	40.56	0.041	189.1	0.9	10.0
30	100	1.53	34247.3	549.9	62.3	1.89	64.57	0.065	219.6	1.0	15.8
35	125	1.72	47309.1	618.9	76.4	2.16	102.26	0.102	249.7	1.2	25.0
40	135	1.79	52847.6	644.9	81.9	2.26	119.65	0.120	260.0	1.3	33.3
45	135	1.79	52847.6	644.9	81.9	2.26	119.65	0.120	260.0	1.3	35.9
50	134	1.78	52286.3	642.3	81.4	2.25	117.85	0.118	259.0	1.3	35.6
55	130	1.76	50057.6	632.0	79.2	2.21	110.79	0.111	255.0	1.3	34.3
60	125	1.72	47309.1	618.9	76.4	2.16	102.26	0.102	249.7	1.3	32.0
65	120	1.68	44603.7	605.6	73.7	2.11	94.05	0.094	244.3	1.2	29.4
70	105	1.57	36763.0	564.2	65.2	1.94	71.43	0.071	226.2	1.2	24.8
75	90	1.45	29374.6	520.4	56.4	1.77	51.87	0.052	205.2	1.1	18.5
80	80	1.36	24729.0	489.4	50.5	1.64	40.56	0.041	189.1	1.0	13.9
85	75	1.31	22497.6	473.2	47.5	1.57	35.43	0.035	180.2	0.9	11.4
90	70	1.27	20331.1	456.6	44.5	1.51	30.65	0.031	170.7	0.9	9.9
95	65	1.22	18232.6	439.5	41.5	1.44	26.22	0.026	160.5	0.8	8.5
100	60	1.17	16205.6	421.7	38.4	1.37	22.15	0.022	149.4	0.8	7.3
105	55	1.12	14254.0	403.2	35.3	1.29	18.42	0.018	137.3	0.7	6.1
110	50	1.07	12382.2	384.0	32.2	1.22	15.05	0.015	124.1	0.7	5.0
115	48	1.04	11656.9	376.1	31.0	1.18	13.80	0.014	118.4	0.6	4.3
120	46	1.02	10945.6	368.0	29.7	1.15	12.61	0.013	112.5	0.6	4.0
125	44	1.00	10248.4	359.7	28.5	1.12	11.47	0.011	106.3	0.5	3.6
130	42	0.98	9566.0	351.3	27.2	1.09	10.39	0.010	99.8	0.5	3.3
135	40	0.95	8898.6	342.6	26.0	1.05	9.36	0.009	93.0	0.5	3.0
140	38	0.93	8246.7	333.8	24.7	1.02	8.39	0.008	85.8	0.4	2.7
145	36	0.90	7610.9	324.7	23.4	0.98	7.48	0.007	78.2	0.4	2.4
150	35	0.89	7299.1	320.1	22.8	0.96	7.04	0.007	74.3	0.4	2.2
155	35	0.89	7299.1	320.1	22.8	0.96	7.04	0.007	74.3	0.4	2.1
160	35	0.89	7299.1	320.1	22.8	0.96	7.04	0.007	74.3	0.4	2.1
165	35	0.89	7299.1	320.1	22.8	0.96	7.04	0.007	74.3	0.4	2.1
170	35	0.89	7299.1	320.1	22.8	0.96	7.04	0.007	74.3	0.4	2.1
175	35	0.89	7299.1	320.1	22.8	0.96	7.04	0.007	74.3	0.4	2.1
180	35	0.89	7299.1	320.1	22.8	0.96	7.04	0.007	74.3	0.4	2.1



**Figure A-16: Hydrograph 2, 180min storm simulation with varying total culvert flow**

**Table A-20: Hydrograph 3, 120min storm simulation with varying total culvert flow**

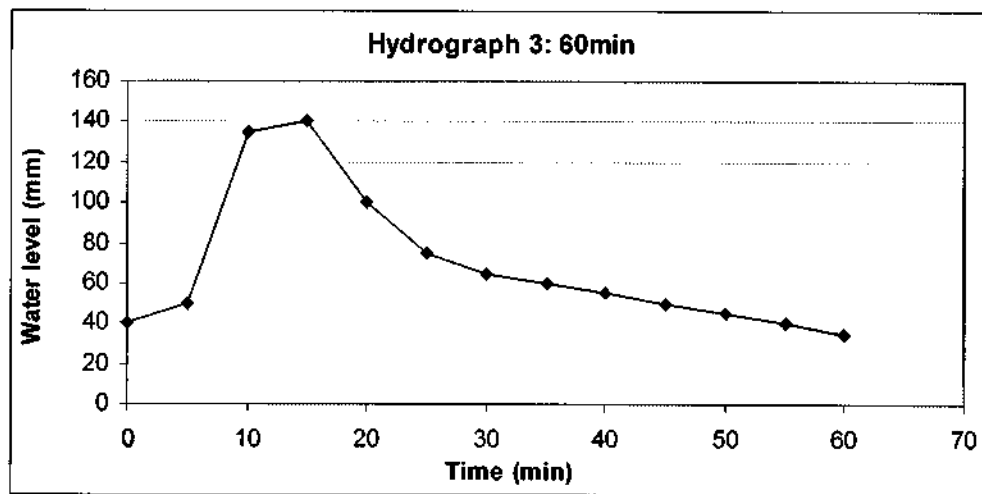
Time (min)	Water level (mm)	Theta	Area of flow (mm <sup>2</sup> )	Perimeter (mm)	Hydraulic radius (mm)	Velocity K = 12 (m/s)	Flow Q (l/s)	Flow Q (m/s)	Orifice collection (ml/min)	Total sampled (litres)	Total calc flow (m <sup>3</sup> )
0	35	0.89	7299.1	320.1	22.8	0.96	7.04	0.007	74.3	0.0	0
5	40	0.95	8898.6	342.6	26.0	1.05	9.36	0.009	93.0	0.4	2.5
10	60	1.17	16205.6	421.7	38.4	1.37	22.15	0.022	149.4	0.6	4.7
15	80	1.36	24729.0	489.4	50.5	1.64	40.56	0.041	189.1	0.8	9.4
20	100	1.53	34247.3	549.9	62.3	1.89	64.57	0.065	219.6	1.0	15.8
25	120	1.68	44603.7	605.6	73.7	2.11	94.05	0.094	244.3	1.2	23.8
30	130	1.76	50057.6	632.0	79.2	2.21	110.79	0.111	255.0	1.2	30.7
35	127	1.73	48403.4	624.1	77.6	2.18	105.63	0.106	251.9	1.3	32.5
40	120	1.68	44603.7	605.6	73.7	2.11	94.05	0.094	244.3	1.2	30.0
45	100	1.53	34247.3	549.9	62.3	1.89	64.57	0.065	219.6	1.2	23.8
50	85	1.40	27022.2	505.1	53.5	1.70	46.04	0.046	197.4	1.0	16.6
55	75	1.31	22497.6	473.2	47.5	1.57	35.43	0.035	180.2	0.9	12.2
60	70	1.27	20331.1	456.6	44.5	1.51	30.65	0.031	170.7	0.9	9.9
65	65	1.22	18232.6	439.5	41.5	1.44	26.22	0.026	160.5	0.8	8.5
70	60	1.17	16205.6	421.7	38.4	1.37	22.15	0.022	149.4	0.8	7.3
75	55	1.12	14254.0	403.2	35.3	1.29	18.42	0.018	137.3	0.7	6.1
80	50	1.07	12382.2	384.0	32.2	1.22	15.05	0.015	124.1	0.7	5.0
85	48	1.04	11656.9	376.1	31.0	1.18	13.80	0.014	118.4	0.6	4.3
90	46	1.02	10945.6	368.0	29.7	1.15	12.61	0.013	112.5	0.6	4.0
95	44	1.00	10248.4	359.7	28.5	1.12	11.47	0.011	106.3	0.5	3.6
100	42	0.98	9566.0	351.3	27.2	1.09	10.39	0.010	99.8	0.5	3.3
105	40	0.95	8898.6	342.6	26.0	1.05	9.36	0.009	93.0	0.5	3.0
110	40	0.95	8898.6	342.6	26.0	1.05	9.36	0.009	93.0	0.5	2.8
115	38	0.93	8246.7	333.8	24.7	1.02	8.39	0.008	85.8	0.4	2.7
120	36	0.90	7610.9	324.7	23.4	0.98	7.48	0.007	78.2	0.4	2.4



**Figure A-17: Hydrograph 2, 120min storm simulation with varying total culvert flow**

**Table A-21: Hydrograph 3, 60min storm simulation with varying total culvert flow**

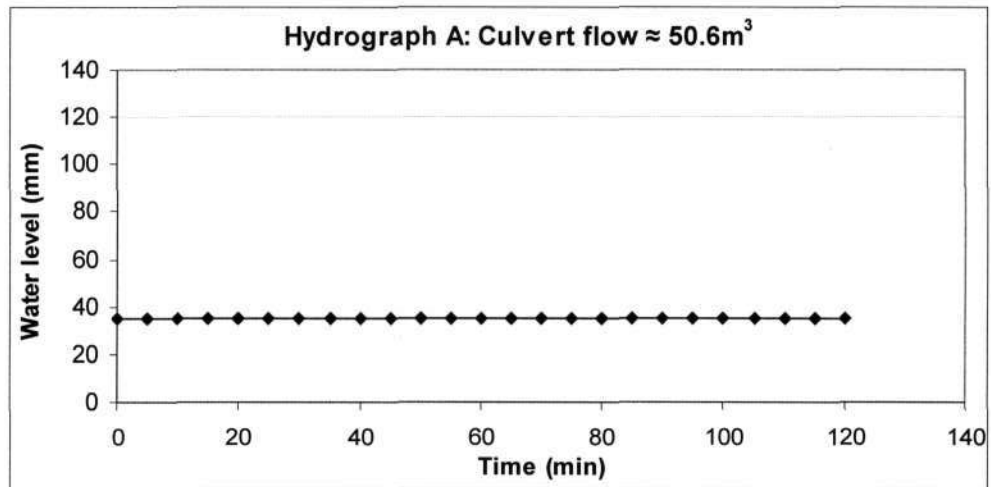
Time (min)	Water level (mm)	Theta	Area of flow (mm <sup>2</sup> )	Perimeter (mm)	Hydraulic radius (mm)	Velocity K = 12 (m/s)	Flow Q (l/s)	Flow Q (m/s)	Orifice collection (ml/min)	Total sampled (litres)	Total calc flow (m <sup>3</sup> )
0	40	0.95	8898.6	342.6	26.0	1.05	9.36	0.009	93.0	0.0	0
5	50	1.07	12382.2	384.0	32.2	1.22	15.05	0.015	124.1	0.5	3.7
10	135	1.79	52847.6	644.9	81.9	2.26	119.65	0.120	260.0	1.0	20.2
15	140	1.83	55677.6	657.6	84.7	2.31	128.83	0.129	264.9	1.3	37.3
20	100	1.53	34247.3	549.9	62.3	1.89	64.57	0.065	219.6	1.2	29.0
25	75	1.31	22497.6	473.2	47.5	1.57	35.43	0.035	180.2	1.0	15.0
30	65	1.22	18232.6	439.5	41.5	1.44	26.22	0.026	160.5	0.9	9.2
35	60	1.17	16205.6	421.7	38.4	1.37	22.15	0.022	149.4	0.8	7.3
40	55	1.12	14254.0	403.2	35.3	1.29	18.42	0.018	137.3	0.7	6.1
45	50	1.07	12382.2	384.0	32.2	1.22	15.05	0.015	124.1	0.7	5.0
50	45	1.01	10595.2	363.9	29.1	1.14	12.03	0.012	109.4	0.6	4.1
55	40	0.95	8898.6	342.6	26.0	1.05	9.36	0.009	93.0	0.5	3.2
60	35	0.89	7299.1	320.1	22.8	0.96	7.04	0.007	74.3	0.4	2.5

**Figure A-18: Hydrograph 3, 60min storm simulation with varying total culvert flow****Table A-22: Summary of hydrograph 3 storm simulations with varying total culvert flow**

Sample time	(min)	60	120	180
Total collected	(litres)	9.5	18.9	27.5
Total discharge	(m <sup>3</sup> )	142.5	264.7	414.4
Estimated tot Q	(m <sup>3</sup> )	115.0	232.1	327.4
Error	(%)	19.29	12.32	20.99

