ENVIRONMENTAL IMPACTS OF THE CONSTRUCTION PHASE OF AN INTENSIVE DEVELOPMENT PROJECT ON A COASTAL FOREST WETLAND.
CASE STUDY: SEAWARD ESTATES - BALLITO

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ABSTRACT

Storm water runoff is a leading cause of degradation in the water quality of receiving water bodies. Although legislation requires that Environmental Impact Assessments (EIA) are performed and Environmental Management Plans (EMP) put in place for the construction of high density housing developments, there is generally very little evidence that real measures are developed to monitor and actually assess the extent of the impact that construction activities have on the environment during the physical construction stage.

The water quality of stormwater runoff from a mixed use catchment including construction sites in Seaward Estates, Ballito, KwaZulu-Natal that enters a coastal forest wetland system was characterised by monitoring programmes established at three study areas. The effect thereof on the quality of the wetland water and sediments was further monitored at five points along the drainage line of the system. The investigation focussed on obtaining representative stormwater samples in order to quantitatively identify pollutant constituents transported within stormwater runoff from construction sites during rainfall events.

Storm water runoff event mean concentration (EMC), atmospheric deposition and wetland water and sediment samples were collected over an eight 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 ammonia and nitrates. The majority of contaminant EMC exceeded the South African wastewater discharge general and special limits.

The findings from this investigation will provide planners and decision-makers with a greater understanding of the pollution dynamics of construction sites aiding in improved best management practice decisions with regard to minimizing impacts on coastal forest wetlands and water resources. This will lead to improved EMP and stormwater management plans (SWMP) incorporating stormwater pollution prevention plans (SWPPP) for construction sites.

For

Yvonne and Gordon

PREFACE

I, Anton Appelcryn, 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 Dr C Trois.

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As the candidates supervisor I have approved this dissertation for submission.

Dr C. Trois

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LIST OF ABBREVIATIONS

AD	Atmospheric deposition
ADP	Antecedent dry weather period
Al	Aluminium
BMP	Best management practice
CAD	Computer Aided Design
Cd	Cadmium
COD	Chemical oxygen demand
C_r	Runoff coefficient
Cr	Chromium
Cu	Copper
DWAF	Department of Water Affairs and Forestry
E. coli	*Escherichia coli*
EIA	Environmental Impact Assessment
EMC	Event mean concentration
EMP	Environmental Management Plan
Erf	Stand or plot within a township (Erven – plural)
Fe	Iron
GIS	Geographical Information System
GPS	Global Positioning System device
LCA	Life cycle assessment
Mn	Manganese
Ni	Nickel
NPS	Non point source
NWA	National Water Act
NO_3^-	Nitrogen oxides
PAH	Polyaromatic Hydrocarbons
PCB	Polychlorinated Biphenyls
Pb	Lead
PEMC	Partial event mean concentration
pH	Acidity and alkalinity
SAWQG	South African Water Quality Guidelines
SO_x	Sulphur oxides

SPM	Suspended Particulate Matter
SWMP	Stormwater management plans
SWPPP	Stormwater pollution prevention plan
SWR	Stormwater runoff
TCC	Total coliforms
TS	Total solids
TSS	Total suspended solids
Zn	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 study is to understand how construction activities affect a coastal forest wetland by investigating the dynamics of pollution sources from construction sites and the associated affect on the stormwater runoff quality and the wetland sediments and water.

Although legislation requires that Environmental Impact Assessments (EIA) are performed and Environmental Management Plans (EMP) put in place for the construction of high density housing developments, there is generally very little evidence that anything is done to monitor and actually assess the extent of the impact that construction activities have on the environment during the physical construction stage. Much attention is focused on pristine environments such as wetlands and forests during the initial planning phases of these townships in terms of geotechnical wetland delineations, the application of buffer zones and no-go areas, but the extent of the environmental damage to these systems by the construction activities is not commonly assessed (USEPA, 1999).

The United States Environmental Protection Agency (USEPA) states that historically, the key objectives during times of urbanization when storm drainage infrastructure systems were developed was to limit nuisance and potential flood damage due to the large volumes of storm water runoff generated. Little, if any, thought was given to the environmental impacts of such practices (USEPA, 1999). Storm water management has traditionally been, and in many cases still is, seen as a flood control rather than a quality control program. Awareness of the damaging effects storm water runoff causes to the water quality and aquatic life of receiving water bodies is a relatively recent development (USEPA, 1999). The other key question is to know whether these impacts are of such a nature that the environment is detrimentally affected.

In line with the provisions in the National Water Act, 1998 (Act No. 36 of 1998), the Department of Water Affairs and Forestry (DWAF) has identified water quality management as a priority in South Africa. As stated by DWAF (1996):

'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.'

According to DWAF (1996), the above can be attained through focusing on:

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

Ultimately, an improved understanding of the effects of stormwater runoff and its associated pollutant loadings from construction sites is required in order to properly specify pre-construction preventative measures and during and post construction mitigation. This study should therefore assist in improving current best management practice decisions with regard to minimizing impacts on coastal forest wetlands and water resources, thus leading to improved Environmental Management Plans (EMP) and Stormwater Management Plans (SWMP) incorporating Stormwater Pollution Prevention Plans (SWPPP) for construction sites.

1.2. Motivation for the Investigation

The focus of this investigation is to characterize the water and sediment quality of a coastal forest wetland and the quality of stormwater runoff entering the wetland from various mixed use catchments within a development under construction in Ballito. The characterization aims to qualitatively and quantitatively identify trace metals transported within stormwater runoff from construction sites during rainfall events.

Chrystal (2006) indicates that the quality of surface runoff during rainfall events is affected by land use changes from the original natural state to the final end use whether it be for forestry, agriculture, transportation systems or urbanisation. Pollution from construction sites has been identified as a non-point source (NPS) (Pitt *et al.*, 1995), and Barret *et al.* (1998) identified NPS pollution as one of the leading causes of degradation of water quality in receiving water bodies. This study investigated the status of wetland water and sediments as well as the stormwater runoff into the wetland from three major catchments incorporating construction sites within a developing estate. Trace metals (also referred to as heavy metals) were selected due to their identification as potential toxicants (Maltby *et al.*, 1995).

Although the use of land as a construction site is relatively short term in nature in relation to most other land uses, the pollutant build-up on the sites and surrounding hard pan surfaces such as roads, can be an important contributor, and their effects require management when considering the stormwater runoff quality. In most cases construction sites are generally linked directly to water bodies via artificial drainage systems such as roads and stormwater drains and outlets, but can in some instances have direct overland flow routes if bordering on wetlands and lakes.

1.3. Objectives of the Investigation

The objectives of this investigation were:

1. To study the environmental state of a coastal forest during intensive construction activity.
2. To assess the nature and dynamics of the sources of the impacts of the construction phase on the natural environment with particular reference to coastal forests, and
3. To provide a framework for the assessment of impacts of construction activities through the selection of appropriate environmental indicators.

Seaward Estates in Ballito (see Appendix A) was selected as a case study which was monitored over a period of eight months. Water and sediment samples were taken on a monthly basis from 5 strategically selected positions within the wetland, and representative stormwater runoff samples were taken from three stormwater catchment outlets after storm events. These samples were analysed to assess the physico-chemical state of the runoff water and wetland water and sediments, and to estimate the concentrations of heavy metals present. A series of thematic maps built up from collected and collated Geographical Information System (GIS) data were required to graphically portray the relationships between spatially related entities such as developing erven and catchment areas, and non static events such as rainfall, construction activities and services breakages and spills occurring within and around these entities. The aim was to show the nature and extent of the environmental impact of the construction phase of a development on a sensitive coastal forest.

1.4. Outline of the Dissertation

Chapter two of this dissertation contains a review of literature covering topics of stormwater runoff contaminants, sources of pollution from construction sites, natural wetlands and coastal forests, the application of Geographical Information Systems (GIS), possible effects to aquatic ecosystems and human health, and mitigation options.

Chapter three presents a review of the case study under investigation. A snapshot of the status of construction within the development at inception of the study in January 2007 is given, and a brief review of construction activities on the estate is discussed. Finally, the wetland system under investigation is discussed.

The collection of wetland water and sediment samples and the installation and collection of atmospheric and runoff sampling equipment are presented in Chapter four. Laboratory procedures and chemical analysis relating to stormwater samples and pollutants are discussed. Finally, the development and use of a GIS for the purposes of creating thematic maps are discussed.

Chapter five presents the results and discussion of an eight month monitoring program for wetland water and sediment quality and atmospheric deposition and stormwater runoff. Anthropogenic incidents that occurred during the study period that may have had an effect on the results are also discussed.

Conclusions of the research and recommendations are summarised in chapter six. The objectives of this investigation are addressed and the results are evaluated.

CHAPTER 2

LITERATURE REVIEW

Chapter two introduces construction pollutants and stormwater runoff characteristics. A review of current literature identifies sources of contaminants associated with construction and particularly with stormwater runoff. Methods of estimating pollutant loading and management strategies are reviewed. Coastal forests and wetlands are reviewed and the possible effects on receiving water bodies are introduced with a summary of water quality indicators. Finally, the application and use of GIS software and systems for creating thematic maps of a system are investigated.

2.1. Construction Pollution and its Sources

Non-point source pollution of surface waters in South Africa generally results from atmospheric deposition, seepage, drainage, groundwater flow and river course modification, rainfall and the associated surface runoff or groundwater discharge. These sources may be diffuse and intermittent contributing to the contamination of water resources over a widespread area such as storm washoff and drainage from urban or agricultural areas, or alternatively they may be concentrated from localized high activity areas such as mines, landfills, industrial sites and construction sites. Non-point source impacts of surface washoff are relatively immediate, while the impact of groundwater discharge is often delayed as a result of the time taken for contaminants to become mobile and move through the soil to the receiving surface water (Pegram *et al.*, 2001).

The contaminant sources from construction sites can largely be pinpointed to concrete truck washouts, fuelling areas, materials storage areas, areas of spills, dumping of construction wastes and leaving them exposed to the elements, borrow pits and stockpiles, burning of wastes and rubble and illegal burying of waste on the sites. The pollutants that are most often generated include gasoline (diesel), oil, grease, raw materials from the production of concrete such as aggregate, sand, cement and admixtures, paints and solvents, glass bottles, plastics and styrofoam and other liquid and solid wastes (USEPA, 1991).

2.1.1 Erodible materials

"Sediment is, by weight, the greatest pollutant of water resources" (Burton *et al.*, 2002). Problems that are encountered as a result of erosion from construction sites and stormwater runoff include sediment that destroy fish habitat and fills in lakes, nutrient discharges that produce excessive algae growths and eutrophication, discharges of toxic heavy metals and organics resulting in inedible fish stocks and undrinkable water (Burton *et al.*, 2002; CASQA, 2003). These erosion losses and downstream sedimentation peak during construction as the soil exposure is normally at its greatest, and decline towards completion (Burton *et al.*, 2002; USEPA, 2007). While these impacts to the environment can be severe, they are relatively short term in nature for any specific construction site. However, stormwater runoff and pollutant discharges increase as development progresses and remain at an elevated level due to the impervious surfaces such as roads and sidewalks, driveways and roofs of the final development (Burton *et al.*, 2002).

Willet (1980) concluded that in the United States, despite construction sites taking up a relatively small portion of the land use area (0.0007 percent), construction waste accounts for approximately 10 percent of the sediment load to U.S surface waters. Other studies have shown that construction sites can generate approximately 8 times more sediment and 18 times more phosphorous than industrial sites (Chesters *et al.*, 1979). The activities that lead to this high sediment load include removal of surface vegetation, stripping of topsoil, stockpiling of high mounds of highly erodible excavated soils and the tracking of mud onto roads by construction vehicles.

2.1.2 Construction Materials and Waste

Wastes associated with building/housing construction include unused and excess material generated during site excavation, site clearance, construction, and renovation activities. These materials are most often in the form of building debris, rubble, concrete, timber, steel, earth and mixed site clearance materials. Studies undertaken in various countries where construction activities are rapidly occurring show that construction wastes make up a large percentage of the total wastes deposited in landfills. Ferguson *et al.* (2005) found that in the UK, the percentage of construction waste in landfills was as high as 50%, Craven *et al.* (1994) found that in Australia the percentage of construction waste in landfills was between 20 and 30%, and in the USA, Rogoff and Williams (1994) found the percentage of construction waste in landfills to be in the order of 29%. Furthermore, construction activities also have the potential to generate chemical and special wastes. These wastes are normally strictly regulated for special treatment due to their potential to pollute the environment and pose health risks (Shen *et al.*, 2004).

In the classification of construction wastes, it can be determined that wastes originate throughout the whole process of project implementation. The classification of construction waste sources has been defined in various studies. In their investigation where they compared results obtained from studies in the Netherlands, Germany, Australia, Finland and the United States, Bossink and Brouwers (1996) categorized wastes according to the nature and technology making use of the materials into mortar, sand-lime, concrete, piles, stone tablets, roof tiles, bricks and small fractions of wood and metal. They furthermore identified aspects such as the lack of attention paid to sizes of products used, lack of contractor influence and lack of construction knowledge of the designers as major causes of waste generation. Gavilan and Bernold (1994) categorized waste sources into design error, purchasing or shipping error, materials handling, machine operation error and leftover or residual scraps. In their survey, Faniran and Caban (1998) identified five typical sources, these being design changes, design errors, leftover scraps of material, packaging and consumables and poor weather, whilst Rounce (1998) determined that the design stage posed a major source of waste due to design changes, variability in the numbers of drawings and the variability in design details.

Studies undertaken in the Netherlands of housing construction projects revealed that on average 9% by weight of purchased construction materials ends up as waste (Bossink and Brouwers, 1996). This was derived from surveys done on sites which showed that the largest sources of waste were stone tablet (29%), piles (17%), concrete (13%), sand and limestone elements (11%) and roof tiles (10%). This constituted 80% of the total waste stream generated (Bossink and Brouwers, 1996). This shows further that between 1% and 10% of every purchased construction material leaves the construction site in the form of waste. Similar studies undertaken in Brazil to those done in the Netherlands were compared by Bossink and Brouwers (1996) and these showed slightly different sources as a result of the different building and construction methods employed in the two countries, however the end result was that on average between 20% and 30% by weight of construction materials purchased on these projects ended up as waste (Bossink and Brouwers, 1996). This shows that due to the great variety in types of construction and methodologies employed it is difficult to call these findings representative of the industry as a whole as different firms and projects would generate very different waste streams (Gavilan and Bernold, 1994), however, it has been determined that in most instances investigated, process waste which comes from leftovers from cutting stock material to fit and non-reusable consumables make up the majority of wastes. According to Gavilan and Bernold (1994), process waste accounts for 80-85% of the brick and block waste, 85-90% of the lumber waste, 90% of stone tablet waste whilst improper handling caused about 10-12% waste, and craftsmen error only around 5-10% of wastes. Packaging can make up to 25-30% of all wastes on building construction sites (Gavilan and Bernold, 1994). Other pollutants from construction activities can be identified as well such as fertilizers and pesticides from landscaping, paints and solvents, diesel fuels, oils, antifreeze, degreasers, transmission and hydraulic fluids, and various types of cleaning chemicals. All of these can be transported in stormwater runoff (SWR) from the construction site to local streams. Paper, cardboard and plastic trash that are discarded on-site are pollutants that will end up as floatables in SWR and enter the downstream water bodies.

The construction of a single family home typically produces between two and four tons of debris (Donnelly, 1995). Beyond the issue of quantity, the toxic nature of some of these materials, such as adhesives, solvents, asbestos and lead is leading to increased concern. Construction and demolition waste (C&D) is constituted by wood, steel, metal, gypsum, plastic, insulation and rubble constituting concrete, masonry, plaster and asphalt and can be classified according to its three sources: new construction, renovation or remodeling, and razing or demolition (Laquatra and Pierce, 2004). C&D waste can be further classified into materials that could be recycled, hazardous waste, and stable landfill materials, however, this classification scheme is not as straightforward as it seems. Gypsum board from ceiling and dry walling materials for example, is both recyclable and potentially hazardous. The reason for the potential hazard arises because of hydrogen sulfide that is produced as the material decomposes under anaerobic conditions (Burger, 1993). Table 2.1 and Figure 2.1 illustrate typical waste quantities and volumes generated in the construction of an average size family residence (Smart Growth Network, 2000).

Pollution from construction sites can however be dramatically reduced if waste reduction or recycling measures are implemented on site (Laquatra and Pierce, 2004).

Table 2.1: Typical Construction Waste Estimated for a 185 Square Meter Home in the USA (adapted from Smart Growth Network, 2000)

Material	Weight (in kilograms)	Volume (in cubic metres)
Solid Sawn Wood	726	4.6
Engineered Wood	635	3.8
Drywall	907	3.8
Cardboard (OCC)	272	15
Metals	68	0.76
Vinyl (PVC)	68	0.76
Masonry	454	0.76
Hazardous materials	23	-
Other	476	8.4
Total	**3629**	**38.2**

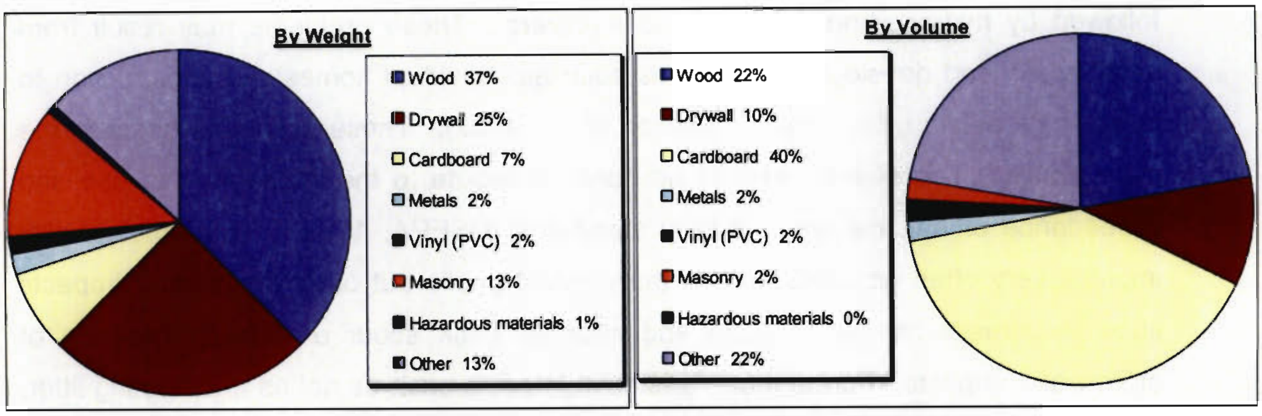


Figure 2.1: Typical Percentages of Construction Waste estimated for a 185 Square Meter Home in the USA (adapted from Smart Growth Network, 2000)

2.2. Introduction to Stormwater Runoff

Stormwater runoff (SWR) is that portion of rainfall that can no longer be retained on the surface or be absorbed by the ground after a rainfall event. Stormwater runoff is categorised as a non-point source (NPS) or diffuse source of pollution as the origin of specific pollutants is often difficult to identify and associated with specific land use (Novotny, 1994). The pollutants present in stormwater runoff originate from a variety of sources and vary depending on the land use patterns in each watershed and can be associated with specific activities such as parking lots, streets, industrial activities, residential or commercial areas, farming or construction. Diffuse sources are difficult or impossible to monitor at the source, are difficult to generalise and have extensive constituent concentration variations due to their being site specific and are therefore not repeatable between events (Novotny, 1994; Thomson *et al.*, 1994). Stormwater runoff naturally contains numerous constituents, however, urban activities such as construction increase the constituent concentrations levels which then impacts water quality. Pollutants that are associated with stormwater include sediment, nutrients, bacteria and viruses, oil and grease, metals, organics and pesticides, some of which can also affect the pH of stormwater (CASQA, 2003).

Horner *et al.* (1994) categorised the pollutants associated with urban runoff that are potentially harmful to receiving water bodies into solids, oxygen demanding substances, nitrogen and phosphorous, pathogens, petroleum hydrocarbons, metals and synthetic organics. Pitt *et al.* (1995) determined that construction sites are a major urban pollution source and responsible for dispersion into the environment of eroded soils comprising suspended and bedload sediments, dissolved solids and turbidity, followed by hydrocarbons, metals and fertilizers. These problems may result from small scale land development activities such as individual homestead construction to large scale public utility projects (Burton *et al.*, 2002). These pollutants degrade the water quality of receiving water bodies and contribute to the impairment of use and exceedance of national water quality standards (USEPA, 1999). The water quality impacts very often go unnoticed by the general public but other stormwater impacts such as stream channel erosion and channel bank scour are direct evidence of stormwater impacts. Furthermore, aesthetic impacts such as debris and floating litter, excessive algal growth and surface scum and odour problems can be attributed to urban stormwater runoff and detracts from the water bodies' recreational value and visual attractiveness (USEPA, 1999).

Stormwater runoff has been found to contain similar contaminants to those found in industrial and municipal waste discharges (Bastian, 1997; Welch, 1992). In their investigations, Bastian (1992) and Welch (1992) compared concentration levels of several contaminants found in sewage and stormwater with that of approximate naturally occurring levels and these are illustrated in Table 2.2. As indicated in the table, the concentration of select water quality parameters of urban runoff is comparable to that of untreated domestic wastewater. Both untreated urban stormwater runoff and final or secondary treated domestic wastewater are discharged directly to receiving streams and thus the pollutant loadings from runoff can be much higher than treated domestic wastewater (USEPA, 1999).

Table 2.2: Water quality comparisons done between the natural state of water, sewage and urban runoff adapted from Bastion (1997) and Welch (1992)

Constituent	Concentration (mg/l)					
	Welch			Bastion		
	Natural	Runoff	Sewage (untreated)	Runoff	Sewage (untreated)	Sewage (treated)
TSS[a]	0.8	630	200	150	200	20
COD[b]	–	–	–	75	500	80
BOD[c]	1.0	30	400	-	-	-
Total N	0.5	3.1	40	2	40	30
Total P	0.02	0.4	10	0.36	8	2
Zinc (Zn)	0.002	0.3	0.16	0.02	0.28	0.08
Copper (Cu)	0.002	0.2	0.11	0.05	0.22	0.03
Lead (Zn)	0.002	0.7	0.04	0.18	0.10	0.05

[a] Total suspended solids [b] Chemical oxygen demand
[c] Biochemical oxygen demand

Urban runoff, apart from the usual pollutants, also contains a variety of other toxic elements such as oils, polyaromatic hydrocarbons (PAH), polychlorinated biphenyls (PCB), lead and other toxic metals (Novotny, 1994).

2.2.1 Stormwater runoff from construction sites

Runoff from construction sites in urban areas is viewed as a non-point source despite the fact that the washoff is generally washed onto roads and then channelled to a stormwater reticulation network and released into the nearest water body or flood plain at a concentrated point (Burton *et al.*, 2002; Pegram *et al.*, 2001).

Although metals may be found naturally occurring in low concentrations as a result of weathering of soil and geology, atmospheric deposition from areas under urban, industrial, mining and transportation land uses, with construction sites comprising a rather mixed use, tends to have high concentrations of copper, lead, chrome, zinc and cadmium in particular (Pegram *et al.*, 2001). According to Ball (1996), the contribution by atmospheric sources to the mass of contaminants may be significant. Heaney and Sullivan (1971) estimate that approximately 70% of material found on a road surface originates from dust fallout. Atmospheric deposition can be categorised into two types depending on the method in which material is transported. Dry deposition occurs during the period between storm events while wet deposition occurs when contaminants in the air are entrained by precipitation removing them from the atmosphere during rainfall events. Typical sources of atmospheric pollutants consist of combustion by-products from passenger and construction vehicles, dust, industrial emissions and agricultural burning. These airborne pollutants are transported by the wind and either settle onto hard pan surfaces such as roads, are blown into streams and wetlands or remain suspended until flushed out by rainfall.

In summary, the magnitude of stormwater impacts depends on construction activities, climatic conditions, and site conditions. The most visible water quality impacts due to construction activities are erosion and sedimentation while other less visible impacts are associated with off-site discharge of pollutants such as metals, oil, grease, nutrients, oxygen demanding substances, soil additives and other toxic substances, pesticides, pathogens, construction chemicals, and other construction waste (Boyd and Gardner, 1990; CASQA, 2003). For this investigation the characterisation of stormwater runoff included heavy metals, oxygen demanding substances, sediments, ammonia and nitrates and physico-chemical analysis for pH and conductivity.

2.2.2 Pollutant Impacts on Water Quality

The activities undertaken during construction result in the generation of wastes in various forms, and these eventually find their way to water courses through the actions of stormwater runoff and atmospheric deposition and wind erosion (CASQA, 2003). Although eroded sediments are the major pollutant associated with construction sites, the other pollutants can potentially have far more devastating and far reaching effects on the environment as a whole (CASQA, 2003). The impacts thereof on the water quality of receiving water bodies are tabled in Table 2.3, and the construction activities that provide sources of the various pollutants are illustrated in Table 2.4.

Table 2.3: Construction Activity Pollutants (adapted from CASQA, 2003)

Sediment	Sediment can be detrimental to aquatic life by interfering with growth, photosynthesis, respiration, reproduction, and oxygen exchange in water bodies. Sediment can transport other pollutants that are attached to it including nutrients, trace metals, and hydrocarbons. Sediment is the primary component of total suspended solids (TSS), a common water quality analytical parameter.
Nutrients	Nutrients including nitrogen and phosphorous are the major plant nutrients used for fertilizing landscapes. These nutrients can result in excessive or accelerated growth of vegetation, such as algae, resulting in impaired use of sources of water supply. In addition, un-ionized ammonia (one of the nitrogen forms) can be toxic to fish.
Bacteria and viruses	Sources of these contaminants include animal excrement and sanitary sewer overflow. High levels of indicator bacteria in stormwater have led to the closure of beaches, lakes, and rivers to contact recreation such as swimming.
Oil and grease	Oil and grease includes a wide array of hydrocarbon compounds, some of which are toxic to aquatic organisms at low concentrations. Sources of oil and grease include leakage, spills, cleaning and sloughing associated with vehicle and equipment engines and suspensions, leaking and breaks in hydraulic systems, restaurants and waste oil disposal.
Metals	Metals including lead, zinc, cadmium, copper, chromium, and nickel are commonly found in stormwater. Many of the artificial surfaces of the urban environment (e.g., galvanized metal, paint, automobiles, or preserved wood) contain metals, which enter stormwater as the surfaces corrode, flake, dissolve, decay, or leach. Metals are of concern because they are toxic to aquatic organisms and bioaccumulate.
Organics	Organics may be found in stormwater in low concentrations. Often synthetic organic compounds (adhesives, cleaners, sealants, solvents, etc.) are widely applied and may be improperly stored and disposed. In addition, deliberate dumping of these chemicals into storm drains and inlets causes environmental harm to waterways.
Pesticides	Pesticides (including herbicides, fungicides, rodenticides, and insecticides) have been repeatedly detected in stormwater at toxic levels, even when pesticides have been applied in accordance with label instructions. Accumulation of these compounds in simple aquatic organisms, such as plankton, provides an avenue for biomagnification through the food web.
Gross Pollutants	Gross Pollutants (trash, debris, and floatables) may include heavy metals, pesticides, and bacteria. Typically resulting from an urban environment, industrial sites and construction sites, trash and floatables may create an aesthetic "eye sore" in waterways. Gross pollutants also include plant debris (leaves and lawn-clippings from landscape maintenance), animal excrement, street litter, and other organic matter. These may harbor bacteria, viruses, vectors, and depress the dissolved oxygen levels in streams, lakes, and estuaries sometimes causing fish kills.
Vectors	Vector production (e.g., mosquitoes, flies, and rodents) is frequently associated with sheltered habitats and standing water. Unless designed and maintained properly, standing water may occur in treatment control Best Management Practice (BMP) for 72 hours or more, thus providing a source for vector habitat and reproduction.

Table 2.4: Construction Activity Pollutants (CASQA, 2003)

Construction Activity	Pollutants						
	Sediment	Nutrients	Trace Metals	Pesticides	Oil, Grease, Fuels	Other Toxic Chemicals	Miscellaneous Waste
Construction Practices							
Dewatering Operations	X					X	
Paving Operations	X			X	X	X	X
Structure Construction/Painting			X			X	X
Material Management							
Material Delivery and Storage	X	X	X	X	X	X	X
Material Use		X	X	X	X	X	X
Waste Management							
Solid Waste	X	X					X
Hazardous Waste						X	
Contaminated Spills	X					X	
Concrete Waste							X
Sanitary/Septic Waste							X
Vehicle/Equipment Management							
Vehicle/Equipment Fueling						X	X
Vehicle/Equipment Maintenance						X	X

Table 2.4 illustrates very basically that waste and pollutants are generated at virtually every activity taking place on a construction site throughout the process, and thus the importance of best management practises is very apparent. It is also obvious from Table 2.3 that ultimately the two main transport mechanisms of the contaminants generated on a construction site are through stormwater runoff and wind erosion.

2.3. Stormwater Events and Runoff Sampling

2.3.1 Stormwater runoff events

Pollutant assessment and comparisons require accurate representative stormwater runoff data from representative storm events. The definition of a representative storm event reduces distortions and variability of the data, which may in turn result in inaccurate assessments (Chrystal, 2006).

Chrystal (2006) identified 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 regarding how many days, how intense and what volume respectively constitute a representative storm event, and Chrystal (2006) eventually concluded that the USA Environmental Protection Agency (EPA) requirement for sampling for the National Pollutant Discharge Elimination System (NPDES) be adopted for sampling of storm events. The requirements for the NPDES are that storm events should meet a minimum depth and antecedent dry period and fall within a reasonable range of the local average depth and duration and would 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.

2.3.2 Sampling Stormwater runoff

Chrystal (2006) investigated and compared various methods of sampling. He investigated discrete sampling methods such as manual and automated grab samples, as well as composite sampling which comprise discrete sample aliquots which represent the average constituent characteristics of an entire stormwater runoff event. Chrystal (2006) eventually designed a flow weighted composite stormwater sampler for undertaking sampling for characterizing stormwater runoff, and these samplers were utilised in this study.

2.3.3 Event mean concentration

There are often variations in pollutant concentrations of several magnitudes during a runoff event so an event mean concentration (EMC) is a single index representing the flow weighted average concentration of an entire runoff event (Chrystal, 2006; Huber, 1993). The EMC is defined as the total pollutant loading divided by the total volume of flow given by:

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

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	= is the total event time

EMC are used to represent data in the majority of SWR investigations and therefore the use of EMC allows the results to be compared to other international studies on SWR (Barrret *et al.*, 1998; Chrystal, 2006.).

2.3.4 Temporal variation of SWR

Studies undertaken by the National Urban Runoff Project (NURP) have investigated the occurrence of the first flush phenomenon in SWR and identified the disproportionately high concentration levels of pollutants in the early stages of a storm and contained in the initial half to one inch of the runoff (USEPA, 1991). 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%. In his review of several investigations done on the first flush phenomenon, Deletic (1998) aimed to define, provide evidence for, and establish factors that influence the first flush, but encountered difficulty defining the first flush as different approaches have been used, such as (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 the first 25-30% of runoff accounted for 80% of the total load. First flushes are more likely to occur with large and intense storms and they are complex and site specific (Deletic, 1998).

For the purpose of this investigation, a first flush will be regarded as a partial event mean concentration (PEMC) that is greater than the EMC, as cited by Sansalone (1997)
(Chrystal, 2006):

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

Where

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

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

2.4. Managing Stormwater Runoff from Construction Sites

An understanding of the first flush phenomenon and the temporal variation of constituent concentrations in stormwater runoff affect management decisions. The information may be utilised in the early planning stages of development of treatment plans which aim to reduce the impact of the NPS pollution as a result of stormwater runoff (Chrystal, 2006). First flush discharge impacts can be mitigated by designing stormwater management facilities that improve the discharge quality of runoff by providing treatment within the structure prior to discharge (USEPA, 1999). The quantity and quality of stormwater discharge from a construction site varies depending on the stage of construction and the effectiveness of on-site controls implemented (US EPA, 1991). Due to the non-point source nature of stormwater runoff pollution, the effect of drainage system types and operations are crucial to BMP that aim to reduce the contaminant loading of receiving water bodies.

Best management practices (BMP) as part of a Stormwater Pollution Prevention Plan (SWPPP) include structural systems known as treatment control and non-structural systems also known as source control, comprising the following (USEPA, 1991, USEPA, 1999, USEPA, 2007):

Structural systems

Engineered on and off-site sedimentation and detention and retention basins, underground vaults, infiltration trenches and basins, constructed wetlands, vegetated ditches or grassy swales, also known as bio filters, silt fences, sand berms and drainage system improvements.