**Table A-23: Hydrograph A, storm simulation with a 50.6m<sup>3</sup> preset total culvert flow**

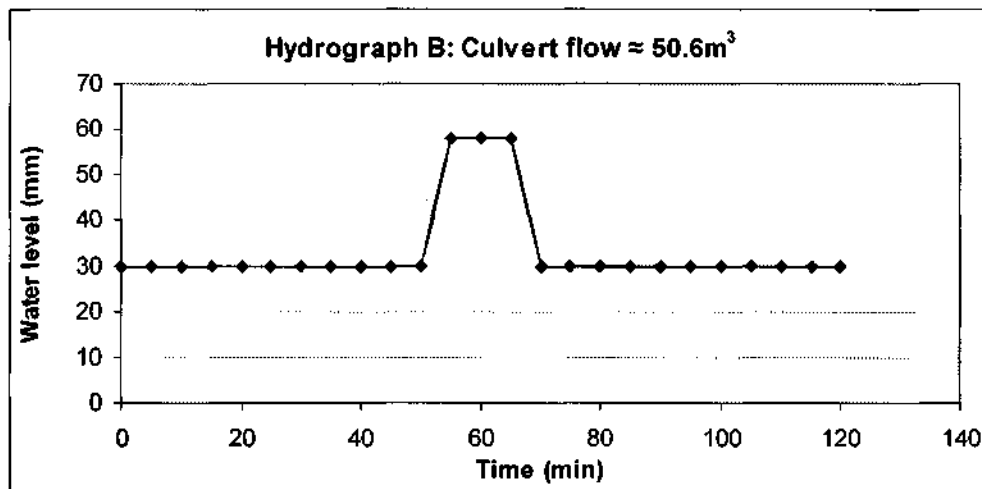
Time (min)	Water level (mm)	Theta	Area of flow (mm <sup>2</sup> )	Perimeter (mm)	Hydraulic radius (mm)	Velocity K = 12 (m/s)	Flow Q (l/s)	Flow Q (m/s)	Orifice collection (ml/min)	Total sampled (litres)	Total calc flow (m <sup>3</sup> )
0	35	0.89	7299.1	320.1	22.8	0.96	7.04	0.007	74.3	0.0	0
5	35	0.89	7299.1	320.1	22.8	0.96	7.04	0.007	74.3	0.4	2.1
10	35	0.89	7299.1	320.1	22.8	0.96	7.04	0.007	74.3	0.4	2.1
15	35	0.89	7299.1	320.1	22.8	0.96	7.04	0.007	74.3	0.4	2.1
20	35	0.89	7299.1	320.1	22.8	0.96	7.04	0.007	74.3	0.4	2.1
25	35	0.89	7299.1	320.1	22.8	0.96	7.04	0.007	74.3	0.4	2.1
30	35	0.89	7299.1	320.1	22.8	0.96	7.04	0.007	74.3	0.4	2.1
35	35	0.89	7299.1	320.1	22.8	0.96	7.04	0.007	74.3	0.4	2.1
40	35	0.89	7299.1	320.1	22.8	0.96	7.04	0.007	74.3	0.4	2.1
45	35	0.89	7299.1	320.1	22.8	0.96	7.04	0.007	74.3	0.4	2.1
50	35	0.89	7299.1	320.1	22.8	0.96	7.04	0.007	74.3	0.4	2.1
55	35	0.89	7299.1	320.1	22.8	0.96	7.04	0.007	74.3	0.4	2.1
60	35	0.89	7299.1	320.1	22.8	0.96	7.04	0.007	74.3	0.4	2.1
65	35	0.89	7299.1	320.1	22.8	0.96	7.04	0.007	74.3	0.4	2.1
70	35	0.89	7299.1	320.1	22.8	0.96	7.04	0.007	74.3	0.4	2.1
75	35	0.89	7299.1	320.1	22.8	0.96	7.04	0.007	74.3	0.4	2.1
80	35	0.89	7299.1	320.1	22.8	0.96	7.04	0.007	74.3	0.4	2.1
85	35	0.89	7299.1	320.1	22.8	0.96	7.04	0.007	74.3	0.4	2.1
90	35	0.89	7299.1	320.1	22.8	0.96	7.04	0.007	74.3	0.4	2.1
95	35	0.89	7299.1	320.1	22.8	0.96	7.04	0.007	74.3	0.4	2.1
100	35	0.89	7299.1	320.1	22.8	0.96	7.04	0.007	74.3	0.4	2.1
105	35	0.89	7299.1	320.1	22.8	0.96	7.04	0.007	74.3	0.4	2.1
110	35	0.89	7299.1	320.1	22.8	0.96	7.04	0.007	74.3	0.4	2.1
115	35	0.89	7299.1	320.1	22.8	0.96	7.04	0.007	74.3	0.4	2.1
120	35	0.89	7299.1	320.1	22.8	0.96	7.04	0.007	74.3	0.4	2.1



**Figure A-19: Hydrograph A, storm simulation with a 50.6m<sup>3</sup> preset total culvert flow**

**Table A-24: Hydrograph B, storm simulation with a 50.6m<sup>3</sup> preset total culvert flow**

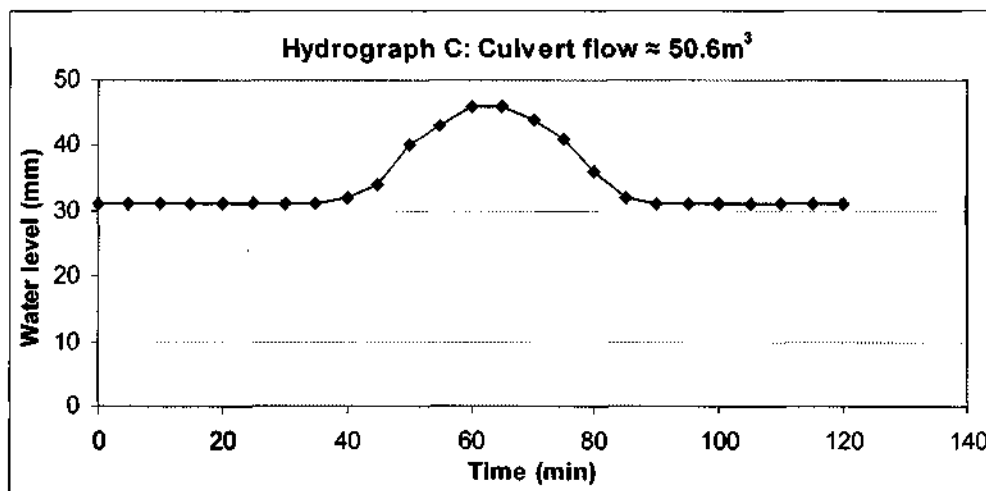
Time (min)	Water level (mm)	Theta	Area of flow (mm <sup>2</sup> )	Perimeter (mm)	Hydraulic radius (mm)	Velocity K = 12 (m/s)	Flow Q (l/s)	Flow Q (m <sup>3</sup> /s)	Orifice collection (ml/min)	Total sampled (litres)	Total calc flow (m <sup>3</sup> )
0	30	0.82	5804.7	296.0	19.6	0.87	5.07	0.005	52.7	0.0	0
5	30	0.82	5804.7	296.0	19.6	0.87	5.07	0.005	52.7	0.3	1.5
10	30	0.82	5804.7	296.0	19.6	0.87	5.07	0.005	52.7	0.3	1.5
15	30	0.82	5804.7	296.0	19.6	0.87	5.07	0.005	52.7	0.3	1.5
20	30	0.82	5804.7	296.0	19.6	0.87	5.07	0.005	52.7	0.3	1.5
25	30	0.82	5804.7	296.0	19.6	0.87	5.07	0.005	52.7	0.3	1.5
30	30	0.82	5804.7	296.0	19.6	0.87	5.07	0.005	52.7	0.3	1.5
35	30	0.82	5804.7	296.0	19.6	0.87	5.07	0.005	52.7	0.3	1.5
40	30	0.82	5804.7	296.0	19.6	0.87	5.07	0.005	52.7	0.3	1.5
45	30	0.82	5804.7	296.0	19.6	0.87	5.07	0.005	52.7	0.3	1.5
50	30	0.82	5804.7	296.0	19.6	0.87	5.07	0.005	52.7	0.3	1.5
55	58	1.15	15415.7	414.4	37.2	1.34	20.61	0.021	144.7	0.6	3.9
60	58	1.15	15415.7	414.4	37.2	1.34	20.61	0.021	144.7	0.7	6.2
65	58	1.15	15415.7	414.4	37.2	1.34	20.61	0.021	144.7	0.7	6.2
70	30	0.82	5804.7	296.0	19.6	0.87	5.07	0.005	52.7	0.5	3.9
75	30	0.82	5804.7	296.0	19.6	0.87	5.07	0.005	52.7	0.3	1.5
80	30	0.82	5804.7	296.0	19.6	0.87	5.07	0.005	52.7	0.3	1.5
85	30	0.82	5804.7	296.0	19.6	0.87	5.07	0.005	52.7	0.3	1.5
90	30	0.82	5804.7	296.0	19.6	0.87	5.07	0.005	52.7	0.3	1.5
95	30	0.82	5804.7	296.0	19.6	0.87	5.07	0.005	52.7	0.3	1.5
100	30	0.82	5804.7	296.0	19.6	0.87	5.07	0.005	52.7	0.3	1.5
105	30	0.82	5804.7	296.0	19.6	0.87	5.07	0.005	52.7	0.3	1.5
110	30	0.82	5804.7	296.0	19.6	0.87	5.07	0.005	52.7	0.3	1.5
115	30	0.82	5804.7	296.0	19.6	0.87	5.07	0.005	52.7	0.3	1.5
120	30	0.82	5804.7	296.0	19.6	0.87	5.07	0.005	52.7	0.3	1.5



**Figure A-20: Hydrograph B, storm simulation with a 50.6m<sup>3</sup> preset total culvert flow**

**Table A-25: Hydrograph C, storm simulation with a 50.6m<sup>3</sup> preset total culvert flow**

Time (min)	Water level (mm)	Theta	Area of flow (mm <sup>2</sup> )	Perimeter (mm)	Hydraulic radius (mm)	Velocity K = 12 (m/s)	Flow Q (l/s)	Flow Q (m/s)	Orifice collection (ml/min)	Total sampled (litres)	Total calc flow (m <sup>3</sup> )
0	31	0.84	6094.8	301.0	20.2	0.89	5.43	0.005	57.3	0.0	0
5	31	0.84	6094.8	301.0	20.2	0.89	5.43	0.005	57.3	0.3	1.6
10	31	0.84	6094.8	301.0	20.2	0.89	5.43	0.005	57.3	0.3	1.6
15	31	0.84	6094.8	301.0	20.2	0.89	5.43	0.005	57.3	0.3	1.6
20	31	0.84	6094.8	301.0	20.2	0.89	5.43	0.005	57.3	0.3	1.6
25	31	0.84	6094.8	301.0	20.2	0.89	5.43	0.005	57.3	0.3	1.6
30	31	0.84	6094.8	301.0	20.2	0.89	5.43	0.005	57.3	0.3	1.6
35	31	0.84	6094.8	301.0	20.2	0.89	5.43	0.005	57.3	0.3	1.6
40	32	0.85	6389.3	305.9	20.9	0.91	5.82	0.006	61.7	0.3	1.7
45	34	0.88	6991.5	315.4	22.2	0.95	6.62	0.007	70.2	0.3	1.9
50	40	0.95	8898.6	342.6	26.0	1.05	9.36	0.009	93.0	0.4	2.4
55	43	0.99	9905.3	355.5	27.9	1.10	10.92	0.011	103.1	0.5	3.0
60	46	1.02	10945.6	368.0	29.7	1.15	12.61	0.013	112.5	0.5	3.5
65	46	1.02	10945.6	368.0	29.7	1.15	12.61	0.013	112.5	0.6	3.8
70	44	1.00	10248.4	359.7	28.5	1.12	11.47	0.011	106.3	0.5	3.6
75	41	0.96	9230.4	347.0	26.6	1.07	9.87	0.010	96.4	0.5	3.2
80	36	0.90	7610.9	324.7	23.4	0.98	7.48	0.007	78.2	0.4	2.6
85	32	0.85	6389.3	305.9	20.9	0.91	5.82	0.006	61.7	0.3	2.0
90	31	0.84	6094.8	301.0	20.2	0.89	5.43	0.005	57.3	0.3	1.7
95	31	0.84	6094.8	301.0	20.2	0.89	5.43	0.005	57.3	0.3	1.6
100	31	0.84	6094.8	301.0	20.2	0.89	5.43	0.005	57.3	0.3	1.6
105	31	0.84	6094.8	301.0	20.2	0.89	5.43	0.005	57.3	0.3	1.6
110	31	0.84	6094.8	301.0	20.2	0.89	5.43	0.005	57.3	0.3	1.6
115	31	0.84	6094.8	301.0	20.2	0.89	5.43	0.005	57.3	0.3	1.6
120	31	0.84	6094.8	301.0	20.2	0.89	5.43	0.005	57.3	0.3	1.6



**Figure A-21: Hydrograph C, storm simulation with a 50.6m<sup>3</sup> preset total culvert flow**

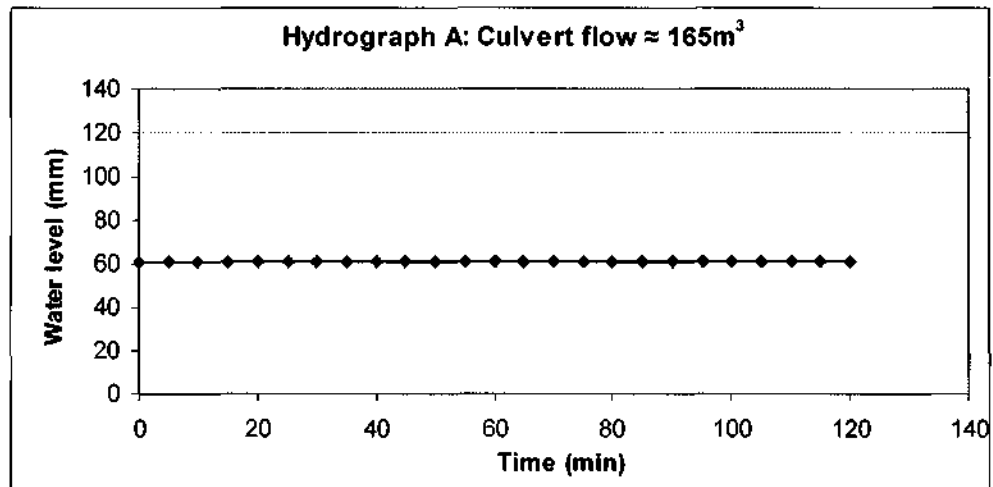
**Table A-26: Summary of hydrographs A-C with a 50.6m<sup>3</sup> preset total culvert flow**

		A	B	C
Sample time	(min)	120	120	120
Total collected	(litres)	8.9	7.7	8.5
Total discharge	(m <sup>3</sup> )	50.7	50.5	50.6
Estimated tot Q	(m <sup>3</sup> )	39.8	31.3	36.4
Corrected estimate	(m <sup>3</sup> )	55.7	43.8	50.9
Error	(%)	21.51	37.98	28.06
Error for corrected	(%)	9.83	13.21	0.67
Q <sub>curve</sub> /Q <sub>calculated</sub>		0.78	0.62	0.72

Correction factor
1.40

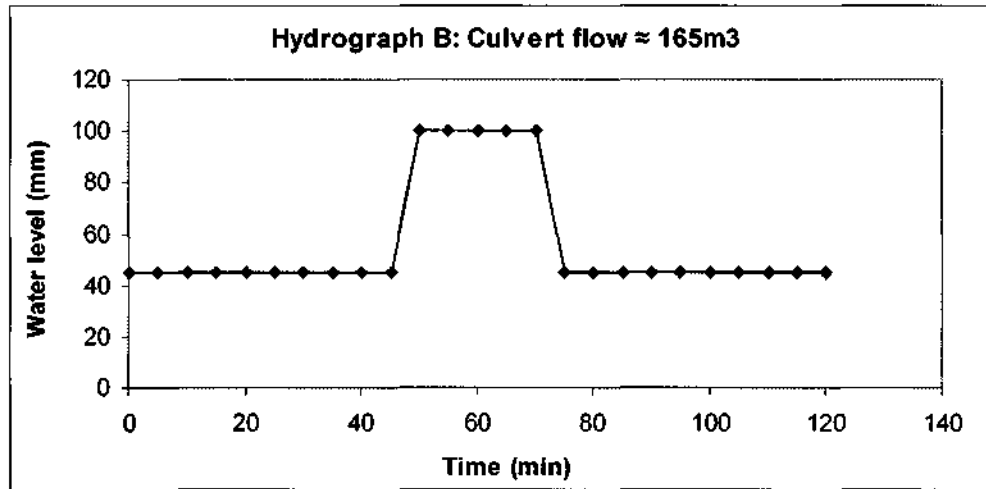
Table A-27: Hydrograph A, storm simulation with a 165m<sup>3</sup> preset total culvert flow

Time (min)	Water level (mm)	Theta	Area of flow (mm <sup>2</sup> )	Perimeter (mm)	Hydraulic radius (mm)	Velocity K = 12 (m/s)	Flow Q (l/s)	Flow Q (m/s)	Orifice collection (ml/min)	Total sampled (litres)	Total calc flow (m <sup>3</sup> )
0	61	1.18	16605.1	425.3	39.0	1.38	22.93	0.023	151.7	0.0	0
5	61	1.18	16605.1	425.3	39.0	1.38	22.93	0.023	151.7	0.8	6.9
10	61	1.18	16605.1	425.3	39.0	1.38	22.93	0.023	151.7	0.8	6.9
15	61	1.18	16605.1	425.3	39.0	1.38	22.93	0.023	151.7	0.8	6.9
20	61	1.18	16605.1	425.3	39.0	1.38	22.93	0.023	151.7	0.8	6.9
25	61	1.18	16605.1	425.3	39.0	1.38	22.93	0.023	151.7	0.8	6.9
30	61	1.18	16605.1	425.3	39.0	1.38	22.93	0.023	151.7	0.8	6.9
35	61	1.18	16605.1	425.3	39.0	1.38	22.93	0.023	151.7	0.8	6.9
40	61	1.18	16605.1	425.3	39.0	1.38	22.93	0.023	151.7	0.8	6.9
45	61	1.18	16605.1	425.3	39.0	1.38	22.93	0.023	151.7	0.8	6.9
50	61	1.18	16605.1	425.3	39.0	1.38	22.93	0.023	151.7	0.8	6.9
55	61	1.18	16605.1	425.3	39.0	1.38	22.93	0.023	151.7	0.8	6.9
60	61	1.18	16605.1	425.3	39.0	1.38	22.93	0.023	151.7	0.8	6.9
65	61	1.18	16605.1	425.3	39.0	1.38	22.93	0.023	151.7	0.8	6.9
70	61	1.18	16605.1	425.3	39.0	1.38	22.93	0.023	151.7	0.8	6.9
75	61	1.18	16605.1	425.3	39.0	1.38	22.93	0.023	151.7	0.8	6.9
80	61	1.18	16605.1	425.3	39.0	1.38	22.93	0.023	151.7	0.8	6.9
85	61	1.18	16605.1	425.3	39.0	1.38	22.93	0.023	151.7	0.8	6.9
90	61	1.18	16605.1	425.3	39.0	1.38	22.93	0.023	151.7	0.8	6.9
95	61	1.18	16605.1	425.3	39.0	1.38	22.93	0.023	151.7	0.8	6.9
100	61	1.18	16605.1	425.3	39.0	1.38	22.93	0.023	151.7	0.8	6.9
105	61	1.18	16605.1	425.3	39.0	1.38	22.93	0.023	151.7	0.8	6.9
110	61	1.18	16605.1	425.3	39.0	1.38	22.93	0.023	151.7	0.8	6.9
115	61	1.18	16605.1	425.3	39.0	1.38	22.93	0.023	151.7	0.8	6.9
120	61	1.18	16605.1	425.3	39.0	1.38	22.93	0.023	151.7	0.8	6.9

Figure A-22: Hydrograph A, storm simulation with a 165m<sup>3</sup> preset total culvert flow

**Table A-28: Hydrograph B, storm simulation with a 165m<sup>3</sup> preset total culvert flow**

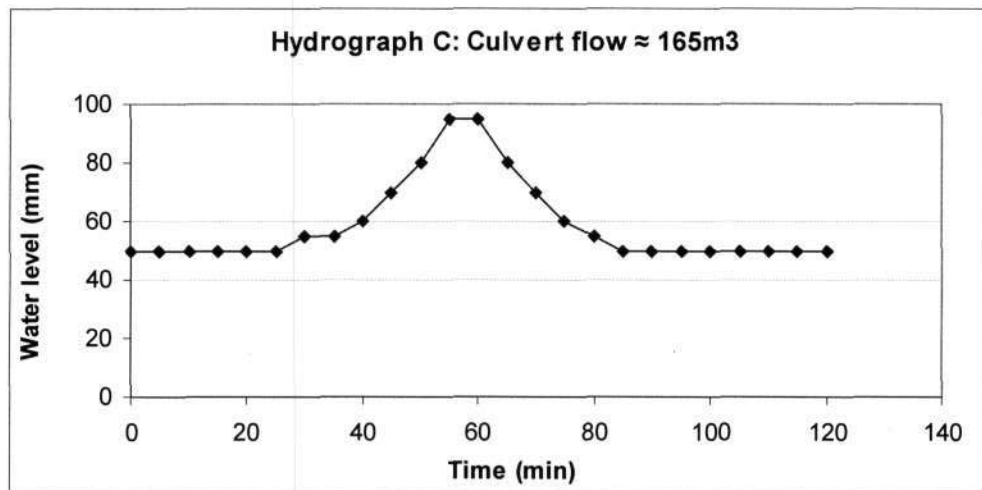
Time (min)	Water level (mm)	Theta	Area of flow (mm <sup>2</sup> )	Perimeter (mm)	Hydraulic radius (mm)	Velocity K = 12 (m/s)	Flow Q (l/s)	Flow Q (m/s)	Orifice collection (ml/min)	Total sampled (litres)	Total calc flow (m <sup>3</sup> )
0	45	1.01	10595.2	363.9	29.1	1.14	12.03	0.012	109.4	0.0	0
5	45	1.01	10595.2	363.9	29.1	1.14	12.03	0.012	109.4	0.5	3.6
10	45	1.01	10595.2	363.9	29.1	1.14	12.03	0.012	109.4	0.5	3.6
15	45	1.01	10595.2	363.9	29.1	1.14	12.03	0.012	109.4	0.5	3.6
20	45	1.01	10595.2	363.9	29.1	1.14	12.03	0.012	109.4	0.5	3.6
25	45	1.01	10595.2	363.9	29.1	1.14	12.03	0.012	109.4	0.5	3.6
30	45	1.01	10595.2	363.9	29.1	1.14	12.03	0.012	109.4	0.5	3.6
35	45	1.01	10595.2	363.9	29.1	1.14	12.03	0.012	109.4	0.5	3.6
40	45	1.01	10595.2	363.9	29.1	1.14	12.03	0.012	109.4	0.5	3.6
45	45	1.01	10595.2	363.9	29.1	1.14	12.03	0.012	109.4	0.5	3.6
50	100	1.53	34247.3	549.9	62.3	1.89	64.57	0.065	219.6	0.8	11.5
55	100	1.53	34247.3	549.9	62.3	1.89	64.57	0.065	219.6	1.1	19.4
60	100	1.53	34247.3	549.9	62.3	1.89	64.57	0.065	219.6	1.1	19.4
65	100	1.53	34247.3	549.9	62.3	1.89	64.57	0.065	219.6	1.1	19.4
70	100	1.53	34247.3	549.9	62.3	1.89	64.57	0.065	219.6	1.1	19.4
75	45	1.01	10595.2	363.9	29.1	1.14	12.03	0.012	109.4	0.8	11.5
80	45	1.01	10595.2	363.9	29.1	1.14	12.03	0.012	109.4	0.5	3.6
85	45	1.01	10595.2	363.9	29.1	1.14	12.03	0.012	109.4	0.5	3.6
90	45	1.01	10595.2	363.9	29.1	1.14	12.03	0.012	109.4	0.5	3.6
95	45	1.01	10595.2	363.9	29.1	1.14	12.03	0.012	109.4	0.5	3.6
100	45	1.01	10595.2	363.9	29.1	1.14	12.03	0.012	109.4	0.5	3.6
105	45	1.01	10595.2	363.9	29.1	1.14	12.03	0.012	109.4	0.5	3.6
110	45	1.01	10595.2	363.9	29.1	1.14	12.03	0.012	109.4	0.5	3.6
115	45	1.01	10595.2	363.9	29.1	1.14	12.03	0.012	109.4	0.5	3.6
120	45	1.01	10595.2	363.9	29.1	1.14	12.03	0.012	109.4	0.5	3.6