Non-structural systems

Good housekeeping practises such as picking up trash, improved street sweeping operations, catchment basin cleaning and stormwater pollution education such as storm drain inlet stencilling.

Source control BMP aim to prevent contaminants from entering stormwater whereas treatment control BMP aim to reduce the level of contaminants transported by SWR. These options can be costly and may be optimised with improved understanding of the pollutant loading characteristics and the timing of the various measures required during construction (Finnemore, 1982). As stated previously, sedimentation from erosion makes up a major component of runoff contamination, and the USEPA has identified six stages of construction requiring particular attention due to the change in erosion pollution potential (USEPA, 1991):

- **Stage 1 Pre-Construction**
  Minimal erosion potential so site perimeter controls should be installed.
- **Stage 2 Clearing and Access Grading**
  Erosion potential starts to increase so protection of off site facilities and inlet protection become necessary. Sediment controls and stormwater management facilities should be installed.
- **Stage 3 Full Clearing and Grading**
  Higher levels of erosion occur. Regular inspection and maintenance of erosion controls and protection measures should take place.
- **Stage 4 Installation of Permanent Stormwater Drainage System**
  Stormwater management facility construction is complete and drains gradually connected to divert runoff to stormwater structures. Erosion continues to increase as disturbed areas increase.
- **Stage 5 Active Construction of Structures**
  Construction at its peak and high erosion occurs as runoff volume approaches maximum. Maintenance of erosion control practises is of great importance to ensure that structures do not have inadequate capacity.

- **Stage 6 Site Stabilization**
  Disturbed areas are stabilized with vegetation and erosion rates decline. Temporary control measures are removed, and permanent structures are cleaned of collected sediment.

Common objectives of a BMP and SWPPP according to USEPA (2007) are:

- Stabilizing of the site as soon as possible.
- Protection of the slopes and channels
- Reduction of impervious surfaces and promotion of infiltration
- Controlling the perimeter of sites
- Protection of adjacent receiving waters
- Following pollution prevention measures for the handling of wastes, and
- Minimizing the area and duration of exposed soils

The BMP prescribed by USEPA (2007) for construction sites are particularly focused towards erosion and sediment control and good housekeeping. Erosion control is undertaken to keep the sediment in place and to minimize the impact of construction, while sediment control is the second line of defence used to capture any sediment that has been moved by stormwater before it leaves the site. Good housekeeping is important on any construction project as they generate large amounts of waste that can pollute stormwater runoff if not properly managed. Six principles for good housekeeping promoted by US EPA (2007) are providing for solid waste management, establishing building material staging areas, designating paint and concrete washout areas, developing a spill prevention plan, controlling equipment and vehicle washing and establishing proper equipment and vehicle refuelling practises. BMP strategies are generally site specific and will combine various BMP which take into consideration the contributing drainage area, local pollutants and conditions with an objective to also providing benefits in flood control, reduced peak runoff flow and soil erosion.

2.5. Naturally Occurring Wetland Habitats in Kwazulu-Natal

In their extensive analysis of the vegetation habitats across the country, Barrie Low and Rebelo (1998) and later Mucina and Rutherford (2006), categorized numerous biomes in the nine provinces as well as in Lesotho and Swaziland. In KwaZulu Natal they found four major categories of vegetation biome namely Forest, Grassland, Savannah and Thicket. In their analysis of the KwaZulu Natal coastline, the wetland that is under investigation in this study is broadly classified as Forest under the sub-category of Coastal Forest (Barrie Low and Rebelo, 1998; Mucina and Rutherford, 2006). In his classification of the bioresources groups in Kwazulu-Natal, Camp (1997) categorised the 20km wide strip from Port Edward to Kosi Bay as Moist Coastal Forest which incorporates Swamp Forest which are imbedded in other forests.

2.5.1 Coastal Forest

Coastal forests are restricted to a narrow belt of high dunes along the coast. They develop in regions where the annual rainfall usually exceeds 700mm, and are more prevalent in summer rainfall regions (Barrie Low and Rebelo, 1998). Environmental factors affecting the occurrence of coastal forests are high temperatures, wind and salt spray as these tend to have a pruning affect and therefore restricts their distribution and height growth to around 30m (Barrie Low and Rebelo, 1998; Camp, 1997; Mucina and Rutherford, 2006). Commonly occurring species include Coast Red Milkwood (*Mimusops caffra*), Natal Wild Banana (*Strelitzia nicolai*) and within wetland areas, the Swamp Fig (*Ficus trichopoda*) (Barrie Low and Rebelo, 1998; Bundy, 2007, Camp, 1997; Mucina and Rutherford, 2006). Coastal forests have distinctive strata of trees, shrubs and herbs and the higher rainfall and stable climate allows for a richly diverse forest (Barrie Low and Rebelo, 1998; Mucina and Rutherford, 2006). Coastal forest however relies on and is able to accommodate coarse grained disturbance such as forest fires. This system is constantly regenerating itself in the form of branches and trees breaking and falling down and new ones coming up, and fire damage recovery is normally very good (Bundy, 2007). It is interesting to note that Barrie Low and Rebelo (1998) refer to the expansion of residential and holiday resorts along the coastline as the major threat to Coastal Forests.

2.5.2 Swamp Forest

Hygrophilous forests are found within wetland systems often accompanied by moist grassland and sedge communities. In Kwazulu-Natal the most common hygrophilous forests are swamp forest (Weisser, 1987; Cooper and Swart, 1992). Swamp forests are sensitive and can only accommodate fine grained disturbances such as branch and single tree falls. Disturbance on a large scale (coarse) may see a reversion to early successional vegetative forms including sedges (*Cyperus spp, Phragmites australis*) or moist grasslands (*Paspalum vaginatum, Ischaenum sp*). The effects of disturbances through these systems are visible for many years after the effect, and most often the recovery and regeneration is not completed (Bundy, 2007).

Swamp forests occur in small highly fragmented patches of fine, muddy, waterlogged soils which are normally acidic with a pH range of 2.5 to 6, and calcium and magnesium concentrations can be quite high (Weisser, 2003). Main threats to swamp forests are clearing for subsistence and small scale agriculture, sugar cane farming, regional development leading to increased access, and an altering of hydrological regimes and the water table (Barrie Low and Rebelo, 1998; Mucina and Rutherford, 2006; Weisser, 2003).

2.5.3 Wetlands

Wetlands are generally very efficient at removing dissolved solids and chemicals such as nitrates, phosphates, sulphates and most heavy metals from water entering into their ecosystems (Ellery, 2007; Fischer, 2000; McCarthy and Venter, 2006). It is for this reason that wetlands are being utilised more and more in the treatment of effluent (Ellery, 2007; McCarthy and Venter, 2006). The solutes are removed through a variety of processes such as plant absorption, bacterial activity and chemical precipitation which are all facilitated by the slow passage of water through the system which allows considerable contact between the water and the wetland sediments (Kotze and Breen, 1994; Mitsch and Gosselink, 1993). The peat that occurs in these systems is a passive accumulator of solutes and has a high affinity for metal cations, which are bound within it due mainly to the formation of complexes with the humic material (Baird, 1995). Peat thus has a twofold role in the removal of metal ions from the water flowing through the wetland as it is the site of deposition of metals immobilised through adsorption onto sediments and chemical precipitation as well as undergoing its own cation reactions (Fischer, 2000).

Many of the inorganic components essential to living plants such as calcium, magnesium and potassium are retained by sediments that are likely to act as a sink for a variety of other potentially toxic metals, which are then retained and prevent uptake by biota and exposure of downstream ecosystems (Barnes *et al.*, 2002; Fischer, 2000; McCarthy *et al.*, 1989; Mitsch and Gosselink, 1993). The status of the wetland as a transformer, sink or source is dependant on its type and position in the landscape. Endorheic pans are soluble sinks while peatlands are likely transformers of inorganic nutrients to organic compounds (Mitsch and Gosselink, 1993). Other micronutrients also required by plants in trace quantities include copper, zinc, iron and manganese, and these nutrients are absorbed by the plants from the water and sediment and incorporated into the plant tissue. The majority of the nutrients are trapped in the plant tissue when the plant dies, and the metals associated with the plant material are retained in organic form in the peat (Fischer, 2000). As a result of their ability to act as sinks for plant macronutrients, wetlands have been increasingly used for the treatment of wastewater (Ellery, 2007; Rogers *et al.*, 1985).

Typical metal concentrations by mass naturally occurring in surface soils are illustrated in Table 2.5.

Table 2.5: Typical natural metal concentrations in surface soils. Adapted from Fifield and Haines (1995)

Trace Metal	Concentration Range	Trace Metal	Concentration Range
Al (%)	0.5 - 4.5	Mn (ppm)	7 - 2000
Ti (%)	0.02 - 1	Fe (%)	3 - 10
V (ppm)	15 - 360	Ni (ppm)	1 - 120
Cr (ppm)	5 - 1100	Cu (ppm)	6 - 60
Zn (ppm)	17 - 125		

From Figure 5.2 it is evident that Berea Red Sands (BRS) are constituted by Hematite (Fe_2O_3) and Quartz (SiO_2). Chemical characterizations on BRS performed in Fanni (2008) and conducted according to USEPA Method 200.7, in both aerobic and anaerobic conditions, illustrate Fe concentrations ranging between 2.9 and 2.6mg/l respectively. No other metals were detected.

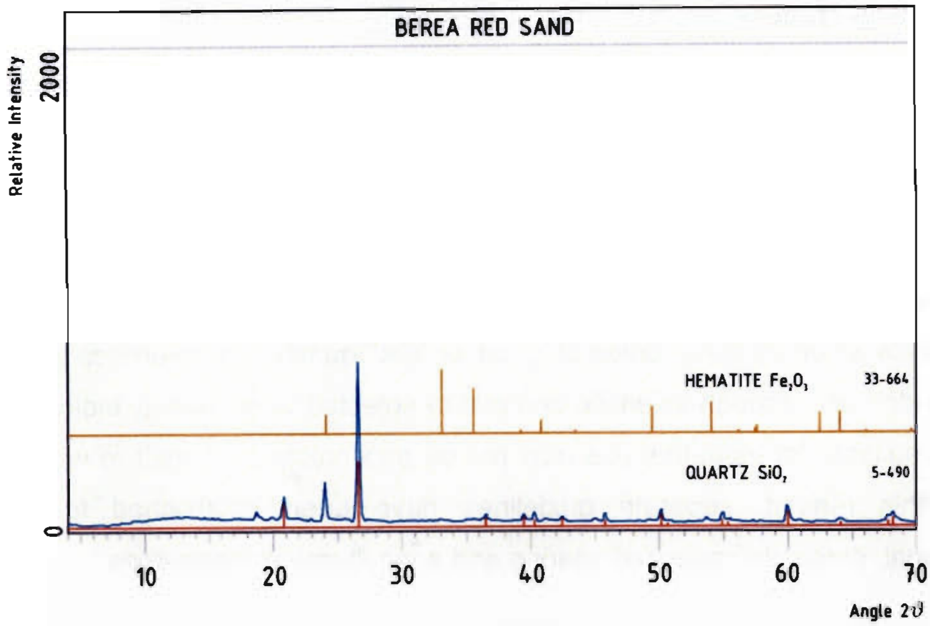


Figure 2.2: Mineralogical characterization of Berea Red Sand (Fanni, 2007)

Chemical elements are primarily transported into wetlands through surface and groundwater inflows. Metal concentrations are affected by a number of factors such as mineral composition of the geological formation of the particular catchments, contact between the water and the parent material and weathering characteristics of rock. Furthermore, land use practises play a significant role in determining metal concentrations in surface flows, and anthropogenic emissions from operations such as mining, heavy industry, agriculture and construction activities are potential pollutant sources (Fischer, 2000).

Wetlands are capable of removing solutes from the water mainly due to their ability to reduce the water flow velocity, which can be attributed to the gentle slopes which are typical of most wetlands, and the dense vegetation that offers resistance to flow (Ellery, 2007; Fischer, 2000). The shallow nature of the water stream and the slow passage through the system allow for considerable contact between the water and the wetland sediment (Kotze and Breen, 1994).

2.6. Water Quality

The term *water quality* is used to describe the physical, chemical, biological and aesthetic properties of water. These in turn determine its fitness for use for various applications and for the protection of the health and integrity of aquatic ecosystems (Pegram *et al.,* 2001). The constituents that are generally used to characterise the water quality are either dissolved or suspended in water (DWAF, 1996). The water quality is classified as either being of 'good' or 'bad' quality with reference to its location and intended use through scientific analysis of selected water quality indicators. Water which is suitable for industrial use may not be acceptable for sensitive water systems so for this reason, separate guidelines have been established for assessing recreational, domestic, industrial, marine and agricultural water sources.

The focus of this investigation is on the characteristics of water quality related to stormwater runoff resulting from rainfall on construction sites into sensitive environments.

2.6.1 Water quality guidelines

There are no specific guidelines pertaining to stormwater runoff. In South Africa, the general practice 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 Department of Water Affairs and Forestry (DWAF, 1996) compiled guidelines entitled the *South African Water Quality Guidelines.* These guidelines provide criteria for water quality of all possible water uses from industrial to recreational, with the intention of maintaining and managing sustainable water resources in South Africa at acceptable quality levels for their intended use.

The introduction of the National Water Act (NWA) (1998) lead to 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 stormwater runoff (Chrystal, 2006). *Wastewater* can be defined as water that contains waste, or has been in contact with waste material (NWA, 1998). The *wastewater limit value* provides the concentration limit that may not be exceeded at any time for specific contaminants. The limit applies to the last point of collection where the discharge enters the receiving water body (NWA, 1998). Table 2.6 presents the wastewater limit values as presented in the National Water Act (1998).

The special limit values in Table 2.6 refer to a significant number of South Africa's specified water bodies, rivers, lakes, dams and estuaries as listed in the National Water Act (1998) such as the Umkomaas river and St Lucia wetlands for example. The list is included for comparison with water quality indicators. The General standards are applicable to wastewater or effluent arising from areas not specified under the Special limit standards. Some contaminants analysed such as aluminium are not covered in Table 2.6, and for these, the guidelines that are considered as the appropriate reference for this investigation are the *South African Water Quality Guidelines for Aquatic Ecosystems* (DWAF, 1996) or SA WQ guidelines, and they cover the majority of pollutant constituents found in SWR.

Table 2.6: 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) as Nitrogen (mg/l)	3	2
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 (µS/m)	70 µS/m above intake to a maximum of 150 µS/m	50 µS/m above background receiving water, to a maximum of 100 µS/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

2.6.2 Target water quality range

The Target Water Quality Range (TWQR) as defined by DWAF is not a set water quality criterion but has been established rather as a management objective (DWAF, 1996). This range of desirable levels of concentrations of pollutants is derived from qualitative and quantitative criteria and the assumptions are that life-long exposure will not result in measurable adverse effects on the health of aquatic ecosystems. The objective of DWAF is to maintain the water quality within the TWQR thus ensuring the protection and sustainability of South African water resources.

2.6.3 Water quality indicators

Of the several methods available to determine water quality, the most widely accepted are biological analysis of organisms present in the water, and chemical analyses of water and sedimentation samples. To characterise the pollutant concentrations of SWR discharge, samples of runoff are analysed and the pollutant concentrations entering the aquatic ecosystems via runoff are then obtained. The water quality indicators selected to characterise the water quality of SWR in this investigation were:

- Concentration of sediments (mg/l)– Total solids (TS), Total suspended solids(TSS)
- Concentration of oxygen demanding substances (mg/l) – COD
- Bacteriological parameters (CFU/100ml) – *E. coli* and Total coliforms (TCC)
- Chemophysical properties – pH, electrical conductivity, Ammonia, Nitrates (NO_3^-)
- Concentration of heavy metals (also known as trace metals) (mg/l) - Al, Ca, Cd, Cr, Cu, Fe, Mn, Ni, Pb, and Zn

These water quality indicators were selected to provide a broad characterisation. A brief description of the selected water quality indicators and their associated standards as presented in Table 2.6 follows.

<u>Total Suspended Solids (TSS)</u>

Total suspended solids (TSS) concentration is defined as the amount of particulate material suspended in water. The majority of the TSS results from erosion of materials and anthropogenic activities, and its levels generally increase with the quantity of sediment that is discharged into the receiving water body. While suspended sediments may reduce light penetration and temperature thus degrading receiving water systems, (Chrystal, 2006 cited Boyd and Gardner, 1990), sediments also carry pollutants such as heavy metals that have adsorbed to their surfaces (DWAF, 1996).

Chemical Oxygen Demand (COD)

Chemical oxygen demand (COD) is a measure of the oxygen equivalent of organic material that is non-biodegradable and can only be chemically oxidised (Metcalf and Eddy, 2003). The measured COD levels in SWR discharge are indicative of the potential for organic wastes to lower the oxygen levels in an aquatic system. Waste water limit values are established by DWAF for dissolved oxygen (DO) and COD, however the EU have biochemical oxygen demand (BOD) guidelines set at 3.0 to 6.0 mg/l for the protection of fisheries and aquatic life (Chapman, 1996).

E. coli

E. coli or *Escherichia coli* are bacteria commonly found in the intestines of humans and other mammals, and its presence in the environment is an indication of faecal contamination. In a built up or developing area it is indicative of anthropogenic pollution (Madigan *et al.*, 2003). Exposure to sewage contaminated soil and water poses a serious health risk as sewage can contain many pathogenic organisms such as cholera, hepatitis, typhoid, *Salmonella*, *Giardia* and others. Most types of *E. coli* are quite harmless, however it is much easier to test for than most of the other organisms and is thus an important marker for sewage contamination (Madigan *et al.*, 2003).

Byamukama *et al.* (2000) determined that Chromocult Coliform Agar, the agar used in this investigation for the detection of *E. coli*, has proven to be a highly efficient, cost effective technique for *E. coli* detection in temperate regions and tropical waters with an approximate error of only 3 percent. The surface plating technique was determined to be successful for spreading of respective dilutions of water sample thus eliminating the need for expensive membrane filters and reducing costs (Byamukama *et al.*, 2000).

Dissolved Oxygen (DO)

Oxygen is only slightly dissolvable in water. Dissolved oxygen is the concentration of oxygen in a sample of water and natural systems must have a minimum DO concentration of 2mg/l to sustain aquatic life forms (Peavy *et al.*, 1985).

Acidity and Alkalinity (pH)

pH is a measure of the hydrogen ion activity in a solution. Chemical and biological reactions in natural waters are influenced by the pH thus its importance as an indicator. The majority of South African freshwater systems display a neutral pH, ranging between 6 and 8, however, in the coastal swamp forests of KwaZulu-Natal, it has been found that the influence of organic acids may cause the pH to drop to as low as 3.9 (DWAF, 1996). The pH level in an aquatic environment also influences the availability and toxicity of constituents, such as trace metals (DWAF, 1996).

Electrical Conductivity (EC)

The electrical conductivity (EC) of the water is a measurement of its ability to conduct an electrical charge (Metcalf and Eddy, 2003). The EC is a useful indicator of the mineral content of the water and generally correlates with the total dissolved solids. EC levels above 370 μS/m in aquatic systems may result in an imbalance of the salt and water equilibrium, and have possible health effects for humans with high blood pressure and renal diseases (DWAF, 1998).

Aluminium (Al)

Aluminium is only soluble under acid conditions i.e. at low pH values, and therefore more bio-available. Although described as a non-critical element, there is growing concern about the elevated concentrations found in the environment which react with acidic water such as acid precipitation. In a study by Schecher and Driscoll (1988) it was found that the concentration of aluminium in many freshwater sources has risen as a result of acid rain. There is no wastewater limit value for aluminium, however elevated levels of bio-available aluminium are toxic to many species of organisms so therefore the SA TWQR criteria for aluminium which is based on acid-soluble aluminium concentrations is used as shown in Table 2.7 (DWAF, 1996)

Table 2.7: 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 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 these concentration levels will have considerable negative impacts on aquatic ecosystems due to the eventual disappearance of sensitive species and their interdependent species (DWAF, 1996).

The Acute Effect Value (AEV) is the concentration at which a there is expected to be a significant probability of measurable toxic effects on up to 5% of the species in the aquatic community. Short term or frequent exposure at these concentration levels will have considerable negative impacts on the aquatic ecosystems due to rapid death or disappearance of sensitive species and their interdependent species.

Cadmium (Cd)

Cadmium is classified as highly toxic to marine and freshwater aquatic life and also poses possible harmful effects to humans (Peavy *et al.*, 1985; DWAF, 1996). The United States Environmental Protection Agency (USEPA) defines Cd as potentially hazardous to most forms of life. As a result of its relative mobility due to its being water soluble, Cadmium is concentrated by the food chain and can therefore bio-accumulate and is also carcinogenic (Peavy *et al.*, 1985; DWAF, 1996; EU Commission 2002; Metcalf and Eddy, 2003).

Chromium (Cr)

Chromium occurs in a variety forms depending on its oxidized state. The effects on the environment and living organisms differ for the various forms. There is a great difference in the toxicity of the reduced forms of Cr (II) and Cr (III) in relation to Cr (VI). Where Cr (VI) may have a number of adverse effects resulting in irritation and is carcinogenic, Cr (III) is an essential nutrient for humans in small dosages (DWAF, 1996; EU Commission 2002; Metcalf and Eddy, 2003).

Copper (Cu)

Copper is a common metallic element abundantly occurring naturally in most waters but is regarded as potentially hazardous by the United States Environmental Protection Agency (USEPA) (DWAF, 1996). The toxicity of Cu is dependent on local water quality conditions and may increase or decrease due to water hardness, dissolved oxygen, presence of other metals and changes to the pH level (DWAF, 1996; Avenant-Oldewage and Marx, 2000).

Iron (Fe)

As the fourth most abundant element in the earth's crust and commonly present in natural waters in varying quantities, iron is classified as a non critical element due to its limited toxicity and bio-availability (Peavy *et al.*, 1985; DWAF, 1996).

Lead (Pb)

DWAF (1996) defines lead as a ready accumulating toxic trace metal and USEPA considers lead toxic and potentially hazardous to most forms of life. Organic lead is more bioavailable and toxic than inorganic lead. Depending on the level of concentration exposure and duration, lead can result in several biological effects, particularly with regards to children (EU Commission 2002).

Manganese (Mn)

Manganese is an abundant metal occurring in a number of ores and is influenced by factors such as DO, pH and presence organic matter. Despite Mn being a necessary micronutrient for animals and plants, high concentrations are considered toxic, resulting in disturbances in metabolic pathways such as the central nervous system (DWAF, 1996).

Zinc (Zn)

Zinc is an essential micronutrient in all organisms. The optimal concentration range varies between species, but is generally narrow (DWAF, 1996). The concentration and toxicity of Zn is influenced by the pH and alkalinity, water hardness, oxygen concentration and presence of other metals and synergistic elements such as cyanide (DWAF, 1996). Zn has relatively low toxicity to humans but even at relatively low concentrations is toxic to fish and aquatic organisms (DWAF, 1996; Alabaster and Lloyd, 1980).

Calcium (Ca)

Calcium is an essential element for all living organisms and is a key constituent of the skeletal system of mammals (DWAF, 1996). Solubility of calcium is influenced by pH and temperature. Calcium has a major influence on the absorption and toxicity of heavy metals. In hard waters, calcium is the cause of scaling in water heating appliances and a high concentration impairs the lathering of soap leading to excessive consumption. There are no adverse health effects as a result of high concentrations of calcium (DWAF, 1996).

2.6.4 Analytical methods for heavy metals

Both the USEPA and NWA (1998) stipulate the measurement of the dissolved fraction for most metals for water quality criteria, however, the adoption of a precautionary approach is recommended in the SA WQ guidelines which stipulates that the methods used measure total metals for Al, Cd and Cu in the form of dissolved and particulate (acid soluble) forms (DWAF, 1996).

The dissolved fraction of metals is considered to more accurately approximate the toxic properties and bioavailability than the total metals (dissolved + particulate) parameter. Variables such as pavement residence time, pH, sample retention time, solids concentration and the type of storage container affect the partitioning of heavy metals between dissolved and particulate bound forms (Sansalone *et al.* 1997). Various studies have also shown that redox potential, hardness, pH, temperature, alkalinity, dissolved oxygen, solids concentration and the combination of metal ions and pollutants affect the availability and toxicity of dissolved metals (Avenant-Oldewage and Marx, 2000; Burton *et al.*, 2001; Riba *et al.*, 2003). The chemical analysis for total metals was therefore selected for this investigation as a result of the uncertainties, primarily associated with the partitioning between the dissolved and particulate fractions, and secondly the bioavailability and toxic properties associated therewith.

2.7. Geographical Information Systems (GIS)

A geographical information system or GIS is a computer-based mapping and information tool. A GIS integrates five basic components needed to perform GIS tasks namely people, data, hardware, software and procedures (see Fig 2.2). The ultimate aim thereof is to be useful for helping us understand and find solutions to real world problems through the main operations of capturing data, storing data, querying data, analysing data, displaying data and outputting information in the form of tables, charts and graphical maps (ArcView).

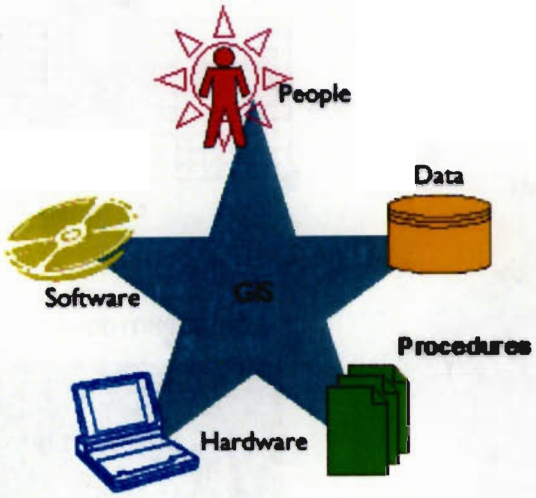


Figure 2.3: Integration of the five basic GIS components (ArcView)

A desktop GIS is software that can link locations or features on a map to descriptive information about the locations. Data can be captured in many forms through inputting tabular (attribute) data or geographic (coordinate) data from many different sources such as spreadsheets such as Excel or computer draughting packages such as AutoCAD. Data in a GIS is stored in two formats, namely vector, which comprises points, lines and areas such as cadastral information, and raster, which is image data based on a grid of cells such as aerial photographs (see Fig 2.3). Querying and analysis of data allows for finding of particular features based on attribute or location data, and answer questions regarding the interaction between spatial relationships between various and multiple datasets. The final aspect of a GIS is the displaying of data which caters for visualizing geographic features in a dynamic format making use of symbology, and outputting the display results in a variety of formats such as maps, graphs and reports (Kasianchuk and Taggart, 2004; ArcView)

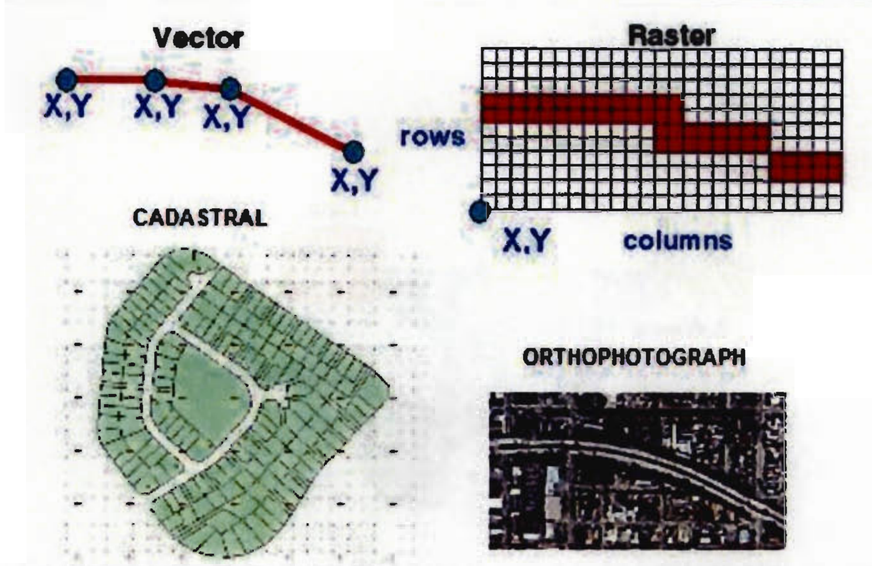


Figure 2.4: The differences between vector and raster data (after UKZN, 2007)

2.7.1 How does a GIS work?

The three main components to a set of geographic data are (see Fig. 2.4):

- Geometry in the form of abstract points, lines and polygons represent the geographic features associated with real-world locations.
- Attributes which are descriptive characteristics of the geographic features are stored in a tabular form and
- Behaviour which is when geographic features can be made to allow certain types of display, analysis or editing. This would depend on the circumstances and is most easily implemented in the geodatabase.

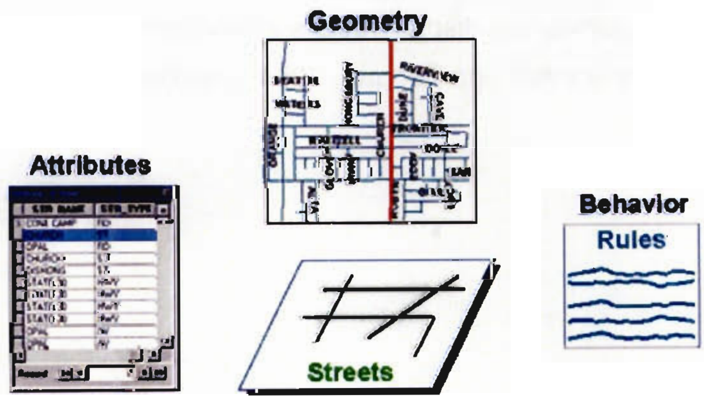


Figure 2.5: Components of Geographic Data (after Kasianchuk and Taggart, 2004)

In a GIS, data about the world, in any scale, whether it be over a country or merely a suburb, is organized as a collection of thematic layers that can be linked by geography.

Each layer contains features having similar attributes that are located within the same geographic extent (Kasianchuk and Taggart, 2004). These layers are overlayed each other creating a composite and integrated view of all the features in the same geographical location (see Fig. 2.5)

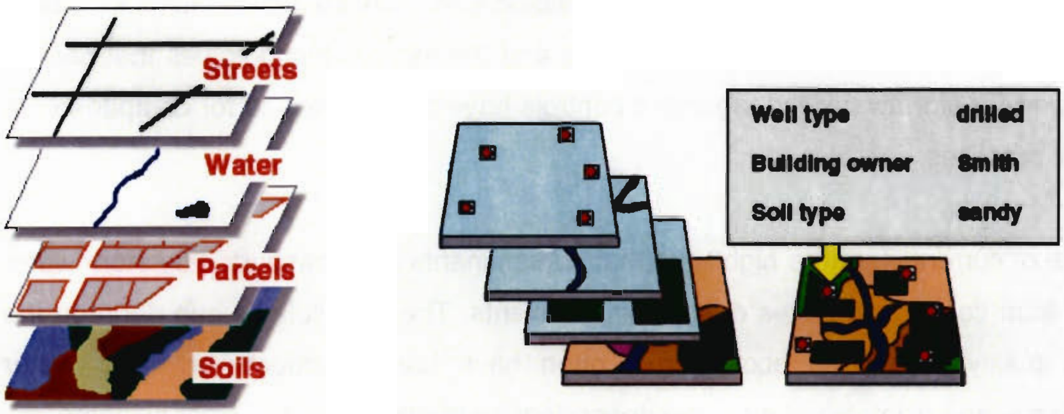


Figure 2.6: Layering of data in a GIS (after Kasianchuk and Taggart, 2004)

The power behind a GIS is its ability to output the information collated into a number of formats depending on the method of communication or distribution. The ultimate output or presentation of the data in the GIS can be in the form of paper maps, individual images, images for the internet and embedded in documents (Kasianchuk and Taggart, 2004). This is illustrated in Fig. 2.6.