**Figure A-23: Hydrograph B, storm simulation with a 165m<sup>3</sup> preset total culvert flow**

**Table A-29: Hydrograph C, storm simulation with a 165m<sup>3</sup> preset total culvert flow**

Time (min)	Water level (mm)	Theta	Area of flow (mm <sup>2</sup> )	Perimeter (mm)	Hydraulic radius (mm)	Velocity K = 12 (m/s)	Flow Q (l/s)	Flow Q (m/s)	Orifice collection (ml/min)	Total sampled (litres)	Total calc flow (m <sup>3</sup> )
0	50	1.07	12382.2	384.0	32.2	1.22	15.05	0.015	124.1	0.0	0
5	50	1.07	12382.2	384.0	32.2	1.22	15.05	0.015	124.1	0.6	4.5
10	50	1.07	12382.2	384.0	32.2	1.22	15.05	0.015	124.1	0.6	4.5
15	50	1.07	12382.2	384.0	32.2	1.22	15.05	0.015	124.1	0.6	4.5
20	50	1.07	12382.2	384.0	32.2	1.22	15.05	0.015	124.1	0.6	4.5
25	50	1.07	12382.2	384.0	32.2	1.22	15.05	0.015	124.1	0.6	4.5
30	55	1.12	14254.0	403.2	35.3	1.29	18.42	0.018	137.3	0.7	5.0
35	55	1.12	14254.0	403.2	35.3	1.29	18.42	0.018	137.3	0.7	5.5
40	60	1.17	16205.6	421.7	38.4	1.37	22.15	0.022	149.4	0.7	6.1
45	70	1.27	20331.1	456.6	44.5	1.51	30.65	0.031	170.7	0.8	7.9
50	80	1.36	24729.0	489.4	50.5	1.64	40.56	0.041	189.1	0.9	10.7
55	95	1.49	31783.7	535.3	59.4	1.83	58.05	0.058	212.6	1.0	14.8
60	95	1.49	31783.7	535.3	59.4	1.83	58.05	0.058	212.6	1.1	17.4
65	80	1.36	24729.0	489.4	50.5	1.64	40.56	0.041	189.1	1.0	14.8
70	70	1.27	20331.1	456.6	44.5	1.51	30.65	0.031	170.7	0.9	10.7
75	60	1.17	16205.6	421.7	38.4	1.37	22.15	0.022	149.4	0.8	7.9
80	55	1.12	14254.0	403.2	35.3	1.29	18.42	0.018	137.3	0.7	6.1
85	50	1.07	12382.2	384.0	32.2	1.22	15.05	0.015	124.1	0.7	5.0
90	50	1.07	12382.2	384.0	32.2	1.22	15.05	0.015	124.1	0.6	4.5
95	50	1.07	12382.2	384.0	32.2	1.22	15.05	0.015	124.1	0.6	4.5
100	50	1.07	12382.2	384.0	32.2	1.22	15.05	0.015	124.1	0.6	4.5
105	50	1.07	12382.2	384.0	32.2	1.22	15.05	0.015	124.1	0.6	4.5
110	50	1.07	12382.2	384.0	32.2	1.22	15.05	0.015	124.1	0.6	4.5
115	50	1.07	12382.2	384.0	32.2	1.22	15.05	0.015	124.1	0.6	4.5
120	50	1.07	12382.2	384.0	32.2	1.22	15.05	0.015	124.1	0.6	4.5



**Figure A-24: Hydrograph C, storm simulation with a 165m<sup>3</sup> preset total culvert flow**

**Table A-30: Summary of hydrographs A-C with a 165m<sup>3</sup> preset total culvert flow**

		A	B	C
Sample time	(min)	120	120	120
Total collected	(litres)	18.2	15.9	17.3
Total discharge	(m <sup>3</sup> )	165.1	165.4	166.1
Estimated tot Q	(m <sup>3</sup> )	213.8	158.7	191.4
Error	(%)	29.49	4.08	15.21
Qcurve/Q calculated		1.29	0.96	1.15

**Table A-31: Hydrograph A, storm simulation with a 290m<sup>3</sup> preset total culvert flow**

Time (min)	Water level (mm)	Theta	Area of flow (mm <sup>2</sup> )	Perimeter (mm)	Hydraulic radius (mm)	Velocity K = 12 (m/s)	Flow Q (l/s)	Flow Q (m/s)	Orifice collection (ml/min)	Total sampled (litres)	Total calc flow (m <sup>3</sup> )
0	80	1.36	24729.0	489.4	50.5	1.64	40.56	0.041	189.1	0.0	0
5	80	1.36	24729.0	489.4	50.5	1.64	40.56	0.041	189.1	0.9	12.2
10	80	1.36	24729.0	489.4	50.5	1.64	40.56	0.041	189.1	0.9	12.2
15	80	1.36	24729.0	489.4	50.5	1.64	40.56	0.041	189.1	0.9	12.2
20	80	1.36	24729.0	489.4	50.5	1.64	40.56	0.041	189.1	0.9	12.2
25	80	1.36	24729.0	489.4	50.5	1.64	40.56	0.041	189.1	0.9	12.2
30	80	1.36	24729.0	489.4	50.5	1.64	40.56	0.041	189.1	0.9	12.2
35	80	1.36	24729.0	489.4	50.5	1.64	40.56	0.041	189.1	0.9	12.2
40	80	1.36	24729.0	489.4	50.5	1.64	40.56	0.041	189.1	0.9	12.2
45	80	1.36	24729.0	489.4	50.5	1.64	40.56	0.041	189.1	0.9	12.2
50	80	1.36	24729.0	489.4	50.5	1.64	40.56	0.041	189.1	0.9	12.2
55	80	1.36	24729.0	489.4	50.5	1.64	40.56	0.041	189.1	0.9	12.2
60	80	1.36	24729.0	489.4	50.5	1.64	40.56	0.041	189.1	0.9	12.2
65	80	1.36	24729.0	489.4	50.5	1.64	40.56	0.041	189.1	0.9	12.2
70	80	1.36	24729.0	489.4	50.5	1.64	40.56	0.041	189.1	0.9	12.2
75	80	1.36	24729.0	489.4	50.5	1.64	40.56	0.041	189.1	0.9	12.2
80	80	1.36	24729.0	489.4	50.5	1.64	40.56	0.041	189.1	0.9	12.2
85	80	1.36	24729.0	489.4	50.5	1.64	40.56	0.041	189.1	0.9	12.2
90	80	1.36	24729.0	489.4	50.5	1.64	40.56	0.041	189.1	0.9	12.2
95	80	1.36	24729.0	489.4	50.5	1.64	40.56	0.041	189.1	0.9	12.2
100	80	1.36	24729.0	489.4	50.5	1.64	40.56	0.041	189.1	0.9	12.2
105	80	1.36	24729.0	489.4	50.5	1.64	40.56	0.041	189.1	0.9	12.2
110	80	1.36	24729.0	489.4	50.5	1.64	40.56	0.041	189.1	0.9	12.2
115	80	1.36	24729.0	489.4	50.5	1.64	40.56	0.041	189.1	0.9	12.2
120	80	1.36	24729.0	489.4	50.5	1.64	40.56	0.041	189.1	0.9	12.2

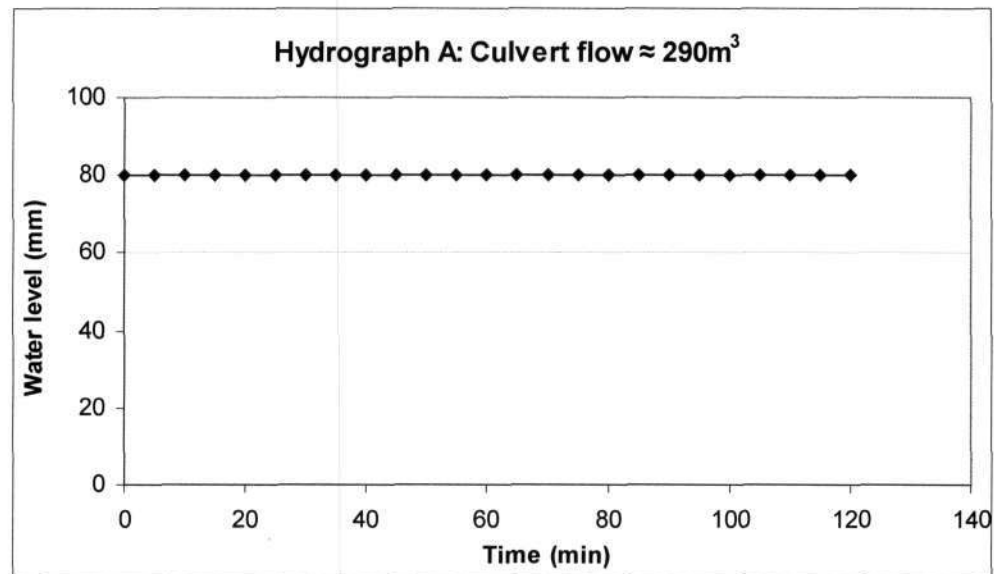
**Figure A-25: Hydrograph A, storm simulation with a 290m<sup>3</sup> preset total culvert flow**

Table A-32: Hydrograph B, storm simulation with a 290m<sup>3</sup> preset total culvert flow

Time (min)	Water level (mm)	Theta	Area of flow (mm <sup>2</sup> )	Perimeter (mm)	Hydraulic radius (mm)	Velocity K = 12 (m/s)	Flow Q (l/s)	Flow Q (m/s)	Orifice collection (ml/min)	Total sampled (litres)	Total calc flow (m <sup>3</sup> )
0	50	1.07	12382.2	384.0	32.2	1.22	15.05	0.015	124.1	0.0	0
5	50	1.07	12382.2	384.0	32.2	1.22	15.05	0.015	124.1	0.6	4.5
10	50	1.07	12382.2	384.0	32.2	1.22	15.05	0.015	124.1	0.6	4.5
15	50	1.07	12382.2	384.0	32.2	1.22	15.05	0.015	124.1	0.6	4.5
20	50	1.07	12382.2	384.0	32.2	1.22	15.05	0.015	124.1	0.6	4.5
25	50	1.07	12382.2	384.0	32.2	1.22	15.05	0.015	124.1	0.6	4.5
30	50	1.07	12382.2	384.0	32.2	1.22	15.05	0.015	124.1	0.6	4.5
35	50	1.07	12382.2	384.0	32.2	1.22	15.05	0.015	124.1	0.6	4.5
40	50	1.07	12382.2	384.0	32.2	1.22	15.05	0.015	124.1	0.6	4.5
45	50	1.07	12382.2	384.0	32.2	1.22	15.05	0.015	124.1	0.6	4.5
50	130	1.76	50057.6	632.0	79.2	2.21	110.79	0.111	255.0	0.9	18.9
55	130	1.76	50057.6	632.0	79.2	2.21	110.79	0.111	255.0	1.3	33.2
60	130	1.76	50057.6	632.0	79.2	2.21	110.79	0.111	255.0	1.3	33.2
65	130	1.76	50057.6	632.0	79.2	2.21	110.79	0.111	255.0	1.3	33.2
70	130	1.76	50057.6	632.0	79.2	2.21	110.79	0.111	255.0	1.3	33.2
75	130	1.76	50057.6	632.0	79.2	2.21	110.79	0.111	255.0	1.3	33.2
80	50	1.07	12382.2	384.0	32.2	1.22	15.05	0.015	124.1	0.9	18.9
85	50	1.07	12382.2	384.0	32.2	1.22	15.05	0.015	124.1	0.6	4.5
90	50	1.07	12382.2	384.0	32.2	1.22	15.05	0.015	124.1	0.6	4.5
95	50	1.07	12382.2	384.0	32.2	1.22	15.05	0.015	124.1	0.6	4.5
100	50	1.07	12382.2	384.0	32.2	1.22	15.05	0.015	124.1	0.6	4.5
105	50	1.07	12382.2	384.0	32.2	1.22	15.05	0.015	124.1	0.6	4.5
110	50	1.07	12382.2	384.0	32.2	1.22	15.05	0.015	124.1	0.6	4.5
115	50	1.07	12382.2	384.0	32.2	1.22	15.05	0.015	124.1	0.6	4.5
120	50	1.07	12382.2	384.0	32.2	1.22	15.05	0.015	124.1	0.6	4.5