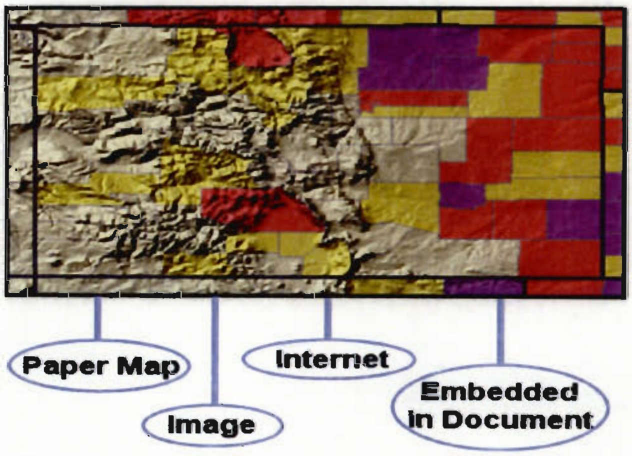


Figure 2.7: Presentation and output of data from a GIS (UKZN, 2007)

2.8. Literature Review Conclusion

Construction sites as non point sources of pollutants have been shown to drastically contribute to the total sediment levels in stormwater runoff as a result of erosion. The contribution by construction activities to waste generation is conceptualized in terms of housing construction activities and the associated construction materials. Best Management Practises of construction sites and the various technologies that can be employed for stormwater management controls have been reviewed for comparison of current practises.

Review of current literature highlights that contaminants are transported by stormwater runoff from construction sites during rainfall events. These pollutants can degrade the water quality of aquatic ecosystems, often have harmful affects on living water organisms, and ultimately the people dependent on the downstream water systems.

The coastline of KwaZulu-Natal has patches of natural vegetation habitats in amongst the canelands that have taken up the land use for over the past century. As human settlement expands, these patches of Coastal forests, Swamp Forests and wetlands are forming part of modern developments and require much attention in terms of protection and incorporation into settlements for the benefit of all, and a greater understanding of the affects of construction activities during these development processes is required.

CHAPTER 3

CASE STUDY

This chapter introduces the case study used for this dissertation with descriptions and explanations of the various aspects of the case study.

3.1. Introduction

Seaward Estates was selected as the appropriate case study for a number of reasons; firstly the development has a substantial coastal forest system which includes a wetland, is currently still predominantly under construction, and some of the areas being developed or with the potential to be developed border this coastal forest system. Furthermore, according to Bundy (2006), the drainage line incorporating the coastal forest and wetland system is one of the very few remaining portions of coastal forest along the Kwazulu-Natal North Coast that has not been destroyed or reduced to an insignificant system of little value, and is thus worth monitoring and conserving. It is for this reason that the Homeowners Association was supportive of the study and agreed to assist and implement measures to facilitate the investigation and use the results and recommendations for the betterment of construction activities on the Estate.

Seaward Estates falls within the Dolphin Coast region in the Kwadukuza Municipal jurisdiction and lies approximately 2km inland of the shoreline of the Indian Ocean. The entire land resource was rezoned from agricultural use to that for residential development with effect from 30th December 1998 (van der Merwe, 2006). It was however retained under sugar cane cultivation and the crop reaped at intervals during the earlier slower stages of development (Theunissen, 2003; van der Merwe, 2006). The first development constructed was the Seaward Villas on the eastern most portion and which was started in October 1999 and shortly thereafter construction of the Church on erf 1797 followed (Reeler, 2006; van der Merwe, 2006). See Appendix A for an overall map of Seaward Estates and the surrounding area.

Seaward Estates forms the catchment of three drainage lines that converge in close proximity to the eastern boundary to flow southwards into the downstream estate known as Zimbali Coastal Forest Estate. The western drainage line, which also happens to be the main drainage system, is the least disturbed of the three systems (Ward, 2003). It consists of a perennial stream resulting from seepage from a steep and unstable hill slope and is situated near the north western corner of the property. The drainage line is furthermore fed by lateral seepage and runoff drainage all along its route to the confluence (Ward, 2003). It is this primary drainage line and its associated wetland systems that is the focus of this study.

The estate constitutes stand lots of different sizes which are zoned for various uses. Table 3.1 shows a breakdown of the components making up Seaward Estates. As illustrated in table 3.1, the estate consists of an educational site occupied by the Seaforth College Primary School, a hospital site for the Alberlito Private Hospital, a commercial node comprising two stands making up a business centre, a lodge / hotel which is still to be developed, and the remainder comprising 838 residential units in the form of single or individual residential erven, sub-development villages and two sectional title clusters.

Table 3.1: Development Components and Associated N° of units

Development Component	N° of Residential Units	N° of Commercial Units	Area (Ha)
School		1	5.12
Hotel		1	1.01
Ballito Business Park		1	2.92
Hospital		1	2.78
San Bush Willows (Sectional title)	125		4.0
San Diego	25		1.56
San Forest View	20		1.06
San Hills	18		1.18
San Hills Sectional Title	23		0.81
San Jerez	83		6.56
San Jose	51		3.23
San Karena	46		4.34
San Lorenzo	22		1.52
San Marco	7		0.69
San Marina (Sectional title)	59		3.09
San Nicholas	23		1.13
San Paulo	16		0.88
San Sebastian	10		0.64
San Tarena	18		0.88
San Te Fe 1	31		1.42
San Te Fe 2	28		1.43
San Thaila	20		0.87
San Tropez	40		1.69
San Zingaro	20		1.51
Seaward Villas	28		2.06
San Marion	12		0.51
Single Res 1	64		6.20
Single Res 2 East	17		1.77
Single Res 2 West	32		3.48
Public Open Space (5 of)			17.5
TOTAL N° of UNITS	**838**	**4**	**82 Ha**

3.2. Status of the Development at inception of the study

The total development of Seaward Estates covers an area of approximately 93.2Ha. The internal land usage or density of development varies. At the planning stage, 17.5Ha of the total were designated as Public Open Space which includes the forest, wetland and drainage lines, 11.3Ha were allocated to roads while the remaining 64.4Ha were allocated for housing development. At inception of the study in January

2007, 38Ha had already been developed, 3.0Ha were under construction and 40.8Ha were still undeveloped. Figure 3.1 shows the spread of the development.

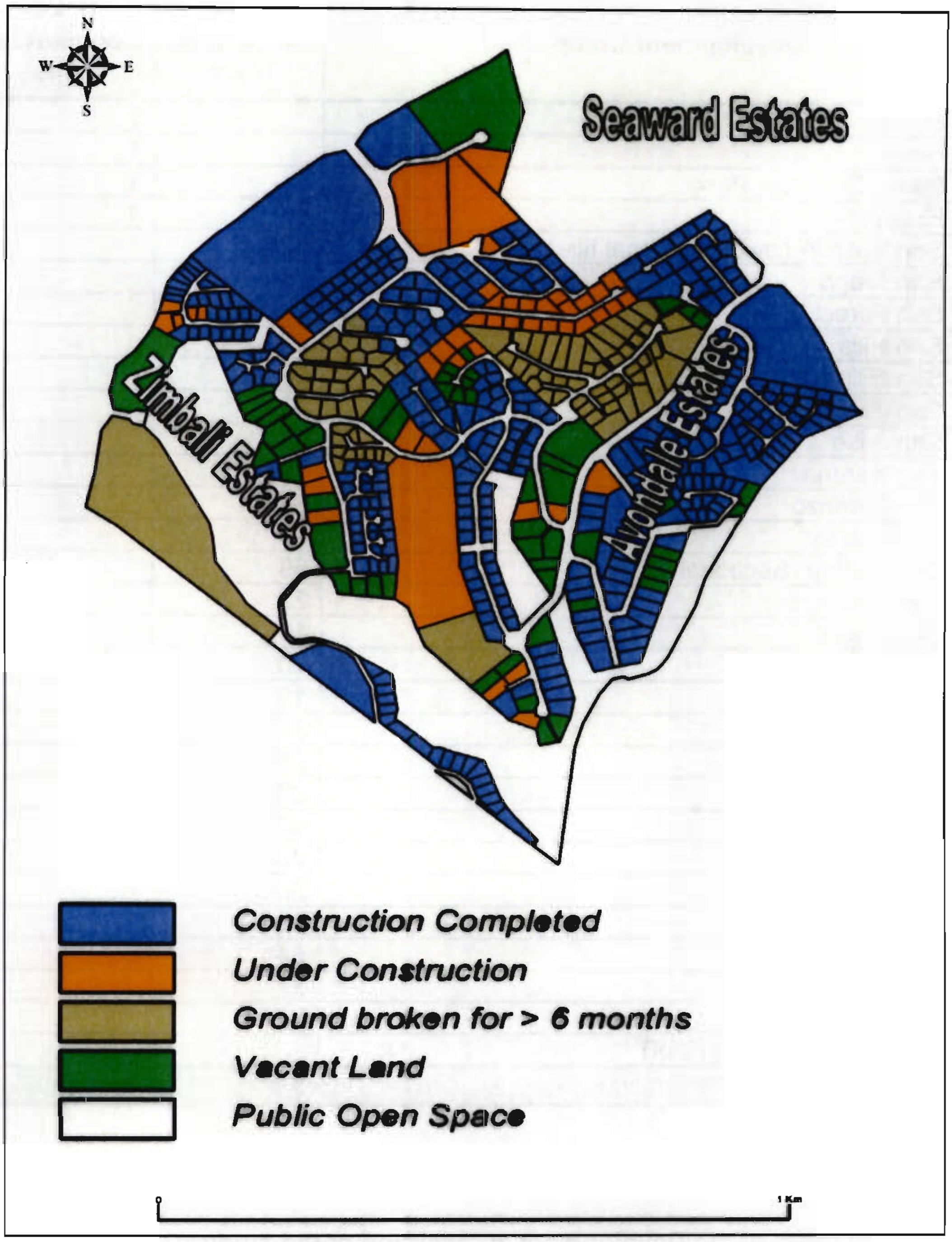


Figure 3.1: Land Development Status as at the Study Inception - Jan 2007

3.3. Anthropogenic Impacts

Seaward Estates is traversed by a number of municipal bulk sewer mains, both gravitational and rising mains leading to the Fraser's local wastewater treatment works situated west of the estate and the M4 national road (See Appendix A). This rising main transports the majority of the Ballito, Salt Rock and Sheffield Beach catchment effluent to the treatment works, and it crosses and runs along the western boundary of the wetland under investigation. One of the estates gravitational outfalls runs along the wetlands eastern boundary (see Appendix A). As the estate is being developed in phases, there are portions that are being inhabited in line with this phasing, and as a result thereof, these outfalls have been under use from the beginning of the development. Occasionally during the study period there have been breaks and spills from both the outfall and the rising main leading to major infiltration of sewerage into the wetland. These spills and their associated impact plumes are described and depicted in Figure 5.2 (a) to (e) in Chapter 5.

3.4. Construction Activities on the Estate

Despite sampling commencing in the early part of January 2007, construction activities had been stopped from 8 December 2006 for the annual builders break, and were prohibited on the estate until 30 January 2007. However, other than individual residents having small items delivered, the first developers/builders were only on site from 19 February 2007.

When this study commenced in January 2007, most of the bulk development infrastructure such as outfall sewers and stormwater outlets, bulk water reticulations and spine roads had already been constructed. However, there was some construction done inside and alongside the wetland during the course of this study in the form of repairs of breakages to lines and manholes and re-routing to some of the sewers and stormwater pipes. From January 2007 to September 2007 the majority of construction comprised some minor internal roads and surfacing, cutting of platforms, piling and building of homes. Various plant and operations were employed by the developers ranging from TLBs (tractor-loader-backhoes) to bobcats, premix concrete trucks and concrete pumps, piling rigs and compactors to on site hand mixing of cement and mortar and transporting via wheelbarrow.

Most developments in the estate were subject to its very own Environmental Management Plan (EMP) compiled by Sustainable Development Projects cc and other consultants. After reviewing the EMP for the specific sites currently under construction, the main areas covered pertaining to construction activities are (Bundy, 2004):

- screening of sites with shade or sack cloth to reduce wind blown nuisance.
- very basic site specific stormwater containment methodologies in the form of earth bunds and channels.
- topsoil stripping and vegetation removal to be phased and no blanket stripping to be performed. Vegetation rehabilitation to embankments to be done.
- Protection of existing services and infrastructure i.e. roads, kerb inlets, sewers etc.
- Sites to have managed waste facilities in place in the form of 3 skips as a minimum, with skip clearance done on a weekly basis.
- No burial of rubble materials permitted on the estate unless as fill within a structure
- Ablutions for site staff to be in the form of chemical toilets or toilet tied directly into commissioned sewerage reticulation if available.

The importance of these findings is that despite the fact that the EMP for each site is very broad yet comprehensive, it only covers some of the areas considered important in the BMP by USEPA and others as stated in Chapter 2. However, the critical aspects of stormwater runoff management and pollution prevention from construction sites have not been adequately covered, and the lack of monitoring and enforcement of the implementation of these EMP is visible in the general failure by the contractors on the estate to adhere to and even institute some of the basic yet crucial measures that were prescribed. The findings in the form of documented photographic monitoring throughout the study period and the results thereof are further discussed in chapter 5.

3.5. The Wetland

The wetland under study is on the western portion of the estate, bordering with Zimbali Estate as shown in Figure 3.2. The aerial orthophoto as shown in Figure 3.2 was taken in July 2006, 5 months prior to commencement of this study.

Portions of the stream were canalised many years ago and drainage ditches were introduced in the wetlands to facilitate sugarcane cultivation (Ward, 2003).

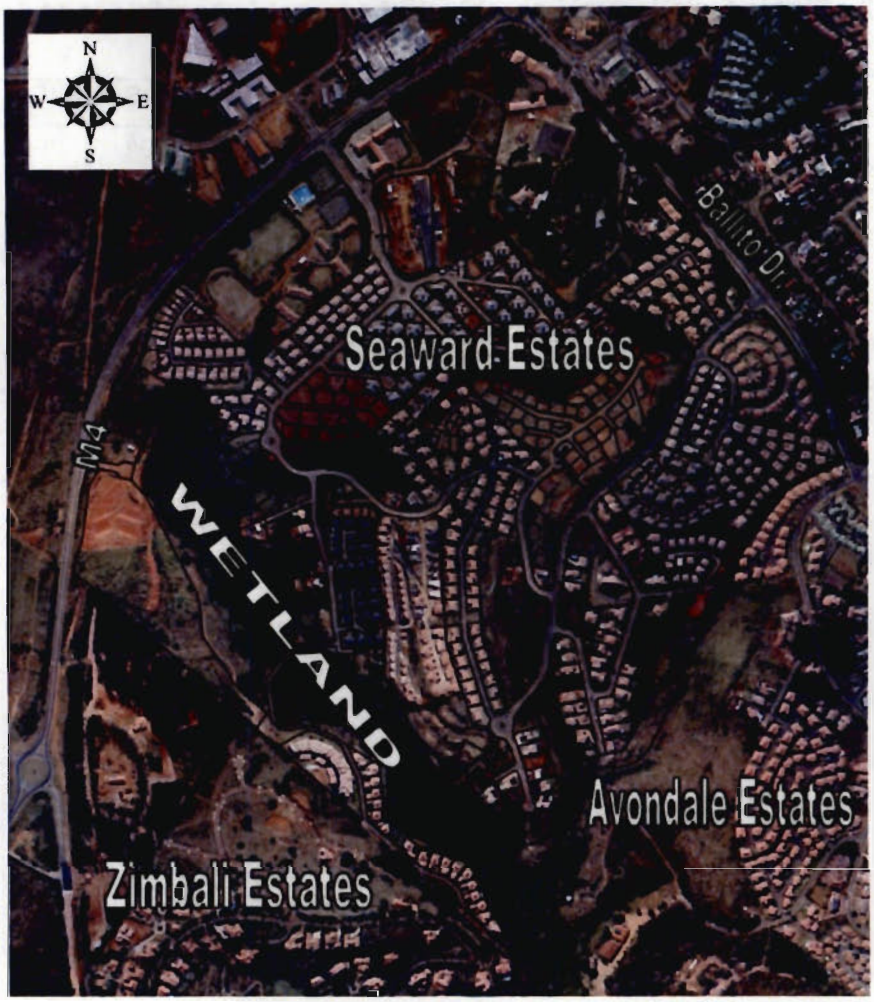


Figure 3.2: Aerial View of Seaward Estates (Courtesy of AF Planning)

The geology of the area comprises a quaternary dune deeply incised by surface runoff and sub surface seepage through Berea Red Formation sands (BRS), however, the soils are hydromorphic (also known as Warrington soils) within the drainage line (Snyman, 2003; Theunissen, 2003). In his investigation of the characteristics of Berea Red Soils, Fanni (2008) conducted Eluate tests on soil samples according to USEPA Method 200.7, and the typical Iron concentration in these sub soils under semi-aerobic and anaerobic conditions is depicted in Table 3.2. The range of Fe concentration is between 2.9 and 2.6 mg/l respectively. It must be noted that no other metals were found in the analysis conducted by Fanni (2007), however in these wetland conditions, the surface soils are covered by humus and topsoil that will most likely contain other metals.

In sieve analysis conducted on these soil samples, a particle size distribution was determined (Fanni, 2007) and this is illustrated in Figure 3.3.

Table 3.2: Eluate tests in semi-aerobic and anaerobic conditions (Adapted from Fanni, 2007)

	pH	Conductivity	TDS	Fe
	-	µS/cm	mg/l	mg/l
Semi-aerobic conditions				
BRS	6.36	60.8	30.4	2.956
Anaerobic conditions				
BRS	6.2	57.4	28.7	2.567

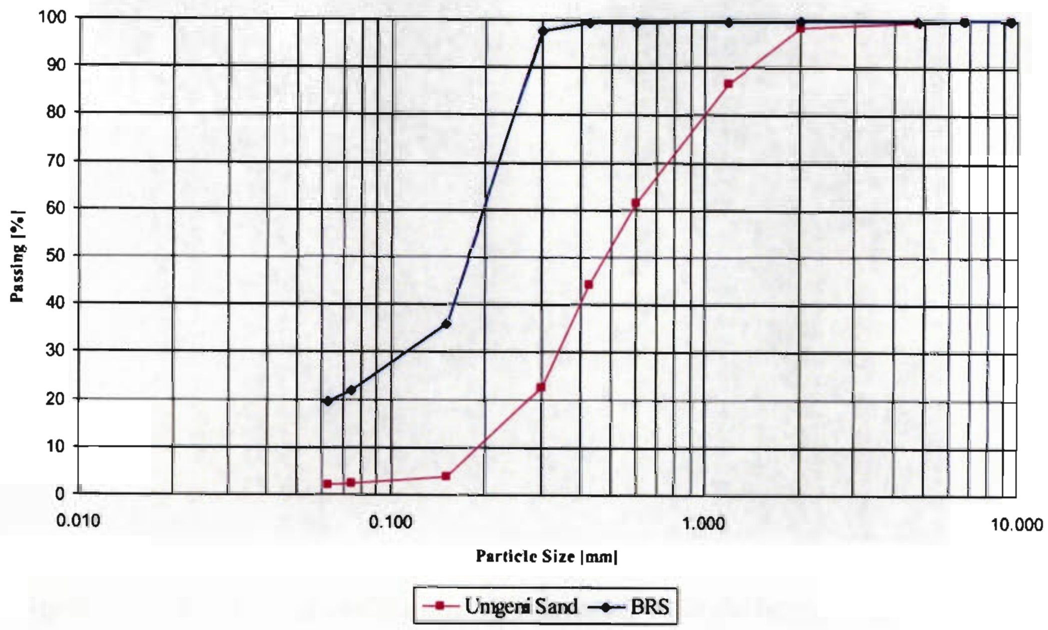


Figure 3.3: Particle size distribution of Berea Red Sands (Fanni, 2007)

Presently the valley is generally well vegetated with indigenous wetland habitats, primarily "swamp forest" and "fen". Relict swamp forest specimens, primarily *Syzigium cordatum*, occur within *Cyperus* dominated sedge communities and there is evidence of recruitment adjacent to such specimens. Existing swamp forest, comprising primarily of *Voacanga thouarsii*, *Syzigium cordatum* and *Ficus trichopoda* forms a significant portion of the forest in the western portions of the study site. Sedge communities occur along the main course primarily in the central and eastern portions of the site, where disturbance has occurred (Bundy, 2007). In addition, where sub-surface movement of water is not as free as it is along the main stream or where crop lands have recently been abandoned, the main vegetation cover is in the form of sedges and other non-woody wetland species (Ward, 2003). On the steeper peripheral slopes and uppermost reaches of the western drainage line, the swamp forest and the mesic coastal forest type of vegetation occur (Bundy, 2006; Ward, 2003).

According to Bundy (2007) there are two forest systems occurring in this system, namely swamp forest and coastal forest. In their reaches four predominant but varying zones can be found within its system. The grassland zone is that area which is constantly subject to drying, the sedges where it is continuously wet and mostly clear of large trees, swamp and riverine habitat and the mesic form coastal forest. In these systems, the sedges mostly occur in areas of clearance and change in hydrology such as occurred due to road construction through the wetland. As swamp forests are sensitive and can only accommodate fine grained disturbance, the effects of disturbances through these systems are visible for many years after the effect, and most often the recovery and regeneration is not completed (Bundy, 2007).

3.5.1 Long-section of the Wetland

In the initial 100m of the system, the average gradient of the wetland is approximately 1:5, and it becomes substantially gentler at an approximate 1:43 for the lowest 1km of the stream course (Ward, 2003). With the aid of the design package Civil Designer 4.0, a ground surface model and contours were generated off a digital elevation model (DEM) created from data generated from 1:30 000 aerial photography and sourced from the Chief Directorate – Surveys and Mapping. The centreline of the wetland was traced off the orthophoto, and the ground profile of the wetland extracted. It was calculated that the elevation at the head of the wetland is approximately 97m above sea level whilst the lowest part before it exits the estate is approximately 29m above mean sea level. The different zones of coastal forestry and wetland habitat as explained further on in this chapter were demarcated by Bundy (2007), and the final long-section drawing of the wetland which was compiled in AutoCAD 2004 is illustrated in Figure 3.3.

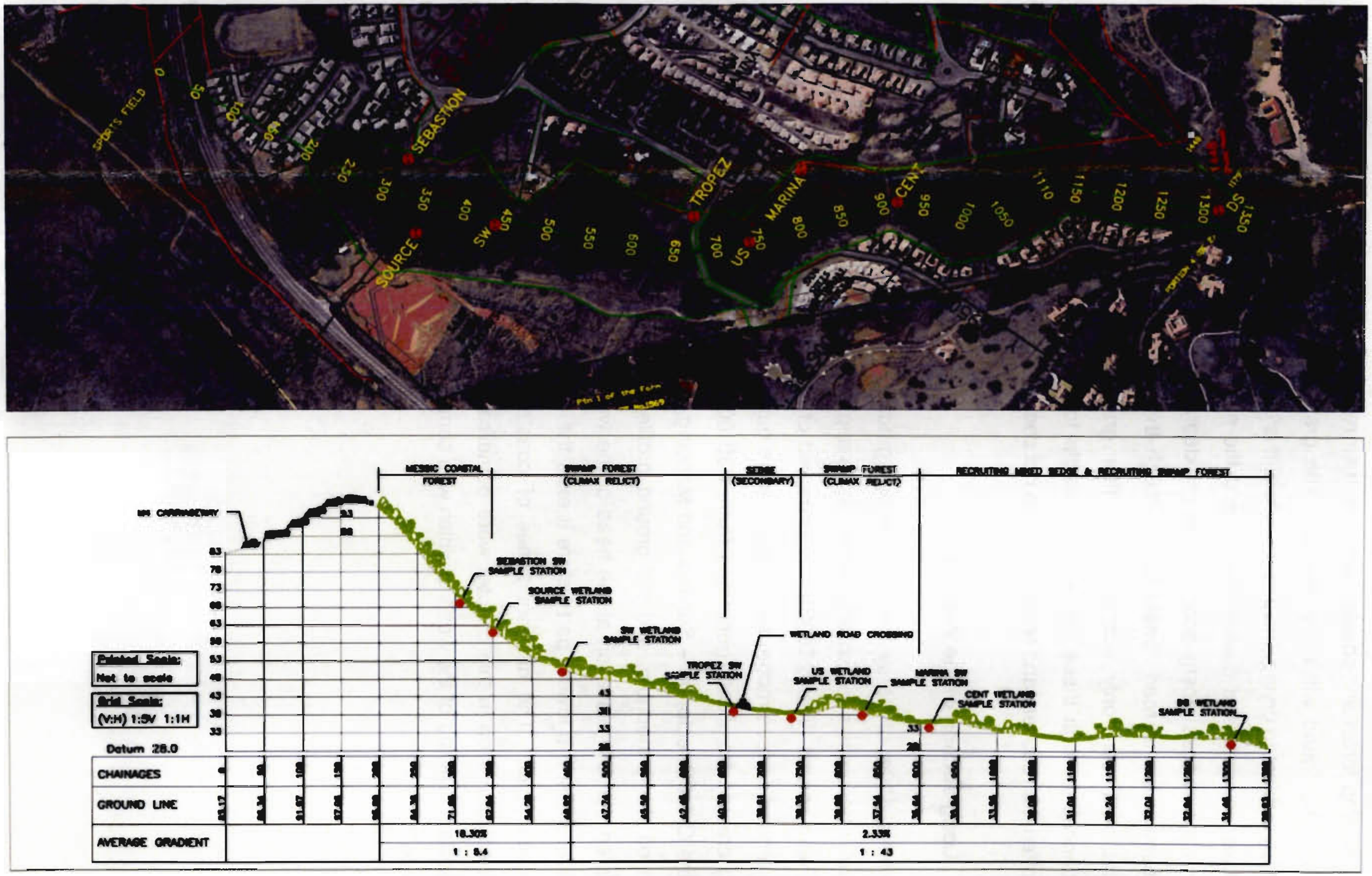


Figure 3.4: Longsection of Wetland depicting coastal forest habitat and sampling stations (Bundy, 2007)

3.5.2 Wetland Habitat

The system under investigation in this study is categorised as coastal forest according to Barrie Low and Rebelo (1998) and Mucina and Rutherford, (2006). On closer investigation, the western drainage line can be further categorised into two zones. The first zone comprises Relict Forest which consists of climax and recruiting portions of swamp forest and secondly the early successionary stages of wetland habitat consisting of the secondary sedges and moist grasslands (Bundy, 2007). Due to previous agricultural practises which included earth disturbances such as tilling and planting of crops right up to the forest belt, drainage of the wetland for land reclamation and burning of the forest during sugarcane burning, there are only portions of relict or original swamp forest remaining, with a large portion of it being recruiting or re-establishing due now to the protection of the system.

Moist Grasslands

The grasslands are very limited due to the previous agric-activities that took place. The main species found are *Paspalum notatum, Eragrostis* spp and exotic *Cynodon dactylon* (Bundy, 2007).

Secondary Sedges

In the sedge areas the predominant species are *Phragmites australis* and *Typha capensis*. These have occurred where the hydrology of the system was changed many years ago by the original farmer at the wetland crossing at chainage ±680m, where he imported fill for the original farm road (Ward, 2003) as depicted in Figure 3.4 and in very small sections in-between the other forest types where disturbance was caused for the construction and installation of services such as sewer and water mains (Bundy, 2007). These can be seen in the gaps in the forest sections at chainages ±500m and ±900m at the Cent sampling station as depicted in Figure 3.4.

Swamp and Riverine Habitat

The swamp forest habitat of this system consist mainly of *Syzygium cordatum, Voacanga thouarsii, Phoenix reclinata* and the indicator species *Ficus trichopoda* or Swamp Fig. Due to swamp forest's inability to accommodate high degrees of disturbance, the construction through its system for the services as mentioned above during the 1980's has left scars in its section, and these patches have not shown any seral progress towards swamp forest and have now transformed to sedges, whilst in the lower reaches the swamp forest is recruiting now that disturbances have been reduced (Bundy, 2007).

Coastal Forest

The mesic forest species present are *Albizia adianthifolia*, *Macaranga capensis* and *Strelitzia Nicolai*. From observations of aerial photography taken between 1937 and 2006, it can be determined that the mesic portion of the coastal forest at the head of the system has been receding northwards over the last few years at a rate of approximately 1m/year (Bundy, 2007).

This portion of Coastal Forest and its associated wetland is not a specified water body as listed in the NWA (1998) and as such any discharges to this water body should comply with the General Limits of the SA Water Quality Guidelines (1996) as amended or where the constituent is not catered for in the Guidelines such as for aluminium, the Target Water Quality Range (TWQR) as stipulated by DWAF.

CHAPTER 4

METHODOLOGY

Chapter four presents the processes of building a GIS and the creation of thematic maps, the identification of monitoring stations for the sampling of wetland water and sedimentation, and the installation of runoff and atmospheric sampling equipment. Laboratory procedures and techniques associated with collection of samples and water quality analysis are discussed.

4.1. Introduction

The objectives of the investigation were to study the environmental state of coastal forestry during construction by assessing the nature and dynamics of the sources of impacts. Various methodological approaches were considered as suggested in the literature review, and the focus was directed to the characterisation of the water quality of stormwater runoff from various surfaces in and around the development that surround the wetland, as well as that of the water and sediments in the wetland watercourse. The characterisation aims to qualitatively identify trace metals and toxins transported within stormwater runoff from road and overland surfaces during rainfall events, and windblown into the wetland.

Various sites for undertaking of a study of this nature and monitoring the abovementioned aspects were investigated, the merits of each analysed and evaluated and a suitable case study finally selected.

A change in land use from its natural state to that for forestry, agriculture, transportation systems or urbanisation, will inevitably affect the quality of surface runoff during rainfall events (Chrystal, 2006). Non-point source pollution has been identified as one of the leading causes of degradation in the quality of receiving water bodies (Pitt *et al.*, 1995; Barret *et al.*, 1998). Whilst many of the contaminants such as trace metals (referred to also as heavy metals) contained in stormwater runoff from impervious surfaces such as roads result from vehicular operation as a result of frictional wear and combustion by-products, runoff from construction sites is a major pollution source of heavy metals and other pollutants (Maltby *et al.*, 1995; Burton and

Pitt, 2002). Due to their identification as potential toxicants, trace metals were selected as pollution indicators for monitoring (Maltby *et al.*, 1995).

To assess the effects that construction activities have on the wetland, a multiple method approach was designed. Firstly, to understand the dynamics of construction progress over time, as well as how and where the various areas contribute to depositing pollutants into the wetland as non-point sources, thematic maps were created. Initially a Geographical Information System (GIS) of the estate and the various land uses and level of development was created to facilitate the identification of drainage flow paths and stormwater catchment areas. Secondly, the three most significant stormwater outlets discharging into the wetland were selected for monitoring of stormwater runoff. Thirdly, two stations on opposite sides of the estate, one in a completed built up area, and the other in close proximity to sites under construction, were selected for the elevated placement of atmospheric samplers.

Finally, a further five sampling station positions were strategically determined along the central course of the wetland for sampling of the water and sediment characteristics of the wetland. From the highest point or the head of the wetland moving downstream, the first station (Source) was placed at the source or seepage point. The other four points were evenly distributed along the length of the wetland, thus the second station (SW) was at the confluence of the stormwater drainage paths in the main body of the upper reach, the third (US) two thirds upstream from the exit point, the fourth at the centre (CEN) and the fifth and final station (DS) at the lowest point before the wetland leaves the property of Seaward Estates (See figure 4.1). Plate 4.4 illustrates the physical characteristics of the five sampling stations.

Analysis of the samples was conducted to determine water quality parameters such as TS, VS, COD, pH, EC, NH_3, Nitrates (NO_3^-), trace metals and *E. coli* levels. This was undertaken to make recommendations concerning the environmental impacts on the coastal forestry system. A more detailed description of the analytical work and methods used is presented in Section 4.7.

Figure 4.1 depicts the final positions of the various stormwater, atmospheric and wetland sampling stations.

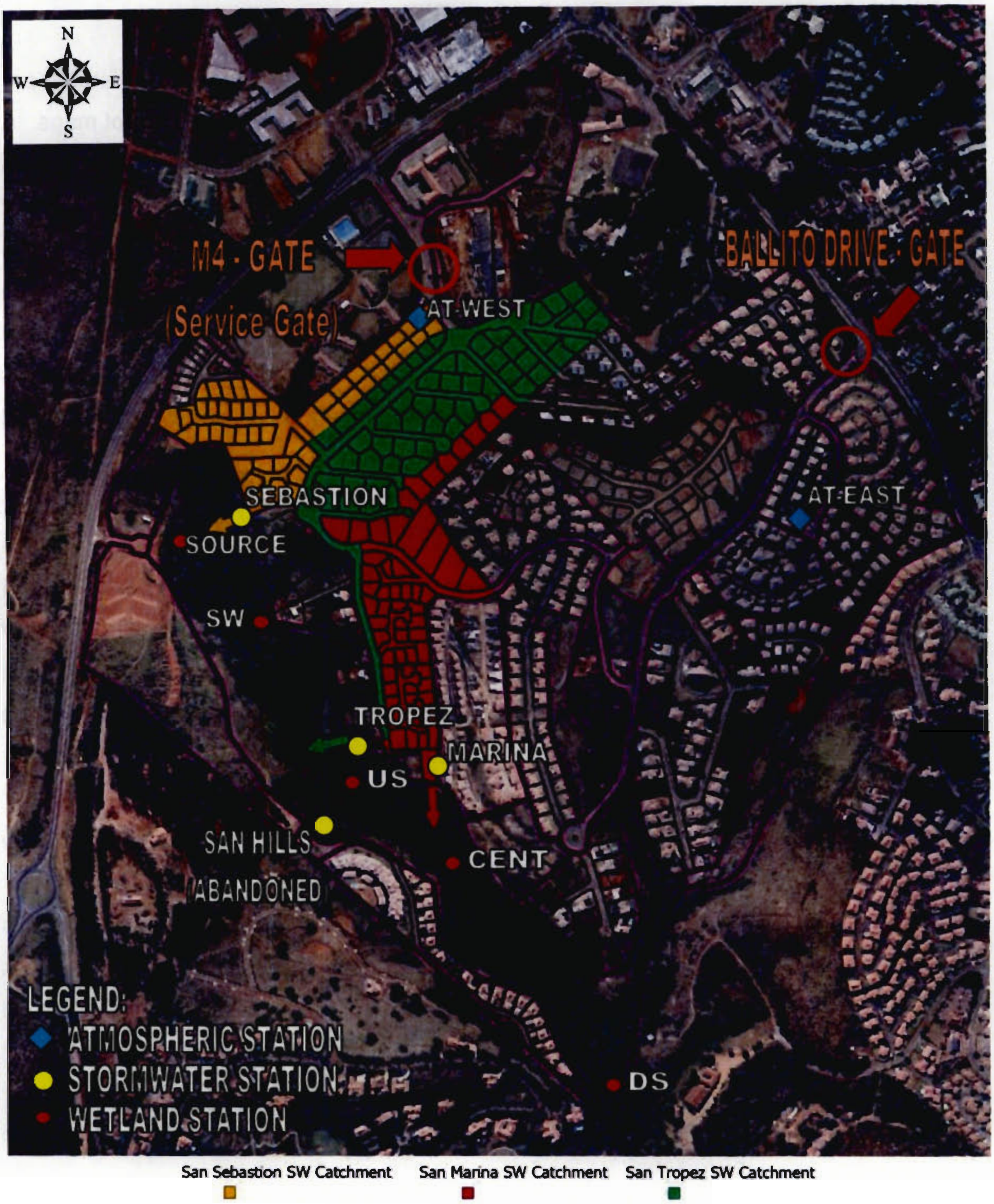


Figure 4.1: SWR catchments and sampling station positions along the wetland

4.2. Geographical Information System (GIS)

When undertaking a study of this nature where entities that are spatially separated are interdependent, it becomes necessary to portray the information in the form of maps. A desktop GIS comprises a mapping and information system that allows one to collect and analyse data, add drawing and edited items, and present the data in a graphical format such as maps. Thematic maps were created to graphically portray the environmental status of the wetland in relation to the development of the construction phases over time both spatially and temporally, and to portray the selected stormwater catchment areas and where they discharge into the wetland. Anthropogenic effects such as sewer spill plumes were also captured, to create a holistic model of all pertinent activities encountered on the Estate during the study.

As a point of departure, it was determined that the base information required for this investigation comprised cadastral information, existing engineering services and contour data. Computer Aided Design (CAD) data of the estate was obtained courtesy of Seaward Estates Homeowners Association in AutoCAD 2004 drawing format. This data contained cadastral information of the erven boundaries, erf numbers and all the necessary engineering services infrastructure data such as roads, stormwater reticulation and appurtenant structures such as outlet headwalls, and sewer and water reticulations. The estate manager maintained an Excel spreadsheet of all property ownerships from purchase transfers, completed and occupied dwellings and their associated water connections and meter readings so it was possible to manipulate this data and set up a database for the ongoing monitoring of construction progress throughout the study period. This spreadsheet was used as the basis for the creation of a Microsoft Access 2003 database that contained all information on each individual stand regarding land use, such as whether it is public open space or under construction, as well as the progress of construction over time and final completion dates.

In order to capture the appropriate information, it was necessary to convert the CAD data to a GIS compatible format. The ESRI ArcView 3.2 shapefile (.shp) format is an industry standard, and is capable of being read by most GIS packages available in the market. Use was made of IntelliGIS 5 which is a South African developed package completely compatible with ArcView and used widely within the consulting engineering industry. Due to known incompatibilities between CAD and GIS systems, a project specific Visual Basic for Applications (VBA) routine was developed in AutoCAD 2004 to automatically retrace the individual erven from the base CAD data into polygons, and then to assign the associated erf number attributes to the polygons. Furthermore, polygons of each sub development boundary, stormwater flow paths and sewer spill plumes were generated. Shape files of these various entities were then imported into IntelliGIS and the Microsoft Access 2003 database linked to this GIS. To create the thematic maps, various queries were set up to graphically portray the appropriate contents of the database.

The engineering services information was then collated and re-grouped into a structured layer system. It was overlayed on maps where required. An orthophoto generated from 1:20 000 RGB colour aerial photography flown in July 2006 was supplied by AF Planning Town & Regional Planners, and used as a backdrop over which the GIS data was overlayed in the creation of the thematic maps.

Figure 4.2 presents a flow diagram depicting the procedures and processes undergone through every stage of the production of the thematic maps, from acquiring the data to processing and converting it, to the final incorporation into the GIS software and creating the spatial queries and overlays that make up the various maps.

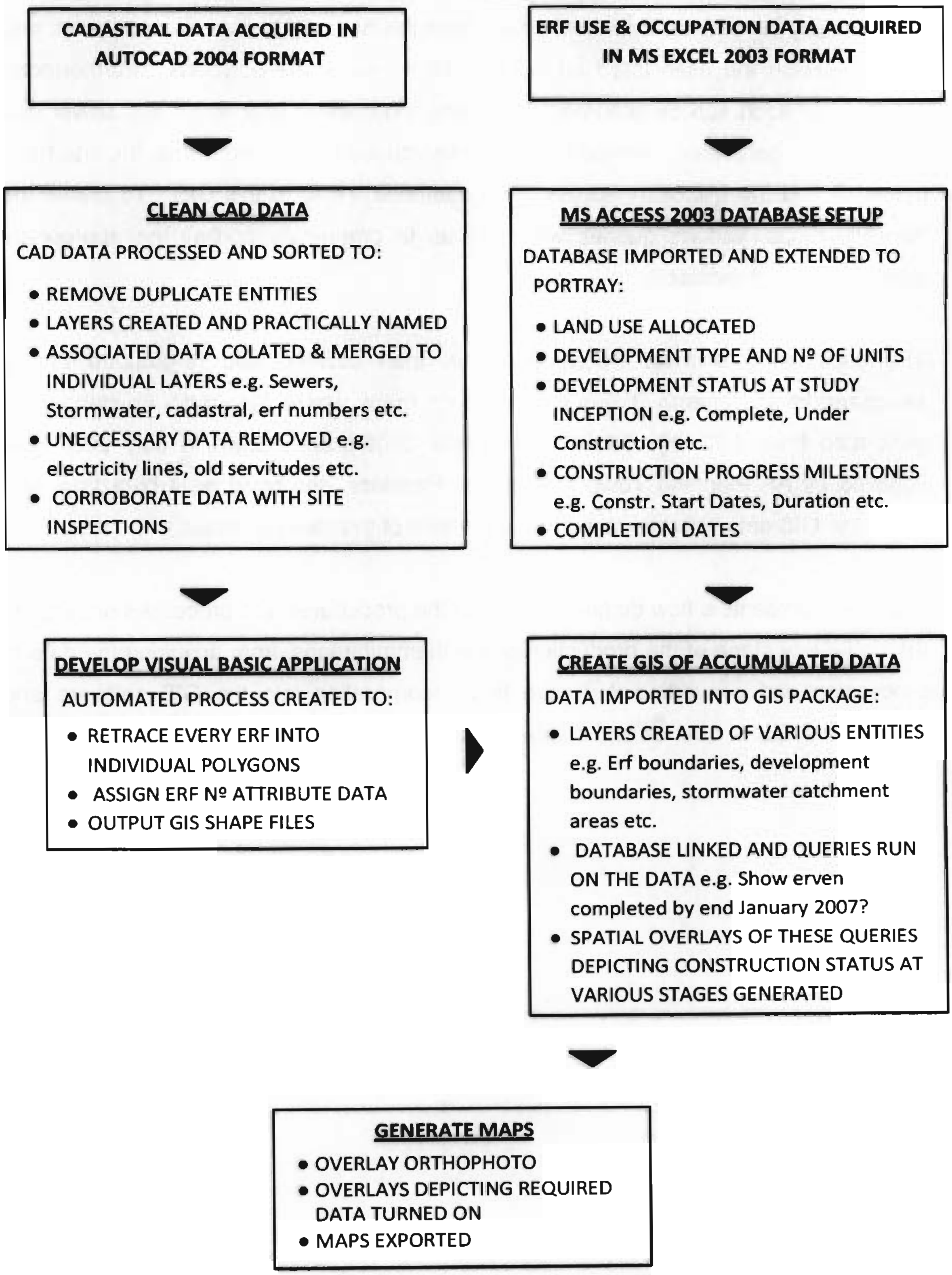


Figure 4.2: Flow Chart depicting map generation flow diagram

4.3. Creating of Thematic Maps

A series of thematic maps built from the GIS data were required to graphically portray the relationships between spatially related entities such as developing erven and catchment areas, and non static events such as rainfall, construction activities and services breakages and spills occurring within and around these entities. The aim was to show the nature and extent of the environmental impact of the construction phase of a development on a sensitive coastal forestry system.

The maps were built up of layers of data to create a model of reality. The starting point was the cadastral information of the erven and boundaries of the various sub-developments within the estate. Catchments were determined by reviewing the existing engineering services plans. Engineering services pertinent to this investigation such as bulk sewers and stormwater infrastructure were also incorporated onto the maps. Point data was added depicting the positions of sampling stations and the catchments discharge points. As a final overlay the orthophoto was imported and set as a background.

By creating queries on the database, spatial overlays were created that depicted the status of the construction phase on a monthly basis. The first map shows the status of the development construction activities from the beginning of the study in January 2007 to the end in two month increments and comprised four compartments (see Figure 5.3 in Chapter 5). The construction progress information depicted was divided into the following categories:

- vacant land
- ground broken for longer than 6 months
- under construction, and
- construction completed

The first compartment depicts the status as at the beginning of January 2007 which remained the same up until mid February due to the national builders break, the second illustrates the change up to the end of April as construction activities only started in March, the third depicts progress over May and June, and the fourth shows progress over July and August.

The second group of maps are compartmentalised materials flow diagrams depicting the flow of materials within the estate coinciding with the construction progress maps (see Figures 5.4 to 5.6 in Chapter 5). The total materials flow makeup to the various development sites from on site delivery surveys is shown in Appendix B – refer to section 4.4.5. The base unit for the monitoring of the incoming material was type and number of truck loads. For the purposes of this investigation, the incoming materials were grouped and categorised in relation to their potential to come into direct contact with rain and be an immediate source of pollution. For graphical representation of the weighted material flow, the information on the various material types was further reduced to approximate tonnes so that all the materials in each category could be added together to get a total weighting. This was done by multiplying the product unit weights by the load capacities. In some instances, the weights of materials such as carpentry had to be estimated due to the range of product being delivered (roof trusses to floorboards), as the size and type of truck used for delivery did not necessarily reflect the actual weight of the cargo, and it was impractical for security staff to climb into these vehicles and assess whether trucks were full or otherwise. The three groups are depicted on the maps as high potential impact in red, intermediate impact in magenta and low potential impact in blue, whilst the materials flow out of the Estate is depicted in green. The thickness of the arrows depicts the relative weighting to and from the various sites.

The third map depicts the three stormwater catchment areas and points of discharge into the wetland at the outlets where stormwater runoff sampling was being conducted (see Figure 4.1)

The fourth map depicts the impact plumes of the five sewer spills that occurred during the period of study (see Figure 5.2 (a) to (e) in Chapter 5).

4.4. Sampling Stations, Monitoring Equipment and Tools

To assess the environmental impacts on the wetland, water quality parameters such as TS, VS, COD, pH, EC, NH_3, Nitrates (NO_3^-), trace metals and *E. coli* levels were determined on wetland water and sediments, and on stormwater runoff and atmospheric samples. Water and sediment samples from the wetland were collected on a monthly basis, while stormwater runoff and atmospheric samples were collected after each representative rain storm event (see Figure 4.1 for sampling station positions).

Painted and labelled stakes were planted at the five wetland sampling stations to mark their positions for capturing with a handheld Garmin IV Global Positioning System (GPS) device for use in the GIS, and to ensure that samples were taken at the same point each time (see Plate 4.6 a-d). Each of the runoff and storm event study areas selected required unique on site preparations to enable the correct installation of stormwater runoff and atmospheric collection equipment. The aim during installation of the equipment was to limit the visibility and accessibility (to the general public) as much as possible, in order to reduce the risk of vandalism, theft and contamination by curious residents. Due to their accessibility and easily obstructable nature, after 2 unsuccessful attempts at locating the atmospheric collectors out in the open field, these were eventually set up at two secure locations (see Figure 4.1).

4.4.1 Wetland water and sedimentation sampling

Sampling bottles for water and sedimentation collection were stored on campus and collected a day or two prior to sampling. Sampling was done mostly on Sunday afternoons so that the samples could be taken into the lab first thing on a Monday morning to prevent contamination of samples and maintain the reliability of results. Directly after collection, the sample bottles were stored in a fridge on site at 4°Celsius, and transported to the lab in cooler boxes with ice bricks within 24 hours.

Once at the lab, the heavy metals samples were treated with nitric acid to keep the metals in solution and to prevent them adhering to the inside of the plastic container. *E. coli* tests were run on the samples as soon as possible after delivery to the lab.

4.4.2 Runoff sampling Equipment

In addition to the sampling of water and sediment in the wetland, it became necessary to employ the use of a sampling device that could be installed in stormwater pipes to facilitate the collection of samples during representative rainfall events. Chrystal (2006) developed a gravity sampler for sampling stormwater in culverts. This device was calibrated to collect a representative flow weighted composite sample, and this sampler was used in this investigation. The installation procedures as prescribed by Chrystal (2006) were followed; however it was necessary in some instances to adapt these due to site specific constraints. See Figure 4.1 for the positions of the runoff sampling stations.

The sampler and its associated delivery tube as depicted in Plate 4.1 (Chrystal, 2006) were attached to the invert of the stormwater pipe leading outwards by installing galvanized plates with two 40mm long 4mm diameter galvanized bolts. These plates were held down by means of drilling holes into the concrete pipe and using Fischer plugs, as well as smearing the underside of the plate with epoxy. Electrical conduit saddles were attached over the protruding bolts with wing nuts providing quick and easy attachment with minimal obstruction to the flow. The delivery pipe and sampler were held in place by the saddle, and this in turn orientated the sampler's orifice entrance directly upstream (see Plate 4.1a). The tail end of the delivery tube was carefully directed at a constant downwards gradient out of the stormwater pipe to a storage vessel or drum. To eliminate outside contamination and to maintain atmospheric pressure in the sampling equipment a special lid was made. A modification was made to the original lid to accommodate a breather tube and the delivery tube to pass through (see Plate 4.1b). This system was devised to ensure ease of setting up the devices prior to rain storm events and removal afterwards (Chrystal, 2006).

a) b)

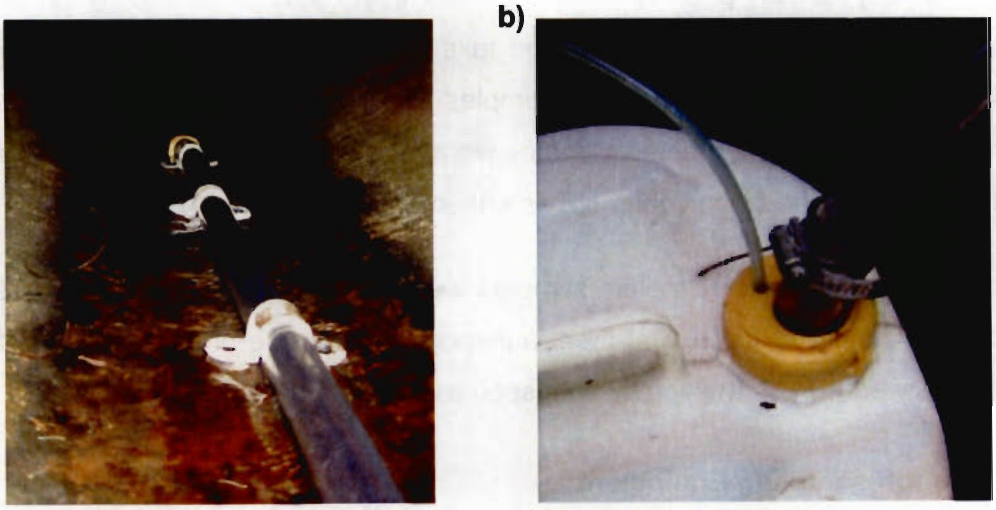


Plate 4.1: a) Saddles used to attach the sampler in the stormwater pipe b) Modified lid to ensure atmospheric pressure was maintained (Chrystal, 2006)

Sampling Stations

The following is a detailed description of the various runoff sampling stations, the characteristics of the sites and the description of any technical issues regarding the installation of the samplers. The positions can be seen on Figure 4.1 and Appendix A.

San Hills

This site was strategically selected as it was the discharge point of a large section of the western neighbouring estate Zimbali, most of which was under construction at the time of the study (see Figure 4.1). However, after the first storm event, it was discovered that the pipe had in fact been closed and decommissioned on the Zimbali Estates side and all their reticulated stormwater had been diverted downstream to beyond the Seaward Estates border. This station was therefore abandoned after the first storm event.

San Sebastian

The San Sebastian outlet installation posed challenges as a few days prior to installation a very large storm had washed the headwall away, and a large portion of the embankment had collapsed, leaving only the two pipe convergence manhole, and the last section of the concrete pipe hanging approximately 5m in the air (see Figure 4.1). Due to the fact that installation at the end of this pipe was dangerous, it was decided that the best position would be inside the tie-in manhole before this last section of pipe, as access was easy through the open top, and estate management agreed that the pipe could be broken into just outside the manhole for the collection pipe to be coupled to the collection vessel. This pipe was to be replaced after the study as a new headwall is to be built (see Plate 4.2).

Plate 4.2: San Sebastian sampler installation setup

San Marina

The San Marina outlet replaced the abandoned San Hills station and was used from the second storm event (see Figure 4.1). Plate 4.3 illustrates how the delivery pipe was secured to the base of the outlet floor to ensure constant fall to the collection vessel which was safely secured and tucked away below the outlet floor slab created by a drop or shelf formed by scour below the outlet structure.

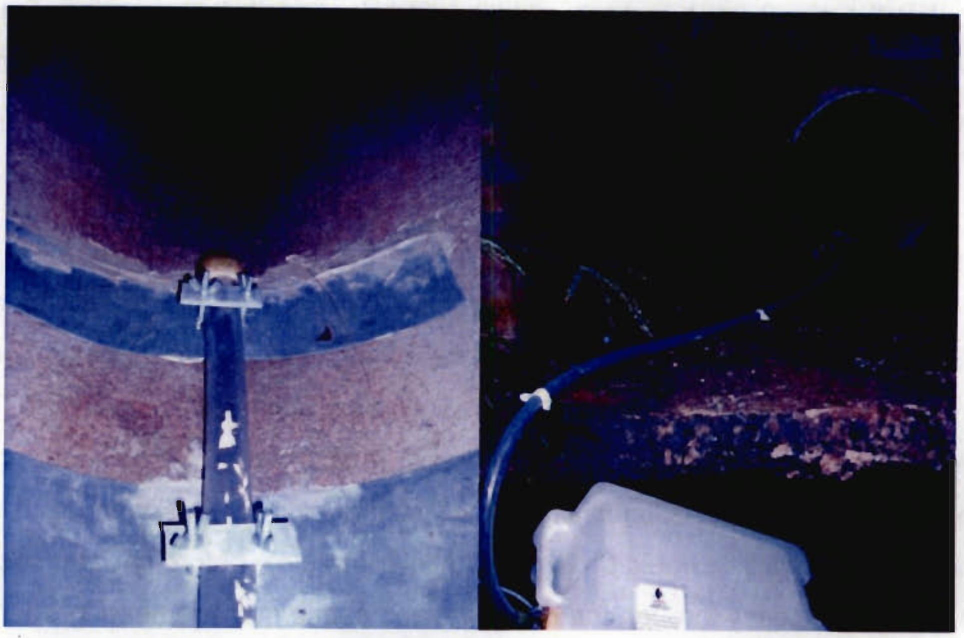


Plate 4.3: San Marina sampler installation setup

San Tropez

During the first sampled storm event, an inspection was held to ensure correct operation and effectiveness of the samplers installed, and it was discovered that at the San Sebastian station, there was very little flow in one of the pipes which according to the services drawings was the main catchment pipe. The following day, plumbers were sent out to the site to inspect the pipe system for blockages but none were found. During the next storm event, the same was discovered, so an in-depth investigation was undertaken and it was discovered that some of the bulk stormwater pipes upstream of the San Sebastian sampler had at some point been diverted, and re-routed to a section of underutilised reticulation with an outlet at San Tropez. This revised catchment became the largest catchment and was thus determined to be a major source of runoff and pollution, so it was decided that a third device be installed at this position (see Figure 4.1).

In this stormwater pipe, due to its very flat gradient, there was less than 50mm fall from the end of the pipe and the outside header wall base. This made it impossible for the installation of the regular equipment and a new method of collection had to be devised. A purpose made container or vessel nicknamed a "Nic-o-Lector" was designed and manufactured from a 1.5m length of 110mm diameter uPVC stormwater vent pipe with an end cap welded onto one end, and a modified cap with a nose cone for water deflection to minimise drag on the upstream side. The cone end had a hole drilled into it to take a short piece of 30mm diameter plastic pipe that was epoxied into place.

The Nic-o-Lector was attached to the invert of the pipe in the longitudinal direction by means of special galvanised saddle plates manufactured and installed with Fischer plugs and epoxy. These saddle plates wrapped around the apparatus and secured it in place with bolts and wing nuts. A stopper bracket was installed at the downstream position of the apparatus as an additional brace, and wooden brandering was installed on either side of the vessel to minimize drag and lifting shear along the sides during storms. The sampling device was attached as normal to the invert of the pipe with a short piece of delivery pipe which lead into the Nic-o-Lector (see Plates 4.4a and b)

a.) b.)

Plate 4.4: a) The Nic-o-Lector installed at the outlet structure at San Tropez b) The Nic-o-Lector with nose cone and side bars for wave protection

4.4.3 Atmospheric sampling stations

Atmospheric sampling stations comprising of an atmospheric fallout collector (funnel) and a rain gauge were located at two sites on the estate that were carefully selected in order to avoid contamination from undesirable particles raised from local disturbances such as wind blown debris like leaves, plastics, grass and grass seed (see Figure 4.1 and Appendix A). Both stations were elevated by placement on roof-tops away from any obstructions or impediments. Plate 4.5 illustrates the positioning of the atmospheric sampling station used on the Eastern side of the estate. These samplers were installed to facilitate the collection of samples during representative rainfall events.

It is important to monitor the atmospheric contributions to urban runoff. Two processes that affect urban runoff pollutants are wind-transported materials or dry dust fall onto impervious surfaces between storm events that eventually get washed off and collected into stormwater conduits, and precipitation quality. In this investigation the samples are combined as a bulk precipitation sample of dry period fallout and precipitation (Burton and Pitt, 2002).

Plate 4.5: Atmospheric sampling station at Seaward East (AT-East).

4.4.4 Rainfall

Rainfall data for this investigation was collected from three sources. Firstly, direct sampling results were obtained from the rain gauges situated on the two atmospheric samplers (see Chapter 4.4.3) whilst independent meter readings were taken and supplied by a developer from his meter on his site on the estate. Finally, data from the Tongaat (Maidstone) weather station was collected from the South African Sugar Research Institute (SASRI) website. The Maidstone station is approximately 10km from the study area.

4.4.5 Construction materials and waste survey

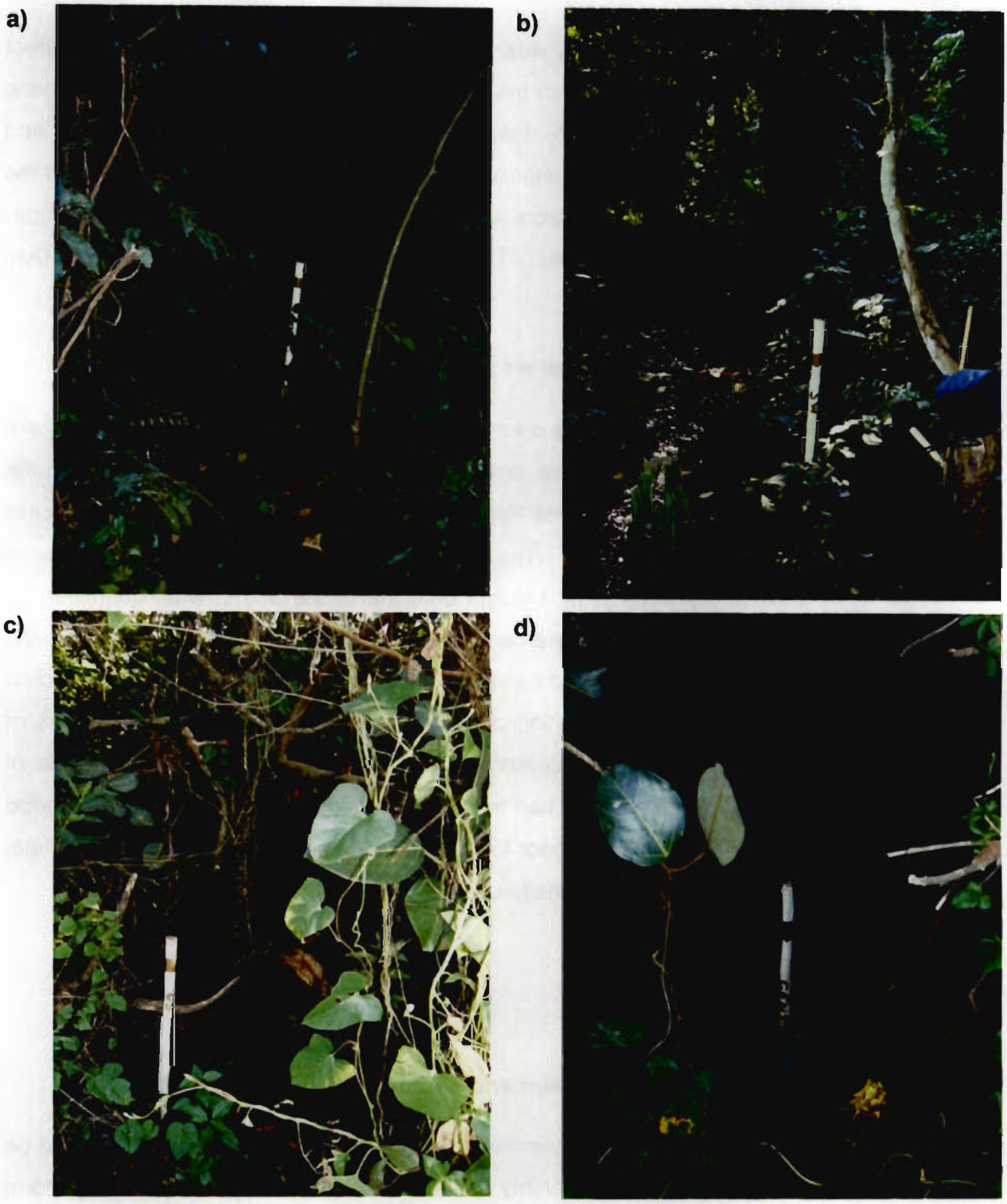
Access in and out of the estate was controlled via manned boom gates. Although there are two access gates into the estate, only the gate off the M4 provincial road past the Seaforth School and Ballito Business Park is used for deliveries and contractor access (see Figure 4.1 and Appendix A). The intention behind this strategy was to assess what type of materials were being brought onto the estate and in what quantities. It was also important to be able to determine the flow of these materials to see where the majority of the materials were being used on the estate during the construction process in relation to the wetland. A questionnaire was set up to be completed by drivers of construction or delivery vehicles entering and leaving the estate. Any removals of materials or waste from the estate had to be designated by the developer and handed in to the security officer in charge prior to the vehicle being allowed to leave the estate. Appendix B illustrates the questionnaire used.

4.5. Field sampling

4.5.1 Procedure for Wetland Water and Sedimentation Sampling

At the onset of the study it was determined that water and sediment samples would be taken at regular intervals on a monthly basis, and then also again after every storm event. Two months into the study, after the stormwater culvert samplers had been installed at San Sebastian, San Marina and San Tropez for monitoring of the stormwater discharges into the wetland, wetland water and sediment samples were taken only on a monthly basis. See Figure 4.1 for positions of the sampling stations.

Plates 4.6 (a) – (e) illustrate the physical characteristics of the 5 sampling stations.


a)
b)
c)
d)

e)

Plate 4.6: Wetland Sampling stations
a) Demarcated station at the source Source)
b) Demarcated station at the stormwater confluence (SW)
c) Demarcated station at the upstream 2/3 (US)
d) Demarcated station at the centre of the wetland (Cent)
e) Demarcated station at the base of the wetland (DS)

At each station as depicted in Figure 4.1 and Plates 4.6 (a) to (e), three water samples were taken in three separate 1litre plastic containers i.e. one for *E. coli* , one for metals and one was used for water quality analysis of TS, VS, COD, pH, EC, water hardness, NH_3 and NO_3^-. At each station, one 250ml container grab sample was taken of the first 50mm surface sediment found for analysis of heavy metals.

Other parameters measured at each station in the field were water depth, ambient temperature, water temperature and dissolved oxygen content. The water temperature and dissolved oxygen content was measured with the aid of a portable Dissolved Oxygen Meter (YSI Model 50B) that was calibrated on each sample day (YSI Model 50B operation manual). As a further test, the probe was inserted into a solution of Sodium Sulphate and the calibration adjusted accordingly.

4.5.2 Procedure for Runoff and Atmospheric Collection

Runoff sampling equipment was stored on campus and installed prior to storm events as predicted by weather forecasts. This strategy was followed to prevent exposure of equipment to tampering or contamination and theft. Runoff samples were collected as soon as possible after events to prevent contamination thereof and to 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. Equipment was inspected upon collection to ensure that a representative sample had been collected. Items checked would include: the sample storage container for breakages; whether the venting tube still operated correctly; damage to the sampler and blockages at the orifice entrance; and the delivery pipe to the sample bottle. The site was also inspected to assess the general appearance and for any objects upstream that may have influenced the sampling. Any abnormalities, which may influence the representativeness of a sample, were recorded.

In order to commence collection in anticipation of the next storm event, clean atmospheric sampling equipment was installed subsequent to rainfall events. If an insufficient build up period occurred (ADP of at least 72hrs – see Section 2.3.1), the equipment was rinsed and cleaned in the field after the rainfall event from when a new build up period started. The rain gauge was also emptied and cleaned after every reading recorded.

For all samples collected the sampling lid was replaced with a sealed lid to ensure no spillage or contamination during transportation. All the runoff instrumentation was returned to the laboratory in plastic bags for cleaning.

4.6. Data Management

Due to the volume of data and information collected and produced in this investigation, extensive data management was required. Processing of information relating to field and equipment operations, volumes sampled, total rainfall volume and intensities, build up periods of storm events and wetland sampling data was required as illustrated by the flow chart in Figure 4.3. Microsoft Excel Spreadsheets were used in the manipulation and analysis of the data.