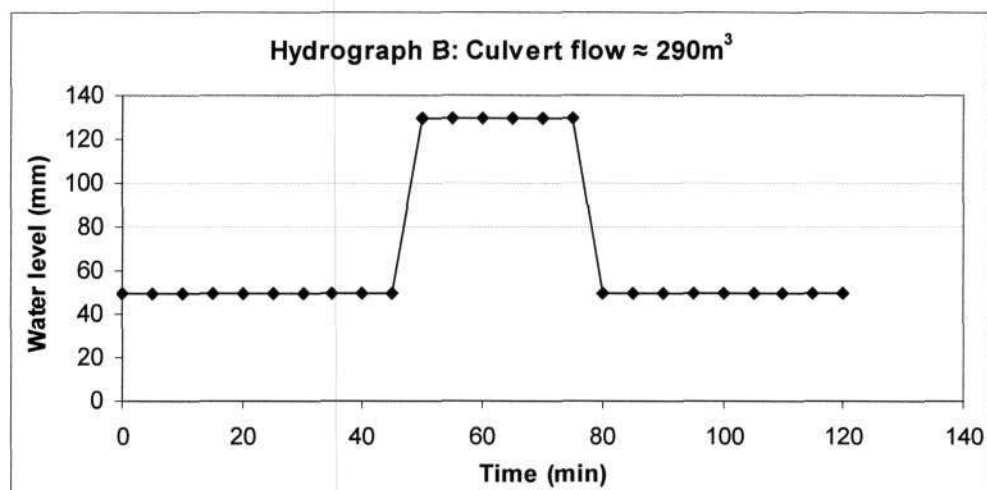
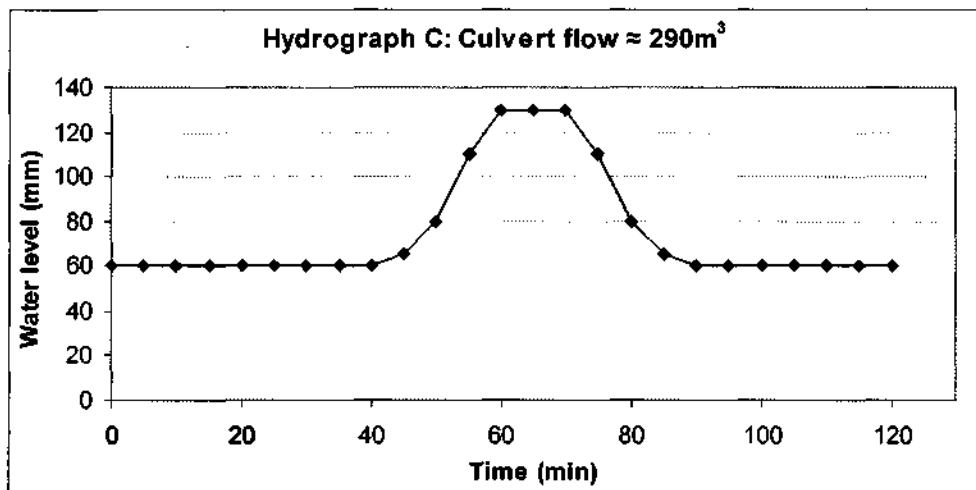
Figure A-26: Hydrograph B, storm simulation with a 290m<sup>3</sup> preset total culvert flow

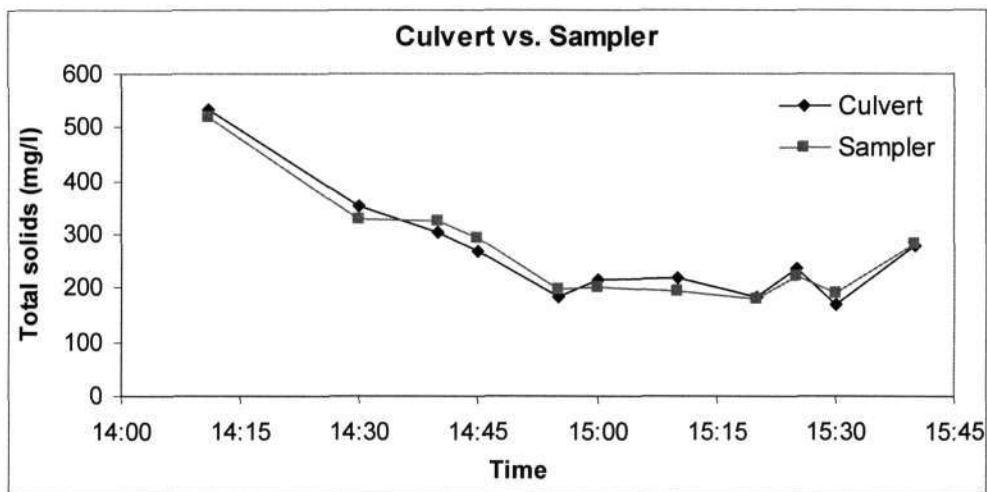
Table A-33: Hydrograph C, storm simulation with a 290m<sup>3</sup> preset total culvert flow

Time (min)	Water level (mm)	Theta	Area of flow (mm <sup>2</sup> )	Perimeter (mm)	Hydraulic radius (mm)	Velocity K = 12 (m/s)	Flow Q (l/s)	Flow Q (m/s)	Orifice collection (ml/min)	Total sampled (litres)	Total calc flow (m <sup>3</sup> )
0	60	1.17	16205.6	421.7	38.4	1.37	22.15	0.022	149.4	0.0	0
5	60	1.17	16205.6	421.7	38.4	1.37	22.15	0.022	149.4	0.7	6.6
10	60	1.17	16205.6	421.7	38.4	1.37	22.15	0.022	149.4	0.7	6.6
15	60	1.17	16205.6	421.7	38.4	1.37	22.15	0.022	149.4	0.7	6.6
20	60	1.17	16205.6	421.7	38.4	1.37	22.15	0.022	149.4	0.7	6.6
25	60	1.17	16205.6	421.7	38.4	1.37	22.15	0.022	149.4	0.7	6.6
30	60	1.17	16205.6	421.7	38.4	1.37	22.15	0.022	149.4	0.7	6.6
35	60	1.17	16205.6	421.7	38.4	1.37	22.15	0.022	149.4	0.7	6.6
40	60	1.17	16205.6	421.7	38.4	1.37	22.15	0.022	149.4	0.7	6.6
45	65	1.22	18232.6	439.5	41.5	1.44	26.22	0.026	160.5	0.8	7.3
50	80	1.36	24729.0	489.4	50.5	1.64	40.56	0.041	189.1	0.9	10.0
55	110	1.61	39328.9	578.3	68.0	2.00	78.63	0.079	232.5	1.1	17.9
60	130	1.76	50057.6	632.0	79.2	2.21	110.79	0.111	255.0	1.2	28.4
65	130	1.76	50057.6	632.0	79.2	2.21	110.79	0.111	255.0	1.3	33.2
70	130	1.76	50057.6	632.0	79.2	2.21	110.79	0.111	255.0	1.3	33.2
75	110	1.61	39328.9	578.3	68.0	2.00	78.63	0.079	232.5	1.2	28.4
80	80	1.36	24729.0	489.4	50.5	1.64	40.56	0.041	189.1	1.1	17.9
85	65	1.22	18232.6	439.5	41.5	1.44	26.22	0.026	160.5	0.9	10.0
90	60	1.17	16205.6	421.7	38.4	1.37	22.15	0.022	149.4	0.8	7.3
95	60	1.17	16205.6	421.7	38.4	1.37	22.15	0.022	149.4	0.7	6.6
100	60	1.17	16205.6	421.7	38.4	1.37	22.15	0.022	149.4	0.7	6.6
105	60	1.17	16205.6	421.7	38.4	1.37	22.15	0.022	149.4	0.7	6.6
110	60	1.17	16205.6	421.7	38.4	1.37	22.15	0.022	149.4	0.7	6.6
115	60	1.17	16205.6	421.7	38.4	1.37	22.15	0.022	149.4	0.7	6.6
120	60	1.17	16205.6	421.7	38.4	1.37	22.15	0.022	149.4	0.7	6.6

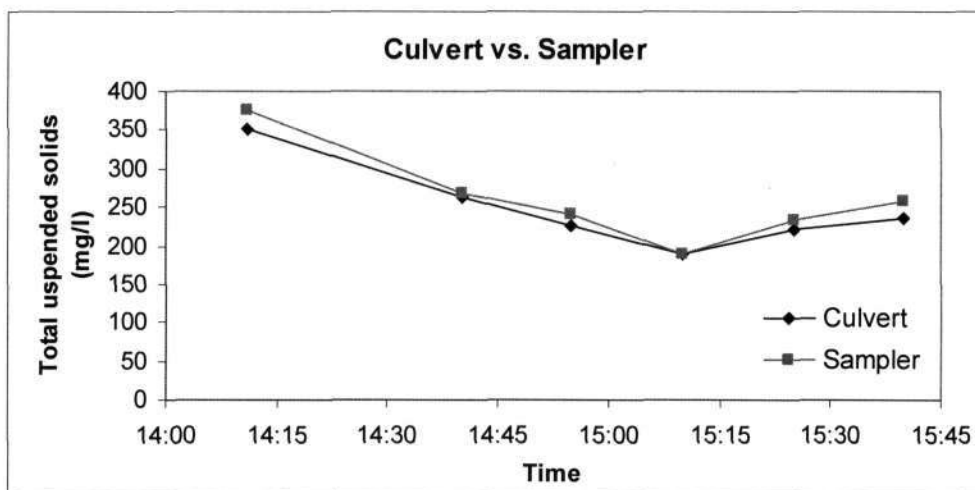
Figure A-27: Hydrograph C, storm simulation with a 290m<sup>3</sup> preset total culvert flowTable A-34: Summary of hydrographs A-C with a 290m<sup>3</sup> preset total culvert flow

		A	B	C
Sample time	(min)	120	120	120
Total collected	(litres)	22.7	18.8	20.9
Total discharge	(m <sup>3</sup> )	292.0	280.7	286.6
Estimated tot Q	(m <sup>3</sup> )	347	229.5	289
Error	(%)	18.82	18.24	0.83
Q <sub>curve</sub> /Q <sub>calculated</sub>		1.19	0.82	1.01