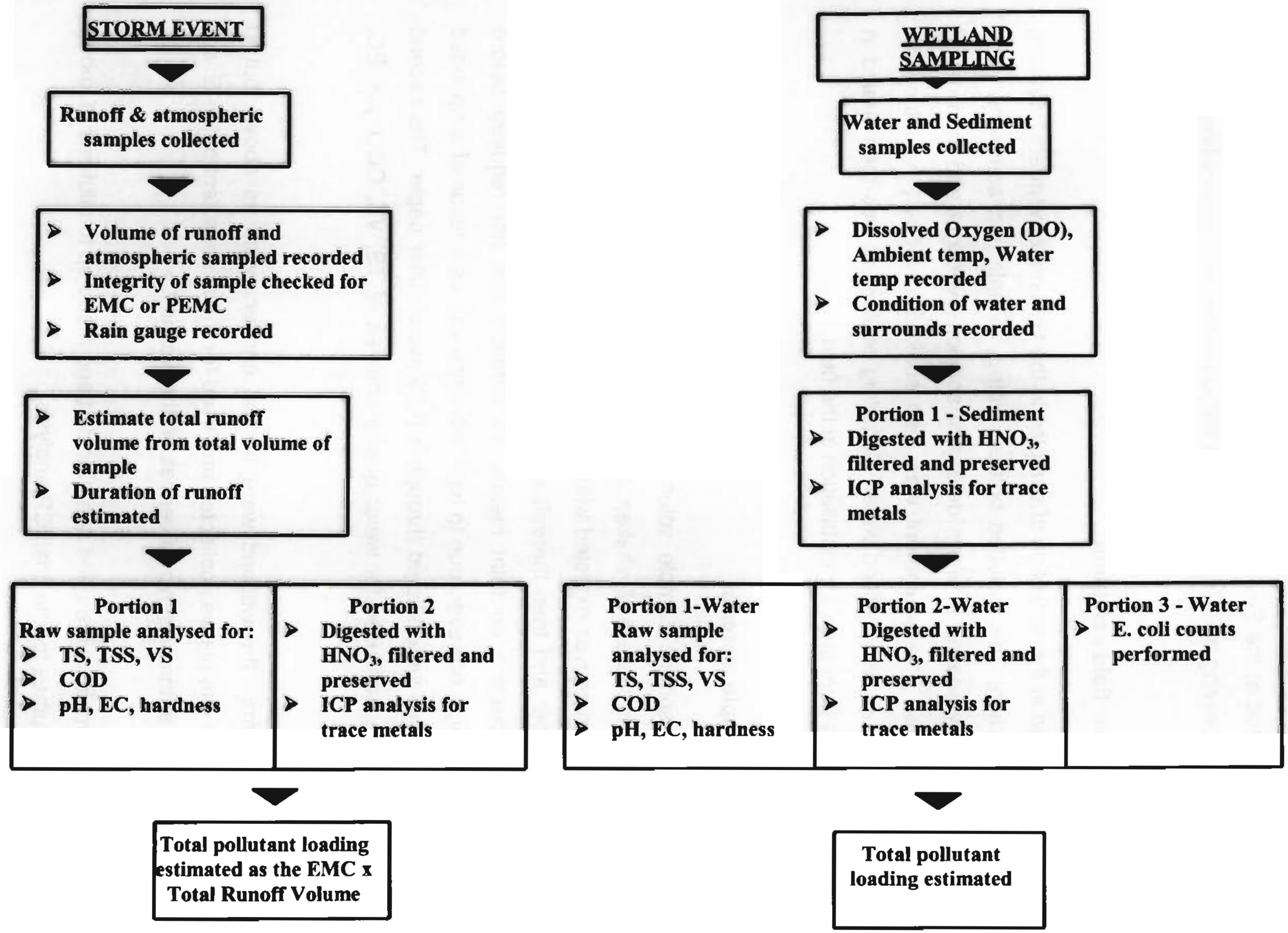


Figure 4.3: Flow chart of sample analysis and data management

4.7. Laboratory Techniques and Analysis

The Standard Methods for the Examination of Water and Wastewater 20th Edition (Clesceri *et al.*, 1998) were used for all laboratory procedures and analysis. Laboratory analysis was conducted at the Environmental Engineering Laboratory of the School of Civil Engineering, Surveying and Construction of the University of KwaZulu-Natal.

4.7.1 Preparation for field sampling

All the equipment used in the collection of samples in the field underwent acid washing to prevent contamination. This included bottles, piping, funnels and samplers. The equipment was initially soaked in warm detergent solution overnight and then rinsed out with distilled water. The equipment was then soaked in 2-5% (v/v) nitric acid overnight and rinsed out with distilled water. Sampling equipment was then sealed in plastic bags, to isolate from dust, for installation in the field.

4.7.2 Collected sample material

The runoff and atmospheric sample volumes for each event were measured and recorded. The samples were well shaken and two representative portions taken for analysis. The first portion was digested with nitric acid before being filtered through a 0.45 micron filter paper and then thereafter preserved at four degrees Celsius. The investigation was focussing on total metals, so filtration was not required before acidification and storage; however, due to high turbidity levels as a result of suspended particulates the samples were filtered through a 0.45 micron filter paper. The second portion of raw sample was used for water quality analysis of TS, VS, COD, pH, EC, NH_3 and NO_3^-.

The water samples from the wetland were treated and analysed as above, but in addition, a further raw sample was collected and used for the assessment of the *E. coli* content to assess the anthropogenic influences on the wetland.

Wetland sediment samples were dried and digested and made up to dilutions of known weight and known volumes for the final ICP analysis.

4.7.3 Analytical procedures

The analytical procedures for the standard types of analyses undertaken in this investigation are outlined below. All samples were thoroughly mixed before any analysis was conducted. Generally samples were collected, preserved (where required) and stored within twenty four hours. Generally analyses were performed in triplicate but if the quantity of sample did not cater for this, duplicate analyses were performed.

pH

In the laboratory, measurement of the pH was done using an Orion 4 pH meter (Model 410A) with a pH probe calibrated with pH 4 and pH 7 standards prior to sample measurement. Samples were measured as soon as possible as these values may change significantly over a twenty four hour period.

EC

The conductivity of a solution gives an indication of the amount of dissolved ionic compounds and the total dissolved solids. In the laboratory, measurement of the electrical conductivity (EC) was done using a Corning calibrated probe (Model CheckMate II). Samples were measured as soon as possible as these values may change significantly over a twenty four hour period. The pH and Conductivity measurement device are shown in Plate 4.7.

Plate 4.7: pH and Conductivity meter

Dissolved, Particulate and Volatile Matter

The Standard Methods (Clesceri *et al.*, 1998) were used for the analysis of total suspended solids, Total Solids and Volatile Solids.

Total Suspended Solids (TSS) solids samples were filtered through a dried and weighed 0.45 micron filter paper and were dried in an oven at 105°C, kept in the dessicator to cool and then weighed on a Denver Instruments Company 4 place balance (Model AA200).

As the samples could be non homogenous due to sediments, variations in Total Solids (TS) and Volatile Solids (VS) could be encountered especially due to the low concentration levels found in the wetland surface waters sampled. TS was determined by firing crucibles in a furnace at 550°C, allowing them to cool in the dessicator before being weighed, and then 25ml of sample added and then allowed to dry in an oven 105°C for 24 hours and then weighed. VS was determined by placing the samples in a furnace at 550°C for 40 minutes, allowed to cool in the dessicator and weighed.

The equations of TS and VS are as follows:

$$TS(g/l) = \frac{[1000 \times (W_{TS} - W_D)]}{V_S} \tag{4-1}$$

$$FS(g/l) = \frac{[1000 \times (W_{FS} - W_D)]}{V_S} \tag{4-2}$$

and therefore:

$$VS(g/l) = TS - FS \tag{4-3}$$

where:

W_D = mass of the dish (g),

W_{TS} = mass of the dried residue in the dish (g),

W_{FS} = mass of the fixed solids remaining in the dish after combustion (g),

V_S = volume of the sample (l),

FS = concentration of non-volatile fixed solids (mg/l),

1000 = multiple to convert the concentrations in g/l.

Oxygen Demand Indicators

The Chemical Oxygen Demand (COD) is a measurement of the amount of oxygen that is required for the chemical oxidation of the organic matter contained in waste water. The chemical oxygen demand (COD) analysis was done using the closed reflux method as prescribed in The Standard Methods (Clesceri *et al.*, 1998) ASTM standard method number 5220. A spectrophotometer (Model Hach DRI 2000) was calibrated and used to calculate the final refluxed COD level by a colorimetric method.

The consumption of effective oxidant which is expressed in terms of oxygen equivalent with the formula:

$$COD(mgO_2) = \frac{[8000 \times N \times (A - B)]}{V} \tag{4-4}$$

where:

A = ml of titrant used in the blank sample

B = ml of titrant used in the sample

N = normality of the titrant

V = volume of sample

The 8000 multiplier is used to express results in units of milligrams per litre of oxygen, since 1 litre contains 1000g and the equivalent weight of oxygen is 8g.

Ammoniacal Nitrogen *(NH_3-N or NH_4-N)*

The ammonia test procedure follows the ASTM standard method number D1426 (Clesceri et al, 1998). Ammonia was tested for using a Pro Nitro 1 steam distillation apparatus. The methodology used is set out in the equipment manual. Ferrous ammonium sulphate was used as a standard to calibrate the equipment.

The ammonia nitrogen (NH_3) exists in aqueous form and as an ion of ammonia; (ammoniacal nitrogen NH_4^+) depending on the pH of the solution in accordance with the following equilibrium reaction equation:

$$NH_3 + H_2O = NH_4^+ + OH^- \tag{4-5}$$

The determination of nitrates (NOx) is carried out according to SABS 210-1990 using the residue sample from the ammonia distillation process; magnesium oxide and Devardas alloy are added to the sample to reduce the nitrates to ammonia and a new flask with the solution of boric acid is replaced and steam distilled.

The apparatus and the ammonia sample are shown in Plates 4.8 and 4.9 respectively.

Plate 4.8: Ammonia distiller apparatus

Plate 4.9: Sample for the ammoniacal nitrogen and nitrates analysis

Metals

The mass of trace metals in samples of atmospheric deposition, transported by stormwater runoff and present in the wetland were estimated from the portion of sample digested, filtered and preserved. Samples were analysed using Inductively Coupled Plasma – Atomic Emission Spectroscopy (ICP-AES) at the chemical laboratory at the University of Kwazulu-Natal's Westville Campus. (ICP-AES) is a widely used and powerful elemental analysis technique. The principles of operation were according to Skoog *et al.* (1996) and Varma (1991). The concentrations of the elements are derived from the light intensity produced by the radiation of the elements and measured by the ICP-AES instrument. The intensity of light at certain wavelengths is proportional to the concentration of the element Skoog *et al.* (1996). An independent certified laboratory supplied calibration standards required for analysis. In the analysis of the 132 samples, quality control checks were built into the sequence to be automatically undertaken after every tenth sample analysed. The procedure of the QC check was that the standards were checked to see whether the standard was within limits of the initial calibration. If they were, the analysis was allowed to continue, and if not, a recalibration was performed and then the next ten samples analysed (See Table D.1 in Appendix D on the included CD).

E. coli and Total coliforms

For this investigation, Chromocult Coliform agar powder which is a selective agar for the simultaneous detection of total coliforms and *E. coli* was used to make up a solution of agar. The surface plate technique prescribed by the pharmaceutical manufacturing company Merck was followed. 10ml of the made up solution was placed into sterile plastic Petri dishes and allowed to set. The water sample for testing was made up of serial dilutions of the original sample, as the *E. coli* content was expected to be high due to numerous sewerage pipeline breaks and spills along the course of the wetland. These diluted samples were then filtered through a 0.45 micron membrane filter, which was then placed on the agar in the dishes and incubated for 24-36 hours at 37 °C, and then the colonies counted.

4.7.4 Quality control and Accuracy Testing

Quality control procedures were used to indicate whether any contamination occurred during any of the laboratory or field methods practised. Method blanks, distilled water blanks and equipment blanks were collected and analysed. Equipment blanks were obtained by flushing a known quantity of distilled water through the sampling equipment to simulate storm event conditions. All storage bottles and glassware used in analytical procedures were washed in 2-10% (v/v) nitric acid. During installation, collection and laboratory analysis, powderless gloves were worn to prevent contamination. Analytical procedures followed standard methods (Clesceri *et al.*, 1998) and were generally done in triplicate or where sample quantity dictated, in duplicate. All equipment was calibrated and where necessary standards were used to confirm the accuracy of both the equipment and the methods. The results presented in Chapter 5 are an average of the measured values; the raw data are presented in the Appendix. For each set of data the median, standard deviation and variation were calculated and an example of these calculations for COD is reported in Table 4.1.

Table 4.1: Chemical Oxygen Demand (COD)

Sample	Sample Date	Reading			Ave	Std Dev	Var	COD (mg/l)
		Wetland Water						
Downstream	14/01/2007	0.004	0.006	0.008	0.006	0.002	0.00000400	14.854
Centre		0.004	0.007	0.006	0.006	0.002	0.00000233	14.028
Upstream		0.005	0.007	0.006	0.006	0.001	0.00000100	14.854
SW		0.008	0.010	0.009	0.009	0.001	0.00000100	22.280
Source		0.000	0.000	0.003	0.001	0.002	0.00000300	2.476
Downstream	05/02/2007	0.007	0.006	0.007	0.007	0.001	0.00000033	14.771
Centre		0.005	0.005	0.010	0.007	0.003	0.00000833	14.771
Upstream		0.004	0.005	0.006	0.005	0.001	0.00000100	10.645
SW		0.008	0.010	0.005	0.008	0.003	0.00000633	17.247
Source		0.004	0.006	0.011	0.007	0.004	0.00001300	15.596
Downstream	04/03/2007	0.007	0.006	-	0.007	0.001	0.00000050	15.844
Centre		0.004	0.004	0.008	0.005	0.002	0.00000533	12.956
Upstream		0.006	0.007	0.007	0.007	0.001	0.00000033	16.256
SW		0.012	0.012	0.012	0.012	0.000	0.00000000	29.460
Source		0.035	0.036	0.035	0.035	0.001	0.00000033	87.224
Downstream	06/03/2007	0.032	0.021	-	0.027	0.008	0.00006050	70.555
Centre		0.009	0.014	0.013	0.012	0.003	0.00000700	34.658
Upstream		0.007	0.008	0.010	0.008	0.002	0.00000233	25.581
SW		0.012	0.008	0.013	0.011	0.003	0.00000700	32.183
Source		0.005	0.005	-	0.005	0.000	0.00000000	17.329

Table 4.1 Continued:

Sample	Sample Date	Reading			Ave	Std Dev	Var	COD (mg/l)
		Wetland Water						
Downstream	15/04/2007	0.003	0.002	0.004	0.003	0.001	0.00000100	6.684
Centre		0.002	0.002	0.002	0.002	0.000	0.00000000	4.209
Upstream		0.002	0.003	0.001	0.002	0.001	0.00000100	4.209
SW		0.002	0.001	0.001	0.001	0.001	0.00000033	2.558
Source		0.006	0.005	0.001	0.004	0.003	0.00000700	9.160
Downstream	15/05/2007	0.007	0.008	0.007	0.007	0.001	0.00000033	16.669
Centre		0.013	0.010	0.007	0.010	0.003	0.00000900	23.271
Upstream		0.012	0.012	0.010	0.011	0.001	0.00000133	26.571
SW		0.003	0.002	0.003	0.003	0.001	0.00000033	5.116
Source		0.002	0.003	0.003	0.003	0.001	0.00000033	5.116
Downstream	18/06/2007	0.002	0.001	0.005	0.003	0.002	0.00000433	5.364
Centre		0.006	0.008	0.008	0.007	0.001	0.00000133	16.917
Upstream		0.023	0.022	0.022	0.022	0.001	0.00000033	54.051
SW		0.004	0.009	0.005	0.006	0.003	0.00000700	13.616
Source		0.011	0.008	0.009	0.009	0.002	0.00000233	21.868
Downstream	30/07/2007	0.005	0.004	0.004	0.004	0.001	0.00000033	9.490
Centre		0.003	0.005	0.004	0.004	0.001	0.00000100	8.665
Upstream		0.005	0.006	0.005	0.005	0.001	0.00000033	11.965
SW		0.004	0.003	0.001	0.003	0.002	0.00000233	5.364
Source		0.004	0.014	0.006	0.008	0.005	0.00002800	18.567
Downstream	19/08/2007	0.007	0.004	0.005	0.005	0.002	0.00000233	12.461
Centre		0.018	0.016	0.017	0.017	0.001	0.00000100	41.343
Upstream		0.004	0.007	0.006	0.006	0.002	0.00000233	13.286
SW		0.004	0.003	-	0.004	0.001	0.00000050	7.922
Source		0.007	0.003	0.008	0.006	0.003	0.00000700	14.111

AVE = average, STDEV = standard deviation, VAR = coefficient of variation

The standard deviations of the data from the triplicates samples were calculated using the following equation, taken from Clesceri et al (1998).

$$S_D = \frac{\overline{R}}{1.128} \qquad (4\text{-}6)$$

where

S_D = standard deviation for duplicates and the average range $\overline{R}$ is:

$$\overline{R} = \frac{\sum |differences|}{n_o} \qquad (4\text{-}7)$$

where

n_0 = number of observations.

Differences = difference between highest and lowest values obtained in every duplicate set

The standard deviation of the data from the multiple analyses of a single sample was calculated using the following equation (Robertson et al, 1995).

$$S_M = \sqrt{\frac{\sum_{Z=1}^{n}(C_Z - \overline{C})^2}{n_o - 1}} \qquad (4\text{-}8)$$

where

S_M = standard deviation for multiple analyses of a single sample,

C_Z = concentration of sample z.

and

$$\overline{C} = \frac{\sum_{Z=1}^{n} C_Z}{n_o}. \qquad (4\text{-}9)$$

The precision tests conducted on the triplicate samples showed a high level of repeatability with a standard deviation below that specified by Clesceri et al (1998).

4.8. Summary

After a detailed investigation of the study area, five wetland monitoring station sites for continual monitoring and three stormwater runoff sites were selected which satisfied the guidelines established from the objectives. Two atmospheric sampling stations were installed at specific locations chosen to best produce representative data. Event Mean Concentrations were obtained from samples exhibiting no form of outside contamination, while Partial Event Mean Concentrations were analysed for from samples which exhibited interference in the form of blockages of the orifice sampling entrance. Wetland water and sediment samples were also analysed for the presence of metals and *E. coli*.

CHAPTER 5

RESULTS AND DISCUSSION

Chapter Five presents the results of the characterisation of wetland water and sediments, atmospheric and runoff collection for the investigation period of eight months (January 2007 to August 2007). 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 levels. The relationship between constituent concentrations and factors such as build-up periods, rainfall and study area characteristics are presented using correlation analysis

5.1 Presentation of Results

The results tables and figures depicted herein are summaries of the large quantity of data collected. Wetland water and sediments were sampled on a monthly basis whilst stormwater runoff and atmospheric deposition were sampled during storm events over a period of 8 months. The results are discussed in an order that is representative of the occurrences of the pollution dynamics as illustrated in Figure 5.1 from the anthropogenic pollution from current residents, the construction activities and progress with associated materials flow, to atmospheric deposition in the form of rainfall, and finally to the wetland through stormwater runoff that is discharged.

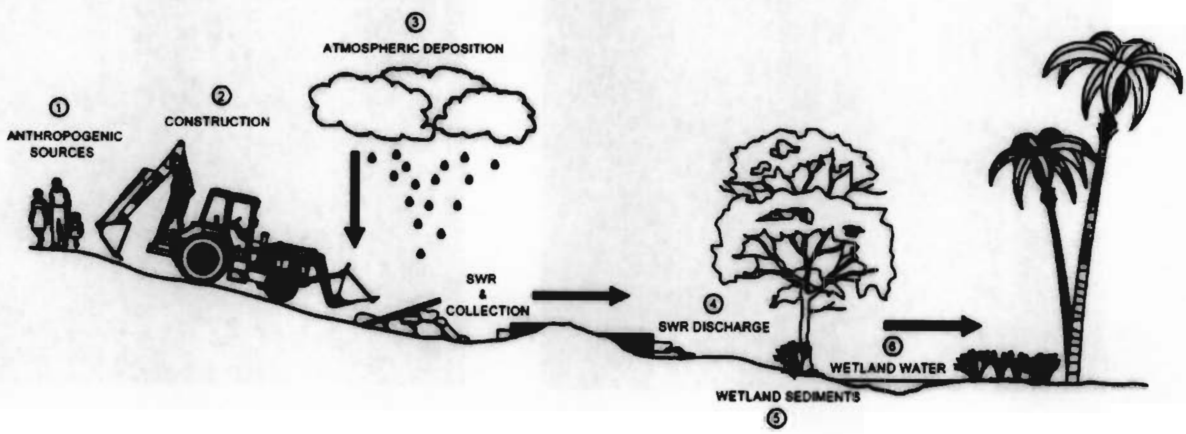


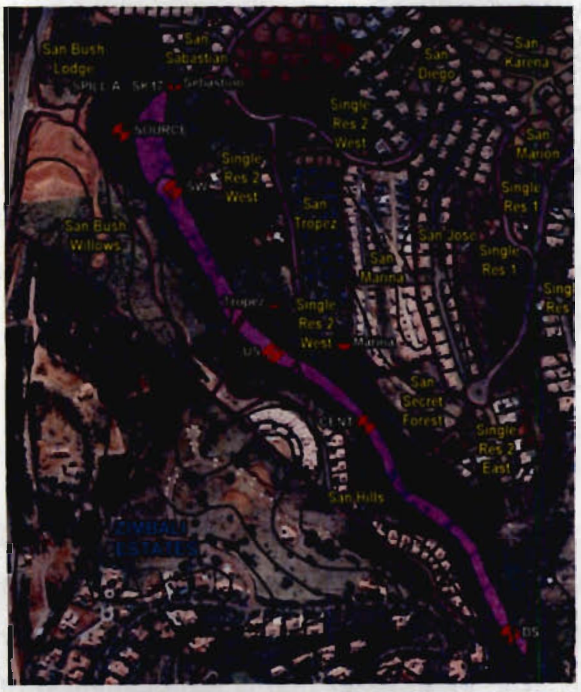
Figure 5.1: Pollution dynamics process flow diagram

5.2 Anthropogenic Pollution

5.2.1 Sewage spills and *E. coli* contamination

During the investigation period five major sewage spills of various durations occurred within the wetland zone spilling raw sewage directly into the wetland stream and surrounds and impact effect plumes of the spills are illustrated in Figure 5.2 (a)-(e).

a)



b)

c)

d)

e)

Figure 5.2: Sewage Spill Plumes a) SK 17 on 4 Feb-07 – Duration 4 days
b) SK 2-1 on 5 Feb-07 – Duration 6 days
c) SK 13a on 26 Feb-07 – Duration 12 days
d) SK 10 on 2 Jul-07 – Duration 26 days
e) Siza 2 on 2 Aug-07 – Duration 16 hours

The nature and duration of the individual spills is shown in Table 5.1. The nature of the spill at SK 17 for Spill D (refer to Figure 4.1 and Figure 5.1) is depicted in Plate 5.1 and is indicative of the nature of the other occurrences.

Table 5.1: Sewer spill occurrences and durations

N°	Start Date (Approx)	Development	GIS Tag	Description	Duration
A	4/02/2007	San Sebastian (Erf 2994)	SK17	Sewer pipe burst	4 days
B	5/02/2007	Single res 2 East (Erf 1596)	SK2	Gravity Main Sewer pipe burst	6 days
C	26/02/2007	Single res 2 West (Erf 2998)	SK13a	Sewer pipe burst @ manhole	12 days
D	02/07/2007	Single res 2 West (Erf 1576)	SK10	Sewer spill @ manhole	26 days
E	02/08/2007	San Bush Willows (Erf 3305)	Siza 2	Rising main burst spilling 6 cumecs	16hrs

Plate 5.1: Sewage spill at SK 10 (Spill d) near San Tropez on 22 July 2007

The majority of the samples tested had *E. coli* colony counts well above the General Limits as prescribed by the DWAF. The first samples taken show low colony counts, however the whole sample was filtered without making use of any serial dilutions and due to the nature of the microbes' growth at high concentrations (colonies can grow on top of one another), the results are not deemed conclusive. The *E. coli* and total coliforms indicator concentration levels at the five sampling stations namely DS, CENT, US, SW and Source (See Figure 4.1) are shown in Table 5.2 and where these exceed the SA wastewater limit they are indicated in red and underlined. The results are presented in Figure 5.3 where they are depicted on two scales so that the General Limits are evident at the second scale.

Table 5.2: *E. coli* and TCC indicator concentration levels

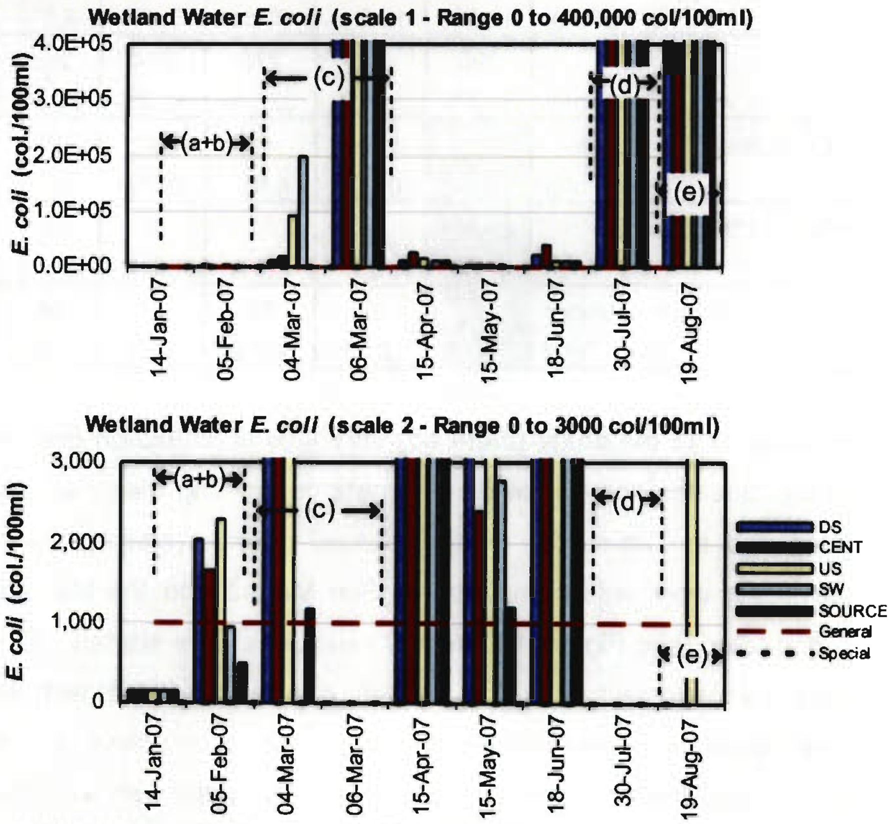
Sample Date	*E. coli* (Col / 100ml)				
	DS	CENT	US	SW	SOURCE
14-Jan-07	1.6E+02	1.6E+02	1.6E+02	1.6E+02	1.6E+02
05-Feb-07	2.0E+03	1.6E+03	2.3E+03	9.6E+02	4.9E+02
04-Mar-07	9.8E+03	1.8E+04	9.1E+04	2.0E+05	1.2E+03
06-Mar-07	1.3E+07	5.3E+06	4.7E+06	1.5E+07	1.3E+07
15-Apr-07	1.0E+04	2.5E+04	1.5E+04	1.2E+04	1.0E+04
15-May-07	5.2E+03	2.4E+03	4.2E+03	2.8E+03	1.2E+03
18-Jun-07	2.2E+04	3.9E+04	1.3E+04	1.1E+04	9.6E+03
30-Jul-07	7.6E+06	8.6E+06	8.8E+06	3.6E+06	4.2E+06
19-Aug-07	1.2E+06	4.0E+05	6.0E+05	1.6E+06	1.0E+06
Median	1.0E+04	2.5E+04	1.5E+04	1.2E+04	9.6E+03
Mean	2.4E+06	1.6E+06	1.6E+06	2.3E+06	2.0E+06
SD	4.6E+06	3.2E+06	3.1E+06	5.0E+06	4.2E+06
COV [a]	1.92	1.97	1.97	2.18	2.13
TWQR Exc % [b]	89%	89%	89%	78%	78%

Table 5.2 Continued

Sample Date	TCC (Col / 100ml)				
	DS	CENT	US	SW	SOURCE
14-Jan-07	2.4E+02	2.4E+02	2.4E+02	2.4E+02	2.4E+02
05-Feb-07	2.0E+04	1.3E+03	4.1E+04	2.7E+03	2.9E+03
04-Mar-07	1.1E+05	6.7E+04	2.4E+05	5.3E+05	8.6E+03
06-Mar-07	3.2E+07	1.1E+07	1.9E+07	8.7E+07	7.4E+07
15-Apr-07	1.2E+05	1.1E+05	1.2E+05	2.2E+05	3.9E+05
15-May-07	8.2E+04	4.2E+04	4.6E+04	3.9E+04	2.6E+03
18-Jun-07	1.4E+05	2.1E+05	2.0E+05	1.1E+05	1.3E+05
30-Jul-07	8.0E+06	9.6E+06	1.0E+07	1.5E+07	3.3E+07
19-Aug-07	7.6E+06	2.6E+06	4.6E+06	5.8E+06	3.4E+06
Median	1.2E+05	1.1E+05	2.0E+05	2.2E+05	1.3E+05
Mean	5.3E+06	2.7E+06	3.8E+06	1.2E+07	1.2E+07
SD	1.1E+07	4.5E+06	6.7E+06	2.9E+07	2.6E+07
COV [a]	1.97	1.70	1.75	2.37	2.07

[a] Coefficient of variation = standard deviation / mean

[b] Exceedance percentages of the SA Wastewater limit values for General Standards



(a)(b)(c)(d)(e) – Denotes sewer spills – see Table 5.1

General = SAWQG General Limit of 1000 col/100ml Special = Special Limit of 0 col/100ml

Figure 5.3: *E. coli* levels at the wetland sampling stations

5.3 Construction Progress

The study site comprised the construction of various residential and commercial erven as part of a larger estate. Construction had begun on a large portion of the estate prior to inception of this study. During the nine months of monitoring of the progress (December 2006 to August 2007), 68 units were completed, 29 new units were started on, whilst 106 units were under construction at the inception of the study. On average over the nine month period there were approximately 86 units under construction at any given time. This is further illustrated in Table 5.3 and Appendix C.

Table 5.3: Summary of construction activity progress throughout the study period

Parameter	Start	Jan-Feb	Mar-Apr	May-Jun	Jul-Aug	Total Units
Construction Complete (Cumulative)	449	451	492	494	517	**68**
% of Total	52.8%	53.1%	57.9%	58.1%	60.8%	**60.8%**
Under Construction	106	104	80	82	65	
% of Total	12.5%	12.2%	9.4%	9.6%	7.6%	
Vacant Land	295	295	278	274	268	
% of Total	34.7%	34.7%	32.7%	32.2%	31.5%	
Construction Completed this Quarter		2	41	2	23	**68**
% of Total		0.2%	4.8%	0.2%	2.7%	**8.0%**
Construction Started this Quarter		2	17	4	6	**29**
% of Total		0.2%	2.0%	0.5%	0.7%	**3.4%**
Total Under Construction this Quarter		104	83	84	85	**356**
% of Total		12.2%	9.8%	9.9%	10.0%	**41.9%**

During the first quarter of the study (Jan-Feb) very little construction occurred due to the builders break besides some individual owners completing their own construction activities as depicted in Table 5.3. In the second quarter (Mar-Apr) a substantial amount of carry over work was completed in San Marina and the Netcare Alberlito hospital was completed (see Figure 4.1) and 17 new units were started. Construction completion progress slackened off during the third quarter (May-Jun) with the majority of the work undertaken being predominantly in the construction phase, and then in the fourth quarter (Jul-Aug) the construction pace quickened again with a further 23 units being completed and still a further 85 under construction. The change of construction status of the various erven on the estate over time but captured per quarter is illustrated in Figure 5.4 (a) – (d).

Figure 5.4: Two Monthly Construction Progress Map

5.4 Materials Flow

Construction materials entering and exiting the estate were monitored, quantified and categorised into three series for incoming materials: High impact, Intermediate impact and Low impact, and one for materials exported in the form of waste. What was evident from the survey and the construction progress monitoring is that there were three main developments receiving materials namely San Jerez, San Karena and San Marco, and then a number of smaller developments and individual homesteads made up the rest of the materials flow. The weighted flows were thus rated from one to four, one being the largest flow and four being the smallest flow. It is evident from the flow rankings presented in Table 5.4 that the development of San Jerez (See figure 4.1) in most instances received the highest quantities of all three categories of materials throughout the study period. San Jerez is also incorporated into one of the three main stormwater catchment areas (Tropez) that feed into the wetland under investigation (See Figure 4.1).

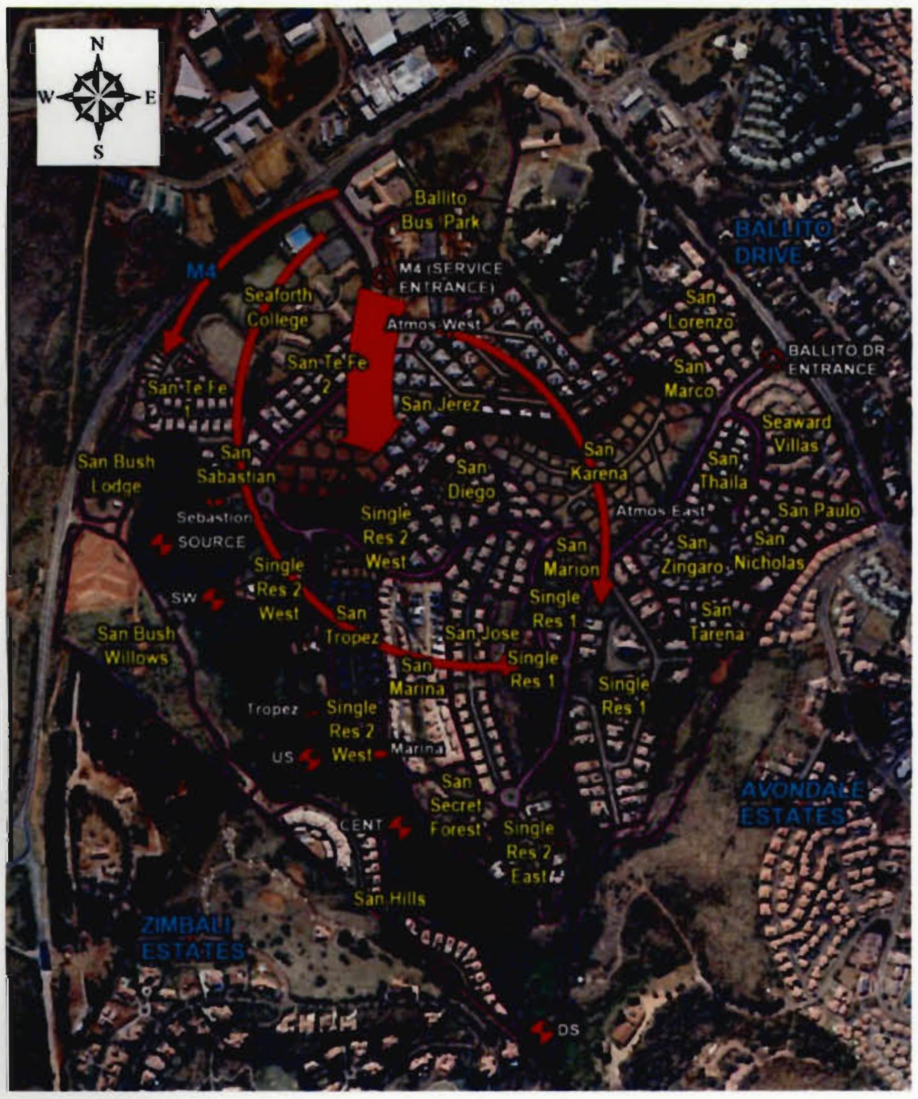
Over the period of the study, there is an even spread of the three types of material flows, starting off rather slowly in the first quarter, and building up over the next three, in line with the construction progress monitored (see Figure 5.4). The three flow categories are illustrated in Figures 5.5, 5.6 and 5.7 for High Impact, Intermediate impact and Low Impact respectively. As illustrated in Figure 5.5 and Appendix B, there was very little removal of material in the form of builders' rubble throughout the entire study period. It was determined that despite EMP's (Bundy, 2004) stating that no dumps were allowed on any construction site and that all waste was to be put in skips and removed on a weekly basis, this was not adhered to and builders dumps were created and left on site for extended periods, and were not removed during the study period – see

Plate 5.2: Construction waste dump on San Jerez (approx. 5 months standing)

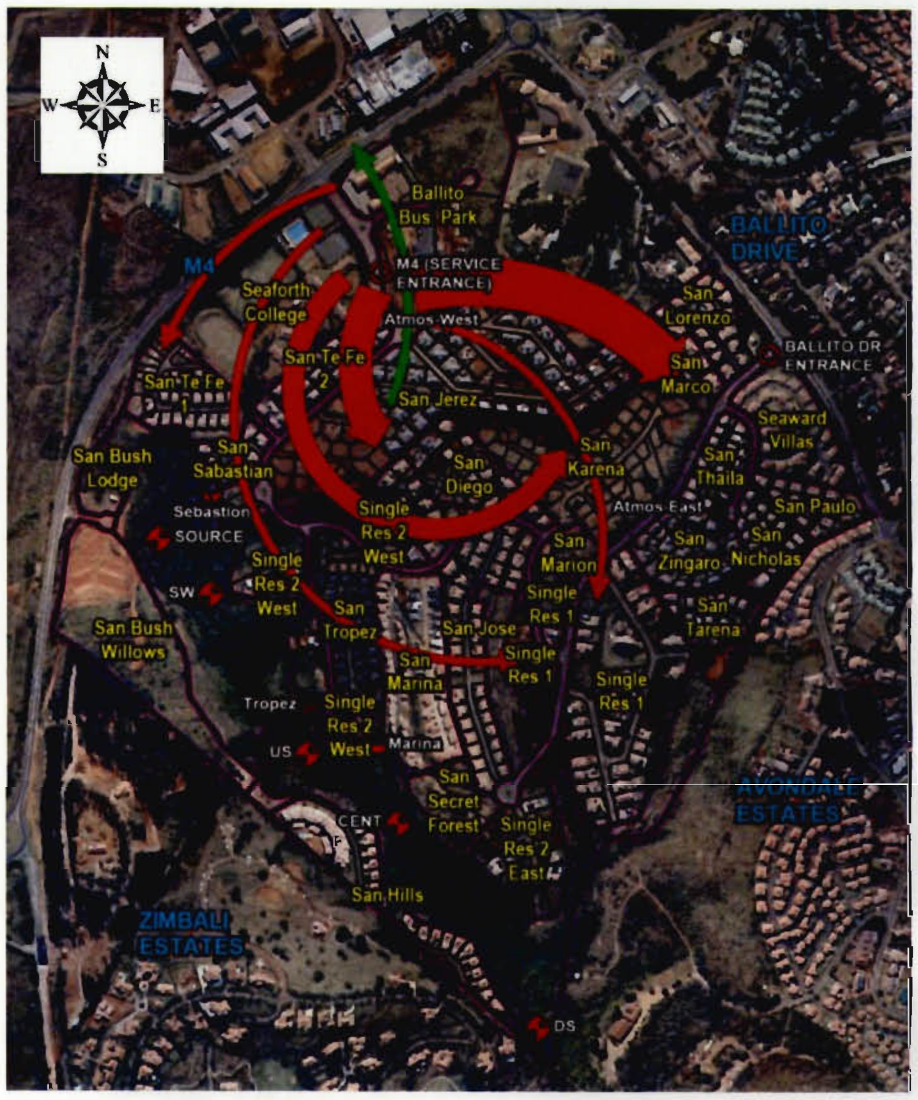
Table 5.4: Materials flow ranking in order of impact potential and tonnage

POTENTIAL IMPACT	San Jerez	San Karena	San Marco	Other
	Equivalent Tons			
MATERIAL IMPORTED	January & February			
HIGH POTENTIAL IMPACT	457 ①	-	-	-
INTERMEDIATE POTENTIAL IMPACT	947 ①	-	-	-
LOW POTENTIAL IMPACT	178 ①	-	-	-
GENERAL RUBBLE EXPORTED	-	-	-	-
MATERIAL IMPORTED	March & April			
HIGH POTENTIAL IMPACT	871 ②	68 ③	2750 ①	50 ④
INTERMEDIATE POTENTIAL IMPACT	2076 ②	377 ③	2904 ①	190 ④
LOW POTENTIAL IMPACT	630 ①	487 ②	254 ④	283 ③
GENERAL RUBBLE EXPORTED	3.6 ①	-	-	-
MATERIAL IMPORTED	May & June			
HIGH POTENTIAL IMPACT	1242 ①	43 ③	25 ④	88 ②
INTERMEDIATE POTENTIAL IMPACT	1794 ①	240 ③	203 ④	358 ②
LOW POTENTIAL IMPACT	446 ①	249 ②	124 ④	192 ③
GENERAL RUBBLE EXPORTED	-	-	-	2.4 ①
MATERIAL IMPORTED	July & August			
HIGH POTENTIAL IMPACT	1333 ①	27 ②	9 ③	9 ③
INTERMEDIATE POTENTIAL IMPACT	1700 ①	130 ②	9 ④	115 ③
LOW POTENTIAL IMPACT	309 ①	283 ②	-	114 ③
GENERAL RUBBLE EXPORTED	2.4 ①	-	-	-

Legend: ① = weight ranking between 1 and 4 from largest flow to smallest



a.) MATERIAL FLOW QTR 1 (JANUARY 2007 – FEBRUARY 2007)



b.) MATERIAL FLOW QTR 2 (MARCH 2007 TO APRIL 2007)

c.) MATERIAL FLOW QTR 3 (MAY 2007 TO JUNE 2007)

d.) MATERIAL FLOW QTR 4 (JULY 2007 TO AUGUST 2007)

LEGEND:	PROJECT:	TITLE:
Material Flow In (High Potential Impact) Material Flow Out	IMPACTS OF CONSTRUCTION ON A WETLAND : SEAWARD ESTATES	MATERIAL FLOW IN AND OUT OF THE ESTATE. HIGH POTENTIAL IMPACT

Figure 5.5: Two Monthly Material Flow Map of High Potential Impact Materials

a.) MATERIAL FLOW QTR 1 (JANUARY 2007 – FEBRUARY 2007)

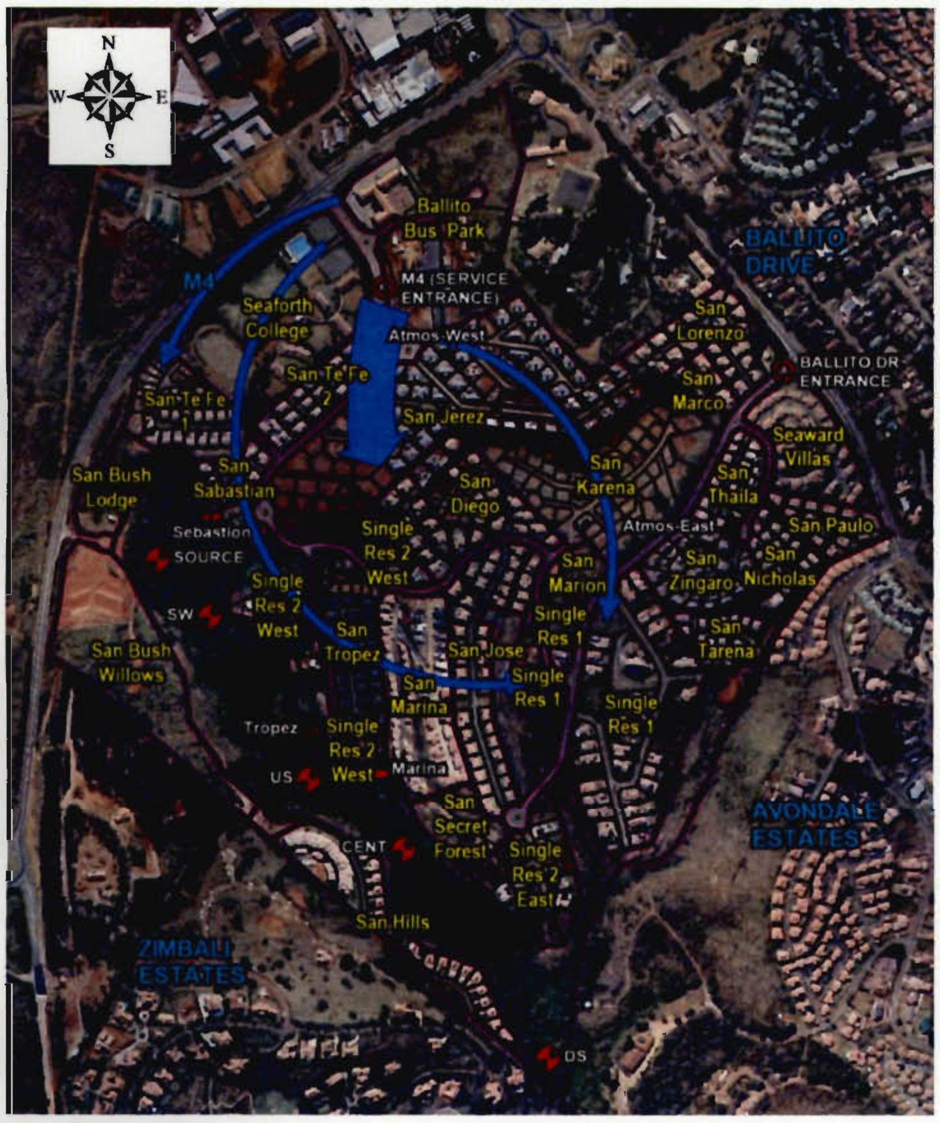
b.) MATERIAL FLOW QTR 2 (MARCH 2007 TO APRIL 2007)

c.) MATERIAL FLOW QTR 3 (MAY 2007 TO JUNE 2007)

d.) MATERIAL FLOW QTR 4 (JULY 2007 TO AUGUST 2007)

LEGEND:	PROJECT:	TITLE:
➡ Material Flow In (Intermediate Potential Impact)	IMPACTS OF CONSTRUCTION ON A WETLAND : SEAWARD ESTATES	MATERIAL FLOW IN AND OUT OF THE ESTATE. INTERMEDIATE IMPACT

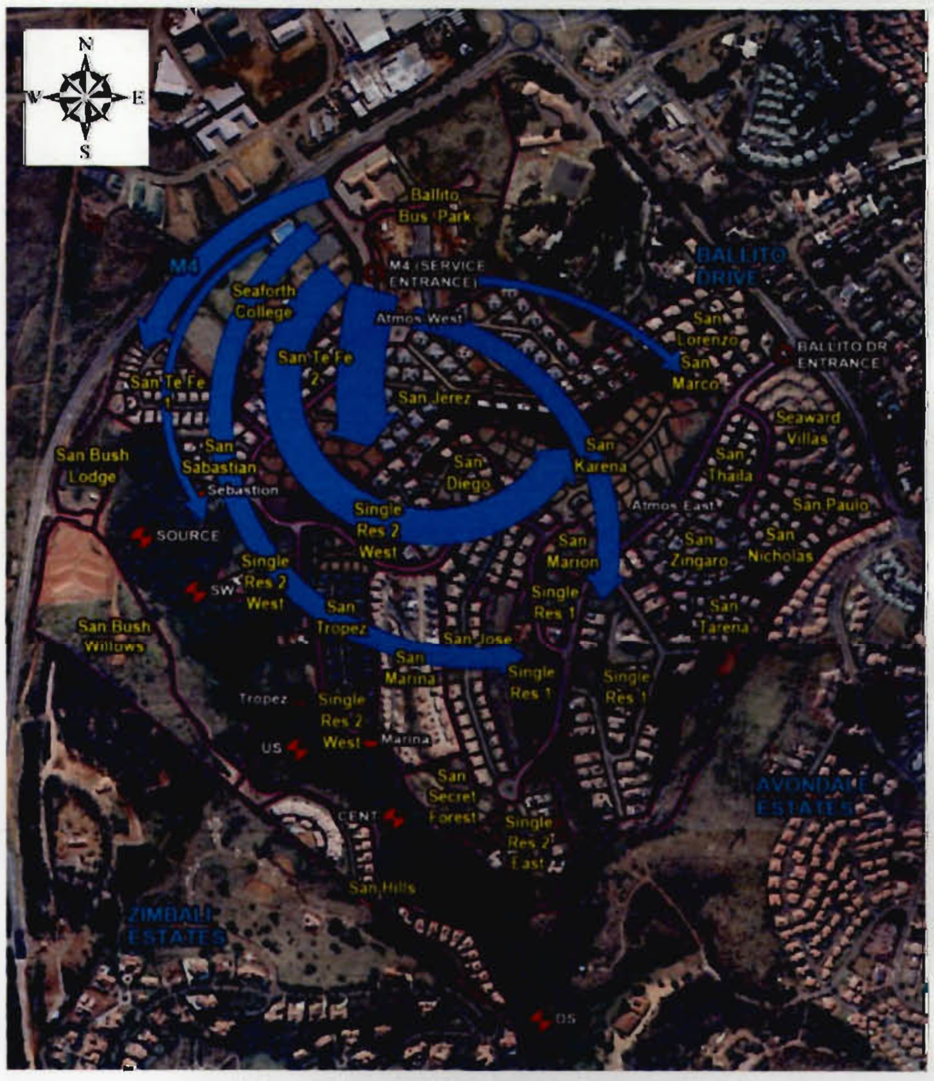
Figure 5.6: Two Monthly Material Flow Map of Intermediate Potential Impact Materials



a.) MATERIAL FLOW QTR 1 (JANUARY 2007 – FEBRUARY 2007)

b.) MATERIAL FLOW QTR 2 (MARCH 2007 TO APRIL 2007)

c.) MATERIAL FLOW QTR 3 (MAY 2007 TO JUNE 2007)



d.) MATERIAL FLOW QTR 4 (JULY 2007 TO AUGUST 2007)

LEGEND:	PROJECT:	TITLE:
Material Flow In (Low Potential Impact)	IMPACTS OF CONSTRUCTION ON A WETLAND : SEAWARD ESTATES	MATERIAL FLOW IN AND OUT OF THE ESTATE LOW POTENTIAL IMPACT

Figure 5.7: Two Monthly Material Flow Map of Low Potential Impact Materials

As can be seen in Table 5.5, the major material impactors encountered were ready mix concrete, aggregates for concrete and plaster comprising builders sand and stone, and cement. Many of the anticipated impactors such as road builders tarmac and associated compounds were not encountered during this study as either the roads infrastructure had already been built, or the internal roads are the final leg of the projects still to be completed in the near future.

Table 5.5: Flow matrix of potentially high impact materials

Category	Quantity	Retention Period	Toxicity	Perceived Impact	Equivalent Tons			
					San Jerez	San Karena	San Marco	Other
					January & February			
Concrete	Large	Short	High	High	433			
Aggregate	Large	Long	Low	High	166			
Aggregate	Large	Long	Low	High	166			
Aggregate	Large	Long	Low	High	126			
Cement	Large	Medium	Medium	Intermediate	56			
					March & April			
Aggregate	Large	Long	Low	High			2700	
Concrete	Large	Short	High	High	1120	288	144	130
Aggregate	Large	Long	Low	High	316	27	18	18
Aggregate	Large	Long	Low	High	316	27	18	18
Aggregate	Large	Long	Low	High	240	14	14	14
Cement	Large	Medium	Medium	Intermediate	83	20	10	10
Paint	Small	Short	High	Intermediate	1	1	0	0
					May & June			
Concrete	Large	Short	High	High	413	187	173	245
Aggregate	Large	Long	Low	High	358	9	9	54
Aggregate	Large	Long	Low	High	358	27	9	27
Aggregate	Large	Long	Low	High	272	7	7	7
Aggregate	Large	Long	Low	High	255			
Cement	Large	Medium	Medium	Intermediate	137	10	5	25
Paint	Small	Short	High	Intermediate	1			
					July & August			
Aggregate	Large	Long	Low	High	585			
Concrete	Large	Short	High	High	267	58		101
Aggregate	Large	Long	Low	High	262		9	9
Aggregate	Large	Long	Low	High	262	9		
Aggregate	Large	Long	Low	High	225			
Cement	Large	Medium	Medium	Intermediate	98	45		5
Aggregate	Large	Long	Low	High		18		
Paint	Small	Short	High	Intermediate	2			

Legend: Long = 2 weeks or more
Medium = ± 1 Week
Short = Day's

5.5 Storm Events

5.5.1 Precipitation

Rainfall data for this investigation was gathered from numerous sources. Two rain gauges were installed on the atmospheric samplers on the estate used for this investigation, whilst the developer of San Jerez also maintained a weather station on the site for his own use, and the South African Sugar Research Institute provided data (SASRI, 2007). The total precipitation for the entire investigation period of eight months (January 2007 to August 2007) was approximately 395mm. Figure 5.8 illustrates the observed monthly precipitation for the study period, shown as bar graphs, with comparisons with historical data shown as line charts, from observations taken on site and by the South African Sugar Research Institute at their Maidstone observation site in Tongaat, which is approximately 10km away from the site.

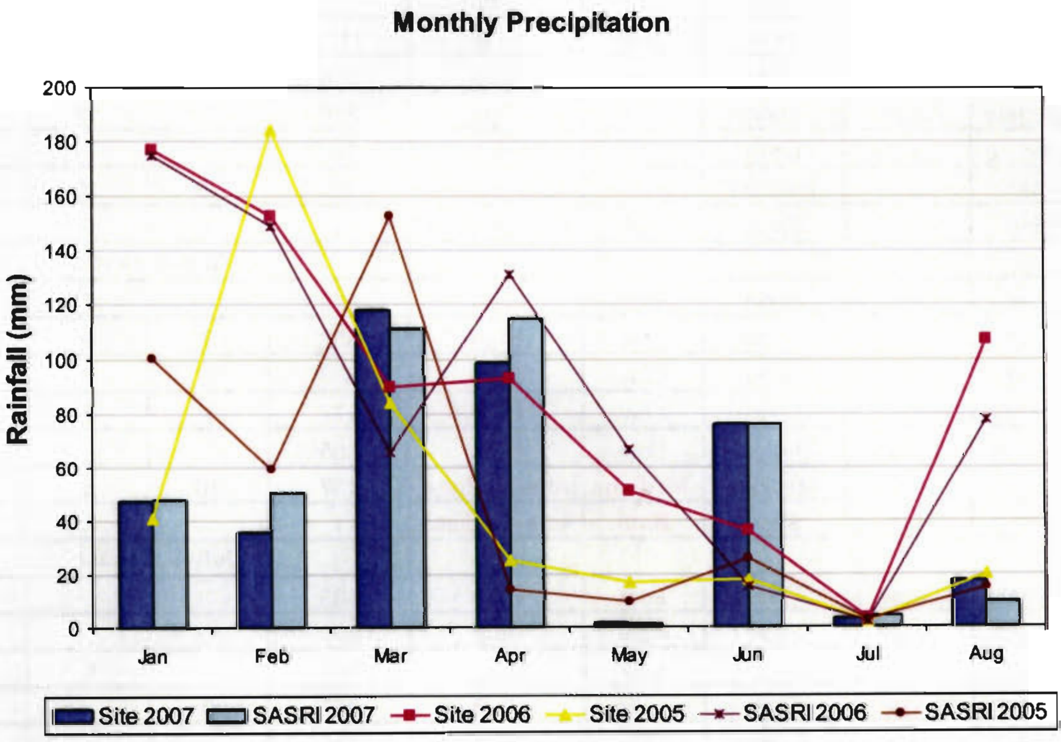


Figure 5.8: Comparison of monthly rainfall over the investigation period

5.5.2 Representativeness of storm events

All of the nine events sampled met or exceeded the criterion of a 72 hour antecedent dry period (ADP) and minimum total depth of precipitation of 2.54mm as illustrated in Table 5.6.

Table 5.6: Storm events sampled with total precipitation and ADP

Storm Event		Total Precipitation (mm)	ADP [a]
N°	Date		Days
1	24-Mar-07	10	4
2 [b]	26-Mar-07	11	1
3	06-Apr-07	4	6
4	18-Apr-07	44	10
5	28-Apr-07	8	7
6	02-Jun-07	8.5	3
7	26-Jun-07	20	20
8	21-Jul-07	2.8	23
9	04-Aug-07	9.1	13
10	24-Aug-07	4.8	19

[a] Antecedent Dry Period
[b] Results of this storm event included with event 1

Storm event 2 on 26 March 2007 however was only sampled at San Marina due to the failure of the San Hills sampler (see Plate 4.1) on 24 March 2007 storm a day and a half prior to this event, but has been portrayed as part of the first event in terms of the analyses conducted and data portrayed. The first two events (events 1 and 3) were sampled at the San Sebastian and San Marina sites and prior storm event 4, the third sampler at San Tropez was installed.

The samples collected were classified according to a checklist used during sample collection. The criteria assessed were storm event characteristics, volume sampled and factors that could have compromised the EMC of a sample. An EMC classification was assigned if:

1) The orifice of the sampler exhibited no form of blockage and an adequate sample volume was collected. A minimum of 2 litres was required to run all the analysis.
2) The orifice of the sampler exhibited some form of blockage but an adequate sample volume as above was collected to indicate that it operated adequately for a significant proportion of the event

A PEMC classification was assigned if:

1) The volume of sample collected indicated that a blockage might have occurred during the initial stages of the event discharge, and represented a first flush (See Table 5.7).

Table 5.7: Runoff sample classification

Storm Event	Runoff Classification		
Date	San Sebastian	San Tropez	San Marina
24-Mar-07	PEMC	-	-
26-Mar-07	-	-	EMC
06-Apr-07	EMC	-	EMC
18-Apr-07	EMC	PEMC	EMC
28-Apr-07	PEMC	EMC	PEMC
02-Jun-07	EMC	EMC	EMC
26-Jun-07	EMC	EMC	EMC
21-Jul-07	EMC	EMC	EMC
04-Aug-07	EMC	EMC	EMC
24-Aug-07	EMC	EMC	EMC

EMC = Event mean concentration
PEMC = Partial event mean concentration
- Indicates a discarded sample or no sampled runoff

During this investigation twenty five stormwater runoff samples were taken, of which only four were classified as a PEMC which represents only 16 percent of the total, so for the purposes of this investigation they were analysed as adequate EMC samples.

5.5.3 Atmospheric Deposition (AD)

Atmospheric deposition (AD) that is built up between storm events and contained in precipitation was collected for this investigation. The two samplers were stationed away from roads thus avoiding the probability of the samples being affected predominantly by vehicular pollutants. This gives a more representative sample of atmospheric fallout comprising a wider spectrum of pollutant contributors from the surrounding areas consisting of anthropogenic (domestic vehicles) and construction activities. Tables 5.8 and 5.9 illustrate chemophysical properties and heavy metal concentrations of atmospheric samples taken in the periods leading up to and including representative storm events at the Atmospheric West and East monitoring stations respectively. Although the TWQR are applicable to wastewater and hence the SWR, AD is set as a baseline and contributor to SWR, so the SA Wastewater limit values for the General Standard (or TWQR in the case of Aluminium) were applied and where these were exceeded, they are indicated in red and underlined. The percentage exceedances of these limits are also depicted.

Table 5.8: Mean concentrations for atmospheric deposition at Atmospheric West monitoring site

Sample Date	COD (mg/l)	TS (mg/l)	VS (mg/l)	NH_3 (mg/l.N)	NO_3^- (mg/l.N)	pH	EC (mS/cm)	Salinity
24-Mar-07	-	-	-	-	-	-	-	-
06-Apr-07	3.30	116	94	3.92	5.60	6.84	142.00	0.20
18-Apr-07	2.48	12	10	4.90	6.16	6.58	18.16	0.00
28-Apr-07	70.97	311	268	3.36	6.02	6.39	335.00	0.20
02-Jun-07	56.94	312	80	5.74	21.00	6.85	150.60	0.10
26-Jun-07	32.18	84	98	3.22	9.24	7.11	89.10	0.00
21-Jul-07	109.92	292	238	5.60	9.24	6.91	452.00	0.10
04-Aug-07	26.57	324	202	4.76	11.34	7.41	169.60	0.10
24-Aug-07	128.65	429	116	4.06	11.20	6.64	215.00	0.10
Median	44.56	301	107	4.41	9.24	6.85	160.10	0.10
Mean	53.88	235	138	4.45	9.98	6.84	196.43	0.10
SD	46.98	145	88	0.96	5.00	0.32	138.33	0.08
COV [a]	0.87	0.62	0.64	0.22	0.50	0.05	0.70	0.76
TWQR Exc % [b]	25%	88%	-	100%	13%	-	88%	-

Sample Date	Al (mg/l)	Ca (mg/l)	Cu (mg/l)	Fe (mg/l)	Ni (mg/l)	Zn (mg/l)
24-Mar-07	-	-	-	-	-	-
06-Apr-07	2.807	9.780	0.022	3.308	0.0068	0.128
18-Apr-07	0.038	0.205	0.004	ND	ND	0.005
28-Apr-07	1.550	5.986	0.013	2.068	0.0010	0.074
02-Jun-07	0.150	4.896	0.008	ND	ND	0.020
26-Jun-07	0.536	2.068	0.010	0.598	0.0054	0.055
21-Jul-07	1.169	13.078	0.027	1.359	ND	0.115
04-Aug-07	0.253	2.378	0.007	0.005	ND	0.056
24-Aug-07	0.309	10.978	0.012	0.359	0.0026	0.030
Median	0.42	5.44	0.01	0.98	0.0040	0.06
Mean	0.85	6.17	0.01	1.28	0.0040	0.06
SD	0.95	4.66	0.01	1.24	0.0026	0.04
COV [a]	1.12	0.76	0.61	0.97	0.6658	0.72
TWQR Exc % [b]	88%	-	50%	63%	-	25%

[a] Coefficient of variation = standard deviation / mean
[b] Exceedance percentages of the SA Wastewater limit values for General standards
[c] ND = not detected Legend: Exceed General Limit (TWQR for Al)
[d] Cd, Cr, Mn and Pb were not detected in any of the Atmospheric samples taken

Table 5.9: Mean concentrations for atmospheric deposition at Atmospheric East monitoring site

Sample Date	COD (mg/l)	TS (mg/l)	VS (mg/l)	NH_3 (mg/l.N)	NO_3^- (mg/l.N)	pH	EC (mS/cm)	Salinity
24-Mar-07	80.87	226	186	3.5	8.12	6.69	147	0.2
06-Apr-07	3.30	66	42	4.2	5.32	6.67	130	0.2
18-Apr-07	4.13	63	53	5.46	5.18	6.84	23	0
28-Apr-07	45.39	208	194	2.38	5.74	6.59	352	0.2
02-Jun-07	50.34	410	104	7.42	9.94	7.08	167.3	0.1
26-Jun-07	38.78	86	94	3.36	9.52	7.1	73	0
21-Jul-07	140.45	264	222	4.2	7.00	6.84	487	0.1
04-Aug-07	24.92	192	154	4.62	9.66	7.54	139.9	0.1
24-Aug-07	91.51	188	33	3.64	9.24	6.6	222	0.1
Median	45.39	192	104	4.20	8.12	6.84	147.00	0.10
Mean	53.30	189	120	4.31	7.75	6.88	193.47	0.11
SD	44.47	111	71	1.45	1.97	0.31	143.80	0.08
COV [a]	0.83	0.58	0.59	0.34	0.25	0.05	0.74	0.70
TWQR Exc % [b]	33%	100%	-	89%	-	-	89%	-

Sample Date	Al (mg/l)	Ca (mg/l)	Cu (mg/l)	Fe (mg/l)	Ni (mg/l)	Zn (mg/l)
24-Mar-07	0.811	2.955	0.039	0.745	0.0105	0.167
06-Apr-07	0.201	0.676	0.011	0.219	0.0044	0.058
18-Apr-07	0.029	0.107	0.004	ND	ND	0.019
28-Apr-07	0.039	2.414	0.004	ND	ND	0.026
02-Jun-07	0.077	4.492	0.005	ND	ND	ND
26-Jun-07	0.138	0.975	0.003	0.096	ND	0.017
21-Jul-07	0.468	3.666	0.014	0.409	ND	0.047
04-Aug-07	0.461	2.114	0.006	0.491	0.0002	0.056
24-Aug-07	0.179	5.630	0.013	0.127	0.0052	0.071
Median	0.18	2.41	0.01	0.31	0.0048	0.05
Mean	0.27	2.56	0.01	0.35	0.0051	0.06
SD	0.26	1.83	0.01	0.25	0.0042	0.05
COV [a]	0.98	0.72	1.04	0.72	0.8345	0.84
TWQR Exc % [b]	67%	-	44%	33%	-	11%

[a] Coefficient of variation = standard deviation / mean

[b] Exceedance percentages of the SA Wastewater limit values for General standards

[c] ND = not detected Legend: Exceed General Limit (TWQR for Al)

[d] Cd, Cr and Pb were not detected in any of the Atmospheric samples taken

In most respects the quality of atmospheric deposition sampled at the two sides of the Estate were very similar, except that at the West station, the mean concentration of aluminium and calcium were significantly higher than that measured at the East station. The TS concentrations were very high exceeding the TWQR limits in 94% of the samples. The average COD concentration is 53mg/l and exceeded the TWQR in 29% of the samples, displaying an unusual trend for atmospheric deposition. This can most likely be attributed to frequent deliberate sugar cane burning as the estate is surrounded by sugar cane land. High concentrations of VS are normally associated with organics, and this could be further attributed to the burning of cane, hence the occurrence of particulate matter that contains a high COD. Al concentrations exceeded the TWQR in 76% of the samples whilst the Cu and Fe targets were exceeded in 47% of samples taken.