**A4: Field storm test comparison of sampled and culvert measured**



**Figure A-28: Storm test culvert and Pro.4 comparison for total solids**



**Figure A-29: Storm test culvert and Pro.4 comparison for total suspended solids**

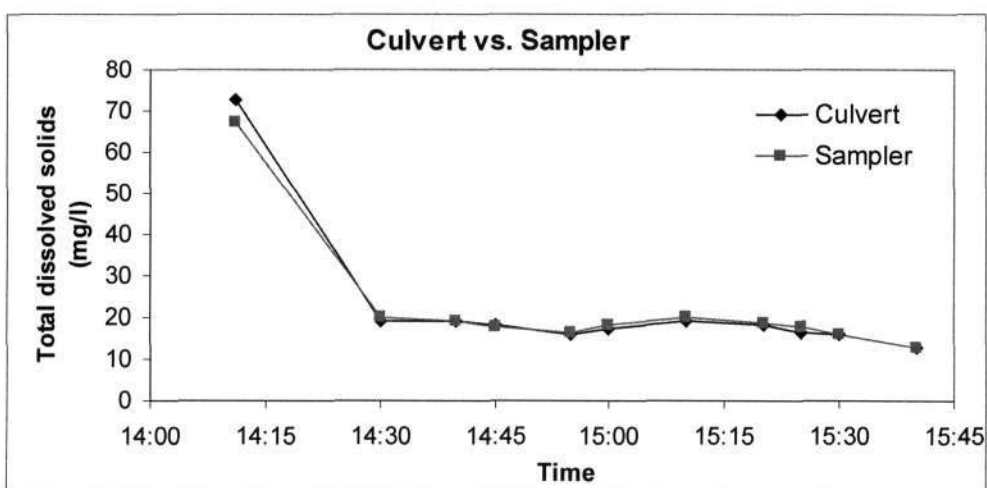


Figure A-30: Storm test culvert and Pro.4 comparison for total dissolved solids

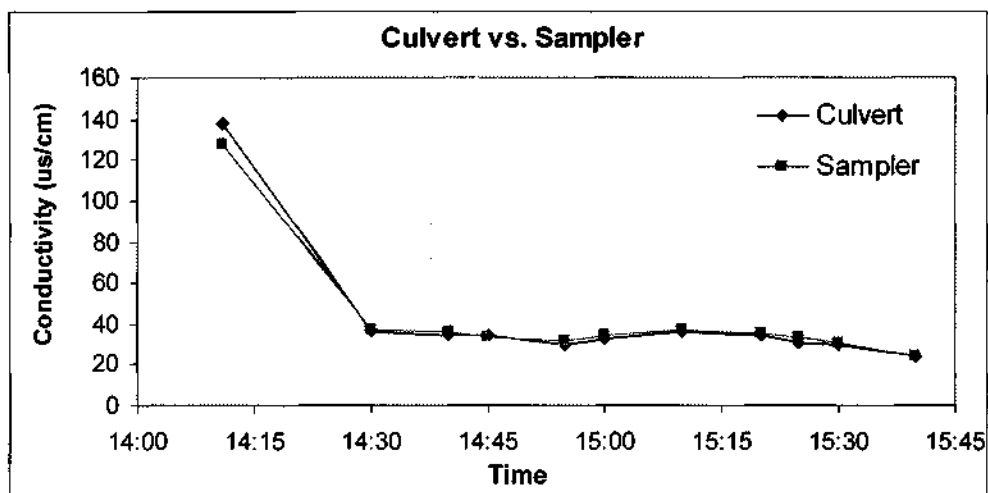


Figure A-31: Storm test culvert and Pro.4 comparison for conductivity

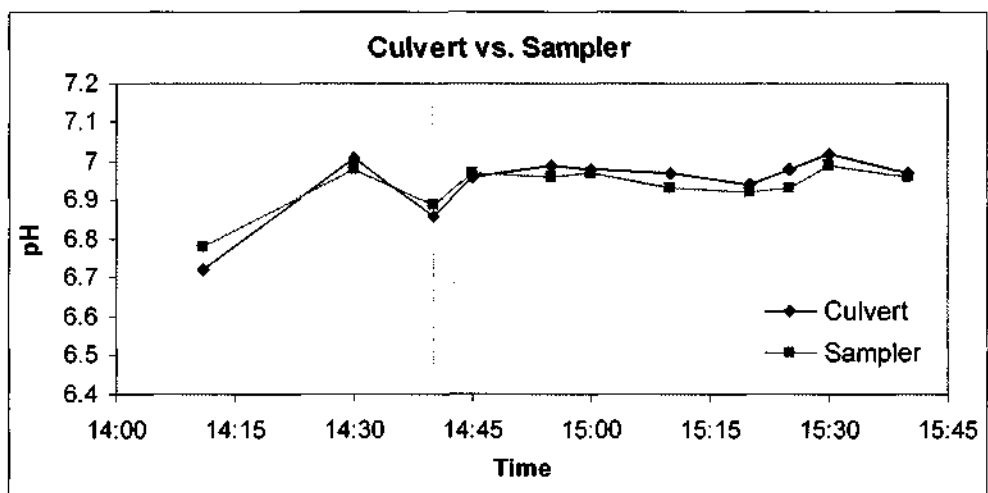


Figure A-32: Storm test culvert and Pro.4 comparison for pH

**APPENDIX B**  
**STORMWATER DISCHARGE LEVEL, VELOCITY AND DURATION**  
**INSTRUMENTATION**

**This Appendix contains information related to the Vegason 61 ultrasonic,  
velocimeter and discharge duration timing device**

## B1: Vegason 61 Ultrasonic Water Level Monitor

Table B-1: Vegason 61 calibration test

Instrument output recorded on TINYtalk data logger			Subtract system voltage required (510mV) (mV)	Converted to distance (mm)	Adjusted for water level (mm)	Measured water level (mm)
Log No.	Test duration	Voltage (0-2500mV)				
141	12:29:51	549	39	504.9	0.1	0
142	12:30:01	549	39	504.9	0.1	0
143	12:30:11	549	39	504.9	0.1	0
144	12:30:21	549	39	504.9	0.1	0
145	12:30:31	549	39	504.9	0.1	0
146	12:30:41	539	29	506.2	-1.2	0
147	12:30:51	549	39	504.9	0.1	0
148	12:31:01	549	39	504.9	0.1	0
149	12:31:11	647	137	492.1	12.9	10
150	12:31:21	755	245	478.0	27.0	20
151	12:31:31	833	323	467.8	37.2	30
152	12:31:41	892	382	460.1	44.9	40
153	12:31:51	931	421	455.0	50.0	50
154	12:32:01	951	441	452.4	52.6	60
155	12:32:11	951	441	452.4	52.6	70
156	12:32:21	971	461	449.8	55.2	80
157	12:32:31	980	470	448.6	56.4	90
158	12:32:41	980	470	448.6	56.4	100
159	12:32:51	980	470	448.6	56.4	110
160	12:33:01	980	470	448.6	56.4	120
161	12:33:11	980	470	448.6	56.4	130
162	12:33:21	980	470	448.6	56.4	140
163	12:33:31	1020	510	443.4	61.6	150
164	12:33:41	1060	550	438.1	66.9	160
165	12:33:51	1070	560	436.8	68.2	170
166	12:34:01	1060	550	438.1	66.9	180
167	12:34:11	1060	550	438.1	66.9	190
168	12:34:21	1060	550	438.1	66.9	200
169	12:34:31	1060	550	438.1	66.9	210
170	12:34:41	1070	560	436.8	68.2	220
171	12:34:51	1090	580	434.2	70.8	230
172	12:35:01	1110	600	431.6	73.4	240
173	12:35:11	1140	630	427.7	77.3	250
174	12:35:21	1170	660	423.8	81.2	260
175	12:35:31	1170	660	423.8	81.2	270
176	12:35:41	1160	650	425.1	79.9	280
177	12:35:51	1160	650	425.1	79.9	290
178	12:36:01	1210	700	418.5	86.5	300
179	12:36:11	1220	710	417.2	87.8	310
180	12:36:21	1240	730	414.6	90.4	320
181	12:36:31	1220	710	417.2	87.8	330
182	12:36:41	1240	730	414.6	90.4	340
183	12:36:51	1240	730	414.6	90.4	350
184	12:37:01	1240	730	414.6	90.4	360
185	12:37:11	1260	750	412.0	93.0	370
186	12:37:21	1280	770	409.4	95.6	380
187	12:37:31	1280	770	409.4	95.6	390
188	12:37:41	1280	770	409.4	95.6	400
189	12:37:51	1150	640	426.4	78.6	410
190	12:38:01	961	451	451.1	53.9	420
191	12:38:11	814	304	470.3	34.7	430
192	12:38:21	676	166	488.3	16.7	440
193	12:38:31	598	88	498.5	6.5	450
194	12:38:41	559	49	503.6	1.4	460
195	12:38:51	0			0	470

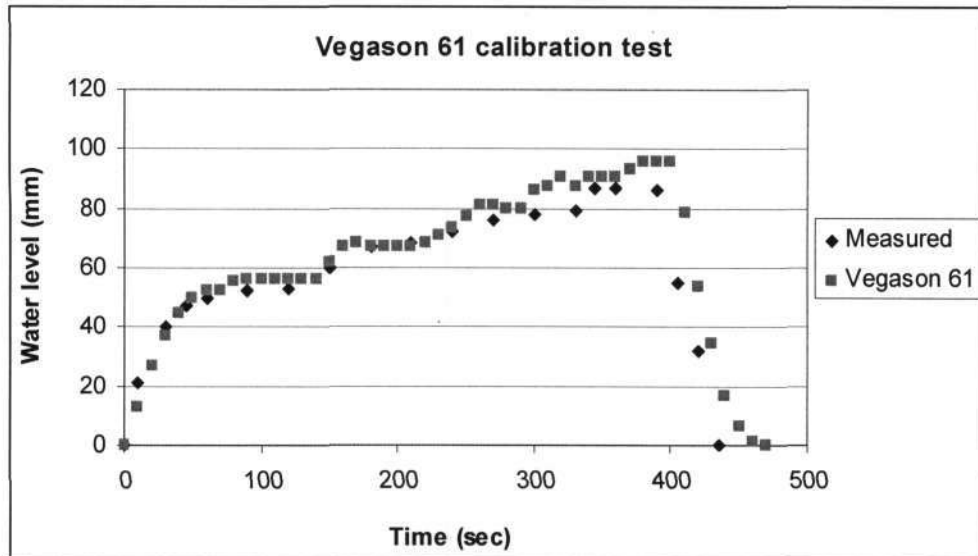


Figure B-1: Vegason 61 water level estimates vs. measured levels

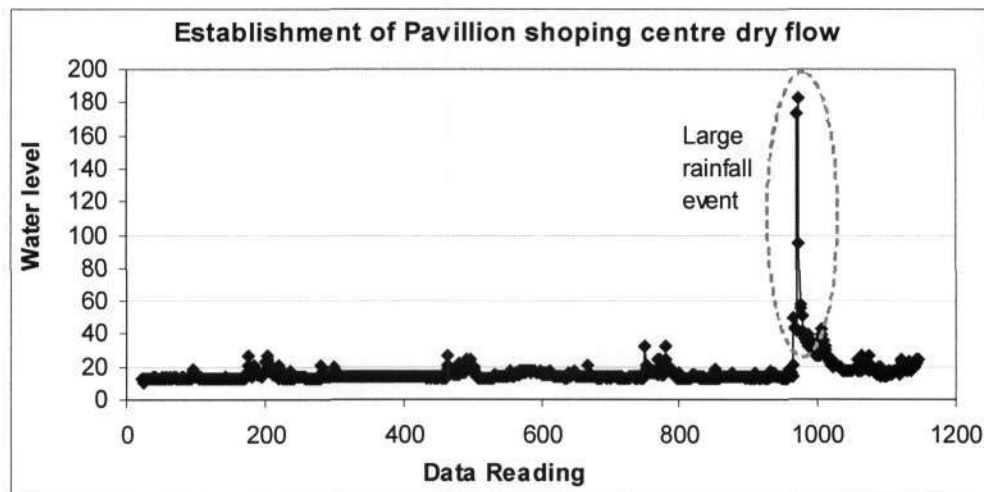


Figure B-2: Pavillion dry flow measurements

Table B-2: Summary of Pavillion dry flow measurements for three periods

	Vegason 61 Pavillion dry flow levels			Average
Mean	14.0	15.0	11.9	13.7
Median	13.4	13.9	11.7	13.0
Standard Deviation	2.4	2.7	2.7	2.6
Range	21.0	23.4	16.6	20.3
Minimum	11.0	11.1	8.8	10.3
Maximum	32.0	34.4	25.4	30.6

## B2: Calibration of propeller probe frequency to estimate velocity

Table B-3: Calibration of propeller used to estimate velocity

Calibration 1			Calibration 2		
Time to travel 1.5m (sec)	Velocity m/s	Propeller (Hz)	Time to travel 1m (sec)	Velocity m/s	Propeller (Hz)
5.1	0.30	8.0	6.7	0.15	3.0
5.0	0.30	8.0	3.7	0.27	10.0
2.9	0.52	15.5	2.6	0.39	15.0
2.8	0.54	15.5	1.3	0.75	33.0
2.2	0.68	22.0	1.0	1.01	38.0
2.2	0.70	22.0	0.8	1.33	44.0
1.7	0.90	30.5	0.8	1.25	45.0
1.6	0.93	30.5			