5.5.4 Stormwater Runoff

Event mean concentrations are shown in Tables 5.10 To 5.12 and where these exceed the SA wastewater limit values for the General Standard (or TWQR in the case of Aluminium), they are indicated in red and underlined. The percentage exceedance of the SA wastewater limit values is also presented. The results in the tables and figures summarise the large quantity of data collected. For several of the elements or parameters analysed and depicted in the figures that follow, the concentration values may seem truncated. This was done as extreme variations in some water quality indicators between storm events and study areas is evident, and an appropriate scale had to be selected to portray the trends in relation to the General and Special Limits. The full values are available in the relevant tables presented in this section.

Sample Date	COD (mg/L)	TS (mg/L)	[illegible] (mg/L)	NH_3 (mg/L)	PO_4^- (mg/L)	pH	EC (mS/m)	Salinity
	75.92	556		5.51	11.28		138.00	
	11.55	164		4.34	7.28		214.00	
	17.33	57		6.72	8.83		63.90	
	99.02	251		3.22	6.90		393.00	
	22.28	220		4.62	19.60		155.80	
	33.83	140		3.64	10.08		80.30	
	123.95	506		4.20	8.58		471.00	
	26.41	450		5.04	10.38		288.00	
	42.83	159		4.90	9.24		169.50	
							169.50	
							218.23	
							130.13	
							0.83	
			-	100%	11%		89%	-

Sample Date	[illegible] (mg/L)	Cu (mg/L)	Cr (mg/L)	Cu (mg/L)	Fe (mg/L)		Ni (mg/L)	Zn (mg/L)
	0.748	39.380						
	1.548	12.730						
	2.086	11.744						
15-Jun-								
22-Jun-								
28-Jun-								
21-Jul-								
04-Aug-								
14-Aug-								
Media								
Mea								
SD								
CV								
TWQR Exc %	89%	-	-					

[1] Coeffic
[i] Exceed
[2] ND = n
[3] Cd and
respecti
Legend:

Table 8.[illegible]: Event Mean Concentrations for Individual [illegible] groups at [illegible]

	-
	-
[illegible]3	76.50
[illegible]4	393.00
[illegible]9	420.00
[illegible]8	143.20
[illegible]8	618.00
[illegible]8	173.40
[illegible]5	870.00

TWSM Exc %	<3%	100%	-

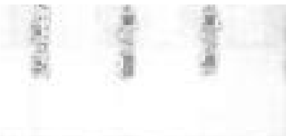


Table 5.12: Mean concentrations of metal[illegible] e at Downstream monitoring

Cu (mg/l)	Cd (mg/l)		Mn (mg/l)
		27.25	1.871
		41.60	5.453
		35.41	4.354
		38.98	4.811
		42.16	3.155
		35.64	5.097
		10.57	ND
		56.09	4.343
		30.09	2.89
		35.54	4.394
		35.31	4.240
		12.43	1.290
		0.33	2.315

[illegible]			
[illegible]-Mar-07	71	**308.0**	[illegible]
[illegible]-Apr-07	7	**248.0**	[illegible]
[illegible]-May-07	17	**210.7**	[illegible]
[illegible]-Jun-07	[illegible]	**257.3**	[illegible]
[illegible]-Jul-07	9	**278.7**	[illegible]
[illegible]-Aug-07	10	**257.3**	[illegible]

TWQR Exc %[b]	-	100%	-	33%	33%	-	100%	-

6.97	0.005
7.08	0.002
6.83	0.002
6.88	0.002
7.17	0.001

16-May-07	**0.18**
10-Jun-07	0.08
30-Jul-07	**0.15**
13-Aug-07	0.09
median	0.12
mean	
SD	
COV	
TWQR [illegible] %	

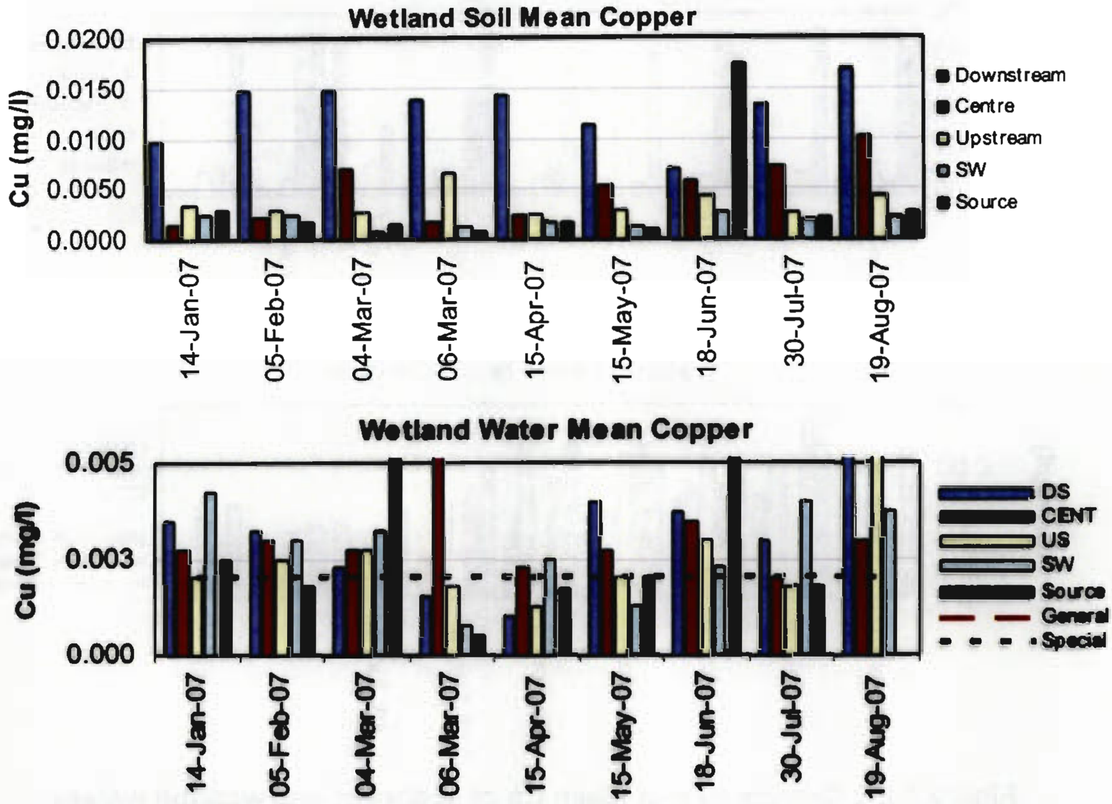


Figure 5.25: Comparison of Mean Cu of sediment and wetland waters

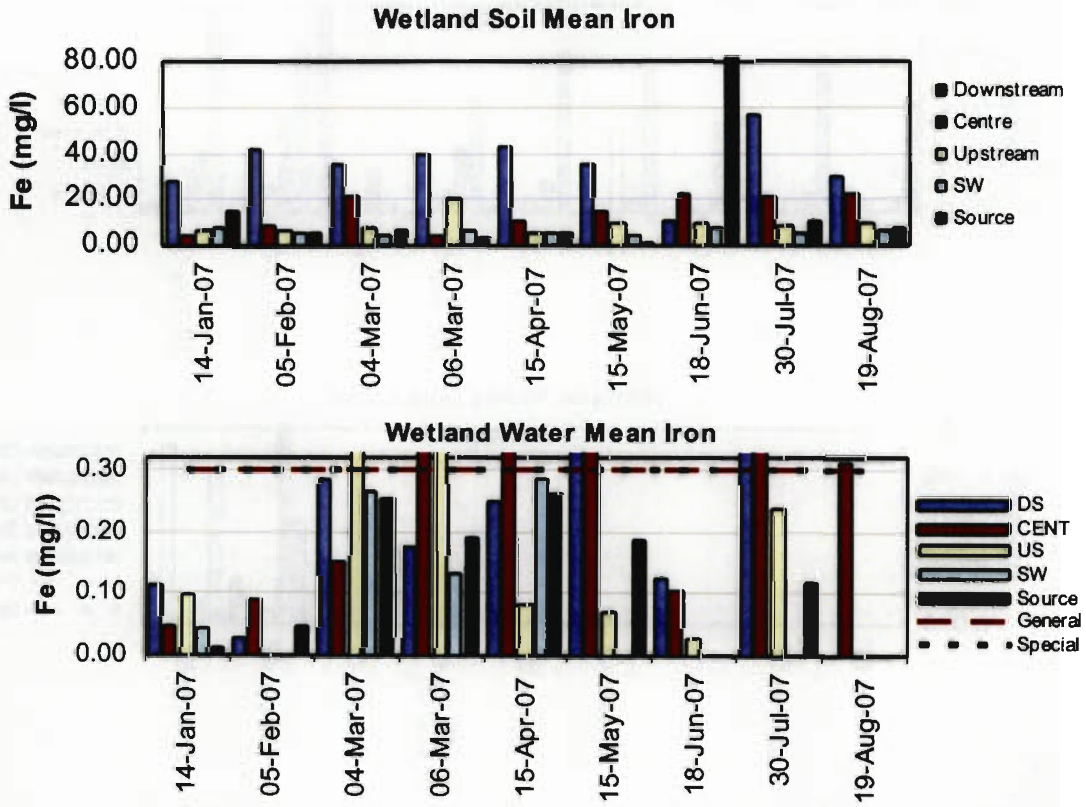


Figure 5.26: Comparison of Mean Fe of sediment and wetland waters

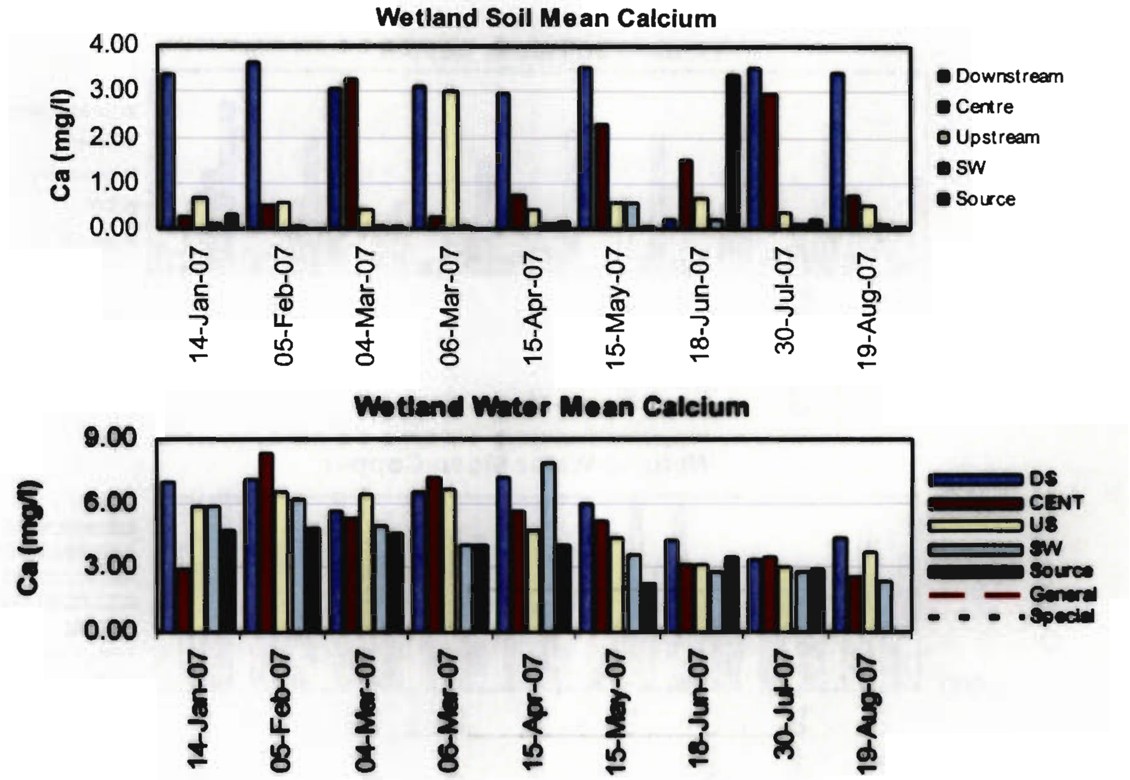


Figure 5.27: Comparison of Mean Ca of sediment and wetland waters

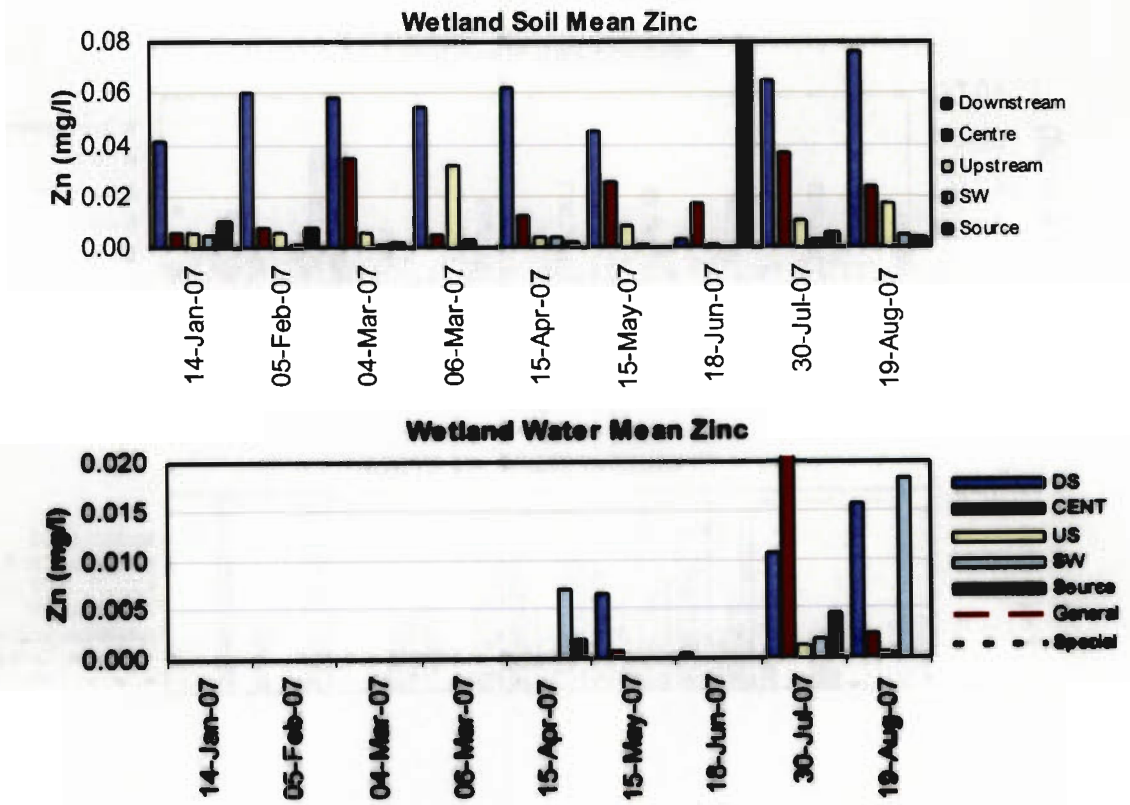


Figure 5.28: Comparison of Mean Zn of sediment and wetland waters

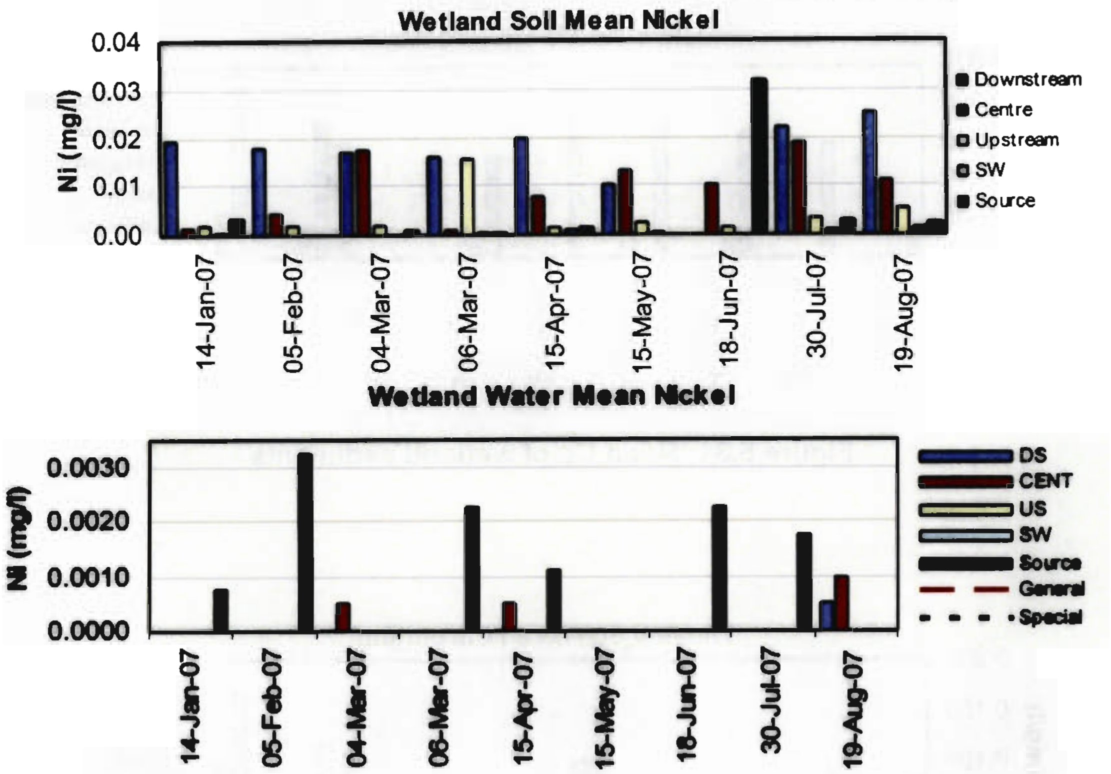


Figure 5.29: Comparison of Mean Ni of sediment and wetland waters

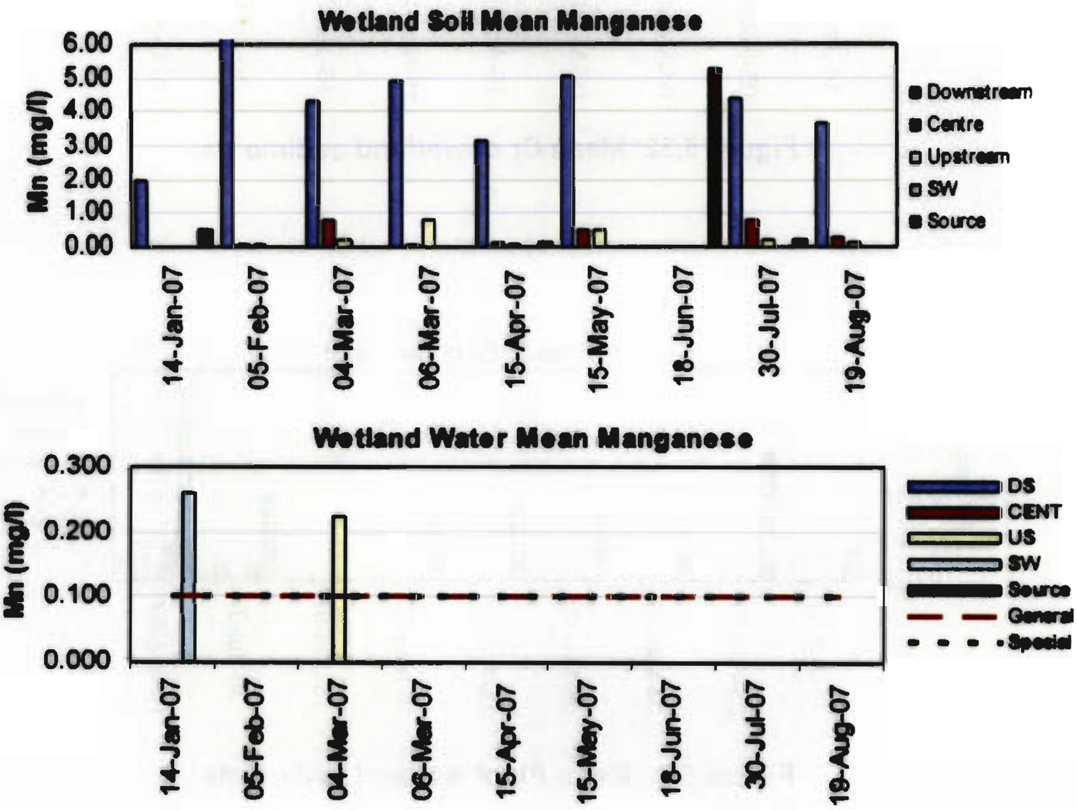


Figure 5.30: Comparison of Mean Mn of sediment and wetland waters

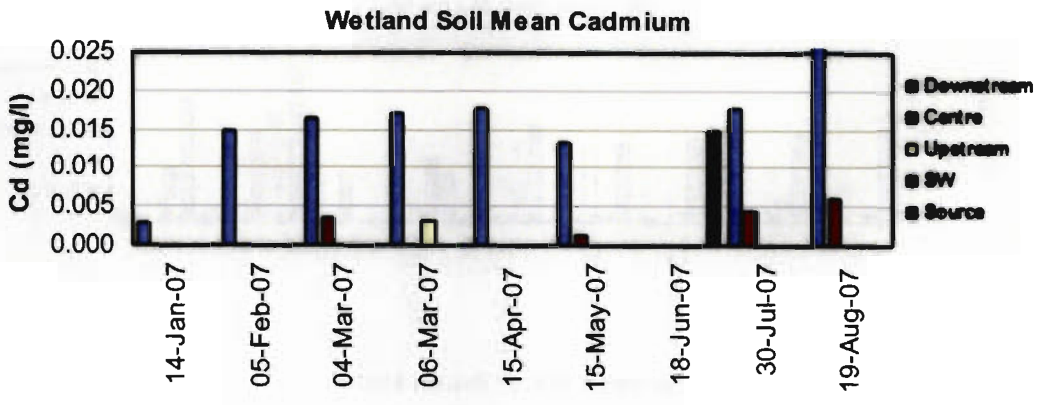


Figure 5.31: Mean Cd of wetland sediments

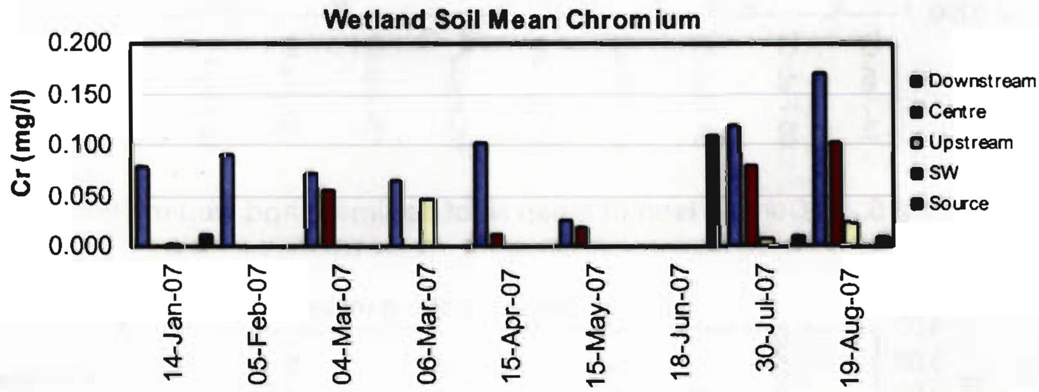


Figure 5.32: Mean Cr of wetland sediments

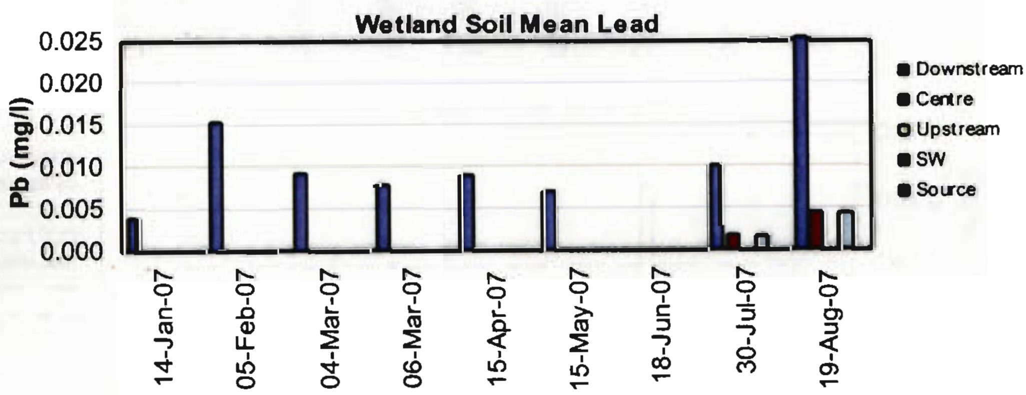


Figure 5.33 Mean Pb of wetland sediments

Comments on the results shown in Figures 5.20 to 5.33 are as follows:

<u>Oxygen Demand Substances</u>

COD concentrations for wetland water were generally consistent except for peaks in March, June and August. The levels of COD were generally below the Special Limit indicating that the quality of water was at most times acceptable. COD levels were generally between 15 and 35mg/l.

<u>Total Solids</u>

There is a large variation of results between the individual study areas and sample dates; however this could be attributed to the presence of sediments at the time of sample collection due to the often shallow waters from which the samples were taken. This has a direct influence on the TS content especially due to the low concentration levels found in the wetland surface waters sampled.

<u>pH</u>

The majority of pH results of all wetland water samples collected range from approximately neutral to slightly acidic. The variation between events is reflected at each collection point as the results generally changed in unison.

<u>Ammonia and Nitrates</u>

In more than 90% of the wetland water samples collected, the General limit level for Ammonia was exceeded and in almost 70% of the samples the level of nitrates exceeded the General limit.

<u>Heavy Metals</u>

Concentrations of all the heavy metals in the sediments were generally much higher at the lowest point in the system i.e. at the Downstream (DS) monitoring site. In relation to the typical natural metal concentrations for surface soils as adapted from Fifield and Haines (1995), only Fe and Pb were beyond the typical limits in 42% and 22% of the samples. Pb was detected in the SWR only at Tropez which feeds the Cent and DS sampling points, the only two stations where Pb was detected in the wetland soils. The concentration of Pb in the SWR was higher than that in the sediment samples for the same time period but peaks in the sediment samples approximately two months later, and was not detected in the wetland water samples so it is probable that Pb has been retained in the sediments or vegetation (sedges – see Figure 3.2) upstream of the sampling stations.

Ca was detected in all SWR, atmospheric deposition, wetland water and wetland sediment sample collected. In the sediments and the wetland waters, the highest concentrations detected were at the two lowest stations namely Cent and DS, whilst in the SWR the highest concentrations were discharged from Tropez, which feeds these two sampling stations.

5.6.4 Correlation of results

From the materials flow and the monitoring campaign, it can be deduced that construction activities peaked during two quarters i.e. March to end April and July to end August. These peaks coincide with obvious peaks in Ca concentrations in the atmospheric samples at AT-West, and the SWR samples emanating from Tropez. The highest Ca concentrations in the wetland sediments were found at DS at the lowest point of the study area (mean of 2.99mg/l), however, the concentrations remained fairly consistent, whilst the concentrations in the wetland water at the same station were approximately double (mean of 5.77mg/l). During these quarters the quantities of ready mix concrete and dry cement use were the highest. There is an evident direct correlation between the material flow during the construction phase and the pollution patterns in the wetland.

During these periods of activity, the concentrations of Fe in the atmospheric samples at AT-West and the SWR at Tropez were significantly higher than that detected at the other sampling stations for the same periods. The wetland water concentrations were the highest for the same period at CENT sampling station which is downstream of the Tropez discharge, and become gradually lower at DS. The concentrations in the soils were generally highest at the Downstream station, and then reducing further upstream at CENT. This is likely due to precipitation of the Fe out of solution as it is transported downstream due to the high dissolved oxygen concentration in the water and the formation of iron oxides and hydroxides precipitates, hence their accumulation in the sediments at the lowest point of the system.

E. coli contamination is as a result of anthropogenic sources and cannot be attributed directly or specifically to the construction activities. Sewage spills occurred during the investigation, contaminating the wetland. COD concentrations in the same order of magnitude as those in the SWR samples indicate that atmospheric deposition contributes a large portion of contamination of SWR. The high particulate COD concentrations in the baseline atmospheric samples are probably as a result of deliberate sugar cane burning in the surrounding area. The immediate response of the wetland system is that the COD is well diluted and oxidised in the system, however, when the peaks are very high, the wetland is slower to respond. The dissolved oxygen (DO) concentrations of the wetland waters show that the COD is slowly biodegradable and that the oxygen in the water is sufficient to perform this function.

CHAPTER 6

SUMMARY AND CONCLUSIONS

Three objectives were set at the onset of this dissertation, with the aim of understanding the nature, extent and dynamics of pollution from construction sites. The quality of stormwater runoff from three catchments was characterised by representative flow-weighted event mean concentration samples, and the contribution of atmospheric deposition was examined. The status of the wetland water and sediments along the wetland over time were examined. Contaminant concentrations were compared to aquatic ecosystem limits and discharge criteria. This chapter presents a summary of the results, conclusions and recommendations.

6.1 Introduction

Worldwide, development and the associated activities of construction are on the increase and do not show any evidence of tapering off. With this comes the reality that the natural habitat that once surrounded our towns and cities is going to be targeted for some form of human expansion at some point or another. With the increase in awareness and attention to environmental aspects in the early planning phases of these developments, what in effect occurs is that pockets of natural habitat, in the form of wetlands, forest belts and grasslands, are kept aside and preserved for incorporation into the overall town planning scheme as protected areas. However, on the ground, construction activities have to occur in, through and around these pockets to create the services, infrastructure and amenities that we as humans rely on to satisfy our every day needs, and these activities have an impact of sorts on the natural habitats that we are trying so hard to protect.

The key question is, do these construction activities detrimentally affect the environment, and just how much?

6.2 Methodological Approach and Research Rationale

How was the objective of studying the environmental status of a coastal forest during intensive construction activities achieved?

A case study of a developing estate which contains a sensitive ecological system comprising coastal forest and an associated wetland was found in Seaward Estates in Ballito along the North Coast of Kwazulu-Natal. The forest and wetland system was divided into 5 equally spaced segments and a monitoring station position was staked and geo-referenced at each of these segments (See Figure 4.1 and Plate 4.7 (a) – (e)). Wetland water and sedimentation samples were taken on a monthly basis and analysed for chemicalphysical properties as well as for the presence of trace metals to get an understanding of how these parameters changed over the period of the investigation. Once the baseline had been set, the source of pollution and modes of transport into the wetland were determined.

How were the objectives of assessing the nature and dynamics of construction impacts on a coastal forest wetland achieved?

In order to assess the affects on the wetland and forest system it was necessary to look at the dynamics of construction pollution and to assess how the pollution would actually enter the system. This was done by looking at stormwater runoff from the catchments incorporating the construction sites and the associated atmospheric deposition that occurs during the dry periods and deposited during storm events as precipitation. The ongoing status of the wetland sediments and waters were monitored over the study period to assess any changes that may take place over time as a result thereof.

To facilitate this, a GIS was created to monitor how construction activities changed over time. Anthropogenic impacts in the form of sewer spills were also modelled on the GIS. A materials flow survey and analysis was undertaken to depict the flow of materials within the estate coinciding with the construction progress. For the purposes of this investigation, the incoming materials were grouped and categorised as explained in Chapter 4, in relation to their potential to come into direct contact with the environment, particularly rain, and be an immediate source of pollution. This grouping was aimed at devising construction materials indicators that portrayed their severity in relation to their nature and contact time with the environment. The various material types were further reduced to approximate tonnes to get a total weighting, and categorised into three main groups namely, high potential impact, intermediate impact and low potential impact.