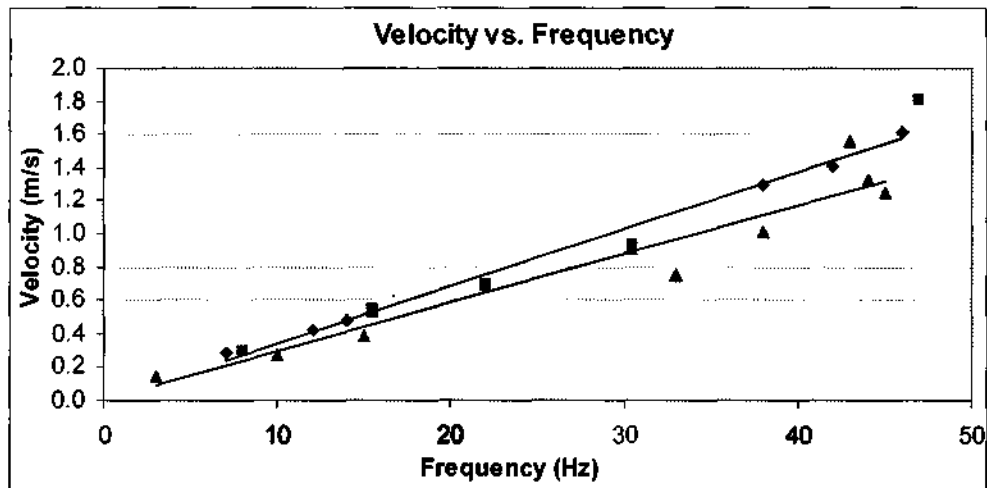
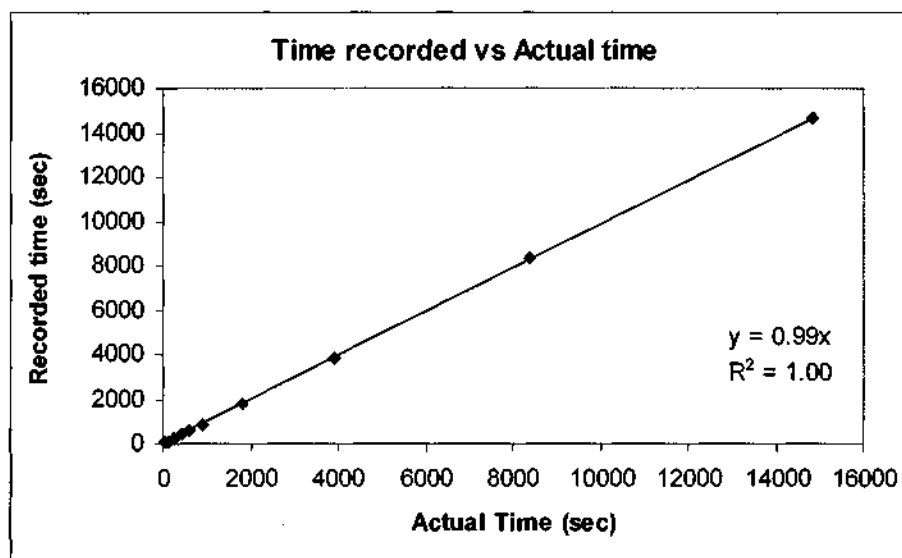


Figure B-3: Calibration relating propeller frequency and velocity

**B3: Calibration of timing device****Table B-4: Calibration of timing device**

Time		Recorded	Error
(min)	(sec)	(sec)	(%)
1	60	60	0.00
2	120	119	0.83
4	240	238	0.83
7	420	417	0.71
10	600	592	1.33
15	900	890	1.11
30	1800	1794	0.33
65	3900	3854	1.18
140	8400	8302	1.17
247	14820	14657	1.10



**Figure B-4: Calibration of the timing device by relating  
the actual time to recorded time**

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**APPENDIX C**  
**STORMWATER CHEMICAL RESULTS**

**This Appendix contains the mean atmospheric deposition concentrations and lognormal distribution tests.**

**C1: Mean concentration for atmospheric deposition**

**Table C-1: Mean concentrations for atmospheric deposition at Booth road**

Rainfall Date	TSS (mg/l)	COD (mg/l)	BOD (mg/l)	EC (us/cm)	pH	Al (mg/l)	Cd (mg/l)	Cr (mg/l)	Cu (mg/l)	Fe (mg/l)	Mn (mg/l)	Ni (mg/l)	Pb (mg/l)	(n
20-May-05	40	-	-	-	-	0.27	nd	0.004	0.035	2.38	0.158	0.005	0.066	0.
07-Sep-05	-	-	-	-	-	2.77	nd	0.013	0.052	2.76	0.220	0.010	0.075	0.
27-Sep-05	-	-	-	-	-	9.07	0.000	0.031	0.060	8.33	0.473	0.024	0.101	0.
06-Oct-05	22	35	-	37	7.3	0.92	0.003	0.770	0.029	1.51	0.036	0.010	0.048	0.
13-Nov-05	68	39	-	393	3.6	2.17	0.002	0.051	0.378	4.12	0.086	0.049	0.179	0.
09-Dec-05	80	28	3	143	6.8	0.42	0.003	0.028	0.039	2.26	0.041	0.058	0.061	0.
16-Dec-05	56	-	-	150	6.9	0.31	0.005	0.018	0.064	2.16	0.105	0.015	0.091	0.
06-Feb-06	1	3	4	11	7.5	0.13	0.000	0.005	0.011	0.39	0.005	0.011	0.016	0.
16-Feb-06	24	20	9	31	7.8	ND	0.001	0.021	0.023	0.75	0.014	0.020	0.041	0.
16-Mar-06	38	13	-	63	4.8	0.60	0.003	0.015	0.026	0.63	0.008	0.019	0.021	0.
23-Apr-06	10	5	-	11	6.5	0.59	0.002	0.015	0.015	0.56	0.010	0.017	0.008	0.
18-May-06	26	19	4	16	6.2	0.40	0.002	0.015	0.014	0.58	0.047	0.014	0.001	0.
25-May-06	-	10	-	97	4.5	0.51	0.003	0.031	0.027	0.49	0.000	0.028	0.019	0.
29-May-06	60	18	-	46	4.6	1.20	0.002	0.020	0.029	0.96	0.051	0.027	0.010	0.
23-Jun-06	600	321	-	197	6.4	23.43	0.014	0.176	0.228	36.53	1.552	0.067	0.058	1.
09-Aug-06	112	90	-	158	6.2	2.67	0.002	0.024	0.035	3.35	0.261	0.016	0.014	0.
Median	26	20	4	37	6.4	0.60	0.002	0.021	0.032	1.84	0.049	0.018	0.044	0.
Mean	67	50	5	82	6.3	3.03	0.003	0.077	0.067	4.23	0.192	0.024	0.050	0.
COV	0.5	2.1	0.6	1.3	0.2	2.0	1.1	2.4	1.5	2.1	2.0	0.7	0.9	1

**Table C-2: Mean concentrations for atmospheric deposition at National 3 highway**

Rainfall Date	TSS (mg/l)	COD (mg/l)	BOD (mg/l)	EC (us/cm)	pH	Al (mg/l)	Cd (mg/l)	Cr (mg/l)	Cu (mg/l)	Fe (mg/l)	Mn (mg/l)	Ni (mg/l)	Pb (mg/l)	(n
20-May-05	-	-	-	-	-	-	-	-	-	-	-	-	-	-
07-Sep-05	-	-	-	-	-	7.80	0.003	0.047	0.052	10.79	0.872	0.055	1.204	1.
27-Sep-05	-	-	-	-	-	24.96	0.000	0.086	0.111	29.07	1.125	0.056	0.391	0.
06-Oct-05	14	28	-	40	8.2	0.94	0.001	0.003	0.034	1.65	0.040	0.000	0.077	0.
13-Nov-05	152	50	-	108	4.9	0.65	0.000	0.028	0.098	2.88	0.123	0.025	0.148	0.
09-Dec-05	120	31	-	146	7.4	ND	0.003	0.028	0.046	1.94	0.042	0.029	0.097	0.
16-Dec-05	30	55	-	76	6.2	1.45	0.003	0.028	0.080	3.98	0.123	0.023	0.205	0.
06-Feb-06	12	17	5	14	7.6	0.08	0.001	0.007	0.016	0.66	0.009	0.008	0.030	0.
16-Feb-06	22	14	9	26	7.4	0.31	0.000	0.011	0.013	1.80	0.019	0.006	0.026	0.
16-Mar-06	46	13	-	47	4.7	0.81	0.004	0.018	0.030	0.80	0.013	0.025	0.035	0.
23-Apr-06	28	12	-	17	6.8	0.46	0.002	0.022	0.016	0.47	0.008	0.022	0.022	0.
18-May-06	36	21	4	18	6.4	0.59	0.002	0.024	0.018	0.67	0.053	0.019	0.023	0.
25-May-06	-	-	-	-	-	-	-	-	-	-	-	-	-	-
29-May-06	90	46	-	51	6.6	5.52	0.013	0.083	0.079	2.69	0.088	0.121	0.088	0.
23-Jun-06	194	188	-	95	6.6	5.68	0.005	0.050	0.098	6.02	0.404	0.048	0.205	0.
09-Aug-06	150	203	-	264	6.9	0.00	0.000	0.000	0.000	0.00	0.000	0.000	0.000	0.
Median	29	29	5	34	6.8	0.81	0.002	0.026	0.040	1.87	0.047	0.024	0.082	0.
Mean	57	56	6	58	6.8	3.52	0.002	0.031	0.049	4.53	0.208	0.031	0.182	0.
COV	0.9	1.5	0.4	1.2	0.2	1.9	1.3	0.9	0.8	1.7	1.7	1.0	1.7	1

**Table C-3: Mean concentrations for atmospheric deposition at Bayhead road**

Rainfall Date	TSS (mg/l)	COD (mg/l)	BOD (mg/l)	EC (us/cm)	pH	Al (mg/l)	Cd (mg/l)	Cr (mg/l)	Cu (mg/l)	Fe (mg/l)	Mn (mg/l)	Ni (mg/l)	Pb (mg/l)	(n)
20-May-05	-	-	-	-	-	-	-	-	-	-	-	-	-	-
07-Sep-05	-	-	-	-	-	-	-	-	-	-	-	-	-	-
27-Sep-05	-	-	-	-	-	0.00	0.000	0.719	0.519	39.26	8.256	0.000	0.349	1.
06-Oct-05	122	167	-	124	7.0	4.68	0.003	0.151	0.231	8.51	2.961	0.041	0.096	0.
13-Nov-05	480	195	-	356	7.0	17.94	0.014	0.443	1.392	35.81	4.054	0.155	0.493	1.
09-Dec-05	144	40	2	271	6.8	0.85	0.001	0.035	0.237	3.29	0.991	0.029	0.068	0.
16-Dec-05	65	85	-	136	7.5	2.64	0.004	0.091	0.155	6.45	1.001	0.046	0.125	0.
06-Feb-06	24	28	7	31	7.7	0.58	0.000	0.008	0.063	1.03	0.058	0.007	0.019	0.
16-Feb-06	68	49	9	44	7.2	1.40	0.001	0.019	0.151	2.54	0.370	0.012	0.030	0.
16-Mar-06	162	91	-	113	6.6	2.48	0.003	0.052	0.312	5.53	3.315	0.033	0.077	0.
23-Apr-06	104	36	-	20	6.9	1.49	0.002	0.038	0.199	3.57	0.241	0.029	0.012	0.
18-May-06	112	54	4	29	6.5	0.00	0.000	0.000	0.000	0.00	0.000	0.000	0.000	0.
25-May-06	-	28	-	49	4.7	1.28	0.003	0.043	0.122	1.51	0.099	0.043	0.028	0.
29-May-06	142	-	-	-	-	2.91	0.005	0.040	0.109	4.12	0.274	0.049	0.042	0.
23-Jun-06	412	329	-	-	-	13.04	0.011	0.841	1.476	32.80	2.874	0.226	0.199	1.
09-Aug-06	40	31	-	134	7.0	2.90	0.002	0.083	0.496	5.46	0.918	0.038	0.047	0.
Median	108	51	5	45	7.0	2.0	0.002	0.048	0.215	4.79	0.955	0.035	0.057	0.
Mean	124	94	5	90	7.0	3.7	0.003	0.183	0.390	10.70	1.815	0.051	0.113	0.
COV	0.9	1.2	0.6	1.2	0.1	1.4	1.2	1.5	1.2	1.3	1.3	1.2	1.3	0.

**C2: Lognormal distribution test for several contaminants**

**Table C-4: Lognormal distribution test for aluminium**

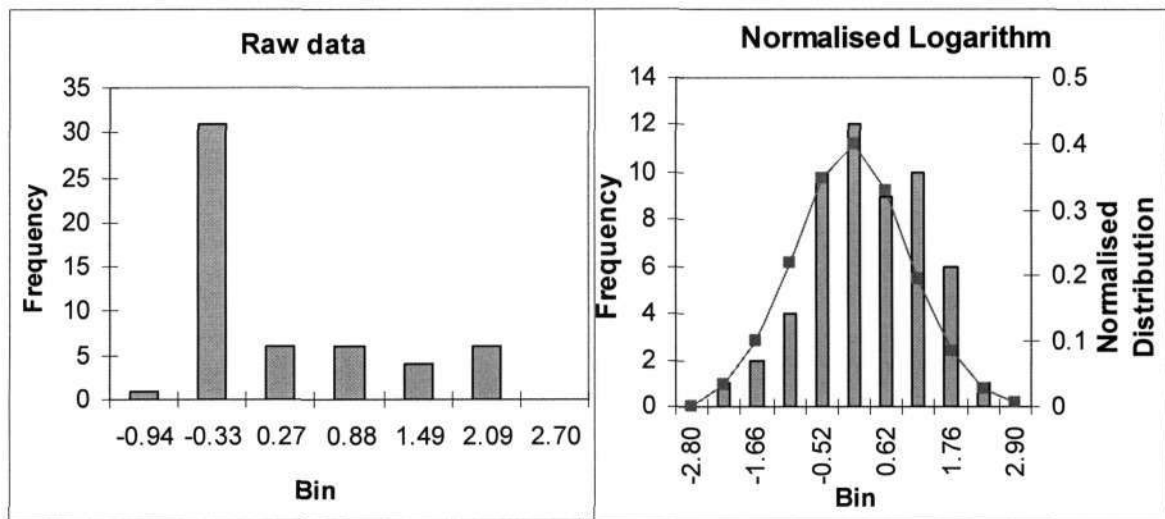
Bin	Frequency	ND <sup>a</sup>	CDF <sup>b</sup>	Chi square test		
				Expected	(Obs-Exp) <sup>2</sup>	(Obs-Exp) <sup>2</sup> /Exp
-2.80		0	0.00			
-2.23	1	0.03	0.01	0.6	0.18	0.32
-1.66	2	0.10	0.05	2.0	0.00	0.00
-1.09	4	0.22	0.14	4.9	0.88	0.18
-0.52	10	0.35	0.30	9.0	0.96	0.11
0.05	12	0.40	0.52	12.0	0.00	0.00
0.62	9	0.33	0.73	11.7	7.15	0.61
1.19	10	0.20	0.88	8.3	3.02	0.37
1.76	6	0.08	0.96	4.3	3.02	0.71
2.33	1	0.03	0.99	1.6	0.36	0.23
2.90	0	0.01	1.00	0.4	0.19	0.44
More	0				<b>Sum</b>	2.96
<b>Degrees freedom</b>						6
<b>p-value</b>						81%
<b>Chi inverse</b>						12.59

<sup>a</sup> Normalised distribution

<sup>b</sup> Cumulative distribution function

Obs = Observed value

Exp = Expected value



**Figure C-1: Distribution the logarithm and raw data for aluminium**

**Table C-5: Lognormal distribution test for iron**

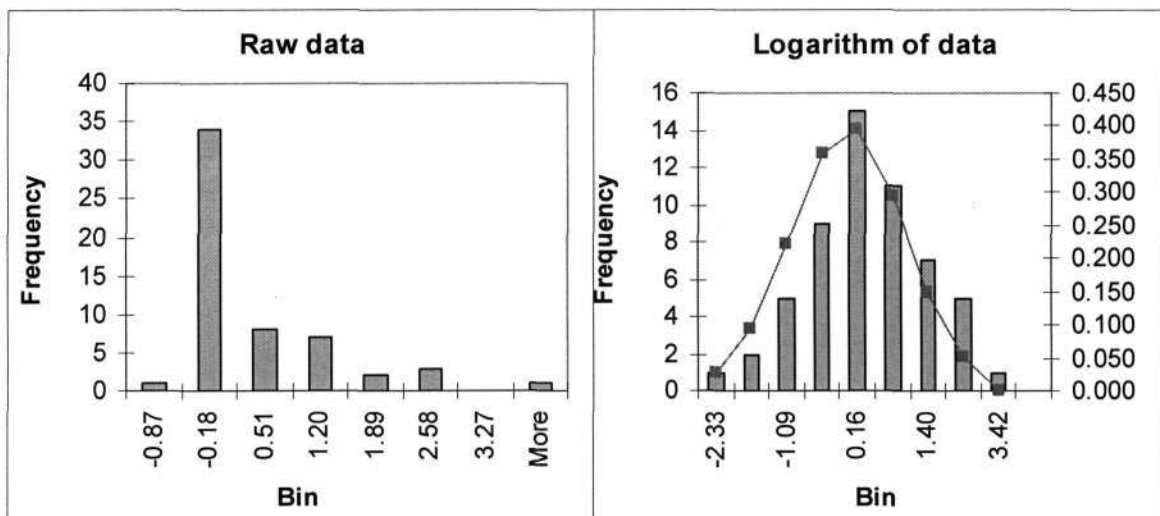
Bin	Frequency	ND <sup>a</sup>	CDF <sup>b</sup>	Chi square test		
				Expected	(Obs-Exp) <sup>2</sup>	(Obs-Exp) <sup>2</sup> /Exp
-2.33	1	0	0	0.55	0.20	0.37
-1.71	2	0.03	0.01	1.87	0.02	0.01
-1.09	5	0.09	0.04	5.22	0.05	0.01
-0.46	9	0.22	0.14	10.03	1.07	0.11
0.16	15	0.36	0.32	13.26	3.03	0.23
0.78	11	0.39	0.56	12.06	1.13	0.09
1.40	7	0.29	0.78	7.55	0.31	0.04
2.02	5	0.15	0.92	3.25	3.05	0.94
3.42	1	0.05	0.98	1.18	0.03	0.03
More	0	0.00	1.00			
<b>Sum</b>						1.82
<b>Degrees freedom</b>						6.00
<b>p-value</b>						94%
<b>Chi inverse</b>						12.59

<sup>a</sup> Normalised distribution

<sup>b</sup> Cumulative distribution function

Obs = Observed value

Exp = Expected value



**Figure C-2: Distribution the logarithm and raw data for iron**

**Table C-6: Lognormal distribution test for zinc**

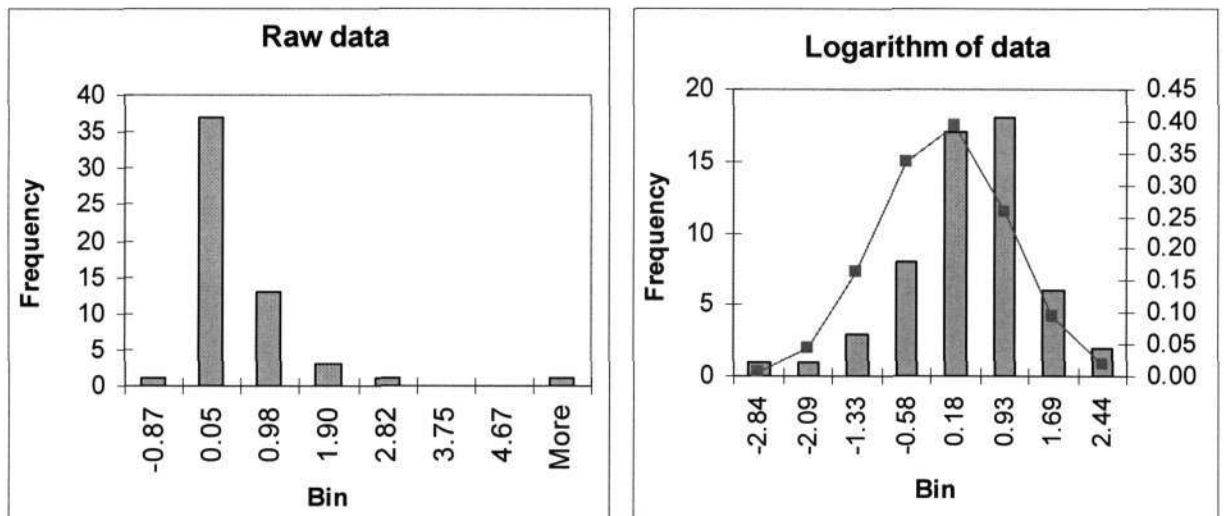
Bin	Frequency	ND <sup>a</sup>	CDF <sup>b</sup>	Chi square test		
				Expected	(Obs-Exp) <sup>2</sup>	(Obs-Exp) <sup>2</sup> /Exp
		0.0	0.0			
-2.8	1.0	0.01	0.00	0.12	0.77	6.15
-2.1	1.0	0.05	0.02	0.90	0.01	0.01
-1.3	3.0	0.16	0.09	4.08	1.16	0.29
-0.6	8.0	0.34	0.28	10.67	7.11	0.67
0.2	17.0	0.39	0.57	16.17	0.68	0.04
0.9	18.0	0.26	0.82	14.23	14.20	1.00
1.7	6.0	0.10	0.95	7.27	1.60	0.22
2.4	2.0	0.02	0.99	2.15	0.02	0.01
				<b>Sum</b>		8.39
				<b>Degrees freedom</b>		6
				<b>p-value</b>		21%
				<b>Chi inverse</b>		12.59

<sup>a</sup> Normalised distribution

<sup>b</sup> Cumulative distribution function

Obs = Observed value

Exp = Expected value



**Figure C-3: Distribution the logarithm and raw data for zinc**

**Table C-7: Lognormal distribution test for total suspended solids**

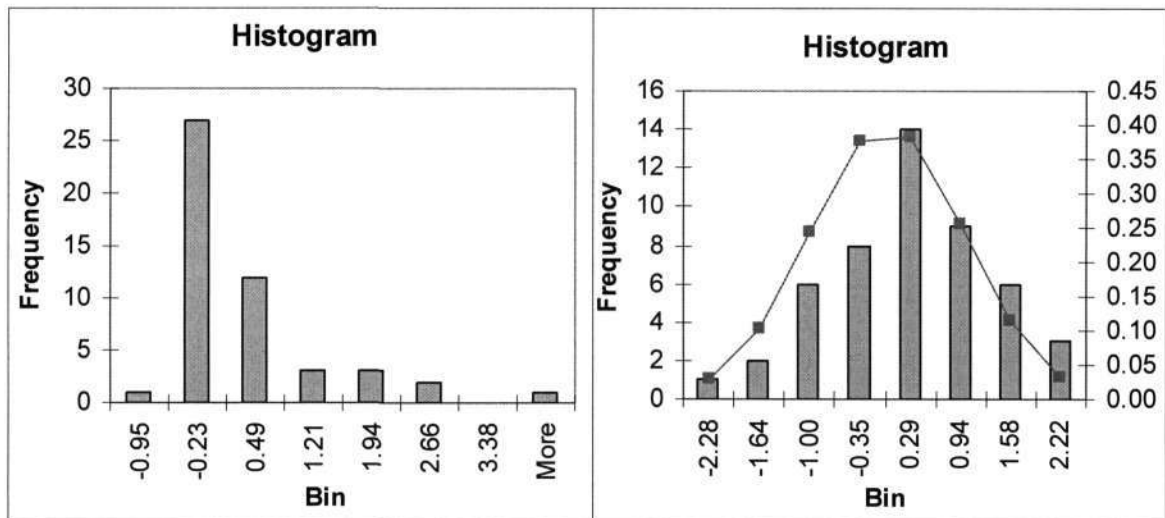
Bin	Frequency	ND <sup>a</sup>	CDF <sup>b</sup>	Chi square test		
				Exp	(Obs-Exp) <sup>2</sup>	(Obs-Exp) <sup>2</sup> /Exp
		0.0	0.0			
-2.28	1	0.03	0.01	0.55	0.20	0.37
-1.64	2	0.10	0.05	1.93	0.00	0.00
-1.00	6	0.24	0.16	5.35	0.42	0.08
-0.35	8	0.38	0.36	9.94	3.76	0.38
0.29	14	0.38	0.62	12.37	2.67	0.22
0.94	9	0.26	0.83	10.31	1.72	0.17
1.58	6	0.11	0.94	5.76	0.06	0.01
2.22	3	0.03	0.99	2.15	0.72	0.33
<b>Sum</b>						1.55
<b>Degrees freedom</b>						5.00
<b>p-value</b>						0.91
<b>Chi inverse</b>						11.07

<sup>a</sup> Normalised distribution

<sup>b</sup> Cumulative distribution function

Obs = Observed value

Exp = Expected value



**Figure C-4: Distribution the logarithm and raw data for total suspended solids**