The analysis of the materials flow is indicated in Tables 5.4 and 5.5. From these it was determined that during the period of study, three main developments were identified as the main importers of materials onto the site namely San Jerez, San Karena and San Marco, and then a number of smaller developments and individual homesteads made up the rest of the materials flow. The outputs of these tables became the input into the GIS and are clearly represented in the flow diagrams in Figures 5.4 to 5.6. High Impact, Intermediate impact and Low Impact materials flows are depicted in red, magenta and blue arrows respectively, while materials removed from site in the form of rubble is depicted in green. It is evident from the flow rankings presented in Table 5.4 that the development of San Jerez (See figure 4.1) in most instances received the highest quantities of all three categories of materials throughout the study period. San Jerez is also incorporated into one of the three main stormwater catchment areas (Tropez) that feed into the wetland under study (See Figure 4.1).

How was the objective of creating a framework for assessing the impacts of construction through the selection of appropriate environmental factors been achieved?

The output of the materials flow analysis and diagram were collated and formed the input into Table 5.5 which is a matrix of all the high impactors rated according to toxicity, volume and retention time. The largest pollutants by weight and volume are concrete and associated aggregates of sand, stone and cement. Included in this figure is imported bulk fill material. This matrix and Table B.6 can be used to assess the types and volumes of materials being brought onto a site and the potential impacts that can be expected.

6.3 Conclusions

The event mean concentrations of atmospheric and SWR samples which generally exceeded the General limits for most heavy metals and chemicalphysical properties indicates that untreated SWR has major polluting potential to downstream water resources. From the high solids in the SWR it is evident that sediments are a major pollutant of water resources and the highest TS encountered were at the Tropez station which was the outlet of a catchment with the highest rate of sites under construction.

Atmospheric samples were used as a baseline for the investigation and the high particulate COD concentrations cannot be attributed solely to the construction activities. They are most likely as a result of deliberate sugar cane burning in the surrounding area. The high concentrations of Fe and the presence of NH_3 are also most likely from the same source. The high concentration of VS which is largely related to organics is further evidence of organic particulate matter that contains COD.

Mean concentrations of metals in the wetland water and sediments were in most instances highest at the two lowest sampling stations namely Cent and DS. These also correspond fairly strongly with high concentrations of SWR constituent metals at the Tropez station which feeds these two sampling points. This can possibly be attributed to the construction site and associated activities which form a major part of the upstream catchment. Although there is no water quality limit for Ca, it is being flushed out and is not accumulating in the sediments. As a result, the concentrations are high in the order of 20-40mg/l. There is an intense accumulation of Fe in the sediments that is not directly related to the construction stage. The wetland response is good as a result of the DO, so Fe is most likely precipitated out in the form of hydroxides, however this could not be physically observed as the natural soils in the wetland are Berea Reds which have a natural red colour which disguise any precipitates.

Anthropogenic pollution in the form of sewage contamination to the wetland had a marked effect on the water quality and at no time during the investigation period were the indicators of *E. coli* contamination below the General Limits except for possibly the first set of samples taken which are likely to be underestimated due to the analysis method utilised in the first round of tests.

6.4 Mitigation options

The answer to the question posed at the beginning of this chapter, is that construction activities do have an impact on the environment. Sediments, concrete and aggregates are the largest impactors from construction activities related to residential housing such as that undertaken during this investigation. These affect the quality of runoff from the sites which eventually find their way into wetlands or watercourses.

From physical evidence throughout the study period, it has become obvious that over and above Environmental Management Plans, special attention needs to be paid to stormwater pollution controls, both during construction and after. From the amount of floatables, sediments and contaminants found in the SWR and discharged uncontrolled and untreated directly to the wetland during this study, a best management practise that could be encouraged is that controls be placed at the outlets of stormwater drains that can serve dual purposes, namely, sediment and debris containment and collection, and SWR treatment.

Gabion stilling basins or boxes constructed at the outlet of stormwater drains as illustrated in Plate 6.1 and Figure 6.1 act as sediment and debris traps making estate maintenance easier as it concentrates the debris and litter in one place instead of scattering into the open wetland, and the geofabric lining and type of rock fill can act as a filter and barrier for sediments and SWR constituents.

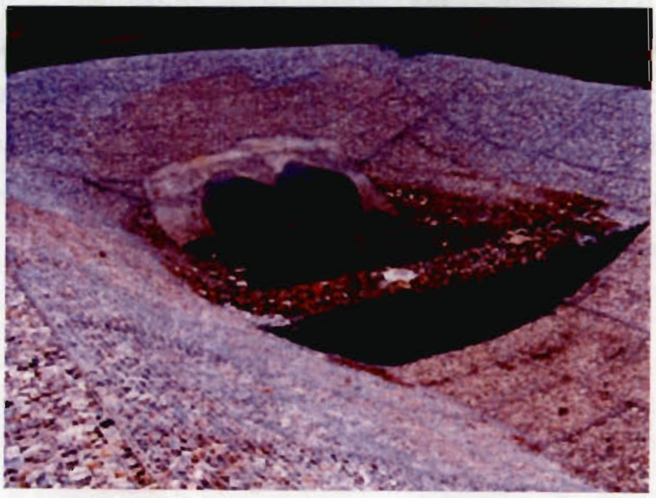


Plate 6.1: Example of Gabion stilling basin (Courtesy of African Gabions (Pty) Ltd)

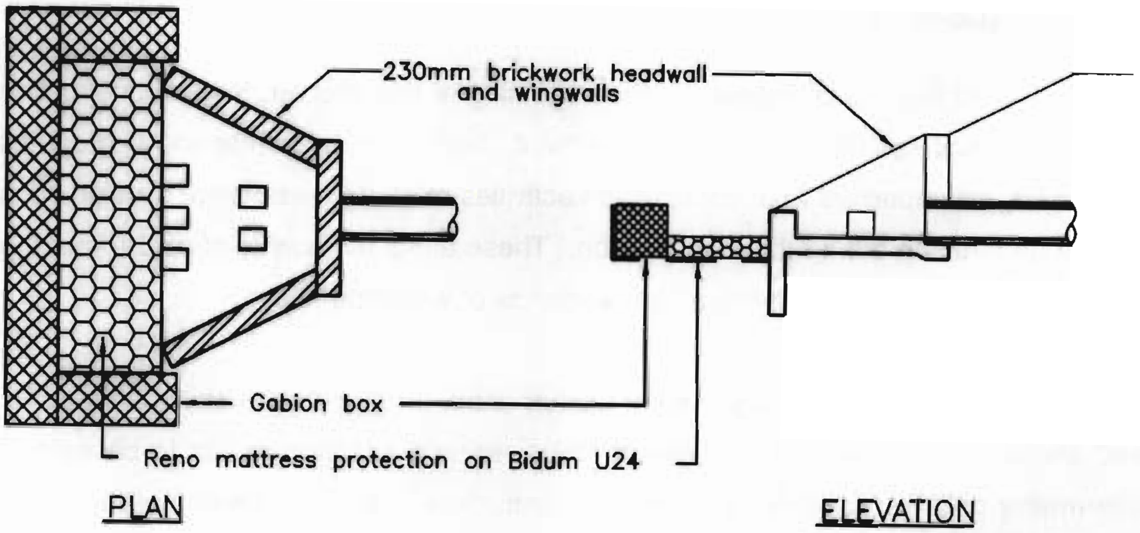


Figure 6.1: Gabion stilling basin (Courtesy of KV3 Engineers (Pty) Ltd)

6.5 Suggestions for further research

In order to further this research, construction waste and pollution dynamics should be further investigated. Closer, contained investigation and monitoring of materials, materials usage, waste generation, waste disposal and stormwater control on and within a construction site could facilitate understanding pollution levels and could be further used to inform decisions by management with regards to mitigation measures.

Stormwater controls and pollution prevention from construction operations and thereafter are becoming more important. It is known from previous research that the quality of SWR from most surfaces and land usages is most often well beyond the limits as laid down in the South African Water Quality Guidelines (DWAF, 1996) and the Target Water Quality Range (TWQR), and particular attention should be paid to methods of treating stormwater prior to discharging it to the environment.

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APPENDICES

APPENDIX A

OVERALL MAP OF SEAWARD ESTATES AND SURROUNDS

This Appendix contains the map of Seaward Estates showing it in context of its surroundings and all the pertinent points as applicable to this investigation


N
W
E
S
BALLITO LIFESTYLE CENTRE
N2 FREEWAY
Ballito Bus
M4
M4 (SERVICE ENTRANCE)
Seaforth College
Atmos West
San Te Fe 2
San Te Fe 1
San Jerez
BALLITO DRIVE
San Lorenzo
San Marco
San Bush
San Sabastia
Sebastion
SOURCE
San Diego
San Karena
San Thaila
Atmos East
Single Res 2
San Jose
San Marion
San Zingaro
San Nicholas
Single Res 2
SW
San Tropez
Single Res 1
San Tarena
San Bush
San Jose
Single Res 1
San Marina
Single Res 1
Tropez
Single Res 2
Marina
US
FRASER'S TREATMENT WORKS
San Secret
CENT
Single Res 2
San Hills
ZIMBALI ESTATES
DS

APPENDIX B

MATERIALS AND EQUIPMENT FLOW SURVEY

This Appendix contains the form used to record and track the flow of construction materials and equipment or plant in and out of the Estate during this investigation and summaries of the results of the survey performed

BULK MATERIAL AND EQUIPMENT DELIVERY / REMOVAL FROM SITE

Contractors Particulars

Erf No or Name of Development ______________________

Date		Delivery				Removal					
Carrying capacity of vehicle [Tonnes]		1	2	3	4	5	6	7	8	9	10
Indicate quantity if applicable		Full	3/4	1/2	1/4	Exact Quantity					

Cement		Cement Mix		Builders sand	
Plaster Sand		Builders stone		Lintels	
Roof Trusses		Roof Tiles		Roof gutters	
Reinforcing		Scaffold		Plates	
Bricks		Retaining Blocks		Paving	
Soil fill		Rubble		General Rubble	
TLB		Bob Cat		Earth moving equip.	
Pile Machinery		Cement Mixers		Compactors	
Road Surfacing		Road gravel		Road Tarmac	
Manhole rings/covers		Pipes		Plumbing	
Electrical		Paints and Solvents		Carpentry	
Other: (specify)					
Authorized by:			Signature		

Figure B.1: Survey form used to undertake material flow study

Table B.1: Weighted material flows for the period January and February

Material Imported	Delivery Unit	January & February Month Total	San Jerez	San Karena	San Marco	Other
HIGH POTENTIAL IMPACT - Group 1		**Equivalent Tons**				
Plaster Sand	5T truck	**166**	166			
Builders sand	5T truck	**166**	166			
Builders stone	5T truck	**126**	126			
Soil fill	10m^3 truck					
Road gravel	5T truck					
TOTAL: HIGH POTENTIAL IMPACT		**457**	**457**			
INTERMEDIATE POTENTIAL IMPACT - Group 2						
Cement Mix	6m^3 truck	**433**	433			
Road Tarmac	5T truck					
Dry Cement	5T truck	**56**	56			
Paints and Solvents	1T truck	**0**	0			
TOTAL: INTERMEDIATE POTENTIAL IMPACT		**489**	**489**			
LOW POTENTIAL IMPACT - Group 3						
Roof Trusses	5T truck					
Roof Tiles	5T truck					
Reinforcing	5T truck	**7**	7			
Bricks	10T truck /28 pallet	**161**	161			
Paving	10T truck /28 pallet					
Retaining Blocks	5T truck					
Pipes	10T truck					
Lintels	1T truck	**10**	10			
Roof gutters	1T truck					
Plumbing	1T truck					
Carpentry	1T truck					
Manhole rings/covers	5T truck					
Electrical	1T truck					
Scaffold	1T truck					
TOTAL: LOW POTENTIAL IMPACT		**178**	**178**			

Material Removed	Delivery Unit	January & February Month Total	San Jerez	San Karena	San Marco	Other
BULK MATERIAL REMOVAL - Group 4			**Equivalent Tons**			
General Rubble	5T truck					

Table B.2: Weighted material flows for the period March and April

Material Imported	Delivery Unit	March & April				
		Month Total	San Jerez	San Karena	San Marco	Other
HIGH POTENT		Equivalent Tons				
Plaster Sand	5T truck	**379**	316	27	18	18
Builders sand	5T truck	**379**	316	27	18	18
Builders stone	5T truck	**281**	240	14	14	14
Soil fill	$10m^3$ truck	**2700**			2700	
Road gravel	5T truck					
TOTAL: HIGH POTENTIAL IMPACT		**3739**	**871**	**68**	**2750**	**50**
INTERMEDIATE POTENTIAL IMPACT - Group 2						
Cement Mix	$6m^3$ truck	**1682**	1120	288	144	130
Road Tarmac	5T truck					
Dry Cement	5T truck	**123**	83	20	10	10
Paints and Solvents	1T truck	**3**	1	1	0	0
TOTAL: INTERMEDIATE POTENTIAL IMPACT		**1808**	**1205**	**309**	**154**	**140**
LOW POTENTIAL IMPACT - Group 3						
Roof Trusses	5T truck	**30**		10	10	10
Roof Tiles	5T truck	**88**		38	25	25
Reinforcing	5T truck	**31**	6	10	10	5
Bricks	10T truck /28 pallet	**1479**	623	413	207	236
Paving	10T truck /28 pallet					
Retaining Blocks	5T truck	**16**		12		4
Pipes	10T truck					
Lintels	1T truck	**7**		3	2	2
Roof gutters	1T truck	**1**		1		
Plumbing	1T truck					
Carpentry	1T truck					
Manhole rings/covers	5T truck					
Electrical	1T truck					
Scaffold	1T truck					
TOTAL: LOW POTENTIAL IMPACT		**1653**	**630**	**487**	**254**	**283**

Material Removed	Delivery Unit	March & April				
		Month Total	San Jerez	San Karena	San Marco	Other
BULK MATERIAL REMOVAL - Group 4			Equivalent Tons			
General Rubble	5T truck	**3.6**	3.6			

Table B.3: Weighted material flows for the period May and June

Material Imported	Delivery Unit	May & June: Month Total	San Jerez	San Karena	San Marco	Other
HIGH POTENTIAL IMPACT - Group 1		Equivalent Tons				
Plaster Sand	5T truck	**430**	358	9	9	54
Builders sand	5T truck	**421**	358	27	9	27
Builders stone	5T truck	**293**	272	7	7	7
Soil fill	$10m^3$ truck					
Road gravel	5T truck	**255**	255			
TOTAL: HIGH POTENTIAL IMPACT		**1398**	**1242**	**43**	**25**	**88**
INTERMEDIATE POTENTIAL IMPACT - Group 2						
Cement Mix	$6m^3$ truck	**1018**	413	187	173	245
Road Tarmac	5T truck					
Dry Cement	5T truck	**177**	137	10	5	25
Paints and Solvents	1T truck	**1**	1			
TOTAL: INTERMEDIATE POTENTIAL IMPACT		**1197**	**552**	**197**	**178**	**270**
LOW POTENTIAL IMPACT - Group 3						
Roof Trusses	5T truck	**55**	25	20	5	5
Roof Tiles	5T truck	**151**	63	63	13	13
Reinforcing	5T truck	**30**	5	15	5	5
Bricks	10T truck /28 pallet	**718**	334	148	89	148
Paving	10T truck /28 pallet	**20**				20
Retaining Blocks	5T truck	**12**			12	
Pipes	10T truck					
Lintels	1T truck	**21**	19	1		1
Roof gutters	1T truck					
Plumbing	1T truck					
Carpentry	1T truck	**2**		2		
Manhole rings/covers	5T truck	**1**				1
Electrical	1T truck					
Scaffold	1T truck					
TOTAL: LOW POTENTIAL IMPACT		**1010**	**446**	**249**	**124**	**192**

Material Removed	Delivery Unit	May & June: Month Total	San Jerez	San Karena	San Marco	Other
BULK MATERIAL REMOVAL - Group 4		Equivalent Tons				
General Rubble	5T truck	**2.4**				2.4

Table B.4: Weighted material flows for the period July and August

Material Imported	Delivery Unit	July & August				
		Month Total	San Jerez	San Karena	San Marco	Other
Group 1		Equivalent Tons				
Plaster Sand	5T truck	**280**	262		9	9
Builders sand	5T truck	**271**	262	9		
Builders stone	5T truck	**225**	225			
Soil fill	10m³ truck	**18**		18		
Road gravel	5T truck	**585**	585			
Cement Mix	6m³ truck	**425**	267	58		101
Road Tarmac	5T truck					
Dry Cement	5T truck	**148**	98	45		5
Paints and Solvents	1T truck	**2**	2			
Roof Trusses	5T truck	**15**	15			
Roof Tiles	5T truck	**80**	42	13		25
Reinforcing	5T truck	**9**	4	5		
Bricks	10T truck /28 pallet	**598**	243	266		89
Paving	10T truck /28 pallet					
Retaining Blocks	5T truck					
Pipes	10T truck					
Lintels	1T truck	**4**	4			
Roof gutters	1T truck					
Plumbing	1T truck					
Carpentry	1T truck					
Manhole rings/covers	5T truck					
Electrical	1T truck					
Scaffold	1T truck					
TOTAL: LOW POTENTIAL IMPACT		**706**	**309**	**283**		**114**

Material Removed	Delivery Unit	July & August				
		Month Total	San Jerez	San Karena	San Marco	Other
BULK MATERIAL REMOVAL - Group 4			Equivalent Tons			
General Rubble	5T truck	**2.4**	2.4			

Table B.5: Total impacts matrix – abridged

Category	Quantity	Retention Period	Toxicity	Perceived Impact	January & February				
					Month Total	San Jerez	San Karena	San Marco	Other
					Equivalent Tons				
Concrete	Large	Short	High	High	433	433			
Aggregate	Large	Long	Low	High	166	166			
Aggregate	Large	Long	Low	High	166	166			
Building	Large	Long	Low	Low	161	161			
Aggregate	Large	Long	Low	High	126	126			
Cement	Large	Medium	Medium	Intermediate	56	56			
Building	Medium	Long	Low	Low	10	10			
Ancillaries	Large	Medium	Low	Low	7	7			
Category	**Quantity**	**Retention Period**	**Toxicity**	**Perceived Impact**	**March & April**				
					Month Total	**San Jerez**	**San Karena**	**San Marco**	**Other**
					Equivalent Tons				
Aggregate	Large	Long	Low	High	2700			2700	
Concrete	Large	Short	High	High	1682	1120	288	144	130
Building	Large	Long	Low	Low	1479	623	413	207	236
Aggregate	Large	Long	Low	High	379	316	27	18	18
Aggregate	Large	Long	Low	High	379	316	27	18	18
Aggregate	Large	Long	Low	High	281	240	14	14	14
Cement	Large	Medium	Medium	Intermediate	123	83	20	10	10
Building	Large	Long	Low	Low	88		38	25	25
Ancillaries	Large	Medium	Low	Low	31	6	10	10	5
Carpentry	Large	Medium	Low	Low	30		10	10	10
Building	Small	Long	Low	Low	16		12		4
Building	Medium	Long	Low	Low	7		3	2	2
Paint	Small	Short	High	Intermediate	3	1	1	0	0
Ancillaries	Small	Medium	Low	Low	1		1	0	0
Category	**Quantity**	**Retention Period**	**Toxicity**	**Perceived Impact**	**May & June**				
					Month Total	**San Jerez**	**San Karena**	**San Marco**	**Other**
					Equivalent Tons				
Concrete	Large	Short	High	High	1018	413	187	173	245
Building	Large	Long	Low	Low	718	334	148	89	148
Aggregate	Large	Long	Low	High	430	358	9	9	54
Aggregate	Large	Long	Low	High	421	358	27	9	27
Aggregate	Large	Long	Low	High	293	272	7	7	7
Aggregate	Large	Long	Low	High	255	255			
Cement	Large	Medium	Medium	Intermediate	177	137	10	5	25
Building	Large	Long	Low	Low	151	63	63	13	13
Carpentry	Large	Medium	Low	Low	55	25	20	5	5
Ancillaries	Large	Medium	Low	Low	30	5	15	5	5
Building	Medium	Long	Low	Low	21	19	1		1

Table B.5 Continued

Building	Large	Long	Low	Low	20				20
Building	Small	Long	Low	Low	12			12	
Carpentry	Small	Short	Low	Low	2		2		
Paint	Small	Short	High	Intermediate	1	1			
Ancillaries	Small	Medium	Low	Low	1				1
Category	**Quantity**	**Retention Period**	**Toxicity**	**Perceived Impact**	**July & August**				
					Month Total	**San Jerez**	**San Karena**	**San Marco**	**Other**
					Equivalent Tons				
Building	Large	Long	Low	Low	598	243	266		89
Aggregate	Large	Long	Low	High	585	585			
Concrete	Large	Short	High	High	425	267	58		101
Aggregate	Large	Long	Low	High	280	262		9	9
Aggregate	Large	Long	Low	High	271	262	9		
Aggregate	Large	Long	Low	High	225	225			
Cement	Large	Medium	Medium	Intermediate	148	98	45		5
Building	Large	Long	Low	Low	80	42	13		25
Aggregate	Large	Long	Low	High	18		18		
Carpentry	Large	Medium	Low	Low	15	15			
Ancillaries	Large	Medium	Low	Low	9	4	5		
Building	Medium	Long	Low	Low	4	4			
Paint	Small	Short	High	Intermediate	2	2			

<u>Legend:</u> Long = 2 weeks or more
Medium = ± 1 Week
Short = Day's

APPENDIX C

WETLAND WATER AND SEDIMENT SAMPLING

This Appendix contains the On-Site sampling data of the various wetland monitoring stations over time during this investigation

Table C.1: Wetland Station sampling data

Date	Time of Sample (Hr)	Sample Station	Sample	Water Depth (mm)	Ambient Temp (°C)	Water Temp (°C)	DO (mg/L)
14-Jan-07	16:30-17:50	DS	M1, C1, 1, S1	325	36	24.00	-
05-Feb-07	16:00-17:30	DS	M1, C1, 1, S1	350	38	24.00	-
04-Mar-07	15:30-17:45	DS	M1, C1, 1, S1	275	38	24.72	4.91
06-Mar-07	7:00-8:30	DS	M1, C1, 1, S1	350	22	21.60	6.77
15-Apr-07	15:30-17:00	DS	M1, C1, 1, S1	400	24	21.60	3.47
15-May-07	15:30-17:30	DS	M1, C1, 1, S1	350	26	19.30	5.28
18-Jun-07	15:50-17:50	DS	M1, C1, 1, S1	350	24	15.80	5.29
30-Jul-07	16:00-18:00	DS	M1, C1, 1, S1	250	22	15.20	5.58
19-Aug-07	15:30-17:30	DS	M1, C1, 1, S1	300	26	17.10	7.46
14-Jan-07	16:30-17:50	CENT	M2, C2, 2, S2	200	36	24.00	-
05-Feb-07	16:00-17:30	CENT	M2, C2, 2, S2	325	38	24.00	-
04-Mar-07	15:30-17:45	CENT	M2, C2, 2, S2	155	38	24.65	4.74
06-Mar-07	7:00-8:30	CENT	M2, C2, 2, S2	325	22	21.80	6.69
15-Apr-07	15:30-17:00	CENT	M2, C2, 2, S2	250	24	21.50	5.39
15-May-07	15:30-17:30	CENT	M2, C2, 2, S2	175	26	19.70	4.92
18-Jun-07	15:50-17:50	CENT	M2, C2, 2, S2	175	24	16.40	5.42
30-Jul-07	16:00-18:00	CENT	M2, C2, 2, S2	350	22	15.80	3.57
19-Aug-07	15:30-17:30	CENT	M2, C2, 2, S2	325	26	17.40	6.21
14-Jan-07	16:30-17:50	US	M3, C3, 3, S3	150	36	24.00	-
05-Feb-07	16:00-17:30	US	M3, C3, 3, S3	150	38	24.00	-
04-Mar-07	15:30-17:45	US	M3, C3, 3, S3	105	38	24.85	3.16
06-Mar-07	7:00-8:30	US	M3, C3, 3, S3	300	22	21.60	6.20
15-Apr-07	15:30-17:00	US	M3, C3, 3, S3	250	24	21.80	5.20
15-May-07	15:30-17:30	US	M3, C3, 3, S3	200	26	20.00	5.48
18-Jun-07	15:50-17:50	US	M3, C3, 3, S3	200	24	16.60	5.77
30-Jul-07	16:00-18:00	US	M3, C3, 3, S3	250	22	16.10	3.68
19-Aug-07	15:30-17:30	US	M3, C3, 3, S3	275	26	17.70	6.98
14-Jan-07	16:30-17:50	SW	M4, C4, 4, S4	50	36	24.00	-
05-Feb-07	16:00-17:30	SW	M4, C4, 4, S4	20	38	24.00	-
04-Mar-07	15:30-17:45	SW	M4, C4, 4, S4	60	38	23.85	7.85
06-Mar-07	7:00-8:30	SW	M4, C4, 4, S4	80	22	21.10	10.57
15-Apr-07	15:30-17:00	SW	M4, C4, 4, S4	50	24	21.80	7.73
15-May-07	15:30-17:30	SW	M4, C4, 4, S4	40	26	20.80	8.07
18-Jun-07	15:50-17:50	SW	M4, C4, 4, S4	30	24	18.80	7.18
30-Jul-07	16:00-18:00	SW	M4, C4, 4, S4	30	22	18.30	7.14
19-Aug-07	15:30-17:30	SW	M4, C4, 4, S4	30	26	19.10	8.91
04-Mar-07	15:30-17:45	SOURCE	M5, C5, 5, S5	10	38	22.80	8.09
06-Mar-07	7:00-8:30	SOURCE	M5, C5, 5, S5	10	22	21.60	9.95
15-Apr-07	15:30-17:00	SOURCE	Am, C_A, A, S5	10	24	21.70	8.09
15-May-07	15:30-17:30	SOURCE	Am, C_A, A, S5	10	26	21.30	7.67
18-Jun-07	15:50-17:50	SOURCE	Am, C_A, A, S5	10	24	20.40	6.80
30-Jul-07	16:00-18:00	SOURCE	Am, C_A, A, S5	10	22	20.00	6.20
19-Aug-07	15:30-17:30	SOURCE	Am, C_A, A, S5	10	26	20.40	8.58

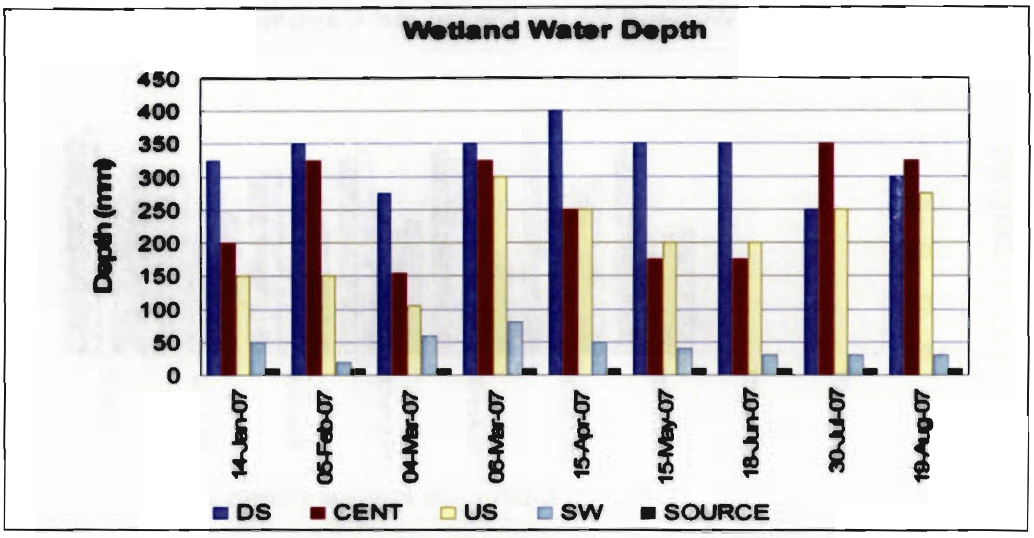

Figure C.1: Wetland water depth at time of sampling

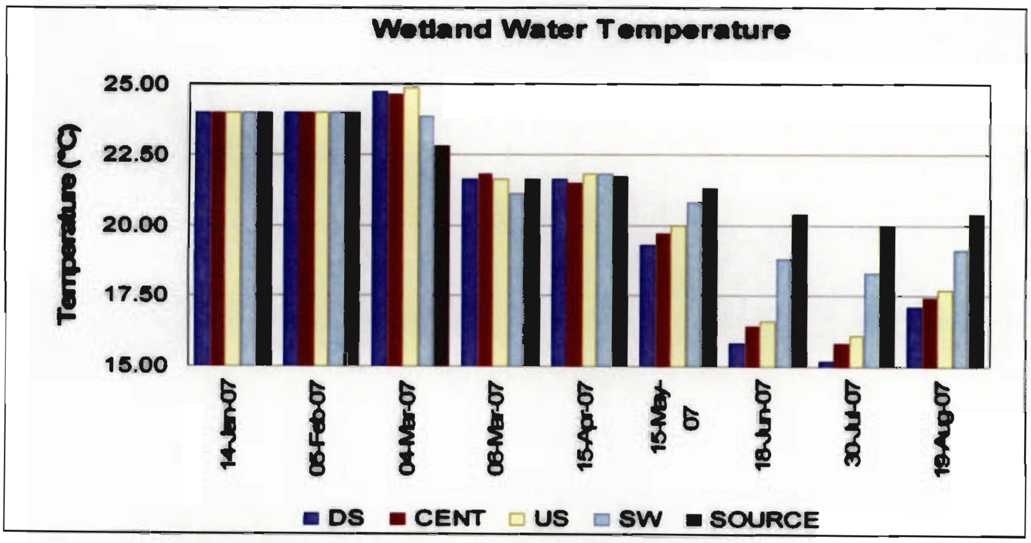

Figure C.2: Wetland water temperature at time of sampling

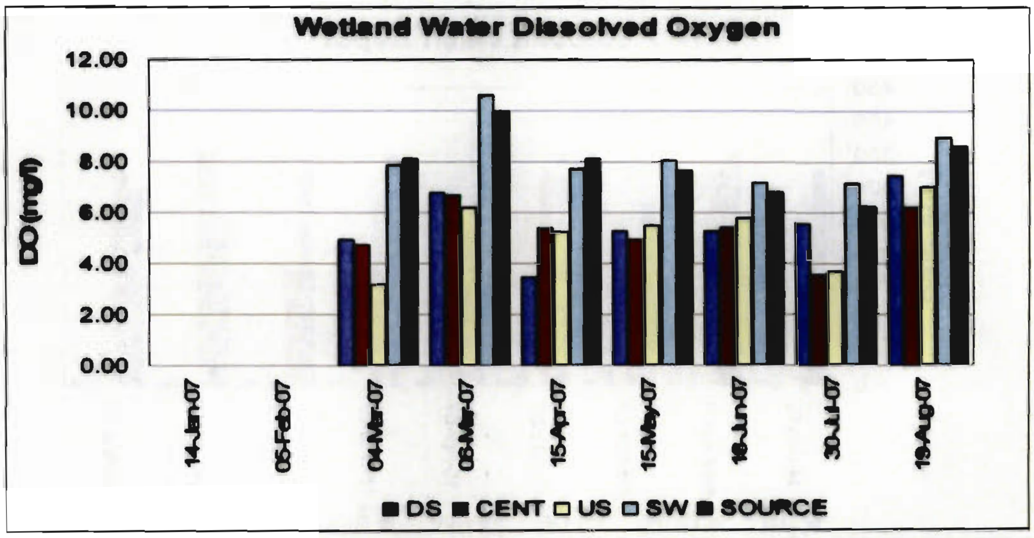

Figure C.3: Wetland water dissolved oxygen content at time of sampling

APPENDIX D

EVENT MEAN CONCENTRATIONS OF STORMWATER AND ATMOSPHERIC SAMPLES AND MEAN CONCENTRATIONS OF WETLAND WATER AND SEDIMENT SAMPLES (ICP ANALYSIS)

This Appendix contains the sampling data of the SWR, atmospheric deposition, wetland water and wetland sediment samples collected and analysed during this investigation from the ICP-AES

SEE ENCLOSED CD